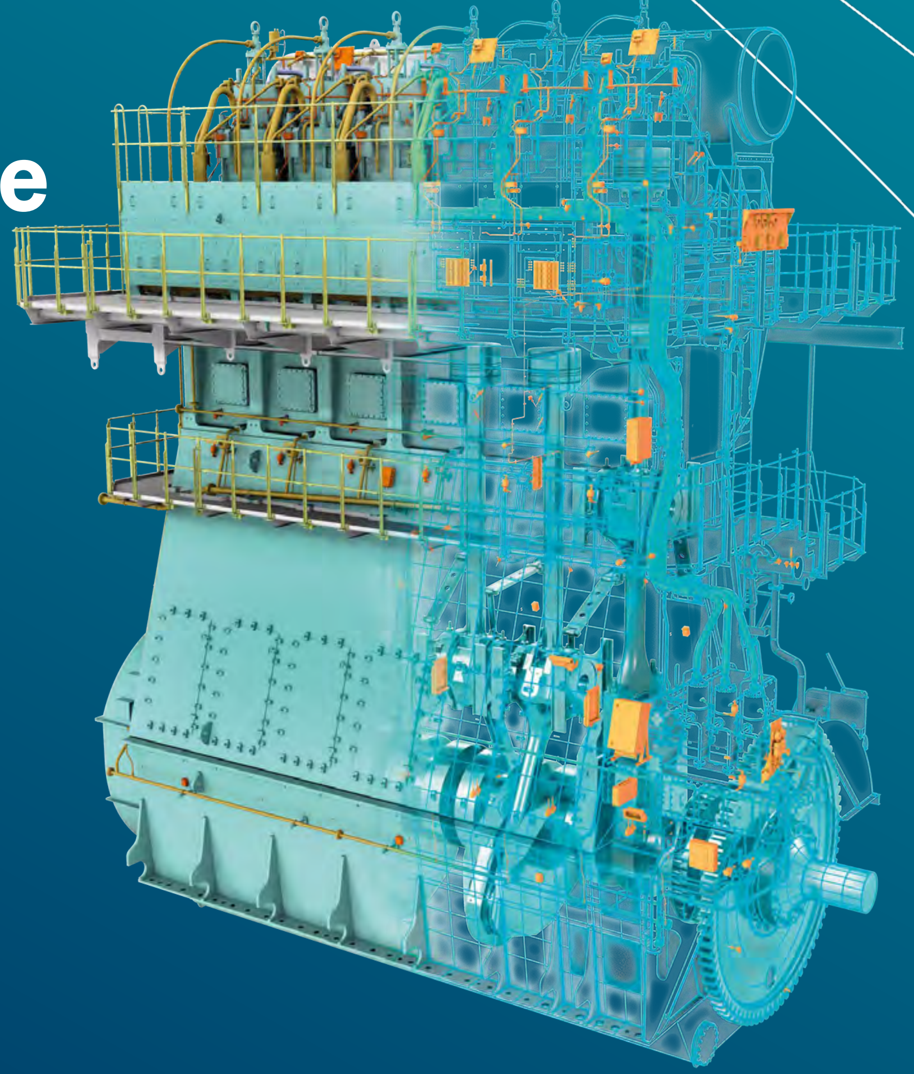
WinGD's X-DF low-pressure dual-fuel marine propulsion engines technology – minimising methane emissions and general environmental footprint

