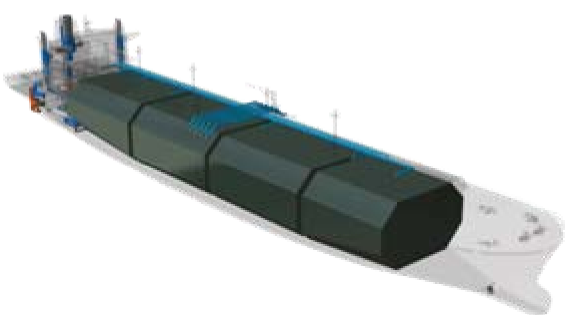
Wärtsilä
Dual-Fuel LNGC

March 2008

Contents



Dual-Fuel-Electric LNGC

- Components
- Machinery Layout
- Fuel flexibility
- Sailing scenarios

Dual-Fuel-Mechanic LNGC

- Components
- Machinery Layout
- Fuel flexibility
- Sailing scenarios

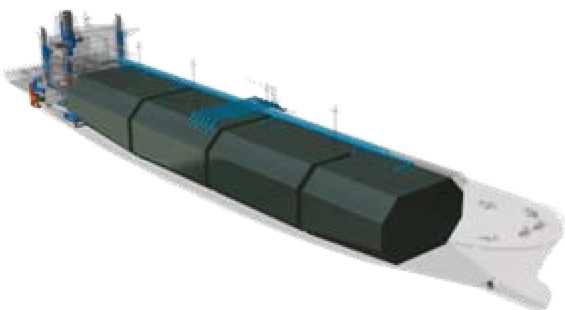
Comparison study

- Propulsion alternatives
  - OpEx
  - CapEx
  - Emissions
  - Fuel bunkering requirements
- Safety
- Reliability
- Redundancy
- Maintainability
- Crewing
- Summary

DF-M vs. DF-E

- Advantages and disadvantages of DF-M propulsion compared to DF-E.

Contents



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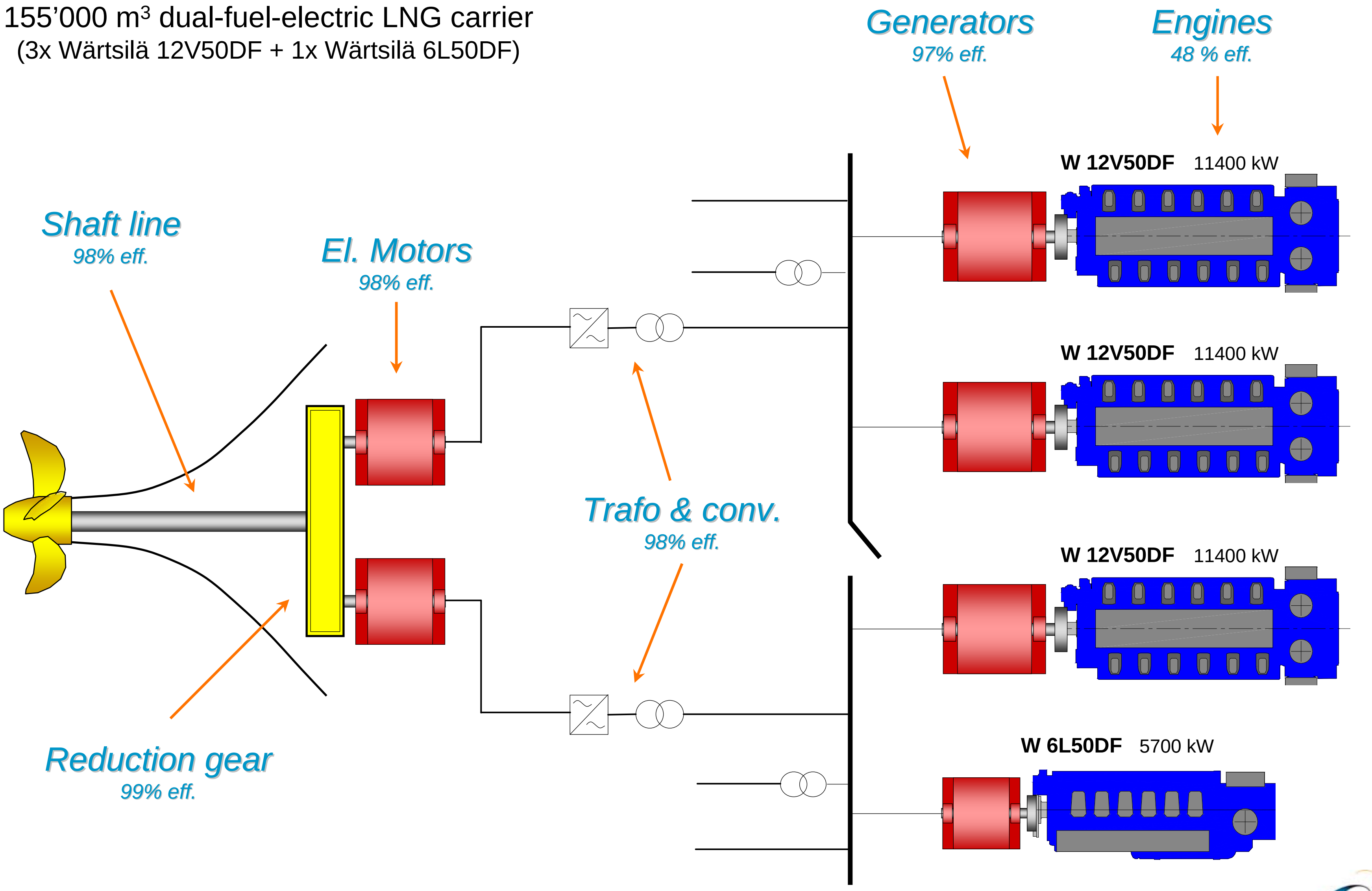
DF-E – Propulsion Components

155’000 m³ dual-fuel-electric LNG carrier
(3x Wärtsilä 12V50DF + 1x Wärtsilä 6L50DF)



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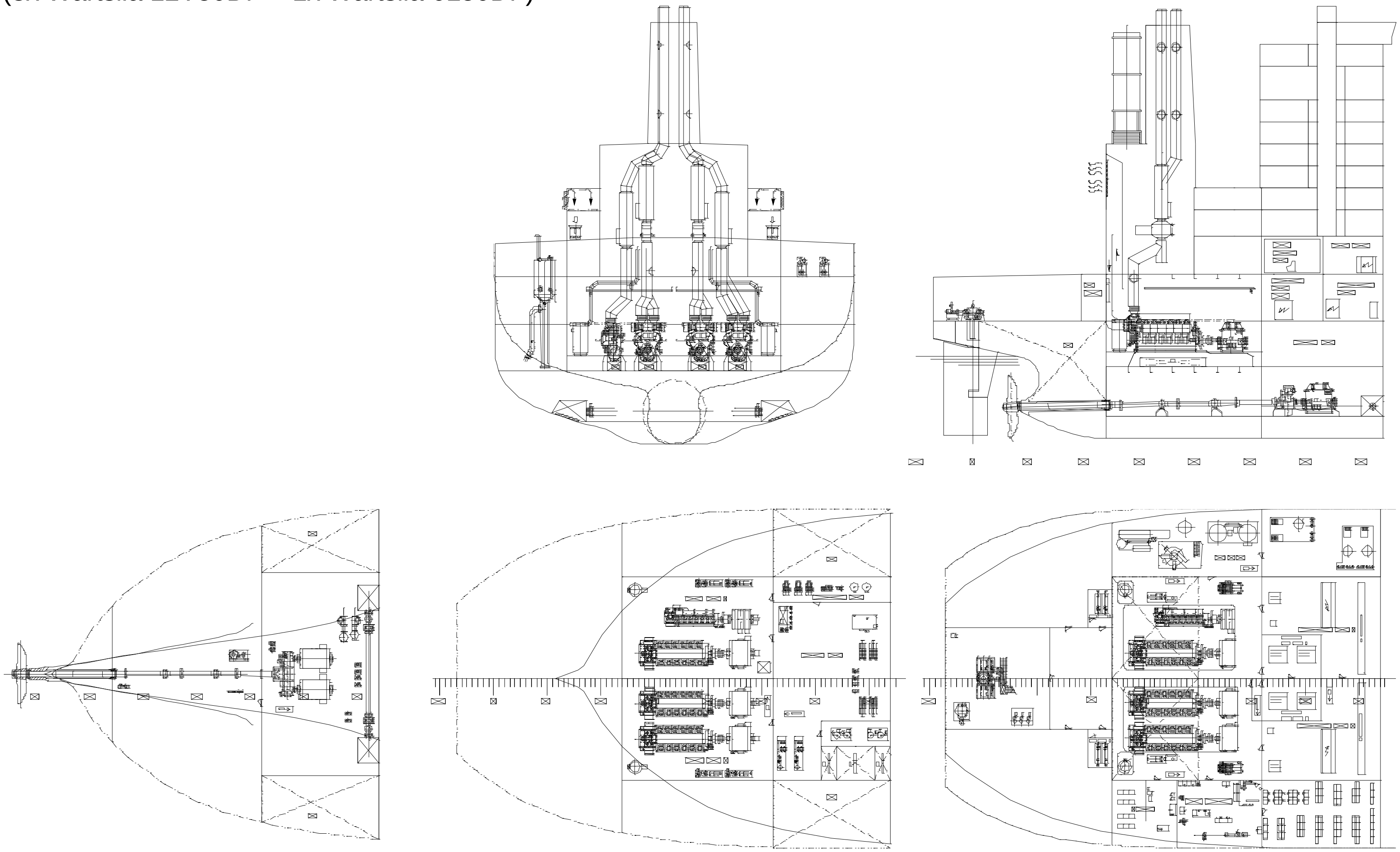
DF-E – Machinery layout (1/2)

155’000 m³ dual-fuel-electric LNG carrier
(3x Wärtsilä 12V50DF + 1x Wärtsilä 6L50DF)



DF-E – Fuel flexibility

DF-E propulsion plant has a complete fuel flexibility.

Gas, MDO or HFO can be selected (or re-selected) as source of energy in a fast, simple and reliable way without stopping the engines and without losses in engine speed and output.

Fuel selection can be manually or automatically controlled.

During laden voyage, ballast voyage or when at loading/unloading facilities the most economical or favourable operating mode can be chosen.

Regional emission regulations, restrictions on heavier liquid fuel utilization, fuel bunkering requirements will have low or no impact on sailing route and schedule.

