

NTIK event
Hamburg, 16 Oct 2018

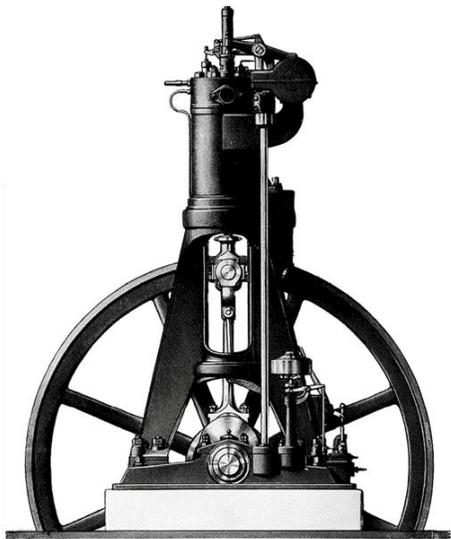
X- and X-DF engine market & technology

R.Wettstein, GM Marketing & Application

Content

- 1) X-type Market update
- 2) X-DF Market update & Technology
- 3) X-DF operational experience

From Sulzer to Winterthur Gas & Diesel



1834

SULZER

1990

**New
Sulzer
Diesel**

1997

WÄRTSILÄ

2015

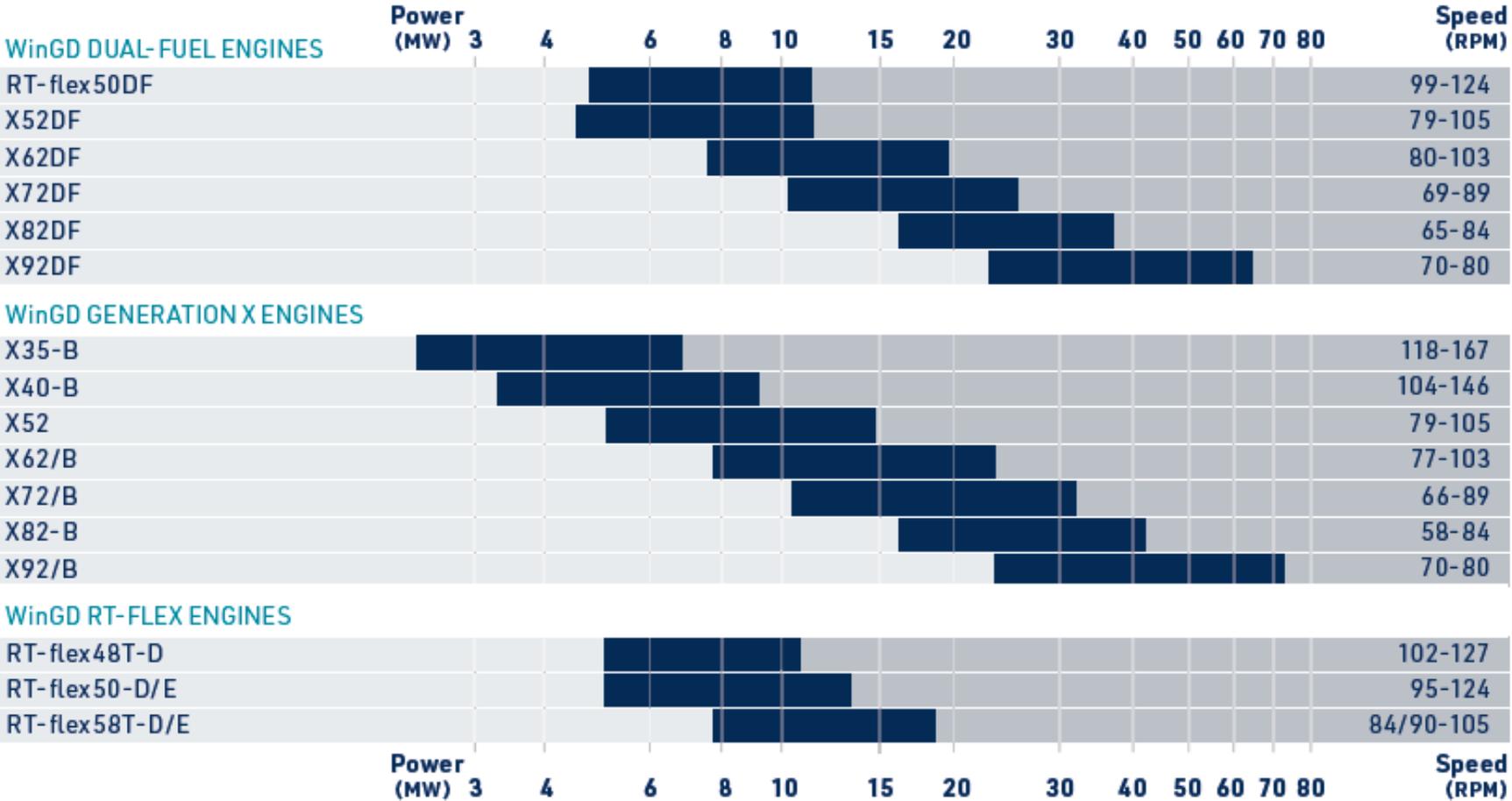
WIN GD

Simply a better different



Engine portfolio

- Small Bulkers, Tankers
C/V -800TEU
- Handysize
C/V -1200 TEU
- Handymax
C/V -1500 TEU
- Panamax
Aframax
C/V -2500TEU
- Suezmax
Capesize
C/V -5000 TEU
- VLCC / VLOC
C/V -9 000 TEU
- Post Panamax
C/V -22 000 TEU



An engine for every need - 10 bore sizes

X- engine references

X engine type	Vessel type		Orders
X35 X40	8K Multi-Purpose Vessels 10-44K dwt Bulk Carriers 11-22K dwt Chemical Tankers 1-2K TEU Feeder CVs 2K cars Car Carriers		66 engines 10 engines
X52	38-60K dwt Bulk Carrier 50K dwt Product Tankers	 	26 engines
X62	56-108K dwt Bulk Carriers 60K dwt Chemical Tankers 115K dwt Crude/Product Tankers 2-3K TEU Feeder CVs	 	58 engines
X72	150-210K dwt Bulk Carriers 158K dwt Crude Oil Tankers 3-8K TEU Intermediate CVs	 	74 engines
X82	250-400K dwt Bulk Carriers 280-310K dwt Crude Oil Tankers 8-12K TEU Neo-Panamax CVs 12-15K TEU Neo-Panamax CVs	 	98 engines
X92	8-12K TEU Neo-Panamax CVs 12-15K TEU Neo-Panamax CVs 15K+ TEU Post-Panamax CVs		50 engines

TOTAL

382 X engines (ca. 9700 MW)

09 October 2018

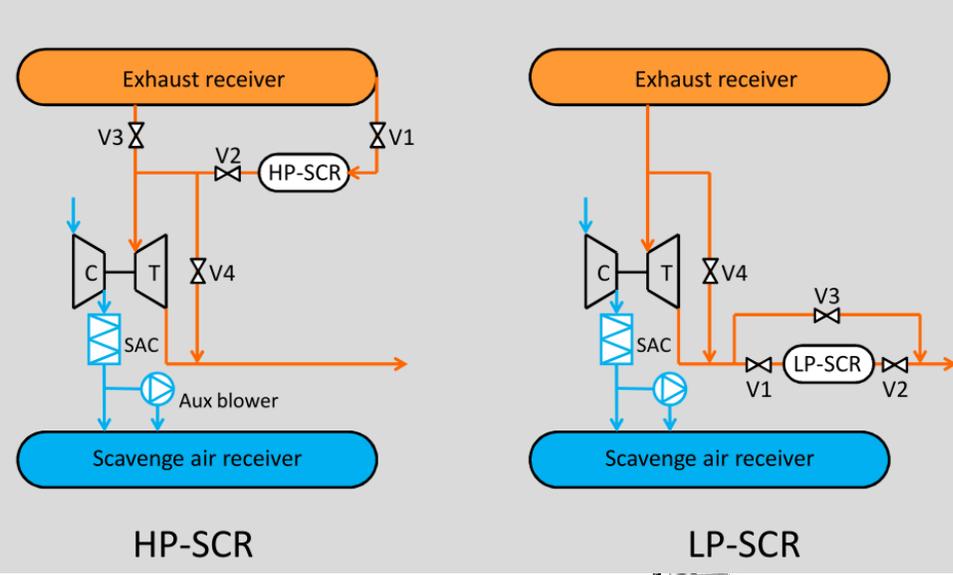
How to reach emission compliance ?

Fuel options	Sulphur content	SOx compliancy		NOx compliancy		Equipment needed to comply with	
		SECA Operation	Global Operation	NECA Operation Tier III	Global Operation Tier II	SO _x Rules	NO _x Rules
LNG	~0% S	Compliant	Compliant	Compliant with X-DF	Compliant	None with X-DF	
HFO	3.5% S	Scrubber to 0.1% S	Scrubber to 0.5% S	HP SCR	Compliant	Scrubber	HP SCR
HFO	3.5% S	Compliant with 0.1% S Fuel	Scrubber to 0.5% S Fuel	LP or HP SCR with 0.1% S Fuel	Compliant	Scrubber	LP or HP SCR
Ultra Low Sulphur	0.1% S						
Low Sulphur	0.5% S	Compliant with 0.1% S Fuel	Compliant with 0.5% S Fuel	LP or HP SCR with 0.1% S Fuel	Compliant	None	LP or HP SCR
Ultra Low Sulphur	0.1% S						