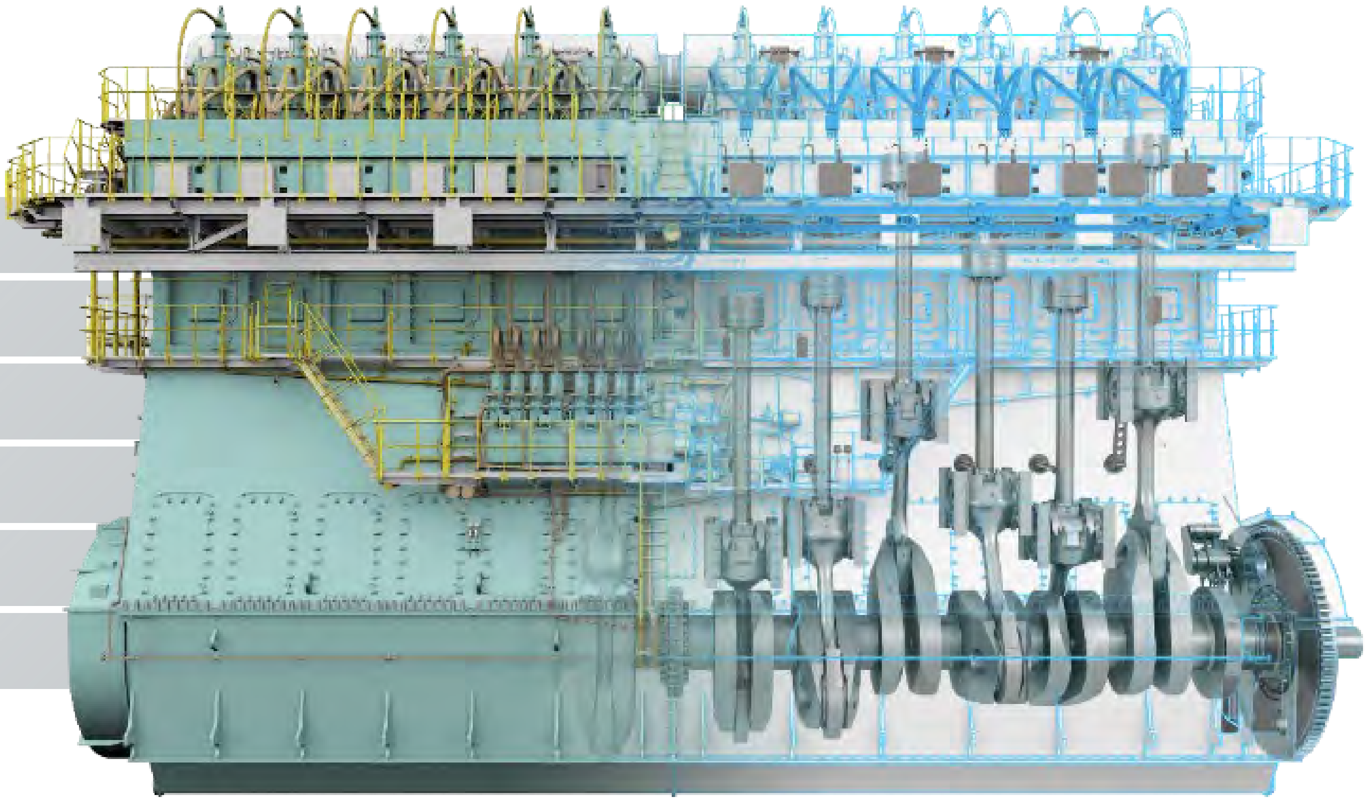


IMO Technical Seminar methane-based fuels

Dirk Kadau, May 2026

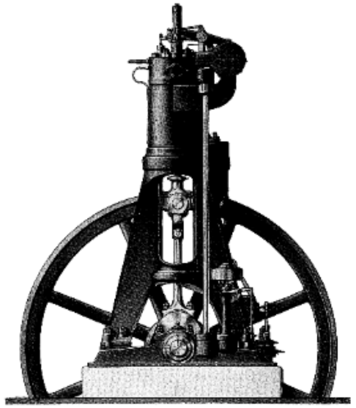
WIN GD

Presentation Outline



WIN GD

Over a Century of Leading Engine Innovation



SULZER

WÄRTSILÄ

WIN GD

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

1912

First two-stroke for ocean vessels

First turbocharged diesel engine prototype

1915

1972

First mechanically controlled low-pressure dual-fuel engine

Super-long-stroke Sulzer RTA engine series

1982

2001

First electronically controlled two-stroke common-rail engine

RT-flex96C: World’s largest diesel engine

2005

2013

X-DF

First electronically controlled low-pressure dual-fuel engine

WIN GD

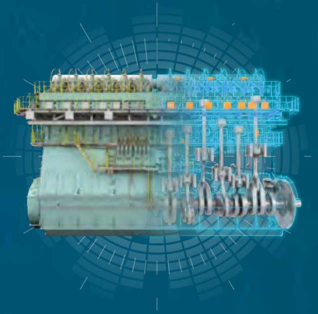
WiDE by WinGD

WinGD integrated Digital Expert

2018

2019

12X92DF:
Largest Otto-cycle engine



X-DF 2.0 by WinGD

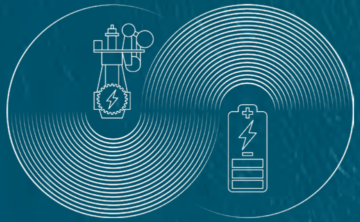
With iCER technology

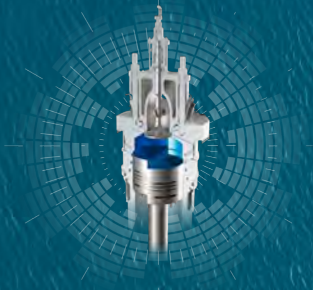
2020

2021

X-EL by WinGD

Energy Management launched





X-DF VCR by WinGD

First order VCR technology

2023

Global Service by WinGD

Global Service Launched

2025

2025

First WinGD Retrofit project

2025

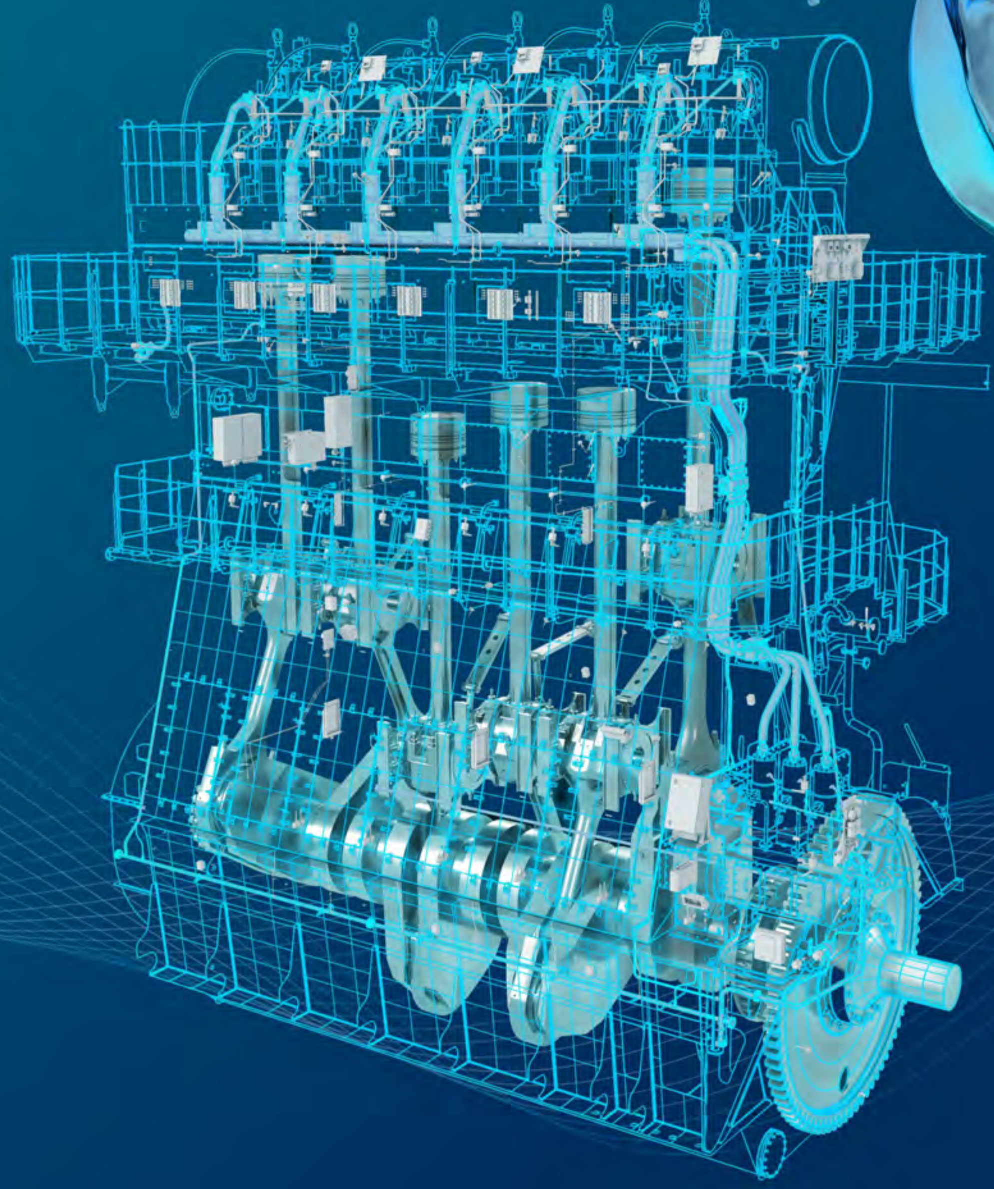
First X-DF-M and X-DF-A engines delivered