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DF-E – Sailing scenarios (1/4)

Power distribution calculation

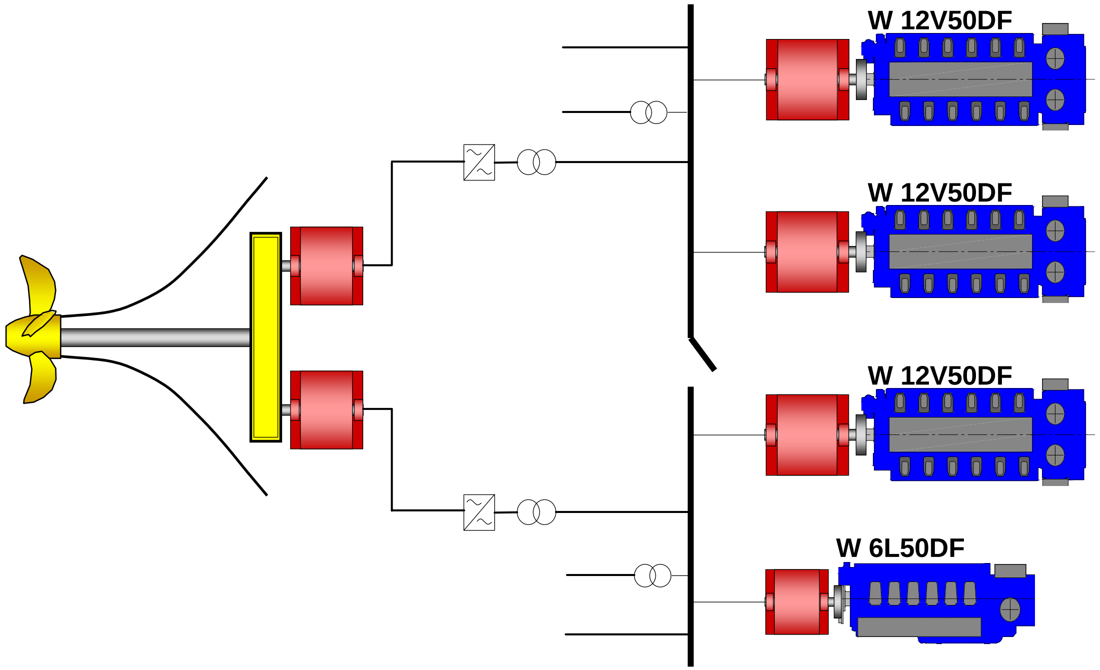
Ship size	m^3	155 000	
Ship service speed	kn	19,5	
Engine configuration:		1x6L50DF + 3x12V50DF	
Propulsion power	kW	21600	
Ship service power	kW	1500	
Propulsion losses	kW	2400	(chain efficiency of 90%)
Ship service power losses	kW	46	(chain efficiency of 97%)
Total required mechanical power	kW	25546	

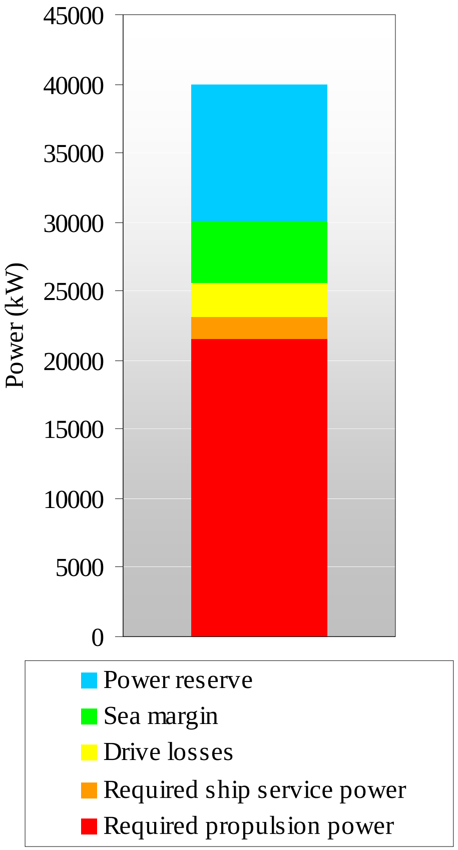
		All engines in operation	One 6L50DF engine not connected	One 12V50DF engine not connected
Total available power	kW	39900	34200	28500
Propulsion power without sea margin	kW	21600	21600	21600
Ship service power	kW	1500	1500	1500
Propulsion & Aux. gen. losses	kW	2446	2446	2446
Extra available power	kW	14354	8654	2954
Sea margin	kW	4536	4536	2954
Sea margin	%	21	21	14
Power reserve	kW	9818	4118	0
Missing power for contractual speed	kW	0	0	0
Power utilized for propulsion	kW	21600	21600	21600
Corresponding ship speed	kn	19,5	19,5	19,5

DF-E – Sailing scenarios (2/4)

1x6L50DF + 3x12V50DF

All engines in operation





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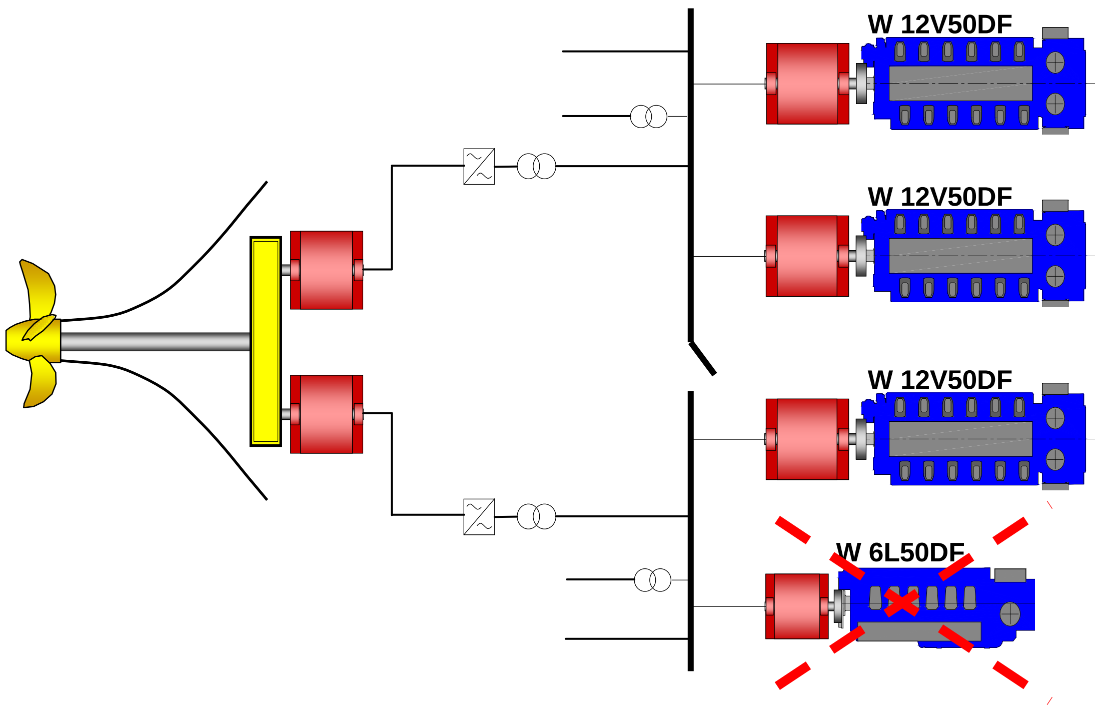
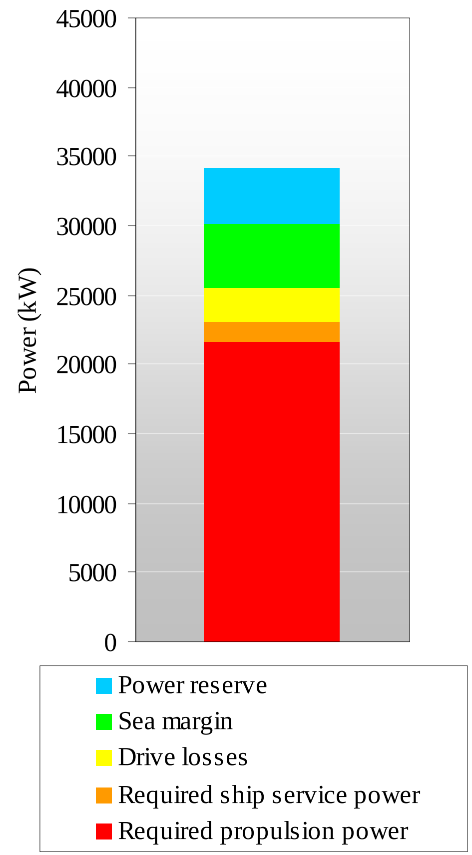
DF-E – Sailing scenarios (3/4)

