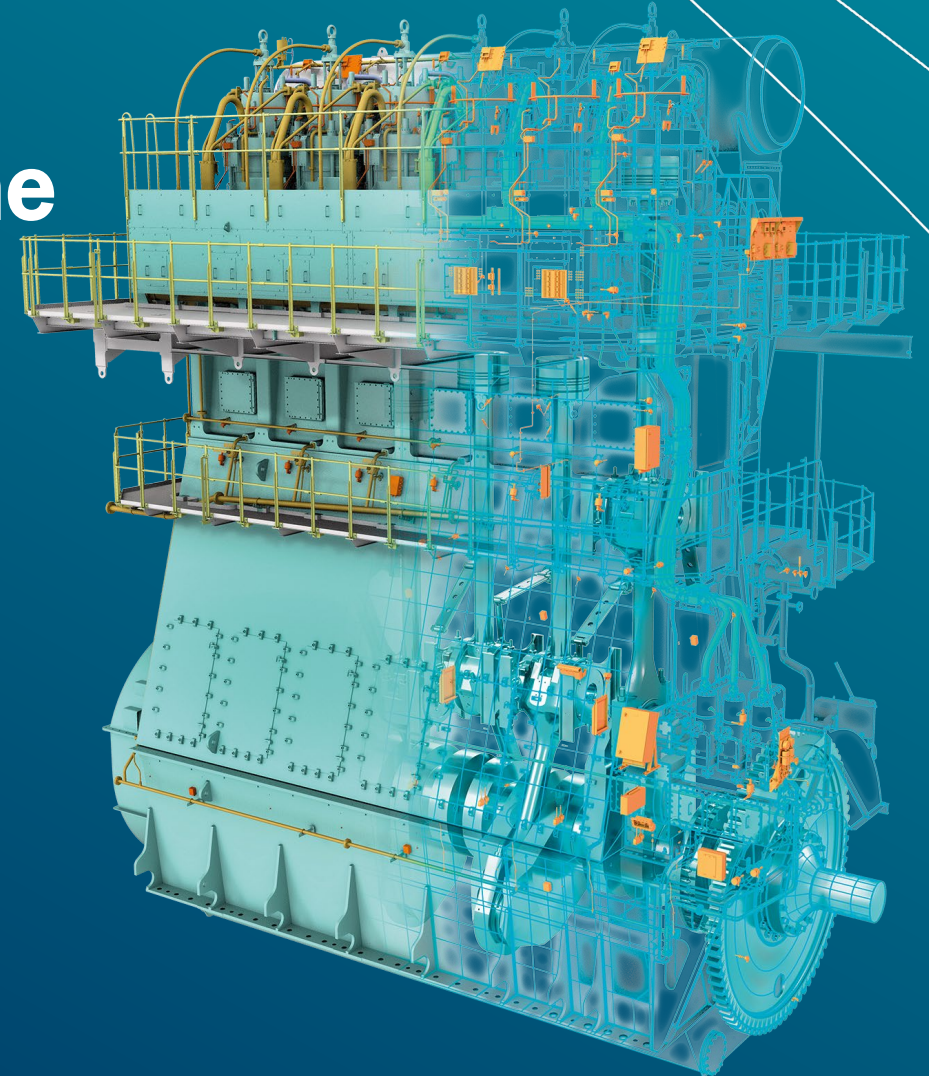


WinGD's X-DF low-pressure dual-fuel marine propulsion engines technology – minimising methane emissions and general environmental footprint

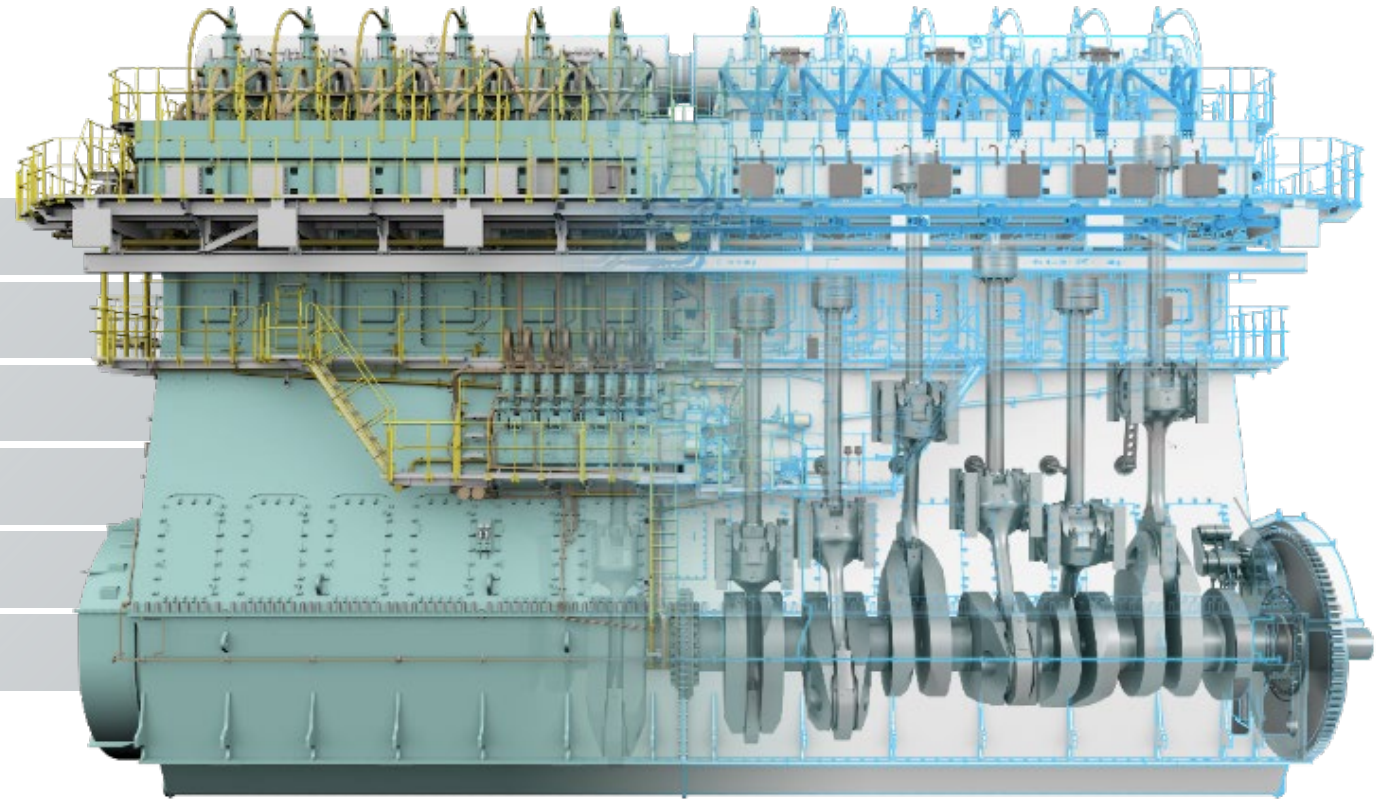
IMO Technical Seminar methane-based fuels

Dirk Kadau, May 2026

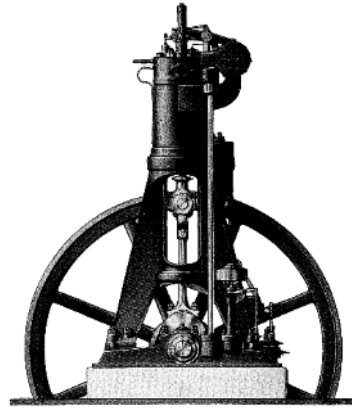


Presentation Outline

- 1 Introduction
- 2 WinGD's low pressure X-DF
- 3 iCER technology
- 4 Variable compression ratio (VCR)
- 5 Environmental/GHG footprint
- 6 Conclusion