X-DF M by WinGD   X-DF A by WinGD

Net-zero emissions from maritime transportation

2050

X-DF by WinGD



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

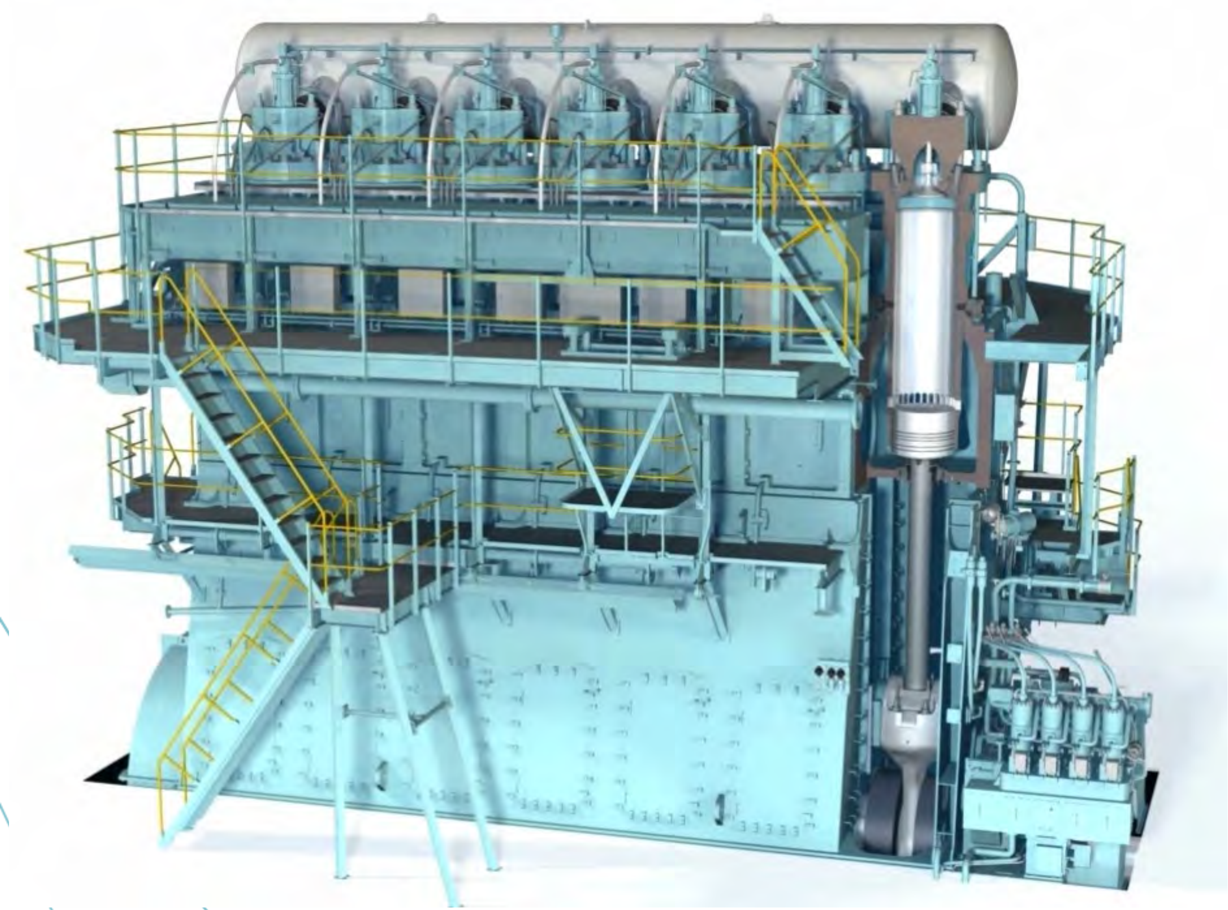
Lower operating costs

Reduced Methane slip and CO_2 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

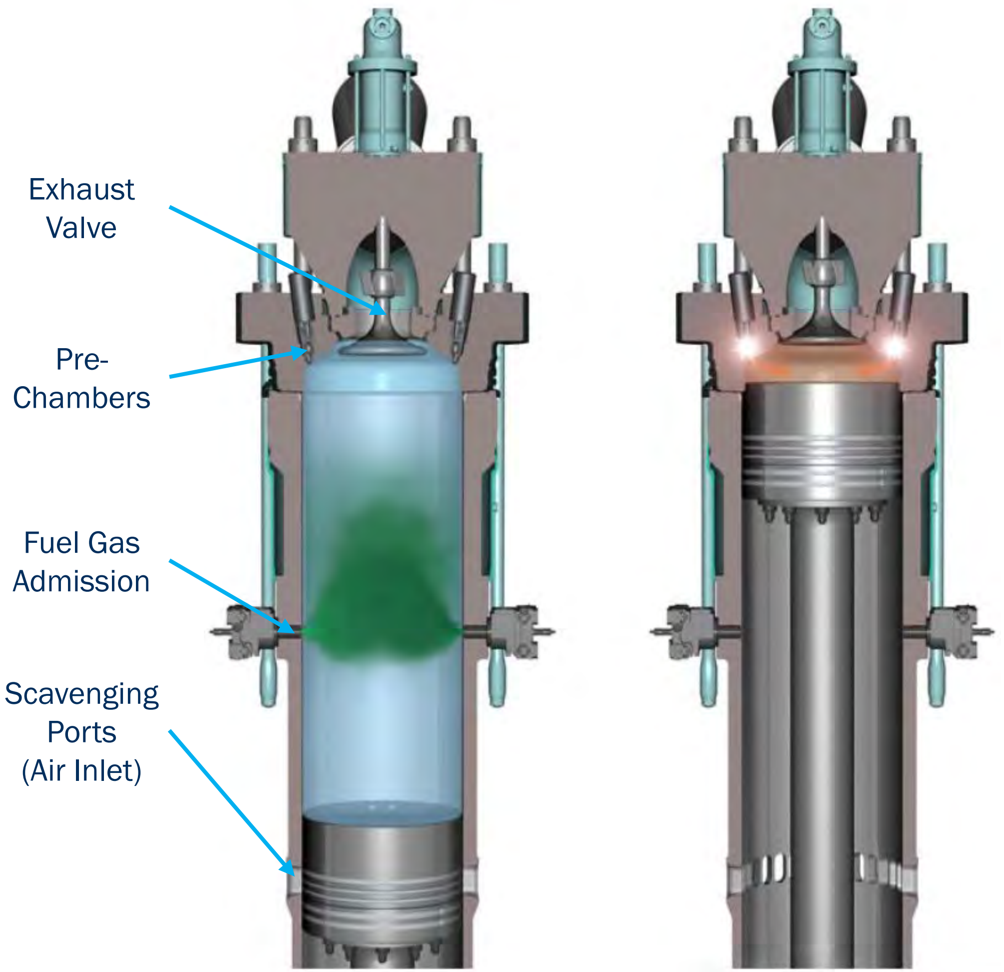
- Simple and reliable gas supply system
- Simple gas sealing
- Wide selection of proven compressors / cryogenic pumps

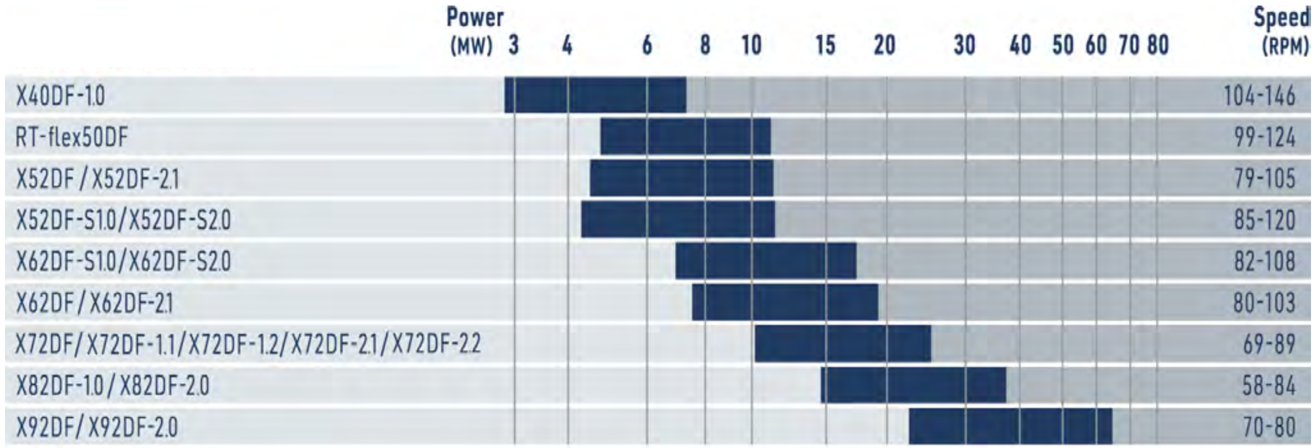
Lean Burn 'Otto' combustion means IMO Tier III compliance