1x6L50DF + 3x12V50DF

One 6L50DF not connected



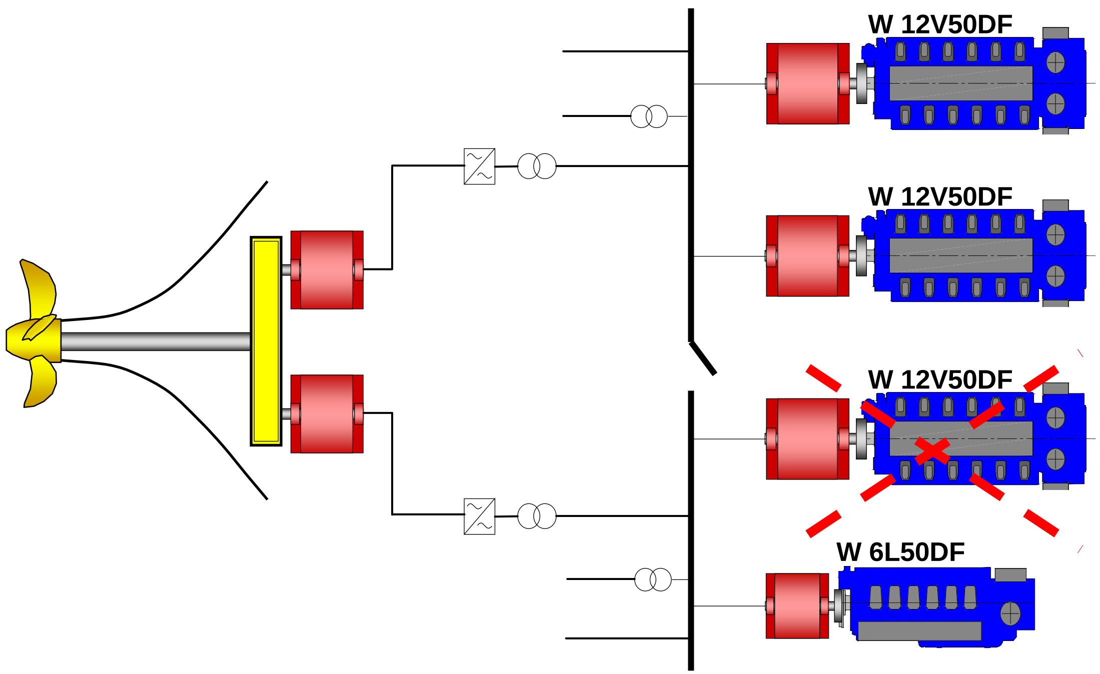


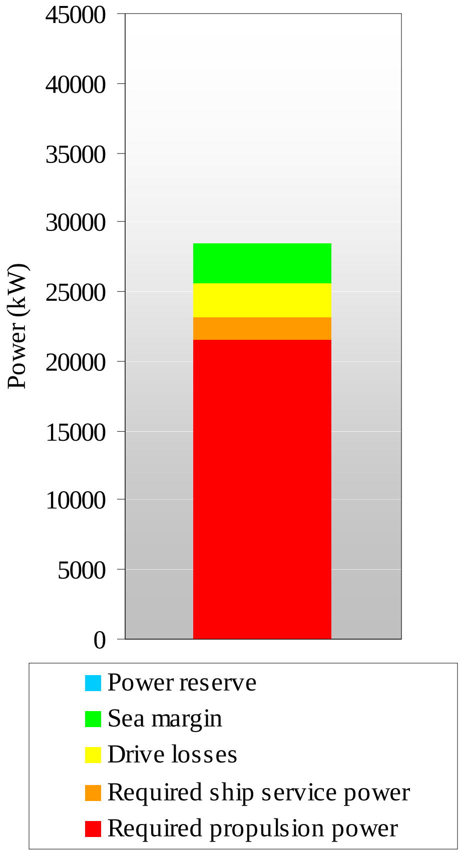
The vessel maintain contractual sailing speed of 19,5 kn

DF-E – Sailing scenarios (4/4)

1x6L50DF + 3x12V50DF

One 12V50DF not connected





The vessel maintain contractual sailing speed of 19,5 kn

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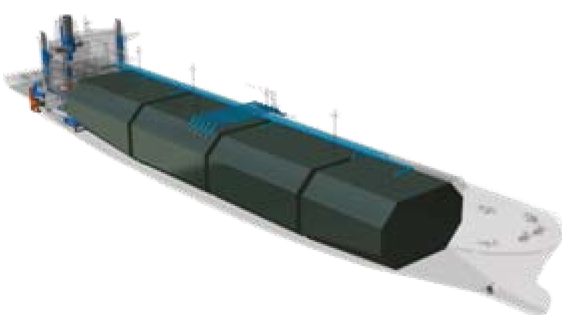
Contents



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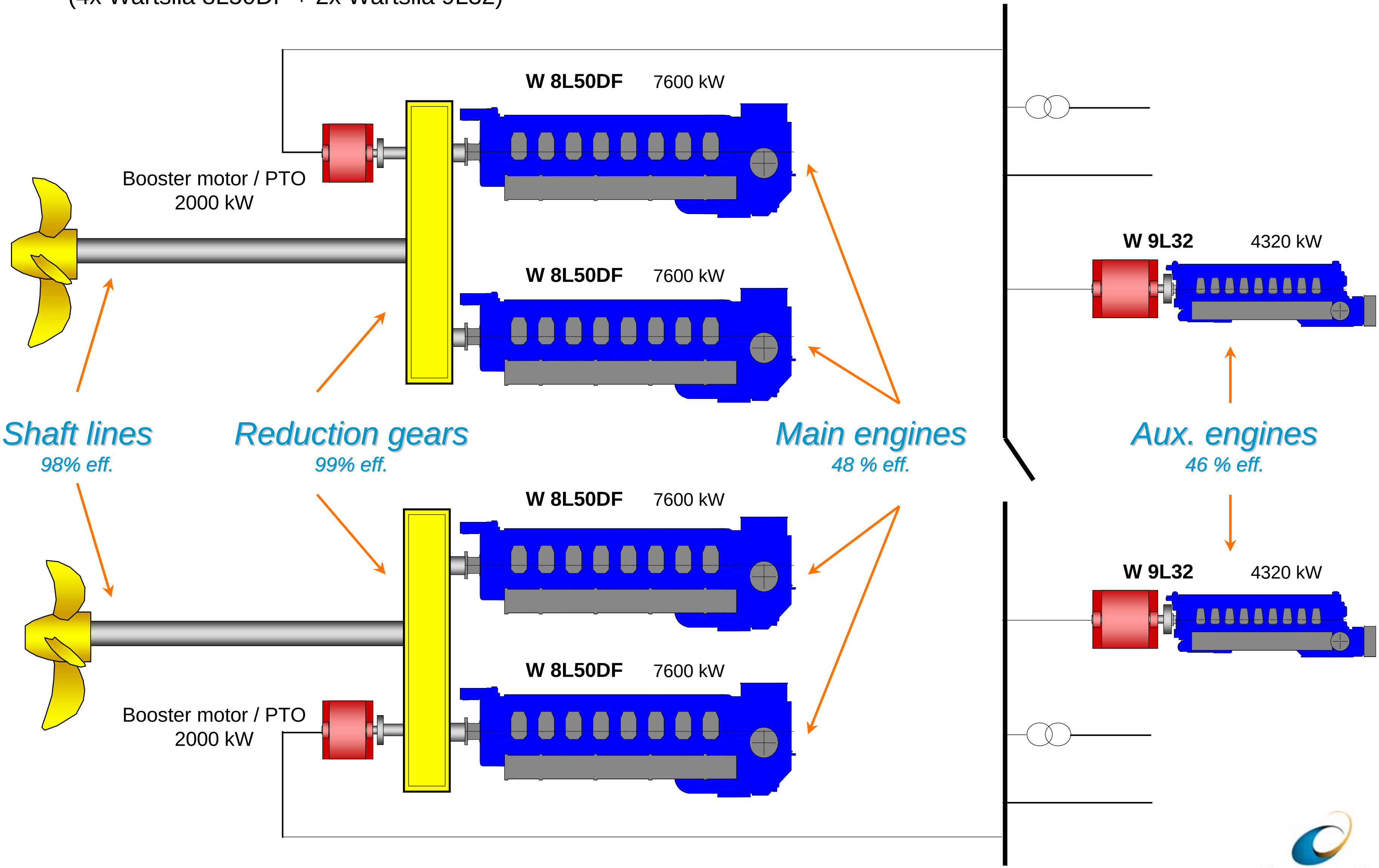
DF-M – Propulsion Components

155’000 m³ dual-fuel-electric LNG carrier
(4x Wärtsilä 8L50DF + 2x Wärtsilä 9L32)



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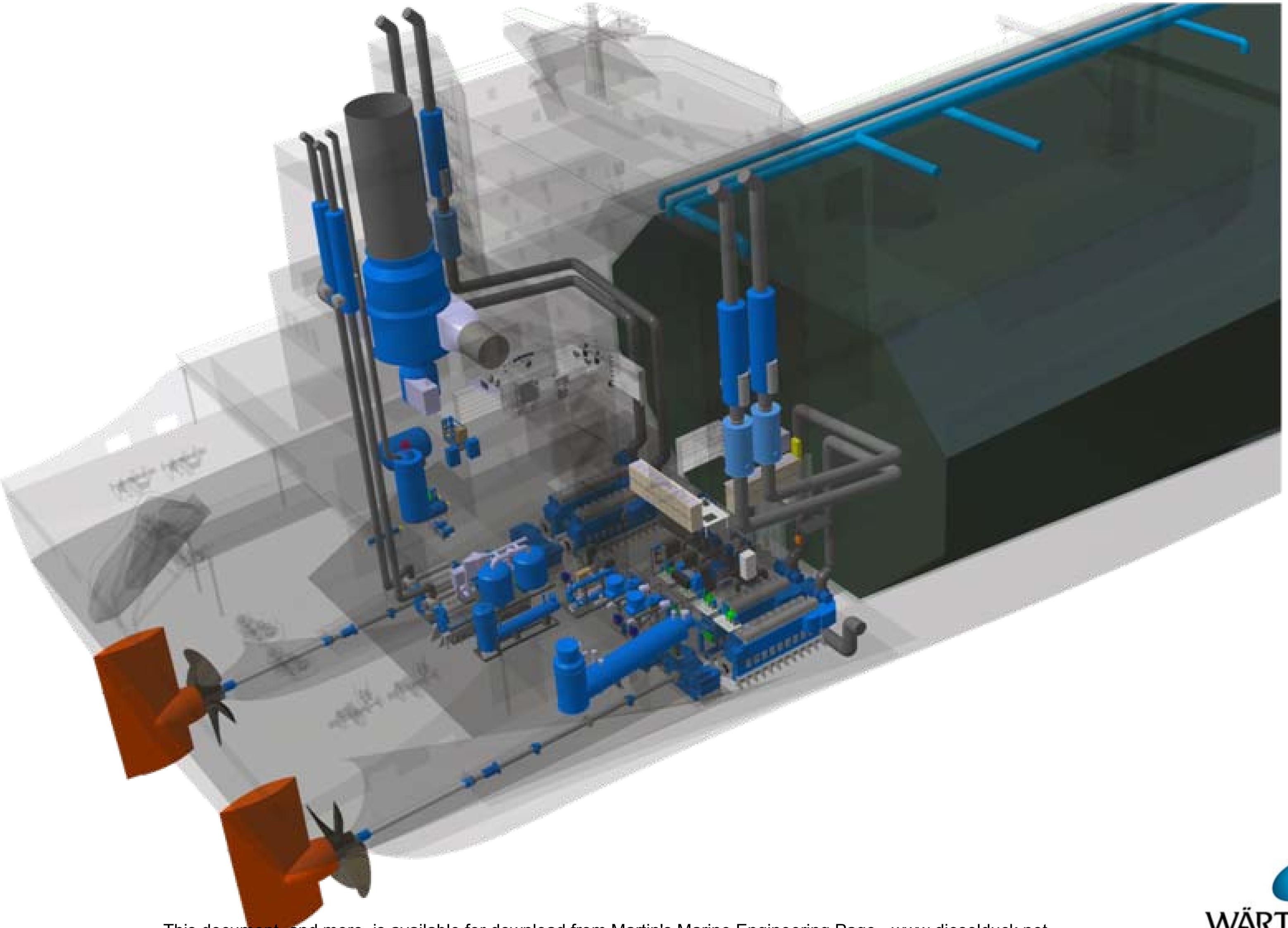
DF-M – Machinery layout

