Dual-fuel-electric LNG carriers

LNG Shipping Operations

Hamburg, September 27, 2006

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Wärtsilä Finland Oy
Ship Power Solutions

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Contents

- Introduction
- Dual-fuel engines
  Characteristics, systems, applications
- Dual-fuel-electric LNG carriers
  Concept, fuel alternatives, advantages
- Conclusions

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Introduction

Introduction

- Machinery standard, until recently
- Machinery alternatives
- Innovation triggers and stoppers

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Machinery standard, until recently

Steam turbine machinery:

- Two boilers, most commonly fired with Natural Boil-Off Gas (N-BOG) and Heavy Fuel Oil (HFO)
- Steam turbine, driving a single fixed-pitch propeller through a high-speed reduction gear
- Two steam turbine generators
- One or two diesel generators

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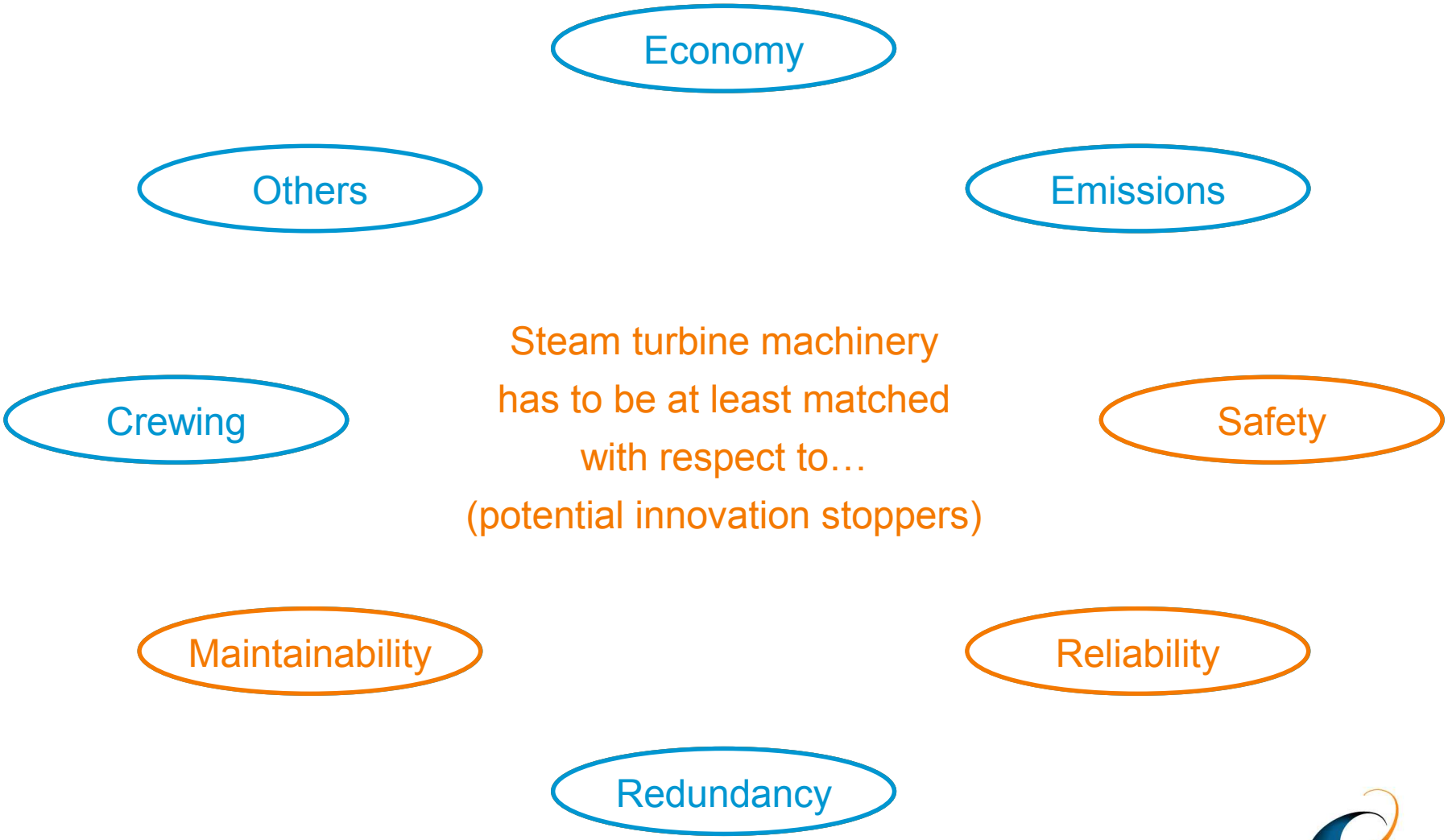
Machinery alternatives

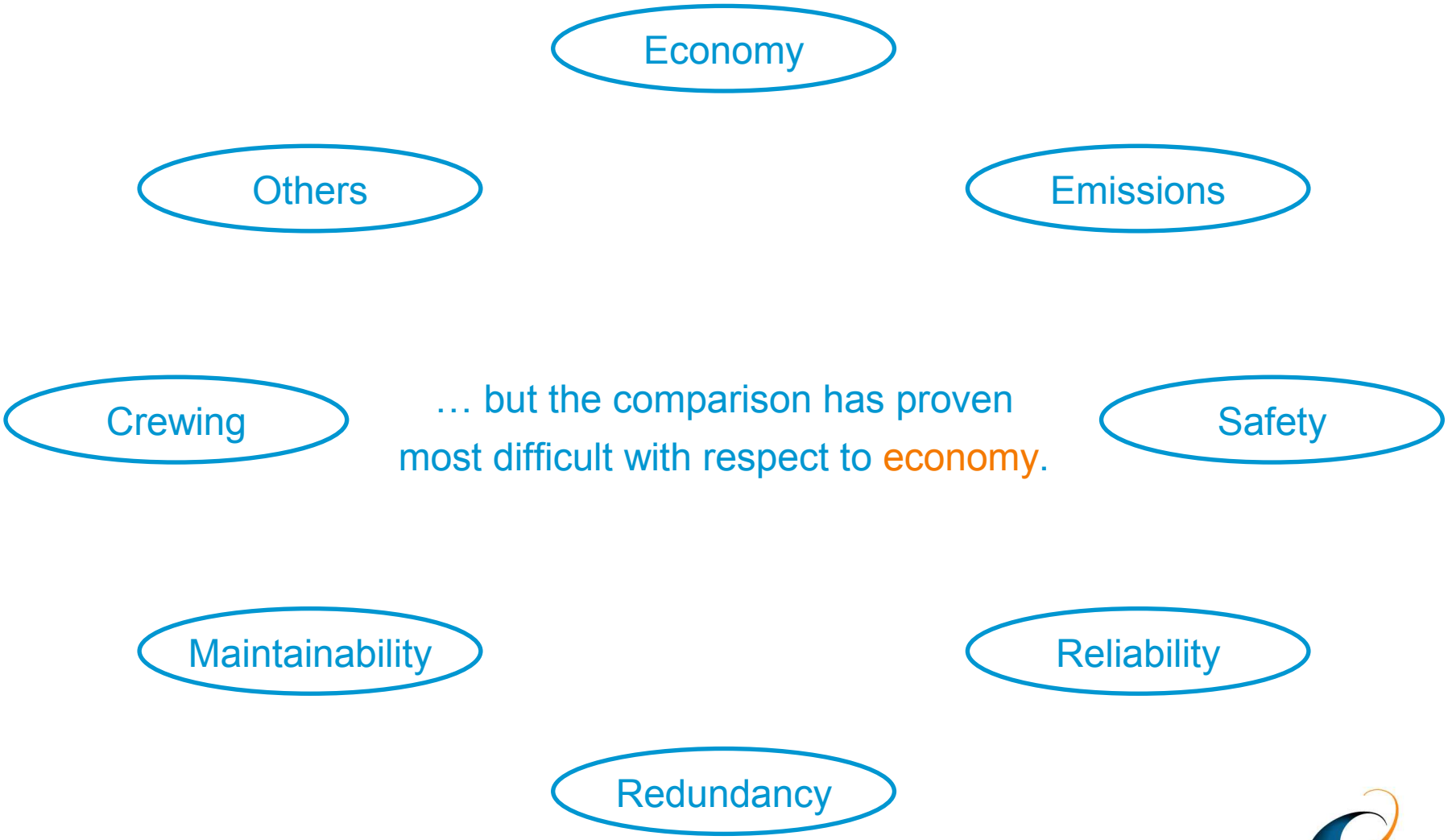
Machinery alternatives based on:

- Diesel engines
- Gas turbines
- Gas-diesel engines
- Spark-ignition gas engines
- Dual-fuel engines

Innovation triggers and stoppers

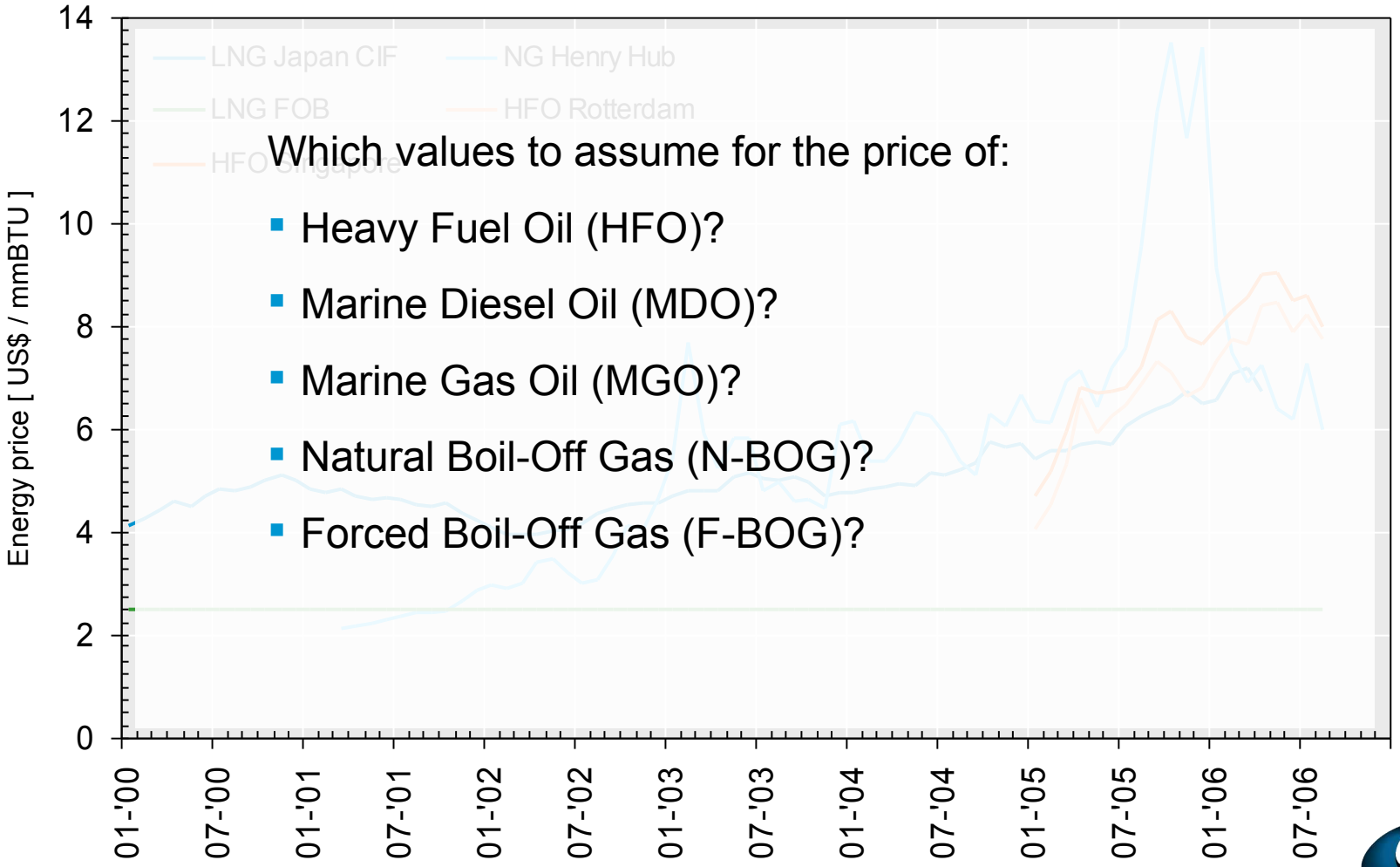


Innovation triggers and stoppers



Fuel price development

Volatile energy / fuel prices today (and tomorrow?)