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

X-DF engines

Working principle, product portfolio and test engine particulars





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

2011

Kick-off:

- Concept development
- Rig and one cylinder testing

2013

Full scale engine testing with RT-flex50DF:

- Concept verification
- Performance, automation and component design

2015

Start up of X72DF tech. demonstrator

RT-flex50DF:

- First customer engine deliveries
- Type Approval Test

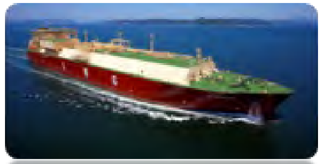
2016

First sea trial completed

First large-bore production engines

2017

First large LNGC seatrial, June 2017



2018/ 2019

Surge of orders, topping 200 end of 2019

2020

X-DF 2.0 is launched

2021

iCER Diesel mode (Tier III) & iCER on-engine

2023

VCR (Variable comp. ratio) launch

X-DF2.0

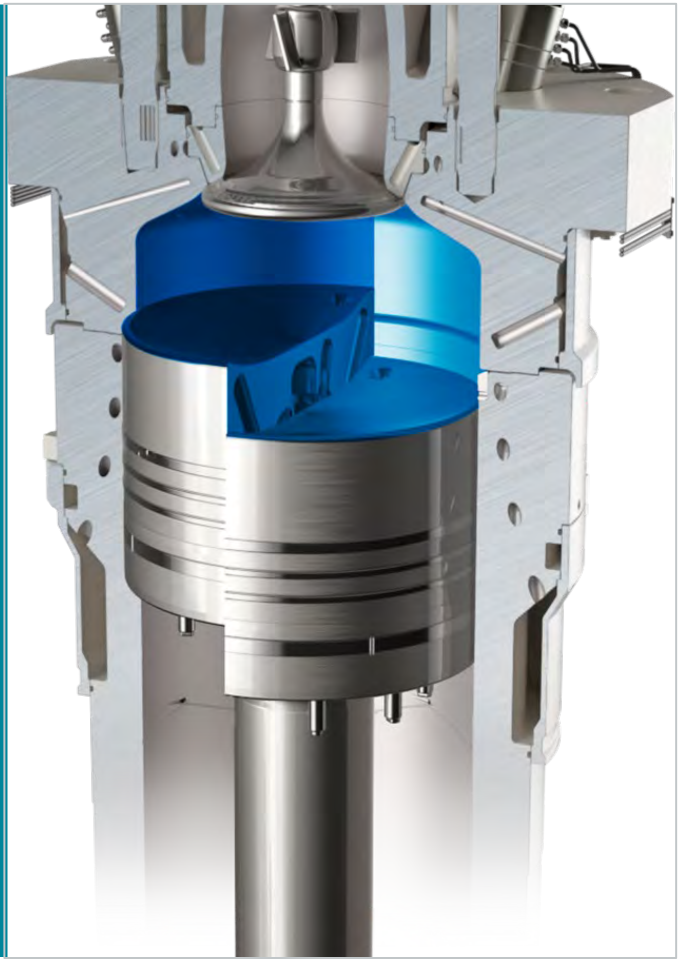
iCER and VCR are the two key technologies of XDF-2.0