155’000 m^3 dual-fuel-mechanic LNG carrier
(4x Wärtsilä 8L50DF + 2x Wärtsilä 9L32)



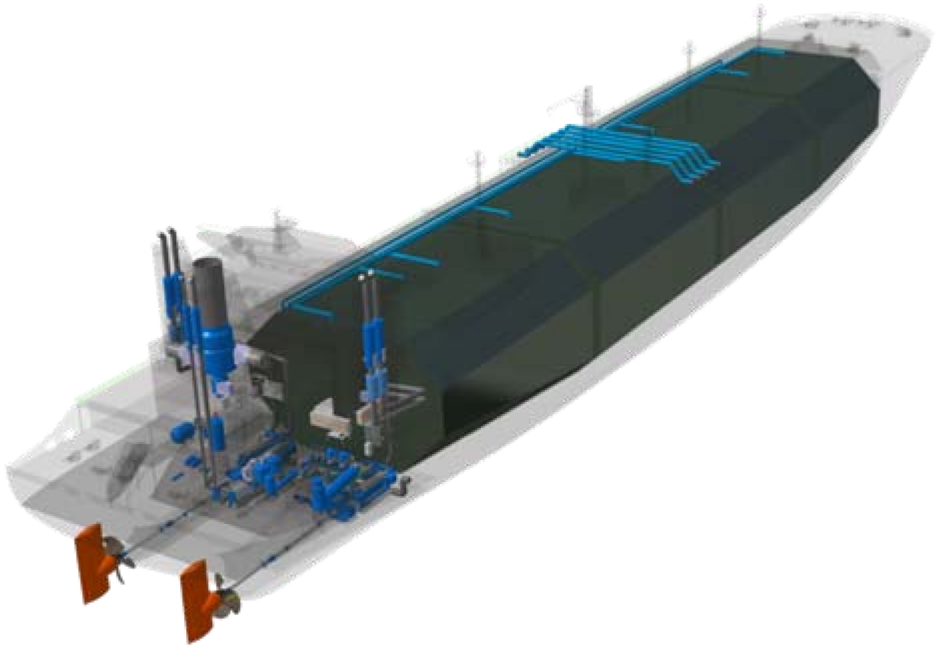
DF-M – Fuel flexibility

DF-M propulsion plant has a complete fuel flexibility.

Similarly to DF-E plant, gas, MDO or HFO can be selected with the same easiness and reliability.

Engines don't need to be stopped and do not loose power or speed when changing operating mode.

Clutch-in operation, rump-up and rump-down periods must be performed in liquid fuel mode for ensuring the fastest and most reliable result.



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DF-M – Sailing scenarios (1/3)

Power distribution calculation

Ship size	m^3	155 000	
Ship service speed	kn	19,5	
Engine configuration:		4x8L50DF	
Propulsion power	kW	21600	
Ship service power	kW	1500	
Propulsion losses	kW	668	(chain efficiency of 97%)
Ship service power losses	kW	79	(chain efficiency of 95%)
Total required mechanical power	kW	23847	

		All engines in operation	One 8L50DF engine not connected
Total available power	kW	30400	22800
Boost from booster motor	kW	-	2000
Propulsion power without sea margin	kW	21600	21600
Ship service power	kW	1500	1500
Propulsion & Aux. gen. losses	kW	747	747
Extra available power	kW	6553	953
Sea margin	kW	4536	953
Sea margin	%	21	4
Power reserve	kW	2017	0
Missing power for contractual speed	kW	0	0
Power utilized for propulsion	kW	21600	21600
Corresponding ship speed	kn	19,5	19,5

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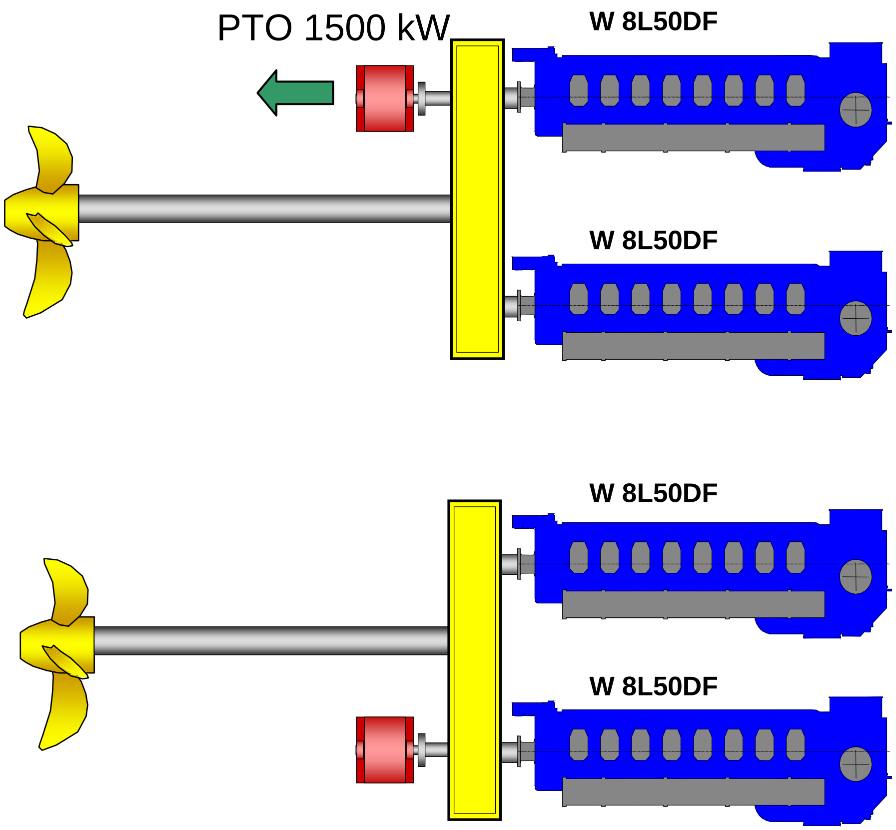
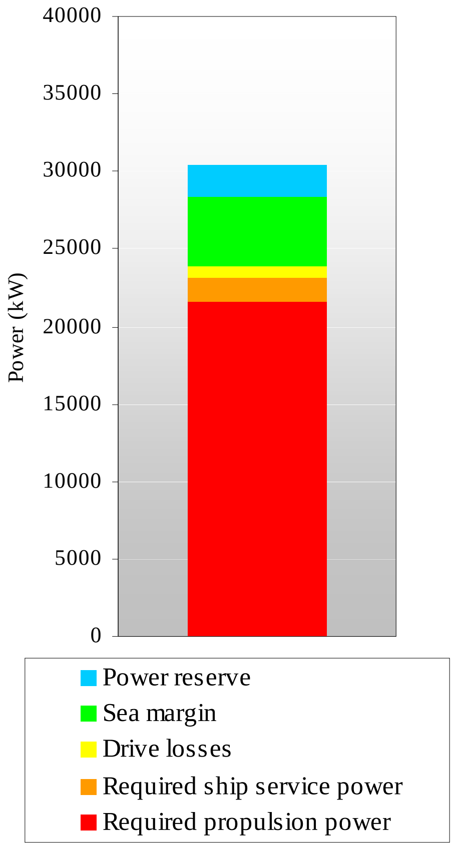
DF-M – Sailing scenarios (2/3)

4x8L50DF

All engines in operation





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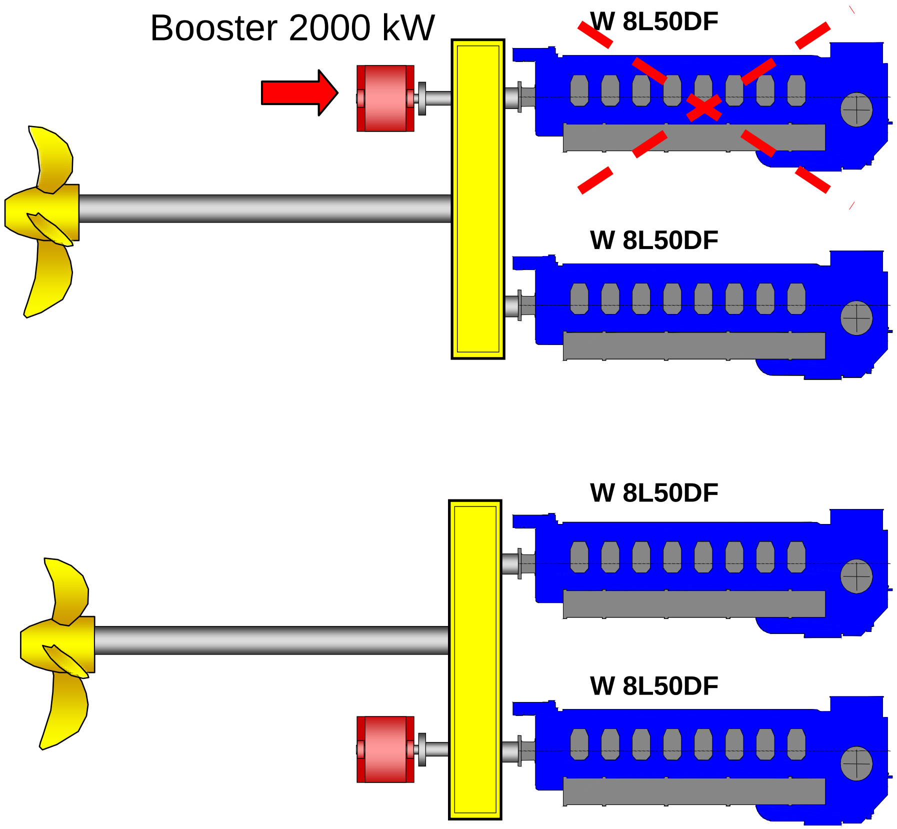
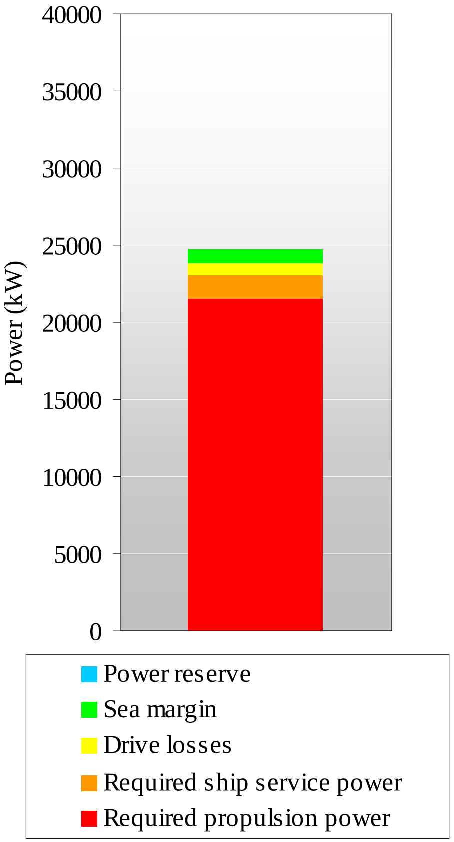
DF-M – Sailing scenarios (3/3)

4x8L50DF
One 8L50DF not in operation
Booster from booster motor





The vessel maintain contractual sailing speed of 19,5 kn

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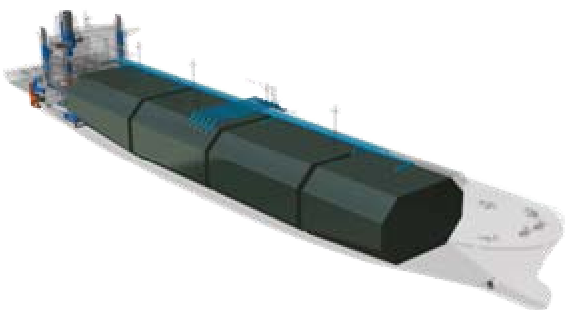

DF-M vs. DF-E

- Advantages and disadvantages of DF-M propulsion compared to DF-E.