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Dual-fuel engines

Dual-fuel engines

- Introduction
- Characteristics
  Operation modes, operating mode changes, parameters
- Systems
  Gas and pilot fuel system, control system
- Applications
  On land, at sea, in LNG carriers

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Three distinct gas engine technologies

Gas-diesel (GD) engines:

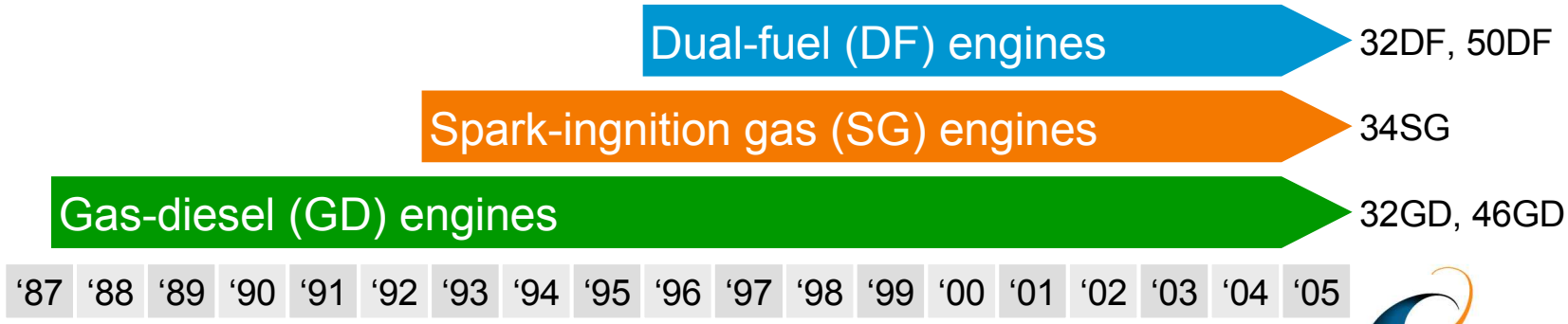
- Runs on various gas / diesel mixtures or alternatively on diesel.
- Combustion of gas, diesel and air mixture in Diesel cycle.
- High-pressure gas injection.

Spark-ignition gas (SG) engines:

- Runs only on gas.
- Combustion of gas and air mixture in Otto cycle, triggered by spark plug ignition.
- Low-pressure gas admission.

Dual-fuel (DF) engines:

- Runs on gas with 1% diesel (gas mode) or alternatively on diesel (diesel mode).
- Combustion of gas and air mixture in Otto cycle, triggered by pilot diesel injection (gas mode), or alternatively combustion of diesel and air mixture in Diesel cycle (diesel mode).
- Low-pressure gas admission.



Dual-fuel engine characteristics

Wärtsilä 6L50DF

- High efficiency
- Low gas pressure
- Low emissions, due to:
  - High efficiency
  - Clean fuel
  - Lean burn combustion
- Fuel flexibility
  - Gas mode
  - Diesel mode
- Two engine models
  - Wärtsilä 32DF
  - Wärtsilä 50DF

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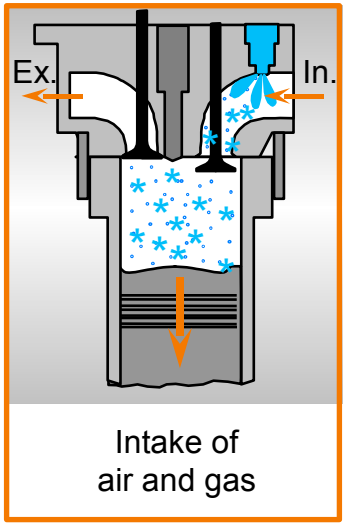
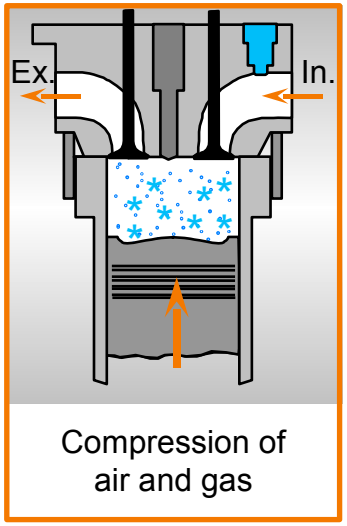
Engine characteristics - Operating modes

Gas mode:

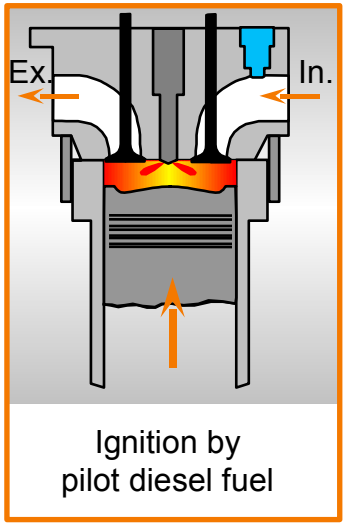
- Otto principle
- Low-pressure gas admission
- Pilot diesel injection



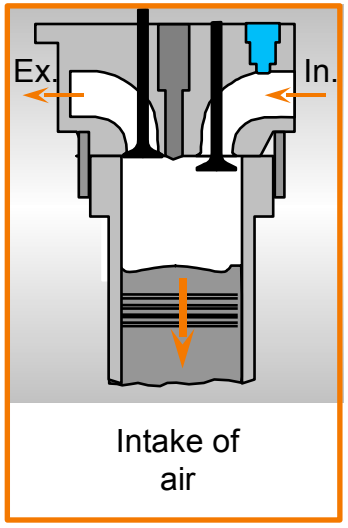
Intake of air and gas



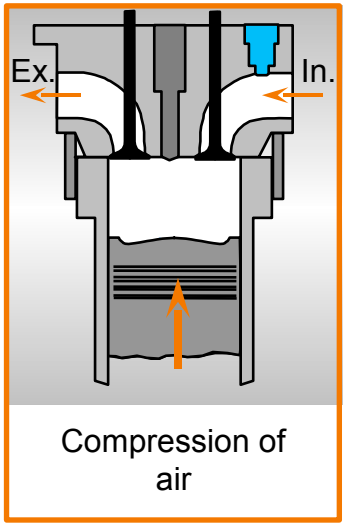
Compression of air and gas



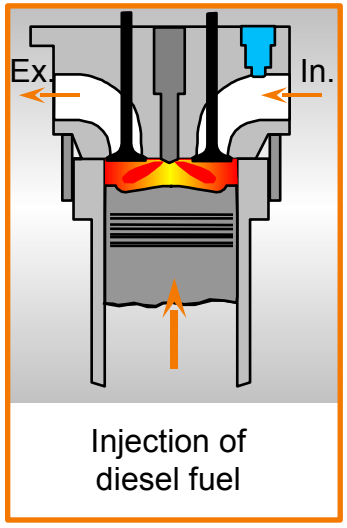
Ignition by pilot diesel fuel



Intake of air



Compression of air



Injection of diesel fuel

Diesel mode:

- Diesel principle
- Diesel injection

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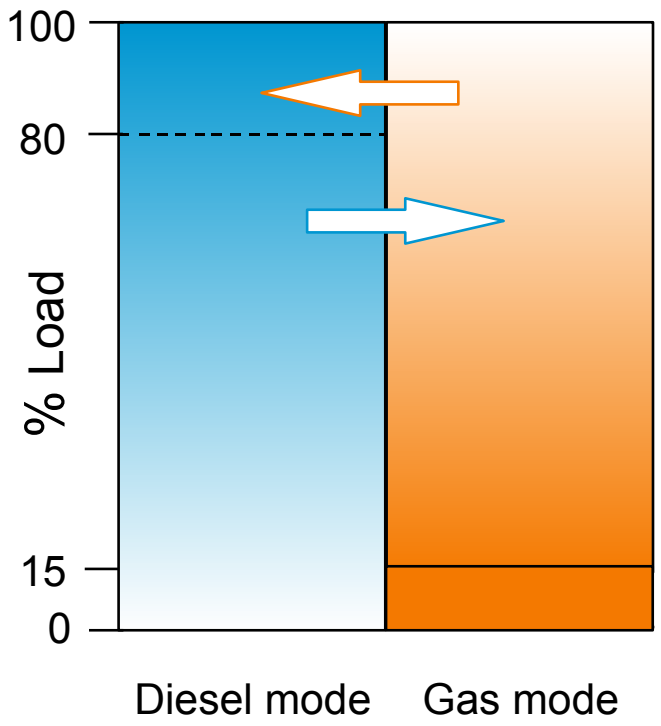
Engine characteristics - Operating mode changes

Gas mode:

- Running on gas and MDO pilot fuel injection.
- Automatic and instant trip to diesel mode in alarm situations without loss of engine power and speed.
- Automatic transfer to diesel mode on request at any load without loss of engine power and speed.
- Automatic trip to diesel mode after 3 minutes at engine loads below 15%.