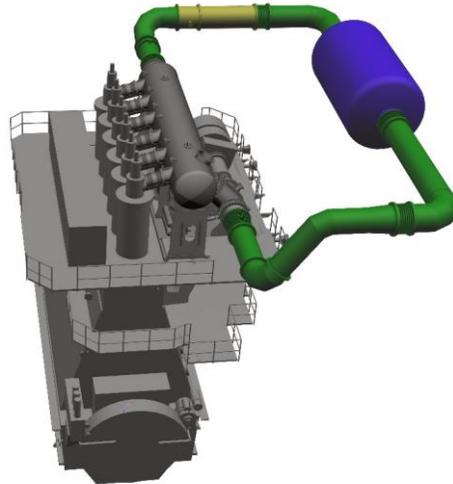
SCR – a proven marine technology

- For 40 years, selective catalytic reduction (SCR) technology is used in powerplants to clean exhaust gases from NO_x.
- After the year 2000 it found application also in truck and car industry ("AdBlue"), replacing the EGR technology to achieve lowest NO_x emissions
- Wärtsilä and WinGD have a long and wide experience with SCR systems with **> 800 units ordered / installed** in a large variety of engine applications:
 - Application of SCR for all Diesel and high-pressure gas engines
 - Marine (1/3) and stationary (2/3) applications
 - 4- and 2-stroke engine applications
- Application of SCR on large 2-stroke marine engines is a logic step

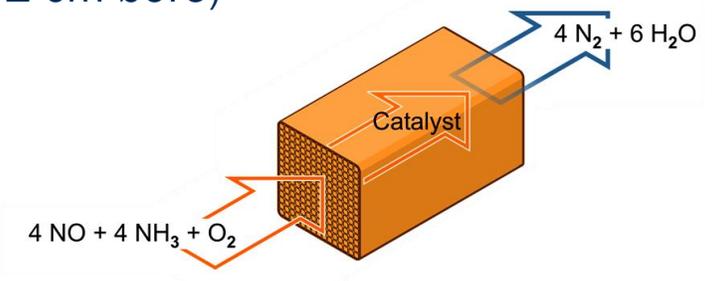
HP- and LP- SCR system overview



HP-SCR References
 >80 units
 (52 to 82 cm bore)



LP-SCR References
 >90 units
 (52 to 92 cm bore)



Content

- 1) X-type Market update
- 2) X-DF Market update & Technology**
- 3) X-DF operational experience

37 LNG-fueled vessels with X-DF



RT-flex50DF (5,7 cyl)

- 4 x 15k dwt Chemical Tanker, Sweden
- 4 x 1400 TEU Vessel, Germany / Finland
- 4 x 15k dwt Asphalt Carrier, Canada

X52DF (7,8 cyl)

- 2 x 125k dwt twin-screw Shuttle Tanker, Singapore / Norway
- 1 x 7000 unit PCTC

X62DF (6,7 cyl)

- 6 x 114k dwt Aframax Tanker, Russia
- 2 x 115k dwt Aframax Tanker, Singapore
- 5 x 114k dwt Aframax Tanker, Russia

X92DF (12 cyl)

- 9 x 22'000 TEU Container Vessels, France

**39 engines on order,
hereof 15 delivered,
hereof 8 in operation**



X-DF powered Aframax Tanker



- Owner Sovcomflot
- Charter Shell
- Main engine 7X62DF
 - Power 13 800kW / 86 rpm
 - Bore 620 mm
 - Stroke 2 658 mm
 - Length 9 215 mm
 - Weight 435 tons
- Fuel gas tank
 - Type C 2 x 850 m³
- Vessel Ice 1A
- Seatrials July 2018

The order that will change the future

9 x 22 000 TEU C/V



Main engine	12X92DF
Power	63 840 kW / 80 rpm
Bore	920 mm
Stroke	3 468 mm
Length	23 000 mm
Weight	2 140 tons

Gensets	
Wärtsilä	6 x L34DF

Fuel Gas Supply System	
Wärtsilä	

Fuel gas tank	
GTT	18 600 m ³

Press Release of Nov. 7, 2017

<http://www.cma-cgm.com/news/1811/world-innovation-cma-cgm-is-the-first-shipping-company-to-choose-liquefied-natural-gas-for-its-biggest-ships>

Announced during COP 23 (UN Climate Change Conference) in Bonn, Nov 6 - 17, 2017

46 LNG Carriers with X-DF

5RT-flex50DF

1 x 14k m³ Coastal LNGC

6X62DF

5 x 180k m³ LNGC

5X72DF

36 x 174k / 180k m³ LNGC

6X72DF

4 x 180k m³ LNGC

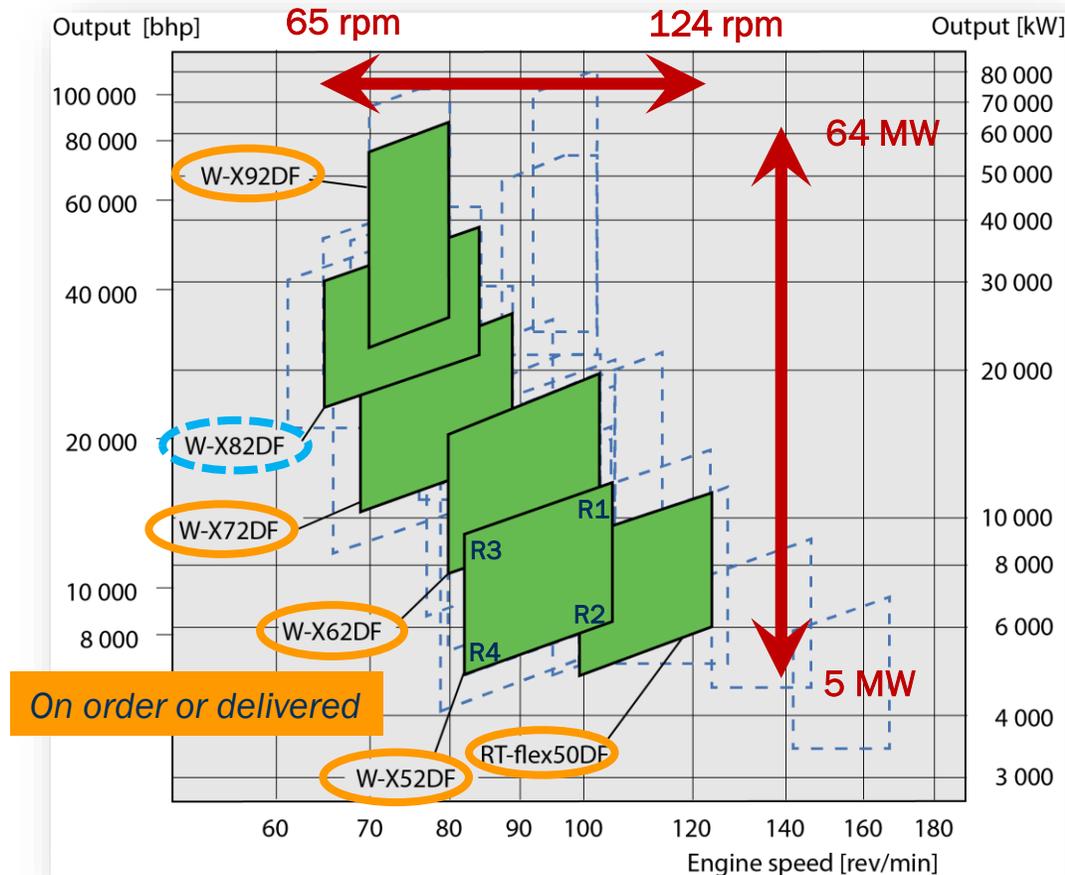
Shipbuilders: SHI, HHI, DSME, Hudong



91 engines on order, hereof 35 delivered, hereof 16 in operation

TOTAL 130 engines + options (end August)

The X-DF engine program



Gas Tankers

- ✓ Small LNGC
- ✓ Large LNG Carriers: twin-screw 2 x 5/6X72DF
- Large LNG Carriers: single-screw 7X82DF

Container Vessels

- ✓ 1400 TEU Feeder CV
- ✓ 22 000 TEU Ultra Large CV

Tankers

- ✓ Product (Chemical & Asphalt)
- ✓ Aframax
- ✓ Aframax Shuttle
- Suezmax
- VLCC