Comparison study (1/16)

Propulsion alternatives:

- DF-Electric
- DF-Mechanic
- Two-stroke + reliquefaction
- Two-stroke gas injection engine
- Steam Turbine
- Reheated Steam Turbine
- Gas Turbine + WHR

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Comparison study (2/16)

Diesel engine alternatives – CapEx simple comparison

DF-Electric

1x6L50DF+3x12V50DF	13 M€
Electric Drive	9 M€
Propellers, shafts, gearboxes	1,5 M€
TOTAL	**23,5 M€**

DF-Mechanic

4x8L50DF + 2x9L32 (Aux)	13,5 M€
2 sets of CPP+shafts+Gearboxes	6 M€
TOTAL	**19,5 M€**

Two-stroke + reliquefaction

2x6S70ME	8,5 M€
Generating sets (4x8L32)	4 M€
Reliquefaction unit	10 M€
Propellers and shafts	1 M€
TOTAL	**23,5 M€**

Two-stroke gas injection engine

2x6S70ME	8,5 M€
Upgrade to Gas-Injection system	1 M€
Generating sets (4x8L32)	4 M€
Gas compressor	9 M€
Propellers and shafts	1 M€
TOTAL	**23,5 M€**

Note: all values are estimated

Comparison study (3/16)

Data for the calculation

Cargo capacity	155 000 m^3		
Boil-off rate, laden	0,13 %		
Boil-off rate, ballast	40 % of laden		
Leg length	6500 nm		
Service speed, laden	19,5 kt		
Service speed, ballast	19,5 kt		
Loading time	15 h		
Discharging time	15 h		
Value NBOG	2,5 US / mmBTU		
Value FBOG	8,29 US / mmBTU		
Price HFO	470 US / ton	equal to	12,3 US / mmBTU
Price MDO	780 US / ton	equal to	19,3 US / mmBTU
Price MGO	820 US / ton		
Price lube oil	490 US / ton		
Price cylinder oil (two-stroke engine)	640 US / ton		
Propeller shaft power, laden	25,0 MW		
Propeller shaft power, ballast	24,0 MW		
Ship service power, laden	1,4 MW (for steam turbine vessel)		
Ship service power, ballast	1,3 MW (for steam turbine vessel)		
Maintenance costs			
DF installation	4,00 US / MWh		
Two-stroke + reliq. Installation	1,50 US / MWh		
Four-stroke auxiliary engines	4,00 US / MWh		
Ultra Steam turbine installation	0,80 US / MWh		
Ultra Steam generator installation	0,70 US / MWh		
Gas turbine installation	4,50 US / MWh		
WHR installation (gas turbine)	0,70 US / MWh		

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Comparison study (4/16)

Alternatives' efficiency chains

DF-Electric

Fuel	100%
DF engine	48%
Alternator	97%
Trafo & Converter	98%
El. propulsion motor	98%
Gearbox	99%
Shaftline	98%
Propulsion power efficiency	**43,4%**

DF-Mechanic

Fuel	100%
DF engine	48%
Gearbox	98%
Shaftline	98%
Propulsion power efficiency	**46,1%**

2-Stroke + reliq.

Fuel	100%
2-stroke engine	49%
Shaftline	98%
Propulsion power efficiency	**48,0%**

2-Stroke gas diesel engine

Fuel	100%
2-stroke engine	49%
Shaftline	98%
Propulsion power efficiency	**48,0%**

Steam turbine

Fuel	100%
Boiler	89%
Steam turbine	34%
Gearbox	98%
Shaftline	98,0%
Propulsion power efficiency	**29,1%**

Reheated Steam turbine

Fuel	100%
Boiler	89%
Ultra Steam turbine	39%
Gearbox	98%
Shaftline	98,0%
Propulsion power efficiency	**32,9%**

Gas turbine combined cycle

Fuel	100%
GT	44%
Alternator	97%
Trafo & Converter	98%
El. propulsion motor	98%
Gearbox	98%
Shaftline	98%
Propulsion power efficiency	**39,4%**

DF-Electric

Fuel	100%
Auxiliary power	48%
Alternator	97%
Electric power efficiency	**46,6%**

DF-Mechanic

Fuel	100%
DF engine	48%
Gearbox	98%
Alternator	97%
Electric power efficiency	**45,6%**

2-Stroke + reliq.

Fuel	100%
Auxiliary engine	45%
Alternator	96%
Electric power efficiency	**43,2%**

2-Stroke gas diesel engine

Fuel	100%
Auxiliary engine	45%
Alternator	96%
Electric power efficiency	**43,2%**

Steam turbine

Fuel	100%
Boiler	89%
Aux. steam turbine	34%
Gearbox	98%
Alternator	96%
Electric power efficiency	**28,5%**

Reheated Steam turbine

Fuel	100%
Boiler	89%
Aux. steam turbine	34%
Gearbox	98%
Alternator	96%
Electric power efficiency	**28,5%**

Gas turbine combined cycle

Fuel	100%
Auxiliary power	44%
Alternator	97%
Electric power efficiency	**42,7%**

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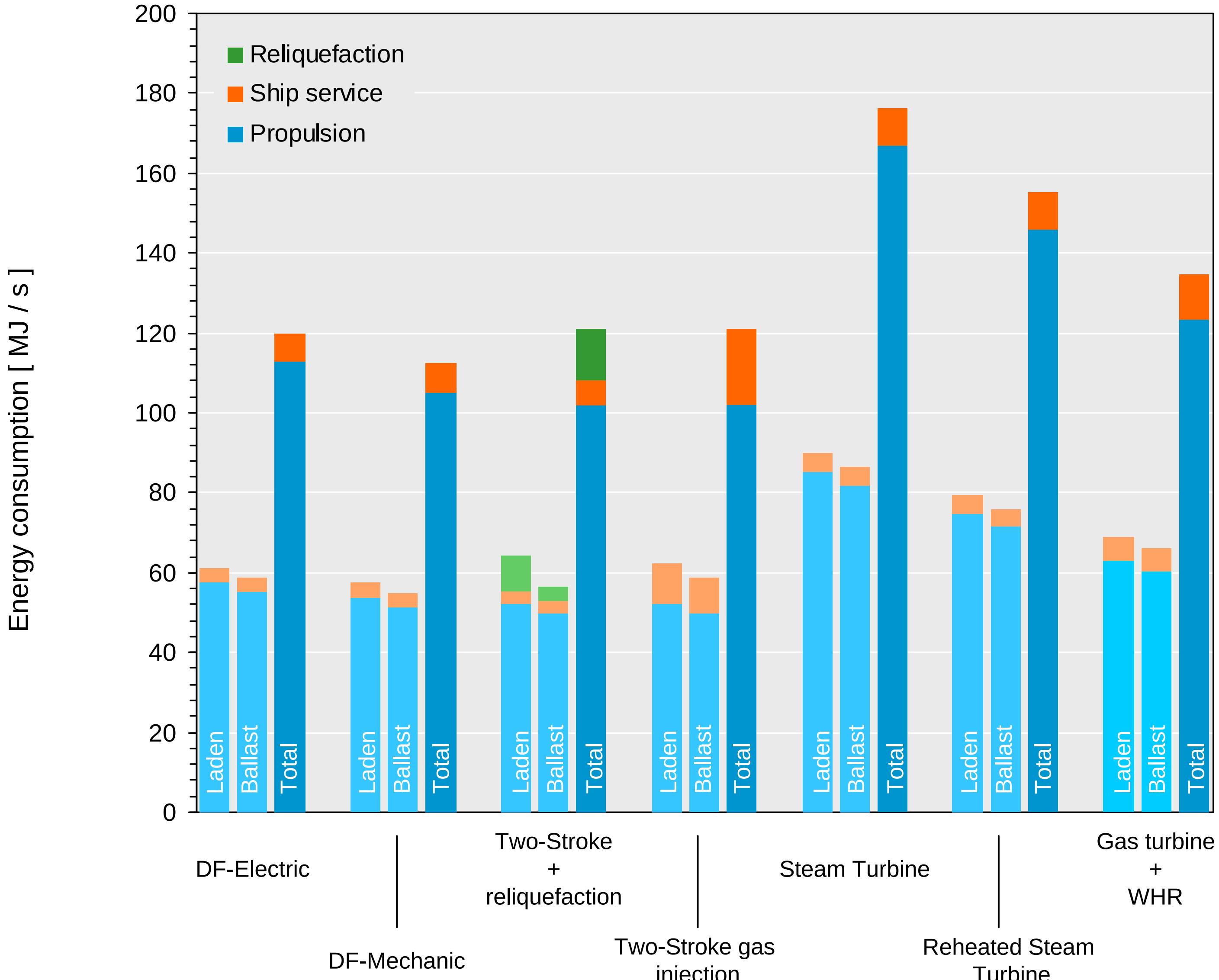
Comparison study (5/16)

Energy consumption



Comparison study (6/16)

Fuel Flexibility

Possibility of each alternative to be operated on different fuels

	Natural-BOG	Forced-BOG	MDO	HFO	MGO
DF-Electric	x	x	x	x	x
DF-Mechanic	x	x	x	x	x
Two-stroke + rel.			x	x	x
Two-stroke gas injec.	x	x	x	x	x
Steam Turbine	x	x	x	x	x
Reheated Steam Turbine	x	x	x	x	x
Gas Turbine + WHR	x	x			x

