Hochschule Flensburg
University of Applied Sciences

Maritimes Zentrum
Hochschule Flensburg

43. ISF-Tagung

20. Mai 2022

Neue Entwicklungen und Betriebserfahrungen in der Schiffsbetriebstechnik

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Wir danken unseren Sponsoren, Förderern und Ausstellern!

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Messsysteme

propulsion
engineering

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43. Informationstagung zur Schiffsbetriebsforschung

Freitag, den 20. Mai 2022
Im Hörsaalzentrum der Hochschule Flensburg
Kanzleistraße 91-93

Programm

08:00 Uhr Registrierung
09:00 Uhr Begrüßung und Eröffnung der Tagung
Dr. Christoph Jansen
Präsident der Hochschule
Prof. Dr.-Ing. Michael Thiemke

Vortragsgruppe 1: Optimierung in der Schiffstechnik
Chairman: Rasmus Brandt

9:15 Uhr Decarbonisation target with optimized propulsion
Elis Boletis, Director
Wärtsilä Propulsion and Transmission

9:45 Uhr Erste Betriebserfahrungen zur Bleed-Off-Treatment-Unit des Forschungs-Scrubbers der Hochschule Flensburg
Dennis Fischer, M. Eng.
Boll & Kirch Filtertechnik GmbH

10:15 Uhr Kaffeepause

10:40 Uhr Kess: Kompakte und effiziente Abgasnachbehandlung zur Minimierung von Stickoxiden und Schallemissionen
Daniela Backhaus
Lürssen

11:10 Uhr From engine analytics to fleet performance software Digitalization in the marine industry
Dipl.-Ing. Oliver Heinrich, Manager Partnership – DigitalSolutiond
Olaf Stolp, Manager Customer Support
Abb Turbo Systems

11:40 Uhr Mittagspause
Besichtigung des Schiffsmaschinensimulators der HS Flensburg

Vortragsgruppe 2: Motorentechnik
Chairman: Prof. Dr. Rom Rabe

13:30 Uhr Wärtsilä Two-Stroke Future Fuels Conversion platform
Stam Achillas, Head of Business Development and Sales, 2-stroke Fuel Conversions

14:00 Uhr Alternative Antriebssysteme für mobile Arbeitsmaschinen in der Hafenlogistik Vorentwicklung
Dr.-Ing. Georg Töpfer, Koordinator Vorentwicklung
Deutz AG

14:30 Uhr Field study for validation of wear pairing valve spindle / seat ring through 32.000 operating hours
Jan-Peter Edelmann, Team Leader Design &
Work Planning, Research & Development
Märkisches Werk GmbH und Mitsubishi Heavy
Industries Engine and Turbocharger Ltd.

15 Uhr Kaffeepause

Vortragsgruppe 3: Kraftstoffe
Chairman: Prof. Dr. Peter Boy

15:20 Uhr Paraffinische Kraftstoffe in der Schifffahrt –
Erfahrungen & Ausblick
Klaus Schlame
Shell Global Solutions (Deutschland)

15:50 Uhr Studies on combustion of current and future marine fuels (online)
Prof. Dr. Koji Takasaki
Kyushu University, Japan

16:20 Uhr Schlusswort
Prof. Dr.-Ing. Michael Thiemke

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Inhaltsverzeichnis

DECARBONIZATION TARGETS WITH OPTIMIZED PROPULSION

ELIAS BOLETIS

ISF FLENSBURG 2022

OBJECTIVE | SIMULATED CASES | VARIOUS TECHNOLOGIES | OPERATING PROFILE | RESULTS | ZERO EMISSION

THE CHANGE OF THE SHIPPING WORLD

WÄRTSILÄ

THE 'FOSSILE FUEL WORLD'

- OPERATORS/ CHARTERERS
- OWNERS
- CLASS
- FLAG AUTHORITIES
- INSTITUTES/ DESIGNERS
- SHIPYARDS
- OEMS
- SUPPLIERS

THE 'GREEN WORLD'

- IMO
- REGIONAL LEGISLATIVE AUTHORITIES
- OPERATORS/ CHARTERERS
- POLICY MAKERS
- OWNERS
- BANKING SYSTEM
- TECHNOLOGY INTEGRATORS
- CLASS, AUDITING CONSULTING
- FLAG AUTHORITIES
- INSTITUTES/ DESIGNERS
- GREEN SOLUTION PROVIDERS
- FUEL PROVIDERS
- PUBLIC OPINION
- SHIPYARDS
- OEMS
- COOPERATIVE RESEARCH
- SUPPLIERS

WHY VESSEL ENERGY EFFICIENCY IS IMPORTANT

- **Phase 1:** The low/ zero carbon fuels are still not available

  Energy saving technologies improve the EEDI/ EEXI and reduce the vessel OPEX

- **Phase 2:** The low/zero carbon fuels become available

  Energy saving enables integration solution at vessel level and reduces the vessel OPEX, especially at the higher fuel prices

A PATH TO DECARBONIZATION

Optimized propulsion systems, propulsion energy saving devices, hull and ballast optimization, trim optimization, air lubrication

Highest efficiency and cleaner fuels

Increasing price per ton of CO2 emission avoided

Optimized Voyage

Vessel Energy Need

Power Distribution

Efficient Energy Generation

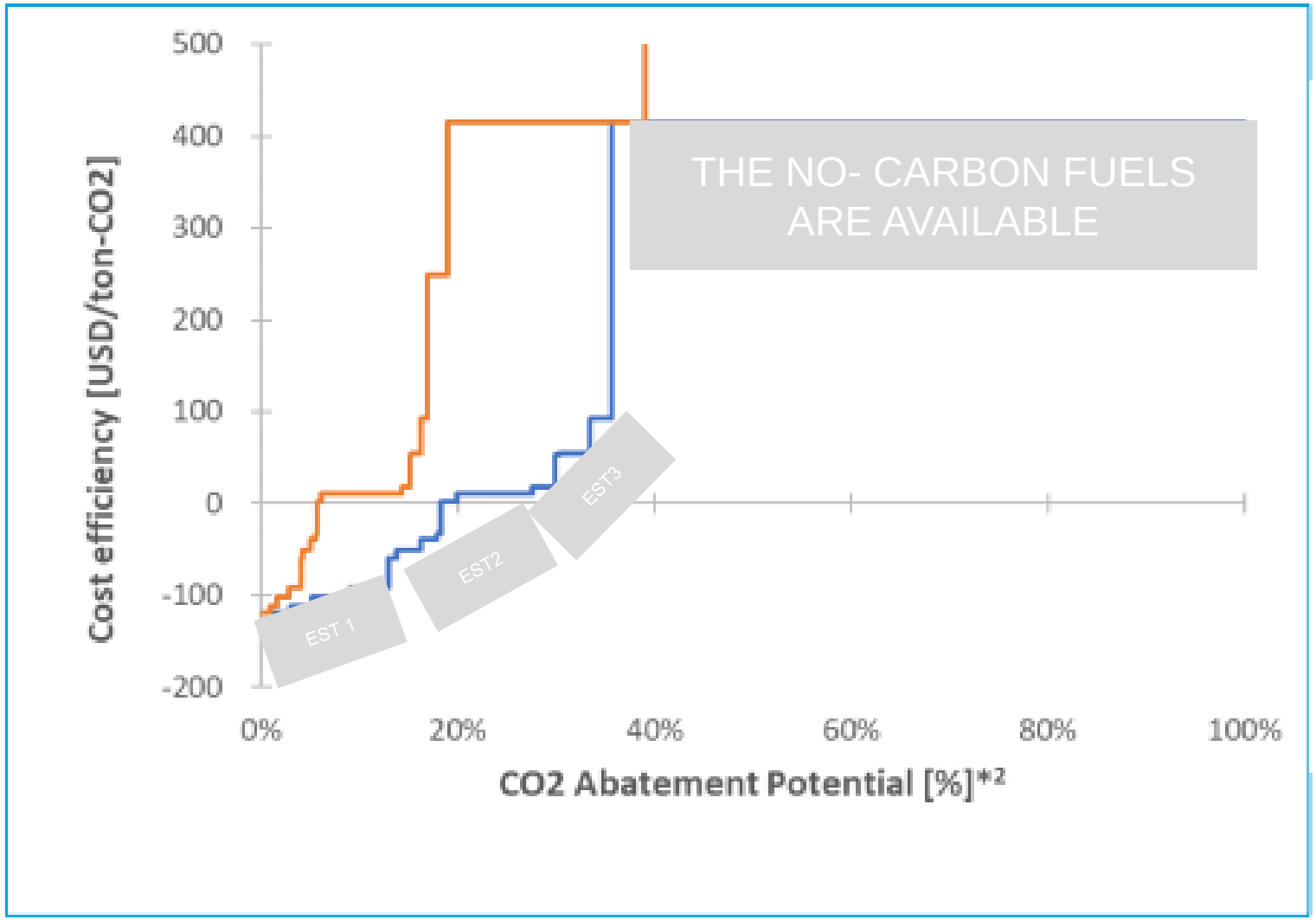
Fuel price determines technology uptake “profitability limit”

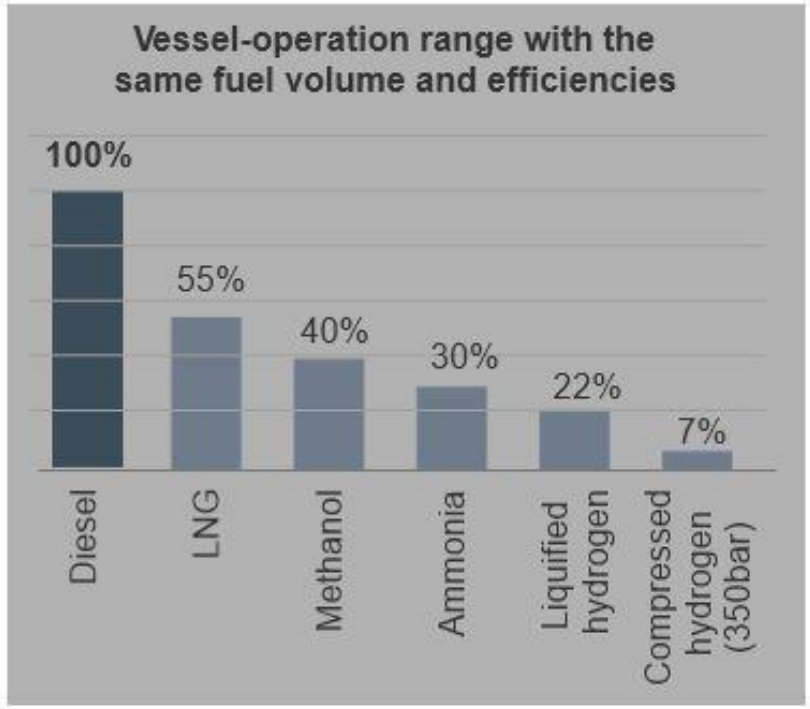
Lowest possible speeds, optimum turnaround and digital port integration

Hybrids and associated battery storage, power-take-in from renewable sources such as wind, solar

The omnivorous ship

THE ROLE OF ENERGY SAVING TECHNOLOGIES
THE IMPORTANCE OF COST EFFICIENCY

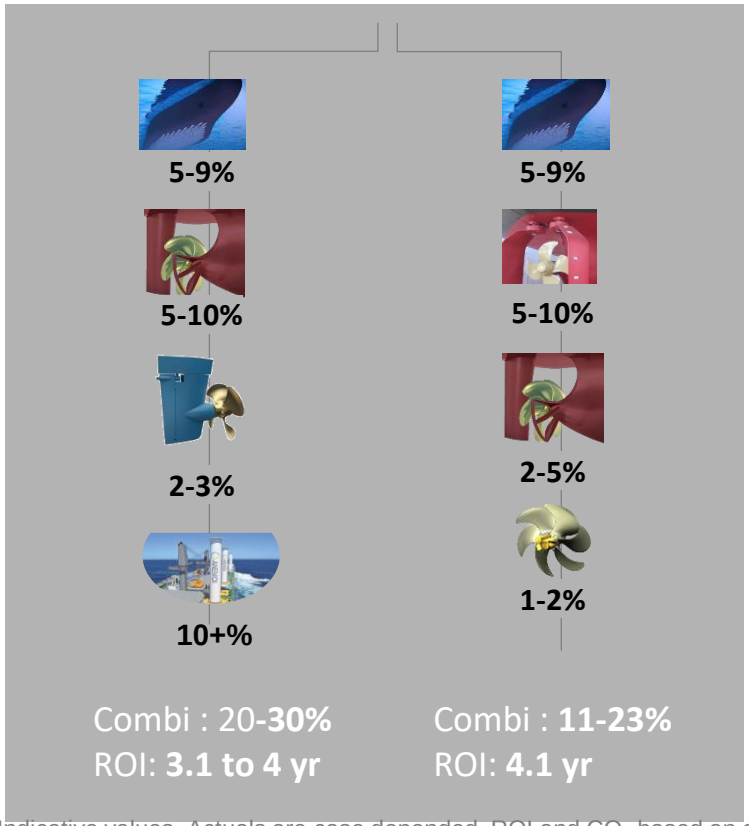




A MULTI-OR- FUTURE?

- Will we see fuel convergence or divergence in shipping? The jury's out on that one…
- Example of convergence:

INTEGRATED EFFICIENCY PACKAGES (EXAMPLES)

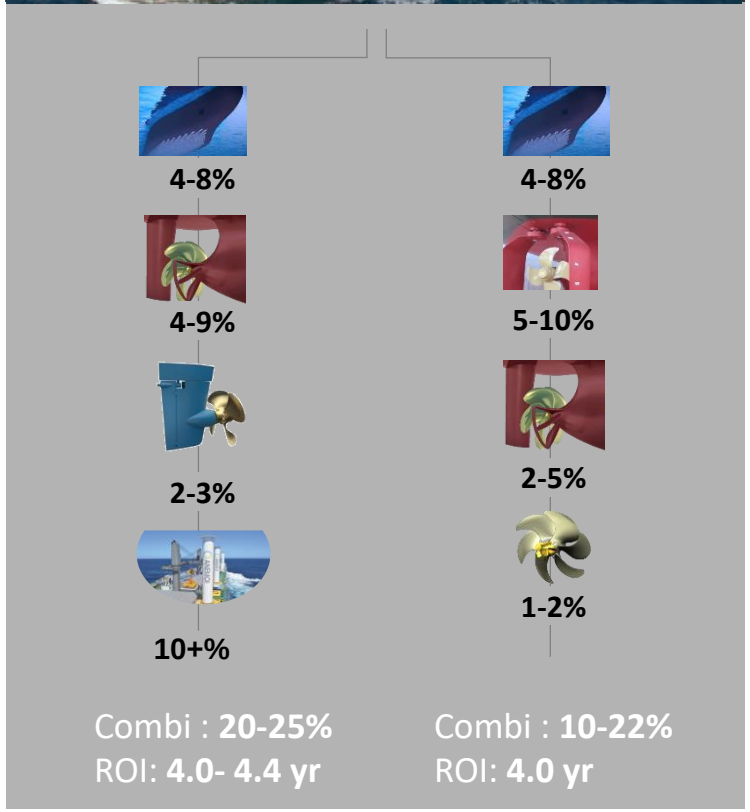


Integration of:

1) Propeller technologies

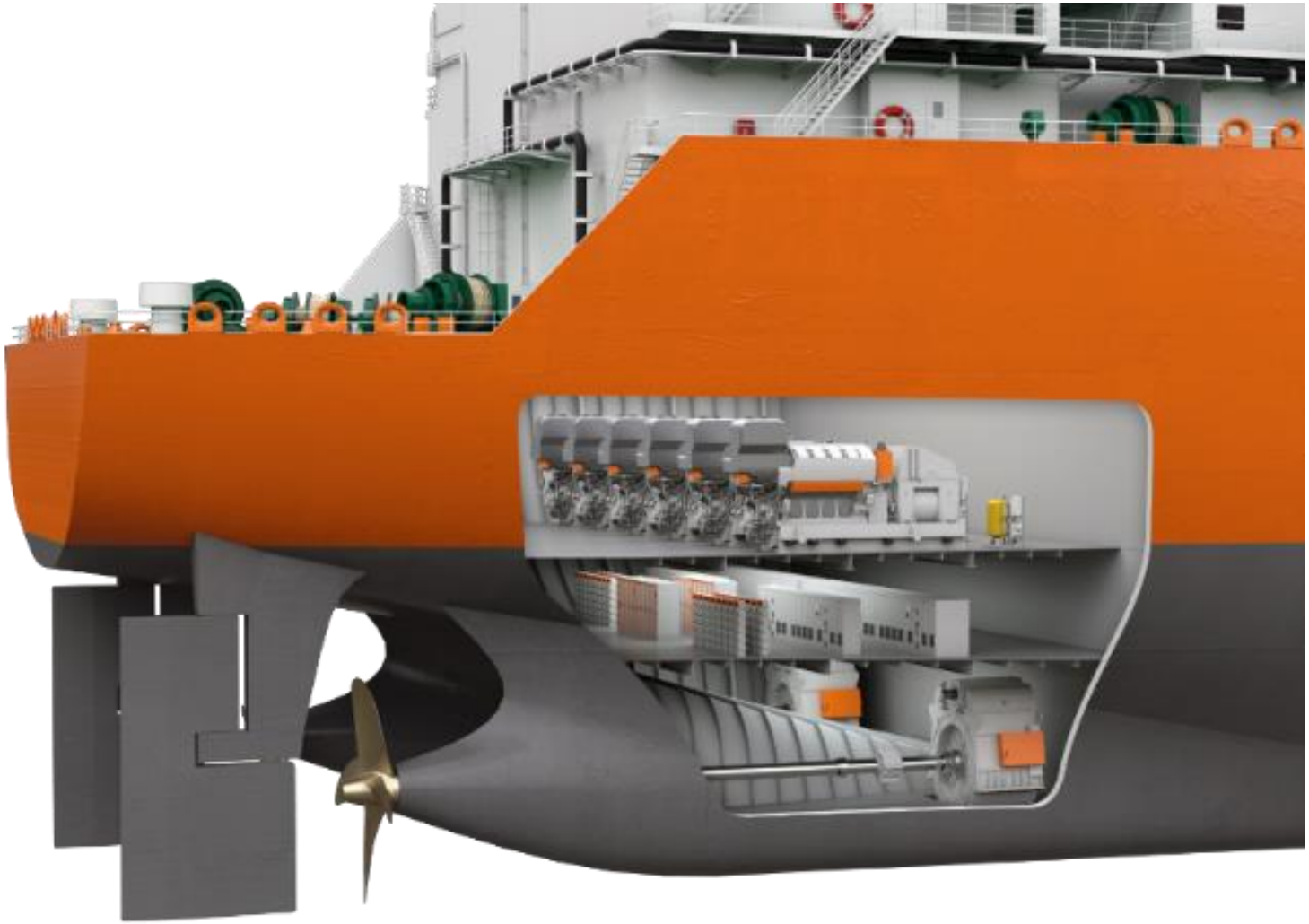
2) Air lubrication

1) Moderate to high wind intensity routes:
   Wind assist technologies (sail rotors)



* Indicative values. Actuals are case depended. ROI and CO_2 based on averaged improvement. Based on bunker 350$/ton. Incl yard installation cost for New Build

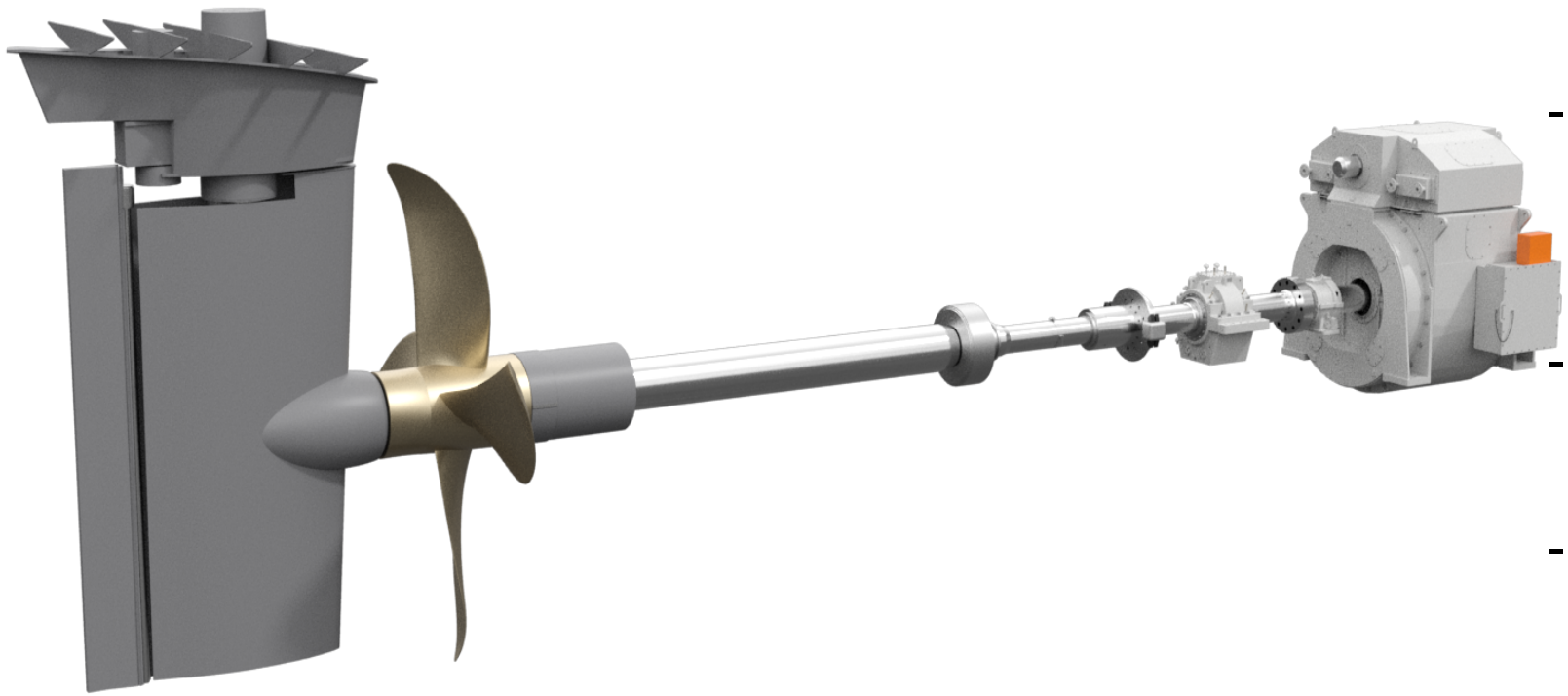
MACHINERY ROOM INTEGRATION – HYBRID ELECTRIC



NEW MACHINERY LAYOUTS ENABLE:

- EASIER IMPLEMENTATION OF THE NEW FUELS
- BETTER INTEGRATION OF ENERGY SAVING TECHNOLOGIES

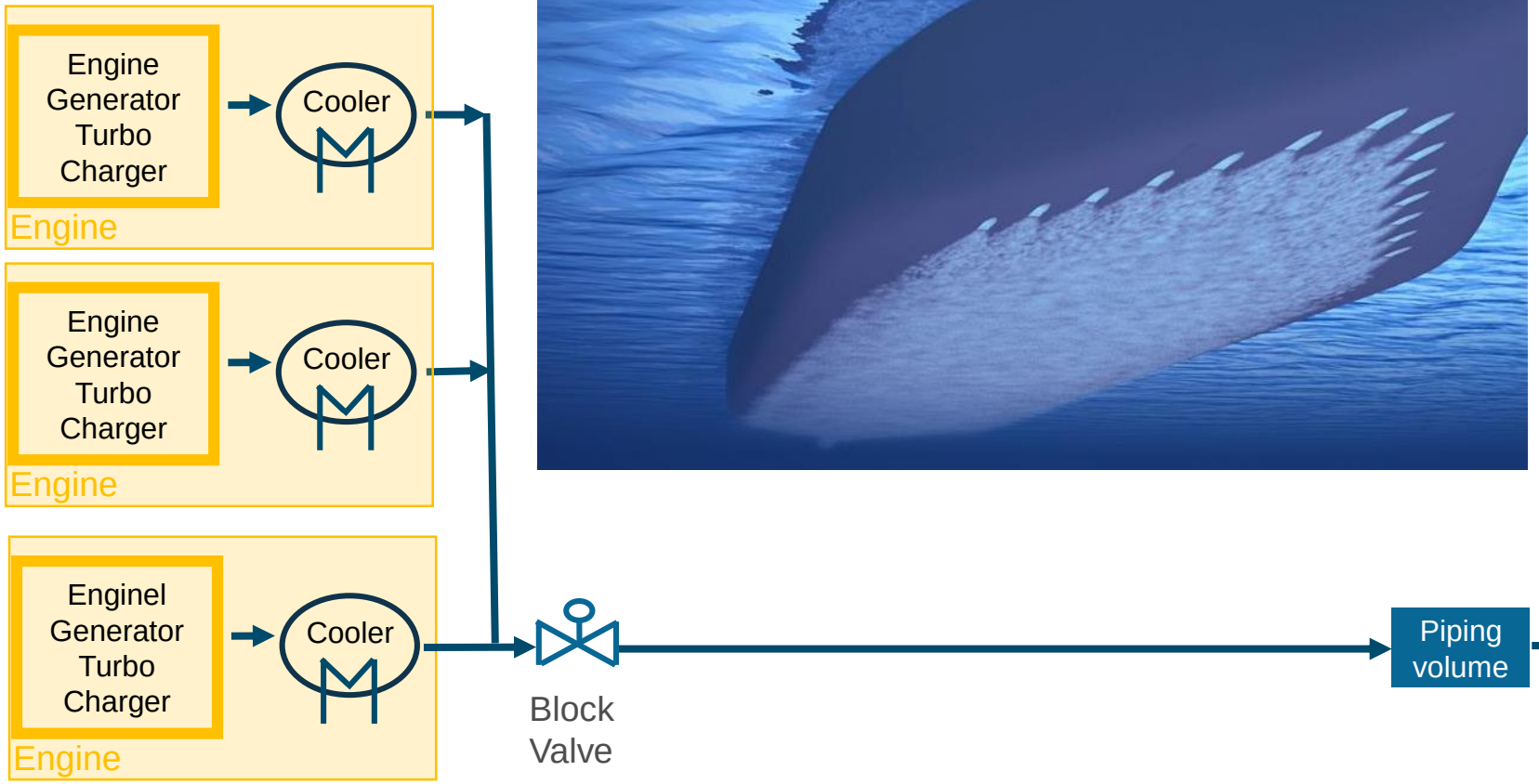
INTRODUCTION: PROPULSION BASIC ARRANGEMENT



The layout enables:

- Concept Simplicity (FPP)
- Very low propeller rpm (50- 60)
- Highest propulsive efficiency with a big FPP
- Matching propeller with el. motor
- Re- define the Rough Sea & Propeller Light Running Margins

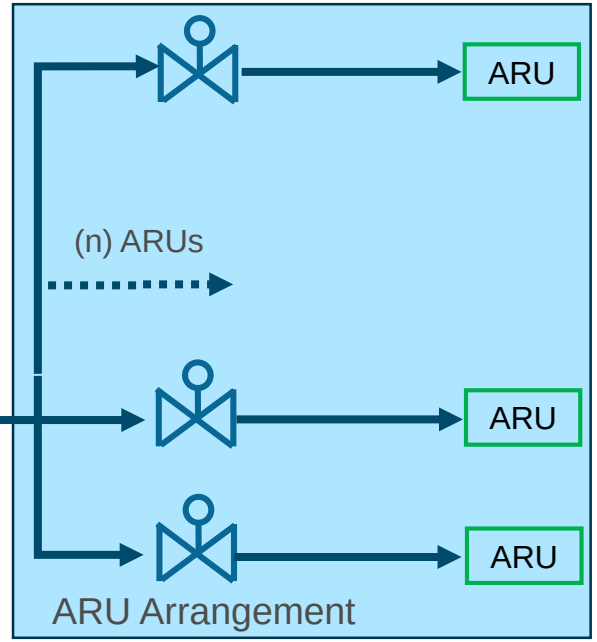
INTEGRATING THE AIR LUBRICATION SYSTEM INTO THE HYBRID ELECTRIC



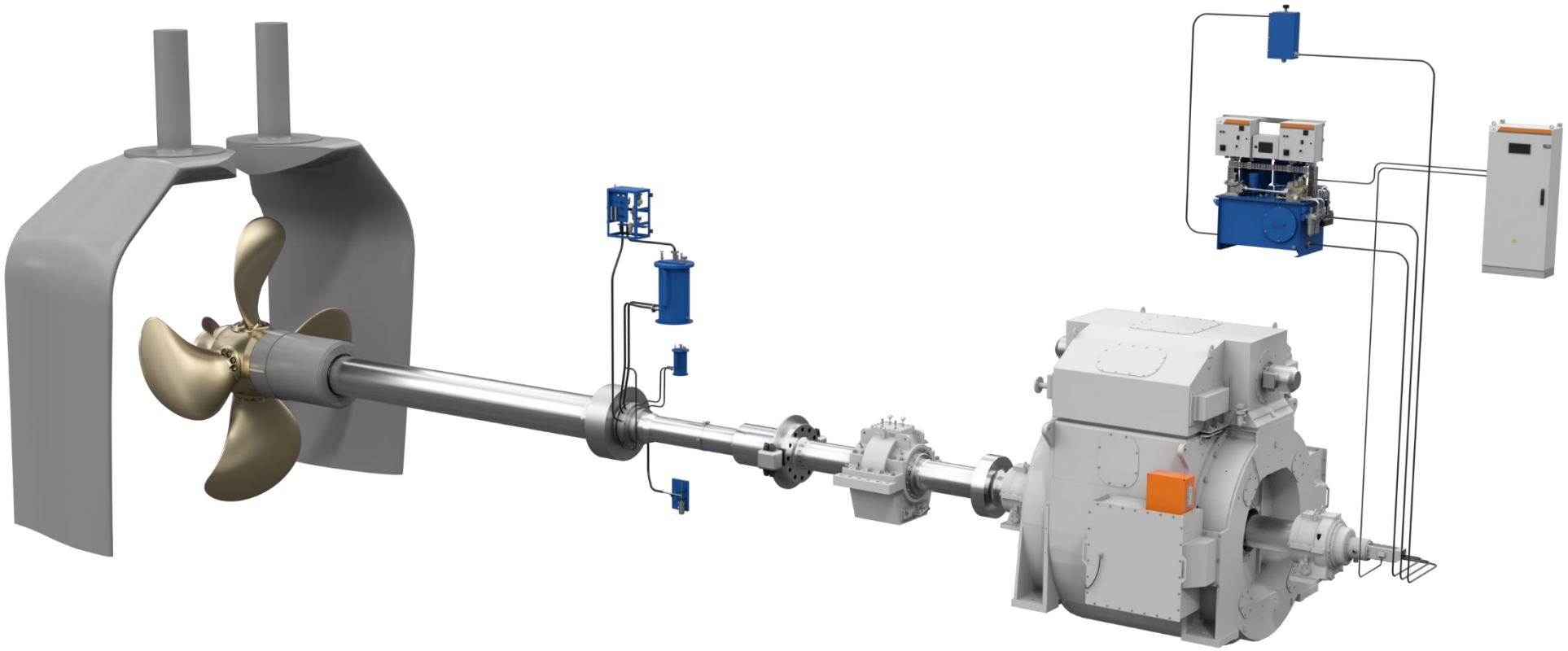
Eliminating the need for separate Compressors for air lubrication

Direct air feed from the gensets

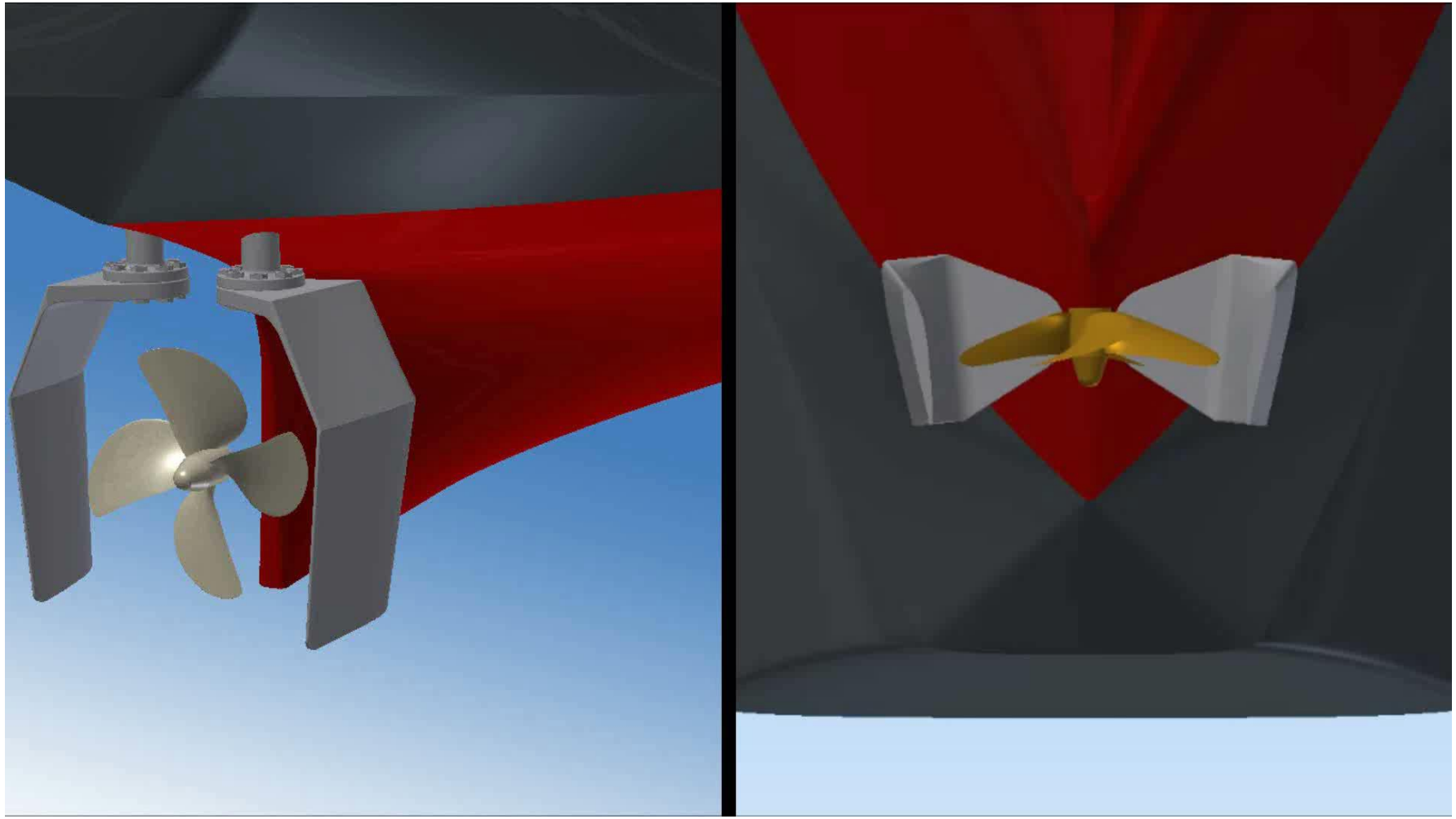
Increase in total efficiency gains



SECOND PHASE- PROPULSION FUTURE POTENTIAL ARRANGEMENT BASED ON GATE RUDDER

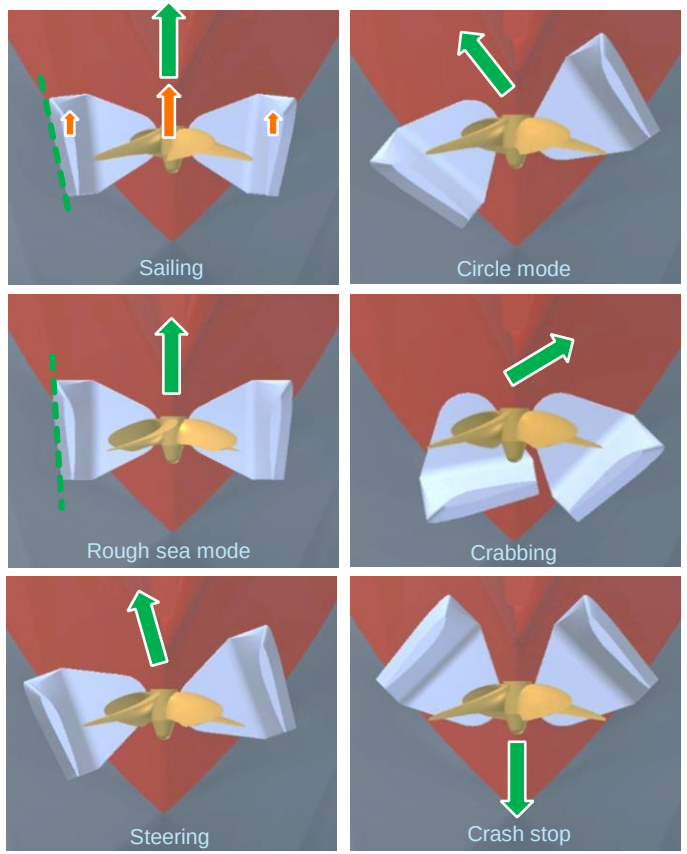


GATE RUDDER – AN INNOVATIVE INDUSTRY CHANGING RUDDER ARRANGEMENT



GATE RUDDER – AN INNOVATIVE INDUSTRY CHANGING RUDDER ARRANGEMENT

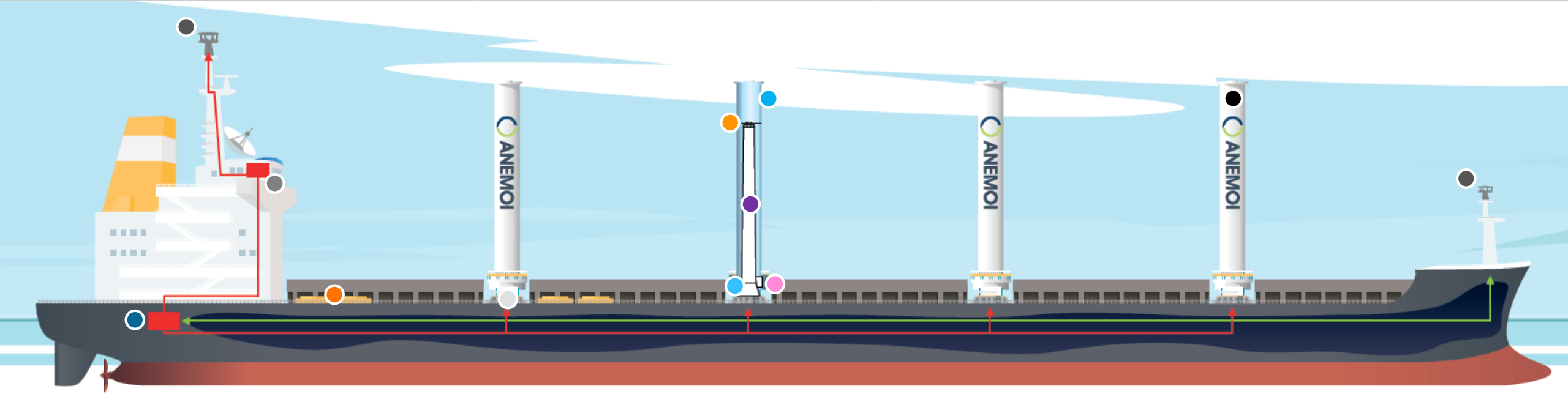
Thrust direction



WÄRTSILÄ

Japanese
Patent holders

Rotor Sails: The Anemoi Rotor System proposed by Wartsila



- Wind Sensors
- Control System
- Electrical Hardware
- Deployment System
- Foundations
- Flettner Rotors
- Upper Bearing
- Tower
- Electric Drive
- Lower Bearing
- Rotor Skin