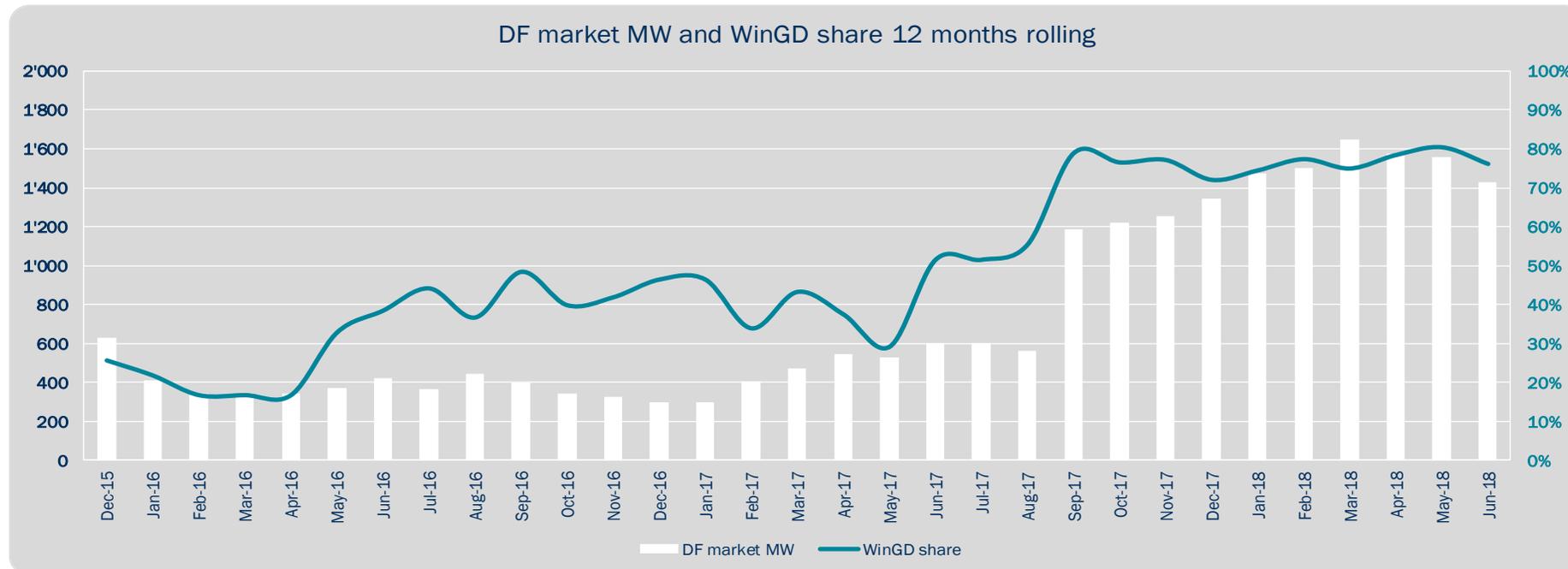
Bulkers

- Handysize
- Handymax
- Panamax
- Capesize
- VLOC

- ✓ PCTC, CONRO

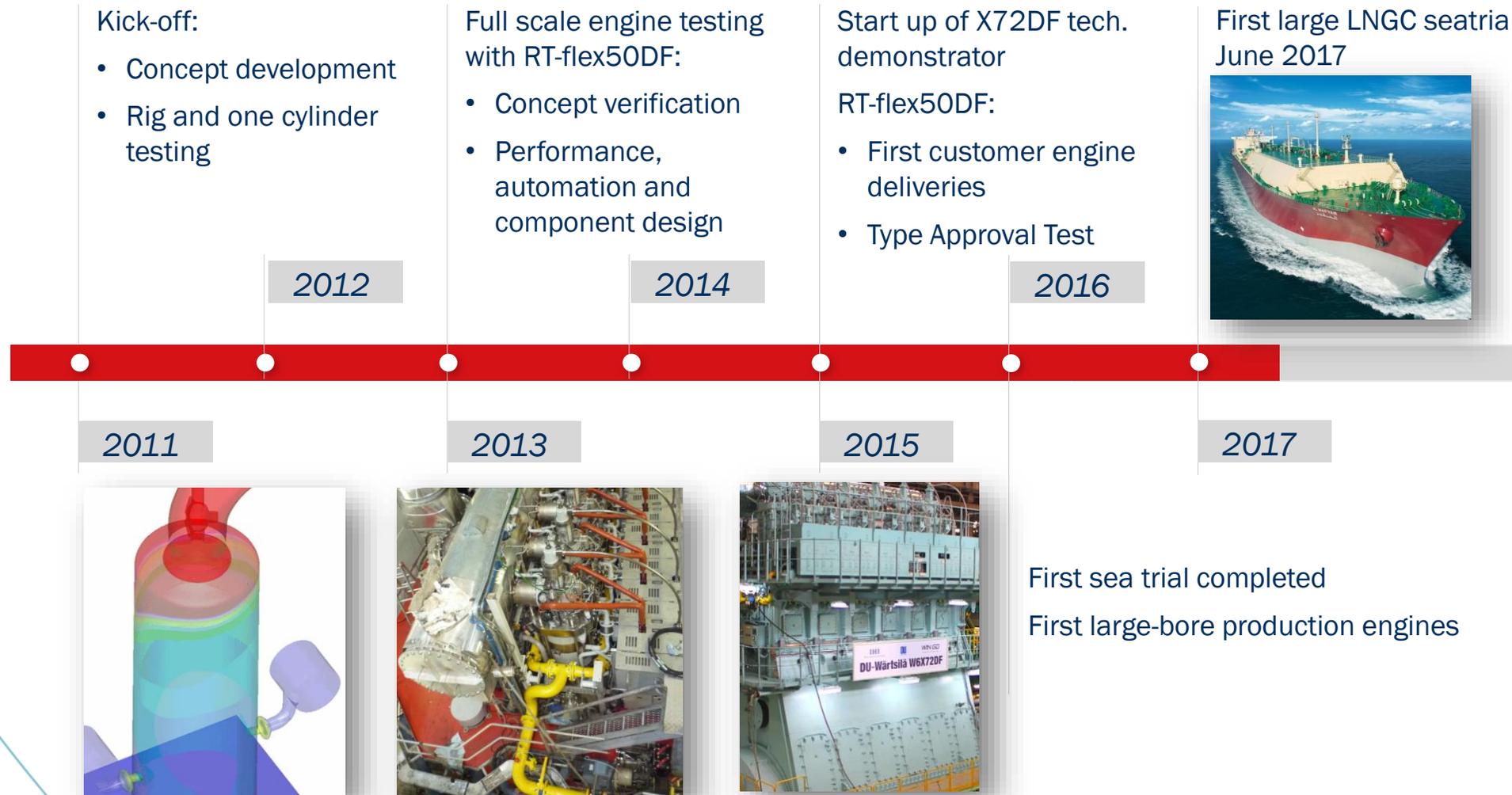
X-DF capturing LNG fuelled ships

The propulsion of choice!



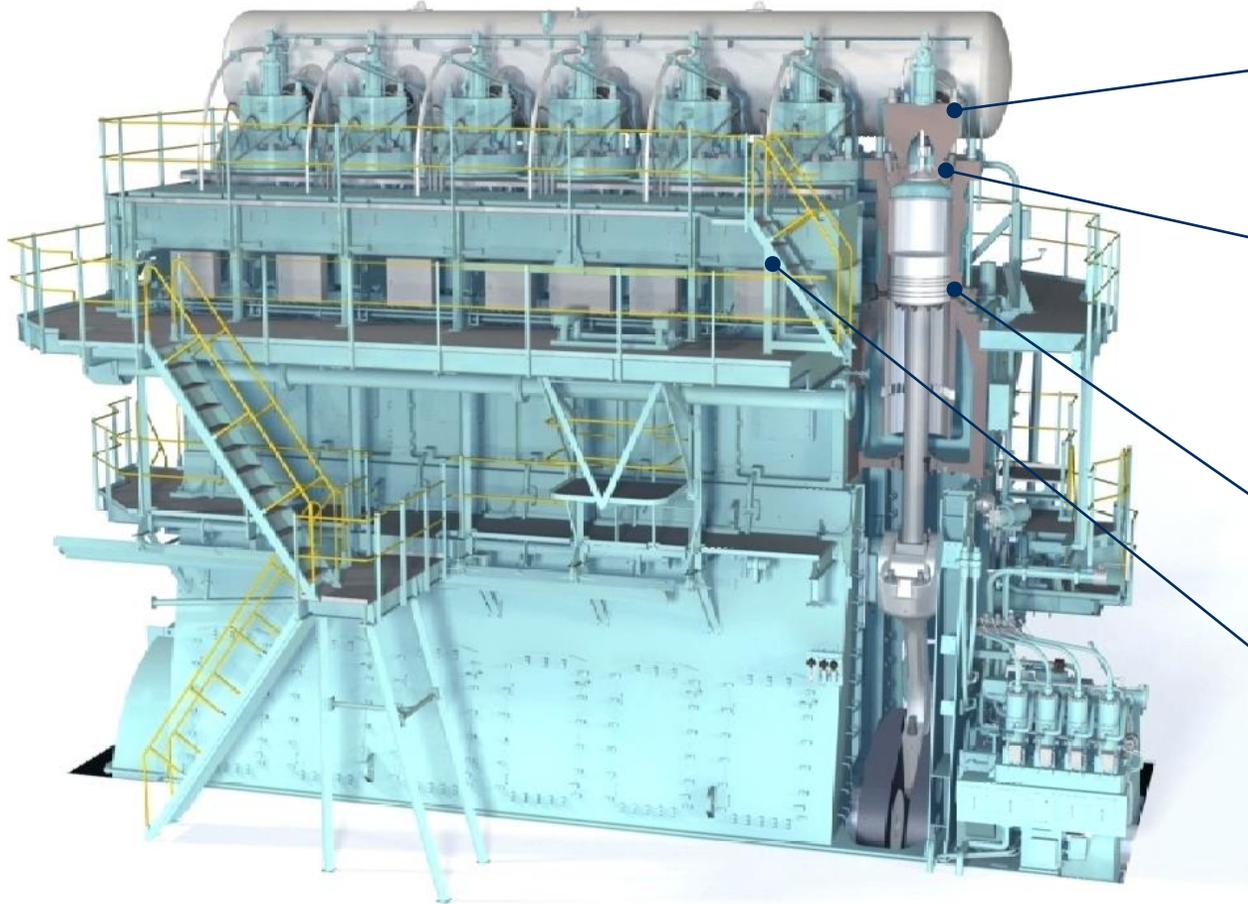
- Captured majority share of DF market
- Propulsion of choice for majority of LNGC orders
- Simplicity appreciated for LNG-fuelled vessels

Development & introduction timeline



X-DF Low-Pressure key components

Key technologies that make the difference!



Micro-pilot common-rail system

- Low pilot-fuel consumption < 1%
- Low NO_x

Pre-chamber technology

- Low NO_x and THC / 'methane slip'
- Good combustion stability

Gas admission system

- Safe and reliable gas admission &
- Simple sealing technology with low-pressure

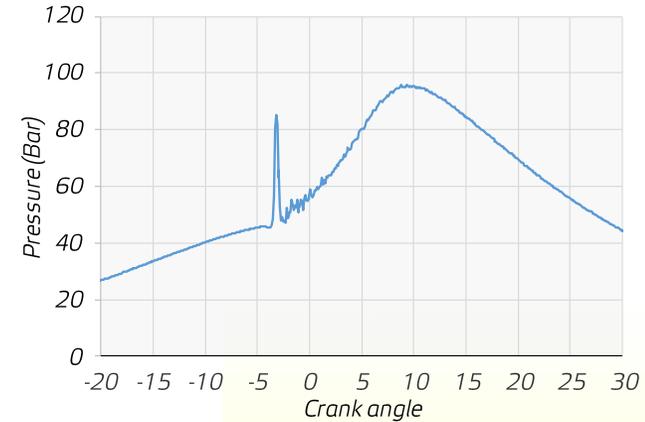
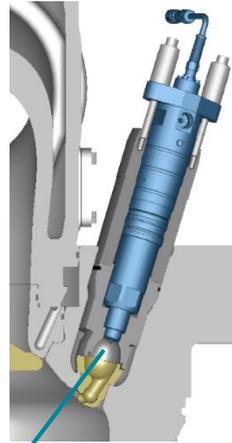
Engine Control & Automation