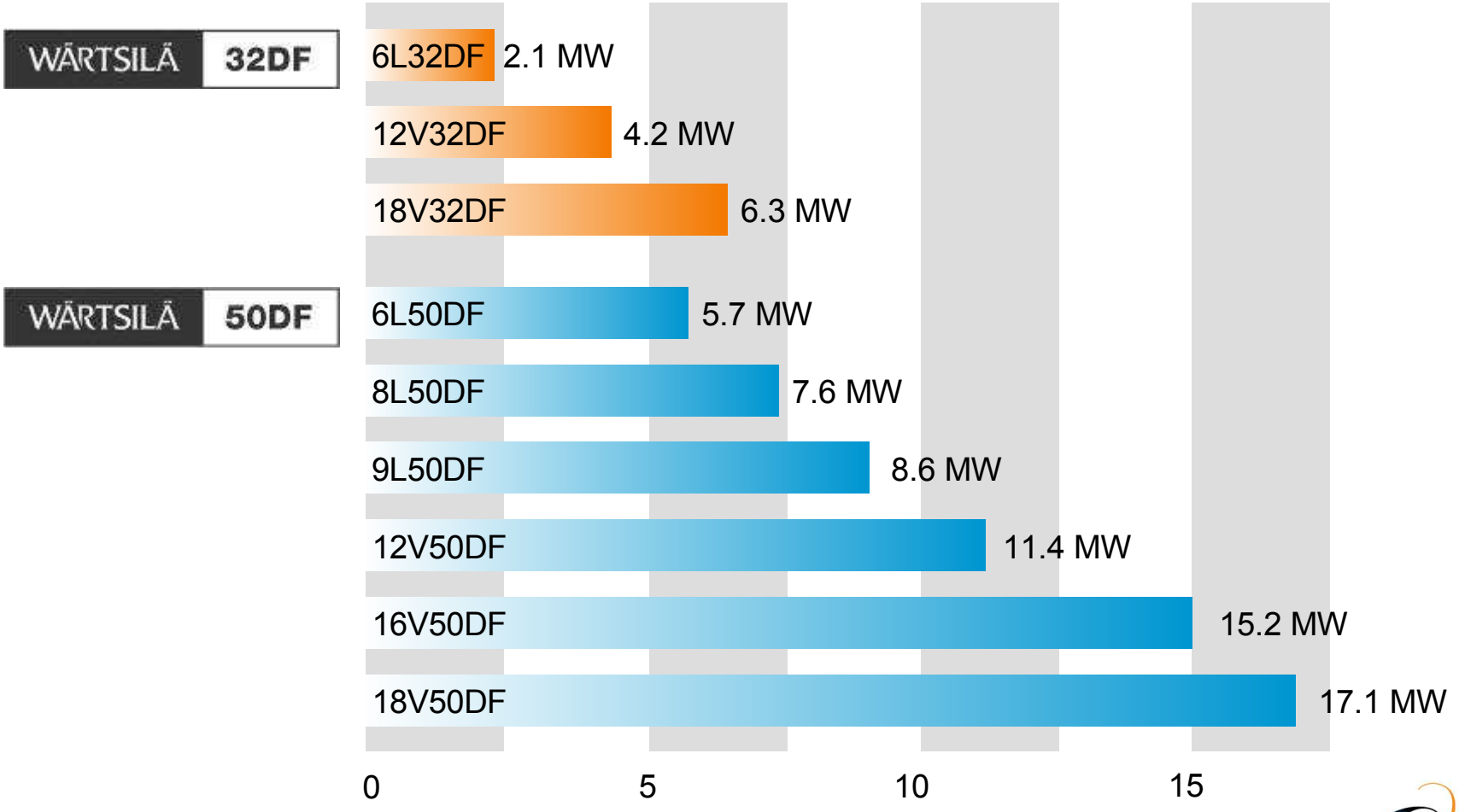
Diesel mode:

- Running on HFO* or MDO and MDO pilot fuel injection.
- Automatic transfer to gas mode on request at loads below 80% without loss of engine power and speed.