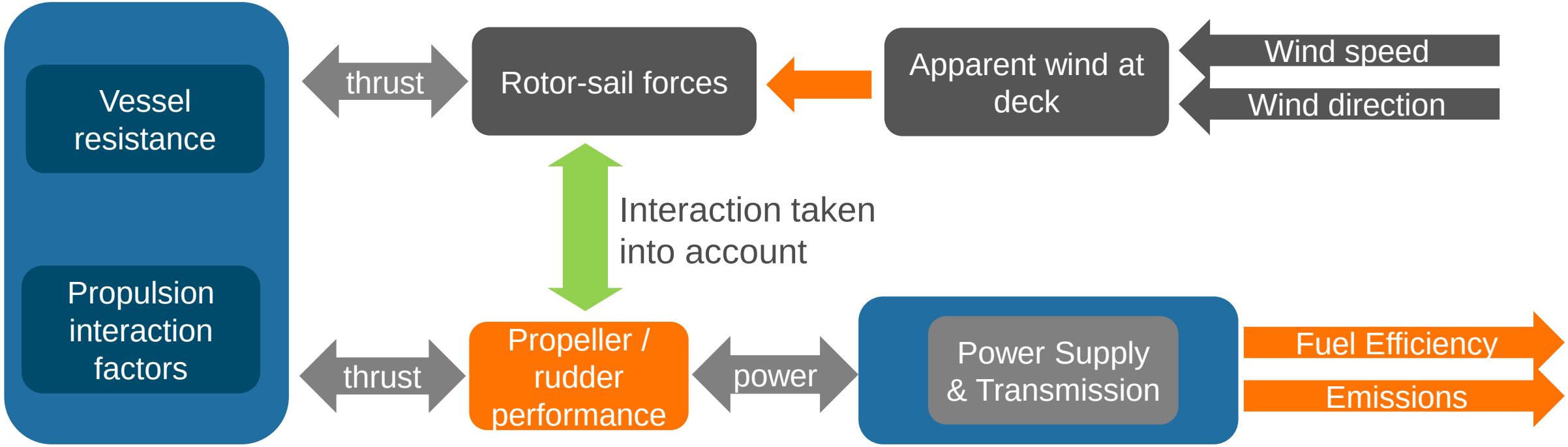
TYPICAL WASP ARRANGEMENTS (ROTORS)

Vessel size	Option 1	Option 2
Capesize	4Units 5mx30m Transverse Rail	
Kamsarmax	3Units 5mx24m – Transverse Rail	3Units 5mx35m – Transverse Rail
Newcastlemax	4Units 5mx35 – Folding	4Units 5mx30 – Transverse Rail
VLOC	5Units 5mx35m –Transverse Rail	5Units 5mx35m – Folding
Supramax	4Units 3.5mx24.5m – Longitudinal Rail	
Ultramax	4Units 3.5mx24.5m – Longitudinal Rail	
MR Tanker	3Units 5mx24m – Fixed	3Units 5mx35m – Fixed
LR Tanker	5Units 5mx24m – Fixed	5Units 5mx35m – Fixed
VLCC	4No/6Units 5mx24m – Fixed	6Units 5mx35m – Fixed
RoRo	4Units 5mx35m – Fixed	4Units 5mx35m – Folding

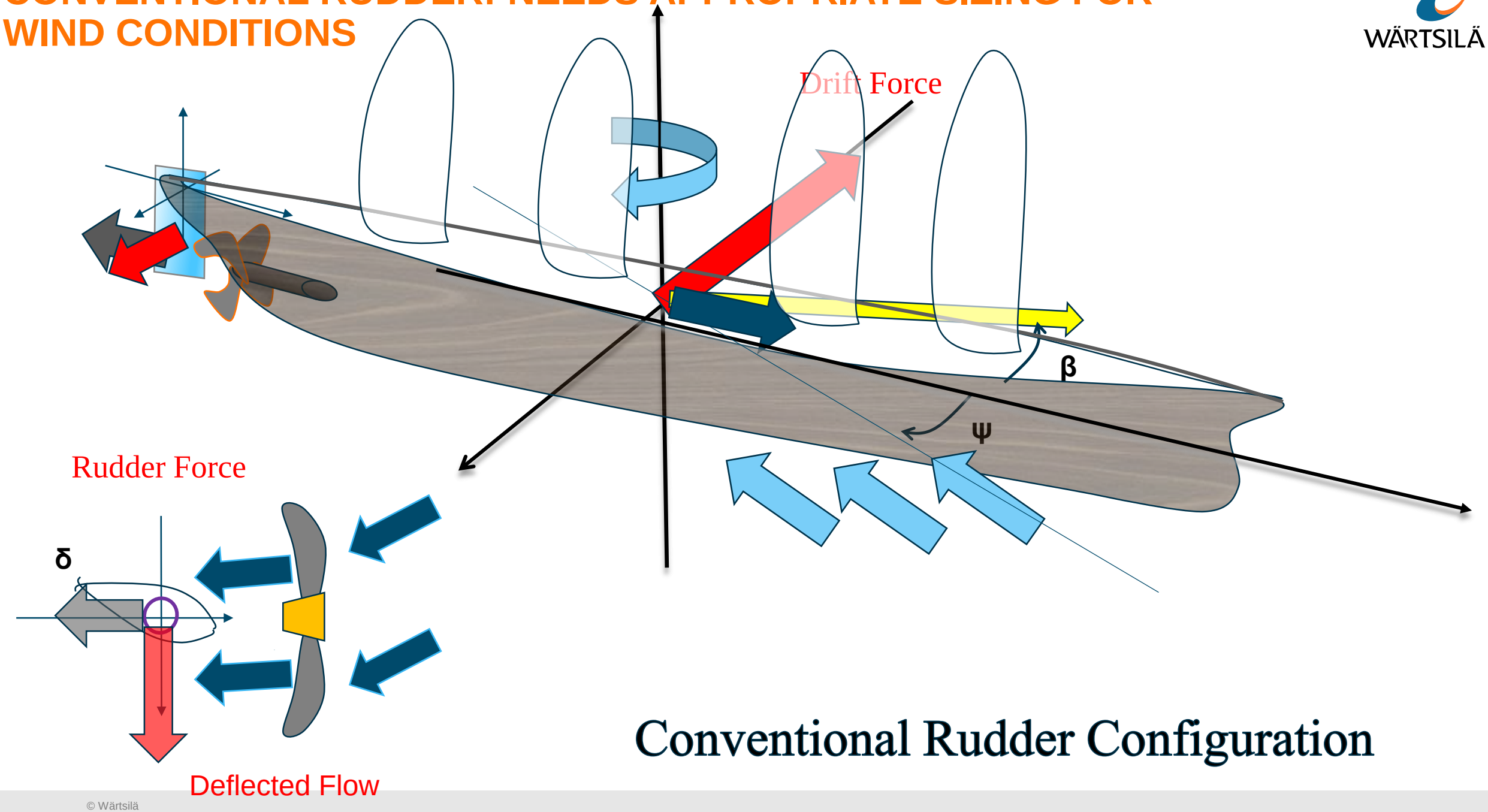
VESSEL INTEGRATION APPROACH: THE CASE OF WIND ASSIST PROPULSION

- System approach for Wind-Assisted Propulsion performance evaluation
- Weather data for main shipping routes need to be implemented

Issue becomes more important with Wind Thrust/ Total Required Thrust ratio's higher than 15%

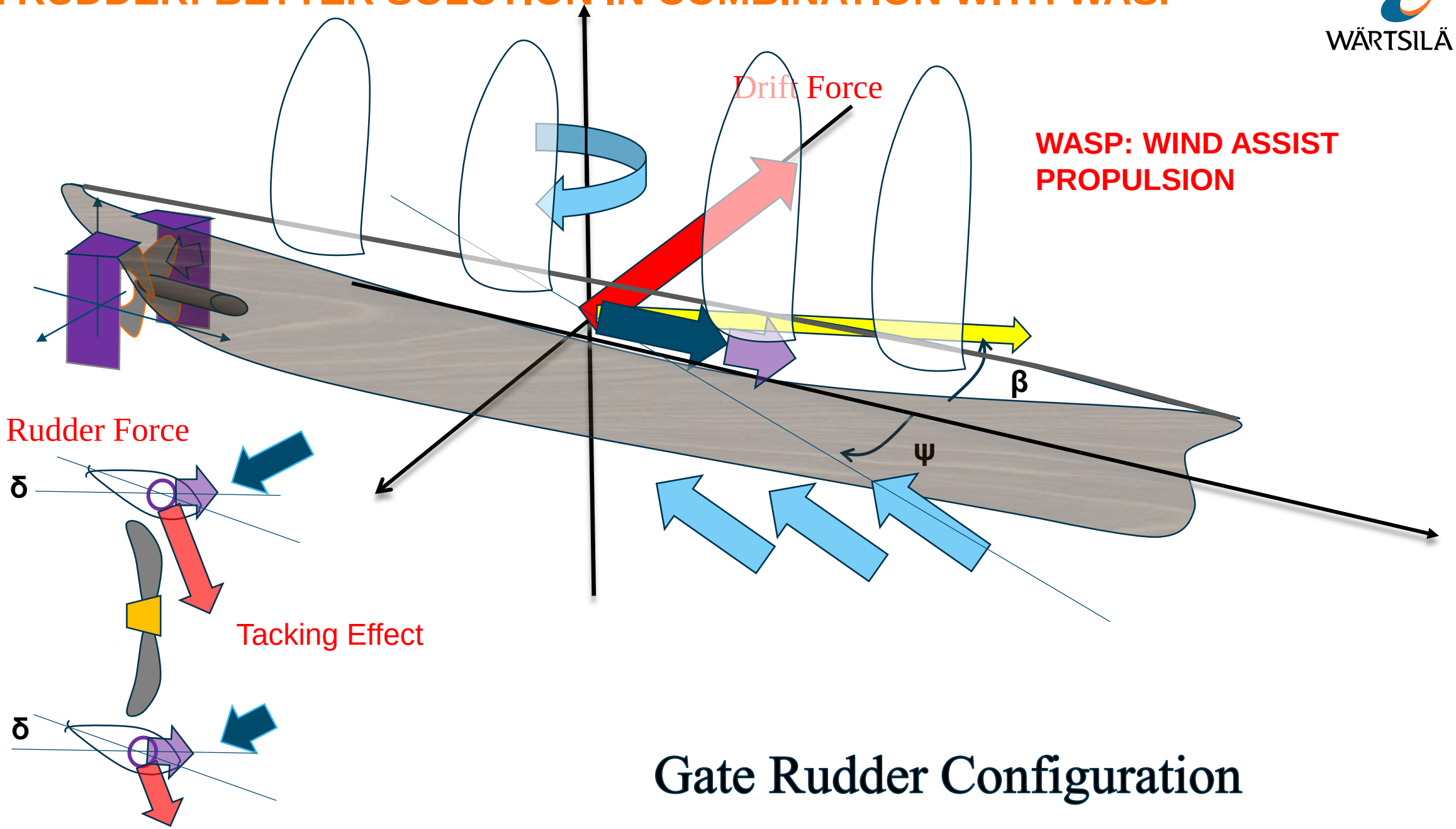


CONVENTIONAL RUDDER: NEEDS APPROPRIATE SIZING FOR WIND CONDITIONS



Conventional Rudder Configuration

GATE RUDDER: BETTER SOLUTION IN COMBINATION WITH WASP



Gate Rudder Configuration

TECHNICAL READINESS LEVELS – TECHNOLOGIES AT THE DEPLOYMENT PHASE

PERFORMANCE AT THE FIELD IS MONITORED

FINDINGS ARE EVALUATED

PRODUCTIONIZATION CONTINUES

SEVERAL VESSELS APPLICATIONS ARE CONSIDERED FOR THE NEAR FUTURE

COMMERCIALIZATION PROCESS IN AGREEMENT WITH THE DECARBONIZATION STRATEGY

BOLLFILTER
Protection Systems

Erste Betriebserfahrungen zur Bleed-Off-Treatment-Unit des Forschungs-Scrubbers der Hochschule Flensburg

08.05.2022

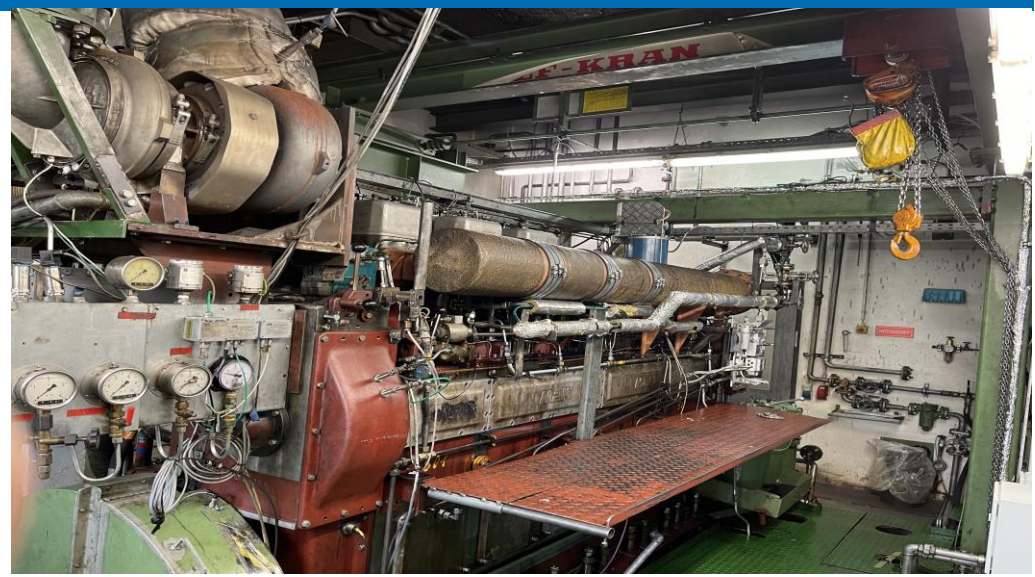
Dennis Fischer M. Eng

Inhalt

- **Vorstellung der Forschungsanlage**
  - Schiffsmotor
  - Scrubber
  - ***Bleed-Off-Treatment-Unit***
- **Grundlagen Querstrom-Filtration**
  - Terminologie
  - Funktionsprinzip
- **Filtrationsverlauf und Ergebnisse**
  - TMP und FLUX im zeitlichen Verlauf
  - Feed, Permeat und Retentat
- **Emissionsgrenzwerte im Vergleich**
  - IMO MEPC 340 (77)
  - BOTU Water-Monitoring
  - Laboranalysen
- **Ausblick**

Forschungsmotor

- Hersteller: MAK
- Wirkprinzip: 4-Takt Diesel
- Zylinder: Reihen-6-Zylinder
  => reduziert auf 3 Zylinder
- Bohrung: 240 mm
- Hub: 450 mm
- Leistung: 723 kW
- Max. Drehzahl: 600 1 min^{-1}
- Max. Drehmoment: 11500 Nm
- Kraftstoff: Diesel, Schweröl



BOLLFILTER Protection Systems

Forschungs-Scrubber

- Hersteller: PureteQ
- Typ/Bezeichnung: Inline Turbo Scrubber
- Wirkprinzip: Closed Loop
- Höhe: 6,8 m
- Innendurchmesser: 0,75 m
- Vorlagevolumen: 3,15 m^3
- Abgasmassenstrom: 5200 kg h^{-1}
- SO_2/CO_2-Verhältnis: < 4,3 ppm/Vol%
- Waschwasser-Volumenstrom: 21-36 m^3 h^{-1}

Bleed-Off-Treatment-Unit

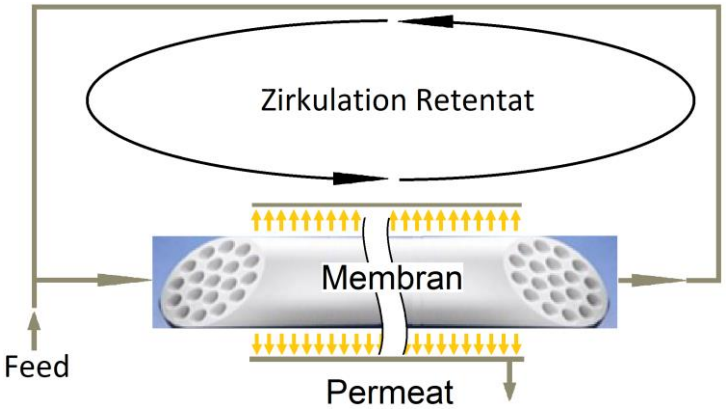
- Hersteller: BOLL & KIRCH
- Typ/Bezeichnung: MUFBK_MK2
- Wirkprinzip: Querstrom Filtration
- Anz. Membran-Module: 2
- Modul-Betrieb: Einzel und Parallel
- Feed Vorlagevolumen: 1,2 m^3
- System-Volumen:
  - Bei Betrieb eines Moduls: 10 dm^3
  - Im Parallel-Betrieb: 12 dm^3
- Zirkulations-Volumenstrom 10 $m^3\ h^{-1}$
- Bleed-Off Filtrationsleistung: bis zu 160 $dm^3\ h^{-1}$

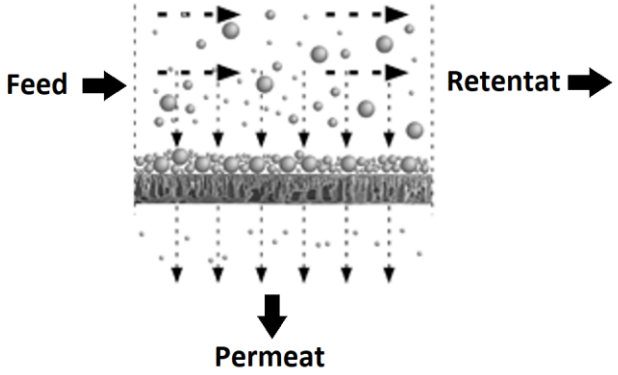
BOTU Sensorik (Online Messungen)

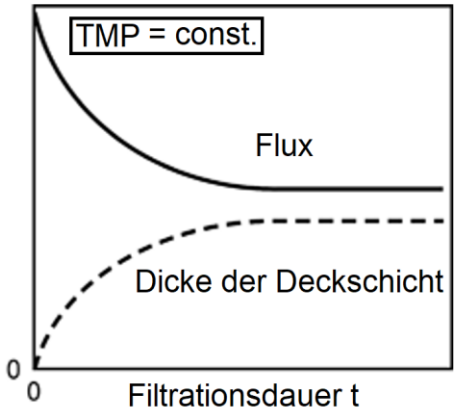
- Zulauf / Zirkulation
  - Temperatur
  - Druck
  - Volumenstrom
  - pH
  - Redox Potential
  - Leitfähigkeit
  - PAK_{phe}
  - Trübung
  - Dichte (in Bearbeitung)
  - Viskosität (in Bearbeitung)
- Ablauf
  - Temperatur
  - Druck
  - Volumenstrom
  - Dichte (in Bearbeitung)
  - Viskosität (in Bearbeitung)

Grundlagen Querstrom-Filtration

- Terminologie
  - Feed: Volumenstrom des zu filtrierenden Mediums (hier Scrubber Bleed-Off)
  - Permeat: durch die Membranwand strömendes, gefiltertes Medium
  - Retentat: Konzentrat des zu filtrierenden Mediums
  - Flux: Permeat-Volumenstrom pro Membran-/ Filtrationsfläche [l m^{-2} h^{-1}]
  - Transmembrandruck: beschreibt Druckunterschied zwischen Feed- und Permeatseite einer Membran (Filtrationsdruck)
  - Permeabilität: Filtrationsvermögen beschrieben durch FLUX pro TMP
- Funktionsprinzip

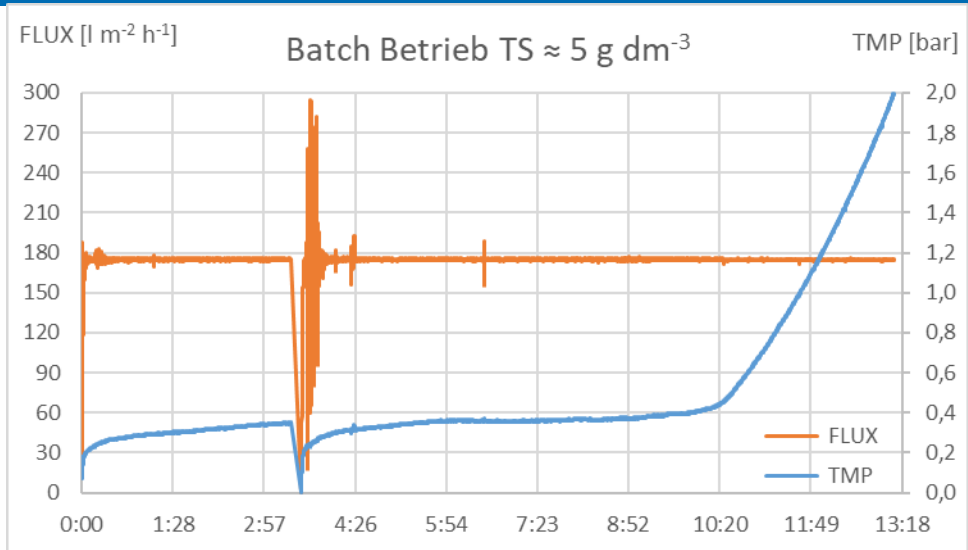




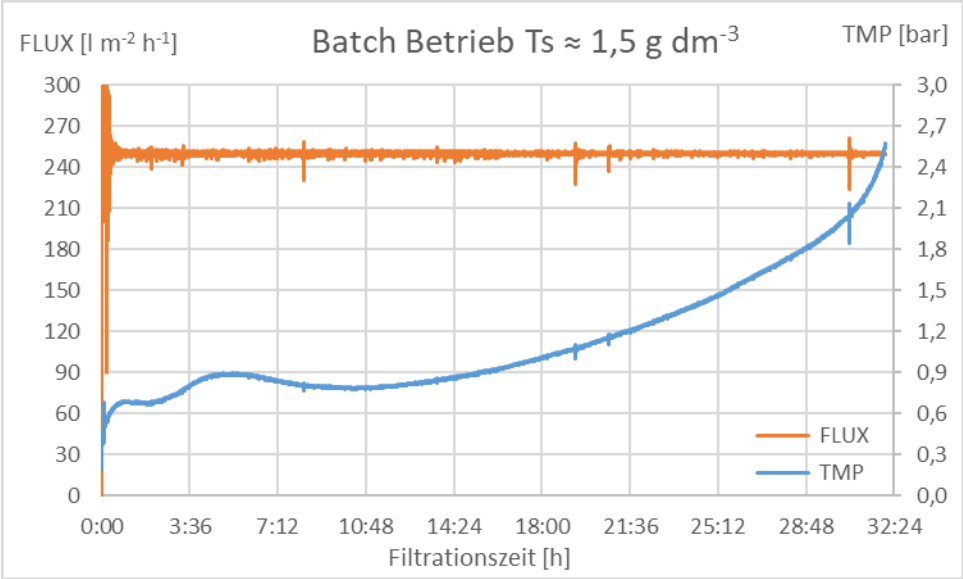


Filtrationsverlauf und Ergebnisse

- Hohe Feststoffbeladung des Feed TS ≈ 5 g dm^{-3}
- Moderater Flux 175 dm^3 m^{-2} h^{-1}
- Permeat Volumenstrom 37,6 dm^3 h^{-1} ≙ 489 dm^3
- Abbruchparameter TMP = 2 bar
- Feststoff im Retentat TS = 201 g dm^{-1}
- Filtrationszeit t = 13 h



- Moderate Feststoffbeladung des Feed Ts ≈ 1,5 g dm^{-3}
- Erhöhter Flux 250 dm^3 m^{-2} h^{-1}
- Permeat Volumenstrom 53,7 dm^3 h^{-1} ≙ 1,73 m^3
- Abbruchparameter TMP = 2,5 bar
- Feststoff im Retentat TS = 212 g dm^{-1}
- Filtrationszeit t = 32 h



BOLLFILTER Protection Systems

Feed, Permeat und Retentat

- Feed bei Motor MCR 60%, HFO 2,5% S,+ 10 h Closed Loop
  - NTU > 10.000
  - TS > 1.000 mg dm^{-3}
  - Leitfähigkeit > 75 mS cm^{-1} (bei T = 50°C)
  - Salzgehalt ca. 90 g dm^{-3}
- Permeat nach 0,5 h Filtration + 10 h Closed Loop Vorlauf
  - NTU < 1
  - Partikelfrei
  - Leitfähigkeit > 75 mS cm^{-1} (bei T = 50°C)
  - Salzgehalt ca. 90 g dm^{-3}
- Retentat je nach Dauer und Filtrationsverlauf
  - NTU nicht messbar
  - (kontinuierlicher Betrieb) max. erreicht 25% TS
  - (Batch Betrieb) max. erreicht 30% TS

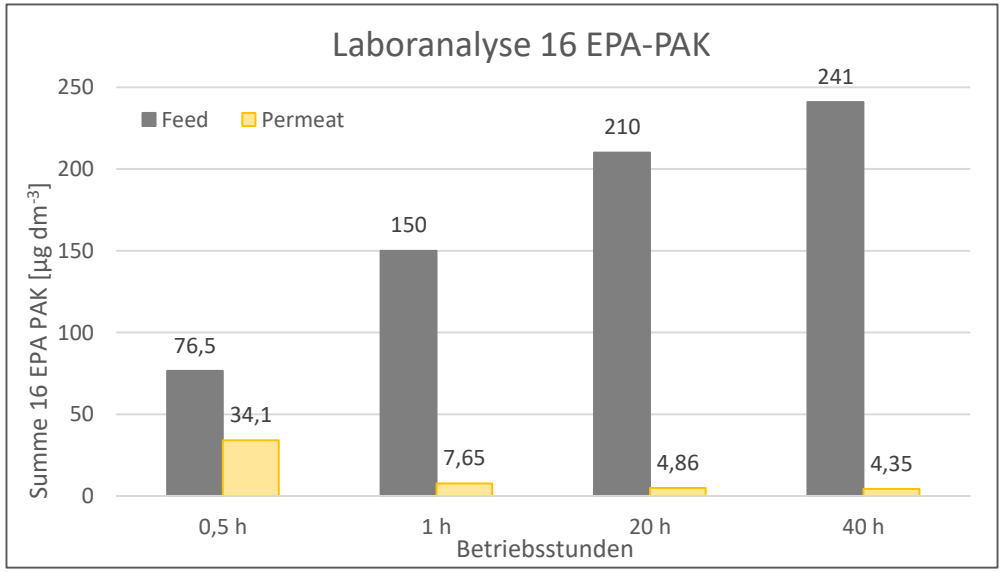
FEED	RETENTAT	PERMEAT
TS ≈ 1 g dm^{-3}	TS ≈ 100 g dm^{-3}	NTU < 1
PAK ≈ 118 µg dm^{-3}	PAK ≈ 4600 µg dm^{-3}	PAK < 5 µg dm^{-3}

Emissionsgrenzwerte im Vergleich

- Filtration des Feed (Scrubber Bleed-Off), ohne Vor- oder Nachbehandlung
- Scharfe Trenngrenze erzeugt permanente Einhaltung der Grenzwerte
- Partikelfreies Permeat ohne signifikante Trübung
- Deckschichtaufbau unterstützt zusätzlich Emissionsreduktion

Parameter (Permeat)	IMO MEPC 340(77)	BOTU Monitoring 1	BOTU Monitoring 2	Labor
Trübung [NTU]	25	1-5	1-8	<1
Nitrat [mg dm^{-3}]	2700	-	-	10-150
PAK_{phe} [µg dm^{-3}]	2250	10-50	50-250	45-4,5
pH	6,5-8	7-8	7-8	7-8

PAK- und Nitrat-Grenzwerte der MEPC 340 (77) wurden auf Permeat-Volumenströme der BOTU (MUFBK_MK2) umgerechnet



BOLLFILTER Protection Systems

Ausblick

- Anpassung und Erweiterung von Reinigungsverfahren
- Erprobung neuer Membranmaterialien
- Erprobung unterschiedlicher Membrangeometrien
- Erweiterung des Feed Water Monitoring
- Leistungssteigerung der Filtration durch Betriebsoptimierung
- Entwicklung integrierter, chemikalienfreier Wasservorbehandlung
- Optimierung des Zusammenspiels von Scrubber und Filtration

ENDE

FRAGEN ?

BOLL FineFilterUnit

KeSS

Kompakte und effiziente Abgasnachbehandlung
zur Minimierung von Stickoxiden und Schallemissionen
- KeSS -

KeSS

Zusammenfassung

Idee:

- Kombination von SCR-Katalysatoren mit Schalldämpfer im gleichen Gehäuse.