- Integrated engine control and safety

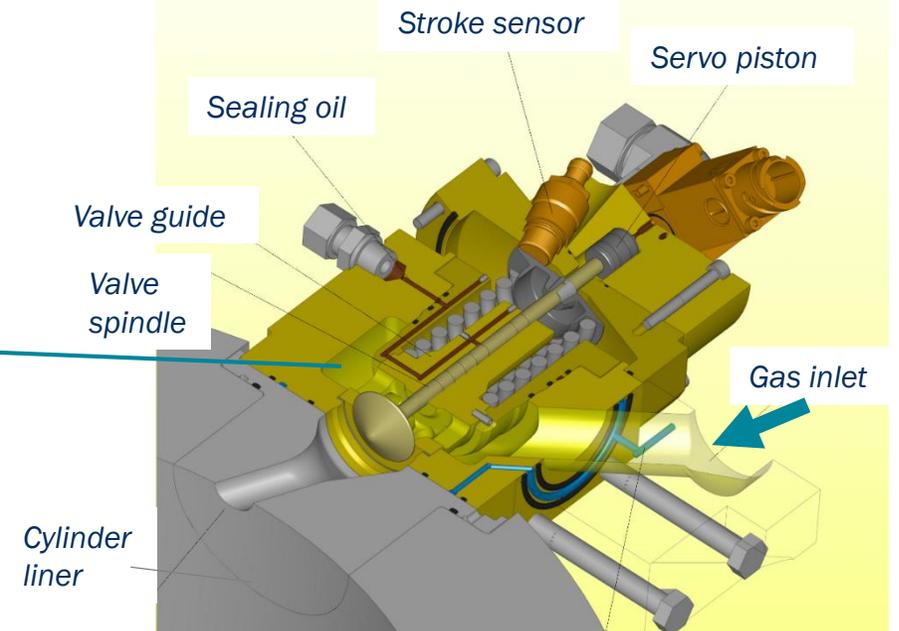
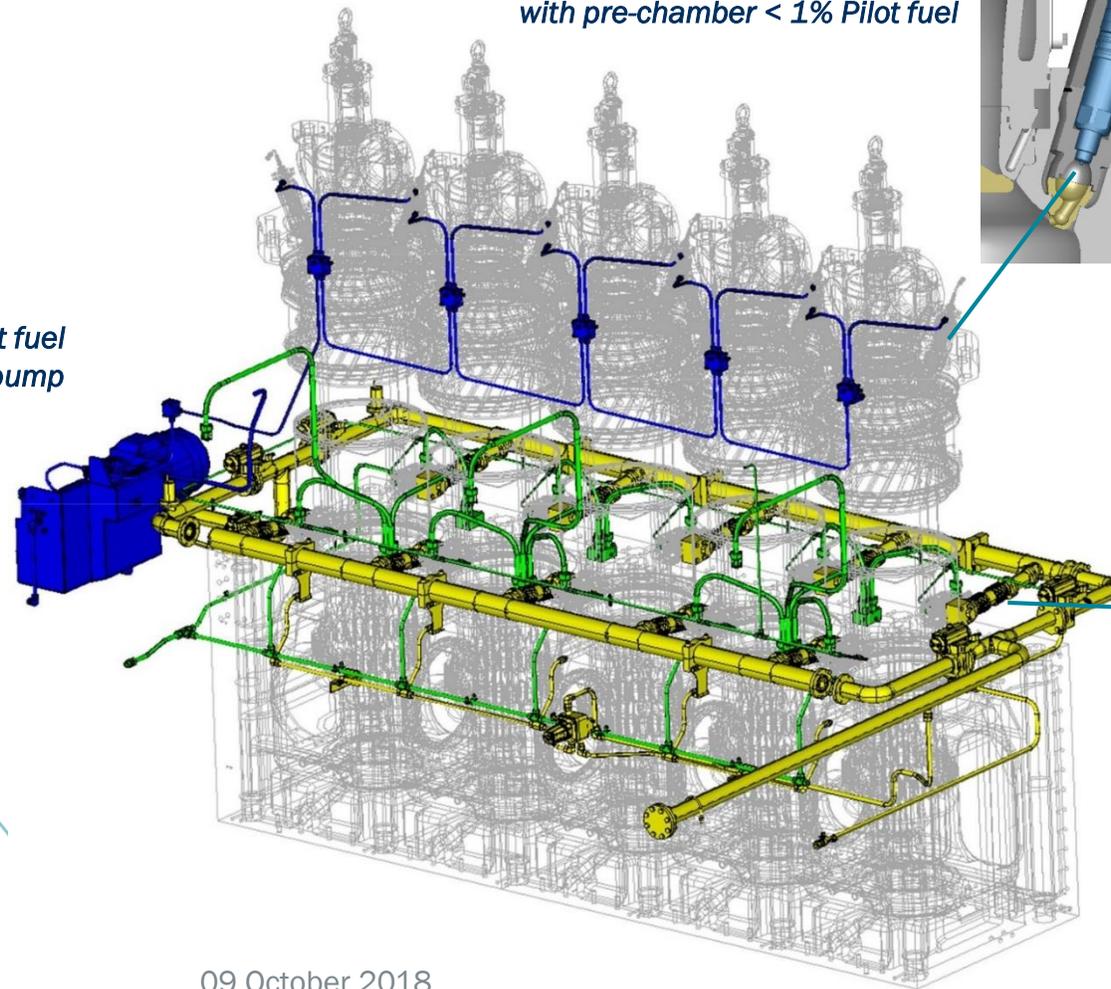
Gas admission & pilot oil injection

Unique WinGD Technology

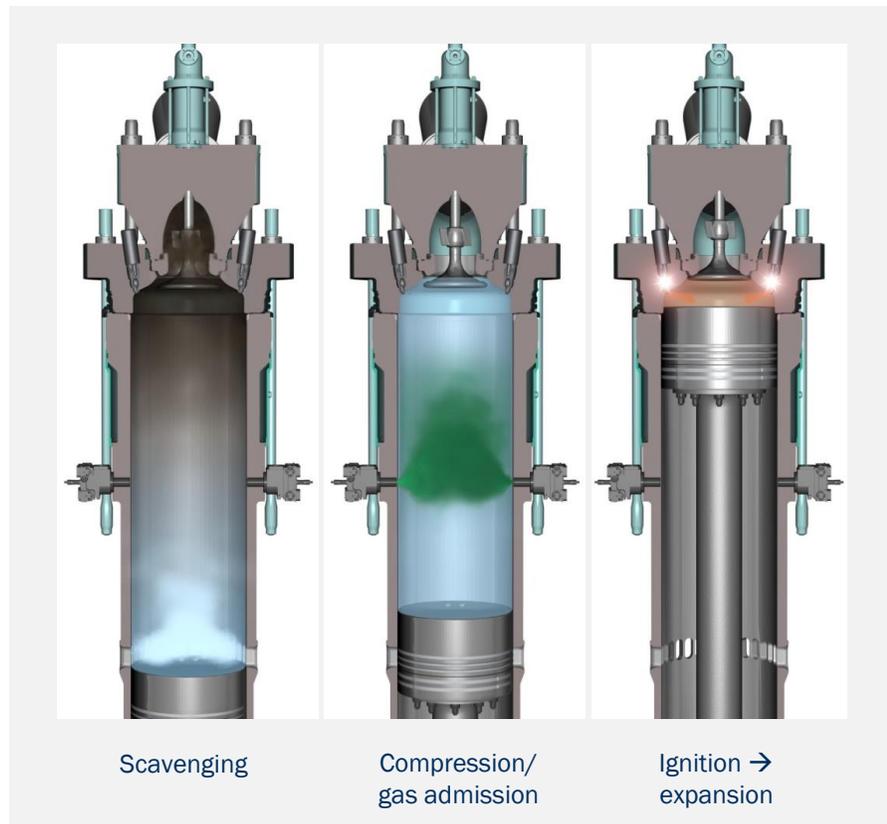
Two pilot injectors/cyl
with pre-chamber < 1% Pilot fuel