Over a Century of Leading Engine Innovation



SULZER



WINGD

1834

Sulzer foundry established in Winterthur

1898

1st Sulzer diesel engine

1990

New Sulzer Diesel (NSD) created

1997

NSD merges with Wärtsilä

2015

Winterthur Gas & Diesel created



First Sulzer diesel engine

1898

First turbocharged diesel engine prototype

1915

Super-long-stroke Sulzer RTA engine series

1982



RT-flex96C: World's largest diesel engine

2005

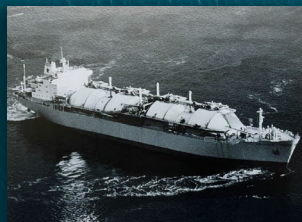
1912

First two-stroke for ocean vessels



1972

First mechanically controlled low-pressure dual-fuel engine

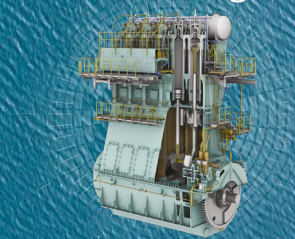


2001

First electronically controlled two-stroke common-rail engine

2013

X-DF
First electronically controlled low-pressure dual-fuel engine

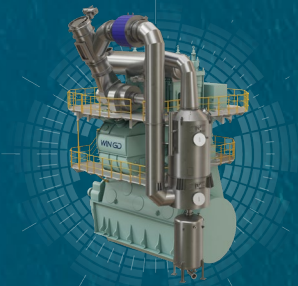




WiDE
by WinGD

WinGD integrated
Digital Expert

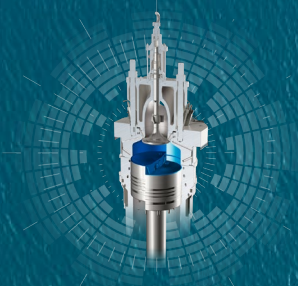
2018



X-DF2.0
by WinGD

With iCER technology

2020



X-DF VCR
by WinGD

First order VCR technology

2023



Global Service
by WinGD

Global Service Launched

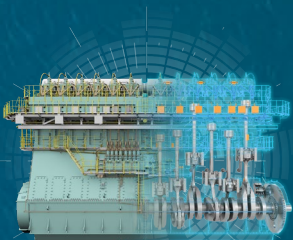
2025

Net-zero emissions
from maritime
transportation

2050

2019

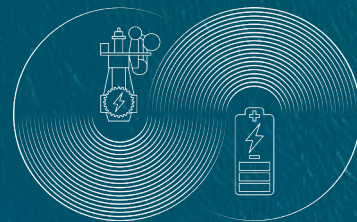
12X92DF:
Largest Otto-cycle
engine



2021

X-EL
by WinGD

Energy Management
launched



2025

First WinGD
Retrofit project



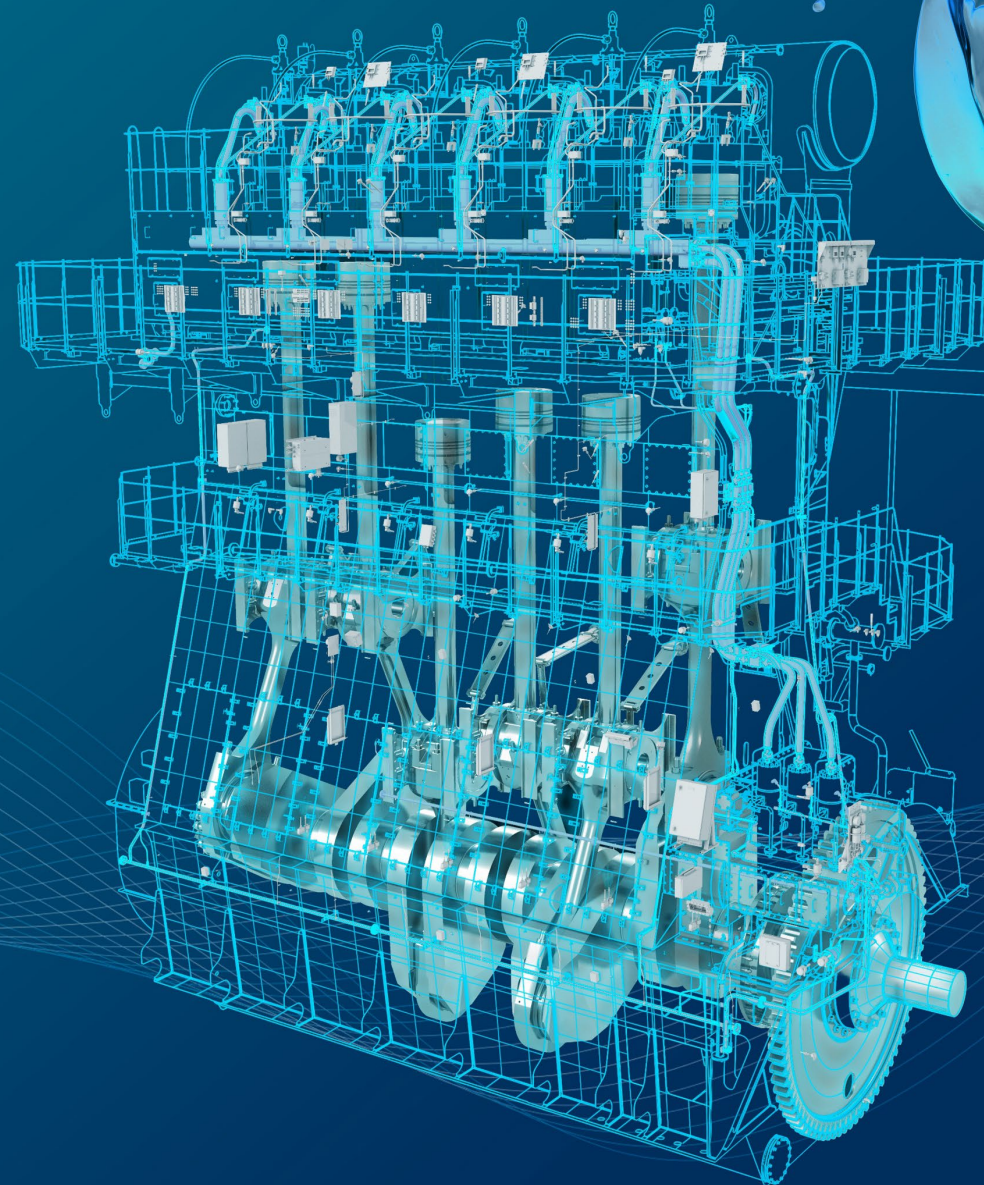
2025

First X-DF-M and X-DF-A
engines delivered

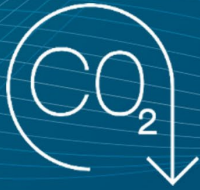


X-DF by WinGD

Proven dual-fuel
technology where it fits.
Powerful where it
matters.