Ziel:

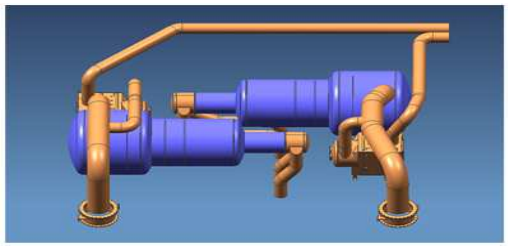
- Erfüllung der NO_x – Grenzwerte nach IMOIII
- Reduzierung Bauraum und Gewicht
- Reduzierung Abgasgegendruck
- Reduzierung Kosten
- Verringerung des Koordinationsaufwandes

Projektdaten:

- Projektdauer: 2,5 Jahre
- Projektabschluss: Q3, 2017

Patentierung: 2021

KeSS:



LÜRSSEN

LÜRSSEN
FR LÜRSSEN WERFT

hugengineering.
Ein Unternehmen der ElringKlinger-Gruppe

Nießing
75 Jahre Impulse

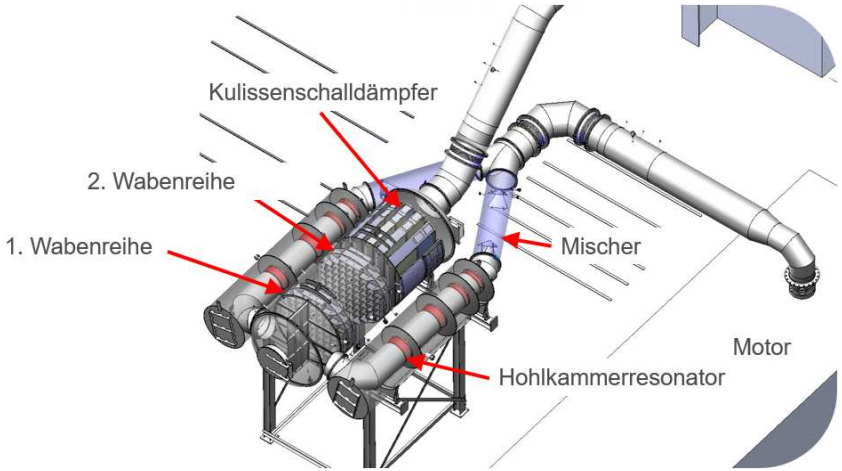
Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

KeSS

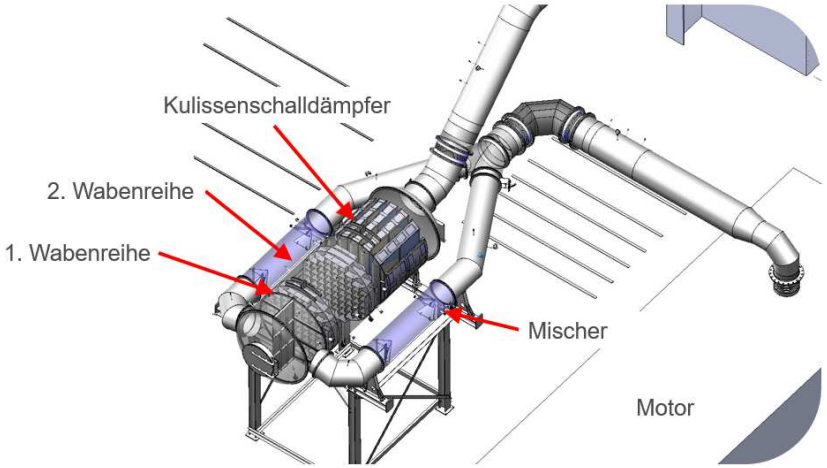
KeSS 1 Entwürfe

LÜRSSEN

Variante 1



Variante 2



KeSS

Aufbau KeSS 1

Nießing Anlagenbau GmbH

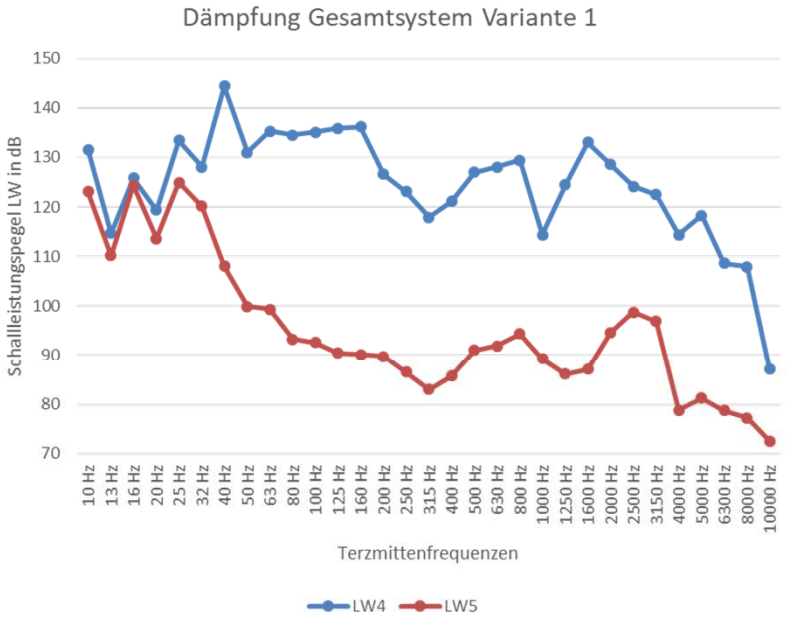
Fertigung Reaktor, Rohrleitungen, Schalldämpfer und Stahlbau

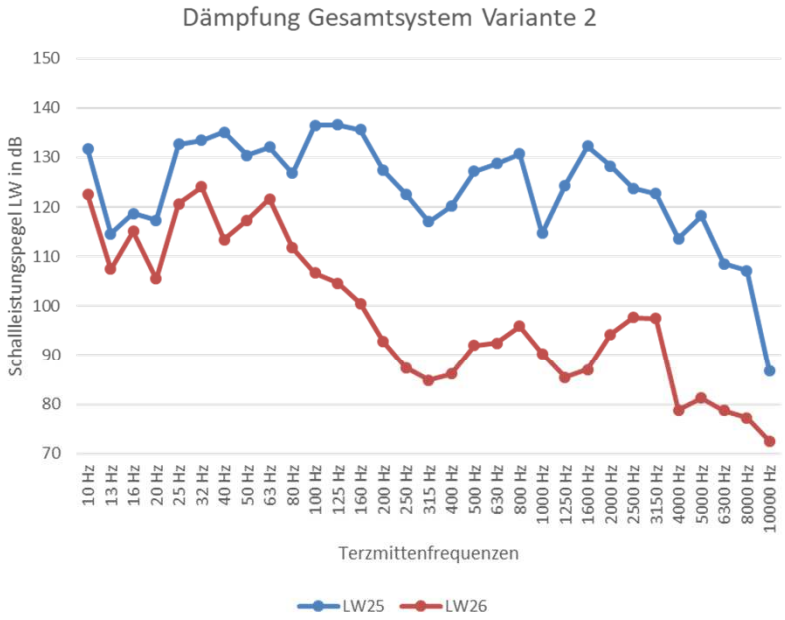
Hug Engineering AG

Kassettierte SCR-Waben, Dosiersystem VariNOx, Sensorik

KeSS

Vergleich KeSS 1





Einfügedämpfung: 35 dB

LW4: nach Motor
LW5: Austrittsleitung

LW25: nach Motor
LW26: Austrittsleitung

KeSS

Perfomance KeSS 1

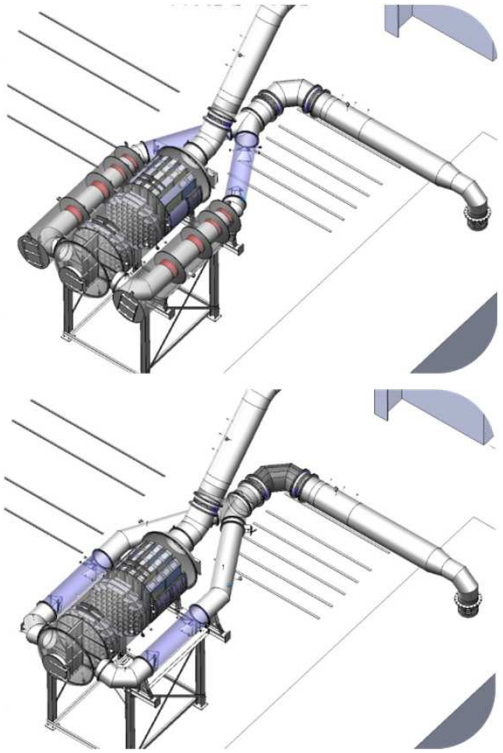
LÜRSSEN

Erreichte Nox-Umsatzraten der Varianten

Variante 1:
Mit Rohrschalldämpfer

Variante 2:
Ohne Rohrschalldämpfer

Variante	Last	SOLL-Umsatz IMO	IST-Umsatz
Variante 1	100 %	80 %	85 %
Variante 2			84 %
Variante 1	75 %	85 %	93 %
Variante 2			93 %
Variante 1	50 %	85 %	96 %
Variante 2			96 %



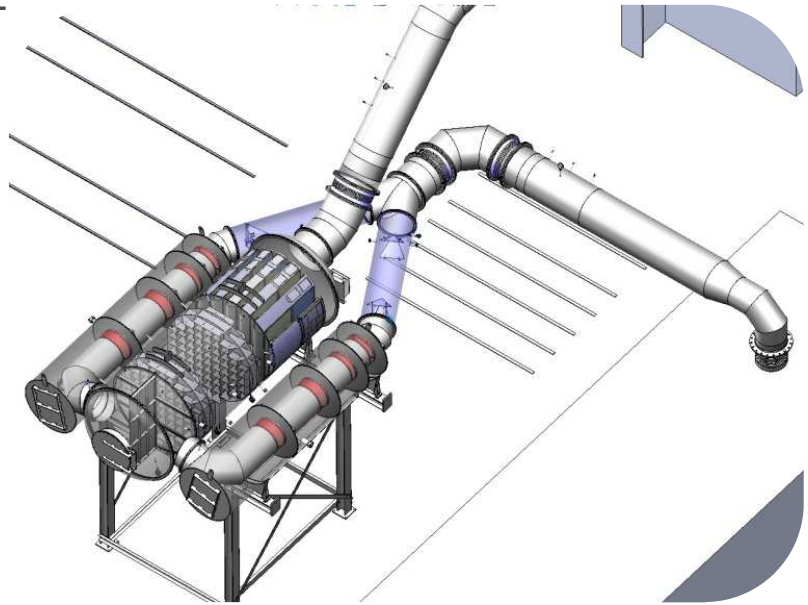
KeSS

Ergebnisse KeSS 1

- System zeigt IMO-konformen NOx-Umsatz
- Schallreduktion entspricht der Auslegung

Verbesserungspotential:

- Nachteilige Platzausnutzung eines runden Reaktors verglichen mit einem eckigen
- Deutliche Platzersparnis durch Kombination von Misch- und Eindüsrohr mit Hohlkammerresonator

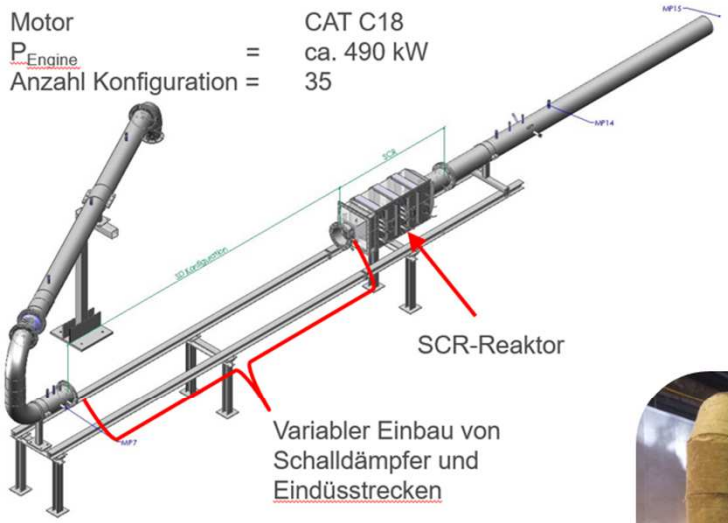


KeSS

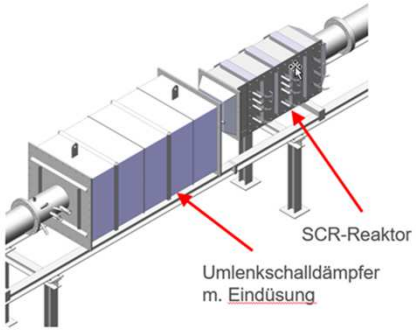
KeSS 2 Aufbau

LÜRSSEN

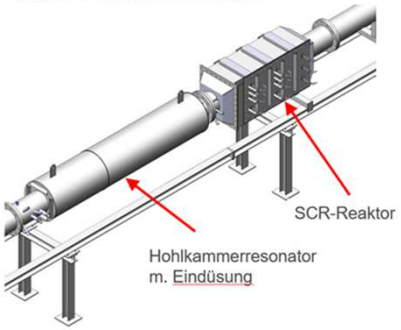
Motor CAT C18
P_{Engine} = ca. 490 kW
Anzahl Konfiguration = 35



Variante 1: Umlenkschalldämpfer



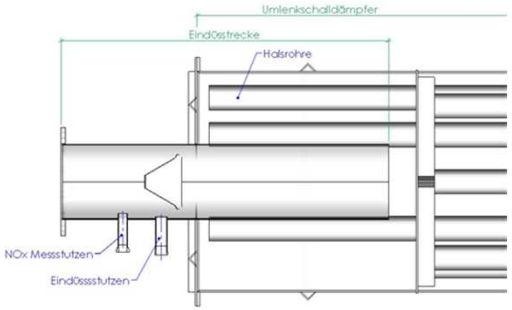
Variante 2: Hohlkammerresonator

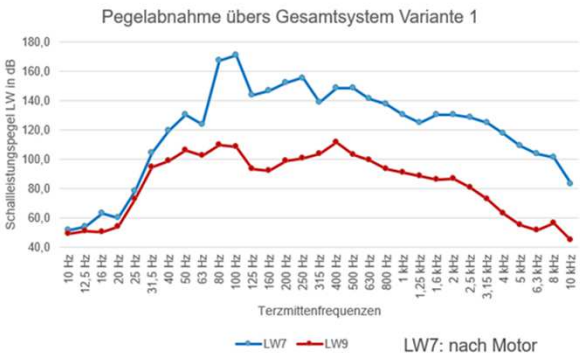


KeSS

Vergleich KeSS 2

Variante 1: Umlenkschalldämpfer

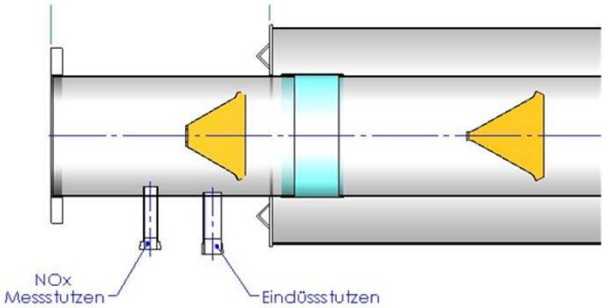


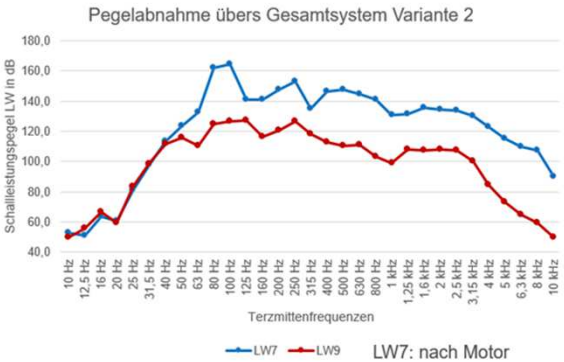


LW7: nach Motor
LW9: Austritt

Einfügedämpfung: 45 dB

Variante 2: Hohlkammerresonator





LW7: nach Motor
LW9: Austritt

Einfügedämpfung: 30 dB

KeSS

Performance KeSS 2

LÜRSSEN

Erreichte NOx-Umsatzraten der Varianten

Variante 1:
Umlenkschalldämpfer

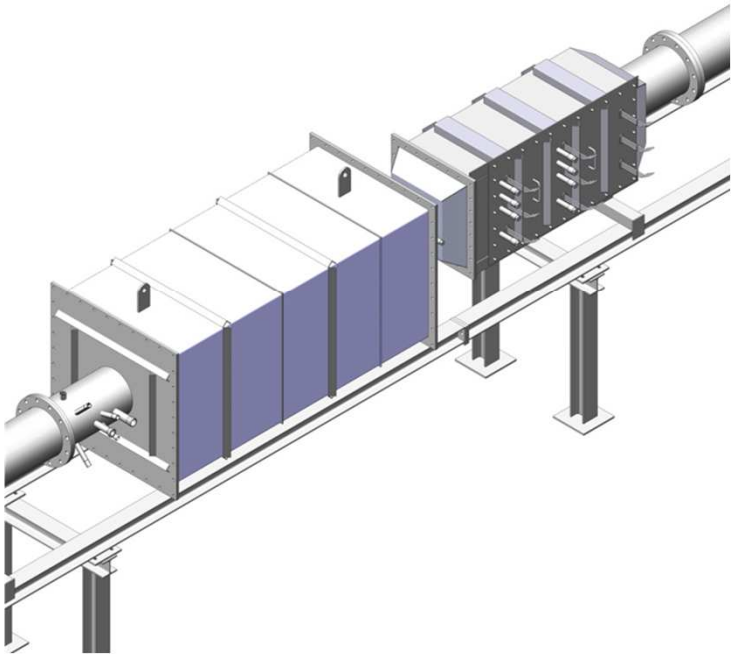
Variante 2:
Hohlkammerresonator

Variante	Last	SOLL-Umsatz IMO	IST-Umsatz	Δp
Variante 1	100 %	80 %	83 %	41 mbar
Variante 2			87 %	19 mbar
Variante 1	50 %	85 %	92 %	23 mbar
Variante 2			92 %	11 mbar

KeSS

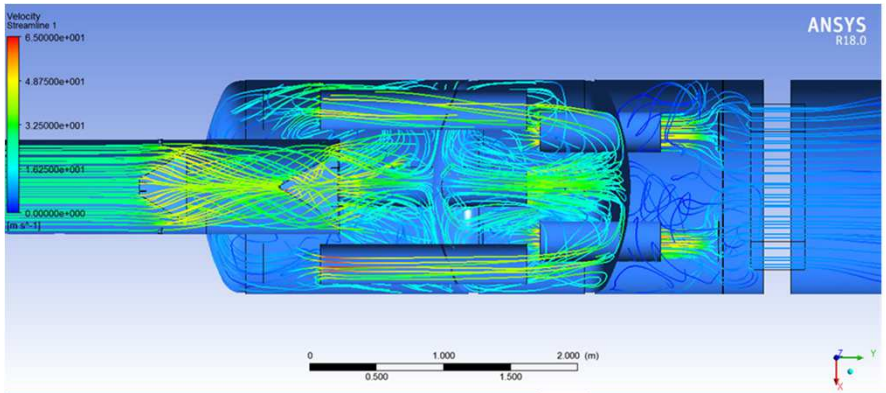
Ergebnisse KeSS 2

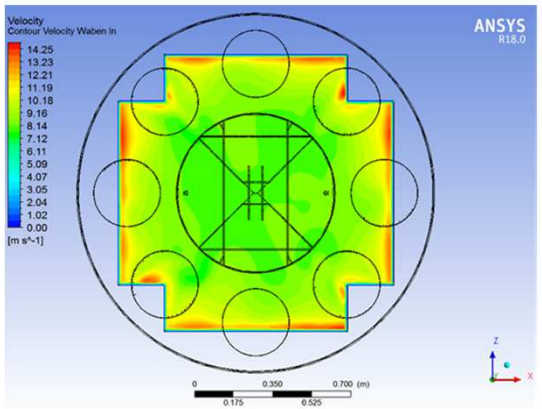
- Kombination von Umlenkschalldämpfer sowie Hohlkammerresonator mit der Eindüsstrecke zeigen gute Ergebnisse
- Die Mischwirkung des Umlenkschalldämpfers kann durch geeignete Maßnahmen noch optimiert werden.
- Keine nachteilige Auswirkung durch den eckigen Reaktor auf die Schalldämpfung

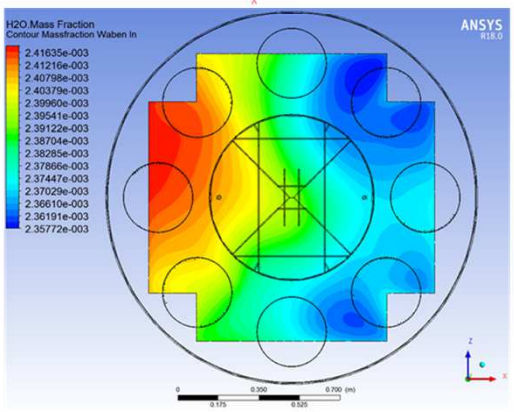


KeSS

Auszug der CFD Simulationen



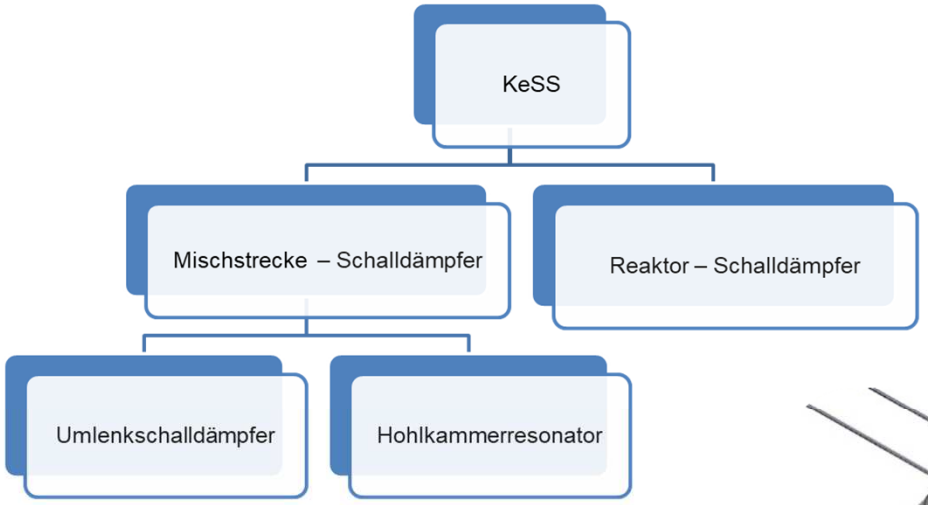


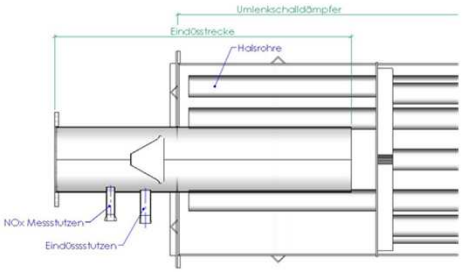


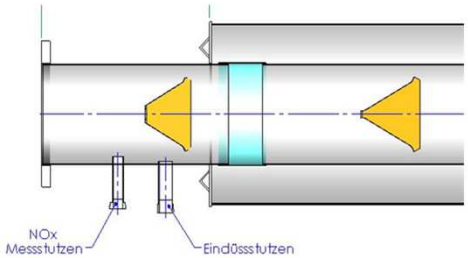
- Sehr gute Strömungsverteilung auf der Wabenfront
- Die Mischgüte beträgt 99.67 auf der Eintrittsfläche der Waben.

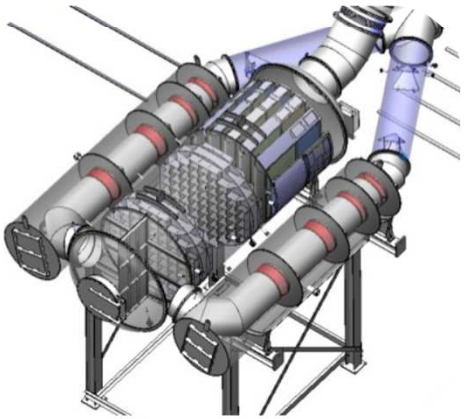
KeSS

Varianten des KeSS System







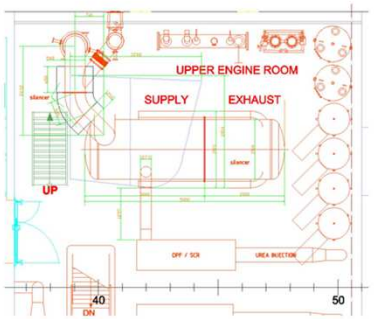


KeSS

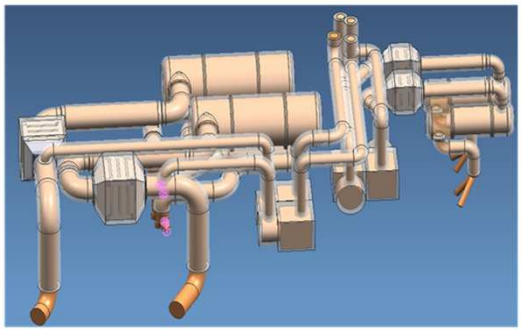
Anwendungsbeispiele

LÜRSSEN

Layout MR Yacht

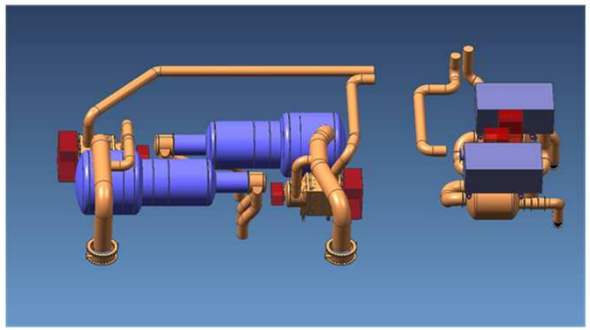


Abgasstrang mit SCR-Reaktor



V ≈ 129 m³

Abgasstrang mit SCR-Schalldämpfer



V ≈ 95 m³

KeSS

Ergebnisse am Beispiel der ersten gesetzten Yacht

LÜRSSEN

Gewicht

- Einsparung durch Entfall von Klöpperböden, Stutzen, Flansche und Halterung

27 %

Volumina

- Einsparung durch Entfall der Klöpperböden, Stutzen und Teilsegment Rohr

24 %

Kosten

- Einsparungen insgesamt ca.

8 - 10 %

Druckverlust

- Optimierung um

15 %

Patent 2021


EUROPÄISCHE PATENTSCHRIFT

EP 3 704 360 B1


Europäisches Patentamt
European Patent Office
Office européen des brevets

URKUNDE

Europäisches Patent

CERTIFICATE

European patent

CERTIFICAT

Brevet européen

3704360

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Hug Engineering GmbH
Otto-Lilienthal-Straße 1
39120 Magdeburg/DE

Fr. Lürssen Werft GmbH & Co. KG
Zum Alten Speicher 11
28759 Bremen/DE

KeSS

Bisherige Projekte mit KeSS System

LÜRSSEN

87 m Yacht Ablieferung im Jahr 2020

142 m Yacht Ablieferung im Jahr 2021

KeSS

Bisherige Projekte mit KeSS System

LÜRSSEN

115 m Yacht Ablieferung im Jahr 2021

160 m Yacht Ablieferung im Jahr 2022

KeSS – Abgasnachbehandlung zur Minimierung von Stickoxiden und Schallemissionen

LÜRSSEN

Vielen Dank für die Aufmerksamkeit

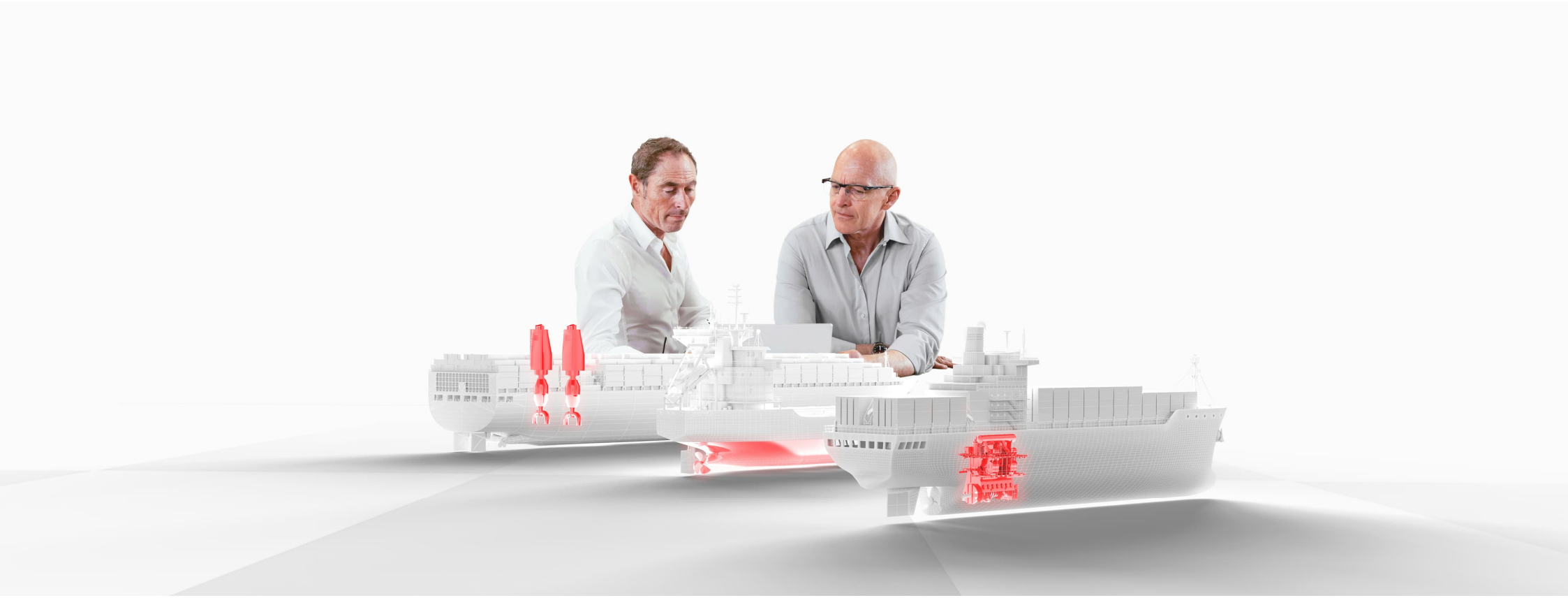


ABB TURBOCHARGING, O. STOLP, O. HEINRICH

From engine analytics to fleet performance software

Digitalization in the marine industry

ISF-Conference May 2022

Introduction

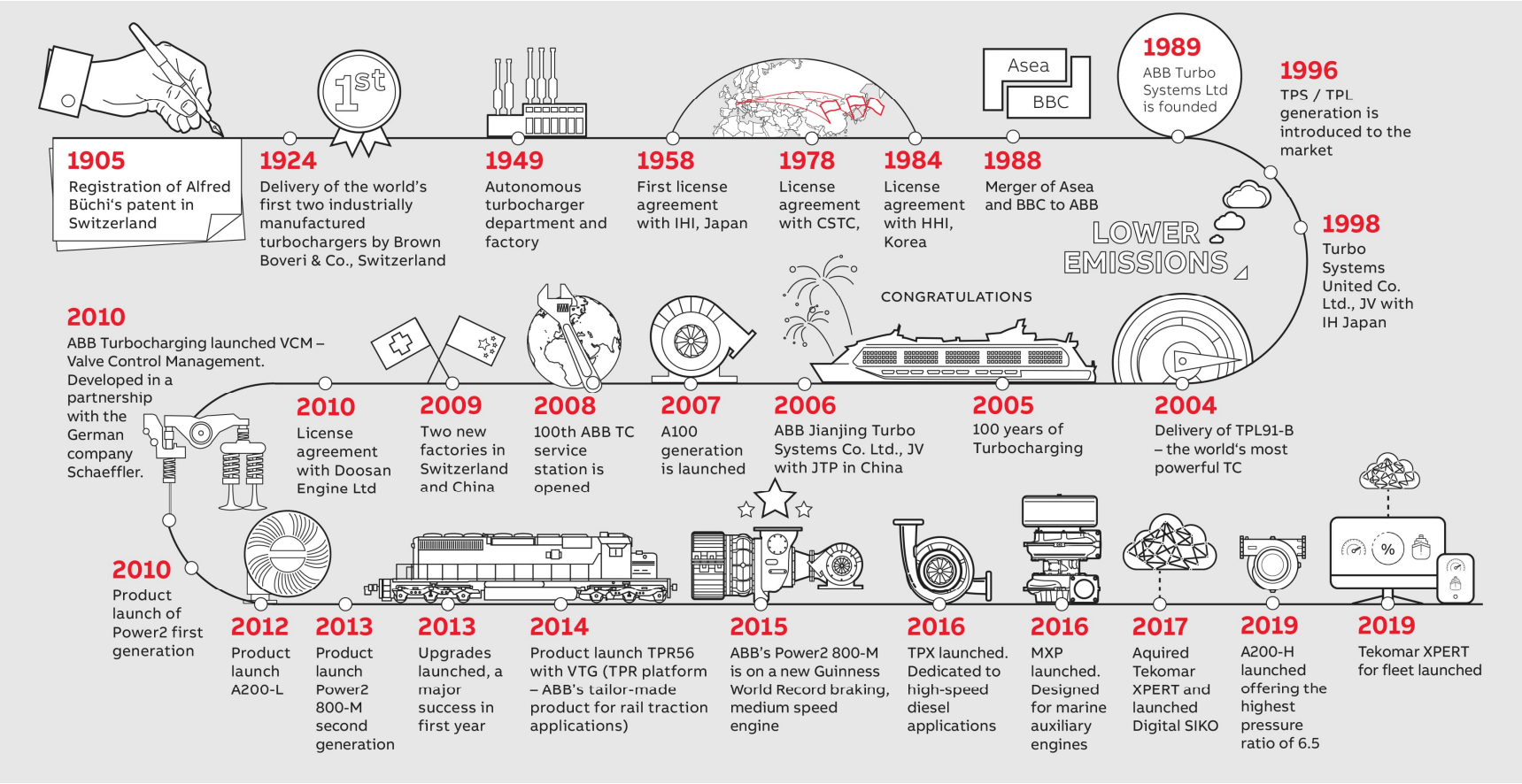
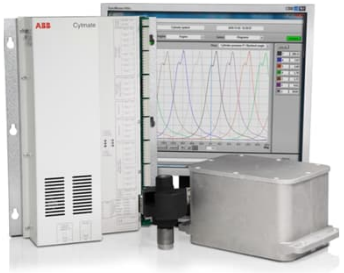
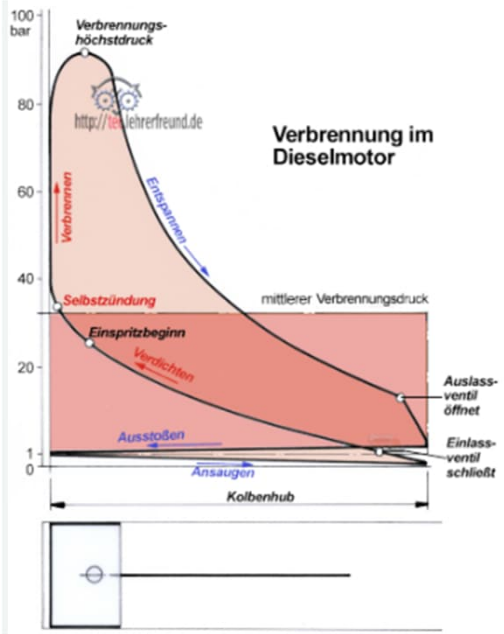


ABB Turbocharging - milestones – YouTube

Introduction

Engine optimization so far





Pictures:
Left: Ingenieur Hugo Maihak: Eine Geschichte - funkstunde.com
Right: Materialien für den Technikunterricht • tec.Lehrerfreund

Engine Optimization

Physical model

1) Engine Model

2) Input

- Comprehensive, engine specific form
- Printout for manual recording
- Field validation
- Tracking of modification after data import
- Instant calculation / evaluation

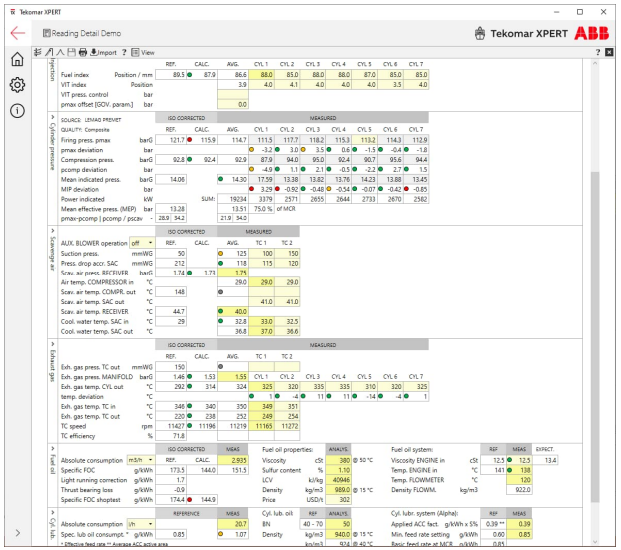
3) Calculation output

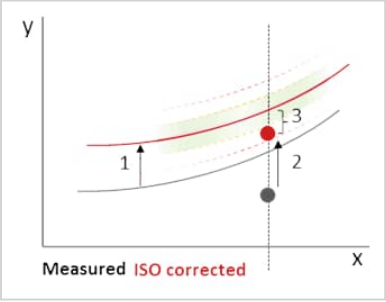
Baseline (1) and Readings (2) ISO corrected, depending on:

- Dynamic limits (load dependent, etc.)
- Static limits

The deviation (3) of Reading from Baseline is classified (normalized) into:

- Green (ok), Orange (critical), Red (alert)





Engine Optimization

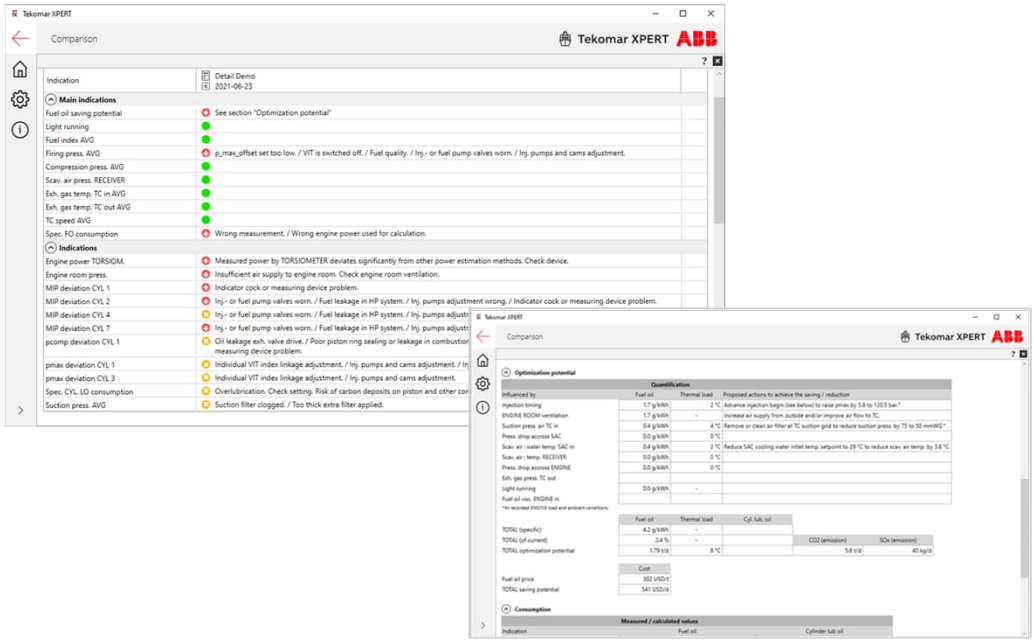
Physical model

4) Instant Advisory

- Classifications computed during evaluation i.e. input for the rule-based system
- Results: comments and recommendations for rectification

5) Potential

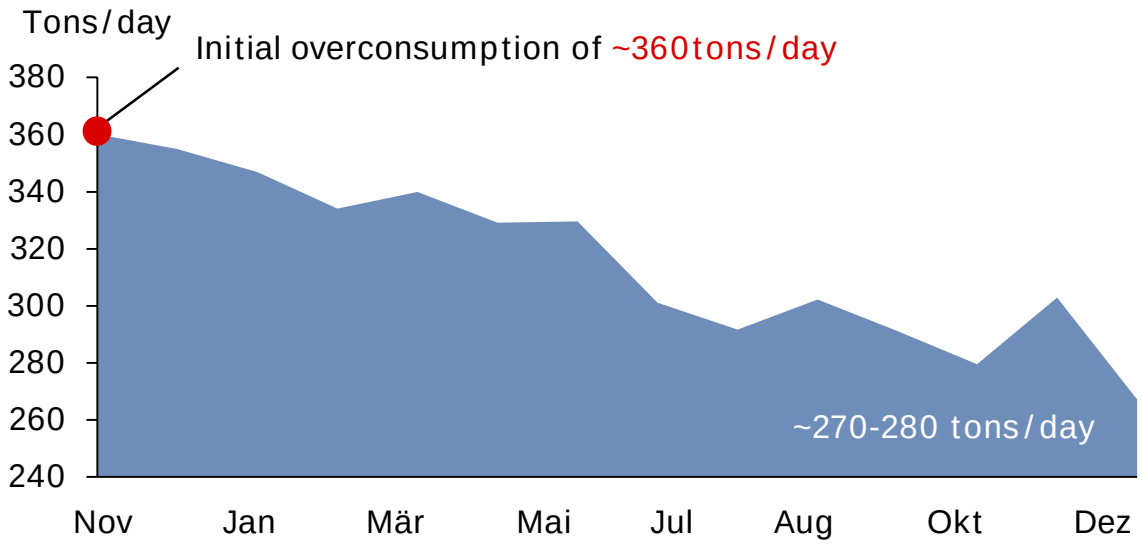
- Optimization potential for energy consumption is quantified
- Proposed actions to achieve savings
- Injection timing adjustments



Engine Optimization

Example 1: Saving Potential

Overconsumption due to engine inefficiency (tons per day – Fleet of more than 100 vessels)



- XPERT for fleet was installed on the whole fleet
- The new software brought the engine performance at the attention of management
- The daily fuel consumption dropped by 90 tons/day

A saving of ~22.000$/day* was achieved

- Overall saving of ~$5m per year
- Payback in >15 days

* Calculation done with 250$/ton of HFO

Engine Optimization

Example 2: How Tekomar XPERT helped to identify premature T/C wear

Starting point:

- Customer trial of Tekomar XPERT for vessel with 2-stroke electronic engine
- No suspected or known engine issues

Indications of Tekomar XPERT:

- Cylinder pressure at optimum, low savings potential and good firing pressures, as the closed loop engine control system was regulating properly
- Main indications show low scavenge air pressure and T/C speed, pointing to TC issue

Indications before actions have been taken:

Main indications	
Fuel oil saving potential	See section "Optimization potential"
Light running	
Fuel index ECU	
Firing press. AVG	
Compression press. AVG	
Scav. air press. RECEIVER	TC needs cleaning or overhaul. / Clogged and/or aged charge air or exh. gas system. / TC efficiency reduced.
Exh. gas temp. TC in	
Exh. gas temp. TC out	
TC speed	Aged and/or clogged scav. air/exh. gas system. / Fuel quality. / Poor engine room ventilation. / TC efficiency reduced. / Poor atomization.
Spec. FO consumption	Check Engine Evaluation report for saving potential. / Wrong measurement. / Wrong engine power used for calculation.