Pilot fuel
oil pump



Combustion principle

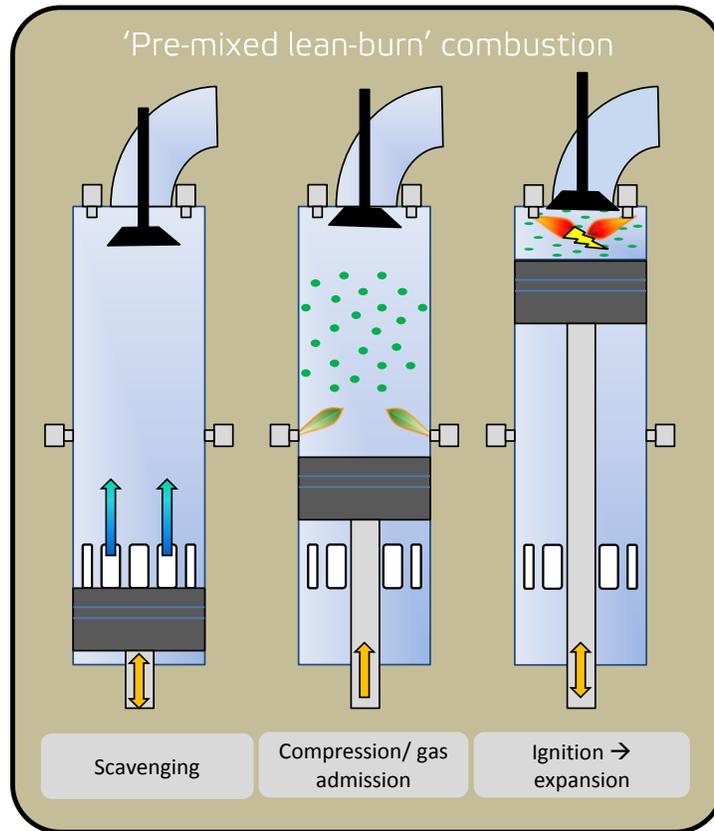


The main merits

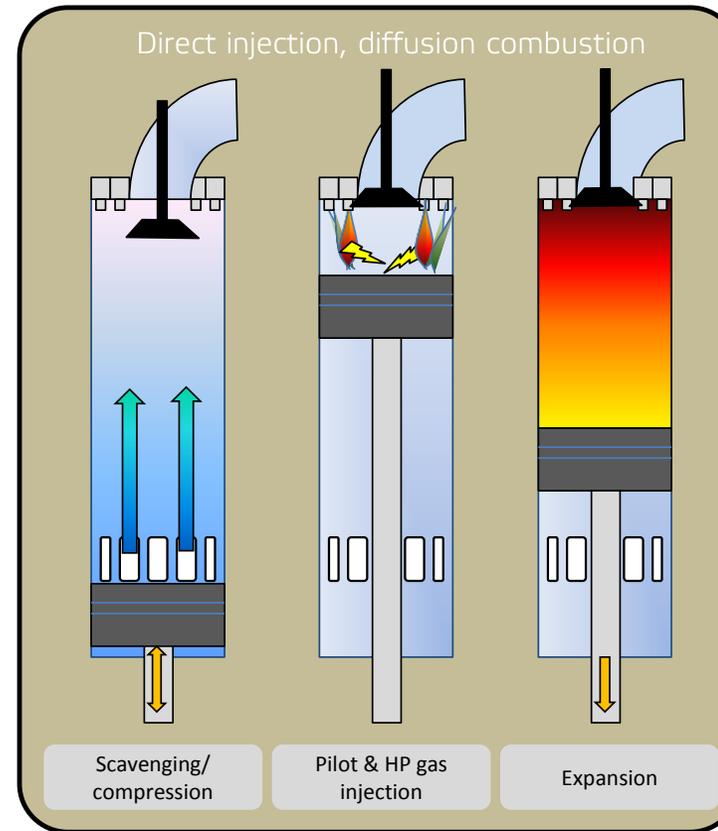
- Low gas pressure of 10 - 15 bar (depending on engine type and rating)
 - Simple and reliable gas supply system
 - Simple gas sealing
 - Wide selection of proven compressors / pumps
- Lean Burn 'Otto' combustion means IMO Tier III compliance:
 - Without additional equipment (EGR/SCR)
 - Without additional fuel consumption
 - Without compromised component reliability

- Gas mode: Pre-mixed lean-burn 'Otto' combustion
- Diesel mode: Diesel process

Combustion: comparison Diesel & Otto cycle



Otto cycle

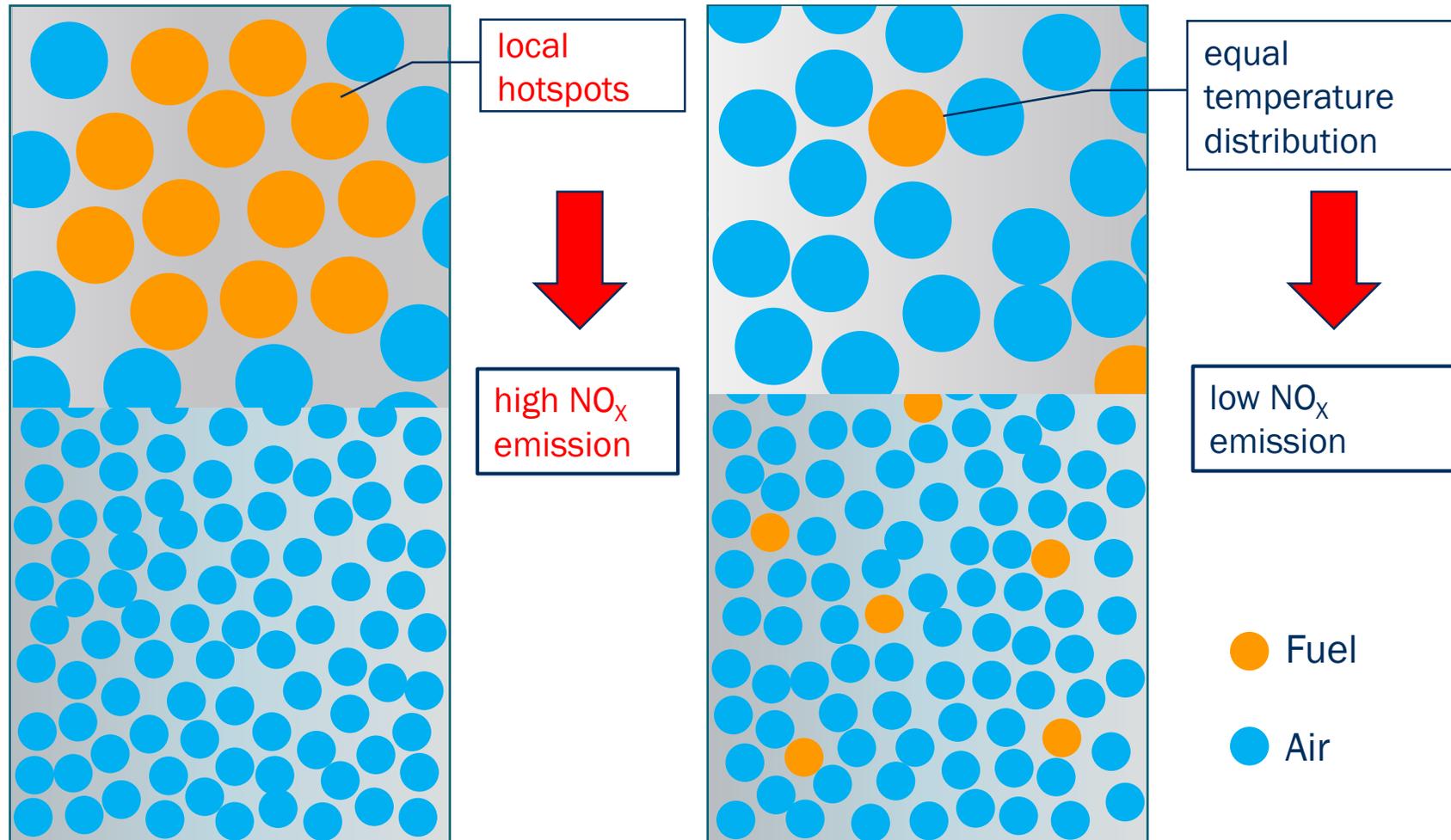


Diesel cycle

Combustion: comparison Diesel & Otto cycle

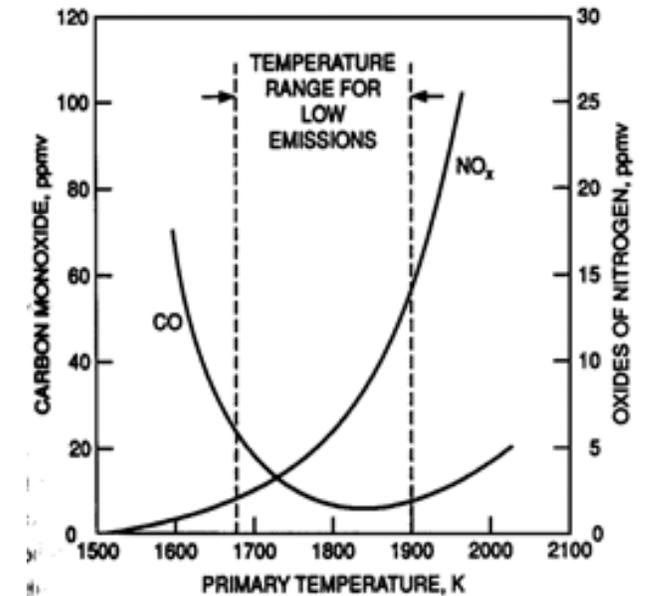
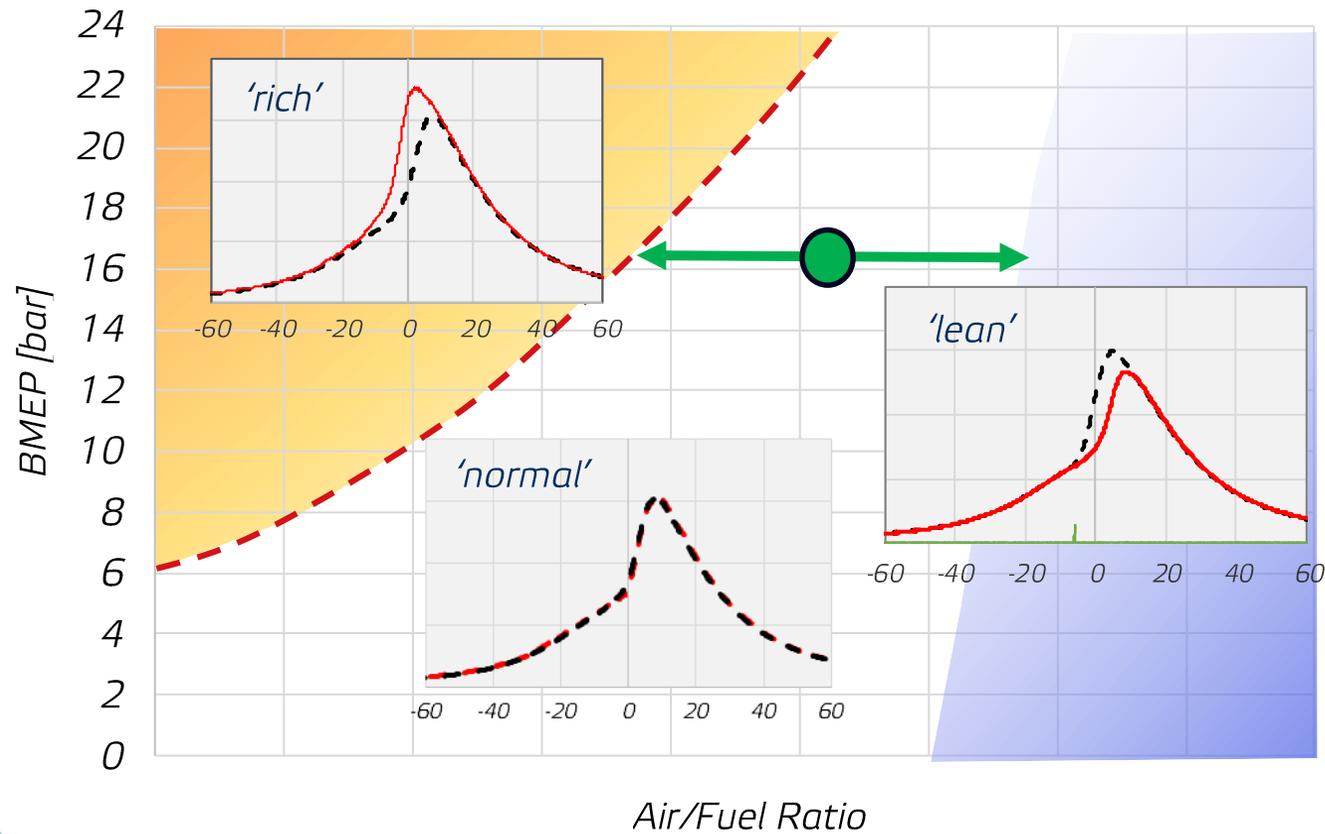
Diesel cycle - rich combustion