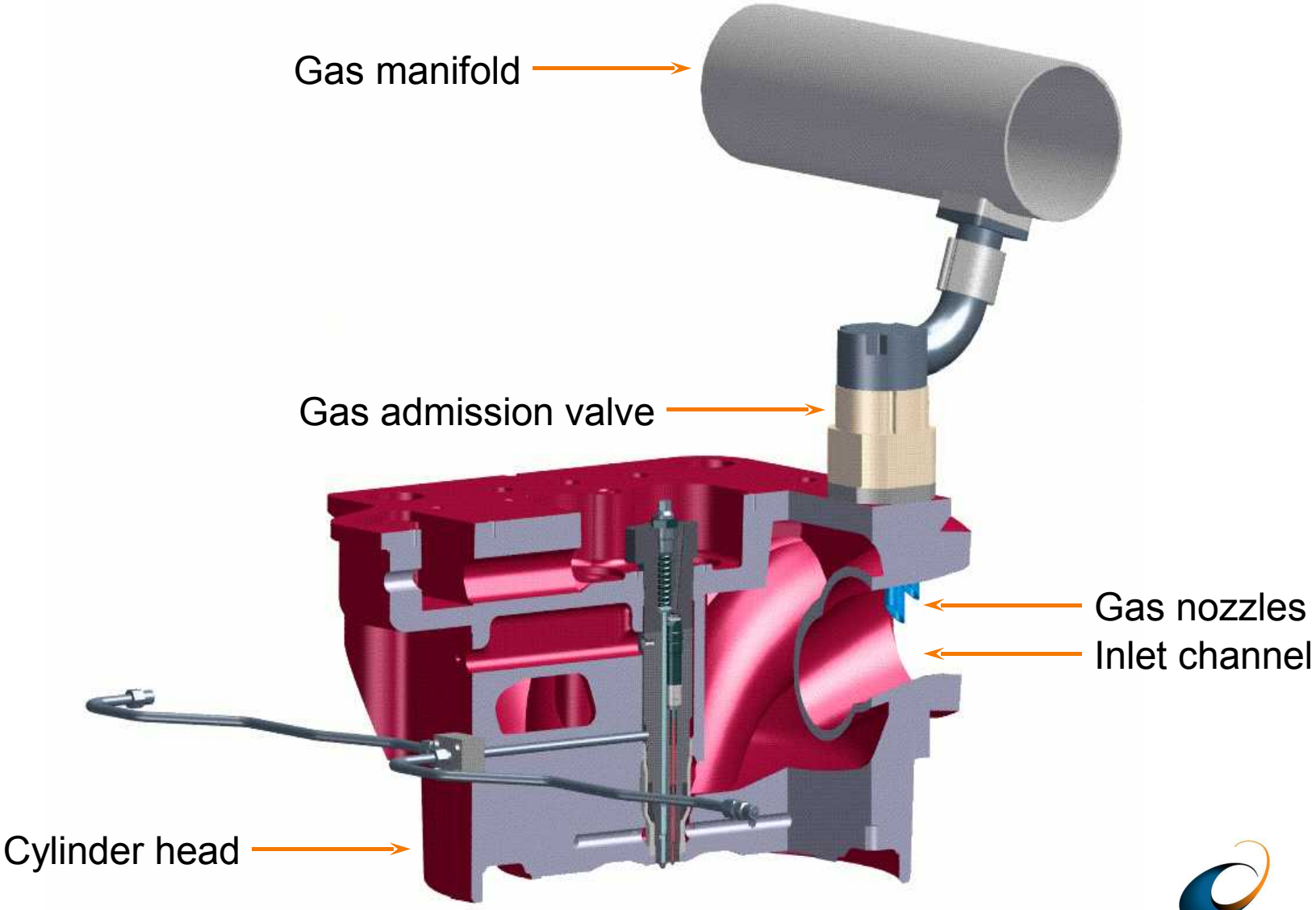


* Wärtsilä 50DF

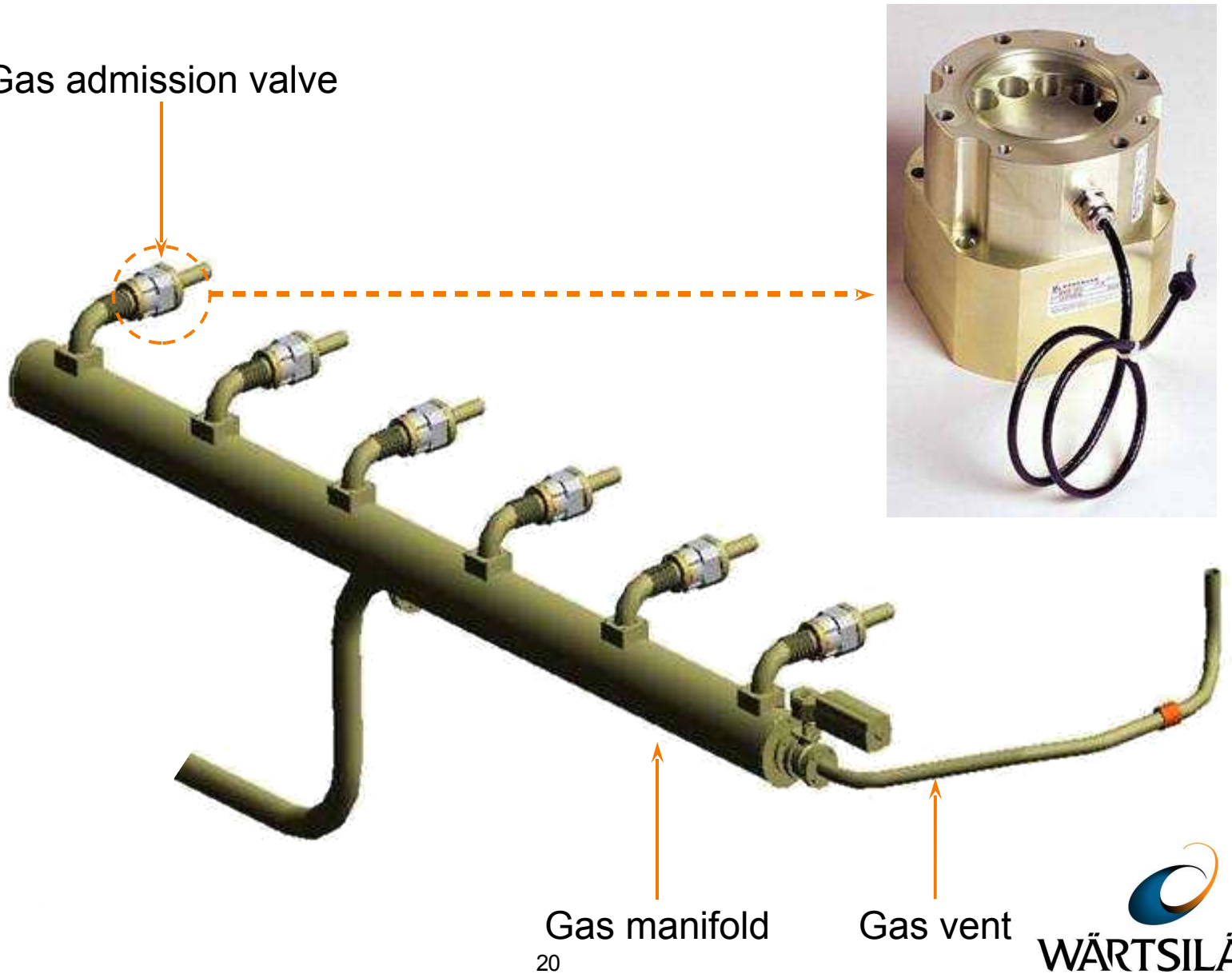
Dual-fuel engine parameters



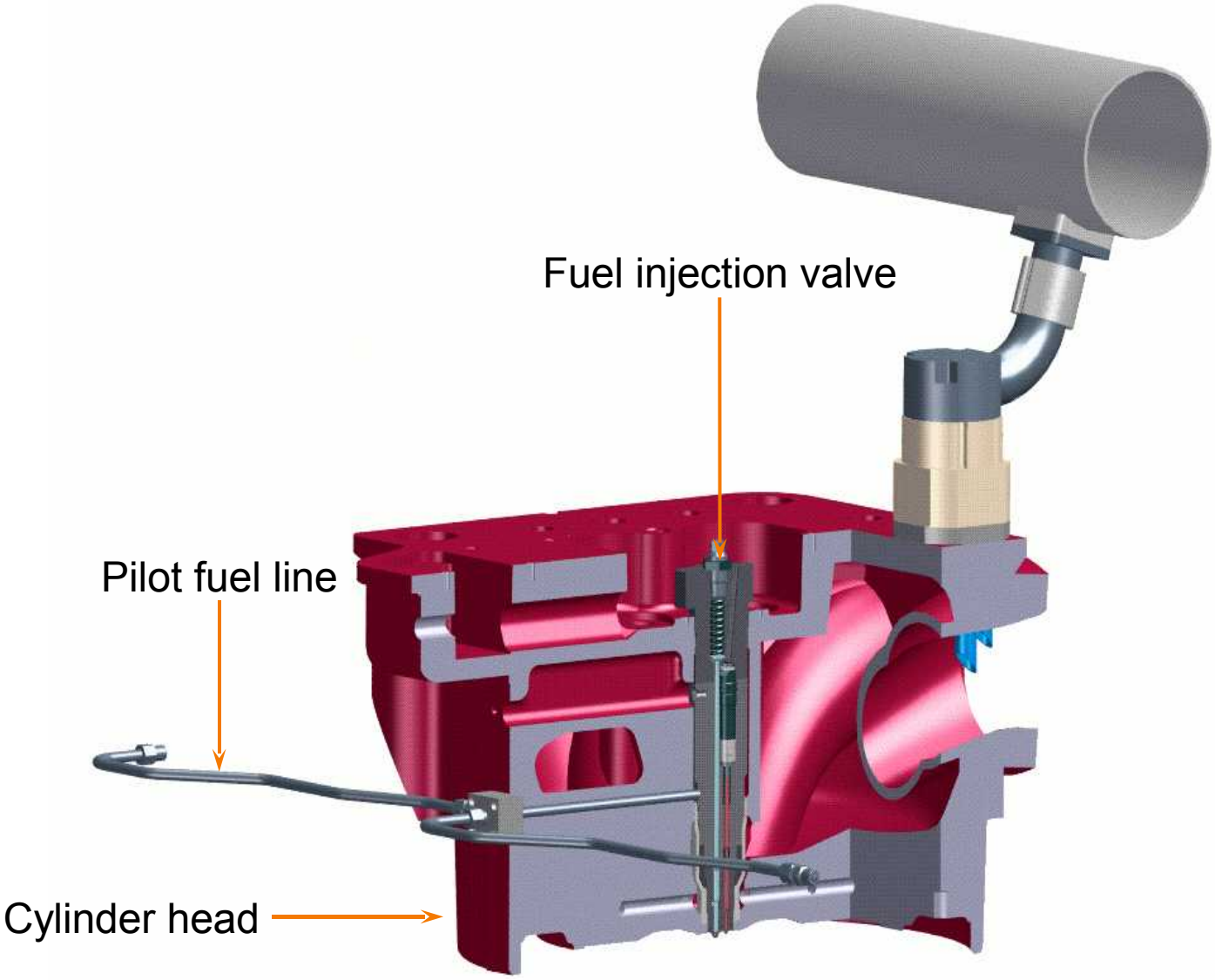
Engine systems - Gas fuel system (1/2)



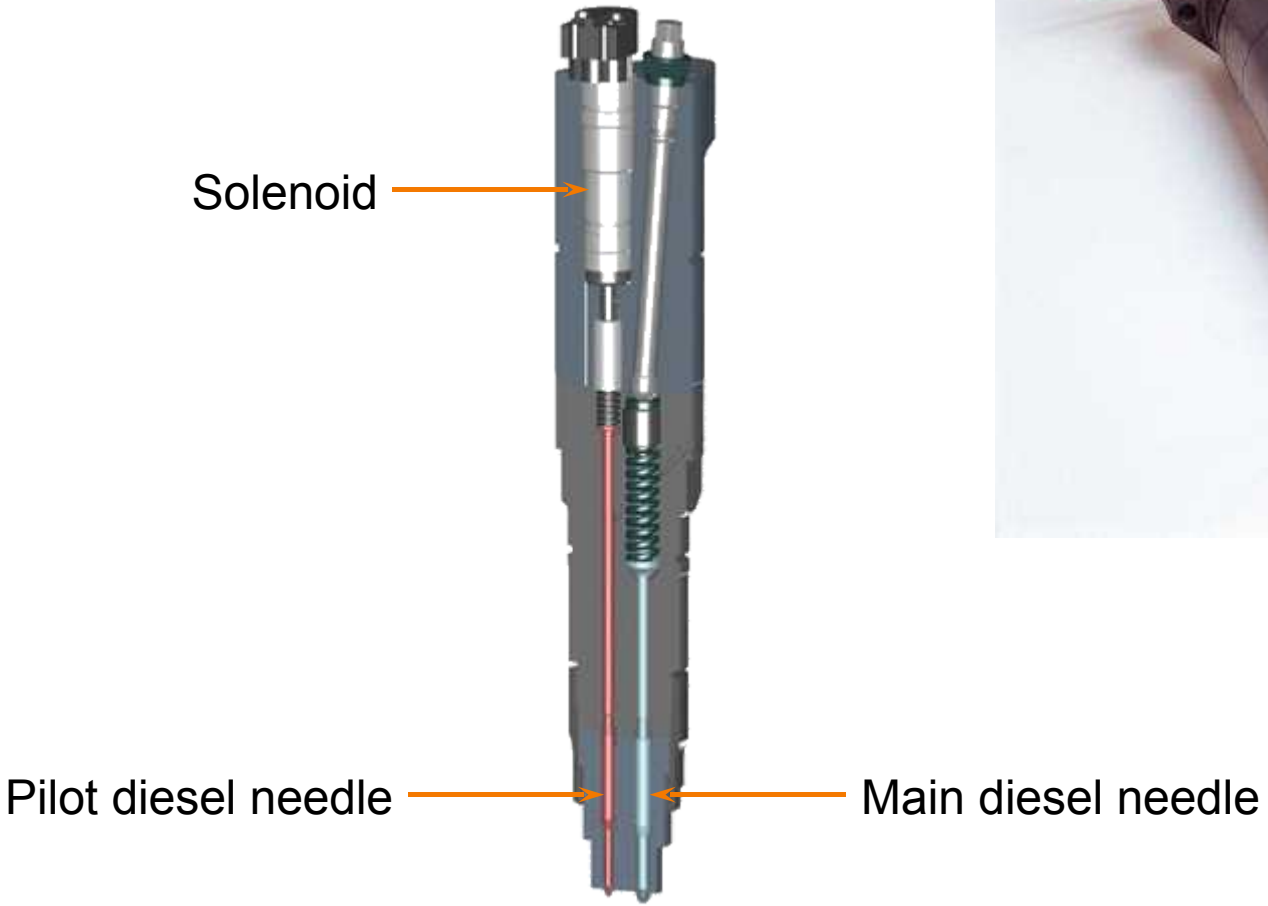
Engine systems - Gas fuel system (2/2)