Lower
operating
costs



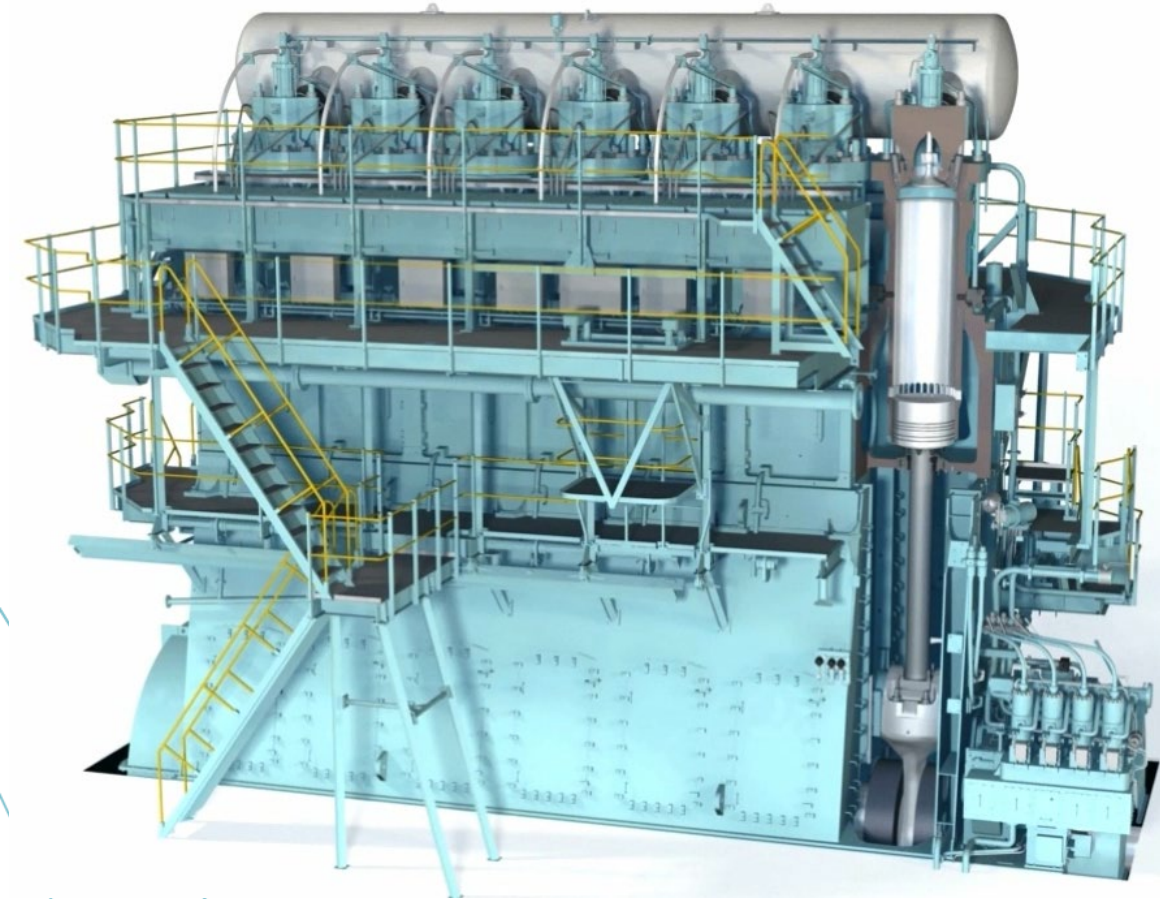
Reduced
Methane slip and
CO₂ emissions



Proven
design for
reliability and
safety

Low-pressure technology sets the standard

Maximum simplicity!



The Principle

- Engine operating according to Otto process
- Pre-mixed 'Lean-burn' combustion technology
- Low-pressure gas admission at 'mid-stroke' location
- Ignition by pilot-fuel into pre-chambers

The main merits with low gas pressure < 13bar

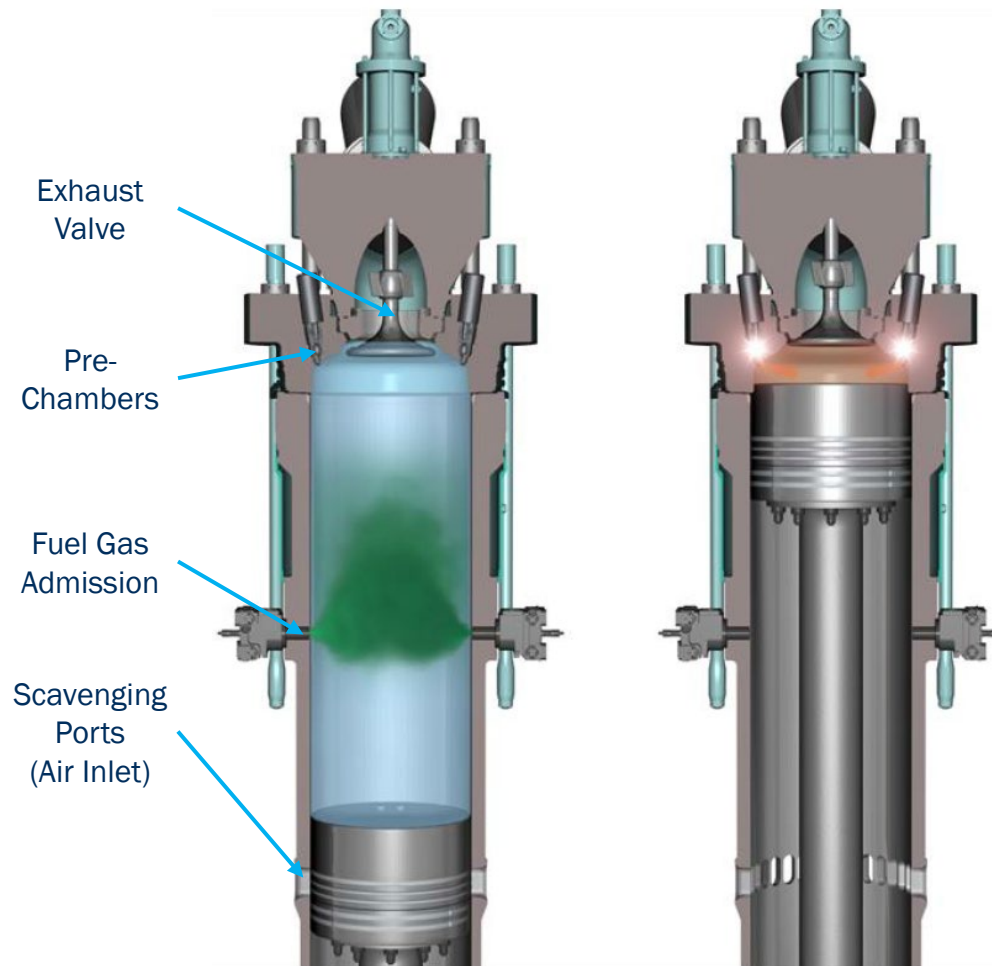
- Simple and reliable gas supply system
- Simple gas sealing
- Wide selection of proven compressors / cryogenic pumps

Lean Burn 'Otto' combustion means IMO Tier III compliance

- Without additional equipment (EGR/SCR)
- Without additional fuel consumption
- Without compromised component reliability

X-DF engines

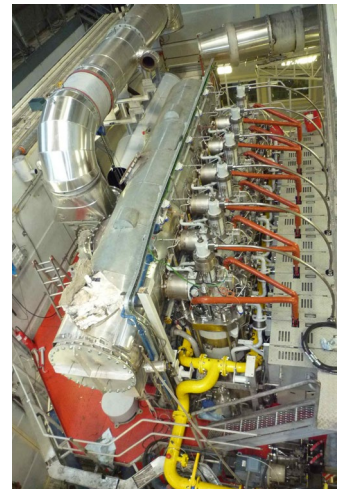
Working principle, product portfolio and test engine particulars



	Power (MW)														Speed (RPM)
	3	4	6	8	10	15	20	30	40	50	60	70	80		
X40DF-10														104-146	
RT-flex50DF														99-124	
X52DF / X52DF-2.1														79-105	
X52DF-S1.0/X52DF-S2.0														85-120	
X62DF-S1.0/X62DF-S2.0														82-108	
X62DF / X62DF-2.1														80-103	
X72DF / X72DF-1.1/X72DF-1.2/X72DF-2.1/X72DF-2.2														69-89	
X82DF-1.0 / X82DF-2.0														58-84	
X92DF / X92DF-2.0														70-80	