Otto cycle - lean combustion



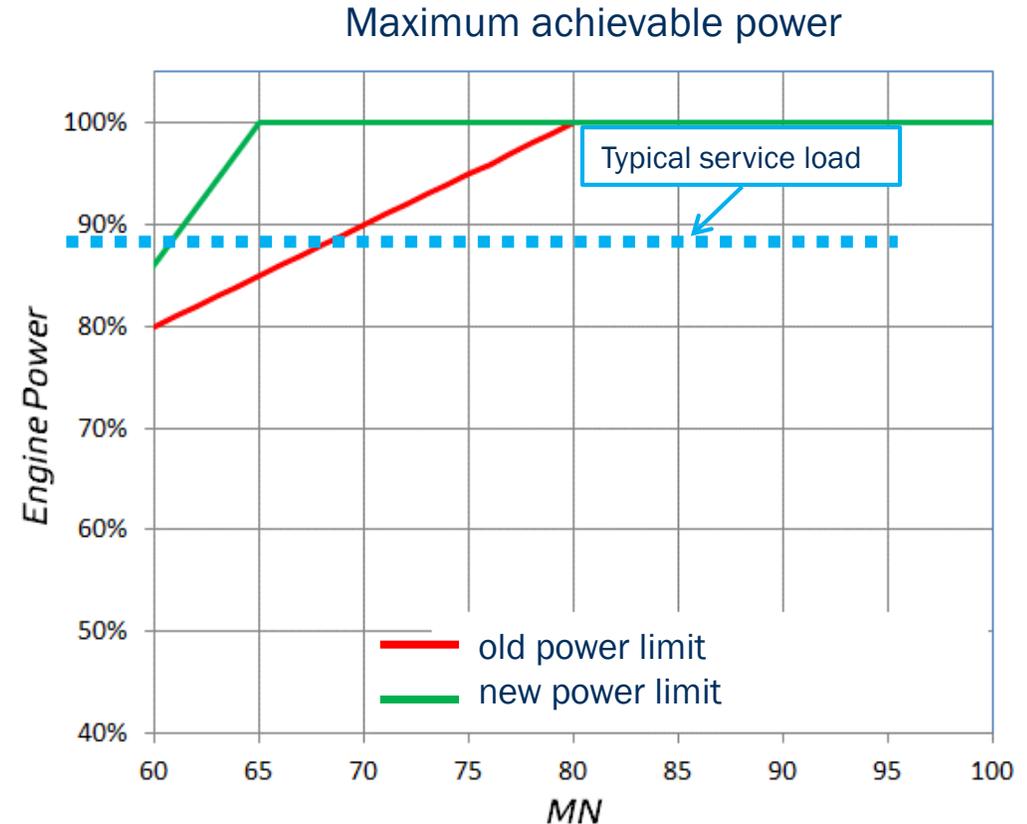
Fundamentals of combustion

- No 'radical' failure when crossing a limit
- Firing pressures, knocking and misfiring constantly monitored



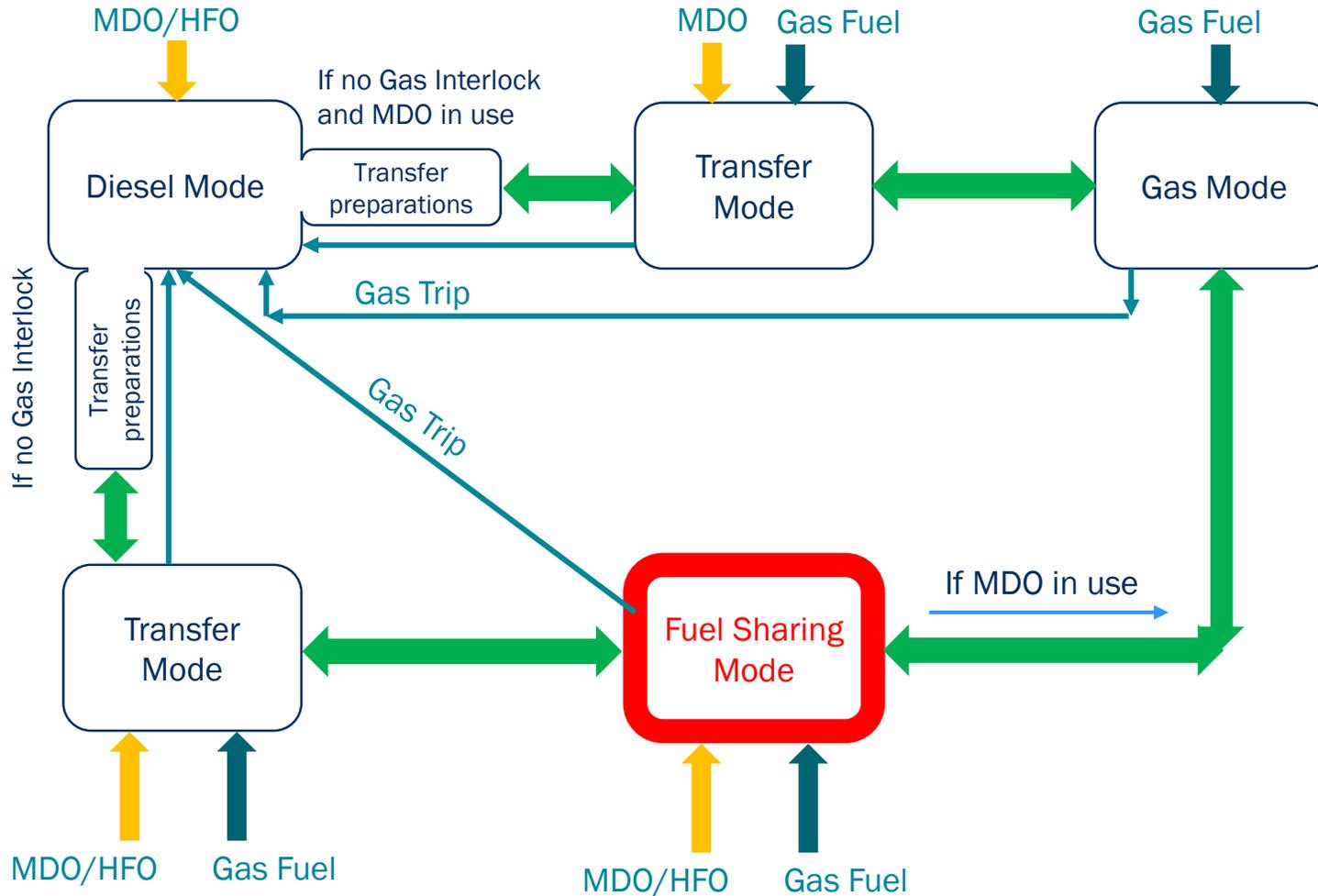
Methane Number (MN) – operating range

- Typically, the MN of LNG is between 70...100
- Under ISO conditions and colder conditions full power output is available for \geq MN 65.
- Typically, operating area for low-speed engines is $<$ 85% CMCR



Fuel sharing LNG - HFO

Automation, operating modes



Fuel sharing Gas/HFO

Maximum fuel flexibility

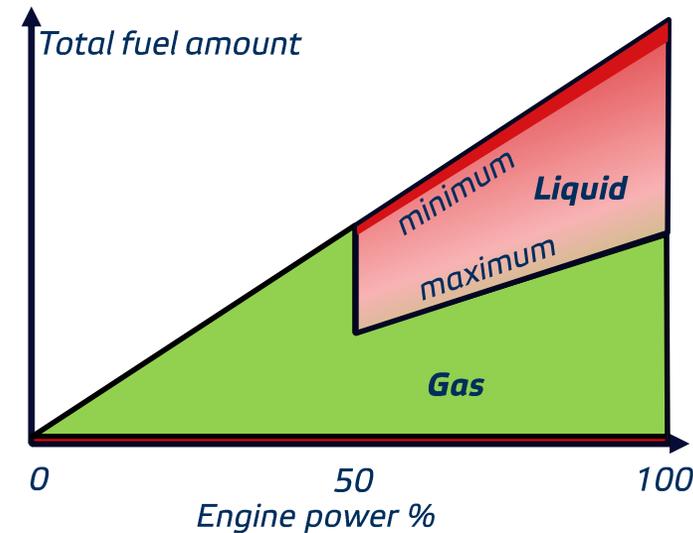
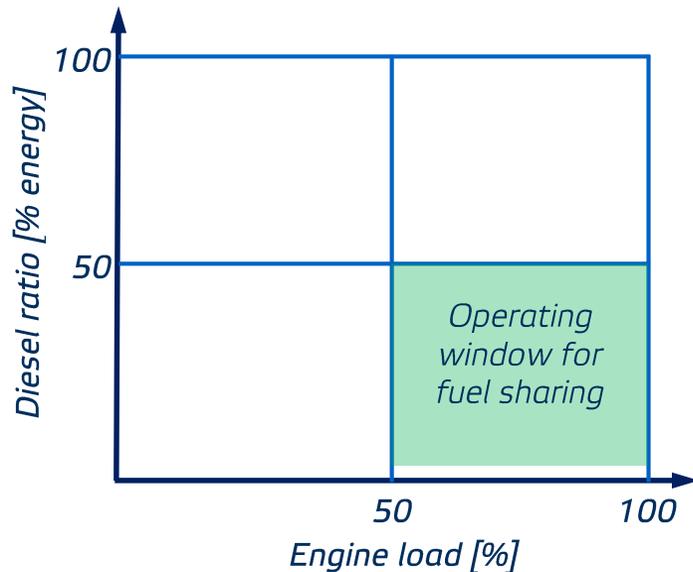
Fuel sharing, for LNGCs in particular:

- With adjustable ratio of gas to HFO. Can be used to balance between available boil-off gas and desired ship speed
- Control parameters are set in engine control system based on liquid/gas-ratio signal from RCS

Fuel sharing operating window:

- >50% engine power (to achieve high ship speed with insufficient NBOG)
- Up to 50% liquid ratio. With twin-engine installation, max 75% liquid ratio can be run

Feature Type Approval Tested and implemented on first LNGCs in service

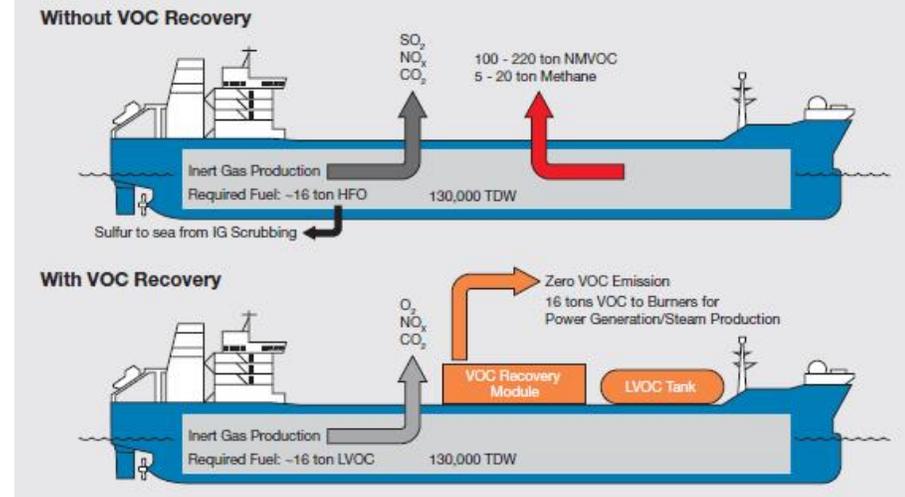


Volatile Organic Compounds as fuel in X-DF

- VOC consist of light- and heavy hydrocarbons in the crude oil which evaporate during ship loading operations
- VOC vapours can be liquefied (to LVOC) and stored in a tank on-board the vessel
- When using natural gas as a fuel, VOC can be blended into the gas and burned by the engine
- Considerable benefits:
 - Environmental: zero VOC-slip (greenhouse potential)
 - Commercial: VOC to substitute LNG for propulsion of the vessel
 - Particularly interesting for Shuttle Tankers with frequent cargo loadings
 - Application on Crude Oil Tankers of various sizes possible (Aframax, Suezmax, VLCC)
- Solution tested on lab engine during Q1/2018 in Trieste

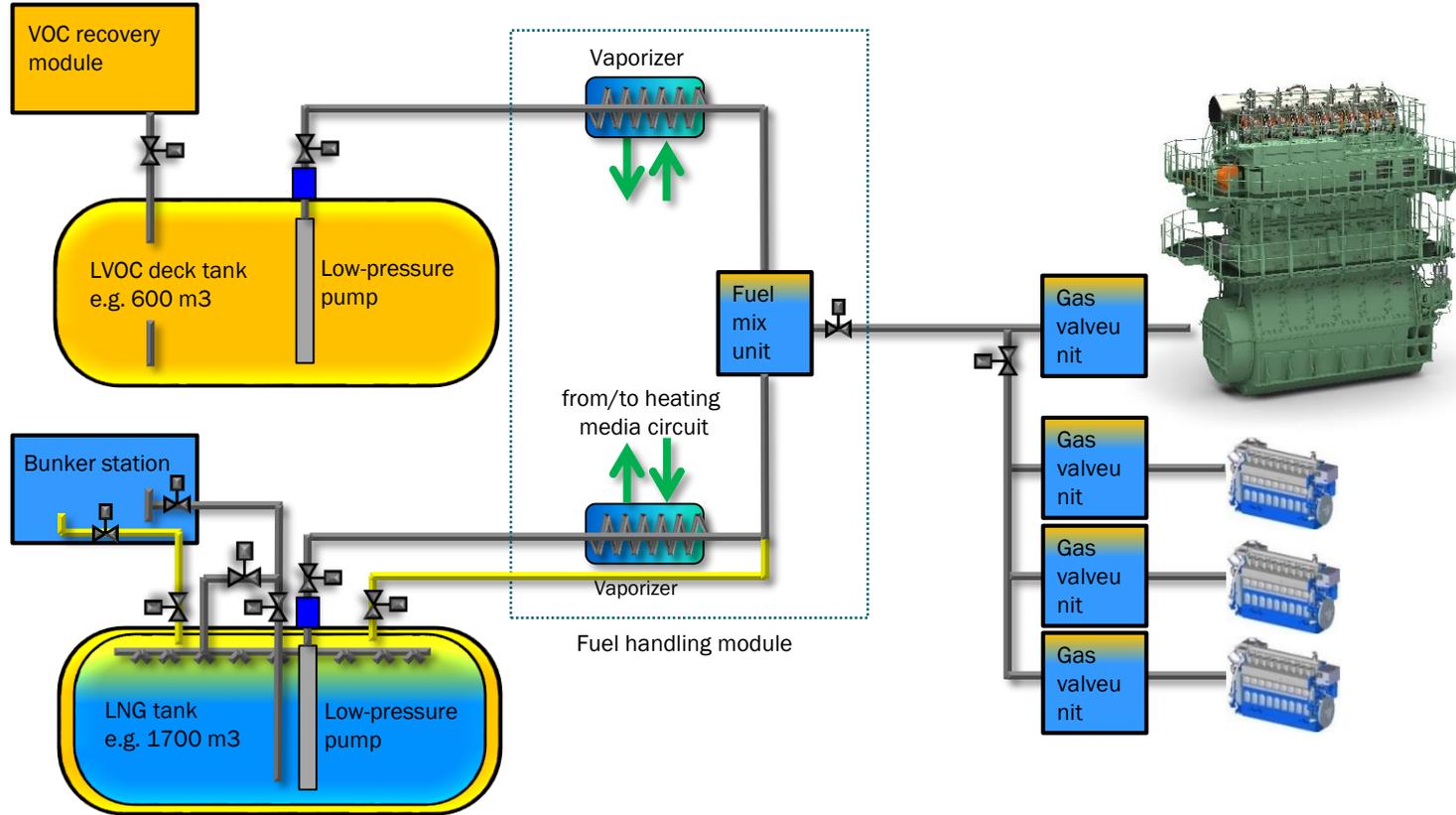
LVOC recovery module

LVOC tank



Picture: Wärtsilä

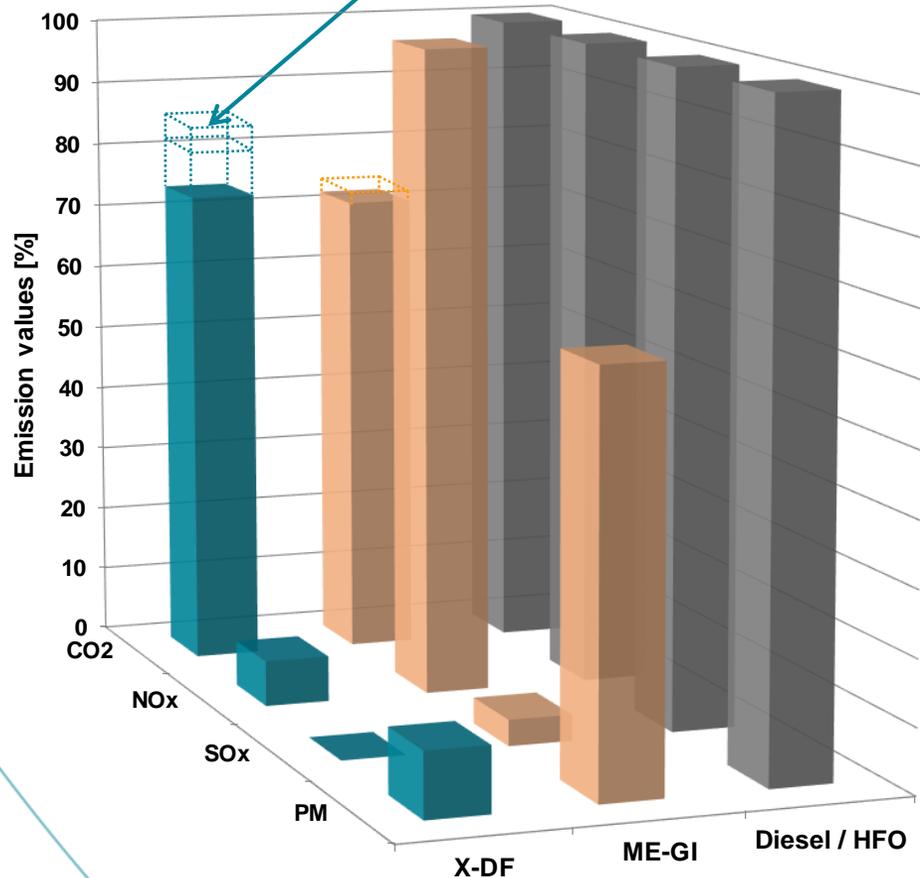
Fuel sharing NG – VOC (Liquid Volatile Organic Compound)



- ✓ Use of low-pressure main- and aux engines
- ✓ No high-pressure LVOC and LNG pumps, evaporators, piping, etc
- ✓ VOC in none supercritical condition
- ✓ Low electrical power demand
- ✓ Low investment costs

X-DF emission overview

CH4 contribution converted to CO₂ equivalent emissions



- **Particle Matters (PM) very low** due to ‘lean-burn’ Otto combustion with pre-chamber ignition
- **Close to zero SOx** due to clean natural gas
- **NOx level far below Tier III** due to ‘lean-burn’ Otto combustion
- **CH4 emissions (Unburned Hydrocarbons) = ‘Methane slip’** is reducing the CO₂ reduction with a conversion factor of 28 *) of -15% to -20% CO₂ equivalent compared to the diesel engine.
- **X-DF contributes positively to reduce the total emissions** compared to any engine operating in the Diesel process