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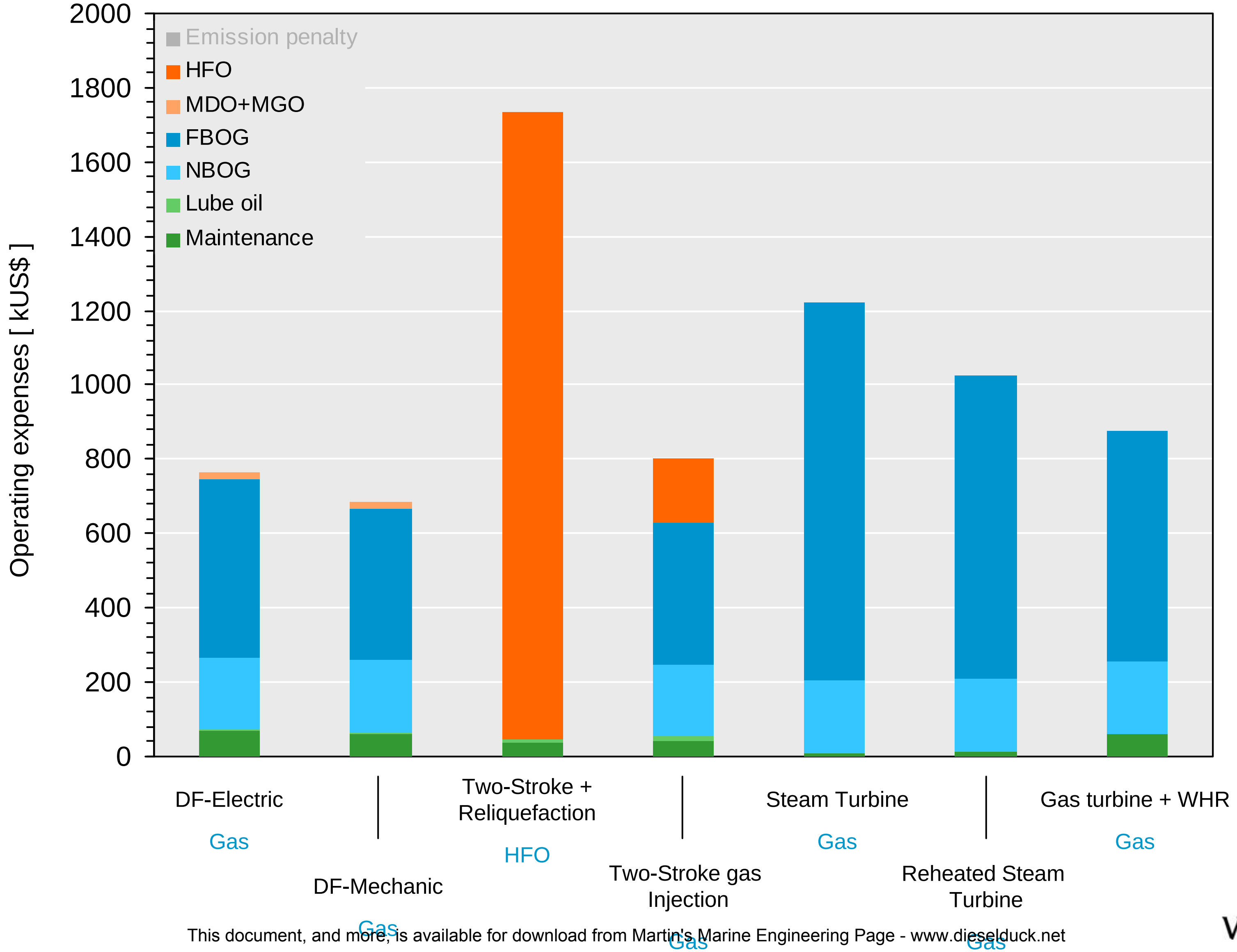
Comparison study (7/16)

Reasonable fuel selection

	Usual operating on:	Reason for fuel selection:
DF-Electric	Natural-BOG + Forced-BOG	High efficiency in gas mode, cleanest energy source.
DF-Mechanic	Natural-BOG + Forced-BOG	High efficiency in gas mode, cleanest energy source.
Two-stroke + rel.	HFO	Only possibility. MDO not profitable.
Two-stroke gas injec.	Natural-BOG + HFO	High percentage of HFO always needed. If NBOG+FBOG selected, high amount of gas to be compressed.
Steam Turbine	Natural-BOG + Forced-BOG	No significant difference. Gas is the cleanest source of energy.
Reheated Steam Turbine	Natural-BOG + Forced-BOG	No significant difference. Gas is the cleanest source of energy.
Gas Turbine + WHR	Natural-BOG + Forced-BOG	MGO utilization not profitable.

Comparison study (8/16)

Operating expenses per roundtrip
Maximization of gas use



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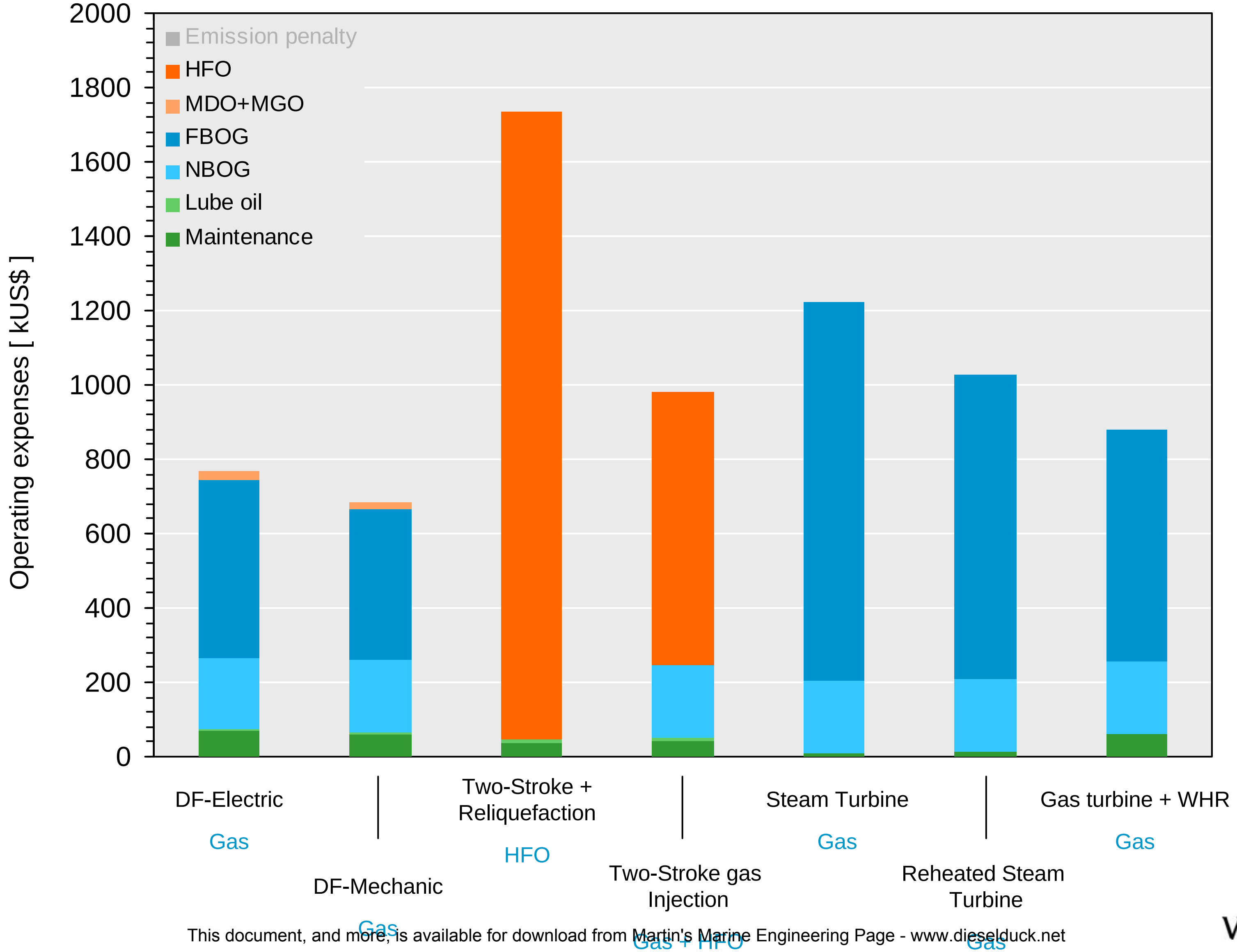
Comparison study (9/16)

Operating expenses per roundtrip
Reasonable fuel selection



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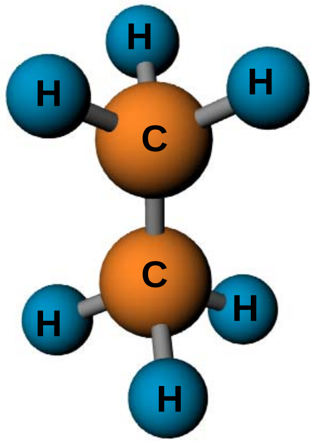
Comparison study (10/16)

Very low emission levels:

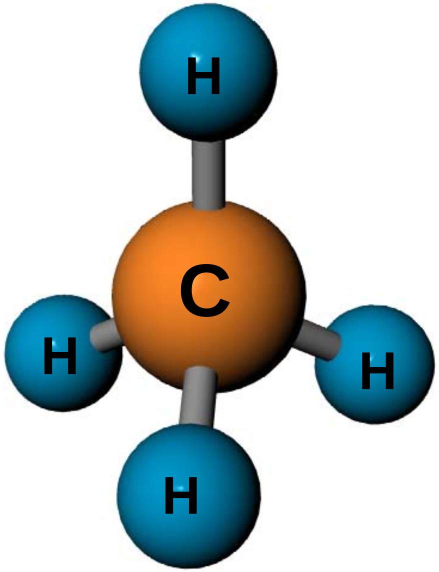
- Clean burning
- Relatively free of contaminations
- Methane contains the highest amount of hydrogen per unit of energy of all fossil fuels -> lower CO_2 emissions
- Lean burn Otto process provides very low NO_x emissions

Natural gas compared to diesel:

- CO emissions reduction approx. 75%
- CO_2 emissions reduction approx. 20%
- NO_x emissions reduction approx. 80%
- No SO_x emissions
- Benzene emissions reduction approx. 97%
- No lead emissions
- Less particle emissions
- No visible smoke



Ethane (C_2H_6)



Methane (CH_4)