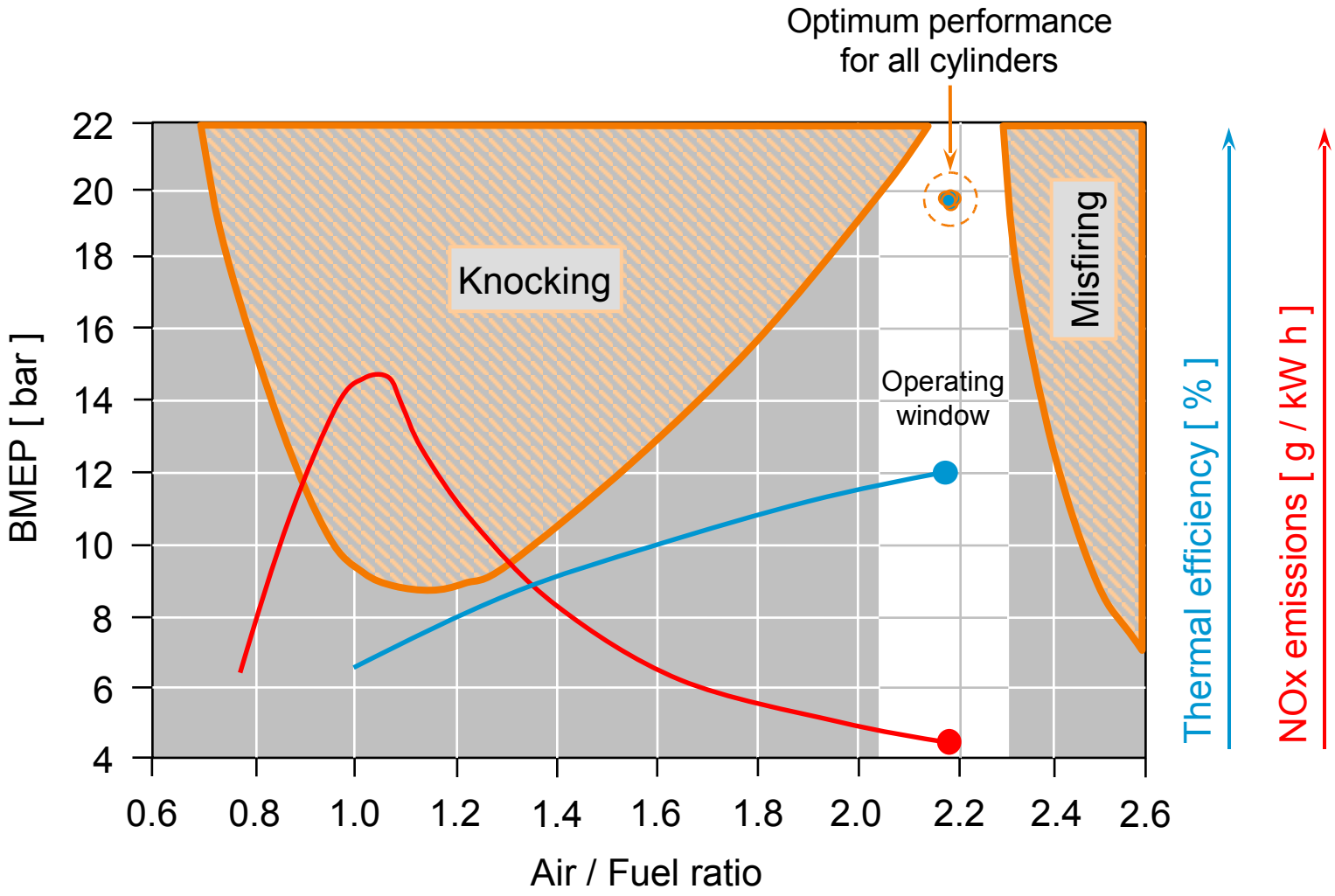
Engine systems - Pilot fuel system



Engine systems - Fuel injection valve

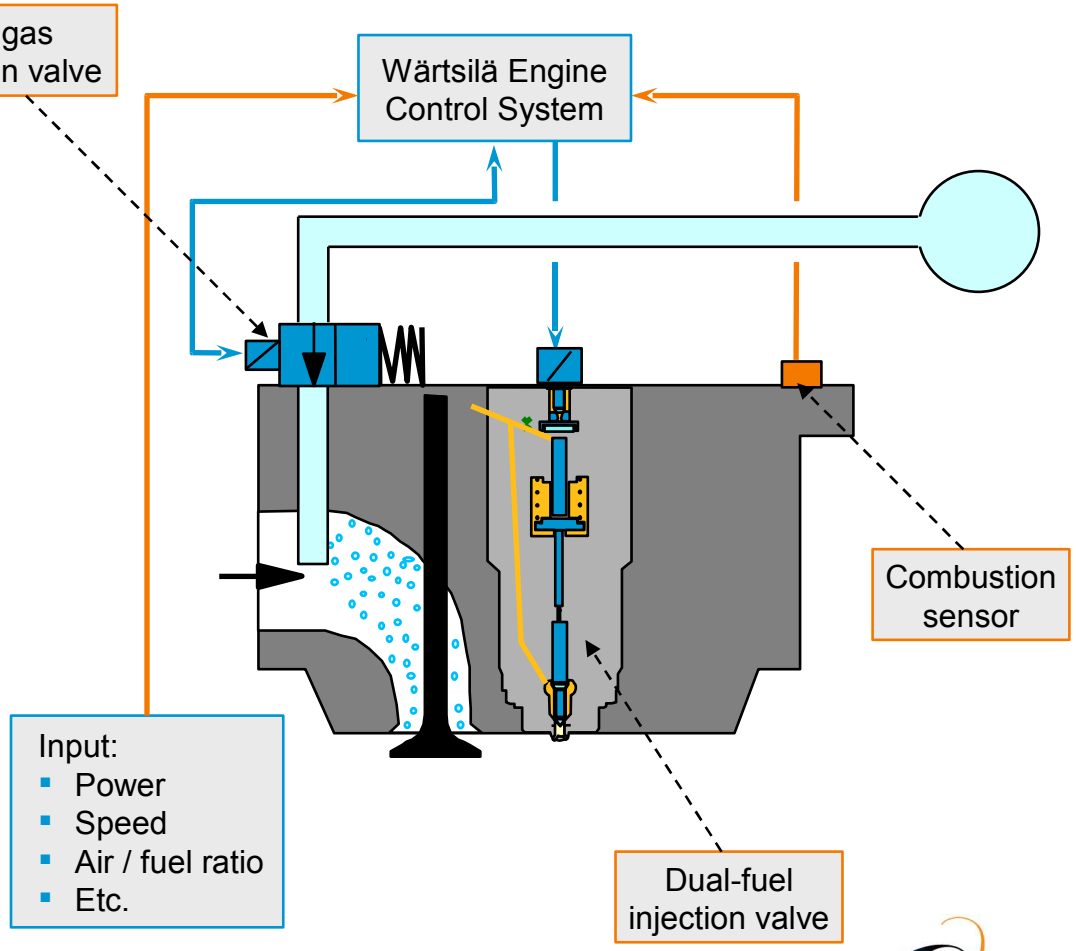


Engine systems - Control system (1/2)



Engine systems - Control system (2/2)

- Individual adjustment of gas feed and injection for each cylinder.
- Combustion sensor on each cylinder.
- In case of knocking, only concerned cylinder is adjusted.



Dual-fuel engine applications

22 installations
featuring 48 engines
with approx. 500’000 running hours

Power Plants

3 installations
featuring 12 engines
with approx. 100’000 running hours

Offshore Supply Vessels

Floating Regasification Units

3 installations
featuring 6 engines
with approx. 70’000 running hours

Floating Production Units

56 installations
featuring 210 engines

Liquefied Natural Gas Carriers

Coastal Vessels

In service, under construction, or on order

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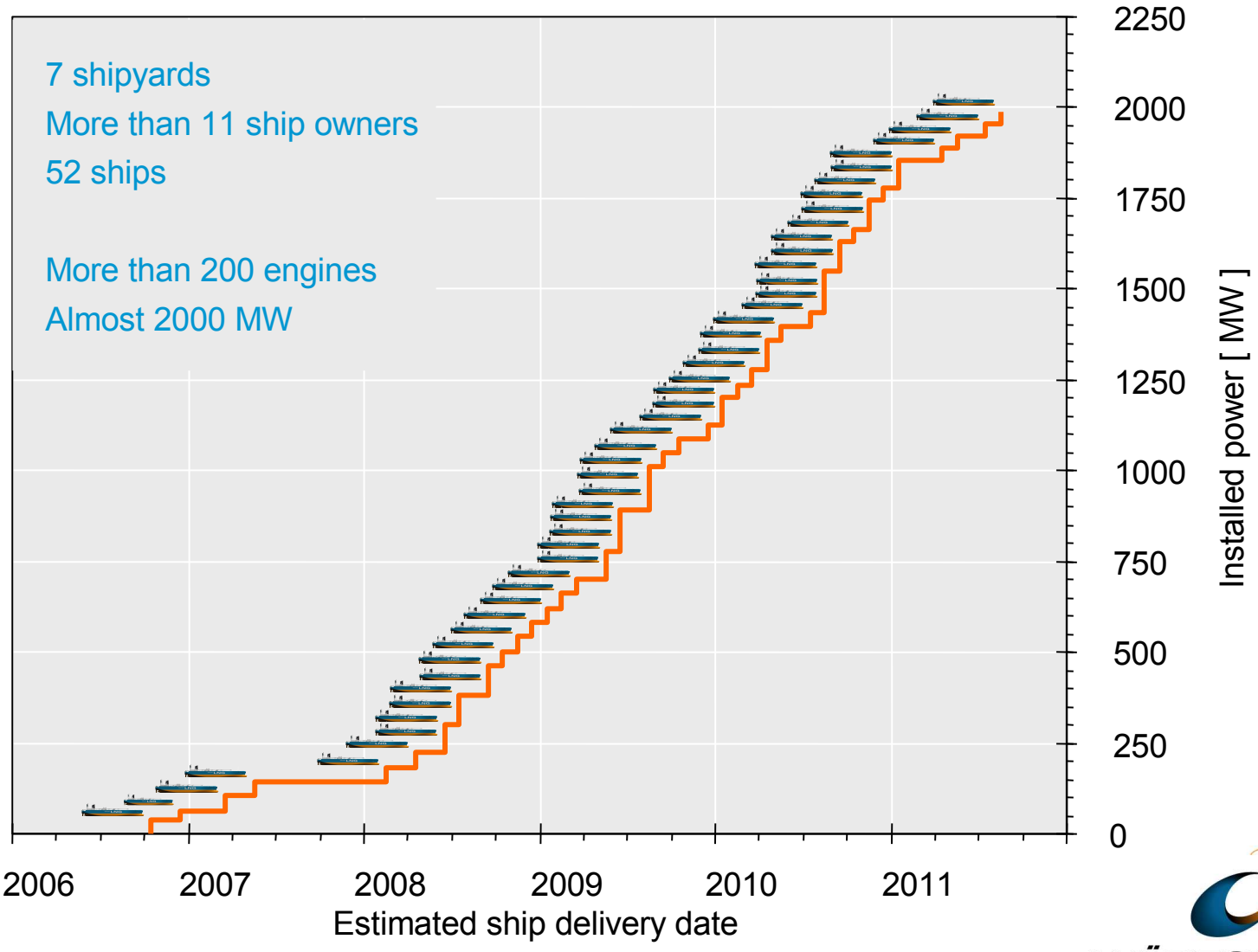
Dual-fuel-electric LNG carrier applications



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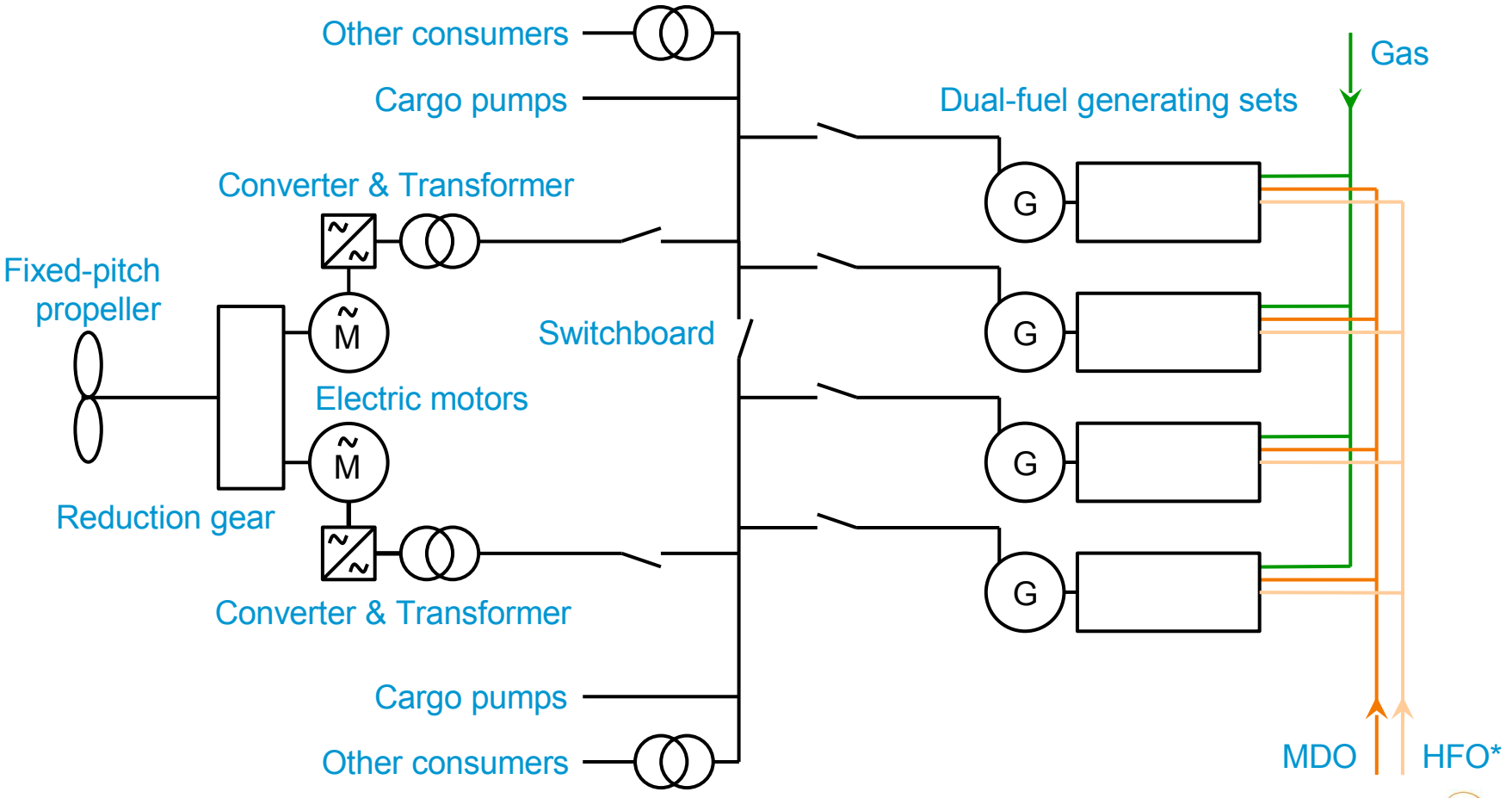
Dual-fuel-electric LNG carriers

Dual-fuel-electric LNG carriers

- Concept
  Components, lay-out
- Fuel alternatives
- Advantages
  Economy, emissions, safety, reliability, redundancy, maintainability, crewing

Machinery concept (1/2)