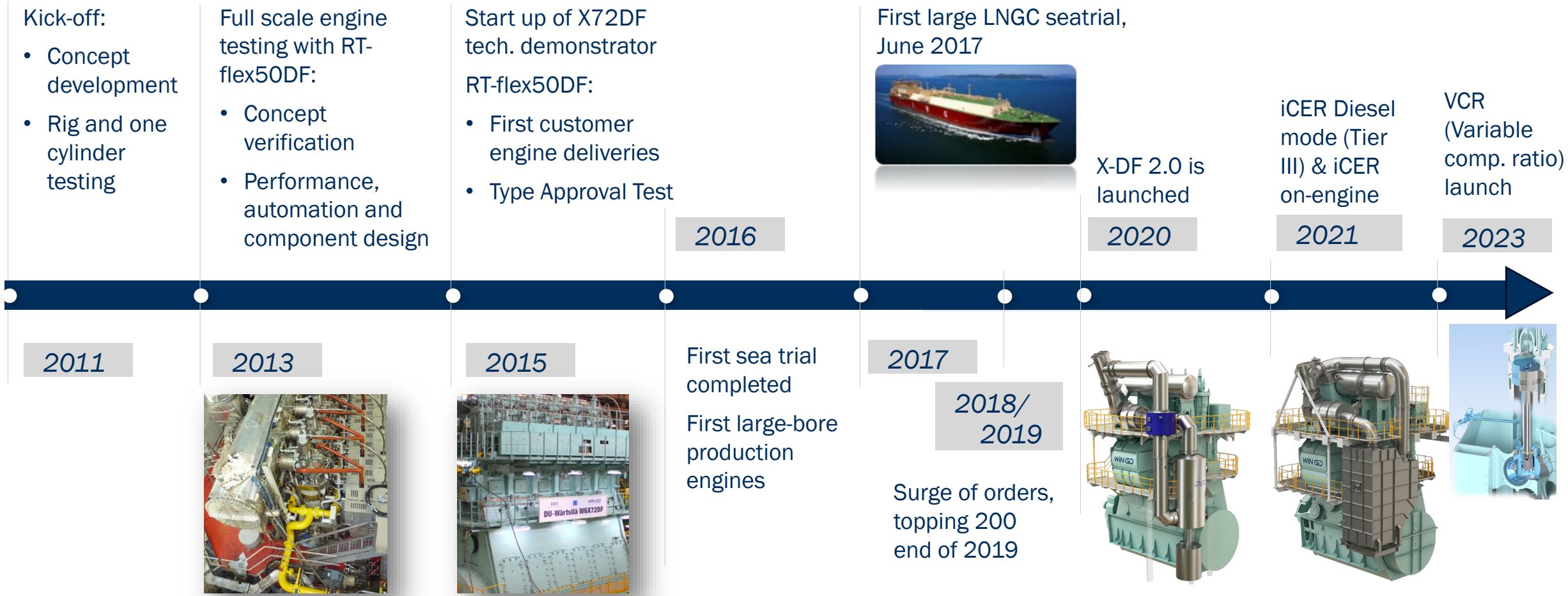
Specification of RTX-5 test engine

Bore	[mm]	500
Stroke	[mm]	2050
Rated Power	[kW]	6900
Rated Speed	[RPM]	99.0
Rated BMEP	[bar]	17.3
Number of Cylinders	[-]	6
Gaseous Fuel	[-]	Natural Gas
Liquid Fuel	[-]	Marine Gasoil