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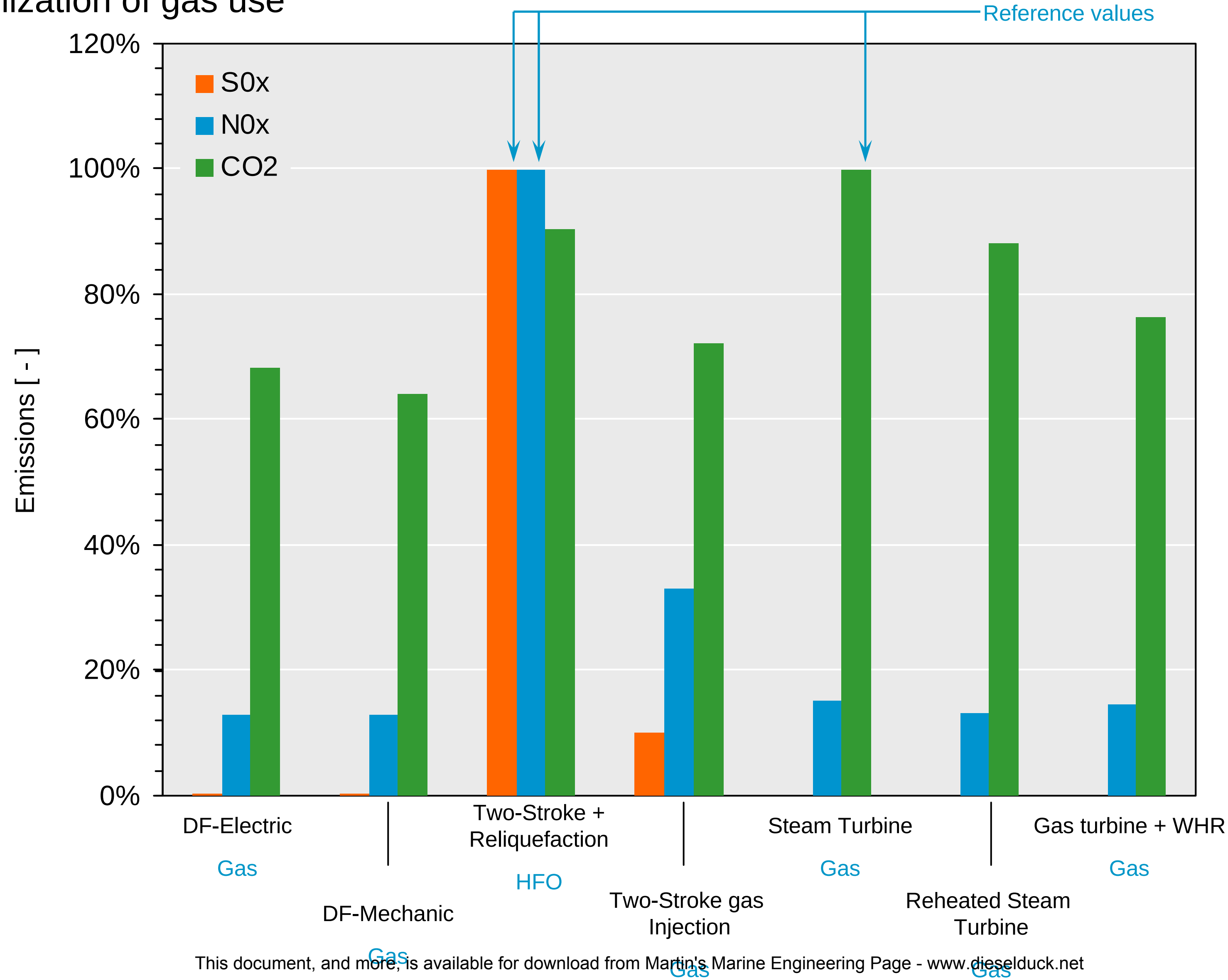
Comparison study (11/16)

Emissions
Maximization of gas use



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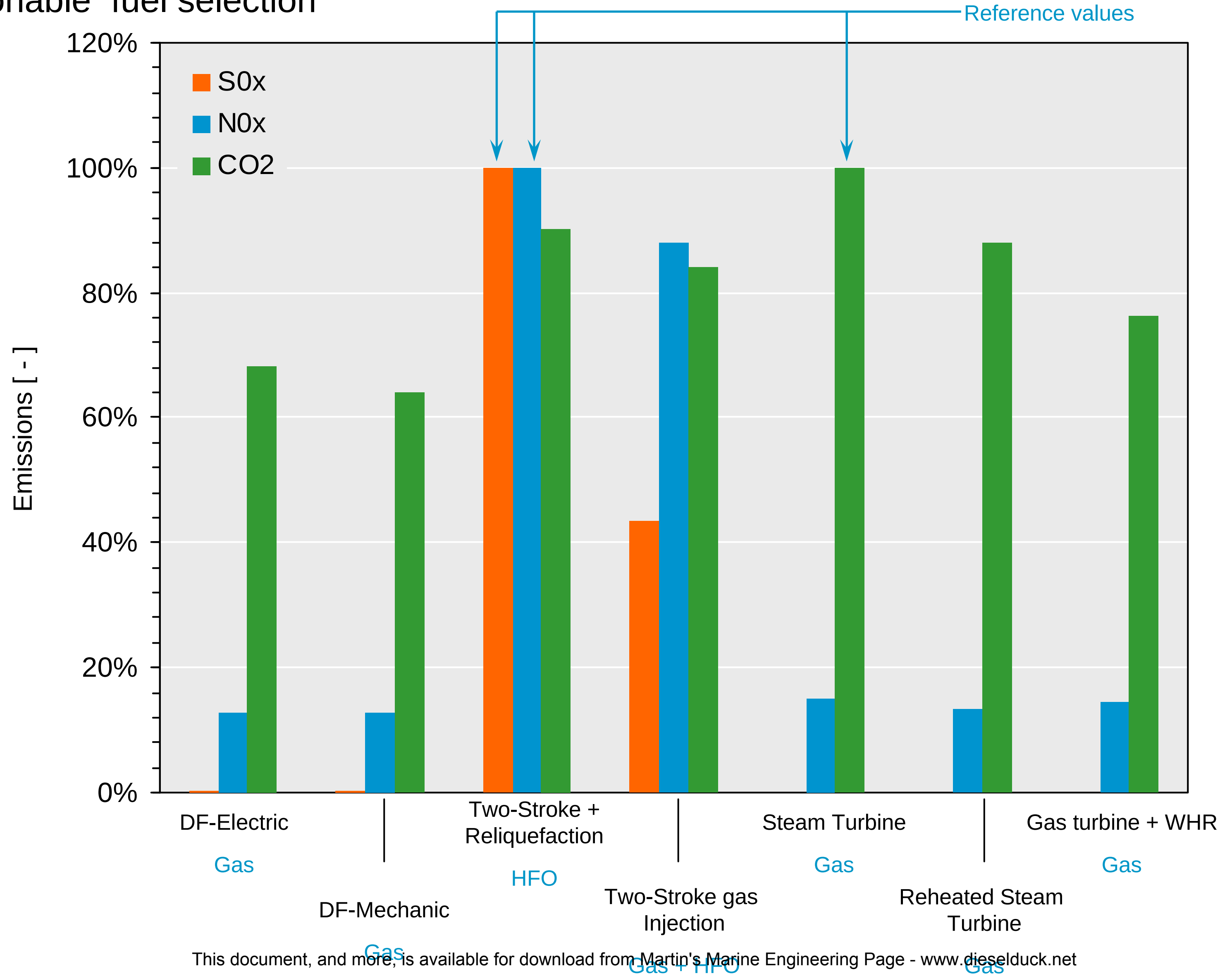
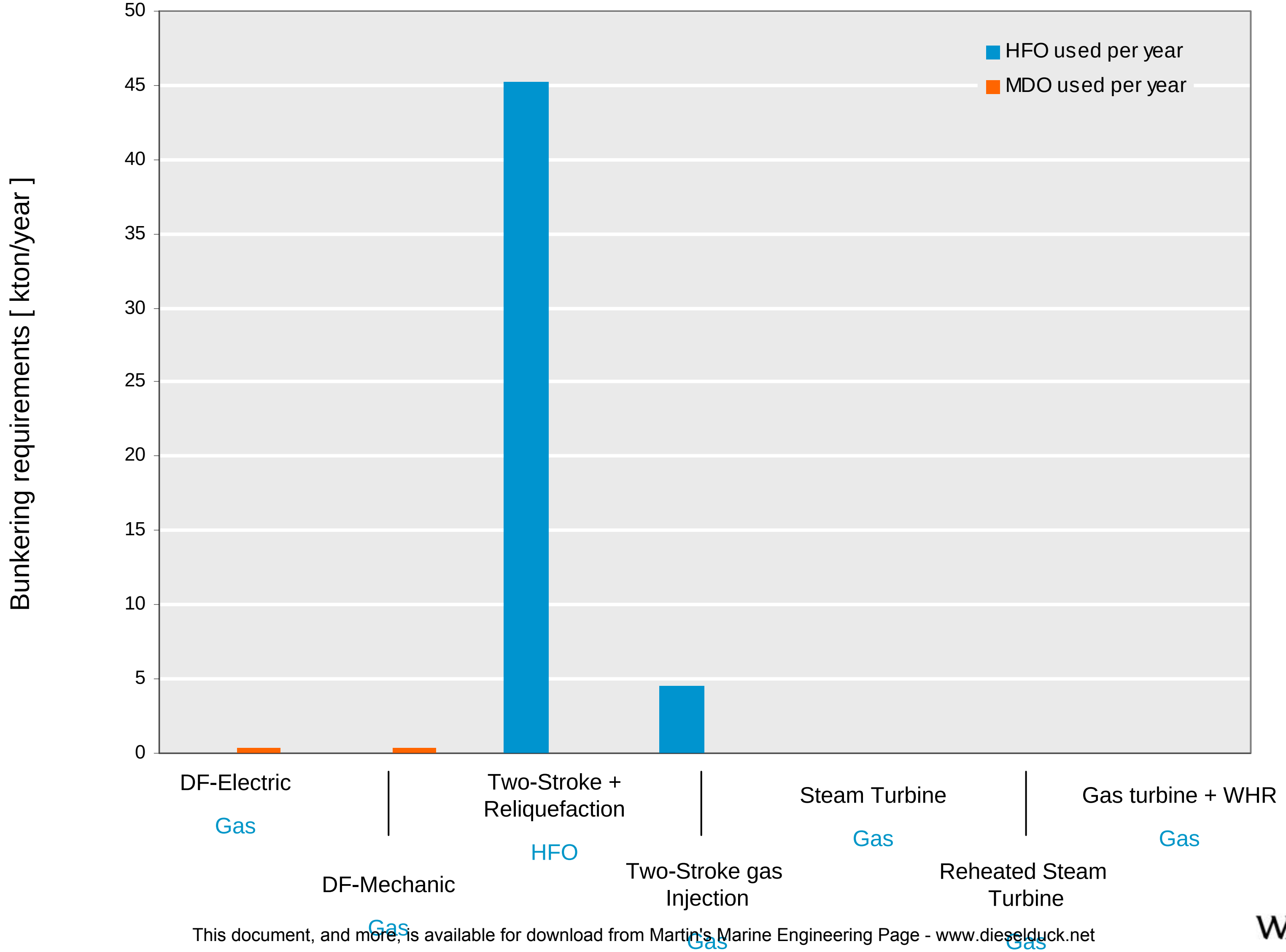
Comparison study (12/16)