*) : IPCC report ‘Climate Change 2014’, GWP factor 28

**NECA & SECA
emission regulation
compliant**

Content

- 1) X-type Market update
- 2) X-DF Market update & Technology
- 3) **X-DF operational experience**

X-DF Shop trials successfully completed

50 engines passed FAT and are partly delivered to ship yards

- 13 sets RT-flex50DF (in China & Japan)
- 17 sets W-X62DF (in Korea)
- 20 sets W-X72DF (in Korea)
- IMO EIAPP issued proving compliance with IMO Tier III NOx limits in gas operation
- Type approval testing (TAT) successfully completed on RT-flex50DF, X62DF and X72DF
- X52DF first project under manufacturing, bedding Oct 2018



X-DF Sea-Trials successfully completed

16 -with X-DF technology powered - vessels successfully completed sea trails

- Locations: China, Turkey and Korea
- Ship types:
 - One 14,000 m³ Coastal LNGC (no seatrial)
 - Four 15,000 dwt Chemical Tanker
 - Three 14,000 dwt Asphalt Carrier
 - Three 180,000 m³ LNGC with 2 x 6X62DF
 - Four 174'000 m³ LNGC with 2 x 5X72DF
 - Two 115k Crude oil Tanker with 7X62DF
- Engine types: RT-flex50DF, X62DF, X72DF
- Fifteen vessels in service (August 2018)



Picture: 5RT-flex50DF powered chemical tanker



Picture: Twin 5X72DF powered LNGC (source Gaslog LNG)



Picture: 7X62DF powered Aframax (Ice class) tanker

First RT-flex50DF ever in operation

The early movers

“M/T Ternsund” in regular service in the Baltic / North Sea since August 2016.

- Approx. 12’500 running hours accumulated (Sept 2018), running more than 90% of time on gas (only port operation in diesel mode)
- All four vessels of the “Terntank” series are in operation with about 40’000 accumulated running hours totally

“M/T Damia Desgagnes”

- Handed over Aug 2017. In service on the Great Lakes, ~5000 rhrs

“M/T Mia Desgagnes”

- Handed over Nov. 2017, operating on Great Lakes, about 3000 rhrs
- Ship 3 and 4 delivery in 2018

Nordic Container Vessel

- First 7RT-flex50DF vessel (Owner Nordic) expected delivery November 2018



Picture: Port of Gothenburg

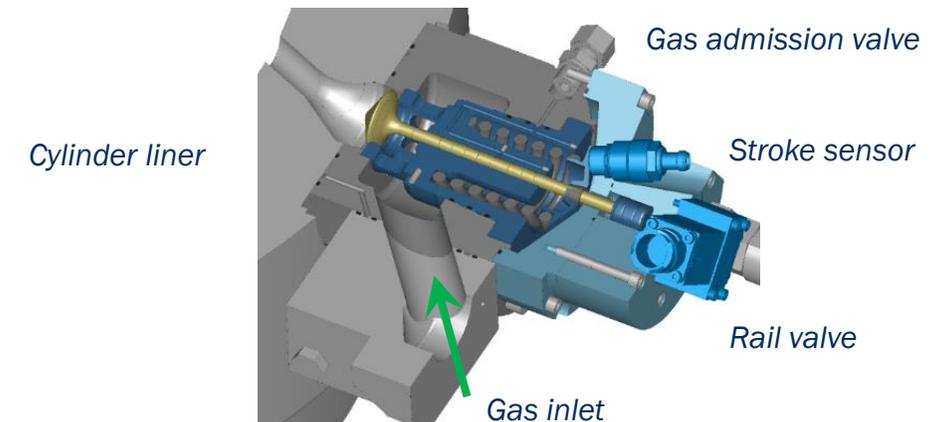
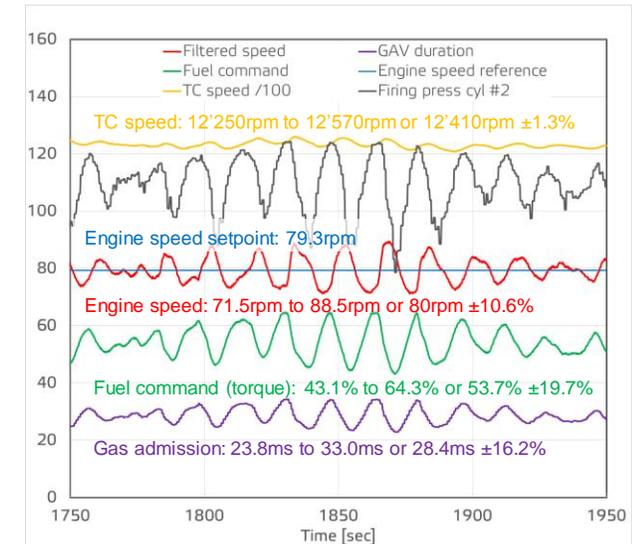


Picture: Besiktas Shipyard

Findings on low-pressure technology

After 50'000rhs on RT-flex50DF engines

- 7 engines in operation with a total running hours of about 50'000
- Low-pressure gas technology works well:
 - Stable combustion process
 - Stable engine loading in rough sea
 - Very low load operation on gas down to 5% proven in service
- Optimisation of the DCC function for certain tuning combinations introduced:
 - For high load operation
 - At tropical conditions
 - For CPP operation
- Gas admission system working excellent:
 - No malfunction or gas leakage experienced
 - 2 cases of sticking GAV during testbed commissioning encountered (particle contamination rail valve), resulting in GT → safety system worked as designed, plus GAV filter introduced



RT-flex50DF liner lubrication & piston running

Teething problems resolved

Cylinder lubrication

Feed rate down to 0.7 g/kWh on BN25 cylinder lube oil seem feasible

A number of initial piston running issues on RT-flex50DF:

Leaking pilot injectors lead water enter cylinder

- Design changed → resolved

Initially excessively fast loading ramps with CPP

- Settings adjusted to regular spec. → resolved

Scavenge air pressure for combinator mode operation (CPP)

- Improved tuning introduced → resolved

Reduced cylinder liner surface temp. to ensure stable cylinder oil lubrication film

- Tuning parameter adopted → resolved

Recently one new case experienced → under follow up



Almost 100% running on LNG

Start / Stop / Manoeuvring in Diesel - the rest in LNG mode

Overall X62/72DF fleet

Vessel references	Vessel Delivery	R/H After ship delivery	Gas mode R/H after 1st gas loading
LNGC Twin 6X62DF #1	29.07.2017	9000	7760
LNGC Twin 6X62DF #2	09.01.2018	5080	4000
LNGC Twin 5X72DF #1	09.01.2018	4550	2950
LNGC Twin 5X72DF #2	19.03.2018	3830	2850
LNGC Twin 5X72DF #3	30.03.2018	3640	2400
LNGC Twin 6X62DF #3	16.04.2018	3000	1850
Tanker 7X62DF #4	31.07.2018	740	-
LNGC Twin 5X72DF #4	31.07.2018	740	-
Total running hours (05/09/2018)		60'400	



The Gas availability (after first bunkering) is excellent; typically 97~98% of voyage running on Gas

Piston running behaviour on LNG carriers

Good running behaviour

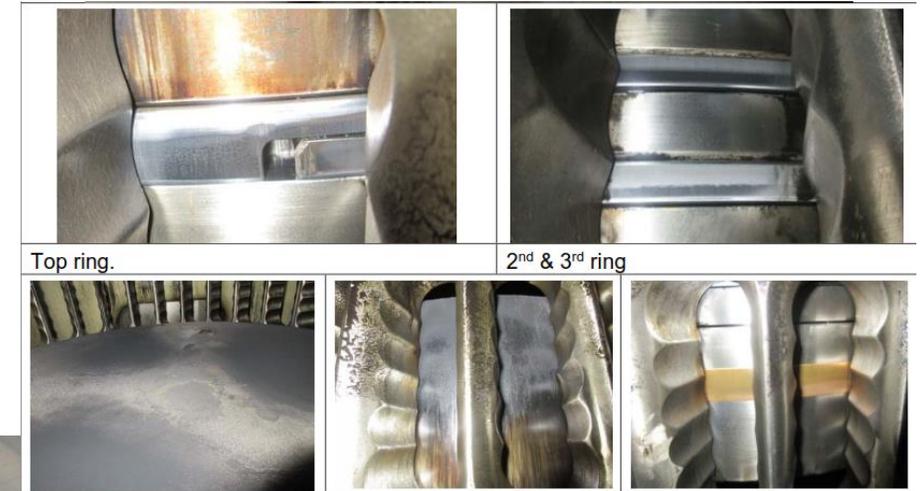
In general X-DF LNGC's

- Running behaviour excellent
- Cylinder oil used for "lubrication & cleaning" not neutralization of Sulphur
- Regular piston underside sampling recommended (iron content, BN)

One specific case with piston running issue shortly after overhauling unit – reason under investigation.

Other LNGC in operation with excellent conditions.

Low BN (25) cylinder oil for Gas mode operation recommended, high BN (100) for HFO operation.



Operational Experience: Summary

110.000 operating hours on WinGD low-pressure dual-fuel engines

- X-DF engines are running very well under real service conditions
- Teething problems noted and resolved, none of which being major
- Some operational issues on the first commercial engine RT-flex 50DF, resolved in time
- As of today, the RT-flex50DF engines are showing good operational behaviour
- X62DF and X72DF engines gained from experience gathered on RT-flex50DF. Only minor operational issues seen after 60'000 hours
- On LNGC's, engines run on gas for 97~98% of the total running hours! → excellent availability of gas mode
- Diesel mode only used for berthing respectively engine starting after port call
- Operator feedback positive

2018 Awards & Nominations

Emissions Reduction Award

WinGD's X-DF technology was awarded the **Marine Propulsion Emissions Reduction Award**.



**Emissions Reduction
Award Winner**

Marine Engineering of the Year

WinGD's lean burn pre-mixed combustion technology was awarded the **2017 Marine Engineering of the Year** by the **Japan Institute of Marine Engineering**