Engine Optimization

Example 2: How Tekomar XPERT helped to identify premature T/C wear

Findings:

- Inspection on board confirmed premature wear on T/C cover ring (see pictures on the right)

Results:

- Exchange of part fixed decrease in T/C efficiency and helped to prevent additional damage or sudden breakdown of the T/C
- After exchange of T/C cover ring, main indications in XPERT show no more issues

Visible wear on T/C cover ring

Indications after actions have been taken:

Main indications	
Fuel oil saving potential	●
Light running	●
Fuel index ECU	●
Firing press. AVG	●
Compression press. AVG	●
Scav. air press. RECEIVER	●
Exh. gas temp. TC in	●
Exh. gas temp. TC out	●
TC speed	●
Spec. FO consumption	Check Engine Evaluation report for saving potential. / Wrong measurement. / Wrong engine power used for calculation.

One Step Back:

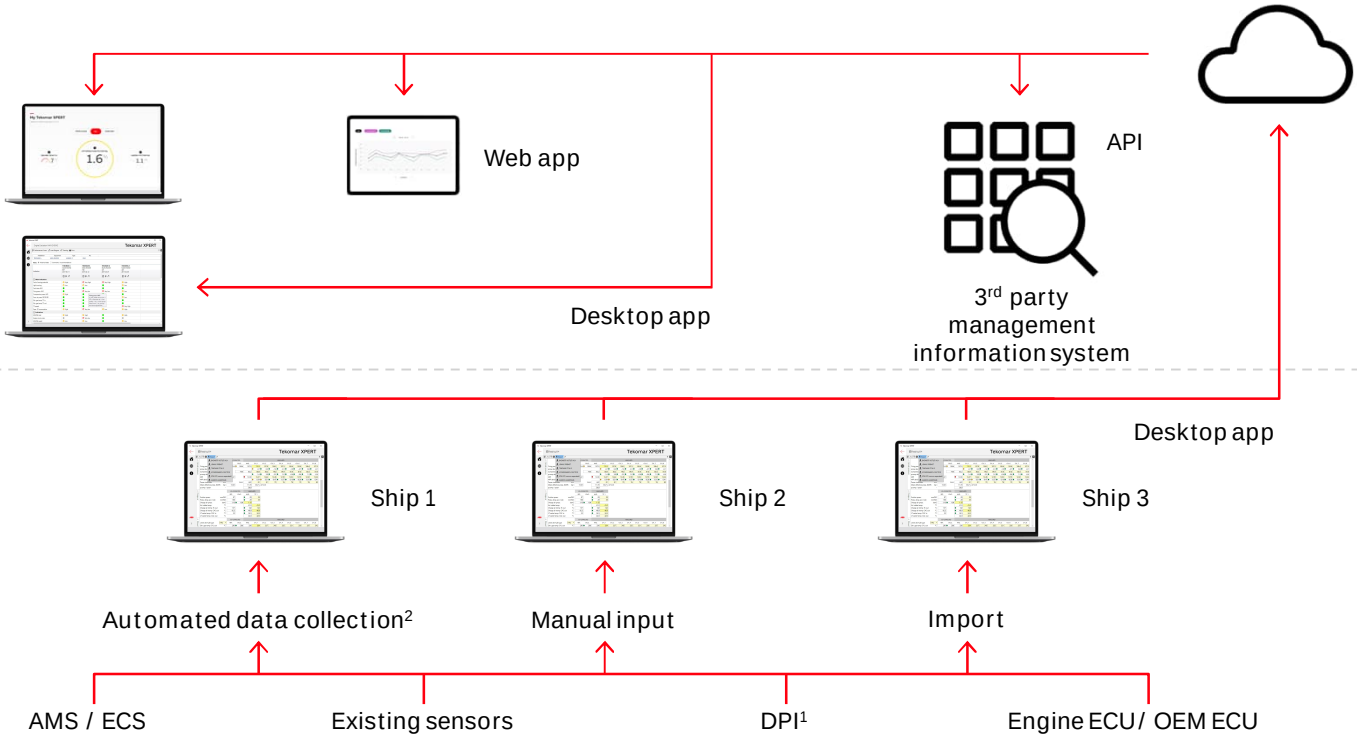
Who's interested in which kind of information?

Technical Director:
- Assess fleet performance
- Benchmark fleets

Fleet Manager:
- Compare vessels in fleet
- Benchmark against other fleets

Superintendent:
- Check engine
- Evaluate performance
- Interact with Chief Engineer

Chief Engineer
- Collect / import data
- Evaluate performance
- Implement recommendation

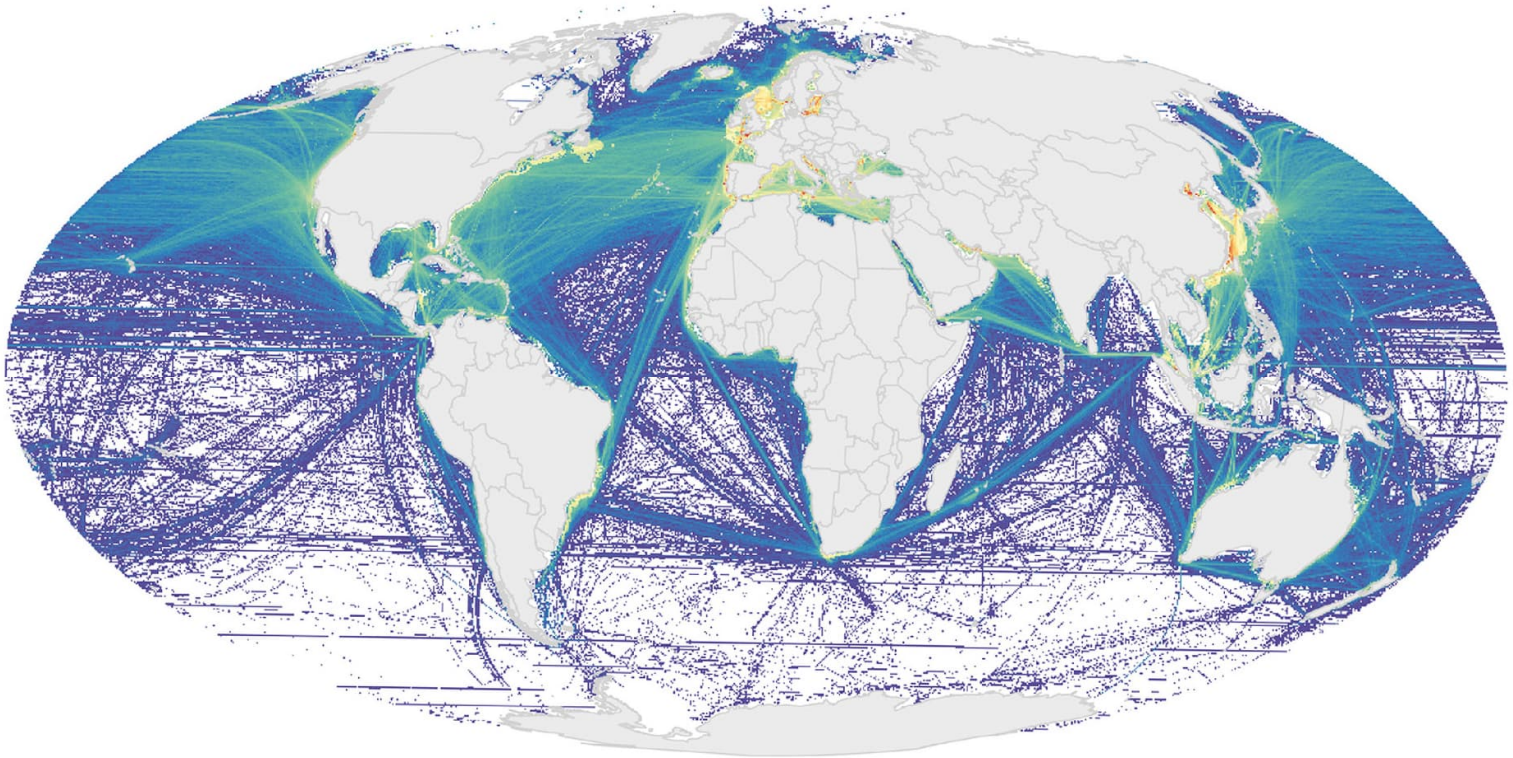


Main engine / Diesel generator

1. TCM-S handheld indicator device
2. Continuous evaluation option, 3rd party edge data collection

Global Challenges

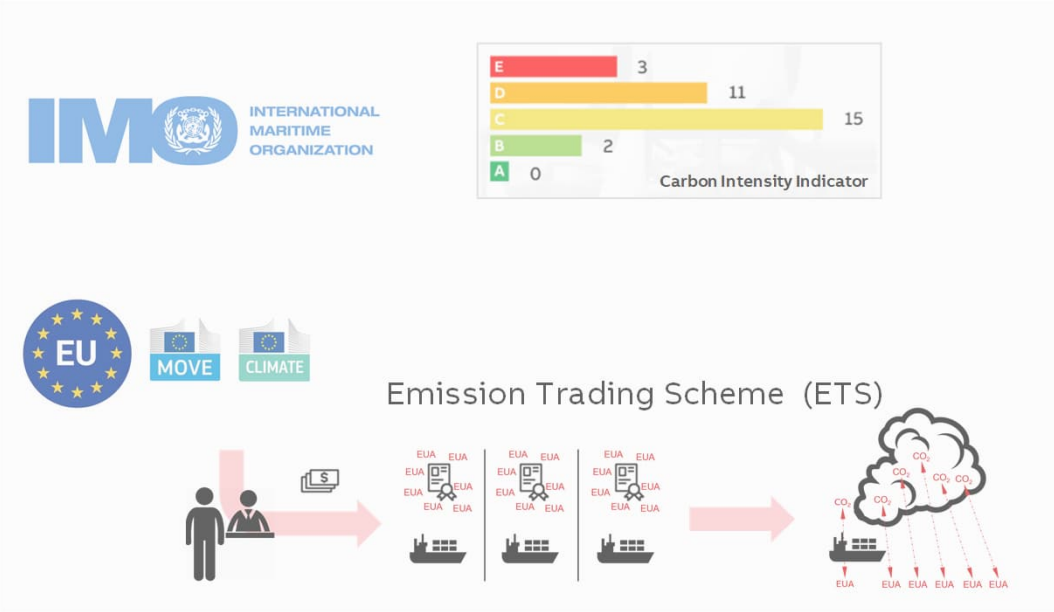
… calling for more than engine optimization alone …



Global Challenges

… calling for more than engine optimization alone …

Authorities



Green Fonds

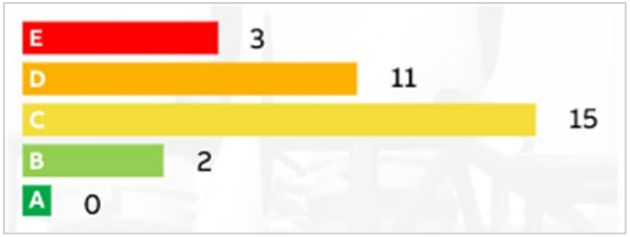
Photos: Nike Purpose

Stakeholders

Global Challenges

… calling for global answers

If you had the option:
Which vessel from which company would you prefer / order / charter?



Global Challenges

Example: Emissions by IMO and the CII

Operational factors

(semi-) static factor

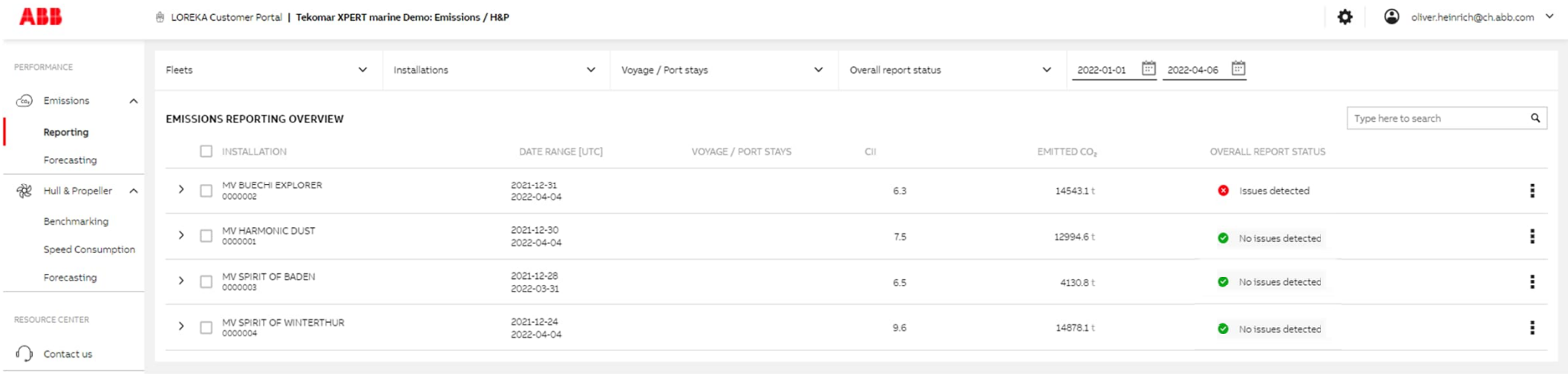
$$\text{CII} = \frac{\text{Fuel oil consumption} \times CO_2\ \text{factor}}{\text{Capacity} \times \text{Nautical miles}} \times \text{Corr.}$$

static factor

(semi-) static factor

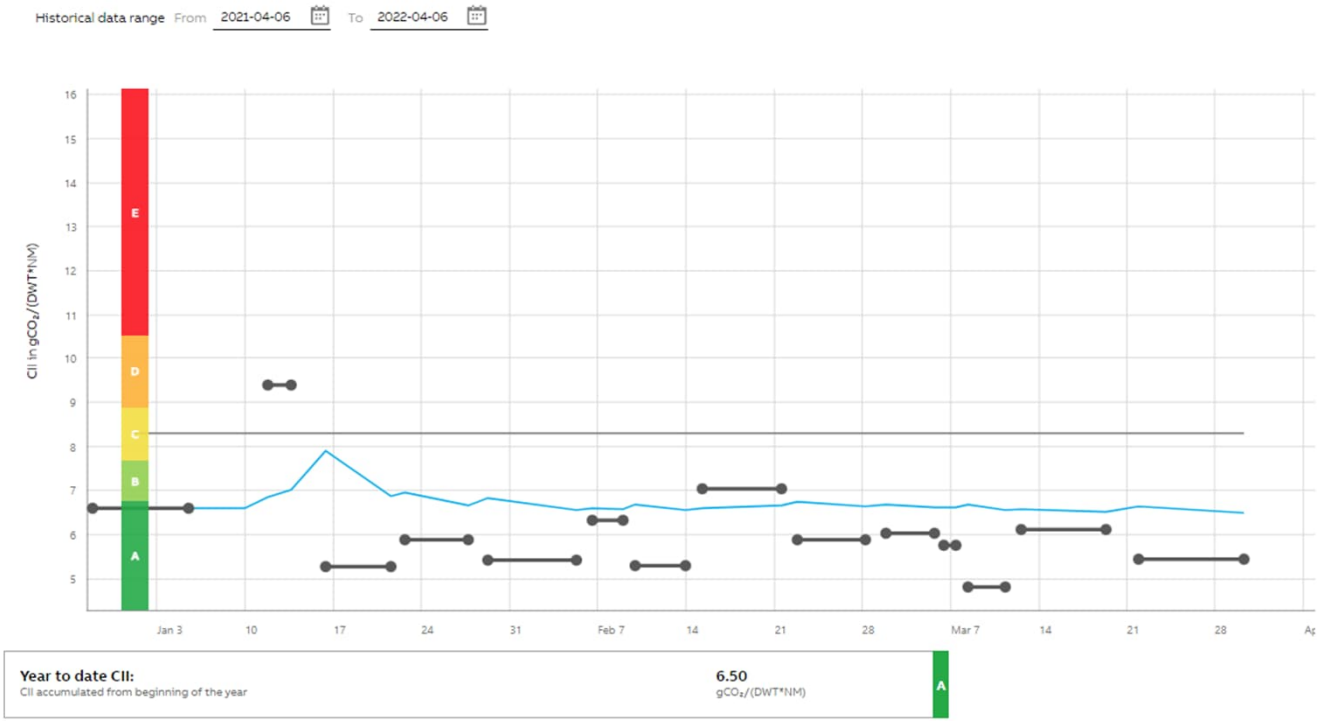
Emissions

Step 1: Transparancy



Emissions

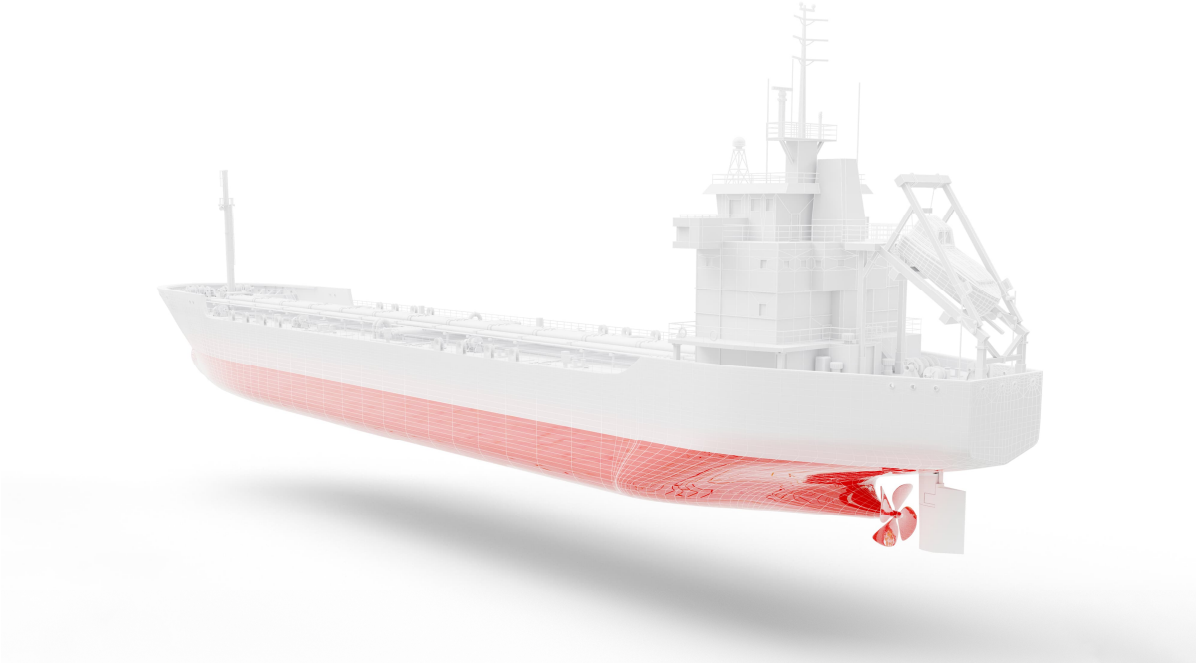
Step 2: Transparency, analytics and status quo



Emissions together with Hull & Propeller

Knowing the condition of your hull & propeller can be a game changer

- Hull & propeller fouling can significantly increase fuel consumption and Emissions
- Cleaning of hull & propeller helps to reduce potential overconsumption and improves the CII rating
- Having transparency on ship operations, benchmarked against charter party reference helps to avoid charterer party disputes
- Identifying the correct timing of cleaning maximizes the return on investment



Hull and Propeller

Solution approach

Dashboard

- KPIs related to Hull & Propeller overconsumption
- Comparison to charter party and technical reference
- Benchmarking on Company, Fleet and Vessel level

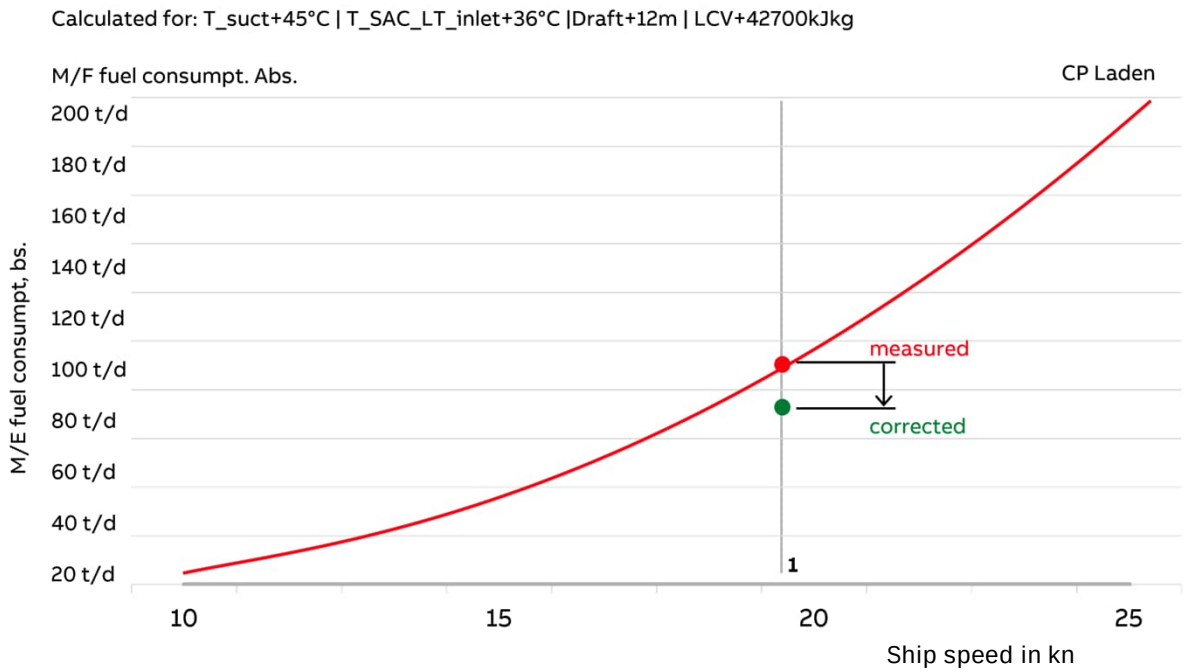
Analytics

- Speed consumption corrected to respective reference
- Indication of applied corrections
- Hull ageing trends

Hull and Propeller

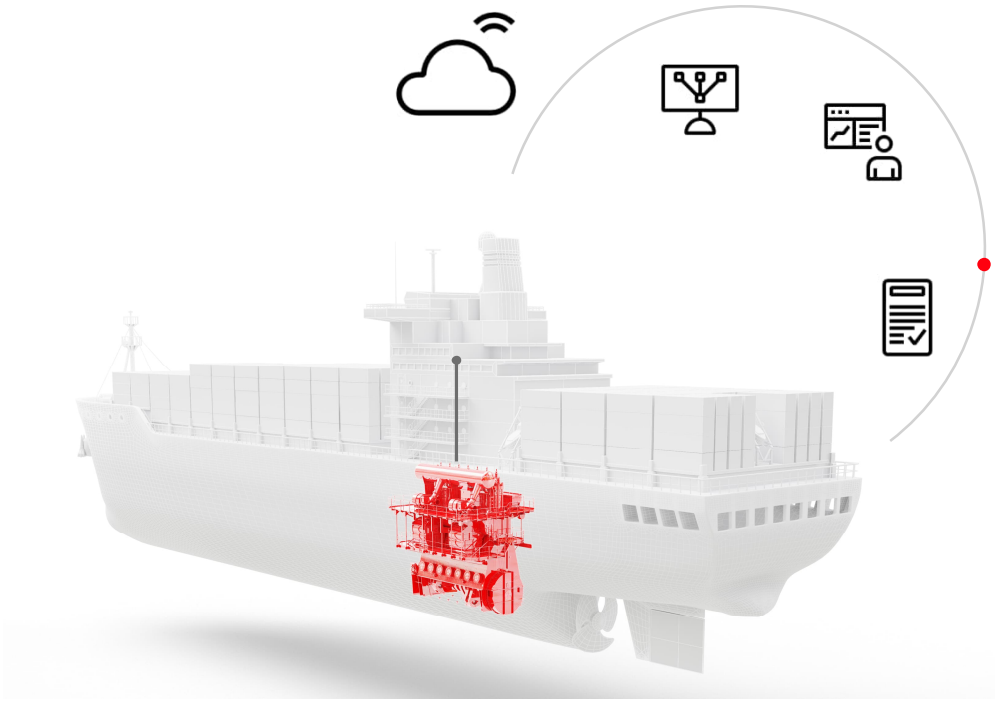
Continuous and logged data – corrected on the fly

- Every single measurement e.g., 15 min average is evaluated
- Elimination of external influencing factors according to ITTC rules
- Correction to respective reference condition (e.g., contractually agreed draft)



Digitalization in the Marine Industry

Key to tackle ever increasing, global challenges



Digitalization

Ever-increasing challenges in shipping:
- ⇨ professionally incorporating Digitalization is key

Data does already exist
- ⇨ yet not in the right place or combination

Data collection and transfer: Own profession
- ⇨ ABB Turbocharging with co-operations

The Combined Power

Capturing customer needs: Joint developments
- ⇨ Known ship management company

All screenshots taken from our new product,
- ⇨ However it is the journey that lead to it


Q
&
A

ABB

WÄRTSILÄ TWO-STROKE FUTURE FUELS CONVERSION

REDUCE EMISSIONS AND FUTUREPROOF YOUR FLEET

ISF-Tagung
Maritimes Zentrum – Hochschule Flensburg
20 May 2022

MARKET LANDSCAPE

In addition to complying with increasingly stringent environmental regulations while navigating the uncertainties on availability, quality and price of future fuels and the risk of stranded assets, shipping companies must also secure access to green financing and maintain a favourable public image.

A VIABLE UPGRADE PATH

Infrastructure and availability of green fuels need time to mature –
Wärtsilä multi-fuel technology offers a viable upgrade path

Multi-fuel engine

TRANSITION FUELS ▶ DROP IN ▶ FUEL BLENDS ▶ NET-ZERO CARBON FUELS

2021	2023	CO_2	2030	2050
	EEXI	CII	-40% carbon intensity	-70% CI & -50% total GHG

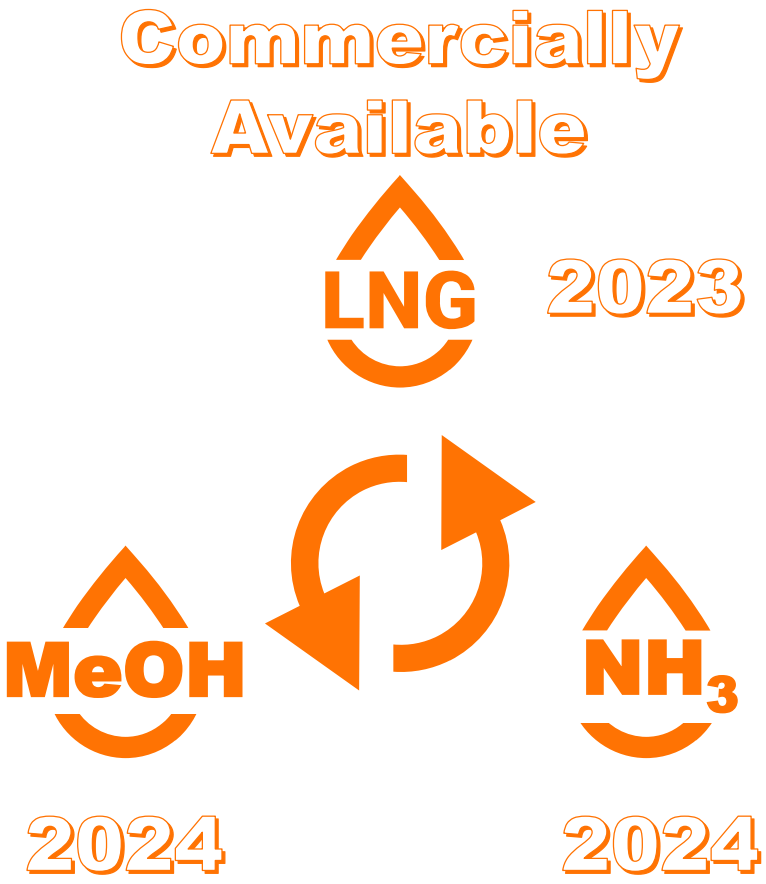
Challenges with fuel conversion solutions

- **Long-term value of the investment**
- **High investment costs**
- **Long off-hire time for conversion**
- **High electrical & heat demand**
- **Lack of free space**

- **Fuel-flexible technology**
- **Retrofit-optimised costs**
- **Streamlined retrofit process**
- **Use of existing energy sources**
- **Low-complexity supply system**

How we address these challenges

INTRODUCING THE WÄRTSILÄ TWO-STROKE FUTURE FUELS CONVERSION PLATFORM



- A retrofit-optimised solution to convert marine electronically controlled two-stroke engines to run on future fuels
- Features a flexible fuel injection and combustion concept that adapts to fuel type and quality eliminating fuel slip
- Fuel preparation takes place on the engine using existing energy sources
- Requires a low-complexity fuel supply system, with low energy demand, minimising CAPEX and OPEX
- The streamlined retrofit process makes the engine fuel conversion possible within three weeks
- Modular design offers true fuel flexibility by switching to different fuels with modest investment and retrofit efforts

HOW IT WORKS FOR LNG

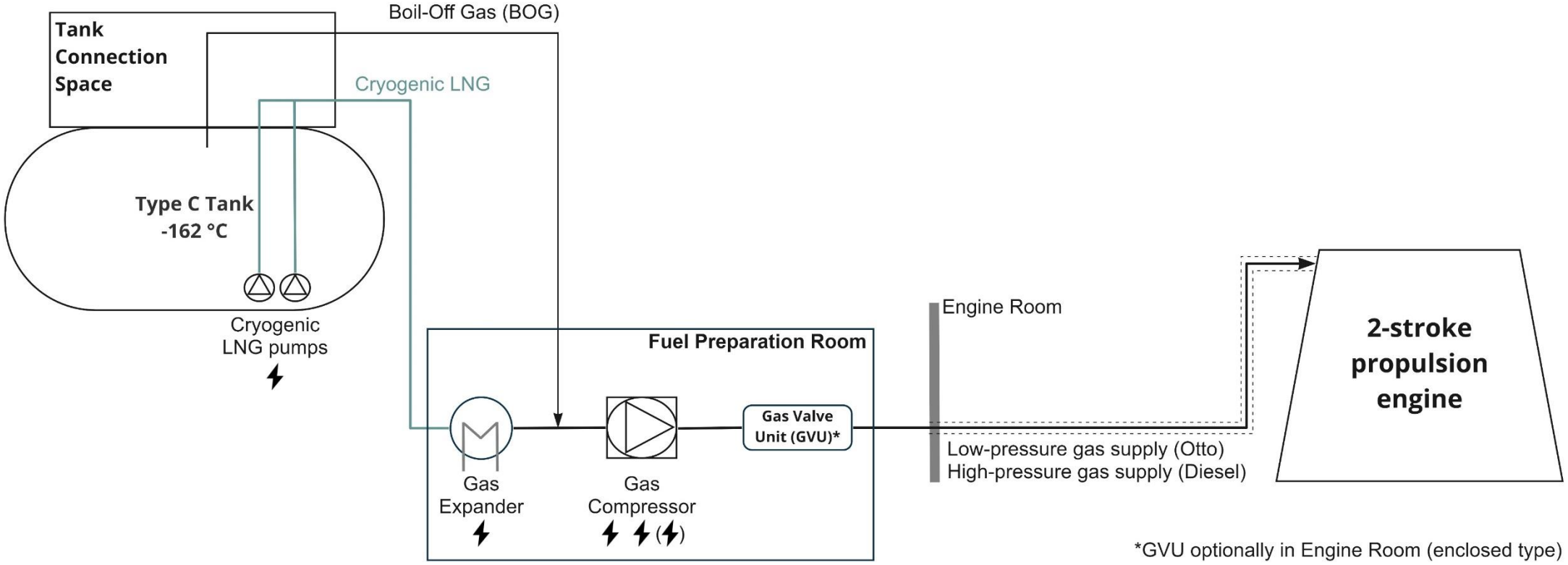
An industry-first solution in which:

- Cryogenic LNG is supplied directly to the engine at low pressure
- Fuel pressure amplification and gas expansion take place on the engine using existing energy sources
- The expanded gas is injected into the cylinder at medium pressure

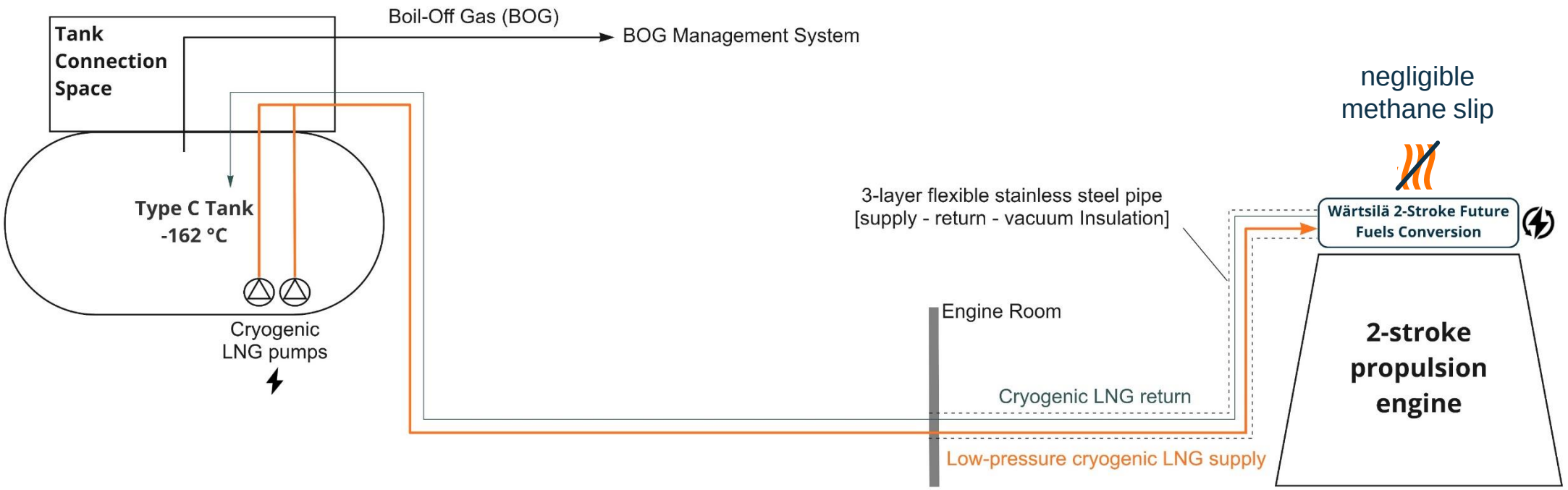
What does it mean for the vessel installation?