Emissions
Reasonable fuel selection



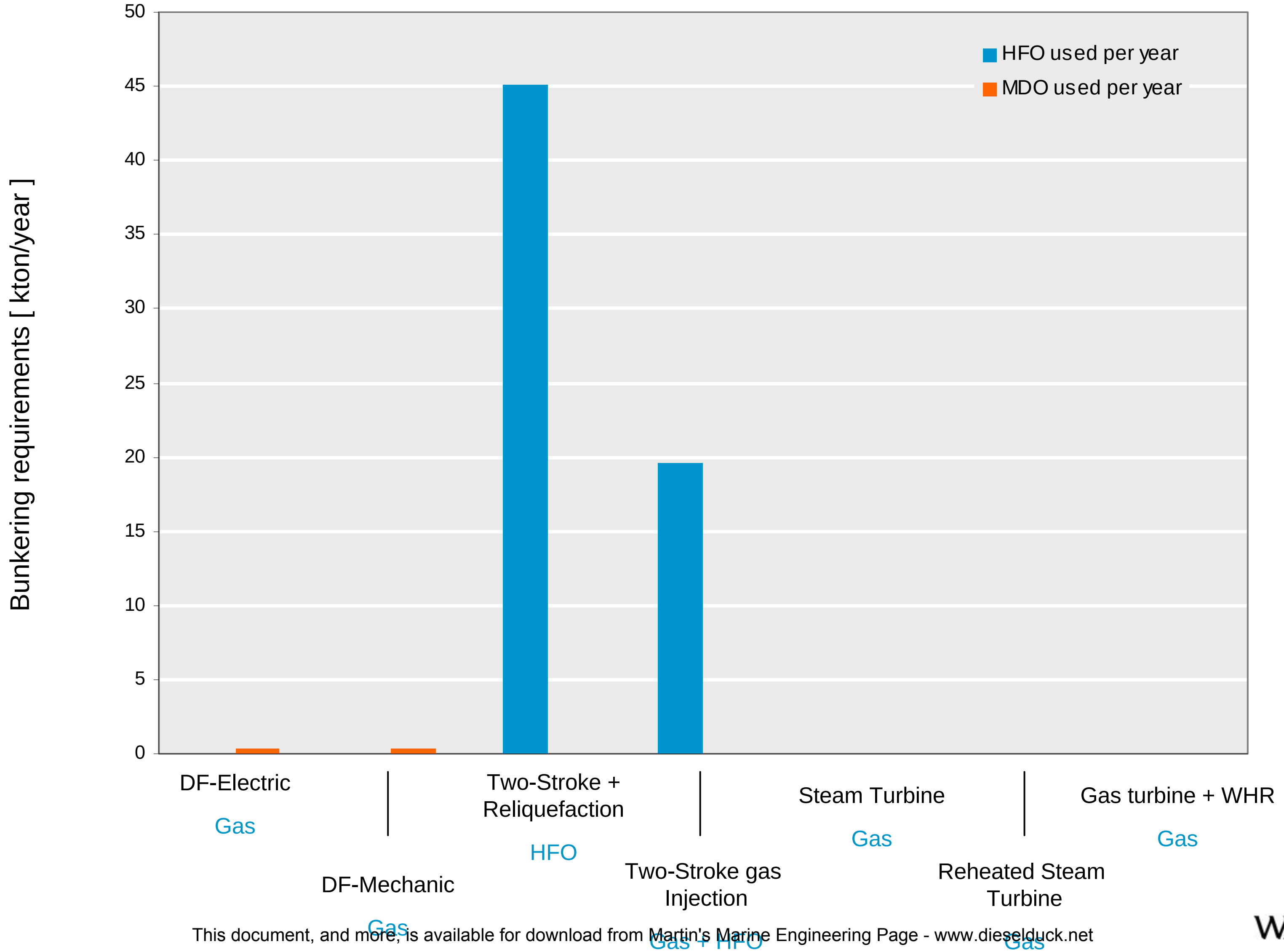
Comparison study (13/16)

Yearly bunkering requirements
Maximization of gas use



Comparison study (14/16)

Yearly bunkering requirements
Reasonable fuel selection



Comparison study (15/16)

Safety, reliability and redundancy

A safety concept has been developed by Wärtsilä for the applications of dual-fuel engines on LNGCs.

The safety concept describes the required measures to make dual-fuel LNGCs as safe as steam turbine LNGCs.

The safety concept has been approved in principle by all major classification societies.

Additionally, many HazId, HazOp and FMEA analyses have been successfully carried out.

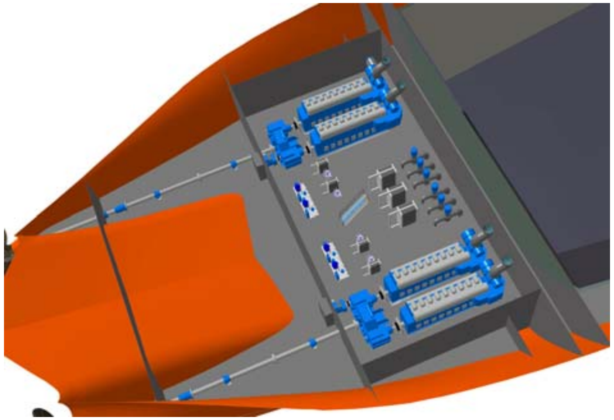
Low pressure gas admission ensures safe operation on gas in every sailing condition.

The dual-fuel engines have inherited reliability from the diesel engines from which they are derived.

Additionally, experience have been gained through the field operation of already sailing Dual-Fuel-Electric LNGC.

Electric propulsion systems featuring multiple generating sets are state-of-the-art with respect to redundancy.

Dual-Fuel-Mechanic alternative imply a high level of redundancy as well, thanks to the multiple engine installation.



Comparison study (16/16)

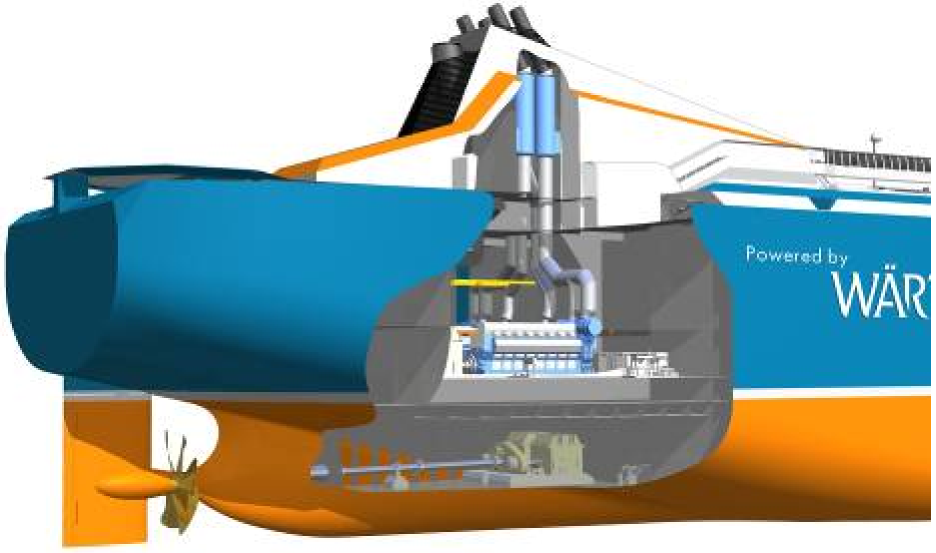
Maintainability and crewing

Dual-fuel engines require substantially less maintenance than diesel engines when running predominantly on gas.

Additionally, the Dual-Fuel machinery concept allows for single engines to be taken out of operation without significantly affecting the ship's performance.

Dual-fuel engines can be operated by regular diesel engine crews with decent training.

No exceptional skills are required as no high pressure steam/gas is present onboard.



Comparison study - Summary

5….Good 1….Bad	Two Stroke + reliquefaction	Two Stroke gas diesel	Steam Turbine	Reheated Steam turbine	Dual-Fuel Electric	Dual-Fuel Mechanic	Gas Turbine + WHR
CapEx	3	4	5	4	3	4	2
OpEx	1	4	2	3	4	5	3
Emissions	1	3	1	2	5	5	3
Fuel bunkering req.	1	3	5	5	5	5	5
Safety	4	1	4	4	5	5	3
Reliability	4	3	5	5	4	4	4
Redundancy	3	3	3	3	5	5	3
Maintainability	3	3	5	5	3	3	4
Crewing	5	4	3	3	5	5	4
Total	***25***	***28***	***33***	***34***	***39***	***41***	***31***

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Contents

DF-Electric Vs. DF-Mechanic (1/2)

Dual-Fuel-Electric has…

- High efficiency with engines running always at high loads
- The constant load entails less thermal load and, therefore, less wear of components
- Fixed pitch propeller can be used with consequent reduction in capital cost and in propeller maintenance
- Auxiliaries engines are not needed

Economical advantages

- Full torque at zero load given by electric motors
- Reduction gear doesn't need any clutch with derived more simple construction and less maintenance required
- The maintenance can be carried out in an easier way as engines are not coupled with the reduction gear
- Very good operational characteristics at ice on in difficult sea conditions

Operational advantages

DF-Electric Vs. DF-Mechanic (2/2)

Dual-Fuel-Mechanic has…

- High efficiency of the complete propulsion system with consequent lower OpEx
- Smaller investment cost. Electric motors, frequency converters, transformers and large switchboards are not needed
- Save in space and weight as all electric drives are not needed. Higher cargo capacity
- At harbour auxiliary engines can run at high load with high efficiency and low SFOC

Economical advantages

- Smaller propulsion engines are needed. The maintenance can be faster and cheaper
- When an engine is under maintenance, PTO can be used as boost
- Simpler and smaller automation system.
- Simple power management system for auxiliary engines

Operational advantages

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THANK YOU FOR YOUR ATTENTION!

For more information, please contact your local Wärtsilä representative or visit wartsila.com