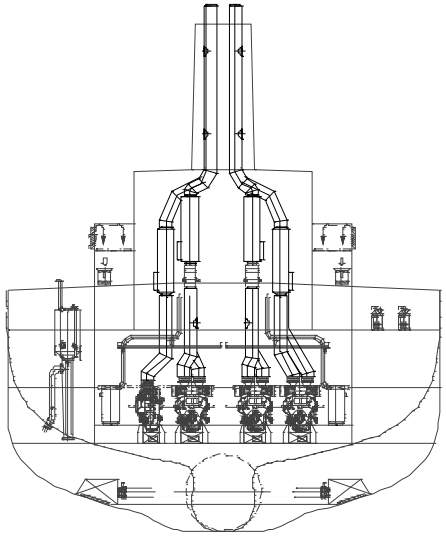
Dual-fuel-electric machinery

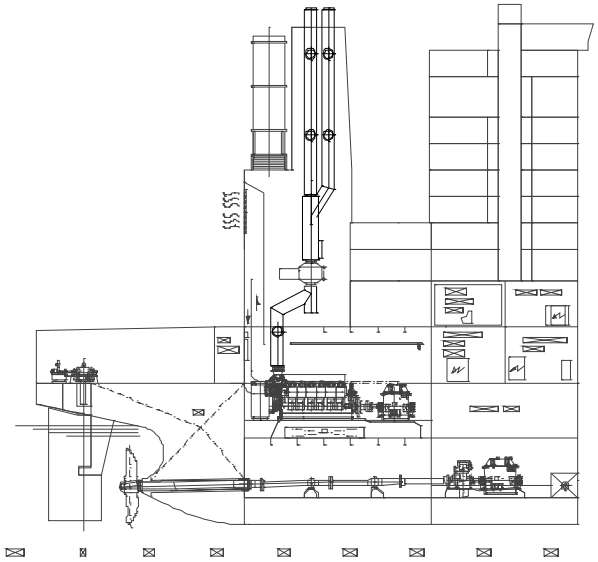


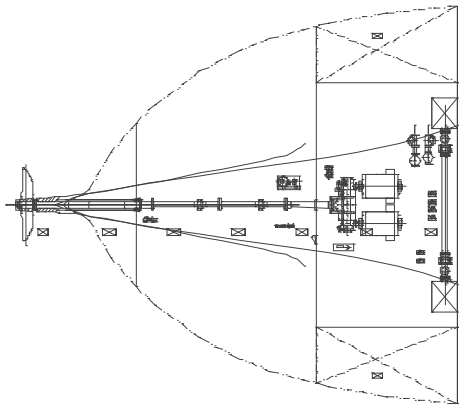
* Optional

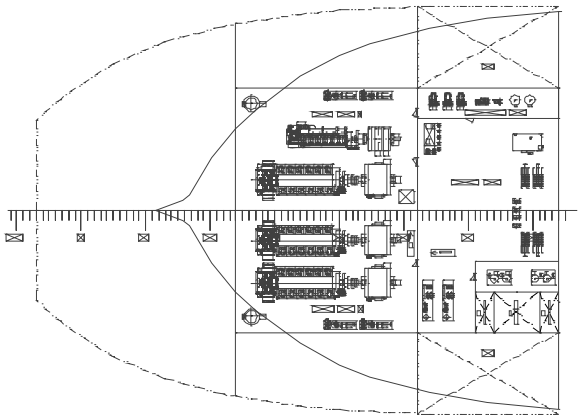
Machinery concept (2/2)

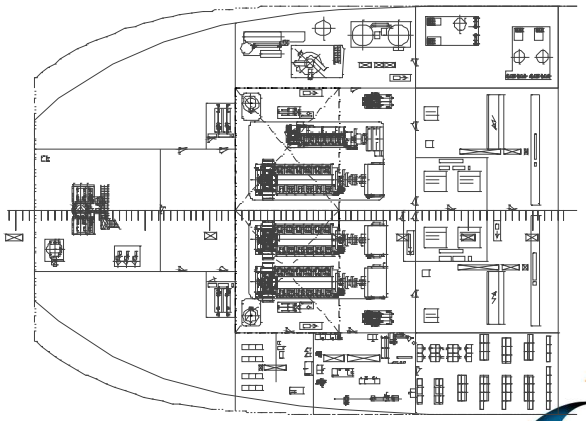
150’000 m³ dual-fuel-electric LNG carrier
3x 12V50DF + 1x 6L50DF











Fuel alternatives (1/2)

Natural Boil-Off Gas (N-BOG), Forced Boil-Off Gas (F-BOG),
Heavy Fuel Oil (HFO) and / or Marine Diesel Oil (MDO)

LNG export terminal

LNG import terminal

Natural Boil-Off Gas (N-BOG), Forced Boil-Off Gas (F-BOG),
Heavy Fuel Oil (HFO) and / or Marine Diesel Oil (MDO)

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Fuel alternatives (2/2)

Alt.	Laden voyage	Ballast voyage	Remarks
1	N-BOG (MDO) + F-BOG (MDO)	N-BOG (MDO) + F-BOG (MDO)	Additional heel on ballast voyage.
2	N		.
3	N		
4	N		.
5	N-BOG (MDO) + HFO (MDO)	HFO (MDO)	Heel-out on ballast voyage.

Provided that the required arrangements for the different fuels are in place,
the ship operator can re-select the most attractive fuel alternative
at the start of every single laden or ballast voyage
to react on changes in gas and liquid fuel oil prices…

Market requirements

Economy

Others

Emissions

Machinery alternatives:

- Steam turbine machinery
- Dual-fuel-electric machinery
- Two-stroke diesel engines with N-BOG reliquefaction machinery

Crewing

Safety

Maintainability

Reliability

Redundancy

Economy (1/6)

Dual-fuel-electric machinery
N-BOG (MDO) + F-BOG (MDO)

- Uses less fuel; carries less bunkers; saves space and weight
- Needs less engine room space; saves space
- Uses lighter fuel; saves weight

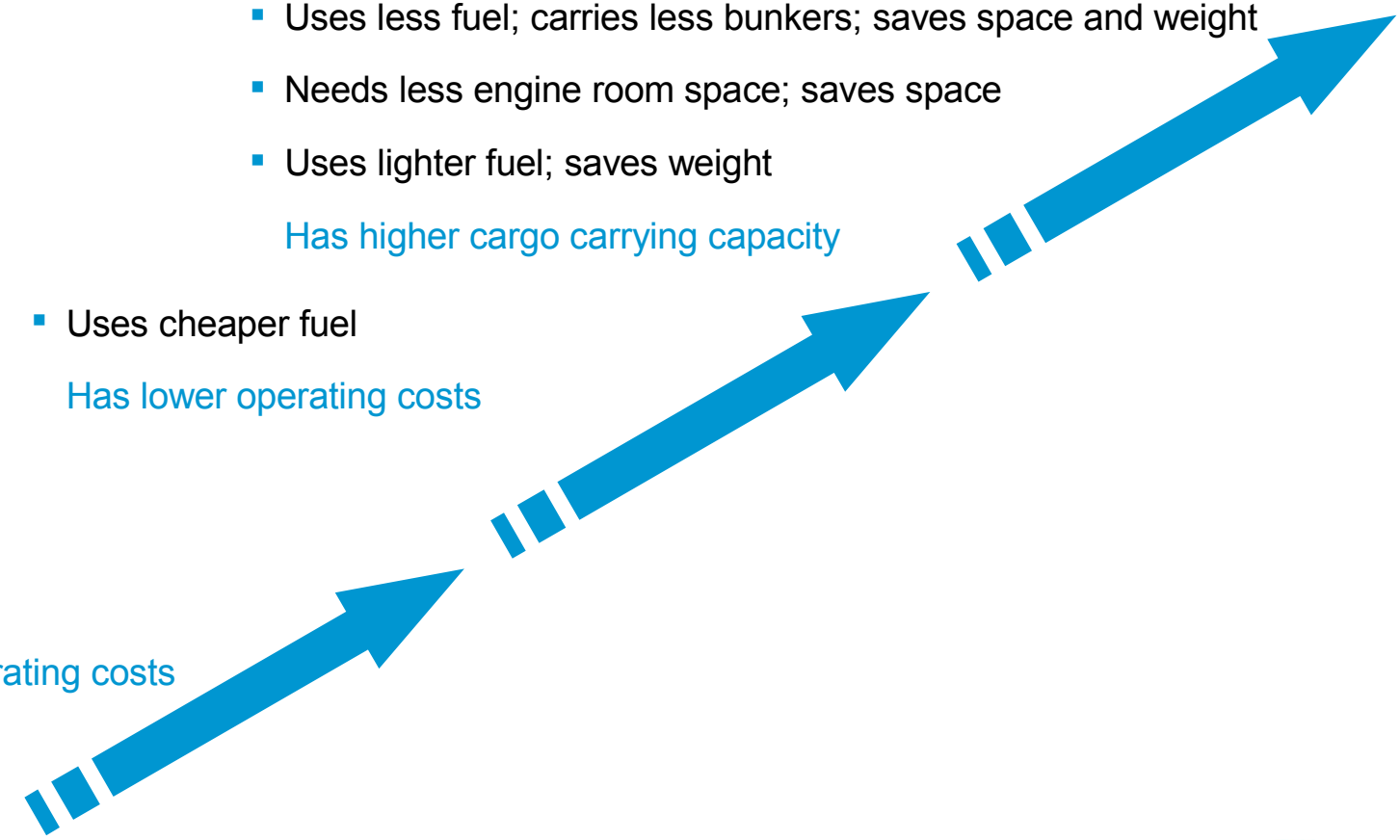
  Has higher cargo carrying capacity

- Uses cheaper fuel

  Has lower operating costs

- Uses less fuel

  Has lower operating costs



Main assumptions

Cargo capacity	267'000	m^3
Boil-off rate, laden	0.11	%
Boil-off rate, ballast	40	% of laden
Leg length	9650	nm
Service speed, laden	19.5	kt
Service speed, ballast	19.5	kt
Loading time	21	h
Discharging time	21	h
Value N-BOG	2.5	US$ / mmBTU
Value F-BOG	6.0	US$ / mmBTU
Price HFO	304	US$ / ton
Price MDO	619	US$ / ton
Price lube oil	490	US$ / ton
Price cylinder oil (two-stroke engine)	640	US$ / ton
Propeller shaft power, laden	34.2	MW
Propeller shaft power, ballast	32.8	MW
Ship service power, laden	1.9	MW (for steam turbine vessel)
Ship service power, ballast	1.8	MW (for steam turbine vessel)
Maintenance costs		
DF installation	3.56	US$ / MWh
Two-stroke + reliq. Installation	1.50	US$ / MWh
Four-stroke auxiliary engines	3.55	US$ / MWh
Steam turbine installation	0.50	US$ / MWh
Steam generator installation	0.70	US$ / MWh
Price steam turbine LNGC	291	MUS$
Price two-stroke diesel +reliquefaction LNGC	285	MUS$
Price dual-fuel-electric LNGC	288	MUS$