X-DF has Become the Standard of the Industry

More than a decade of technical developments and commercial successes



X-DF2.0

iCER and VCR are the two key technologies of XDF-2.0

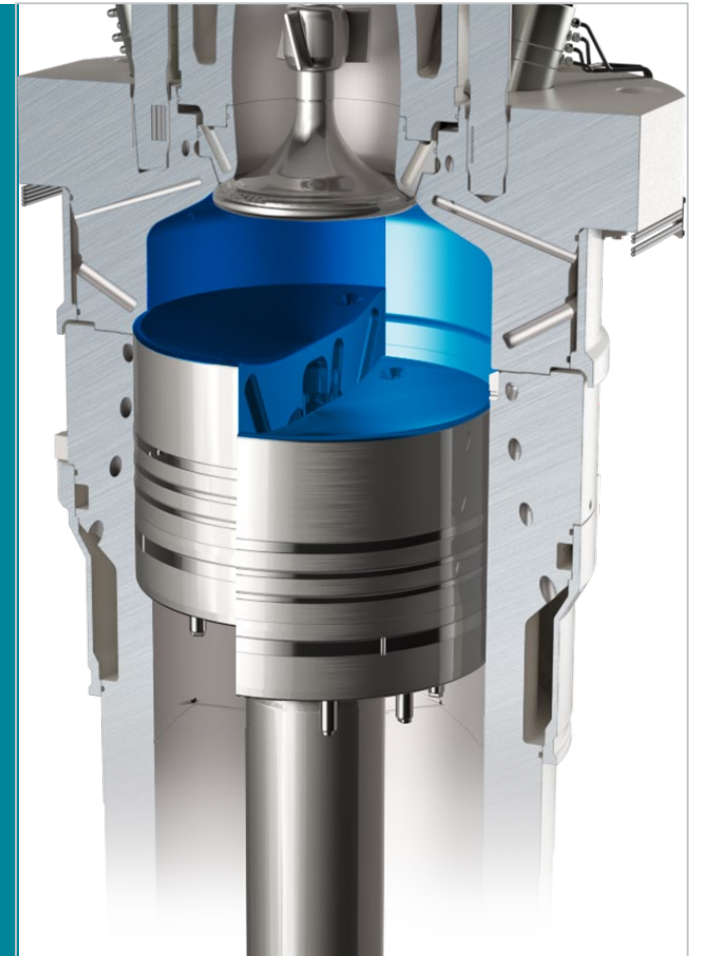
iCER

intelligent Control by
Exhaust Recycling



VCR

Variable
Compression Ratio



iCER by WinGD

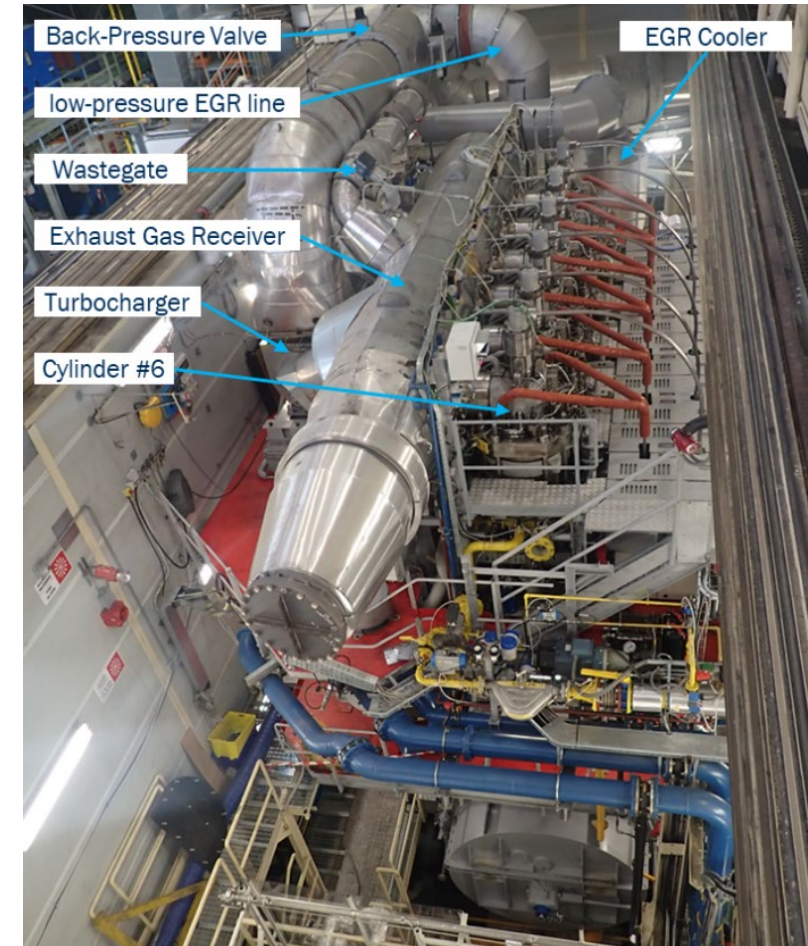
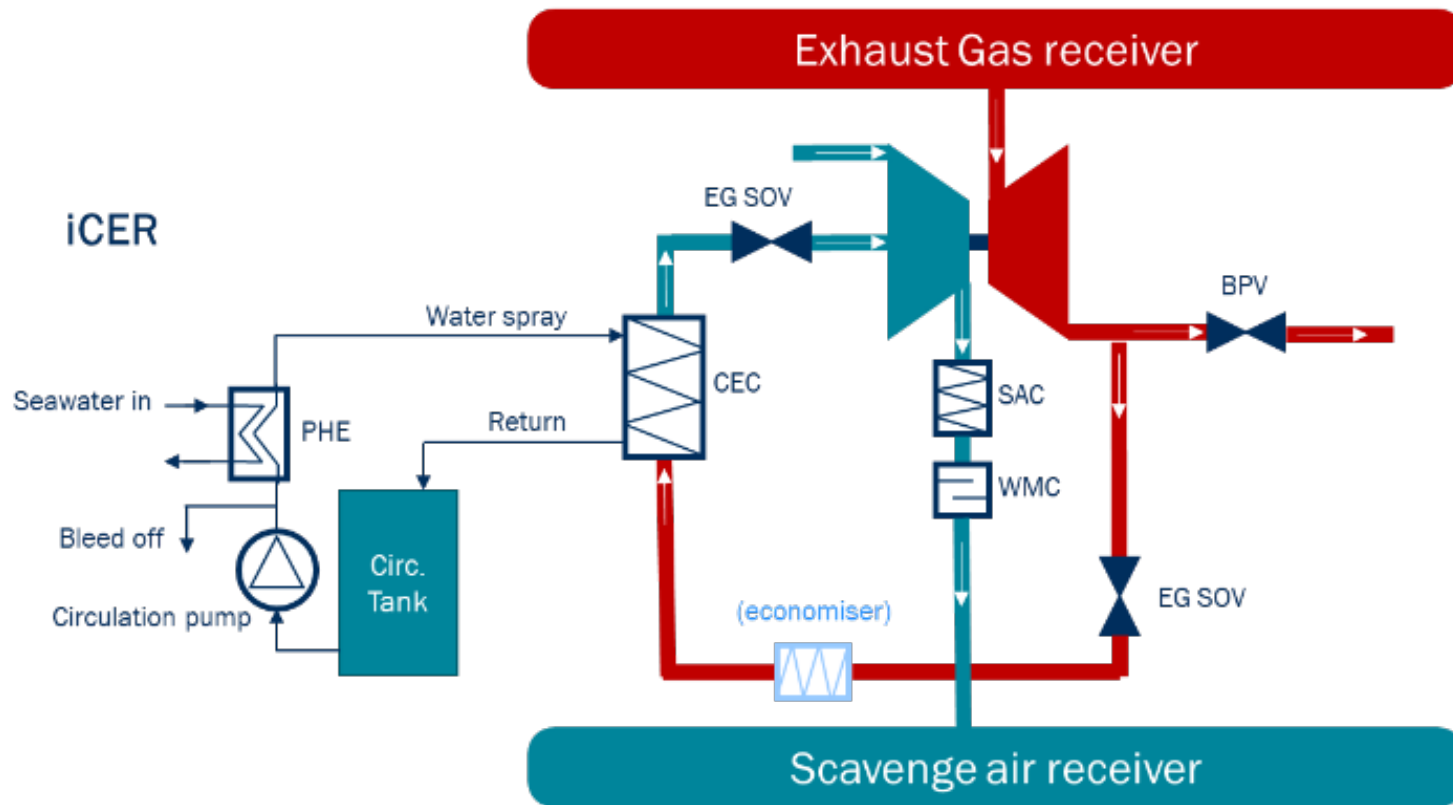
Add more CERtainty
to your future



Further development of X-DF technology

X-DF2.0's iCER (intelligent Control by Exhaust Recycling) low-pressure EGR system

In a first step, the RTX-5 lab engine was equipped with an iCER prototype system for technology demonstration and optimisation



WinGD-iCER Concept

iCER – Key benefits



Off-engine solution



On-engine solution



Reduced Gas
consumption



Reduced Low
Particulate Matter (PM)



Reduced Diesel
consumption



Low
NOx



CH₄ and GHG
reduction

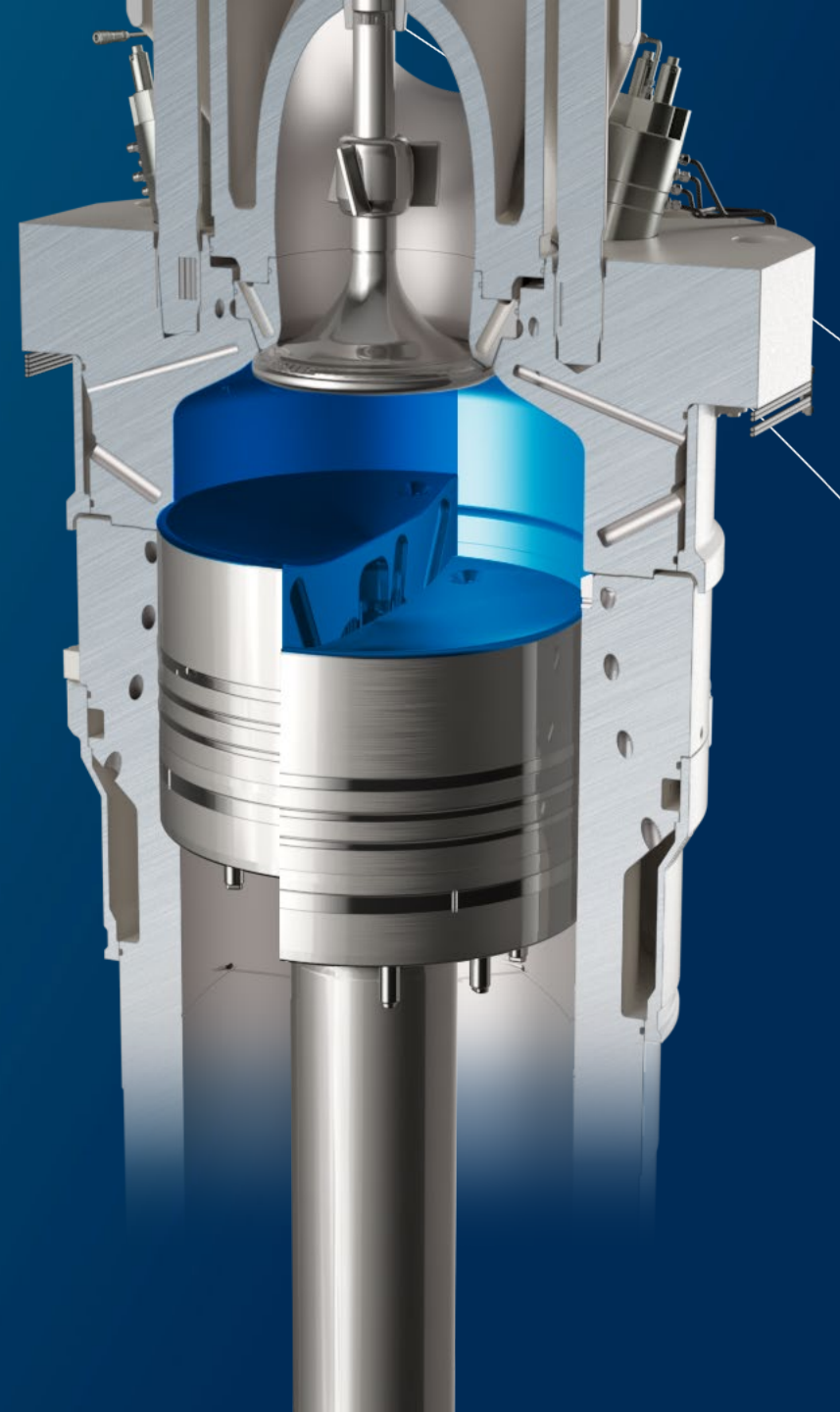


No DCC
activation

X-DFVCR

by WinGD

Compression without compromise:
Status and latest results



WINGD

What is the Compression Ratio?