iCER

intelligent Control by
Exhaust Recycling

VCR

Variable
Compression Ratio



iCER by WinGD

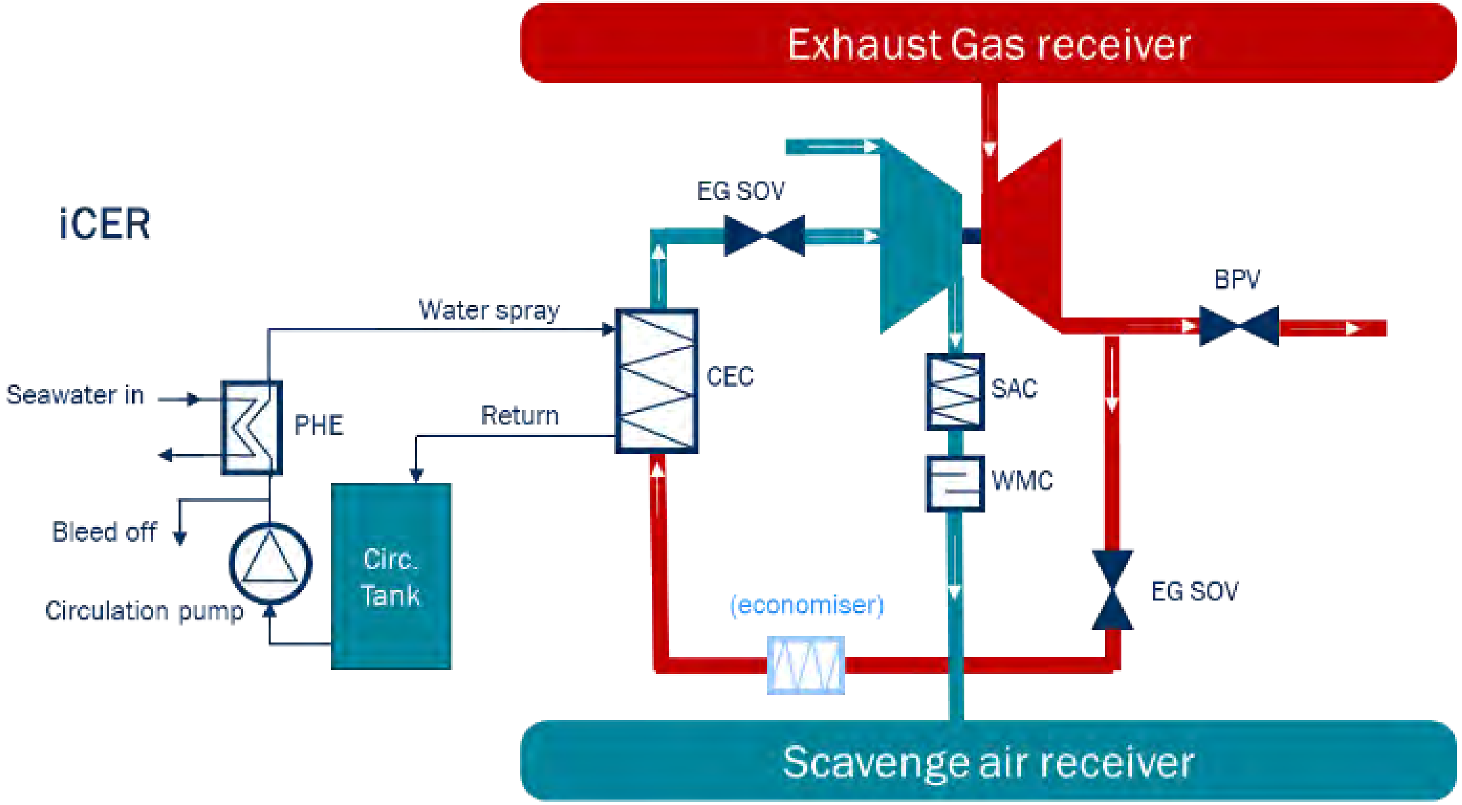
Add more CERtainty to your future

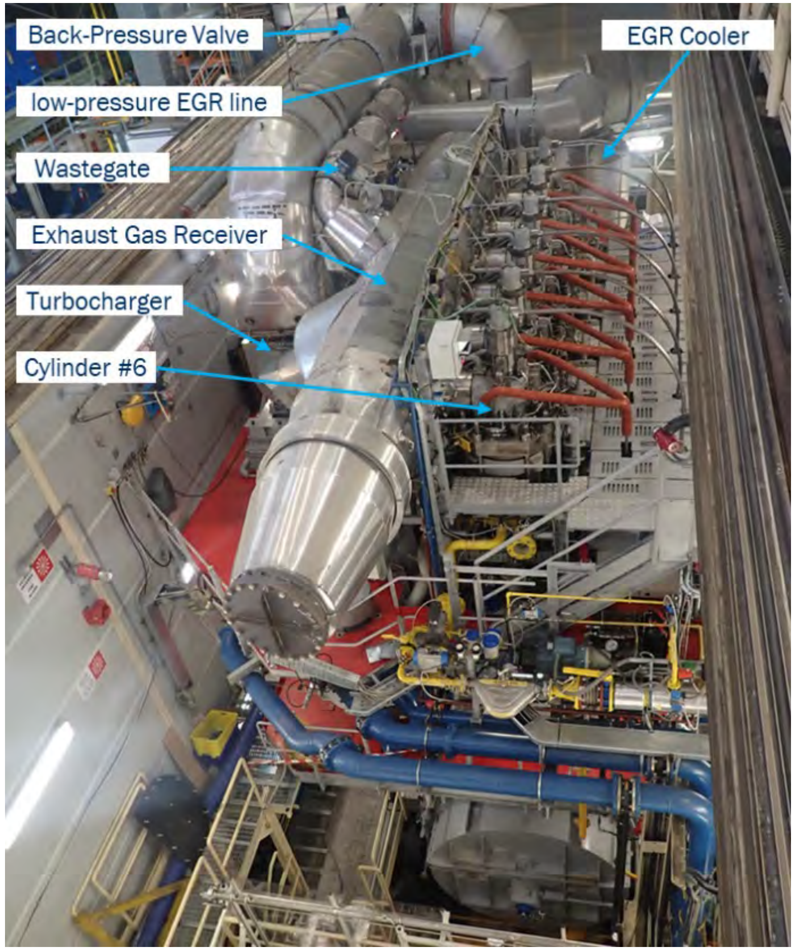
WIN GD

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

CH_4 and GHG reduction

No DCC activation

X-DF VCR by WinGD

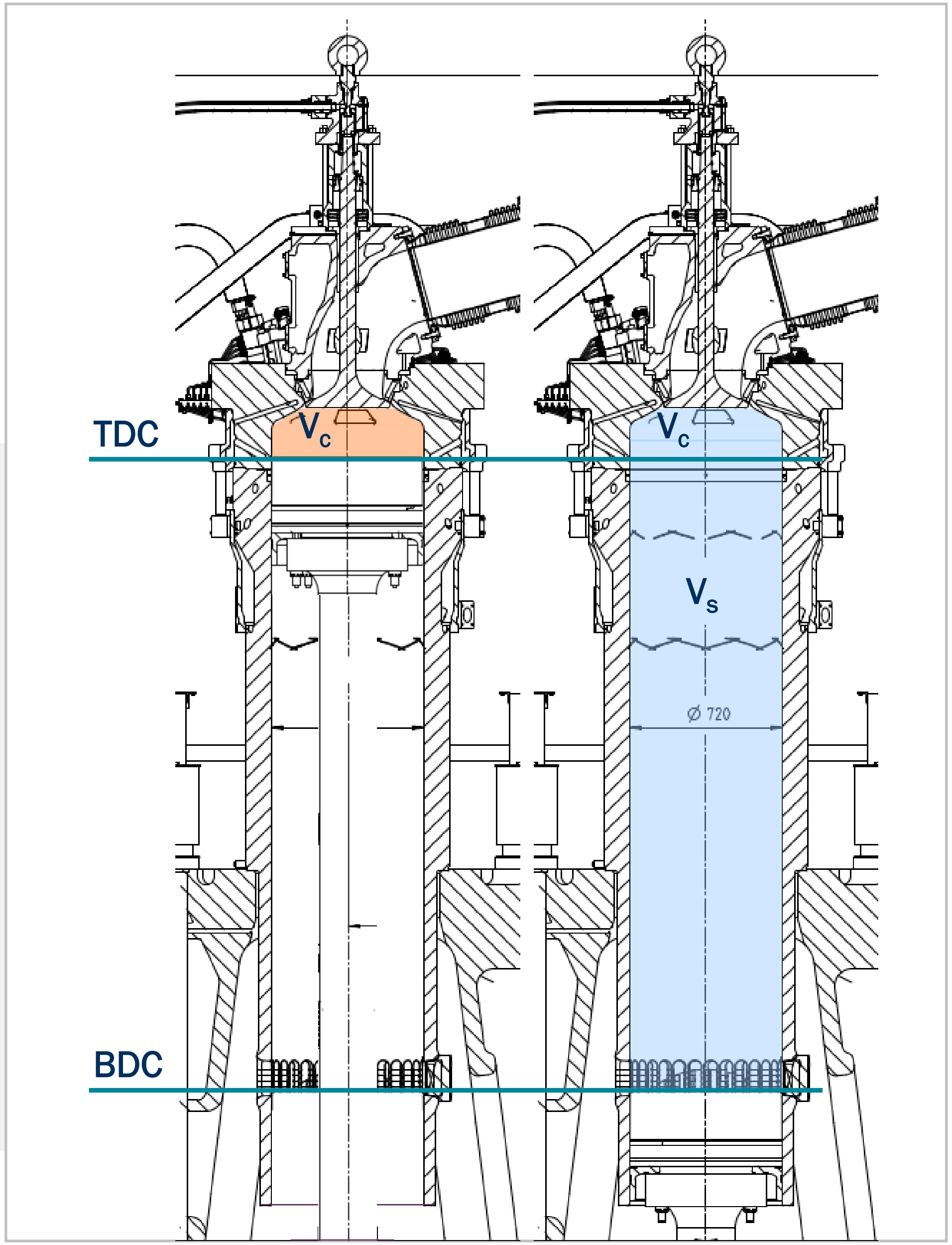
Compression without compromise:
Status and latest results