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Plant efficiencies

Steam turbine	Two-stroke diesel + Reliquefaction	Dual-fuel-electric
Fuel / BOG : 100% Boilers : 89% Steam turbine : 34% Gearbox : 98% Shafting : 98%	Fuel / BOG : 100% Two-str. engines : 49% Shafting : 98%	Fuel / BOG : 100% DF engines : 48% Alternators : 97% Transf. & Conv. : 98% Electric motors : 98% Gearbox : 98% Shafting : 98%
Propulsion Efficiency : 29%	Propulsion Efficiency : 48%	Propulsion Efficiency : 43%
Fuel / BOG : 100% Boilers : 89% Steam turbines : 30% Gearbox : 98% Alternators : 96%	Fuel : 100% Aux. engines : 45% Alternators : 96%	Fuel / BOG : 100% DF engines : 48% Alternators : 97%
Electric Power Efficiency : 25%	Electric Power Efficiency : 43%	Electric Power Efficiency : 47%

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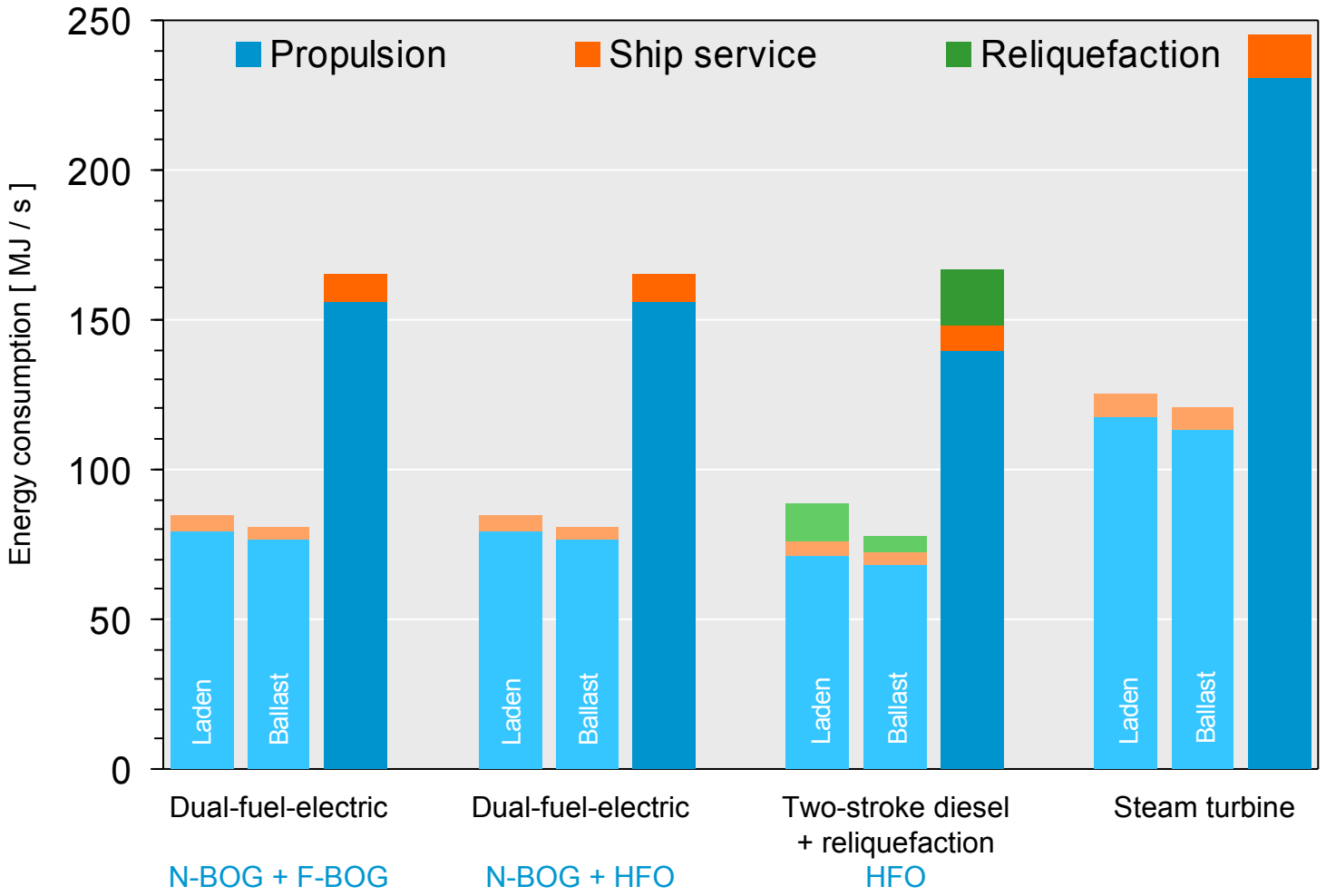
Economy (4/6)

Total energy consumption



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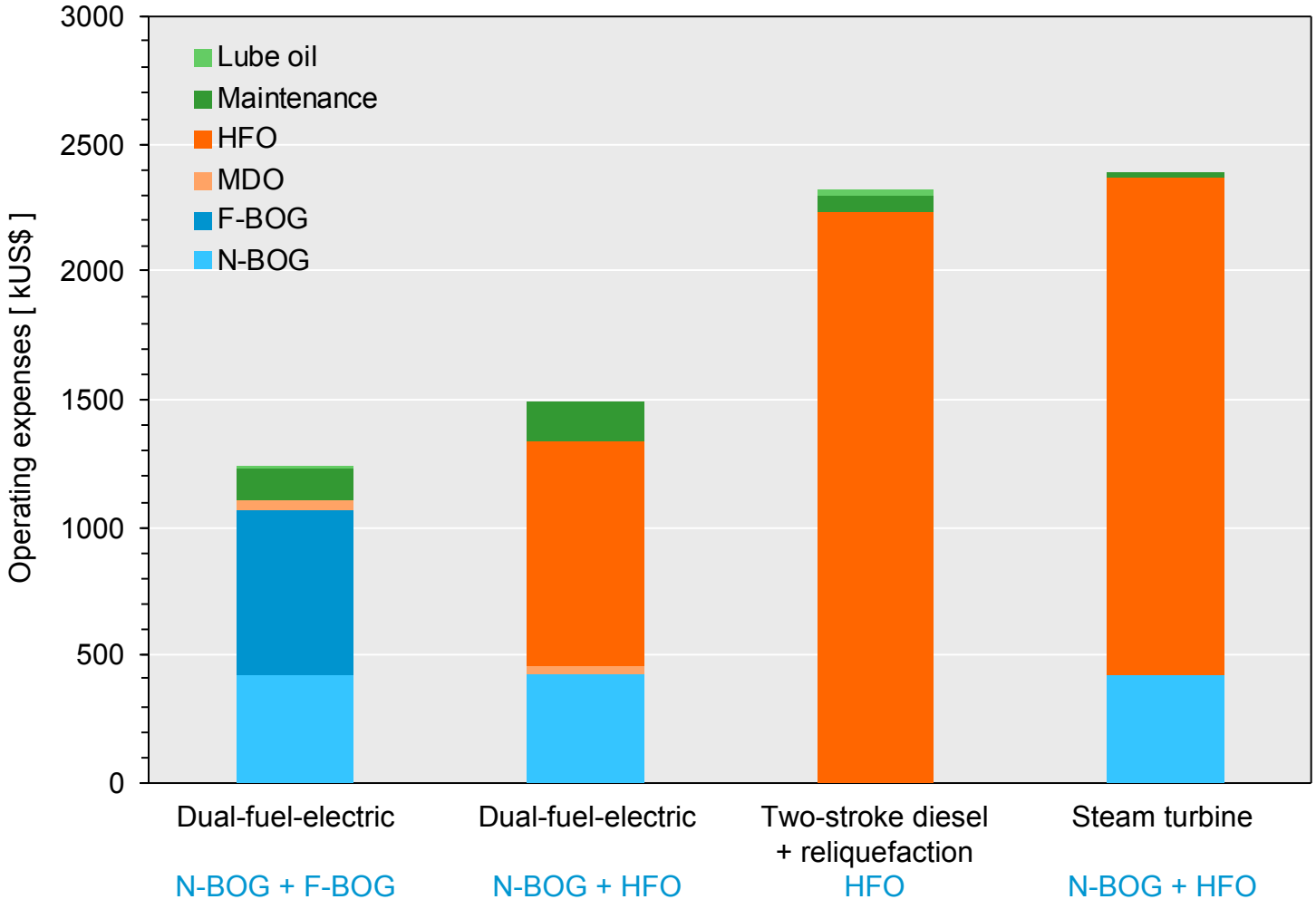
Economy (5/6)