- Supplying cryogenic LNG directly to the engine at low pressure:
  a. eliminates the need for expensive, energy-demanding and high-maintenance equipment in the fuel gas supply system and
  b. means a minimal footprint for the fuel supply system, maximising retrofit installation flexibility
- On-engine pressure amplification and gas expansion using existing energy sources means lower energy costs and associated emissions

CONVENTIONAL TWO-STROKE LNG INSTALLATION

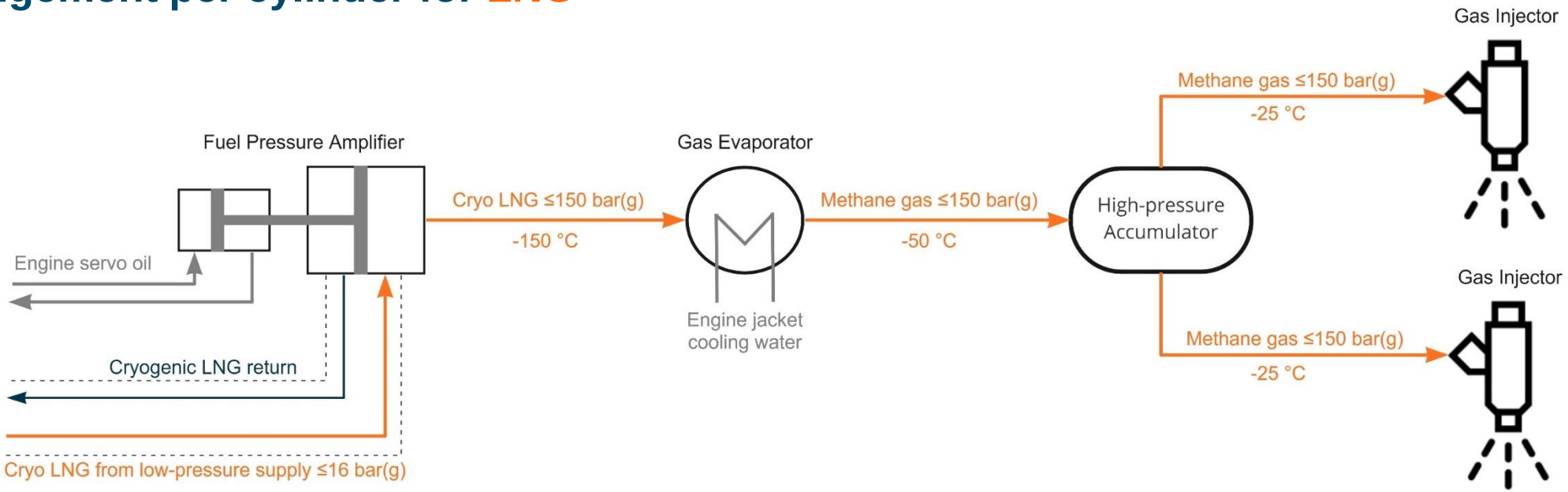


WÄRTSILÄ TWO-STROKE LNG CONVERSION



SIMPLIFIED DIAGRAM ON-ENGINE FUEL SYSTEM

Arrangement per cylinder for LNG



HOW IT WORKS FOR METHANOL

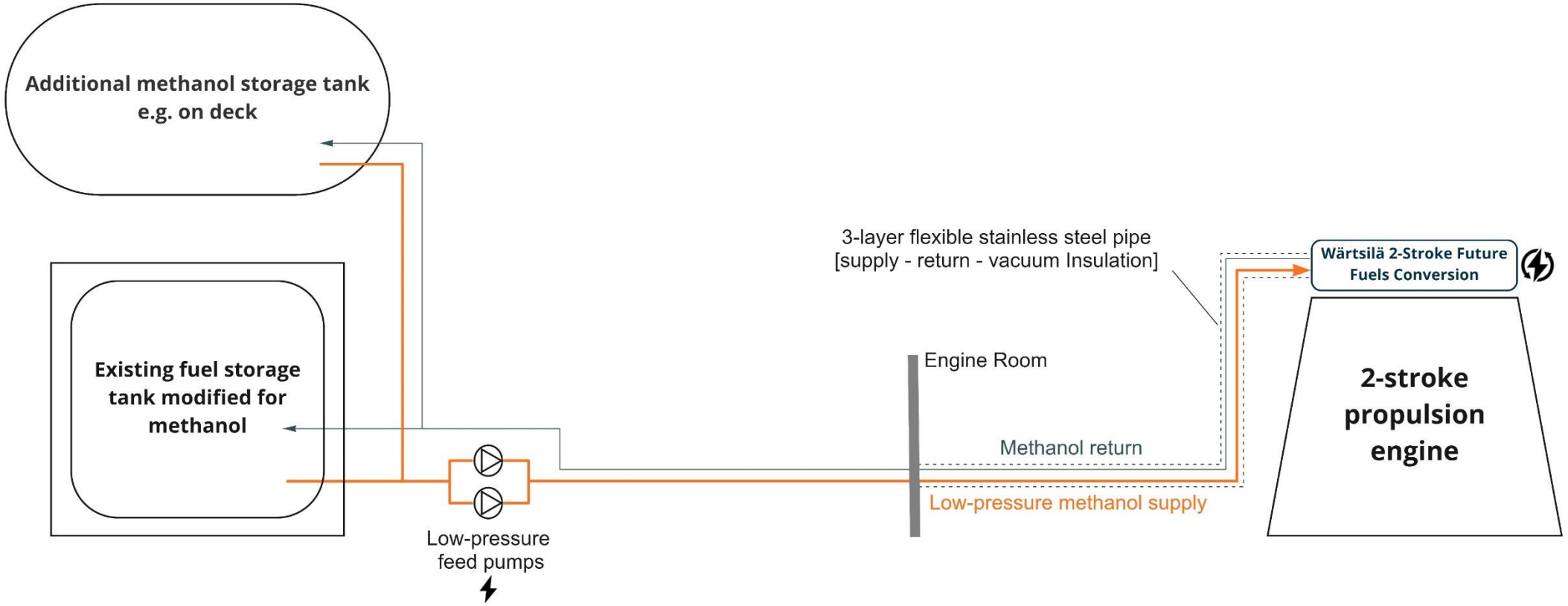
A retrofit-optimised solution in which:

- Methanol is supplied directly to the engine at low pressure
- Fuel pressure amplification takes place on the engine using existing energy from the servo oil system
- Methanol is injected into the cylinder at medium pressure

What does it mean for the vessel installation?

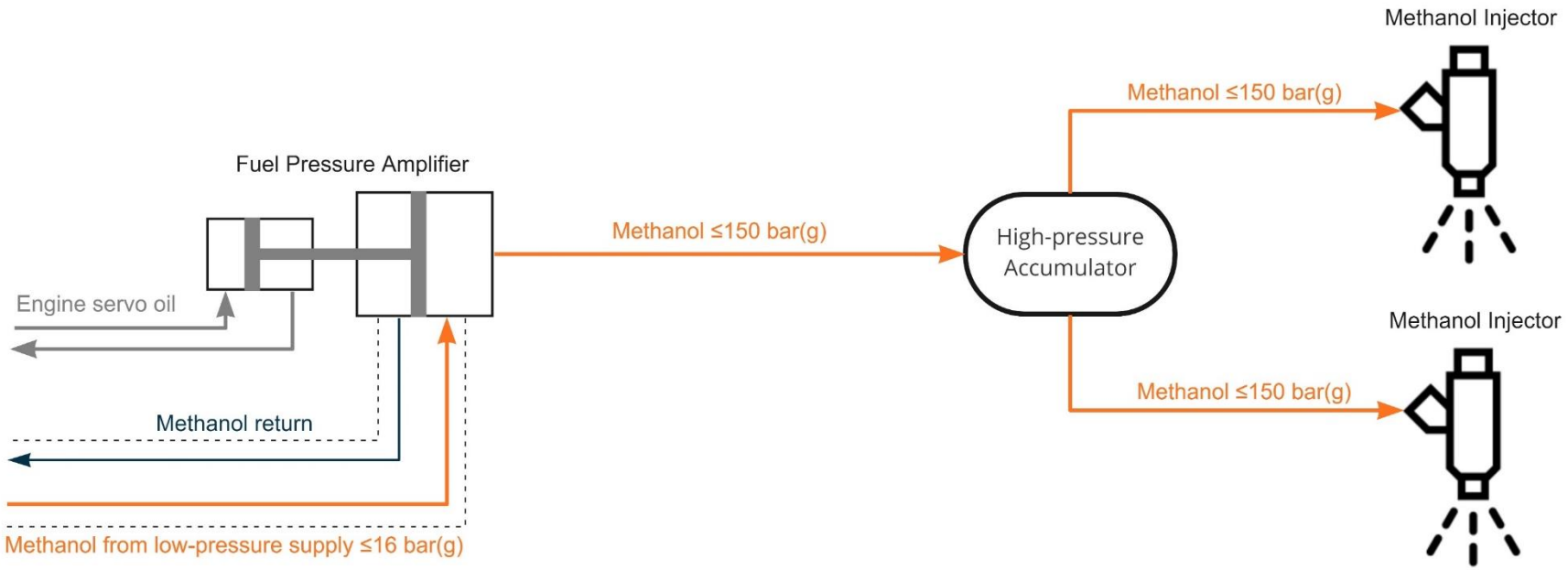
- Supplying methanol directly to the engine at low pressure:
  a. eliminates the need for costly and energy-demanding high-pressure equipment in the fuel supply system and
  b. means a minimal footprint for the fuel supply system, maximising retrofit installation flexibility
- On-engine pressure amplification using an existing energy source means lower energy costs and associated emissions

WÄRTSILÄ TWO-STROKE METHANOL CONVERSION



SIMPLIFIED DIAGRAM ON-ENGINE FUEL SYSTEM

Arrangement per cylinder for methanol



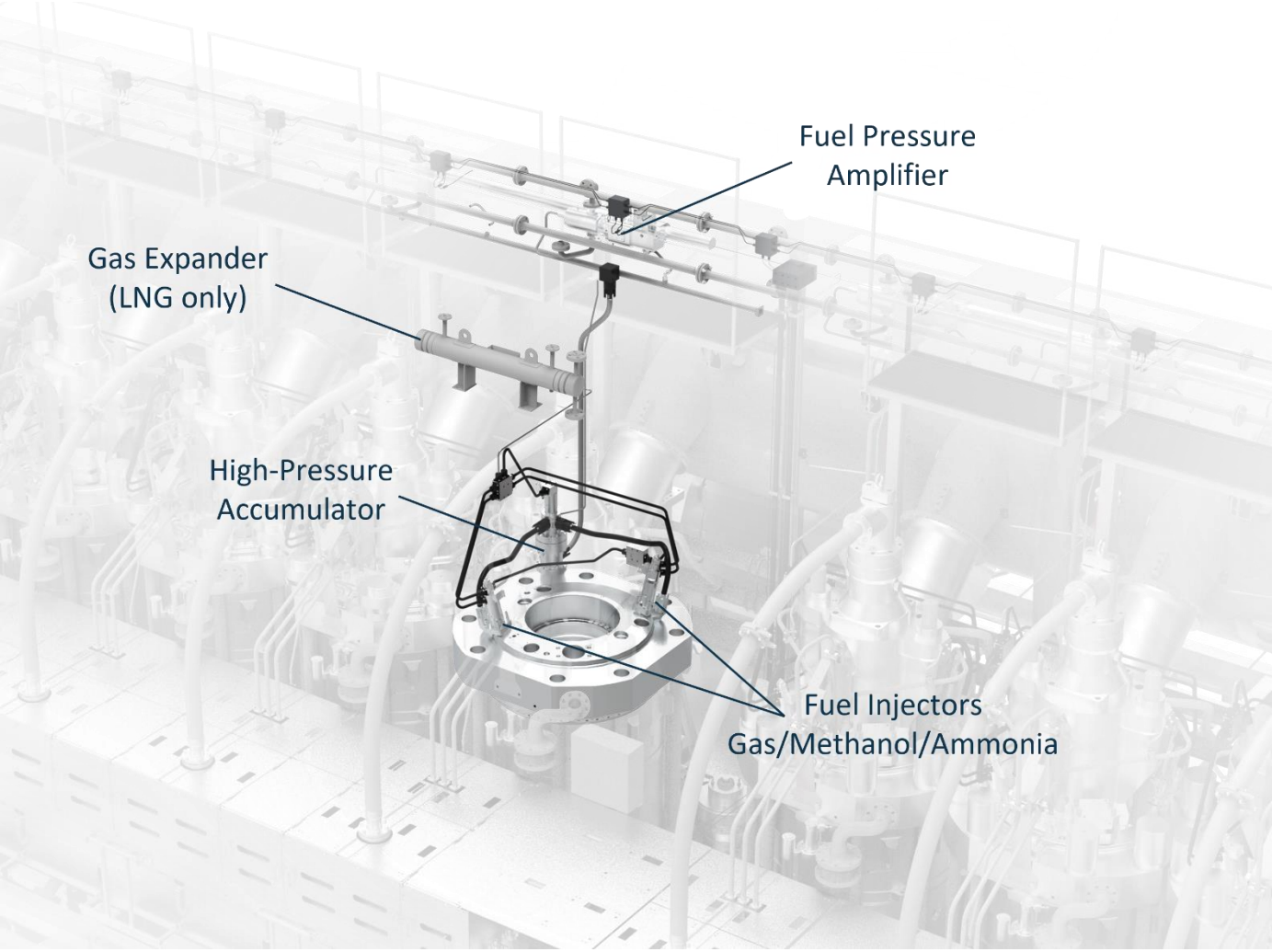
TWO-STROKE ENGINE FUEL CONVERSION SCOPE

Per cylinder

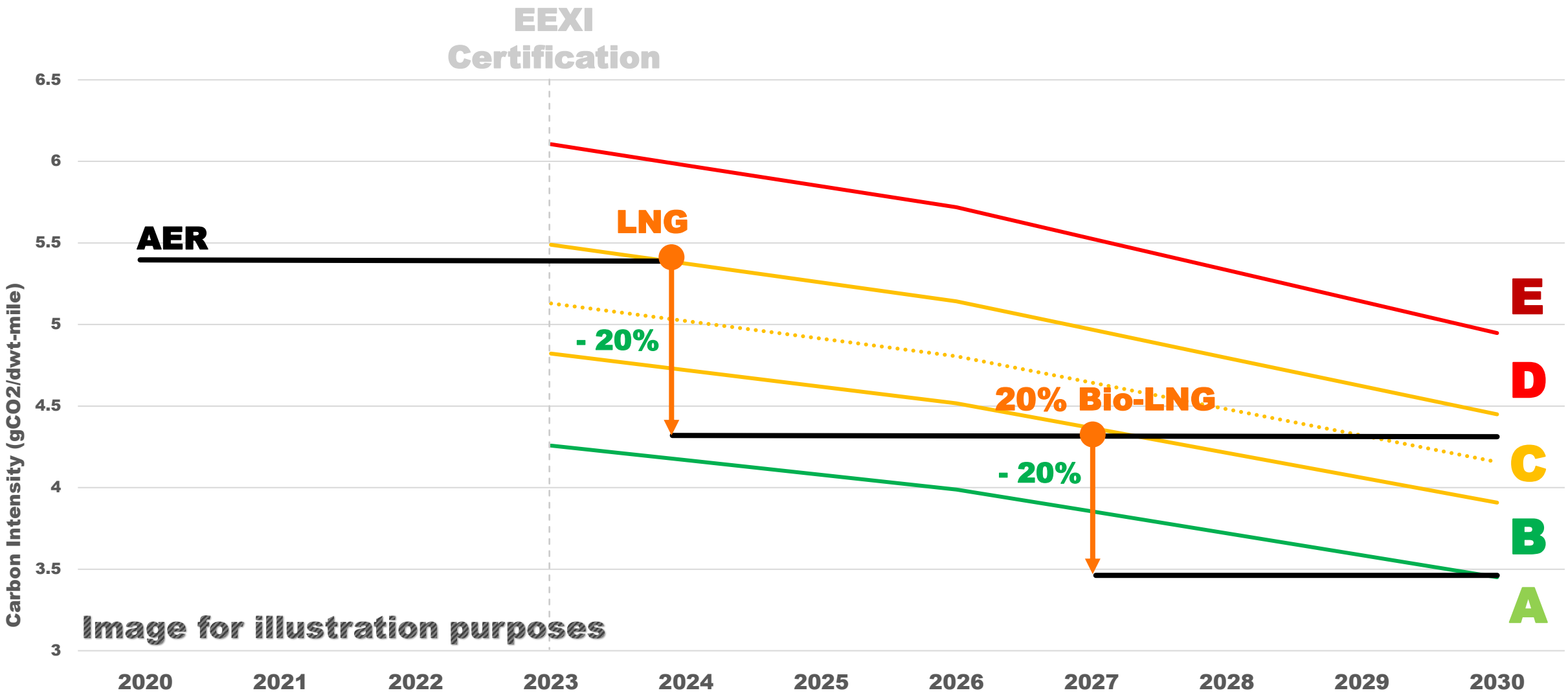
- Cylinder cover with fuel/gas injectors
- High-pressure accumulator
- Gas expander (LNG only)
- Fuel pressure amplifier

Per engine

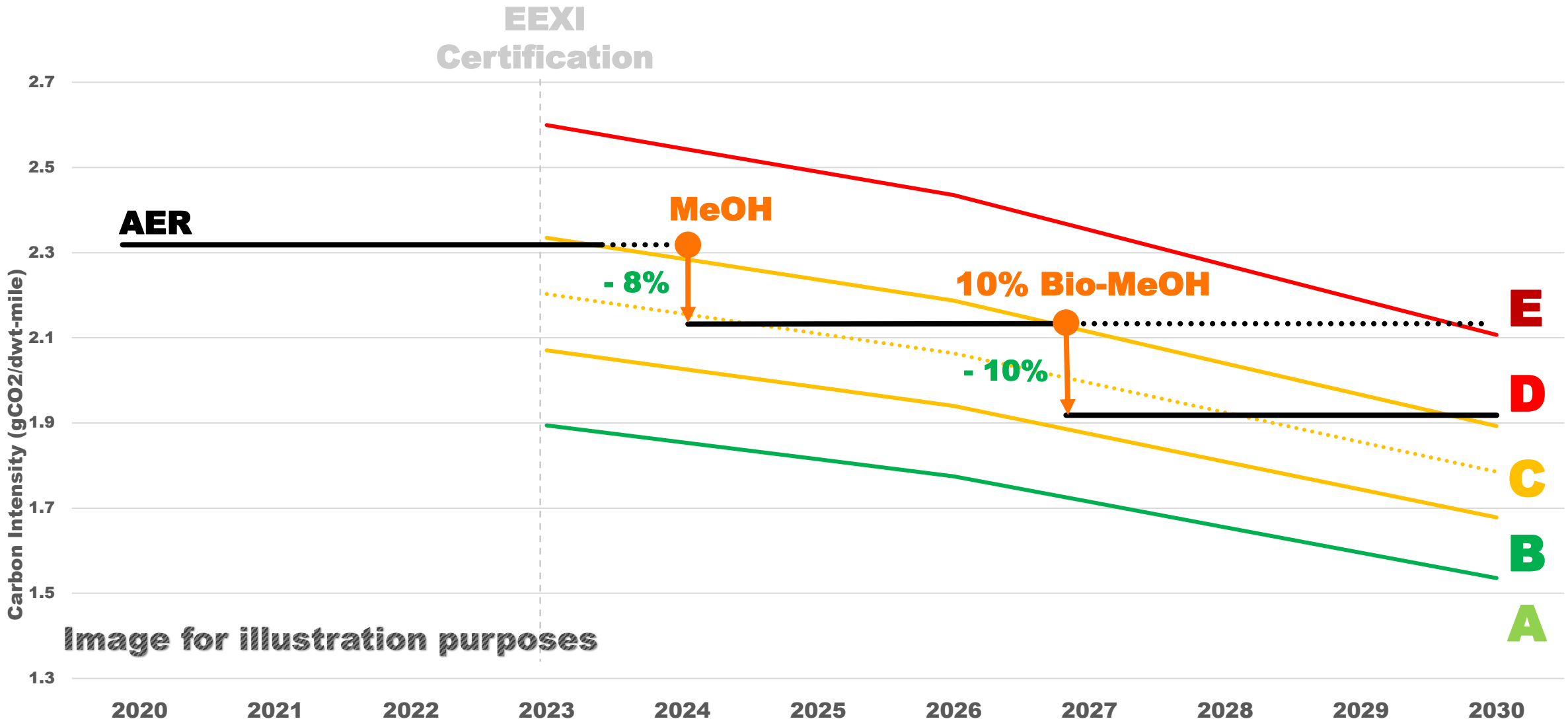
- Rail enclosure with ventilation system
- Engine control system upgrade
- Instrumentation, sensors, cabinets & cables
- Safety & monitoring system extension
- Turbocharger rematching (optional)
- On-engine piping
- On-engine platform modifications
- Safety spare parts



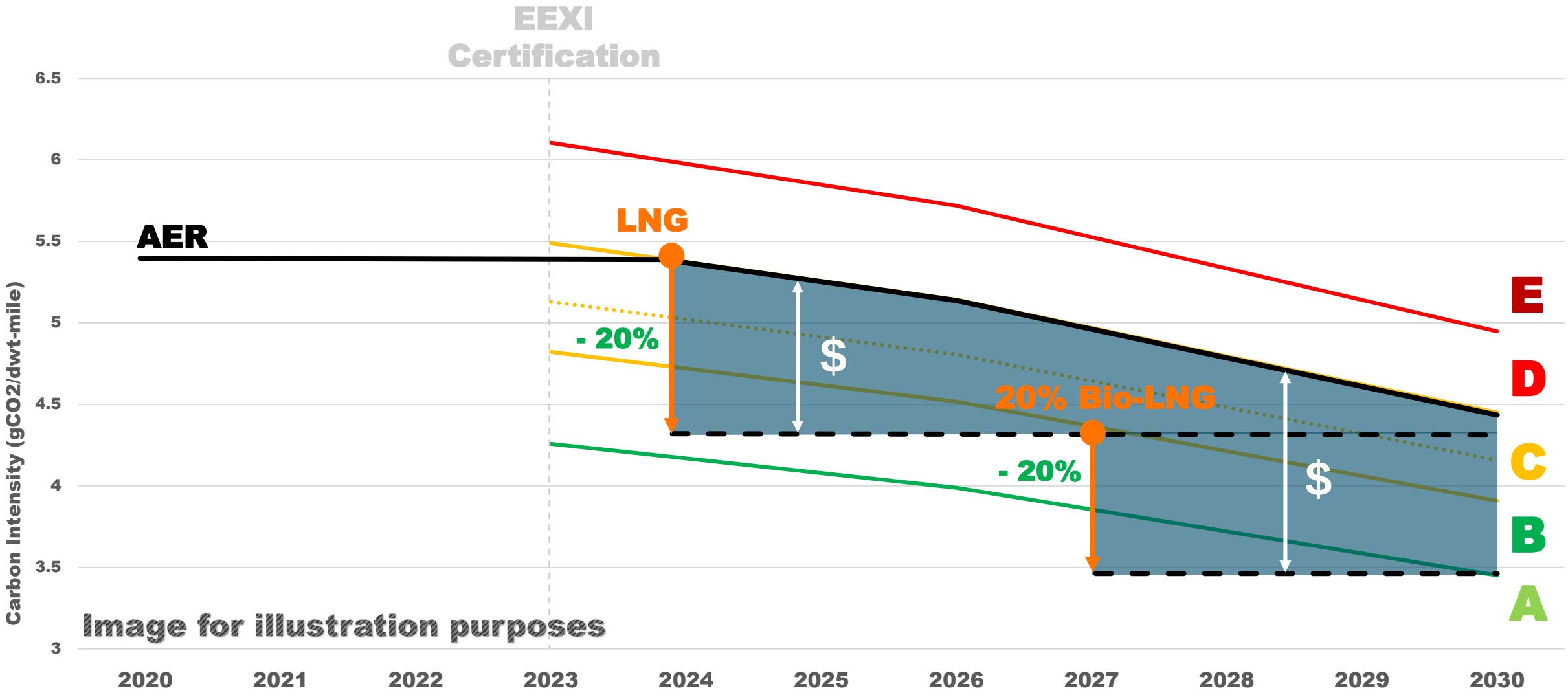
FUTUREPROOFING A 15K TEU CONTAINERSHIP



FUTUREPROOFING A 210K DWT NEWCASTLEMAX BULK CARRIER



FUTUREPROOFING A 15K TEU CONTAINERSHIP EDGE-WALKING “COMPLIANCE”



WÄRTSILÄ FUTURE FUELS CONVERSION OFFERING FOR MERCHANT VESSELS

Fuel Gas Supply System

2-stroke main engine conversion

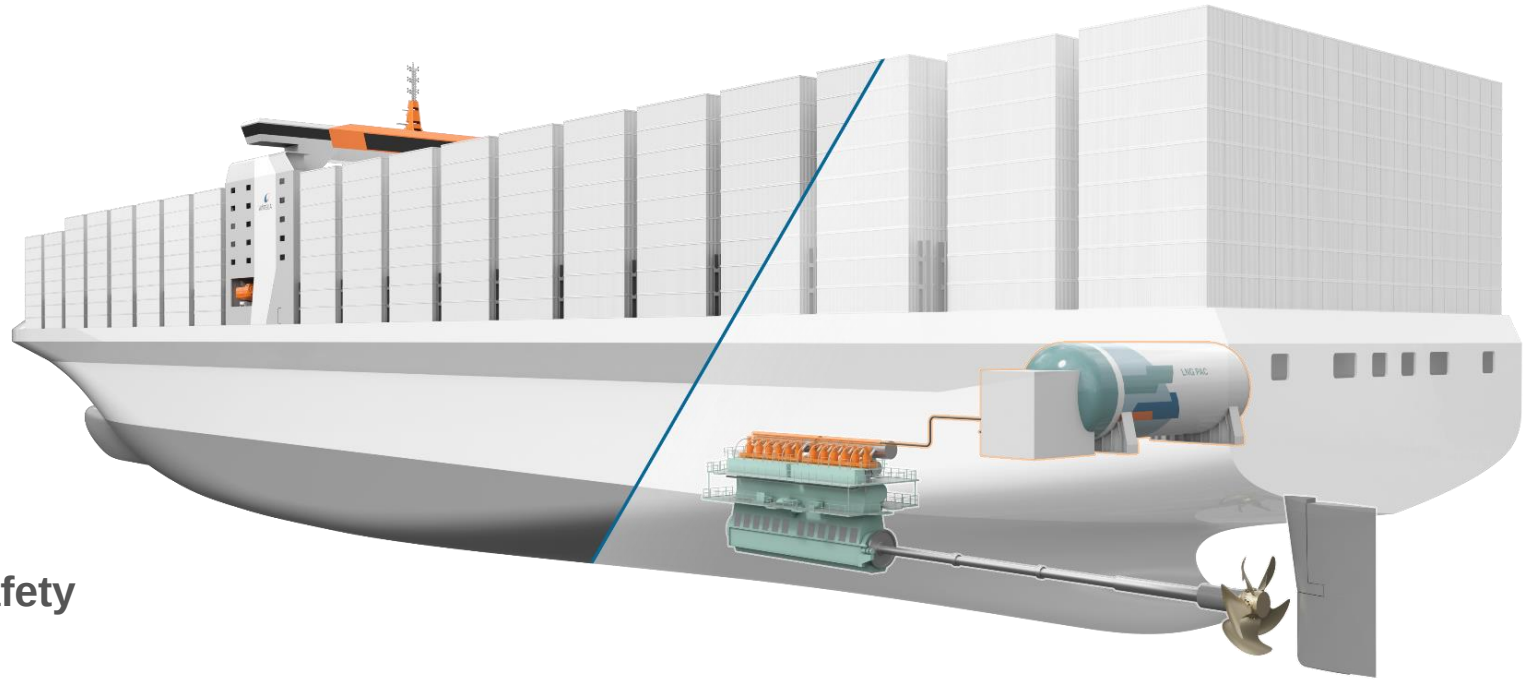
4-stroke DF/multi-fuel auxiliary engines

BOG management system

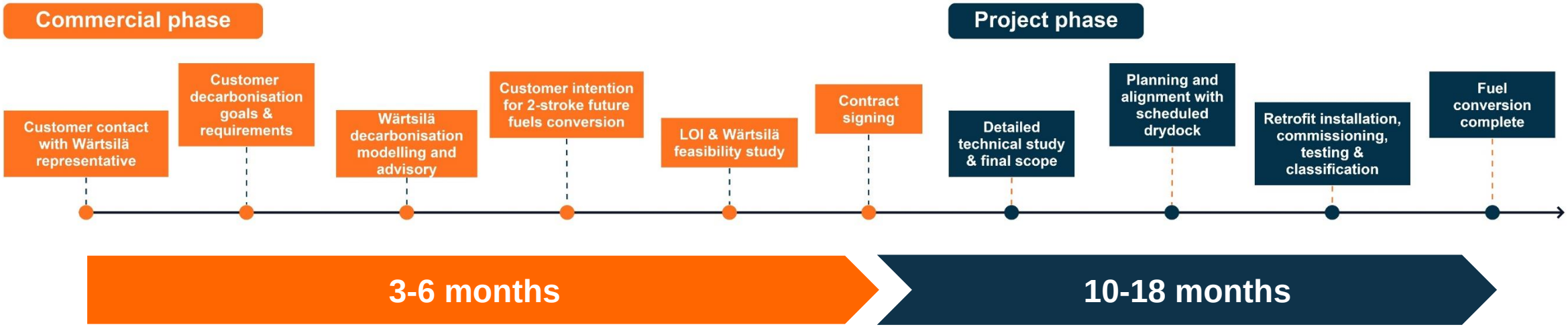
System integration incl. automation & safety

Conversion implementation & vessel integration

Digitally-enabled lifecycle solutions



A TYPICAL CUSTOMER JOURNEY



KEY BENEFITS

- Reduced GHG emissions with negligible fuel slip and overall low energy consumption
- Long-term CII compliance and enhanced operational flexibility
- Straightforward retrofitting concept minimising off-hire
- Fuel flexibility futureproofing your investment
- Access to sustainable financing and shorter pay-back time

WÄRTSILÄ

Alternative Antriebssysteme für mobile Arbeitsmaschinen in der Hafenlogistik

Alternative drive systems for mobile machinery in port logistics

43. Informationstagung zur
Schiffsbetriebsforschung (ISF-Tagung)

Dr. Georg Töpfer
DEUTZ AG, Cologne

Alternative drive systems for mobile machinery in port logistics

Proportion of Revenue and Future Challenges

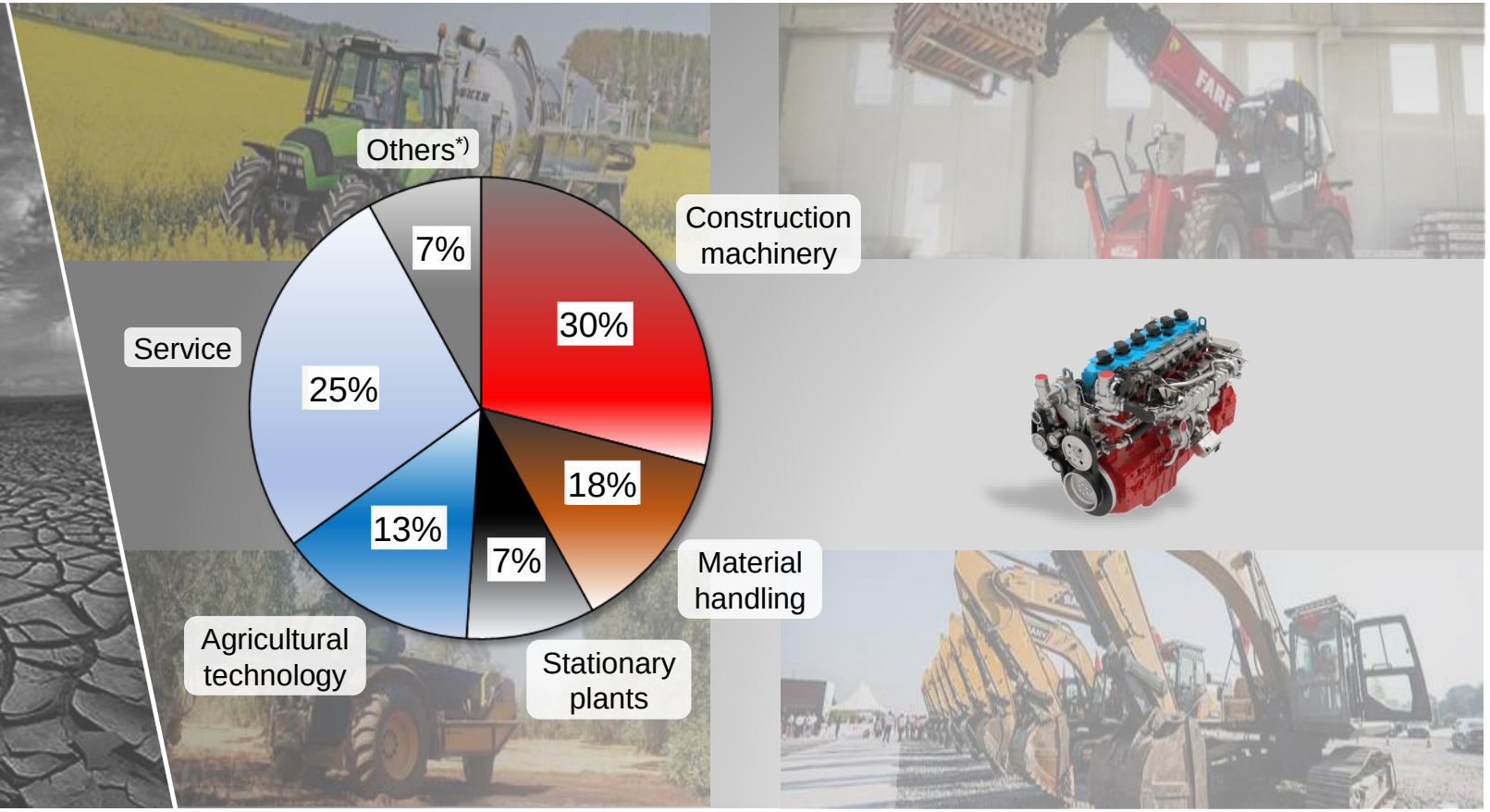
Source: DEUTZ AG Digital Annual Report 2021

Emissions reduction

Noise cancellation

Optimization of drive solutions

Sustainability & 'well-to-wheel' view

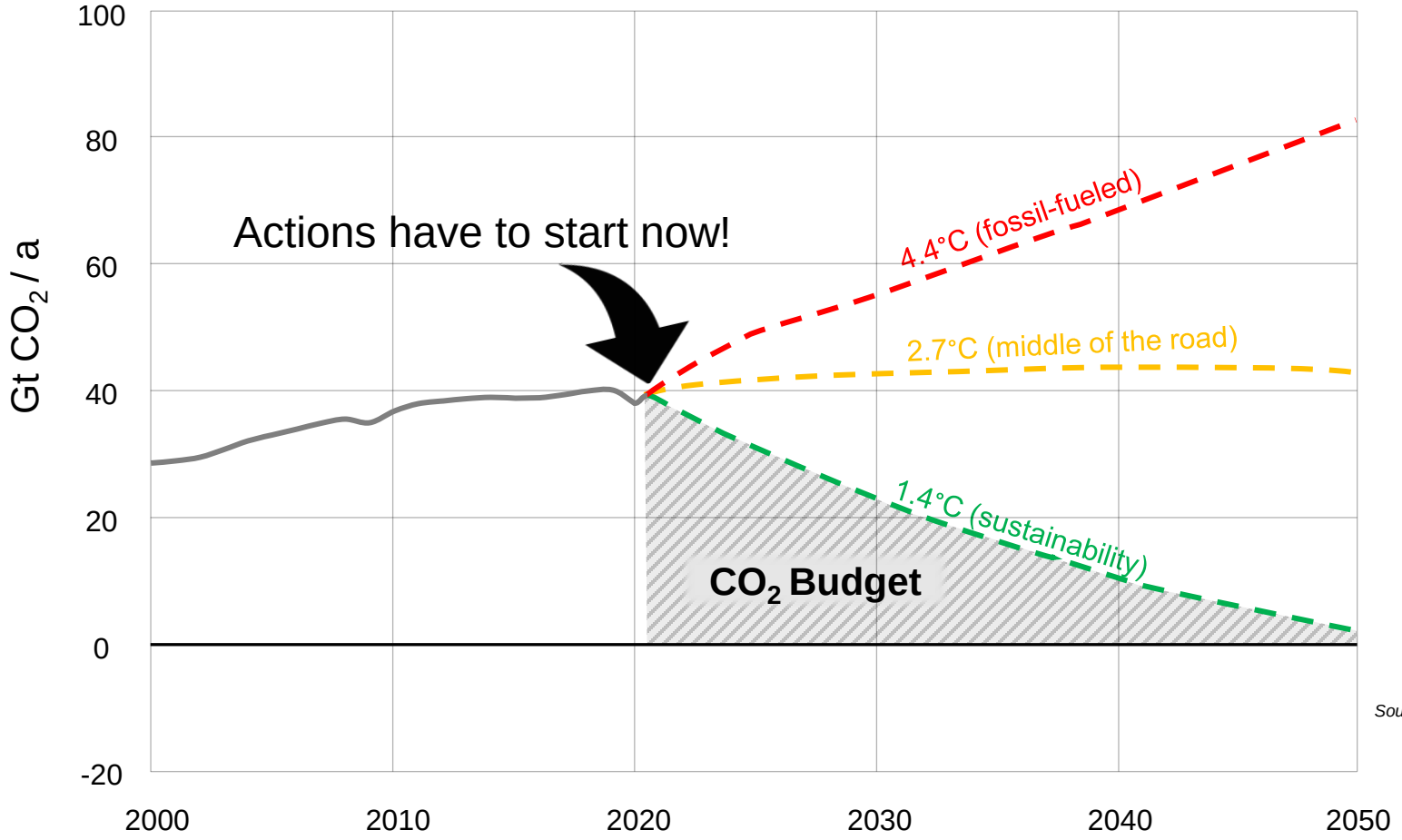


**) Torqeedo and Futavis*

Need for sustainable drive systems, including in off-highway applications.