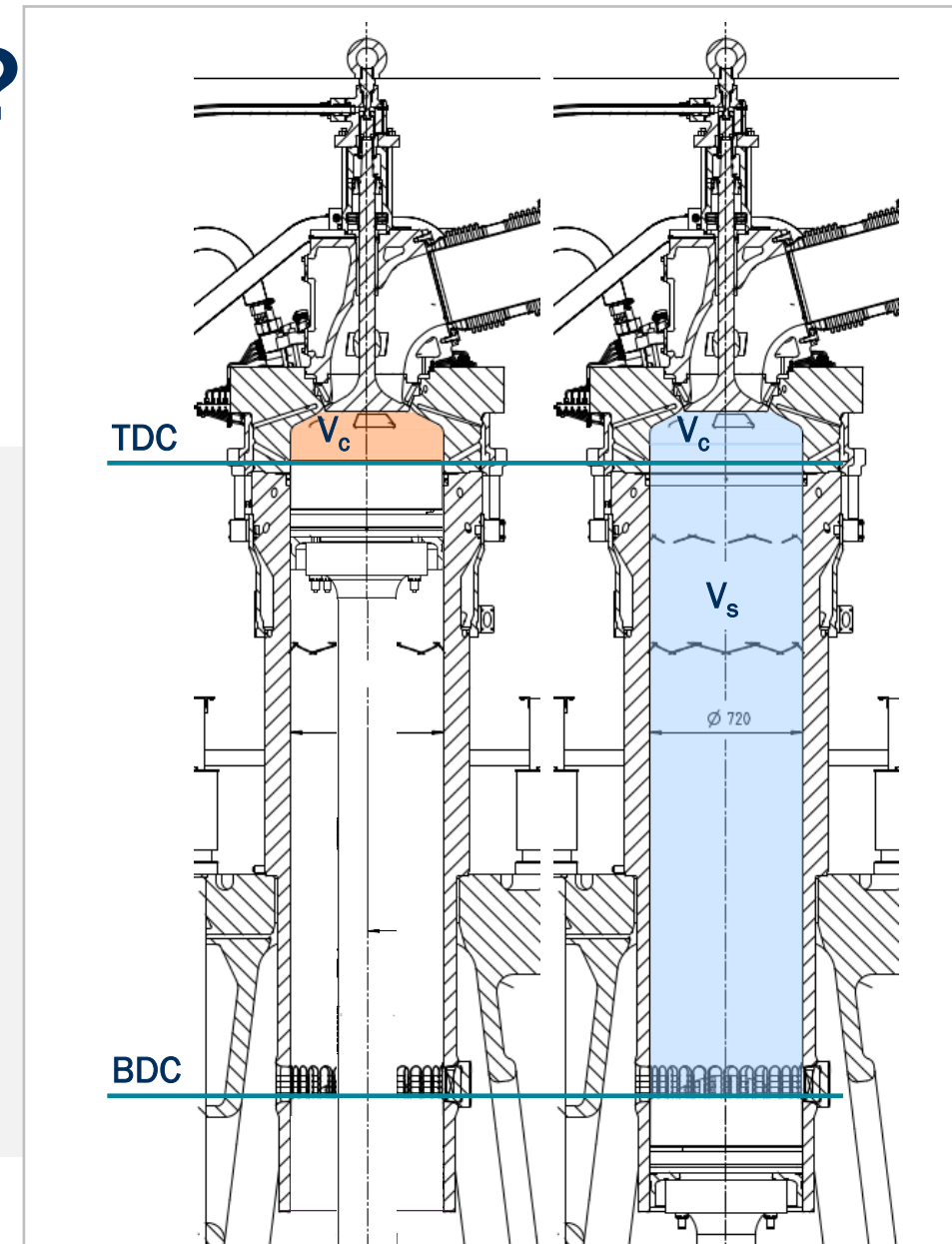
$$CR = \frac{v_c + v_s}{v_c}$$

v_c Compression volume
(volume of the combustion chamber when the piston is at TDC)

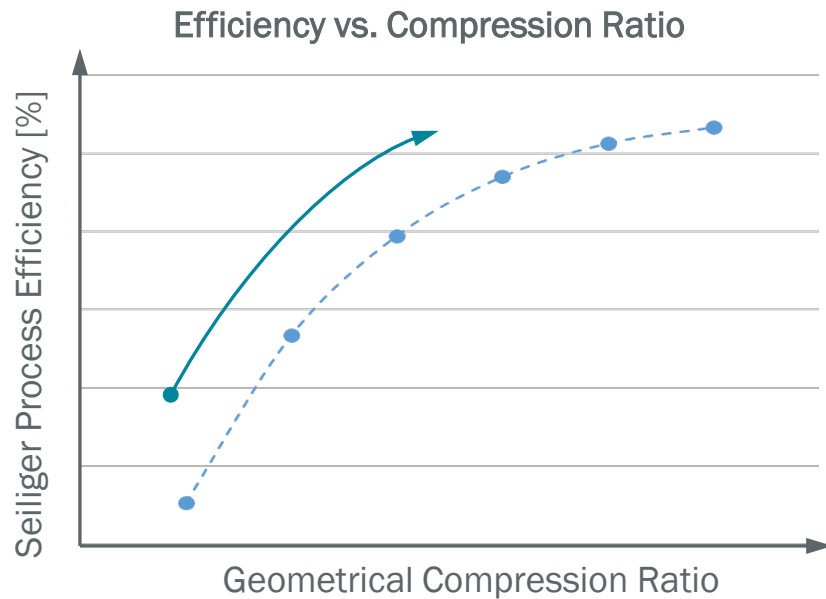
v_s Swept volume
(volume displaced by the piston moving from BDC to TDC)

TDC Top dead centre

BDC Bottom dead centre



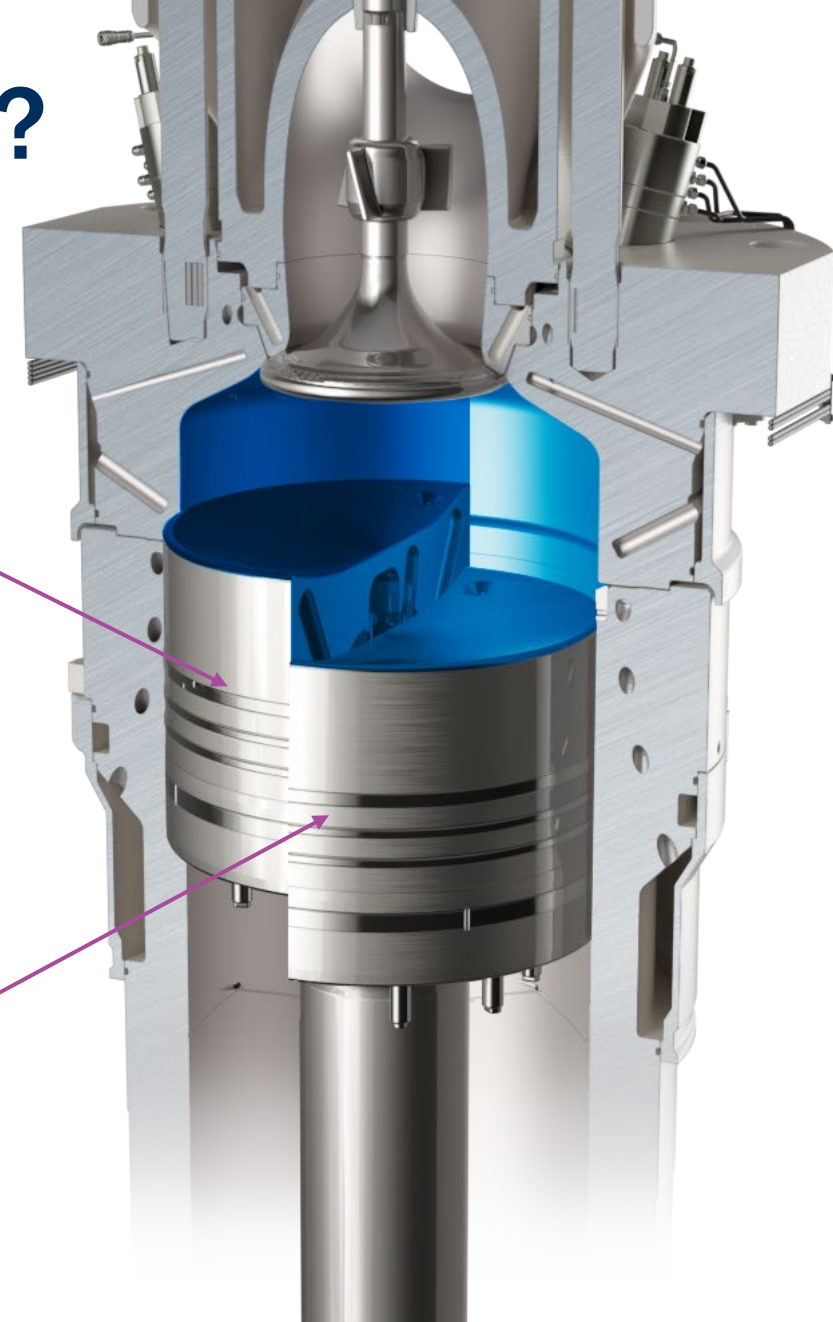
Why adjust the Compression Ratio?