WIN GD

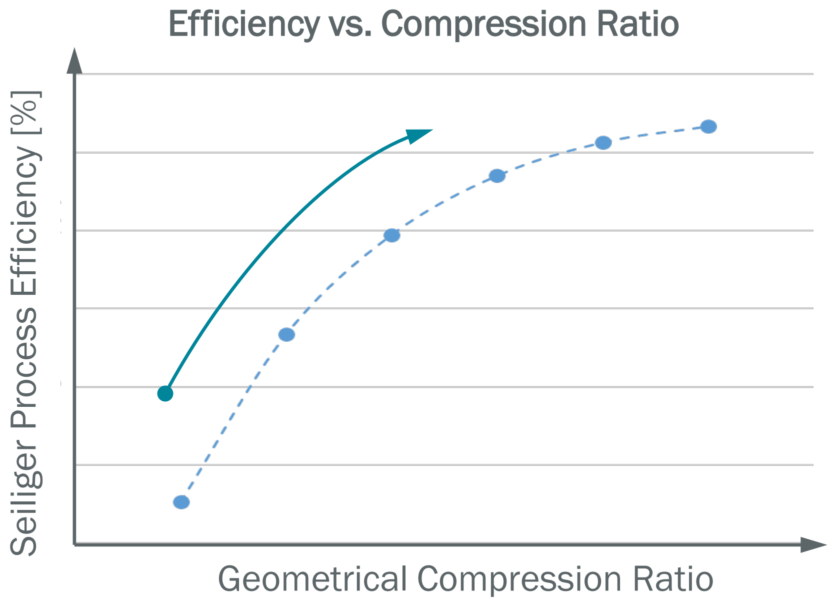
What is the Compression Ratio?

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

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?



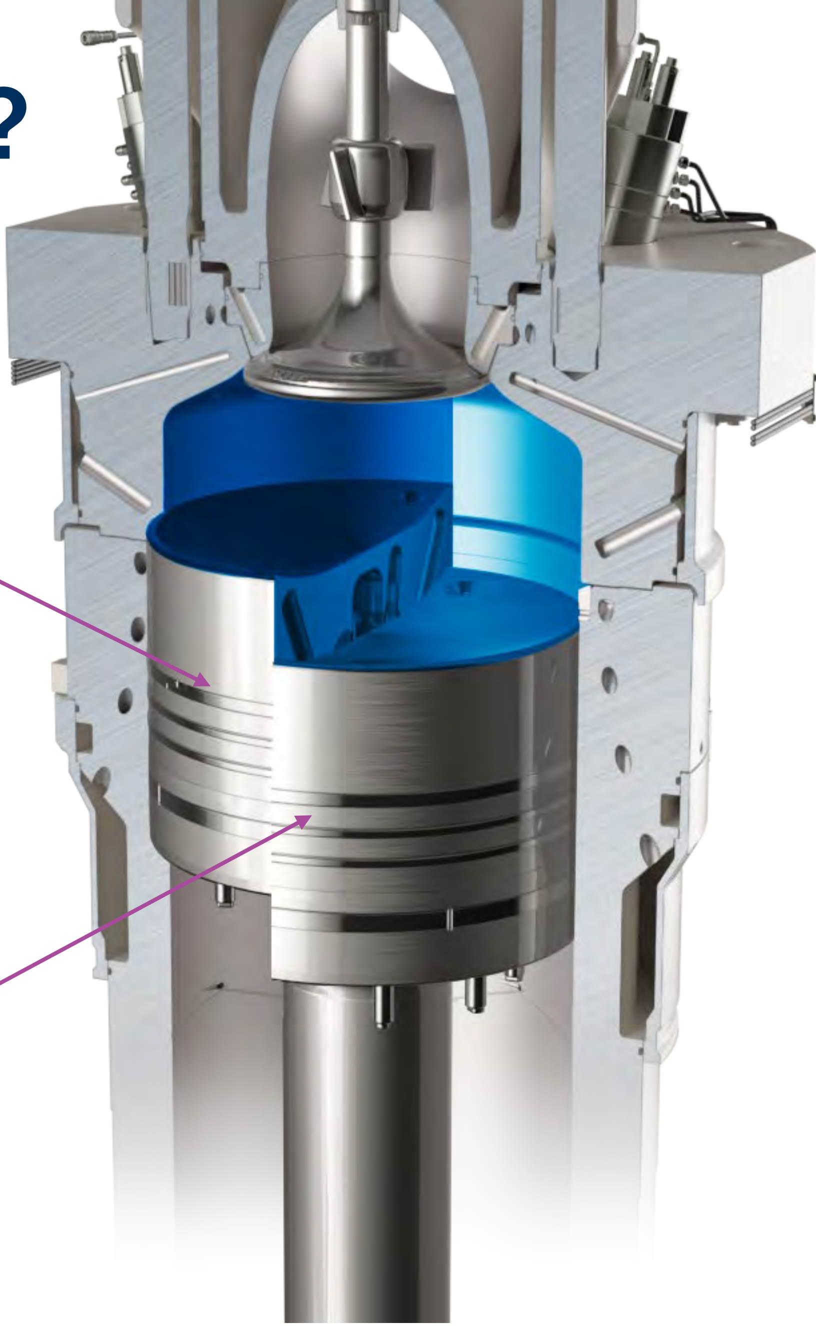
- Continuous adjustment of CR based on actual combustion behavior
- → highest possible efficiency, in any fuel mode, under any operating condition

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

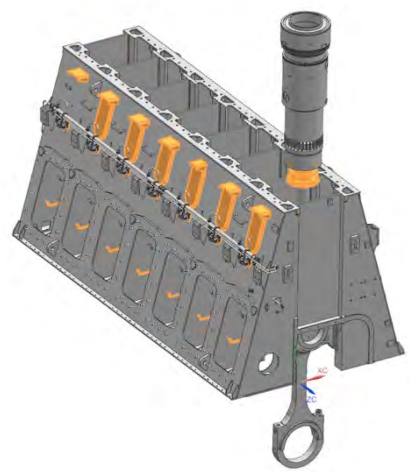
Objective:

Long term full-scale test of VCR to confirm:

- OPEX benefits
- Operability
- and reliability

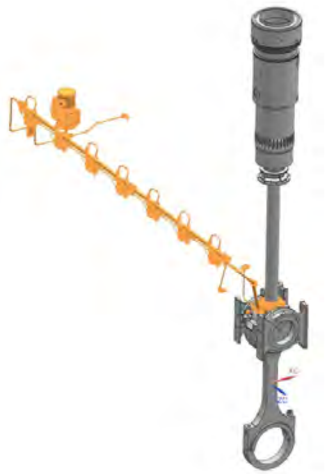
of the complete system on board of a commercially operating vessel