Alternative drive systems for mobile machinery in port logistics

Global Warming: a carbon dioxide problem



Sources: IPCC, Climate Change (2021) – The Physical Science Basis; Global Carbon Project (2021) – Supplemental data of Global Carbon Budget

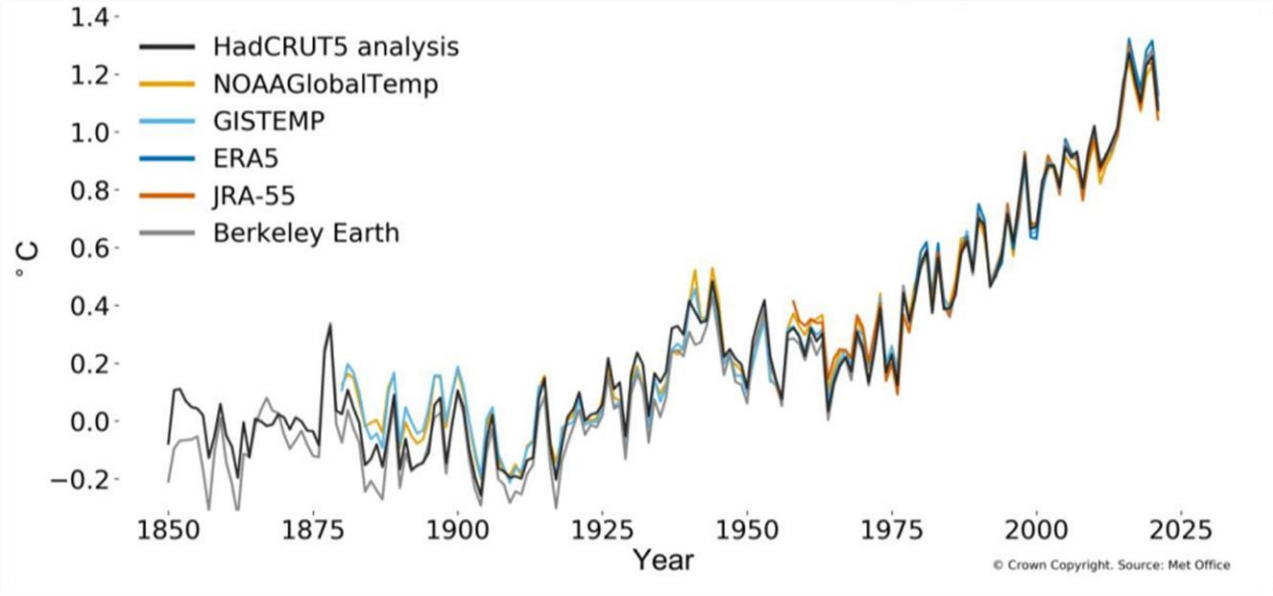
The *2015 Paris Agreement* demands immediate global action: Our CO_2 budget is limited!

Alternative drive systems for mobile machinery in port logistics

Y2022 Global annual climate report from World Meterological Organisation

Prediction of global near-surface temperature from Y2022 to Y2026 in comparison to preindustrial temperature levels (average Y1850 to Y1900):

- Will be +1.1°C to +1.7°C higher
- Risk to exceed +1.5°C **in one year** = 48%
- Risk to exceed +1.5°C **in five-year mean** = 48%
- Risk to have warmest year on record (2016) = 93%.



Global annual mean temperature difference from preindustrial conditions (1850–1900) for six global temperature data sets. For details of the datasets and processing see Data sets and methods

Source: State of Global Climate 2021 WMO Provisional Report

Source: WORLD METEOROLOGICAL ORGANIZATION Global Annual to Decadal Climate Update Target years: 2022 and 2022-2026

Report of World Meterological Organisation reveals further need of activities

Alternative drive systems for mobile machinery in port logistics

CO_2 saving potential by example of a port of transshipment

Inland vessel (242 kW)

- CO_2 / day: 1.96 to.
- CO_2 / year: **489 to.**

Telescopic loader (110 kW)

- CO_2 / day: 0.18 to.
- CO_2 / year: **43.8 to.**

Mobile container crane (140 kW)

- CO_2 / day: 0.3 to.
- CO_2 / year: **75 to.**

Handling excavator (200 kW)

- CO_2 / day: 0.33 to.
- CO_2 / year: **82.7 to.**

2.77 to. CO_2 per day

690 to. CO_2 per year*)

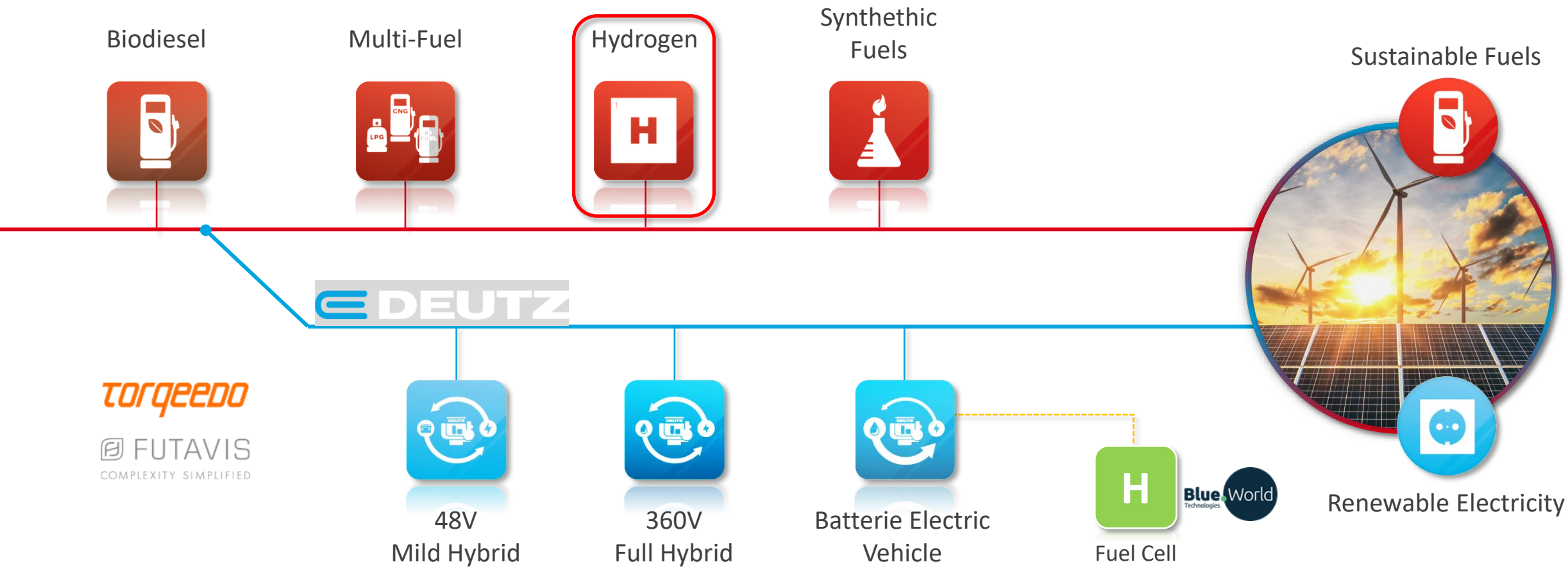
*) 250 working days per year

Defossilization of mobile machinery will significantly contribute to climate protection

Sources:
- *Tremod-MM Studie / Bundesumweltamt,* Bundesministerium für Verkehr und digitale Infrastruktur, Verkehr in Zahlen 2020/20
- DX230WMH-5 | Doosan Infracore Europe (doosanequipment.com)
- Bing
- Agrarprodukte | Hafen, Logistik, Ostsee | Seehafen Wismar (hafen-wismar.de)
- Teleskoplader TH627 wendig und effektiv | Wacker Neuson
- Grúa Que Levanta Encima Del Envase Foto de archivo - Imagen de nadie, coche: 26390404 (dreamstime.com)
- binnenschiff - Bing images

Alternative drive systems for mobile machinery in port logistics

Our Approach: a diversified Engine Portfolio



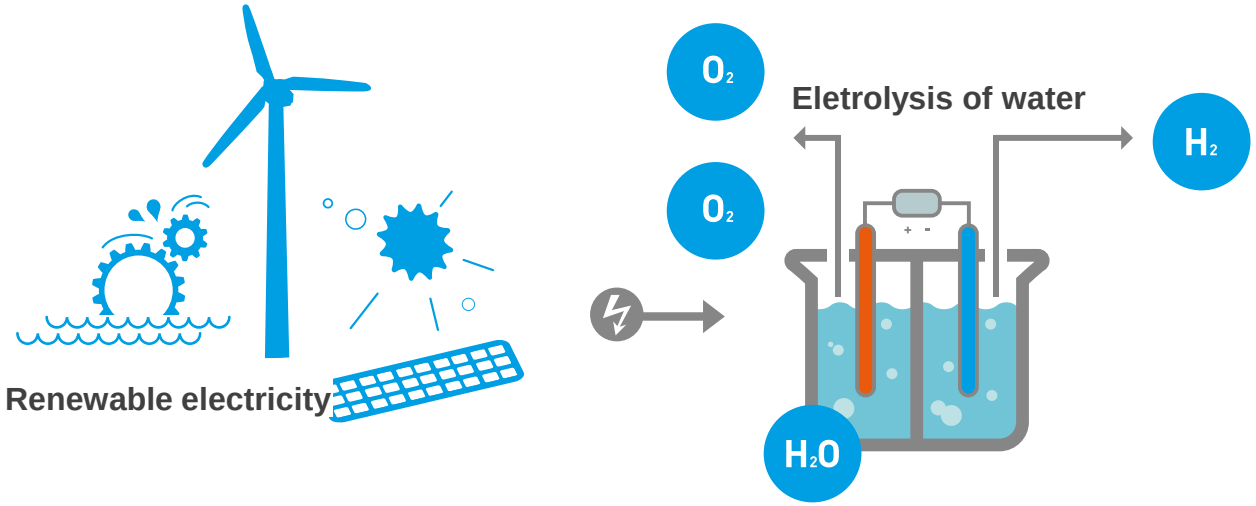
DEUTZ faces the challenges in off-highway sector and is open to all technologies

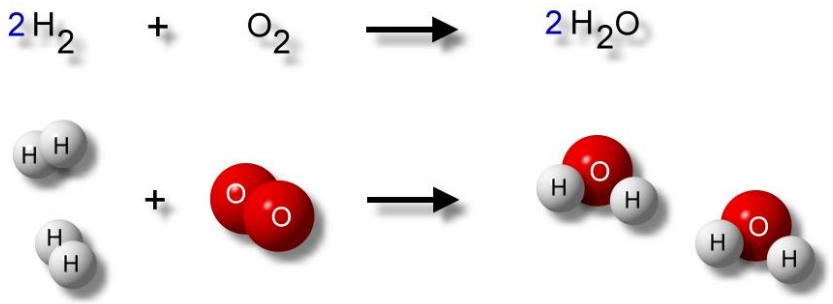
Alternative drive systems for mobile machinery in port logistics

Some facts to Hydrogen

Hydrogen is...

- ...the essential component of the CO_2-free energy economy of the future and the main topic of current climate policy.
- ...very suitable as energy for fuelcells and combustion engines
- Hydrogen can be produced in various ways (grey, blue, turquoise, pink, green)
- Enables technically simple storage of regeneratively generated electricity by means of electrolysis and reconversion.





Combustion of hydrogen

Source: https://www.swe.de/de/News-room/Blog/Klimaschutz-Trinkwasser/Klimaschutz-Trinkwasser1/Energieversorgung-der-Zukunft-Teil-1-Was-ist-Wasserstoff-wie-funktioniert-die-Elektrolyse-und-wo-wird-Wasserstoff-eingesetzt.html
Perbezaan Antara Persamaan Molekul Dan Persamaan Ionik | Kimia Am 2022 (differencevs.com)

Alternative drive systems for mobile machinery in port logistics

Caloric characteristics of Hydrogen and effects to Hydrogen Internal Combustion engine (HICE)

Substance Property	Unit	Methane	Hydrogen	
Mixture heating value [a, b, c] (mixed suction)	MJ/m³	3,40	**3,19**	PFI: Replaces big volume, compensation with high boost pressure necessary
Mixture heating value [a, b, c] (air-aspirating)	MJ/m³	3,76	**4,54**	DI: Potential of high power density
Ignition limit [a, d, e]	λ-Bereich Vol-%	0,6 – 2,0 5,3 - 15	**0,13 – 10** **4,0 - 76**	Ignitable at very lean mixture (lean burn combustion, safety concept)
Minimum ignition energy	mJ	0,29	**0,017**	Extremely low ignition energy (self-ignition, backfiring, knocking)
Laminar flame velocity	cm/s	≈ 42	**≈ 230**	Very high laminar flame speed (high pressure gradient w/o measures)
Ignition Temperature	°C	595	**585**	Spark-ignited (SI) combustion engine

a: At 1,013 bar *b: At 0 °C* *c: At 350 bar und 280K* *d: At =1*
d: At 25 °C *e: In Air*

Source: Der Wasserstoff-Verbrennungsmotor – ein grundlegender Konzeptvergleich, T. Wallner et. Al., HdT Tagung Gasfahrzeuge, September 2004
Eichsleder, M. Klell, Wasserstoff in der Fahrzeugtechnik, ATZ/MTZ-Fachbuch

Alternative drive systems for mobile machinery in port logistics

Comparison of fuel cell to hydrogen combustion engine (HICE)

Fuel Cell	HICE
On-place operation: The remaining waste heat energy should be compensated by the coolant system (low temperature level 80°C, high fan power)	Common engine cooling system
High purity of Hydrogen (99.999%)	Pure hydrogen (99.9%), potential to use lower purity is foreseen
Auxiliary electrical units and cooling system generate high efficiency losses at high load	High efficiency at high load
Lifetime/Ageing depends on transient operation & environmental conditions (dirt, air pollution, vibration)	Familiar robustness of an internal combustion engine

HICE

HICE

H2 tank

Exhaust	Cooling	Work
≈30%	≈30%	≈40%

Fuel Cell

Fuel cell

H2 tank

Battery

Electr. converter

Power electronics

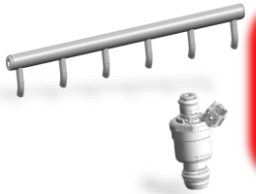
E-Motor

Exh.	Cooling	Work
≈10%	≈40%	≈50%

Alternative drive systems for mobile machinery in port logistics

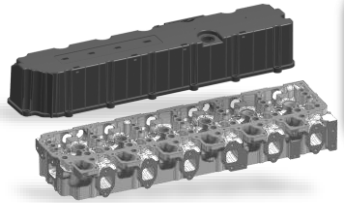
From the Diesel to Hydrogen engine

Improved gas exchange valves and seats

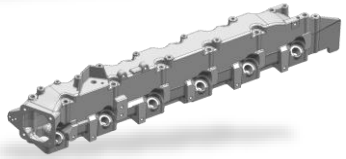


H_2-injectors (PFI)

Ignition system for lean combustion

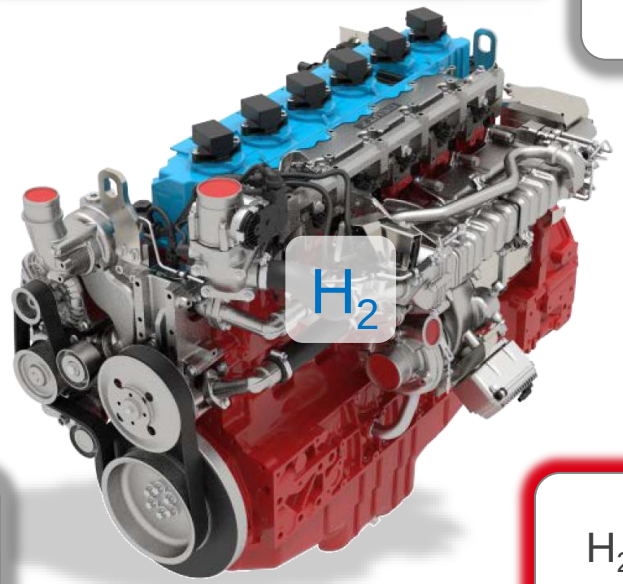


Cylinder head (integration of ignition system)



Inlet port (integration of H_2-injectors)

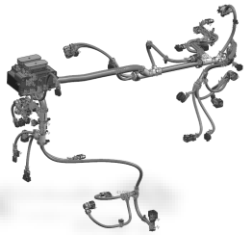
Improved piston



TCG 7.8 H2

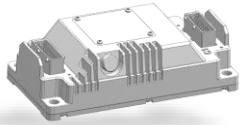
Turbocharger-matching

Exhaust-Gas-Recirculation (EGR)



Sensors and actuators

H_2-ECU and H_2-Software



SCR-system *)

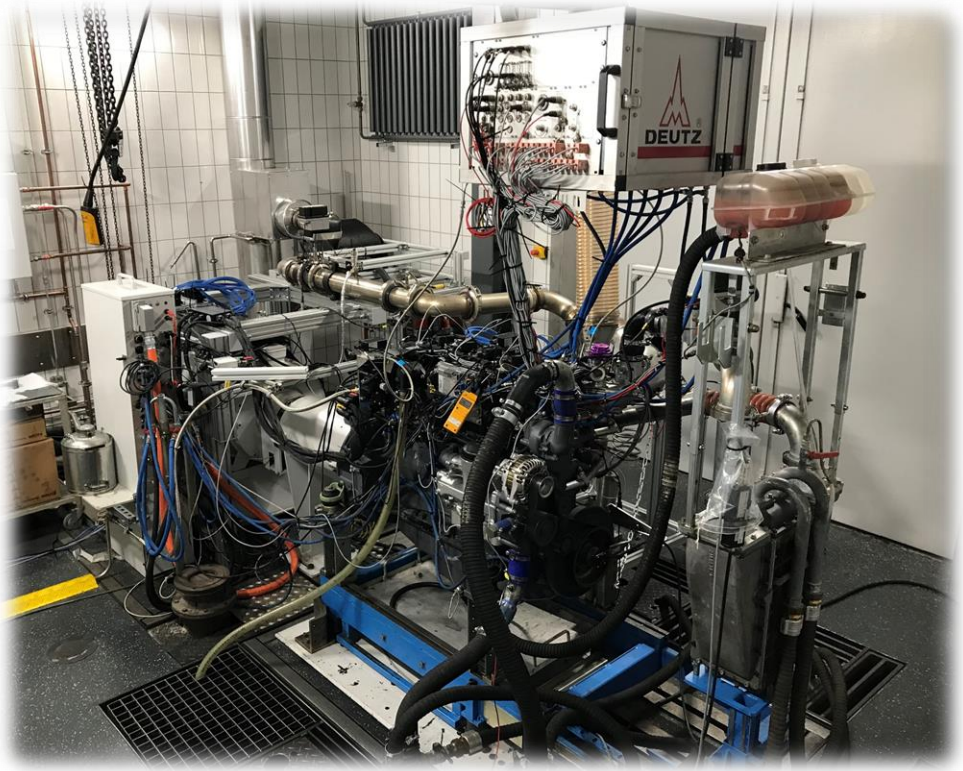
Further Development

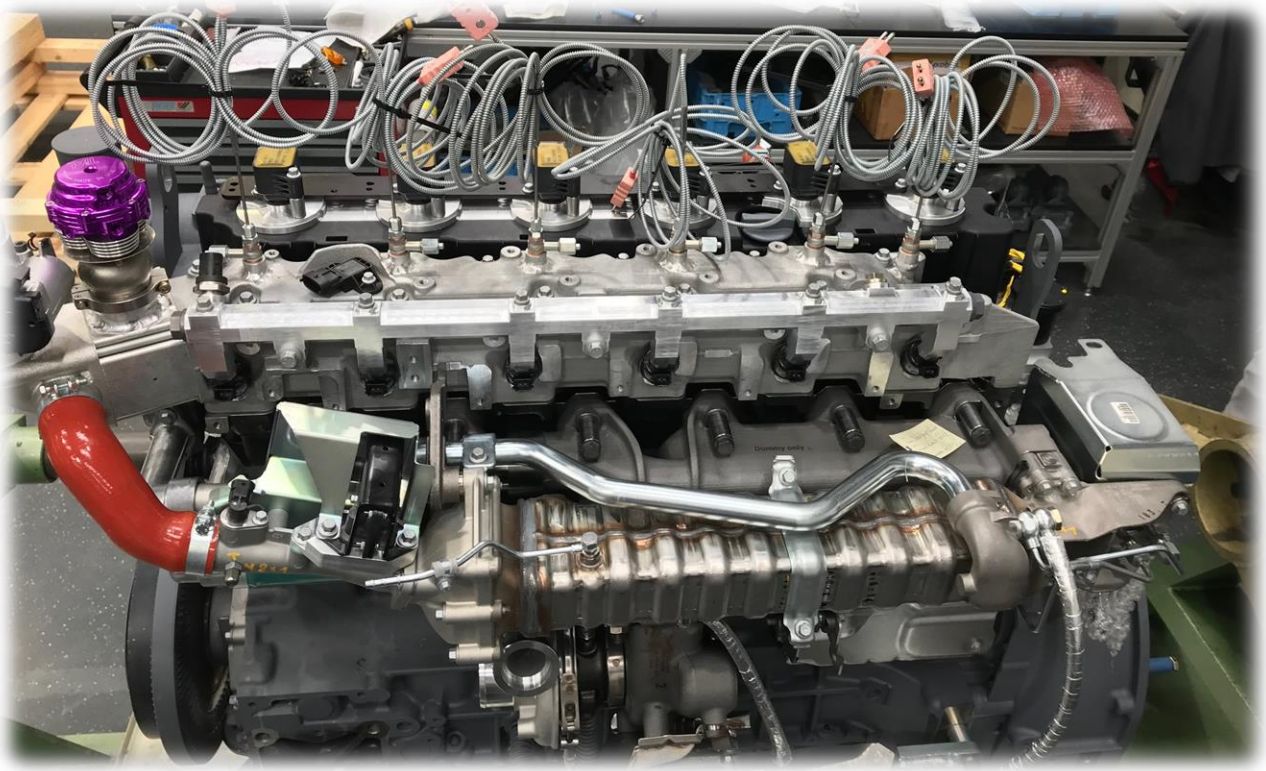
New Development

*) Necessity to be checked

Alternative drive systems for mobile machinery in port logistics

TCG 7.8 – Hydrogen Combustion Engine

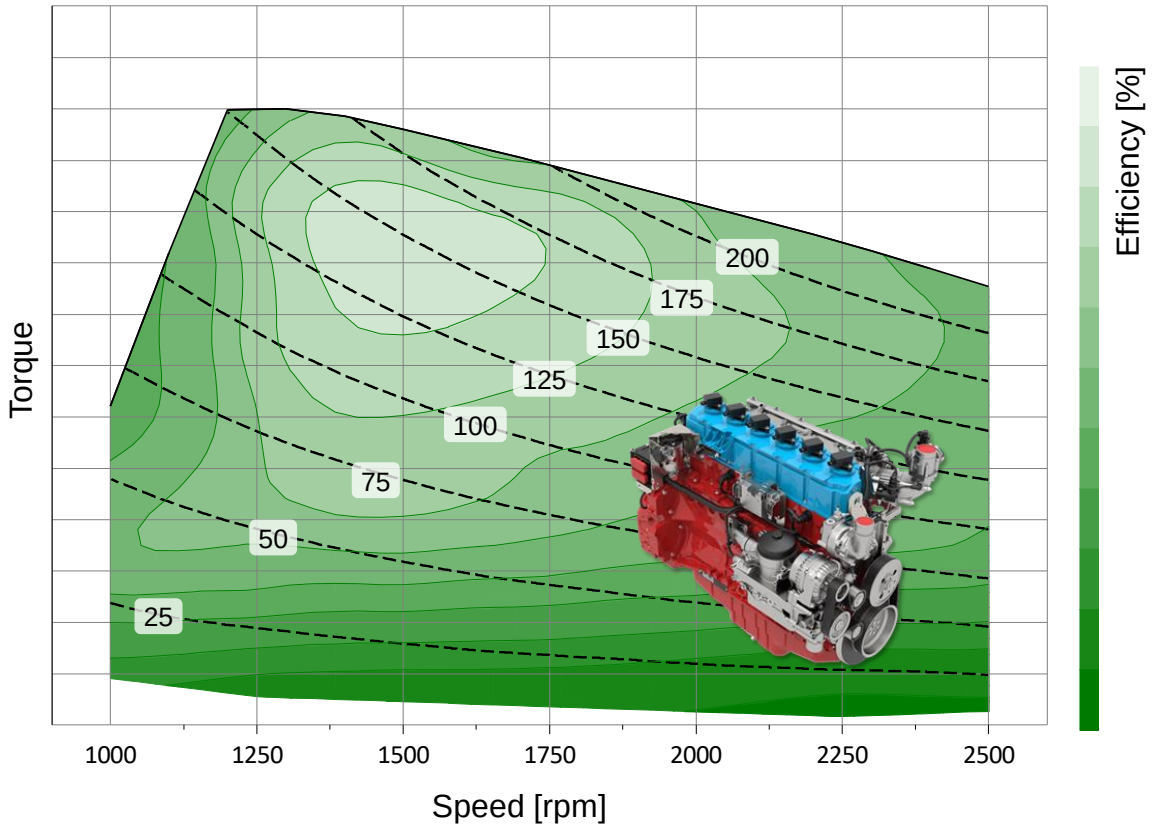




The engine is on test bed – current scope: calibration and validation.

Alternative drive systems for mobile machinery in port logistics

TCG 7.8 H2 – some more information about the Hydrogen Combustion Engine



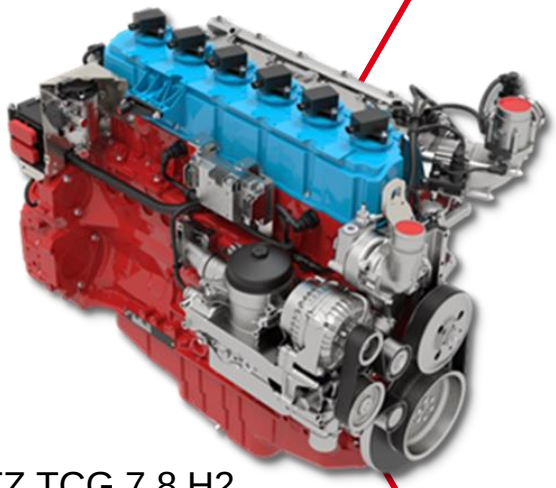
Objective specification	
Cylinder	6 inline
Displacement	7,755 l
Bore / stroke	110 / 136 mm
Max. power	220 kW @ 2200 rpm
Max. torque	1000 Nm @ 1000 - 1600 rpm
Certification	EU COM Stage V (NRMM) EU zero emission*
Exh. Aftertreatment	SCR only**

**) < 1 g CO_2/kWh*
***) Necessary for high power density and high dynamic.*

Almost same performance level as diesel engine at current (early) development stage. Potential exists.

Alternative drive systems for mobile machinery in port logistics

DEUTZ Hydrogen Engine



DEUTZ TCG 7.8 H2

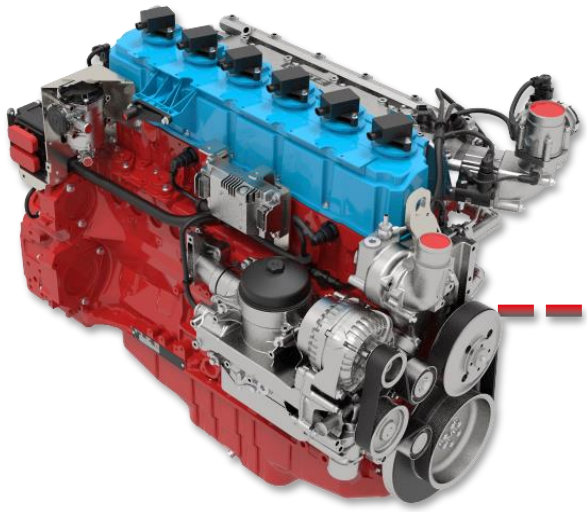
- CO_2-free technology ($2H_2 + O_2 \rightarrow 2H_2O$) fulfills EU *"Zero Emission"* standards*)
- Economical alternative compared to other emission-free technologies
- High reliability based on well-known base-engine technology
- Can be industrialized quickly with established supplier infrastructure and existing production capacities
- Also suitable for low H_2 gas qualities (lower costs, less effort for processing than with fuel cells)
- Increasing H_2-infrastructure, available service network for combustion engine

*) < 1 g CO_2/kWh

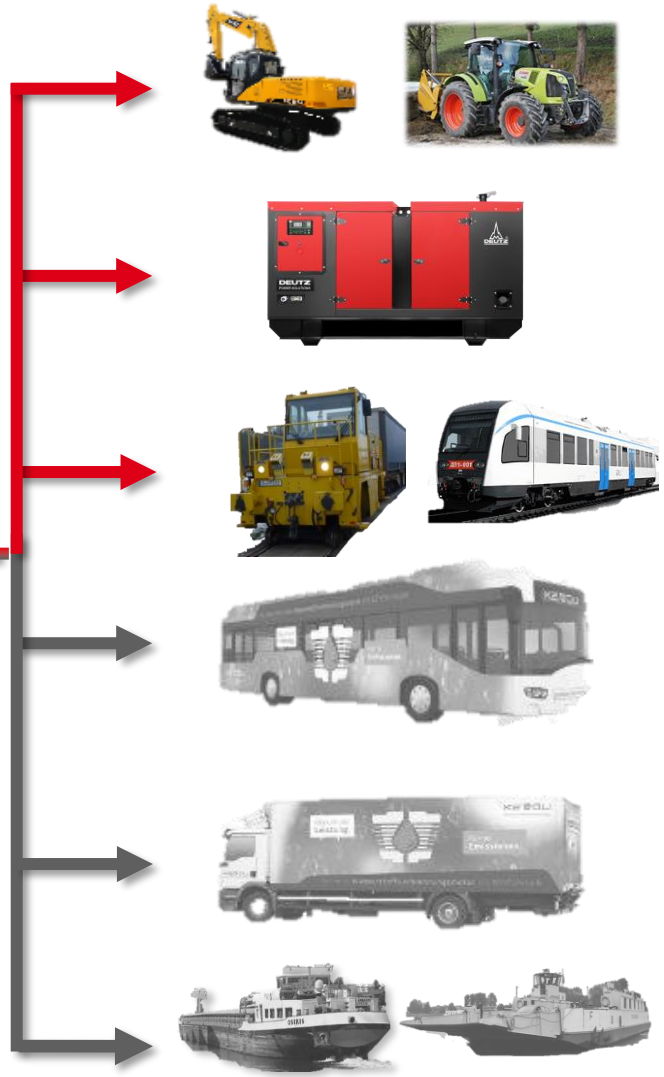
- **Robust technology – available on short term.**
- **Complementary to fuel cell: resolves "chicken-and-egg" problem.**

Alternative drive systems for mobile machinery in port logistics

Applications



DEUTZ TCG 7.8 H_2



Off-road applications

- Hydraulic excavator
- Tractor & agricultural machinery

Local energy generation

- Power generator (GenSets)
- Combined heat and power / BHKW

Railroad applications

- Railroad applications
- Special applications (e.g. shunting locomotive)

City and long distance bus*)

- City bus, 12m
- Complement to battery electric fleets

Truck *)

- 16-18t truck
- Distribution

Ship applications *)

- Barge
- Ferry

*) possible, but not foreseen yet.