- Continuous adjustment of CR based on actual combustion behavior
- → highest possible efficiency, in any fuel mode, under any operating condition

High CR:
Optimal for diesel,
unsuitable for full load on gas

Low CR:
Ideal for full load on gas,
suboptimal for diesel



VCR Pilot Installation

First sea-going VCR Installation

Upgrade executed:

- 7RT-flex50DF on 1,400 TEU container feeder vessel
- Engine upgrade with installation of full VCR system completed in November 2024 at Damen SY, NL.
- No engine room modifications necessary



Objective:

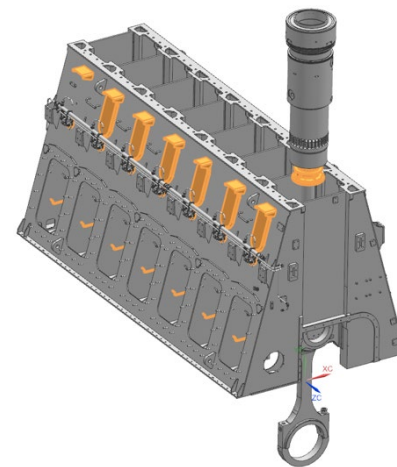
Long term full-scale test of VCR to confirm:

- OPEX benefits
- Operability
- and reliability

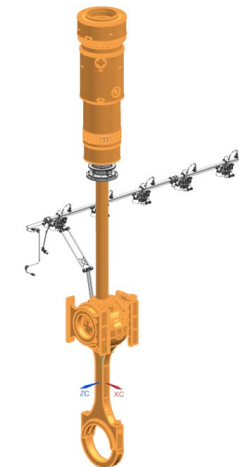
of the complete system on board of a commercially operating vessel



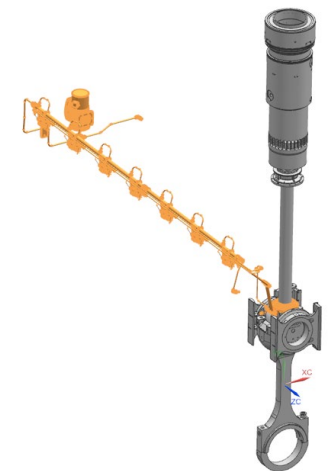
Column Modification



Replaced parts



Additional parts



Methane Slip Performance

General development of methane slip emissions on X-DF engines



Significant reductions of methane slip levels have been achieved since the introduction of the first X-DF engines



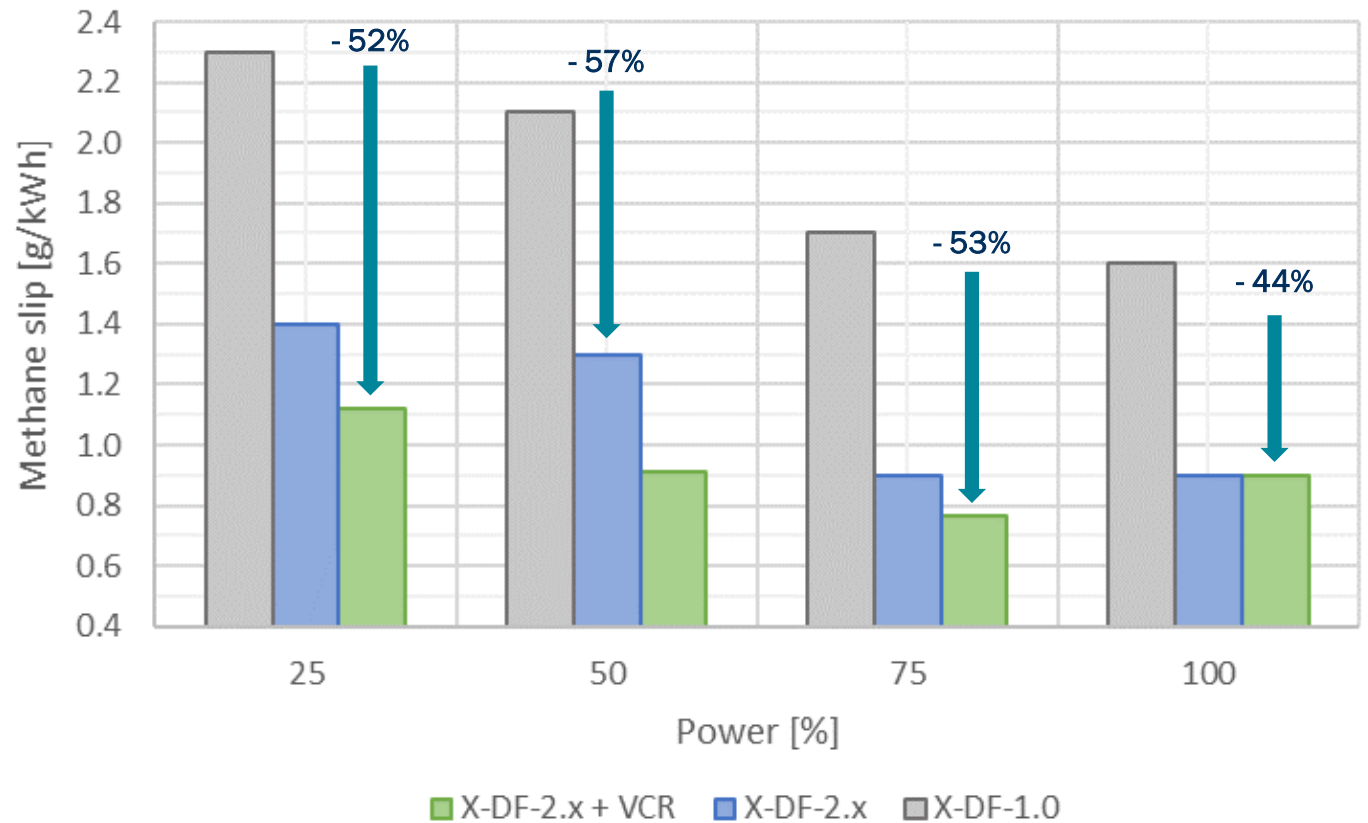
New technologies have resulted in large improvements:

- Introduction of iCER (exhaust gas recirculation) on X-DF-2.x engines
- Introduction of VCR (variable compression ratio)



With further technology introductions in the pipeline, methane slip levels as low as 0.5% (CH₄/BSGC) are feasible