Column Modification



Replaced parts

Additional parts



Methane Slip Performance

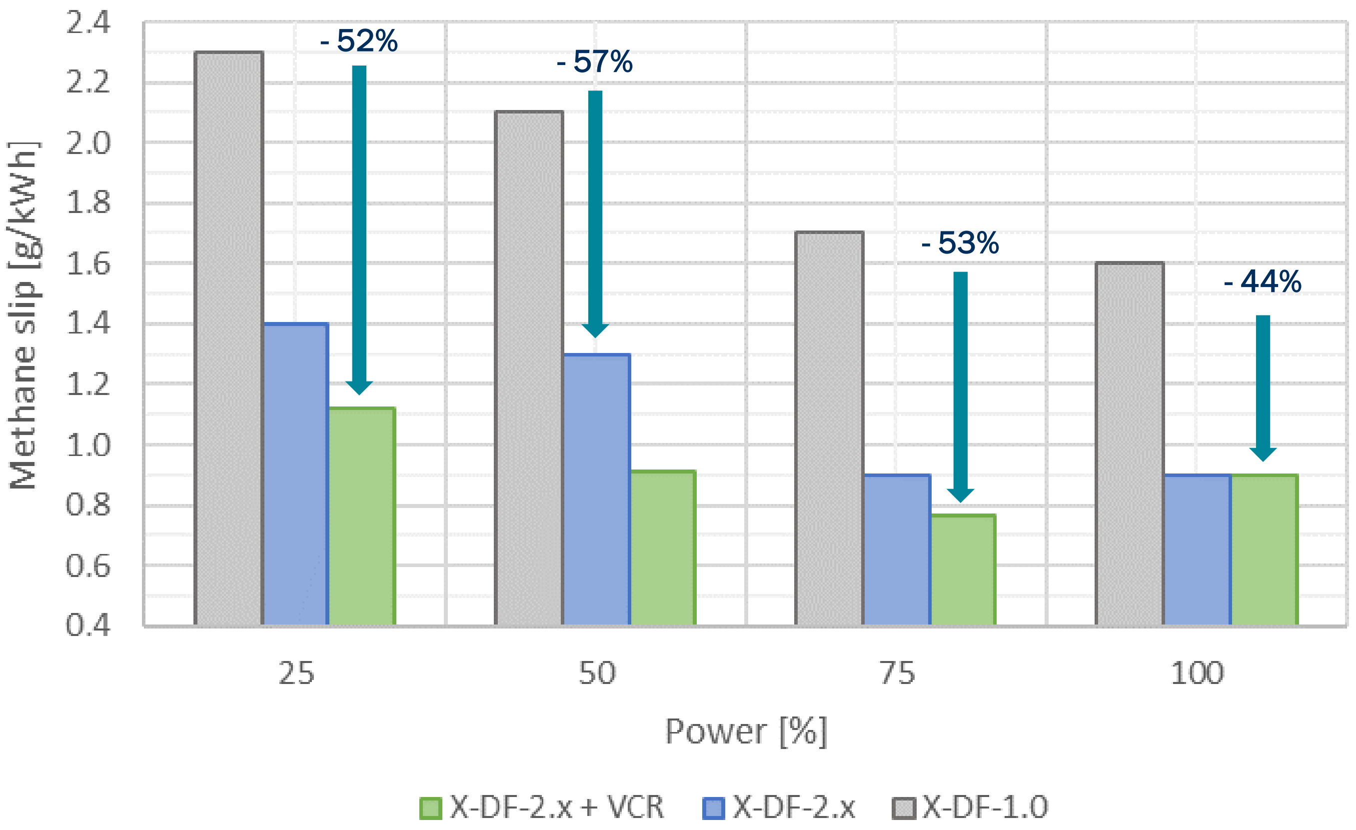
General development of methane slip emissions on X-DF engines

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% (CH_4/BSGC) are feasible**