Innovative application possibilities in shipping

Ship operation & upstream logistic chain - some possible examples (not planed yet)

Cargo handling in the port

based on an example

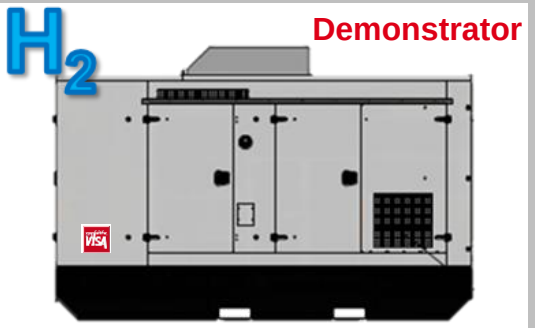
Handling excavator

Container Crane & Truck

Auxiliary electric power unit

36,5 m Sea Rescue Ship

Shore power supply

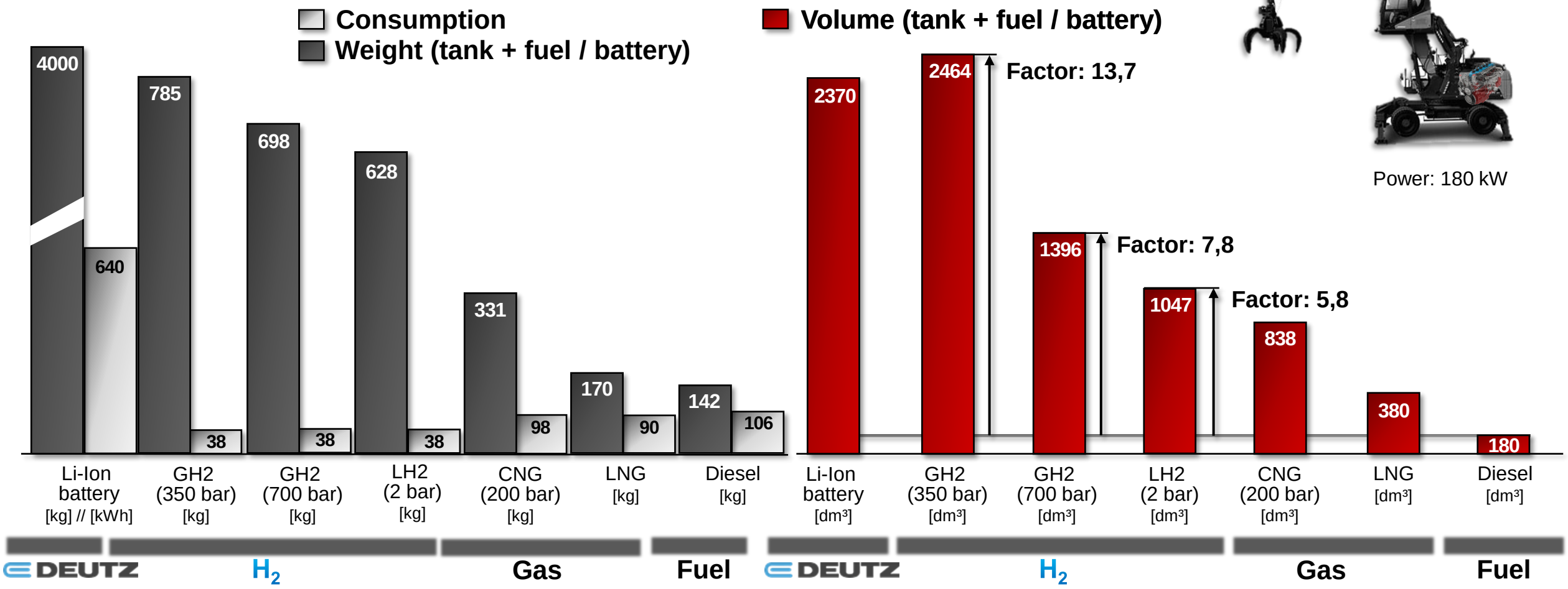


Power generator

Alternative drive systems for mobile machinery in port logistics

8 hours of typical operation: hydraulic excavator on a typical construction site

Power: 180 kW



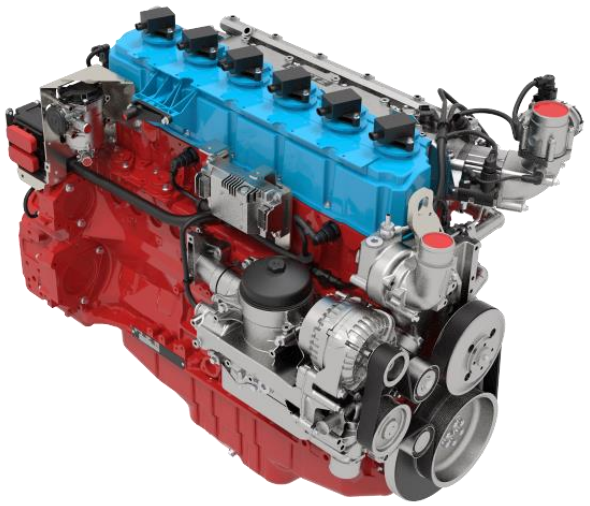
Hydrogen storage and on-site supply are main challenges for vehicle application and usage.

Quelle: ManfredKlell Helmut Eichlseder , Alexander Trattner ; Wasserstoff in derFahrzeugtechnik (Erzeugung , Speicherung, Anwendung)

Alternative drive systems for mobile machinery in port logistics

Summary

- Momentary most of Nonroad Mobile Machinery (NRMM) applications are driven with diesel engines. To contribute to climate policy, it is necessary to operate these machines CO_2-free in the future.
- The Hydrogen Internal Combustion Engine (HICE) is one short-term available powertrain, which enables a CO_2-free drivetrain for several NRMM-applications.
- HICE reveals several advantages in comparison to other Zero-Emission powertrains for NRMM.
- First engine is running on testbench. Development target is to achieve almost same performance level as diesel engine.
- Hydrogen in-vehicle storage is one challenge due to necessary tank volume.
- Series production of the 7.8-liter HICE is planned at DEUTZ from 2024. First application will be with constant engine speed; further applications will follow.



DEUTZ TCG 7.8 H2

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Thank you!

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Tagung:	43. ISF-Tagung
Ort/Datum:	Flensburg, 20.05.2022
Titel:	Feldstudie zur Validierung der Verschleißpaarung Ventilspindel/Sitzring über 32.000 Betriebsstunden
Autoren:	Jan-Peter Edelmann Hajime Suzuki Oliver Lehmann
Kurzfassung des Vortrags von J. Edelmann:	Motiviert durch steigende Anforderungen nach verbesserter Effizienz und Emissionsreduzierung erhalten Verschleißprobleme zunehmend erhöhte Bedeutung. Steigende thermo-mechanische wie auch chemische Belastungen wie zum Beispiel durch den Magerbetrieb von Großgasmotoren führen die Verschleißpaarung Ventilspindel/Sitzring an die Grenzen ihrer Zuverlässigkeit. Vorzeitige Funktionsausfälle sowie höhere Wartungs- und Servicekosten für Zylinderköpfe sind immer häufiger zu beobachten. Die Forschungs- und Entwicklungsarbeit bei Märkisches Werk hat gezeigt, dass Reibung und Verschleiß Systemgrößen und keine Werkstoffeigenschaften sind. Als Systemlieferant für Zylinderkopfkomponenten hat Märkisches Werk in den letzten Jahren verschleißbeständige Werkstoffe und dazu passende Designoptimierungen für Ventilspindel, Sitzringe und Ventilführungen entwickelt. Die vorliegende Feldstudie beschreibt das erfolgreiche Retrofit eines Großgasmotors vom Typ KU30GSI aus dem Hause Mitsubishi Heavy Industries, Engine & Turbocharger Ltd. über 32.000 Betriebsstunden. Als Messintervall für den Ventilverschleiß wurden 4.000 Betriebsstunden definiert. Bei jeder Messung wurden Ventile und Sitzringe für eine eingehende Untersuchung durch das Werkstofflabor der Märkisches Werk entnommen. Ausgehend von 4.000 Betriebsstunden mit einem Ventilrückgang von 0,2 mm nach 1.000 Stunden konnte die Lebensdauer auf die geforderten 32.000 Betriebsstunden bei ansonsten gleichbleibendem Motorbetrieb verlängert werden. Über Analyse der Ist-Situation mit Bestandsaufnahme des Lastkollektivs im fremdgezündeten KU30GSI konnten die vorherrschenden Verschleißmechanismen der Verschleißpaarung Ventilspindel und Sitzring identifiziert werden. Durch werkstofftechnische Maßnahmen in Verbindung mit konstruktiven Änderungen konnte der Ventilverschleiß so um ca. 90% reduziert werden. Darüber hinaus wurde über die Werkstoffauswahl und Tolerierung der Komponenten Einfluss auf die Fertigungstechnologien genommen, welche prozesssicher funktionieren müssen. Im vorliegenden Fall wurden für den Bereich der Ventilsitze die Werkstoffe Stellite 12 für die Ventilspindel und MW-H5428-8 für den Sitzring ausgewählt. Der Werkstoff MW-H5428-8 ist eine neue Verschleißschutzlegierung der Märkisches Werk, besonders geeignet für „trockene“ Kraftstoffe wie Methan im Vergleich zu Dieselkraftstoffen. Die ausgewählten Werkstoffe wurden anhand der tribologischen Prüfkette in Modell- und Komponentenversuchen validiert. Dies umfasst von Pin-on-Disc-Reibversuchen bis hin zum Ventilprüfstand sämtliche Belastungsszenarien des Tribosystems Ventilspindel/Sitzring. Bekannt ist, dass eine Reduktion des Ventilsitzwinkels von 30° auf 20° niedrigere Verschleißraten bewirkt, daher wurden zwei Prototypendesigns mit diesen Sitzwinkeln konfiguriert. Da die 20°-Variante einen messbaren ungewünschten Eingriff in das Einströmverhalten darstellt, wurde aufgrund der kleinen Verschleißraten der 30°-Sitzwinkelvariante nach 20.000 Betriebsstunden entschieden, die 20°-Variante aus den weiteren Versuchen herauszunehmen. Die Ergebnisse über 32.000 Betriebsstunden zeigen durchweg niedrige Ventilrückgänge für die 30°-Variante mit Verschleißraten von 0,015mm nach 1.000 Stunden. Es ist festzustellen, dass sich die Kontaktflächen von Ventilspindel und Sitzring nach dem Einlauf wie erwartet eingestellt haben. Damit konnte die Validierung abgeschlossen werden. Die Feldstudie verdeutlicht, dass Standardlösungen für moderne Großgasmotoren mit anspruchsvoller Emissionsregulierung an die Grenzen ihrer Zuverlässigkeit getrieben werden. Auf Basis eines tiefgehenden Verständnisses der ablaufenden Verschleißvorgänge konnte Märkisches Werk eine nachhaltige Lösung bei Mitsubishi Heavy Industries, Engine & Turbocharger Ltd. entwickeln und umsetzen. Durch die Anwendung einer systemischen Betrachtungsweise auf die Paarung Ventilspindel/Sitzring konnte durch eine anwendungsorientierte Werkstoffauswahl in Verbindung mit dem dazu passenden Komponentendesign die Lebensdauer auf 32.000 Betriebsstunden verlängert werden.

43. Informationstagung zur Schiffsbetriebsforschung, 20.05.2022

Feldstudie zur Validierung der Verschleißpaarung Ventilspindel/Sitzring über 32.000 Betriebsstunden

Field study for validation of wear pairing valve spindle / seat ring through 32.000 operating hours

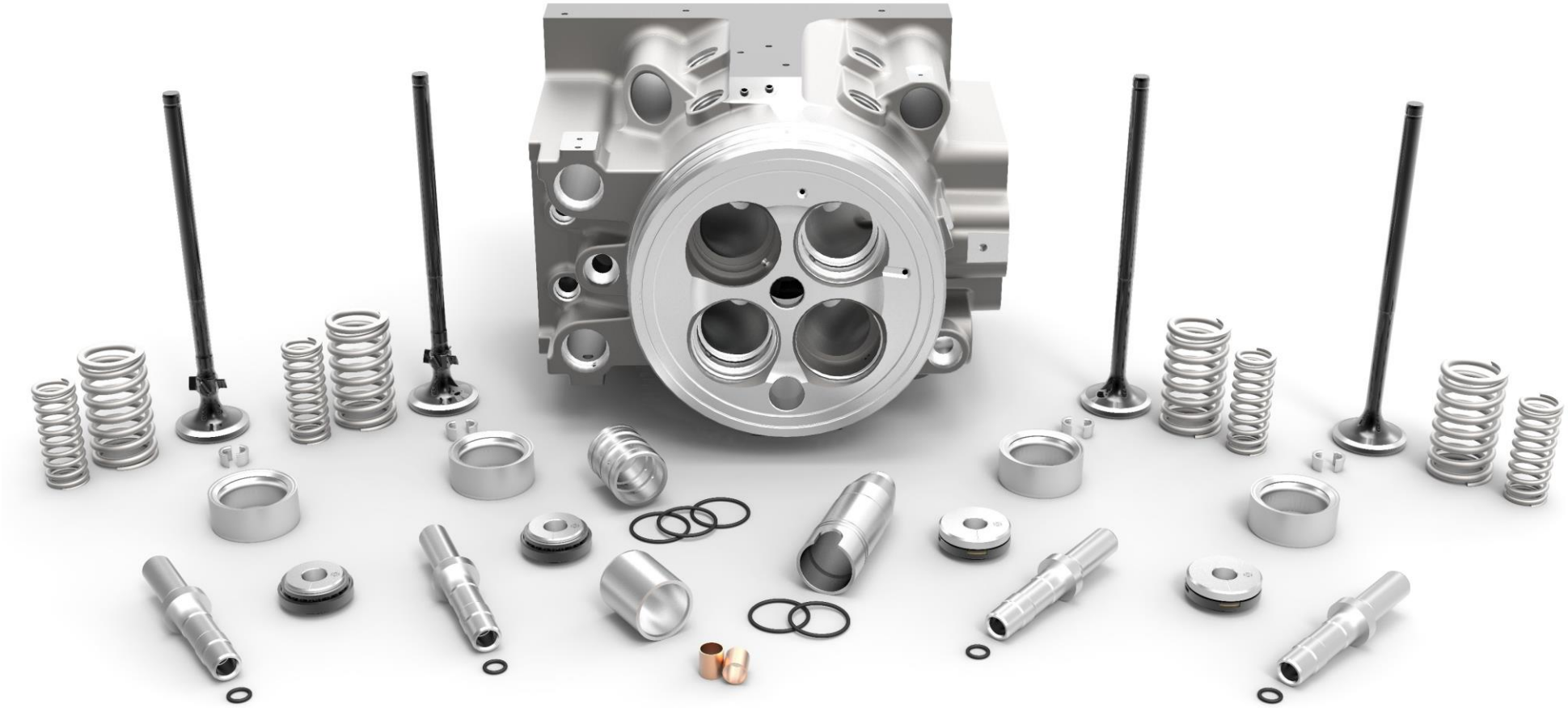
Jan-Peter Edelmann — Märkisches Werk GmbH

Hajime Suzuki — Mitsubishi Heavy Industries Engine & Turbocharger, Ltd.

Oliver Lehmann — Märkisches Werk GmbH

Agenda

Märkisches Werk – System supplier



Märkisches Werk – Fuels

Heavy-Fuel Oil

Diesel

CNG, LNG

Ultra-low sulphur fuel

Fuel pathways to achieve targets of Initial IMO GHG Strategy

Hydrogen

Ammonia

Methanol

Märkisches Werk development status:

Phase 2

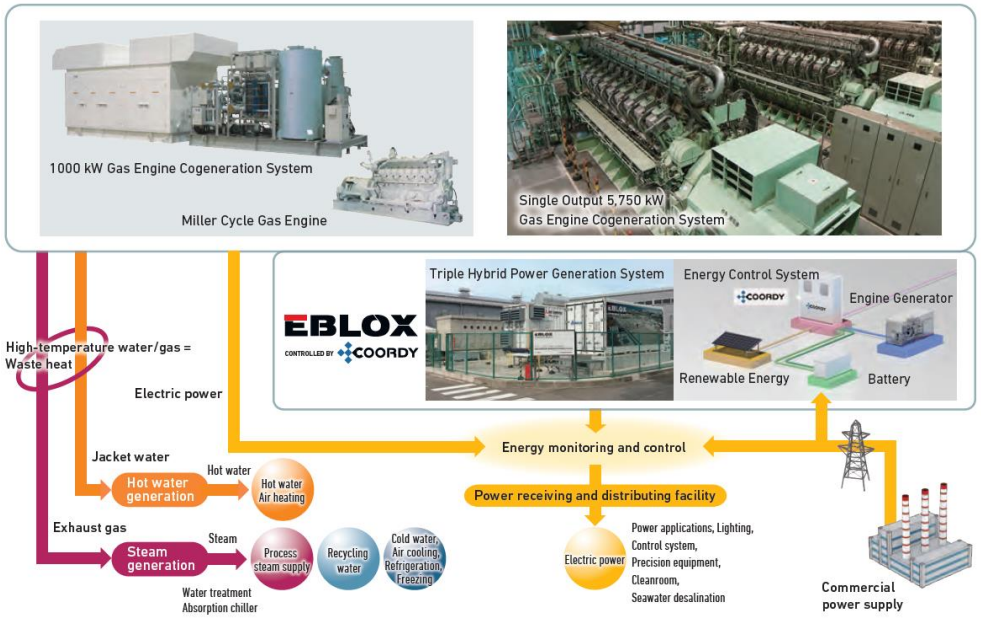
Phase 1

Phase 1

Source: https://pixabay.com/de/, checked 2022-05-13; https://www.mhi.com/products/energy/diesel_power_plant_and_gas_engine_plant.html, checked 2022-05-11

Mitsubishi Heavy Industries Engine & Turbocharger, Ltd.

- MHIET provides energy solutions for off-grid areas and disaster areas all around the world
- The MHIET EBLOX hybrid power generation systems stands for
  - Maximum efficiency
  - Expand functional possibilities
  - Support low-carbon society



Source: https://www.mhi.com/group/mhiet/ , checked 2022-05-11

MHIET corporate profile:

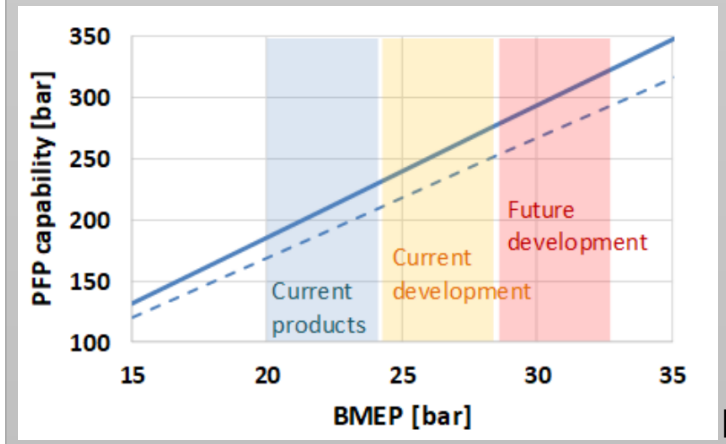
Company Name	Mitsubishi Heavy Industries Engine & Turbocharger, Ltd.
Operation Launch	July 1, 2016
Headquarters	3000 Tana, Chuo-ku, Sagamihara, Kanagawa 252-5293, Japan
President and CEO	Takeshi Kajino
Capital	5 billion yen
Employees (Consolidated)	5,500
Description of Business	- Design, Manufacture, Sales and Servicing of Engines
	- Electric power generating systems (Engineering, EMS)
	*EMS: Energy Management Service
	- Lease and rental of generator sets
	- Design, Manufacture, Sales and Servicing of Turbochargers

Agenda

Valve wear in large bore gas engines

Efficiency trend

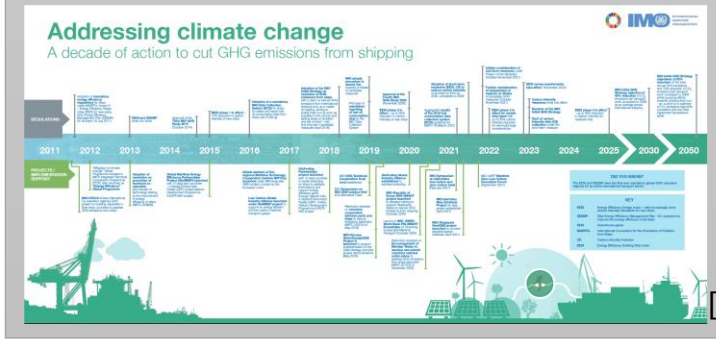
- PFP > 300 bar [1]
- BMEP > 30bar
- 2-stage turbocharging



[1]

Emission legislation

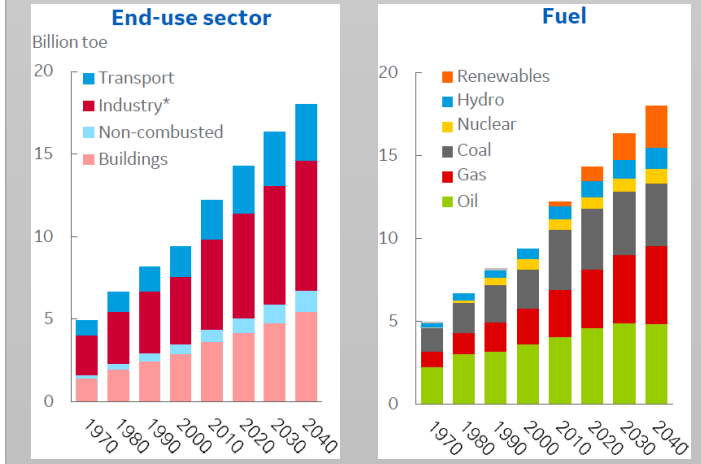
- IMO Tier II/III [2]
- Paris Agreement: 50% GHG emission reduction by 2050
- 0,5% sulphur cap



[2]

Diversification

- Type of fuel
- Increase of natural gas
- Hybridization



[3]

[1] Figer, G., Schmidtleitner, K., Kammerdiener, T., Schoenbacher, M., „Next-Generation High-Speed Engines – Advance Design Features Enabling Highest Engine Efficiency", CIMAC Congress, No. 301, p. 6, 2019
[2] IMO, „Nitrogen Oxides (Nox) – Regulation 13", online at: https://www.imo.org/en/OurWork/Environment/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx, checked 2022-05-02
[3] BP, „BP Energy Outlook, 2018 edition", online at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2018.pdf, checked 2022-05-04

Valve wear in large bore gas engines

Severe Wear

1st generation large bore gas engines:

Valve wear below 20nm/hr

2nd generation large bore diesel or gas engines:

Valve wear up to 600nm/hr

Conventional valve spindles cannot meet future requirements → pre-mature failure risk!

Valve wear in gas engine MHIET KU30GSI

Field study subject: Validation of tribosystem valve spindle/seat ring for 32,000 operation hours

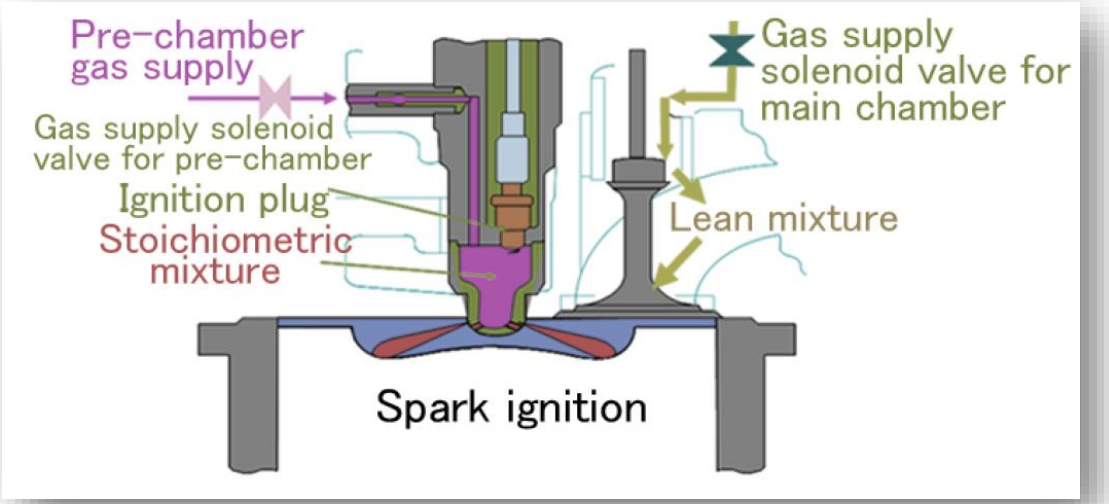


Fig. 1: principle sketch for gas admission and ignition [1]

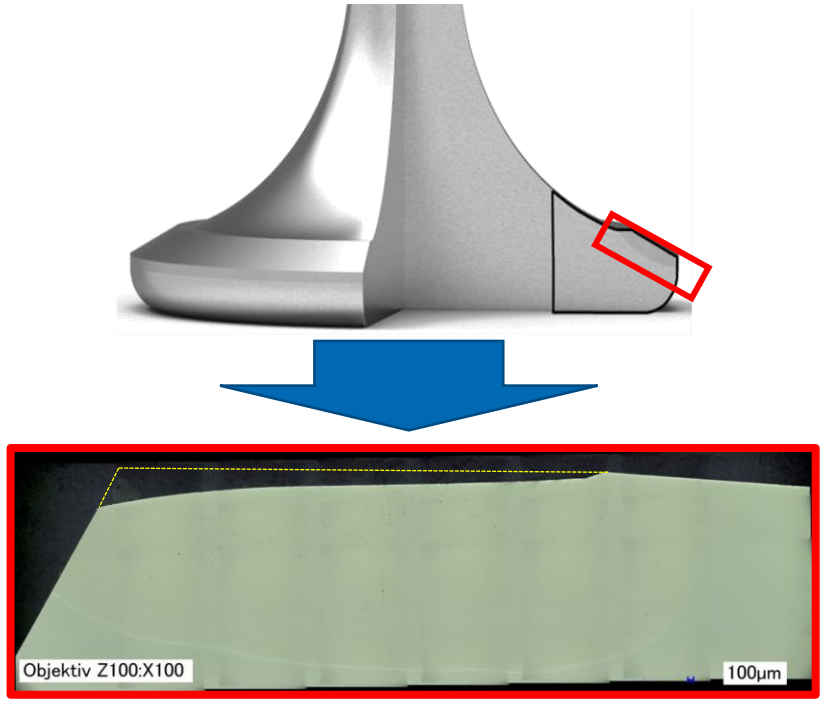


Fig. 2: 100x magnification of valve seating face

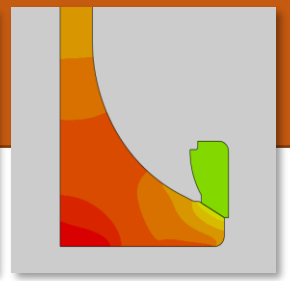
[1] Osaki, R., Inoue, K., Takahashi, Y.: An Environmentally Friendly and Highly Efficient combined Heat and Power Plant with a MACH II-SI (KU30GSI) Gas Engine for the University of Central Florida in the United States, Mitsubishi Heavy Industries Technical Review Vol. 48 No. 1, March 2011

The valve recession exceeded 0.8mm within 4,000 operating hours (occasionally).

Valve wear: Methodology

Analysis of valve wear

Thermal load

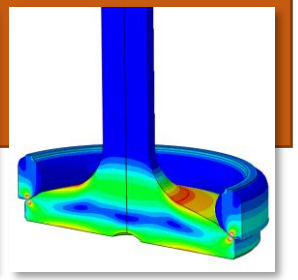


- Temperature distribution
- Combustion temperature
- Heat transfer

Chemical load

- Deposits
- Fuel
- Corrosion

Mechanical load



- Peak Firing Pressure
- Valve closing impact
- Contact situation
- Stress distribution

Agenda

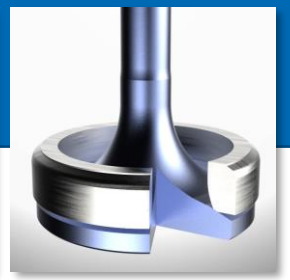
Valve wear: Key influence factors

Valve spindle / seat ring design

Materials

- Material selection
- Wear-resistant material
- Corrosion resistance
- Hot temperature strength

Geometry



- Pressure analysis
- Contact situation
- Stick-slip-effect

Manufacturing Process

- Technology development
- Raw material specification
- Heat treatment
- Welding technology

Materials

Before

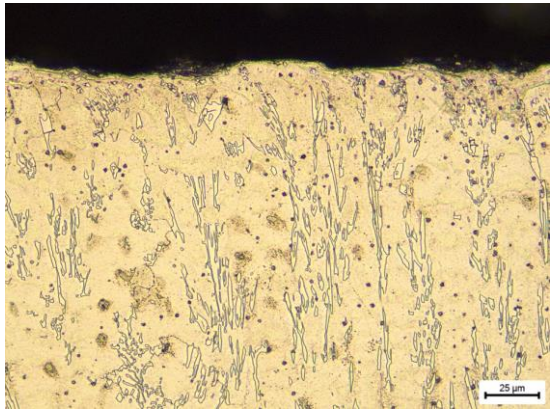


Fig. 1: Valve spindle

Nickel-based hardfacing applied on valve seating face

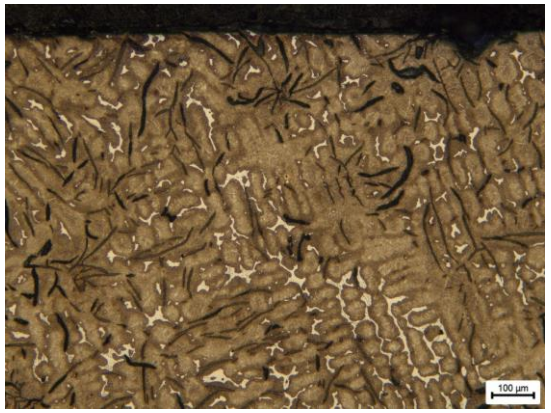


Fig. 2: Seat ring

Iron-based cast material with lamellar graphite

After

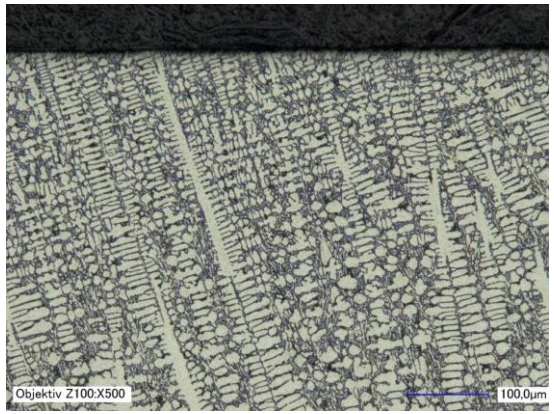


Fig. 3: Valve spindle

Stellite 12 hardfacing applied on valve seating face

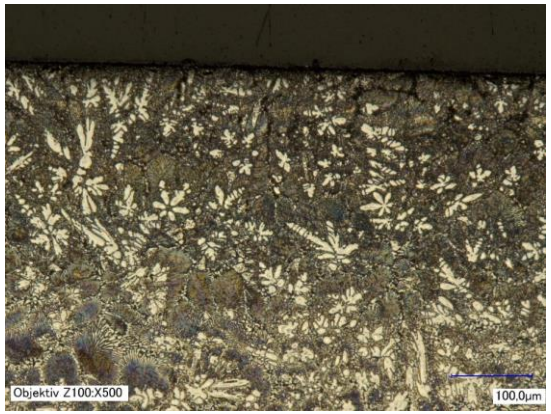


Fig. 4: Seat ring

MW-H5428-8 hardfacing

Geometry / Contact situation

Before

Fig. 1: Valve spindle

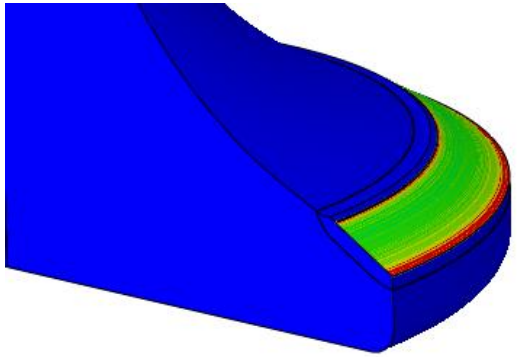


Fig. 2: Contacting surface

- Contact situation valve / seat ring is not defined
- Valve wear is present

After

Fig. 3: Valve spindle

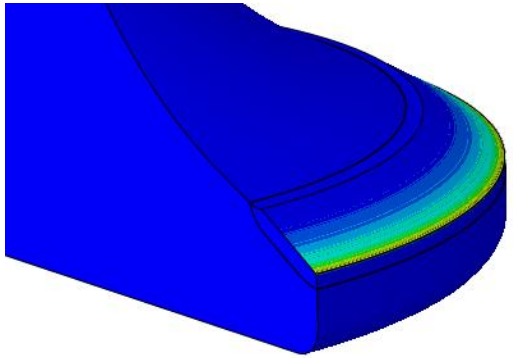
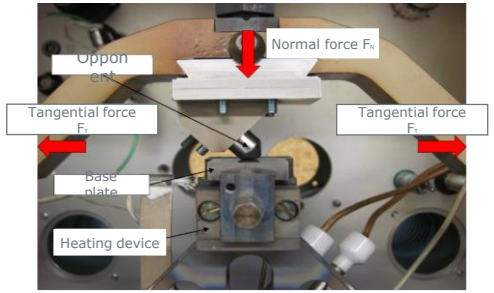


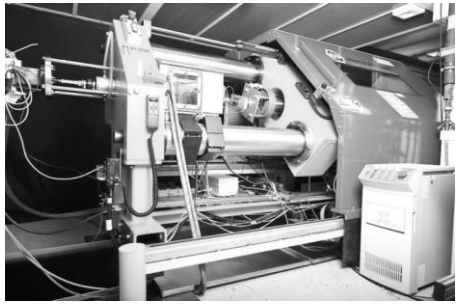
Fig. 4: Contacting surface

- Contact situation valve / seat ring is defined
- Low wear during lifetime

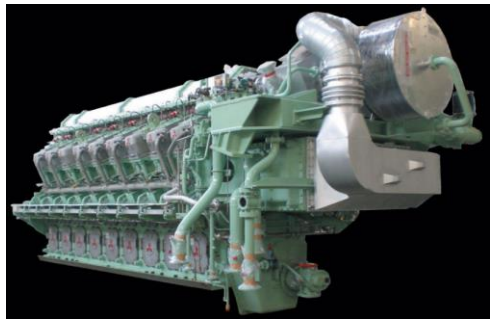
Step-wise tribological validation

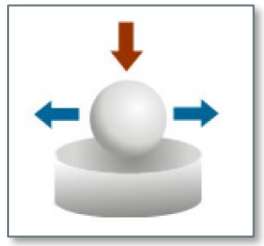
Model Testing → **Test Rig** → **Field Test**

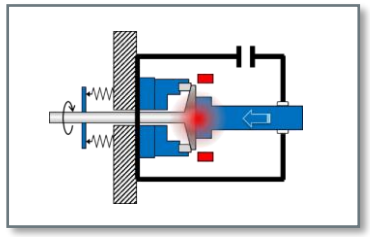


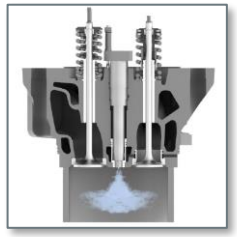


[1]









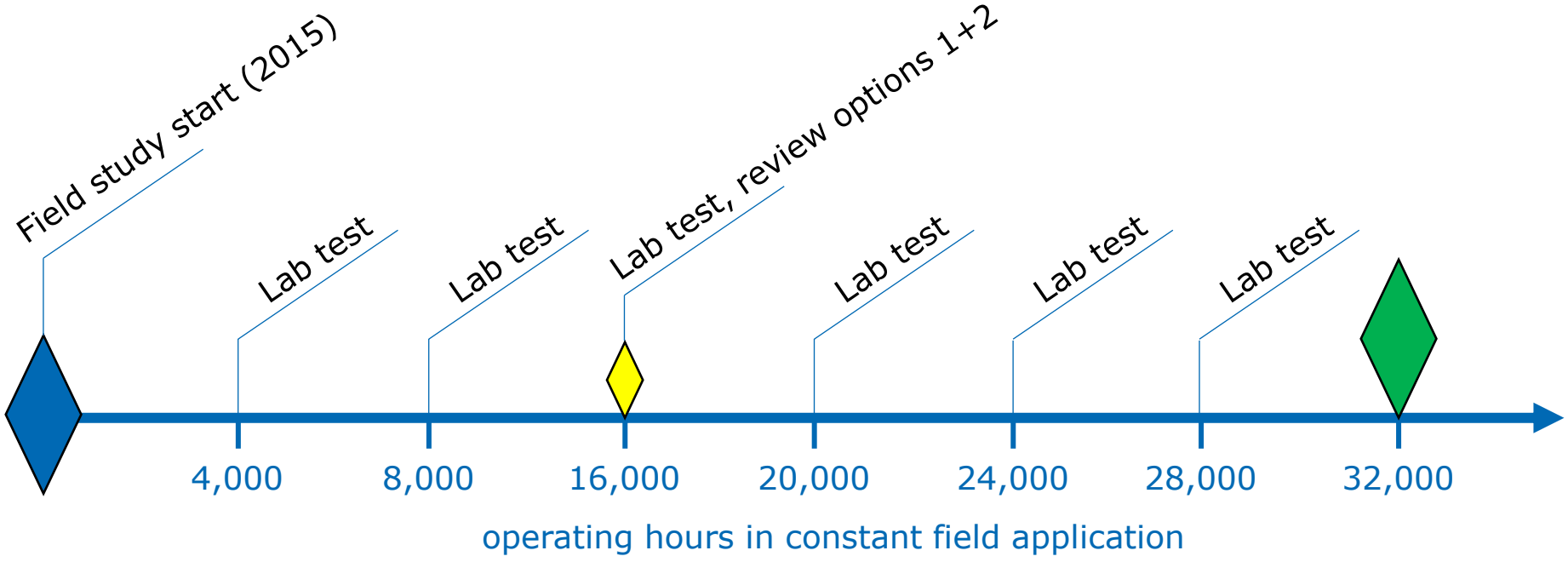
Simplified model → **Component test with modeled test environment** → **Component test in actual engine**

[1] Lehmann O. and Renz, A. 2016. Valve wear in lean-burn large bore gas engines – From engine tests of components to a unique tribological test rig. 28th CIMAC World Congress, Helsinki, Finland, Paper No. 231

Agenda

Field study: Test setup

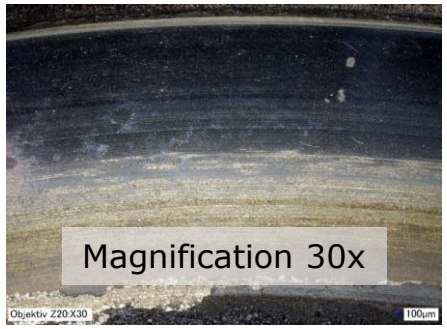
Target of field study	Validate valve spindle and seat ring through 32,000 operating hours		
Test parts: Option 1	Valve spindle / seat ring	30° seating angle	Stellite 12® / MW-H5428-8
Test parts: Option 2	Valve spindle / seat ring	20° seating angle	Stellite 12® / MW-H5428-8

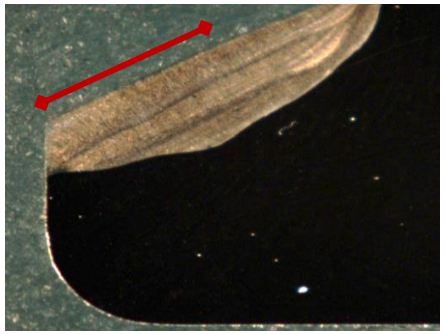


Field study: Investigation after 8,000 operating hours

Valve spindle L7-4

Seating angle: 30°

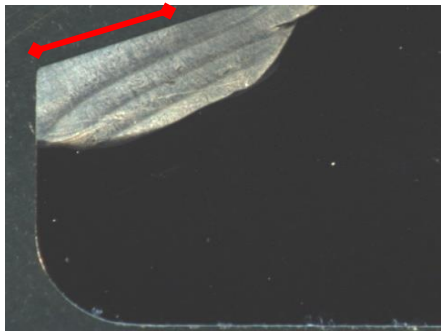


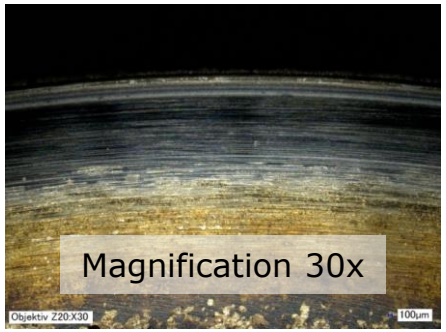


seating contact area:	55%
valve recession:	15 µm
valve wear rate:	1.9 nm/hr

Valve spindle L4-4

Seating angle: 20°





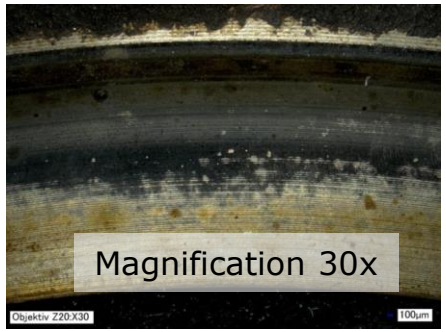
seating contact area:	45%
valve recession:	8 µm
valve wear rate:	1.0 nm/hr

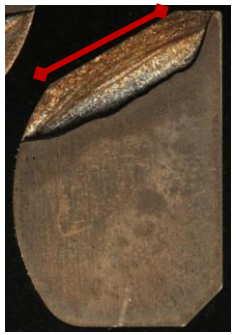
20° seating angle has slightly less valve wear than 30° seating angle.