Example of methane slip evolution on X72DF-versions



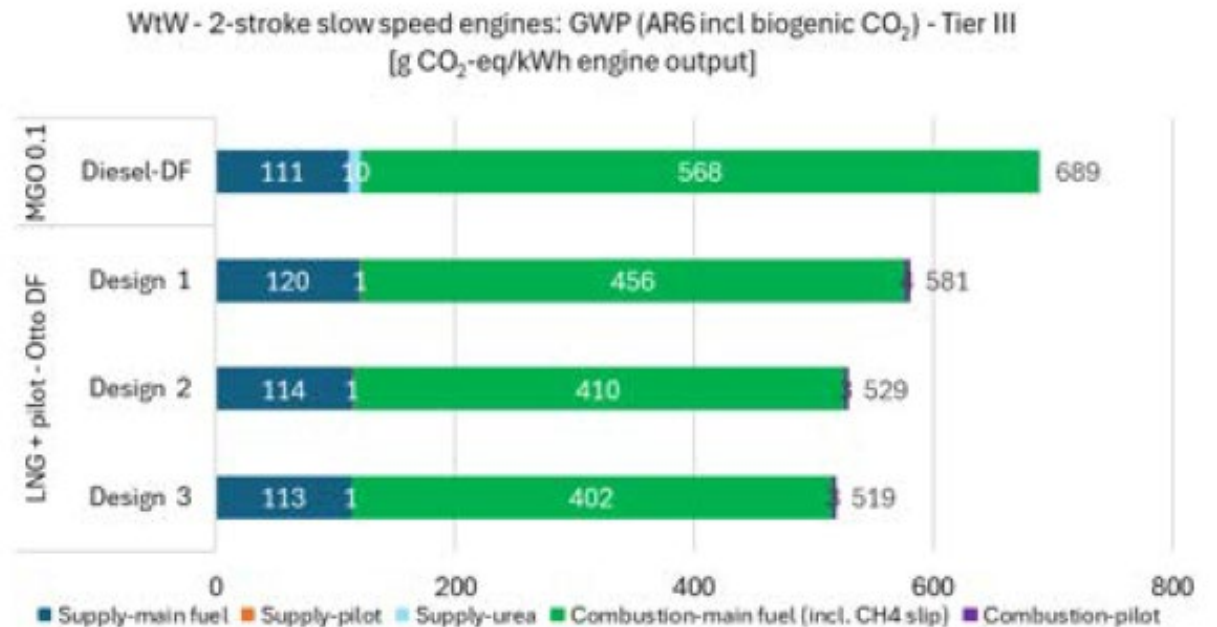
GHG footprint

3rd Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel



Well to wake GHG emissions (specific) significantly reduced

- All Designs compared to Diesel
- Further reduced by technology developments («Design 2» and «Design 3»)
 - By methane slip reduction
 - And efficiency increase



Methane Slip Certification

Current situation

- GHG regulations such as IMO LCA and FuelEU Maritime/EU ETS include methane slip into total GHG
- Default emission factors are used for simplicity reasons
- For Otto-cycle low-speed engines (X-DF), a default factor of 1.7% of gas consumption is assigned so far
- **This factor is not representative** as it neglects the real, lower methane slip figures of latest X-DF2.0 engines
- To account for the actual methane slip performance, WinGD proposes to certify engines based on actual measurements from FAT of the parent engine

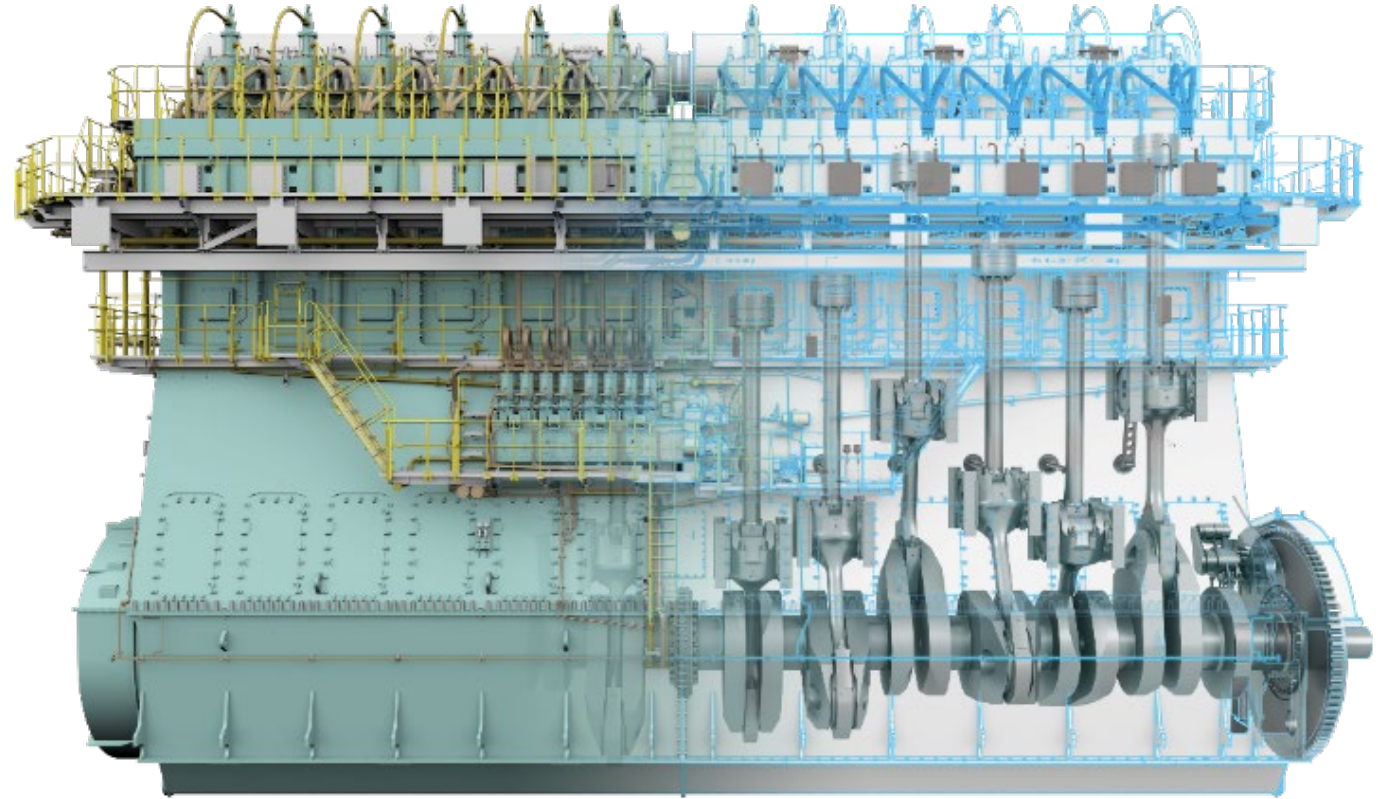
Figure 5: FuelEU Maritime default emission factors, fossil and bio-LNG

Pathway name	LCV [$\frac{MJ}{g}$]	WtT	TtW				C_{slip} As % of the mass of the fuel used by the engine
		$CO_{2eq\ WtT}$ [$\frac{gCO_{2eq}}{MJ}$]	Fuel Consumer Unit Class	C_{fCO_2} [$\frac{gCO_2}{gFuel}$]	C_{fCH_4} [$\frac{gCH_4}{gFuel}$]	C_{fN_2O} [$\frac{gN_2O}{gFuel}$]	
LNG	0,0491	18.5	LNG Otto (dual fuel medium speed)				3,1
			LNG Otto (dual fuel slow speed)	2,750	0	0,00011	1,7
			LNG Diesel (dual fuel slow speed)				0,2
			LBSI				2,6

MEPC.402(83) successfully applied

Summary/Conclusion

- Low pressure DF technology established as industry standard
- References:
 - Over 900 ships
 - Total installed power >16 GW
 - More than 12 million running hours
- Technology improvements result in overall low environmental and GHG footprint
 - iCER
 - VCR
- Further development towards reduction of methane slip
- Actual emission factor verification according to MEPC.402(83)



X-DF by WinGD

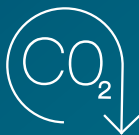
Proven dual fuel technology



From feeder vessels to Ultra Max's,
WinGD's portfolio has the right engine solution



Lower
operating
costs




Reduced
Methane slip and
CO₂ emissions



Proven
design for reliability
and safety

Thank you!

Dirk Kadau
WinGD Ltd.
Schützenstrasse 3
8400 Winterthur, Switzerland
dirk.kadau@wingd.com
www.wingd.com



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ENGINES**

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