Operating expenses per roundtrip



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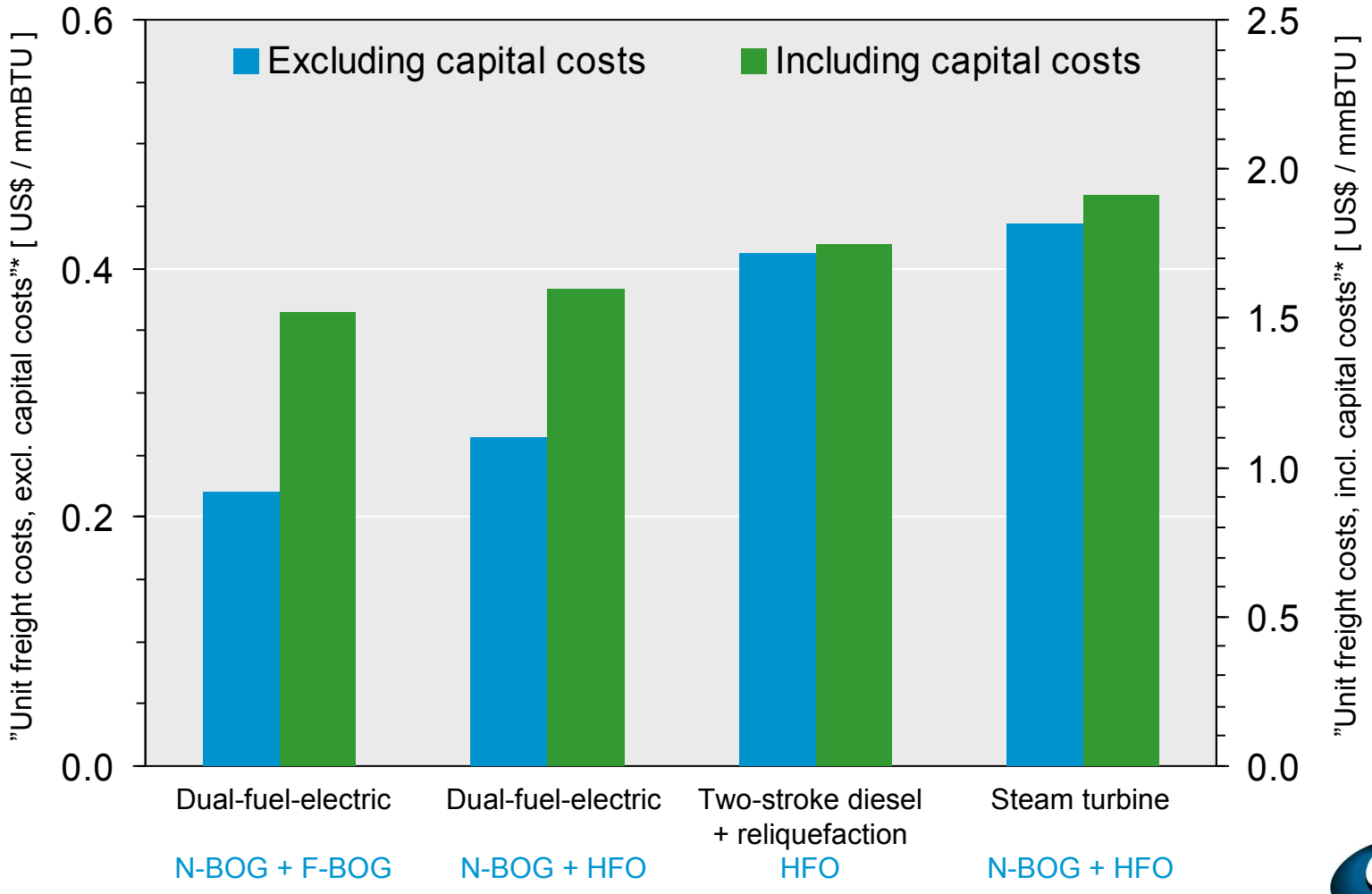
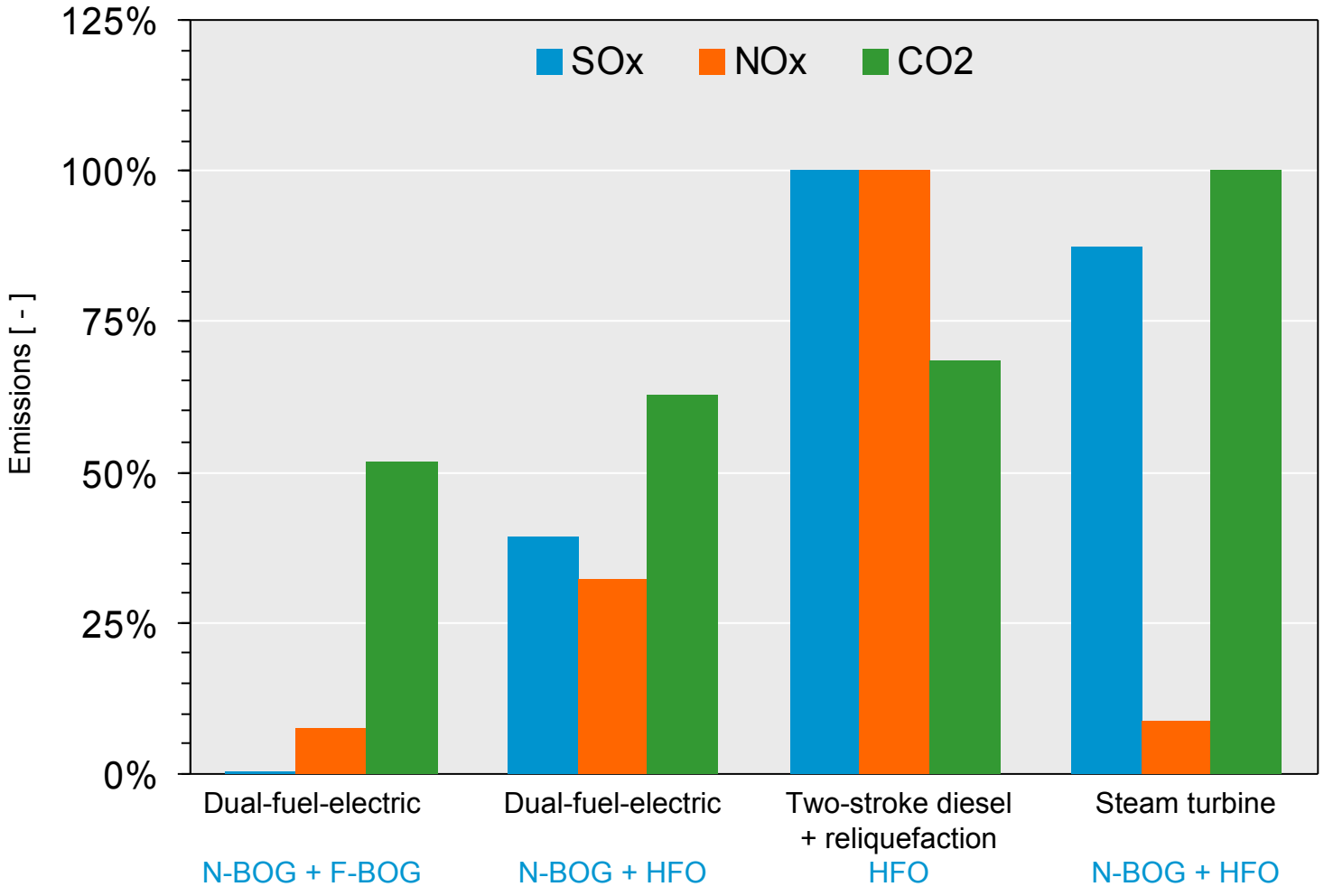
Economy (6/6)

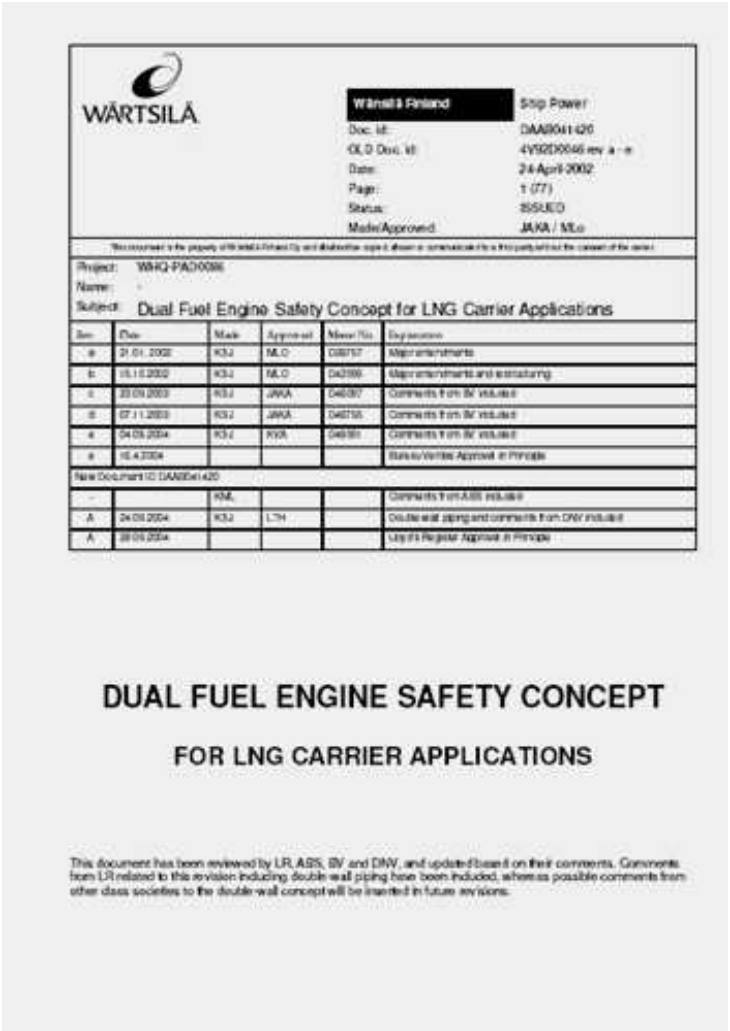
“Unit freight costs”*



Emissions



Safety



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Project: WHQ-PAD0086
Name: -
Subject: Dual Fuel Engine Safety Concept for LNG Carrier Applications

Rev	Date	Made	Approved	Memo No	Explanation
-	21.01.2002	KSJ	MLO	038757	Major enhancements
b	05.10.2002	KSJ	MLO	042999	Major enhancements and restructuring
c	20.09.2003	KSJ	JAKA	046087	Comments from BV included
d	07.11.2003	KSJ	JAKA	046755	Comments from BV included
e	04.05.2004	KSJ	KVA	048351	Comments from BV included
g	16.4.2004				Status Written Approval in Principle
New Document ID: DAA804142G					
-		KML			Comments from ABS included
A	24.09.2004	KSJ	LTH		Double wall piping and comments from DNV included
A	28.09.2004				Lloyd's Register Approval in Principle

DUAL FUEL ENGINE SAFETY CONCEPT

FOR LNG CARRIER APPLICATIONS

This document has been reviewed by LR, ABS, BV and DNV, and updated based on their comments. Comments from LR related to this revision including double wall piping have been included, whereas possible comments from other class societies to the double-wall concept will be inserted in future revisions.

The “Safety Concept” describes the required safety arrangements for dual-fuel-electric LNG carriers.

Available for engines with single- and double-wall gas piping.

Developed with and approved by the major classification societies.

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Reliability and redundancy

The Wärtsilä 32DF and Wärtsilä 50DF have inherited reliability from the Wärtsilä Vasa 32 and Wärtsilä 46 diesel engines, respectively.

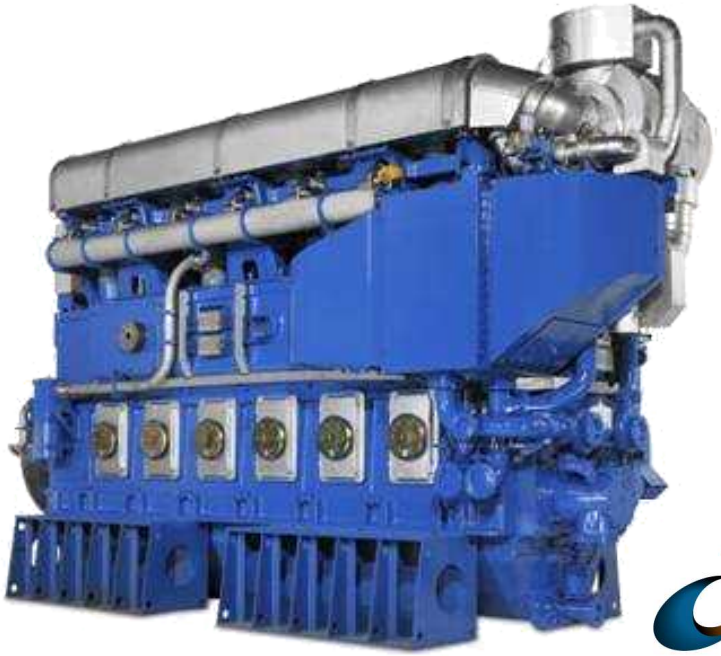
In addition, the Wärtsilä 32DF and Wärtsilä 50DF carry a lower mechanically load.

Furthermore, they are running on cleaner fuel than the conventional diesel engines.

High availability can be guaranteed.

Electric propulsion systems have basically been invented to provide maximum redundancy.

On LNG carriers, a reasonable amount of redundancy will be sufficient.



Maintainability

Dual-fuel engines require substantially less maintenance than conventional diesel engines.

Maintenance does not have to affect ship operations.

Crewing

Dual-fuel engines can be operated and maintained by regular diesel engine crews.

No exceptional skills or experience are required.

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Conclusions

Conclusions

$
and more

Dual-fuel-electric machinery has very significant benefits over steam turbine machinery and other machinery alternatives.

almost
700’000

Dual-fuel engines have accumulated almost seven-hundred-thousand running hours in commercial operation.

52

Engines for fifty-two dual-fuel-electric LNG carriers have been ordered. More orders are expected.

2

Two dual-fuel-electric LNG carriers will enter commercial operation within this year.

Dual-fuel-electric machinery for LNG carriers has established itself as a market standard.

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Thank you

for your attention!

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