Example of methane slip evolution on X72DF-versions



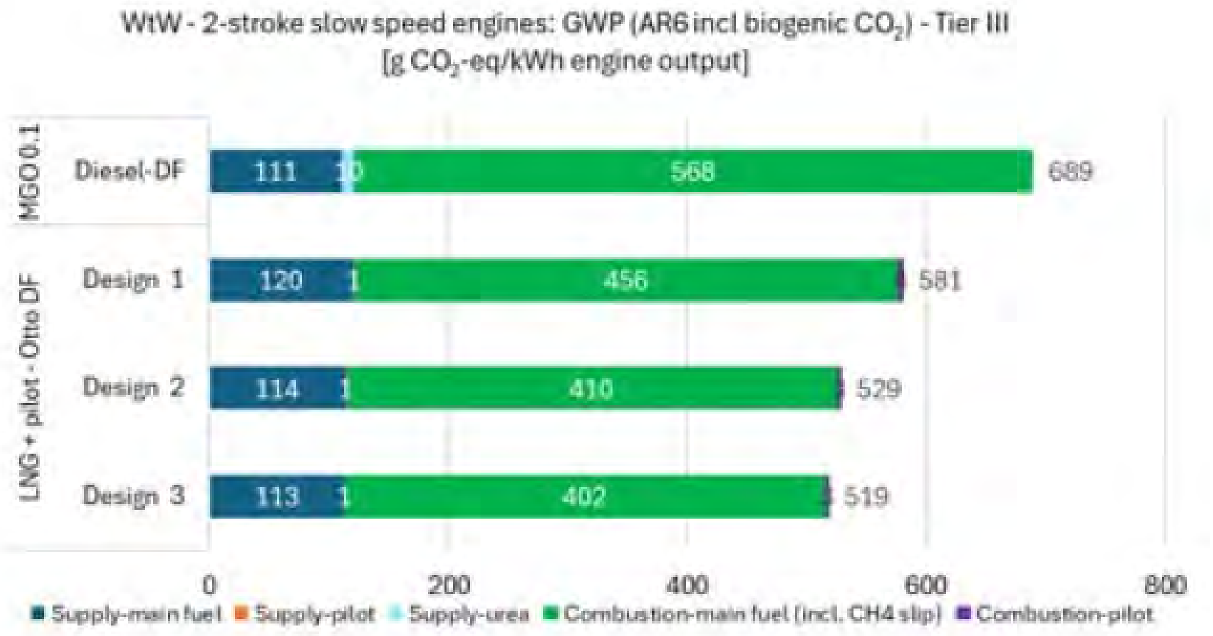
GHG footprint

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

sphera

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**

→ MEPC.402(83) successfully applied

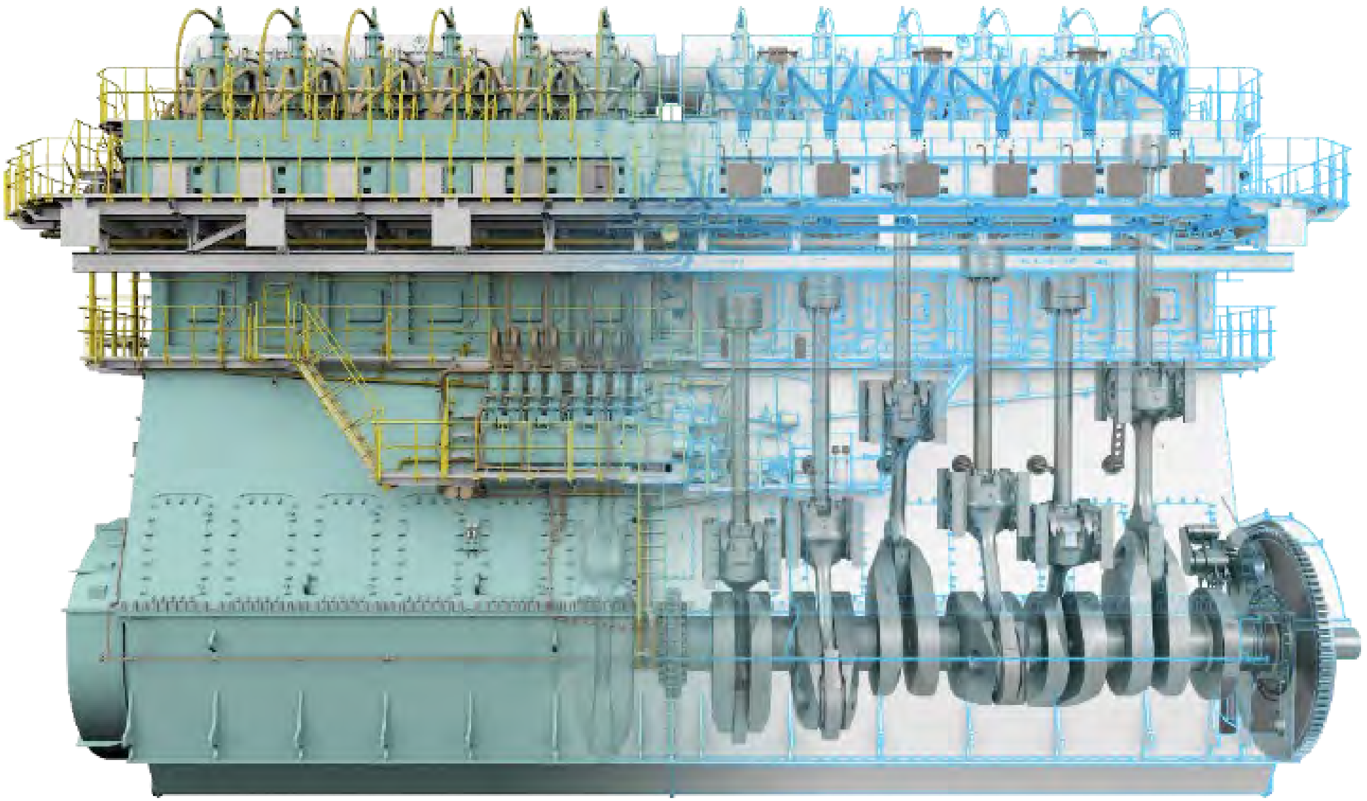
Figure 5: FuelEU Maritime default emission factors, fossil and bio-LNG

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

WIN GD

Summary/Conclusion

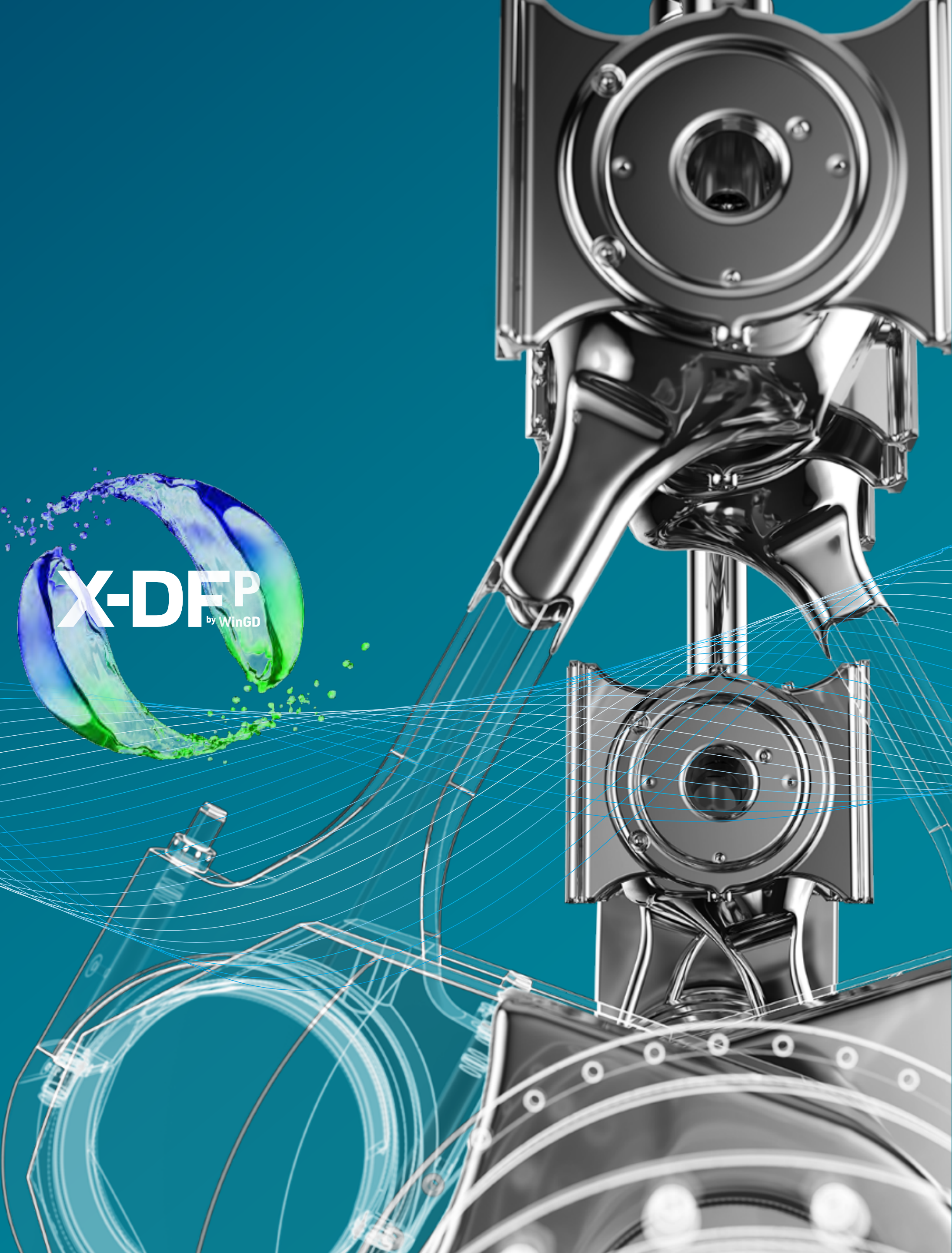
- Low pressure DF technology established as industry standard
- References:
  - Over 900 ships
  - Total installed power >16 GW
  - More than 12 million running hours
- Technology improvements result in overall low environmental and GHG footprint
  - iCER
  - VCR
- Further development towards reduction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



X-DF by WinGD

Proven dual fuel technology

X-DF by WinGD X-DF A by WinGD Ammonia X-DF M by WinGD Methanol X-DF P by WinGD



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

Lower operating costs

Reduced Methane slip and CO_2 emissions

Proven design for reliability and safety

Thank you!

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