Field study: Investigation after 8,000 operating hours

Seat ring L7-4

Seating angle: 30°



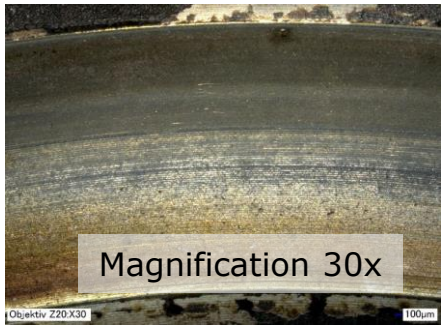


seating contact area: 55%

Wear below measuring threshold

Seat ring L4-4

Seating angle: 20°



seating contact area: 45%

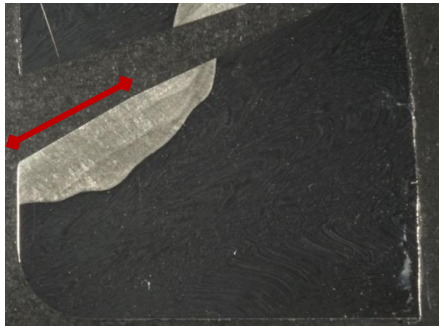
Wear below measuring threshold

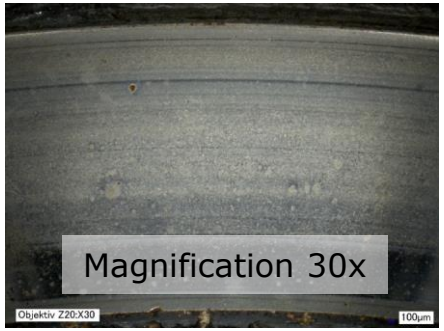
Almost no wear after 8,000 operation hours.

Field study: Investigation after 31,694 operating hours

Valve spindle L8-4

Seating angle: 30°

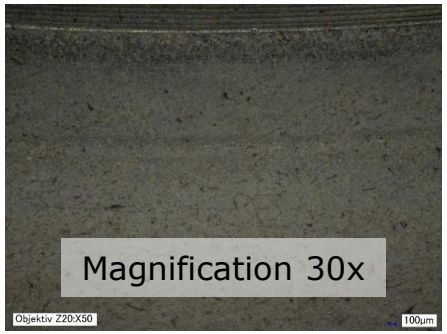




seating contact area: 100%
valve recession: 130 µm
valve wear rate: 4.1 nm/hr

Seat ring L8-4

Seating angle: 30°



seating contact area: 100%
Wear not measurable

Wear rate is on a low level after approx. 32,000 operating hours.

Field study: Results at 32,000 operating hours

Summary:

- 30° seating angle version succeeded the validation
- 20° seating angle testing stopped at 20,000 hours: combustion was varying in some cases
  → 30° seating angle preferred
- Multiple tests confirmed the test results
- Wear rate remains on low level

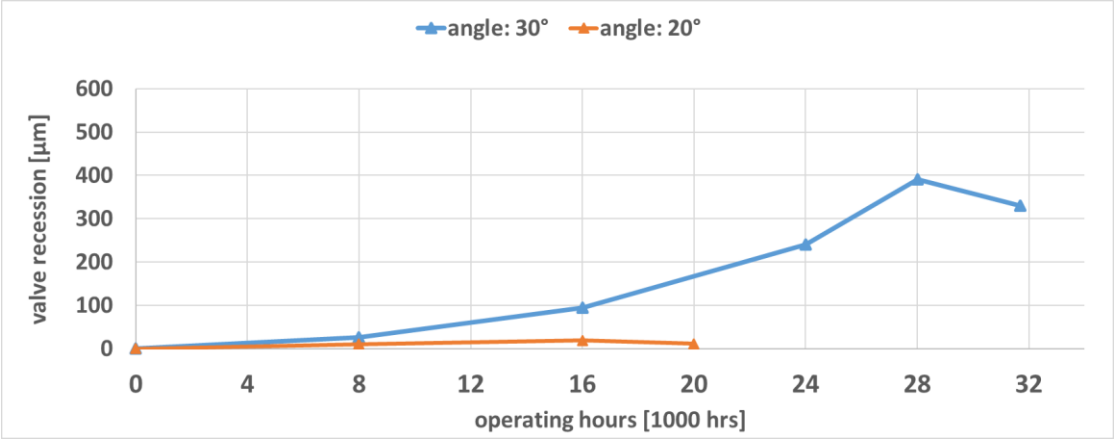


Fig. 1 Valve recession diagramm

Validation for 32,000 operating hours completed. The components are in serial use.

Agenda

Conclusion

Component service time increased from 4,000 to 32,000 operation hours.

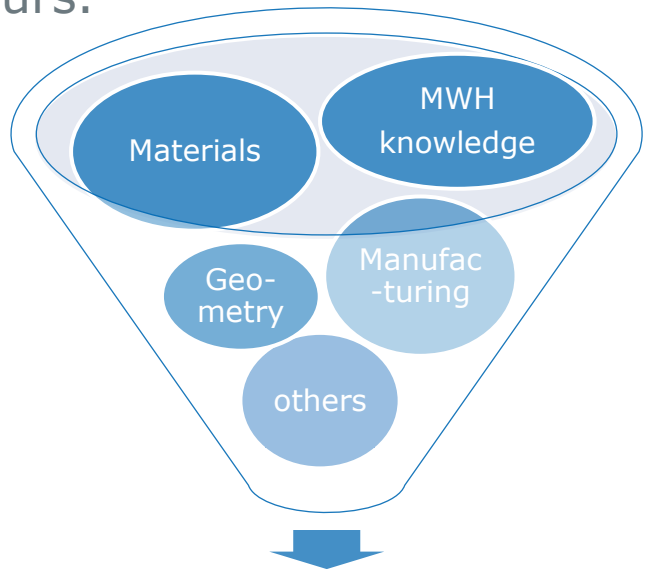
Validation:

1. Model testing for proprietary MWH material developments
2. Component testing
3. Field validation with customer

Holistic view on the component design:

– Understanding materials

– Contact pairing, manufacturing technology and others



MITSUBISHI HEAVY INDUSTRIES
ENGINE & TURBOCHARGER

Material knowledge paired with a systematic design and validation approach enhances component lifetime and engine usability.

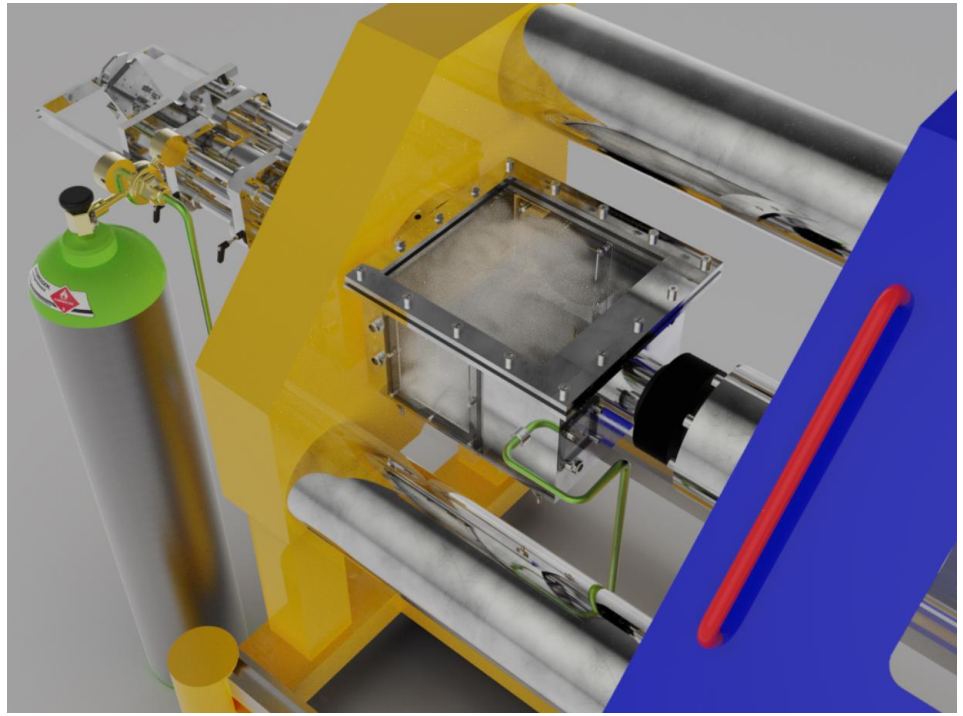
Outlook

Hydrogen

Ammonia

Methanol

E-Fuels



Peak Firing Pressure

Valve Closure

Temperature

Valve wear

Märkisches Werk will provide reliable solutions for future fuels on the way to zero GHG emissions.

Thanks for your attention!

MÄRKISCHES WERK
Your Engine. Our Ingenuity.®

MITSUBISHI HEAVY INDUSTRIES
ENGINE & TURBOCHARGER

Paraffinische Kraftstoffe in der Schifffahrt - Erfahrungen & Ausblick

43. ISF-Tagung, Hochschule Flensburg, 20. Mai 2022

Klaus Schlame,
Shell Global Solutions (Deutschland) GmbH

DEFINITIONEN & HINWEISE

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate legal entities. In this presentation "Shell", "Shell group" and "Royal Dutch Shell" are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words "we", "us" and "our" are also used to refer to Royal Dutch Shell plc and its subsidiaries in general or to those who work for them. These terms are also used where no useful purpose is served by identifying the particular entity or entities. ''Subsidiaries'', "Shell subsidiaries" and "Shell companies" as used in this presentation refer to entities over which Royal Dutch Shell plc either directly or indirectly has control. Entities and unincorporated arrangements over which Shell has joint control are generally referred to as "joint ventures" and "joint operations", respectively. Entities over which Shell has significant influence but neither control nor joint control are referred to as "associates". The term "Shell interest" is used for convenience to indicate the direct and/or indirect ownership interest held by Shell in an entity or unincorporated joint arrangement, after exclusion of all third-party interest.

This presentation contains forward-looking statements (within the meaning of the U.S. Private Securities Litigation Reform Act of 1995) concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management's current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management's expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as "aim", "ambition', ''anticipate'', ''believe'', ''could'', ''estimate'', ''expect'', ''goals'', ''intend'', ''may'', ''objectives'', ''outlook'', ''plan'', ''probably'', ''project'', ''risks'', "schedule", ''seek'', ''should'', ''target'', ''will'' and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this presentation, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell's products; (c) currency fluctuations; (d) drilling and production results; (e) reserves estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including regulatory measures addressing climate change; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; and (m) changes in trading conditions. No assurance is provided that future dividend payments will match or exceed previous dividend payments. All forward-looking statements contained in this presentation are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional risk factors that may affect future results are contained in Royal Dutch Shell's Form 20-F for the year ended December 31, 2018 (available at www.shell.com/investor and www.sec.gov). These risk factors also expressly qualify all forward-looking statements contained in this presentation and should be considered by the reader. Each forward-looking statement speaks only as of the date of this presentation, 02. April 2019. Neither Royal Dutch Shell plc nor any of its subsidiaries undertake any obligation to publicly update or revise any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this presentation.

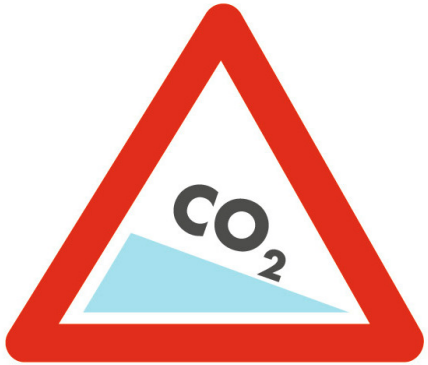
We may have used certain terms, such as resources, in this presentation that the United States Securities and Exchange Commission (SEC) strictly prohibits us from including in our filings with the SEC. U.S. Investors are urged to consider closely the disclosure in our Form 20-F, File No 1-32575, available on the SEC website www.sec.gov.

AGENDA

1. Überblick Paraffinische Kraftstoffe
2. GTL
   - Herstellung
   - Vorteile
   - Erfahrungen
3. PTL
4. OEM Freigaben
5. Fragen

DIE EMISSIONS HERAUSFORDERUNGEN

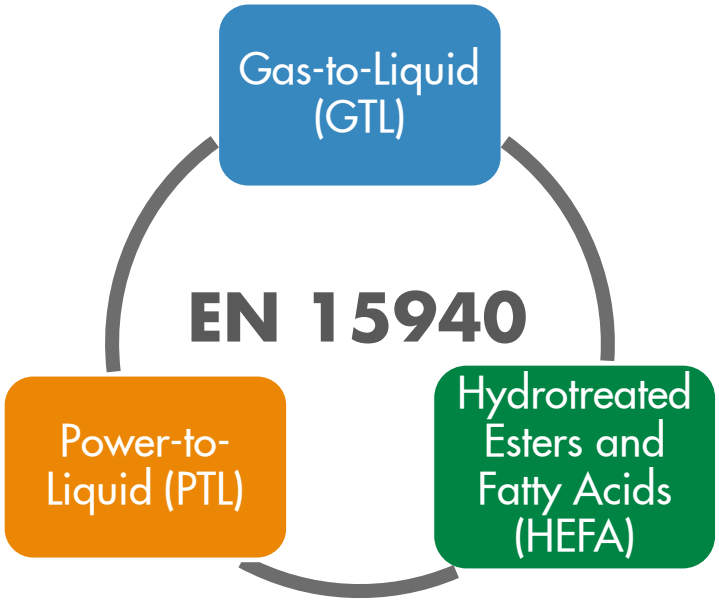
Reduce GHG (CO_2) Emissions



Reduce Local Air quality related Emissions

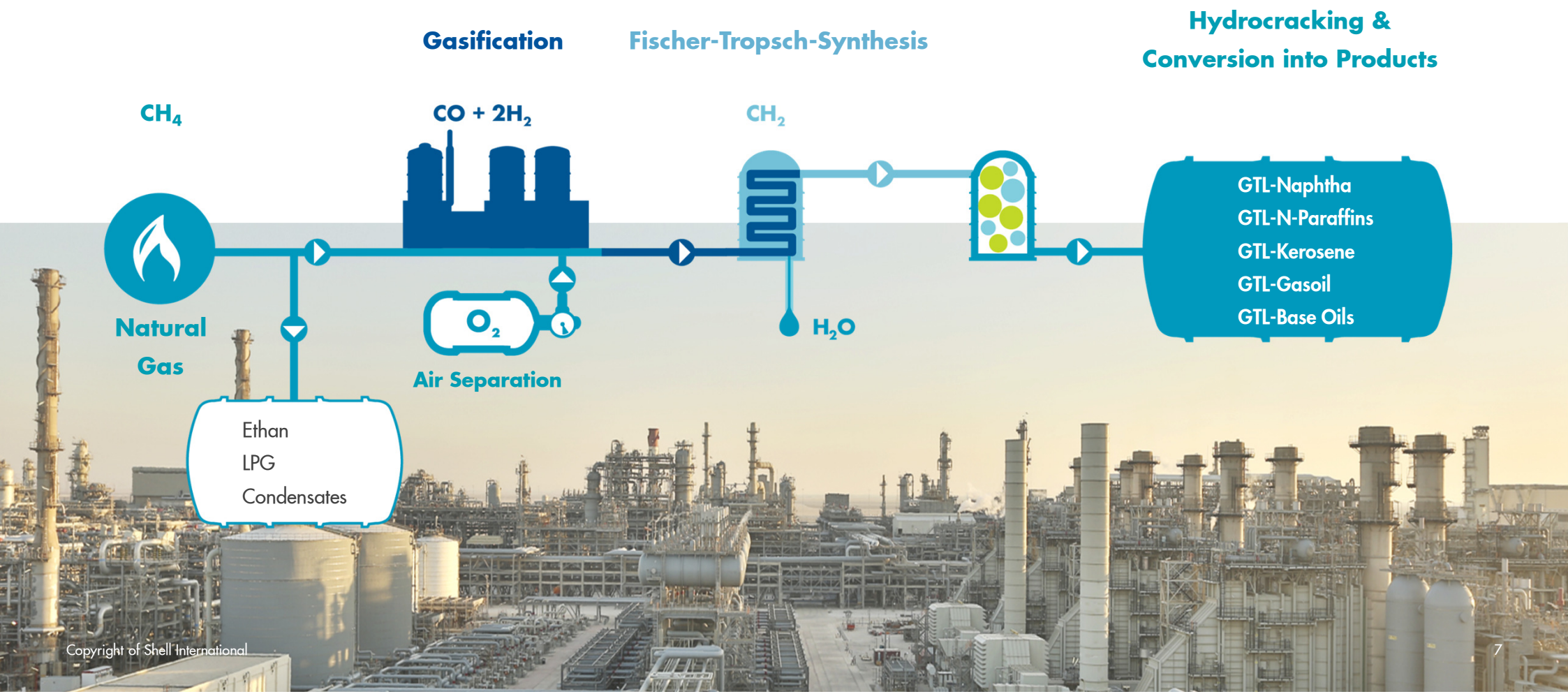
Reduce Noise Emissions

PARAFFINISCHE KRAFTSTOFFE



Shell
GTL Fuel

GAS-TO-LIQUID TECHNOLOGIE



VOM LABOR ZUR KOMMERZIELLEN PRODUKTION

Kontinuierliche Technologie Entwicklung

1973	1983	1993	2012
			
Laboratory Amsterdam grams/d	Pilot plant Amsterdam 3 bbl/d	Bintulu Malaysia current capacity 14,700 bbl/d	Pearl GTL Qatar 140,000 bbl/d

Pearl GTL Qatar in perspective

- World's largest GTL plant on a site the size of Central Park in New York
- Steel used equals to 10 Eiffel towers
- 40.000 workers from 50 nations were involved
- One GTL reactor weighs as much as 7 Jumbo Jets

SHELL GTL FUEL - PRODUKTE

Shell GTL (Gas-to-Liquids) Fuel

Der Einsatz von Shell GTL Fuel in Dieselmotoren kann die lokale Luftqualität durch Reduzierung lokaler Emissionen (z.B. Stickoxide, Feinstaub) verbessern[1]. Shell GTL Fuel kann ohne Modifikation in vorhandenen Dieselfahrzeugen eingesetzt werden[2].

Praxisbericht herunterladen:
Nahverkehr Utrecht mit Shell GTL Fuel
Baufahrzeuge Geistlinger & Co KG mit Shell GTL Fuel
DB Schneker Rail mit Shell GTL Fuel

Shell GTL Fuel Alpine

Bietet alle Leistungs- und Umweltvorteile von Shell GTL Fuel und ist speziell auf den Einsatz in besonders kalten Umgebungen optimiert: Shell GTL Fuel Alpine ist kältestabil bis zu -30 °C (CFPP-Wert) und bietet wie alle Shell GTL Fuel Kraftstoffe ein hervorragendes Kaltstartverhalten dank höherer Cetanzahl.

Praxisbericht herunterladen:
„On Top Of Germany“ mit Shell GTL Fuel Alpine

Shell GTL Fuel Marine

Speziell auf den Einsatz im Bereich der Schifffahrt optimiert. Drei Vorteile der Shell GTL Fuel Kraftstoffe im Vergleich zu Dieselkraftstoff, die in diesem Bereich besonders geschätzt werden: Niedrigere Wassergefährdungsklasse, bessere biologische Abbaubarkeit und geringere Geruchsbelastung.

Praxisbericht herunterladen:
Bayerische Seenschiffahrt mit Shell GTL Fuel Marine
Forgensee Schifffahrt mit Shell GTL Fuel Marine

Shell GTL Fuel Heating

Shell GTL Fuel kann Heizöl EL ersetzen. Für Unternehmen und Gewerbetreibende steht damit ein alternativer, aus Erdgas synthetisierter Brennstoff zur Verfügung – sauber, effektiv, mit hoher Lagerstabilität und sofort einsetzbar.

[1] Shell GTL Fuel verbrennt sauberer und produziert weniger lokale Emissionen als herkömmlicher, aus Mineralöl hergestellter Diesel
[2] Auf der Grundlage der bis heute durchgeführten Shell Betriebsfähigkeitsstudien
[3] Bei bestimmten Motorentypen und unter bestimmten Fahrbedingungen

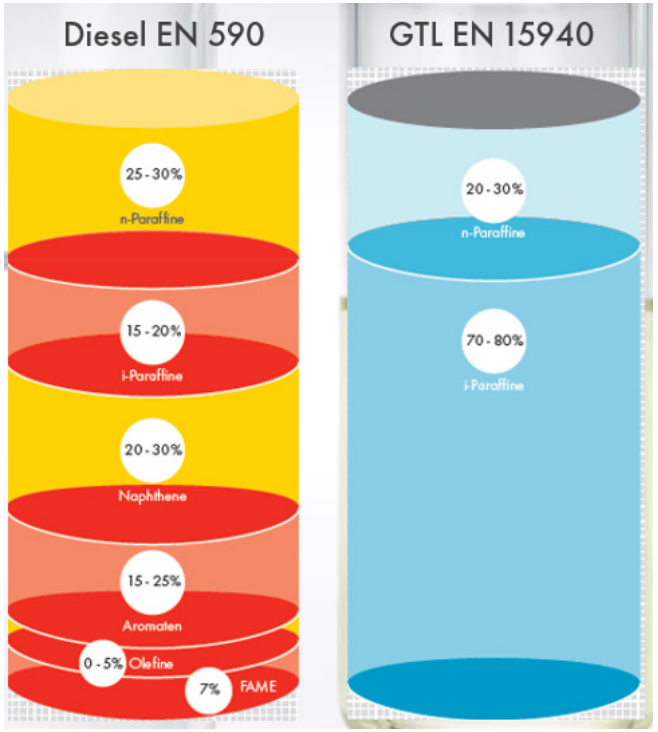
SHELL GTL FUEL – EIGENSCHAFTEN UND VORTEILE

Eigenschaften

- ✓ Flüssiger, farbloser und geruchsarmer Kraftstoff aus Erdgas
- ✓ Klassifiziert nach EN15940 als paraffinischer Kraftstoff
- ✓ Geringerer Schwefel- und Aromatengehalt als Norm-Diesel (EN 590)
- ✓ Hohe Cetanzahl

Vorteile

- ✓ Einsatzmöglichkeit in allen Dieselmotoren
- ✓ Drop-In Kraftstoff, vorhandene Infrastruktur nutzbar
- ✓ Sauberere Verbrennung vs. herkömmlicher Diesel
  - ✓ Senkt lokale Emissionen (Stickoxide, Partikel, etc.)
  - ✓ Kann Wartungsaufwand reduzieren
- ✓ nicht umweltgefährdend
  - ✓ Leicht biologisch abbaubar
  - ✓ WGK 1 (vs. WGK 2 bei Diesel)
- ✓ Biofrei
  - ✓ bessere Lagerstabilität
  - ✓ geringeres Mikrobenwachstum
- ✓ Ganzjährig CFPP -20°C / Shell GTL Fuel Alpine CFPP -30 °C
- ✓ Kann Motorengeräusch reduzieren



EMISSIONS VORTEILE - FELDTESTS

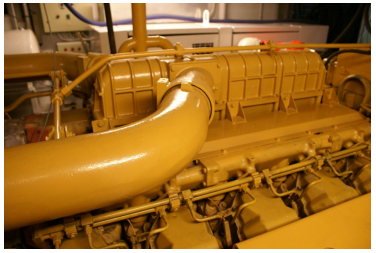
Endelave Fähre (Sep 2018)

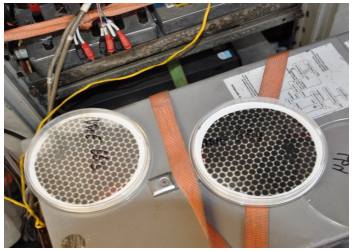
Caterpillar 3508

- Test carried out on one of two main engines.
- Test as per E3 test cycle according to IMP MARPOL Annex VI.
- Two cruise speeds and idle (3 in total)

- **Ergebnisse**
  - **NOx: 12 -18% Vorteil**
  - **PM: 32 - 46% Vorteil**
  - **CO: 0-37% Vorteil**
  - **HC: 6% - 27% Vorteil**

Transport Binnenschiffe Novamente und Invado (Dec 13-Jan 14)





Caterpillar 3512 B

- **CCNR 1,** Two Engines, Separate Exhaust System, Starboard Engine Tested, Engine Power: 1.0, 4 kW, Speed 1.600 RPM, 12 Cylinders, Direct Injection, Two Turbocharger with Aftercooler

Caterpillar 3512 B DITA

- **CCNR 0,** Engine Power: 1.118,5 kW, Speed 1.600 RPM, 12 Cylinders, Direct Injection, Two Turbocharger with Aftercooler, Engine Management (Low Fuel Software & Low NOx Software)

- **Ergebnisse**
  - **NOx: 8 – 9 % Vorteil**
  - **PM: 37 – 59 % Vorteil (bei bestimmten Lastpunkten bis zu 70%)**
  - **CO: 0 – 11 % Vorteil**
  - **HC: 10 – 47 % Vorteil**

EMISSIONS VORTEILE - FELDTESTS

- Hamburg Port Authority (HPA) and Shell collaboratively conducted a trial in June/July 2016
- Emission (PM and NOx) and engine power measurements have been performed by external test houses
- GTL Fuel has been compared to 10 ppm S diesel
- The test cycle was in accordance with ISO 8178-4, Test Cycle E3 for heavy duty marine engines

	g/kWh	Diesel	GTL Fuel	Difference GTL Fuel vs. Diesel	
NOx	Weighted	9,12	8,17	**-10,5**	**%**
PM	Weighted	0,24	0,11	**-52,7**	**%**
CO	Weighted	0,50	0,39	**-21,3**	**%**

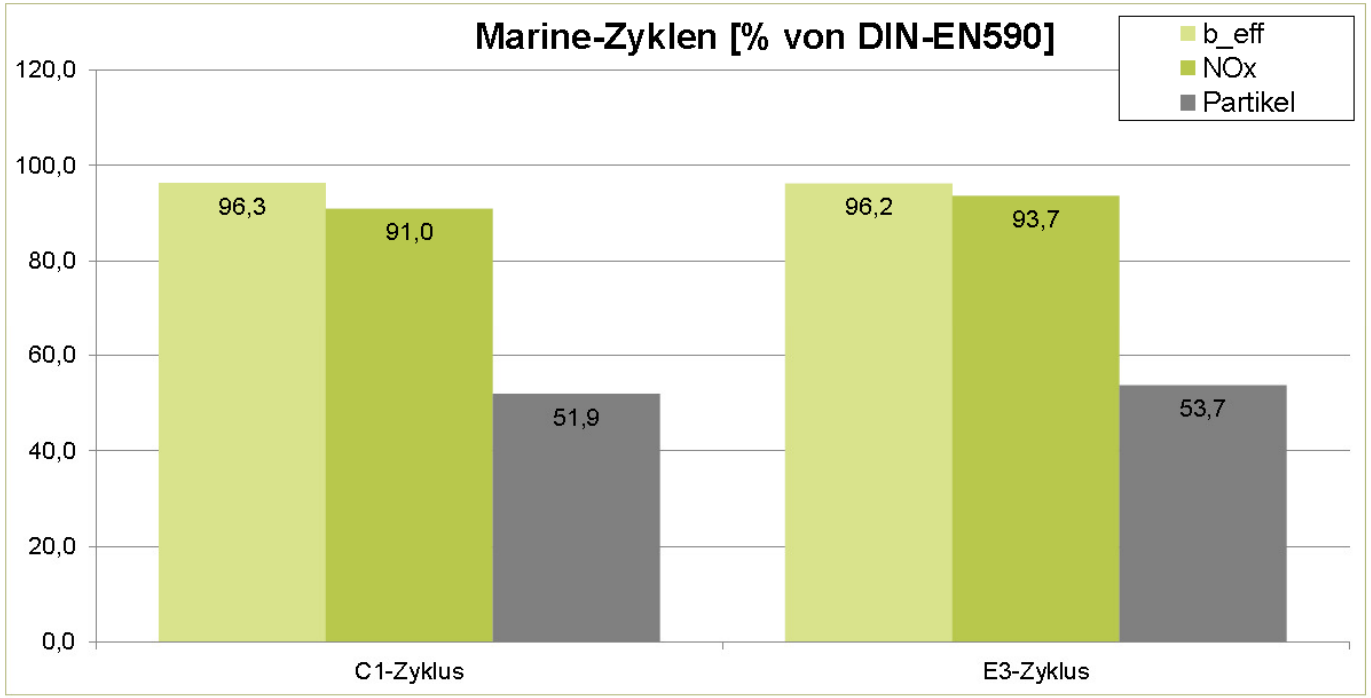
EMISSIONS VORTEILE - MOTORENPRÜFSTAND

01 Vorstellung: Motor und Versuchsdurchführung Motordaten

- Motortyp: 20V4000M93L
- Motornummer: V52
- Emissionsstufe: US EPA Marine Tier 2
- Nennleistung: 4300kW
- Nenndrehzahl: 2100 1/min
- Hubraum: 86,2l
- Bohrung: 170mm
- Hub: 190mm
- Verdichtung: 15,2

EMISSIONS VORTEILE - MOTORENPRÜFSTAND

02 Ergebnisse der Vergleichsmessung
Übersicht Zykluswerte (Marine)



Seite 13 Emissionsmessung am 20V4000M93L - Diesel DIN-EN590 / Shell GTL | TKFV1, Linder | 25.10.2013

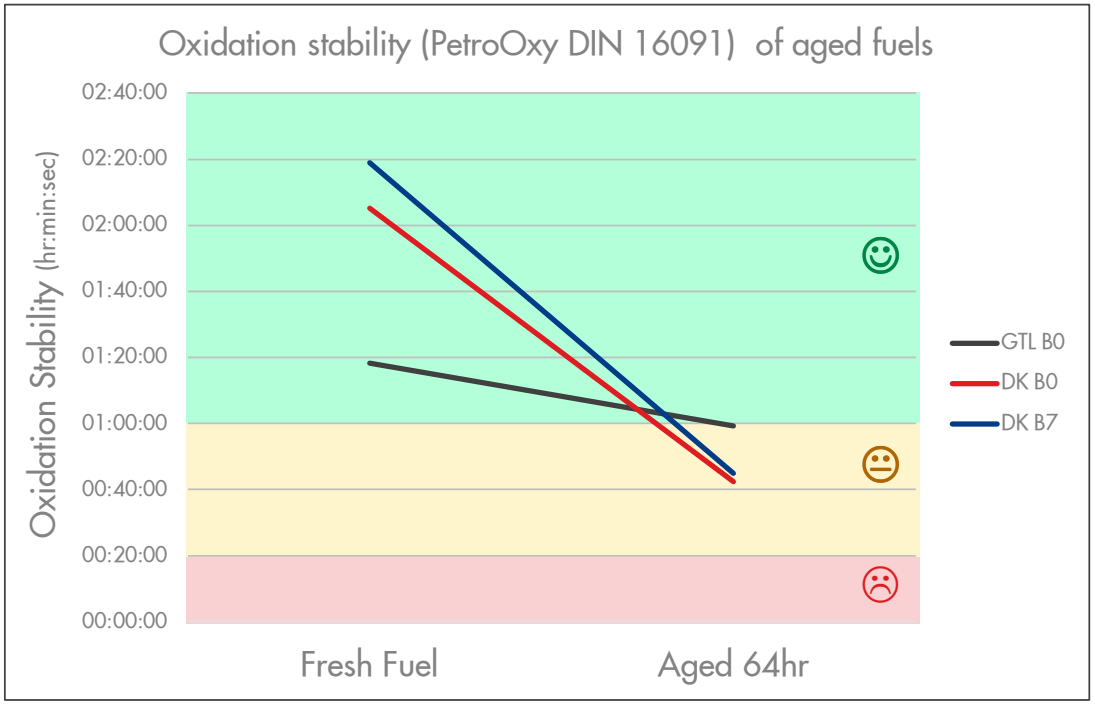
“PetroOxy” OXIDATIONSSTABILITÄT

GTL Fuel bleibt länger stabil als Diesel

In PetroOxy oxidation stability tests, GTL Fuel outperforms conventional diesel after 64hours of aging (high temperature, pressure), indicating it has a longer shelf life.

64hrs of aging ≈ 2 years of storage. Based on these curves, GTL Fuel *theoretically* has a storage life of over 6 years+.

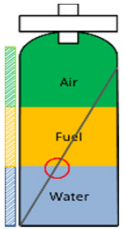
Note: this is an accelerated long term test simulation aimed at understanding the fuel performance over several years, whilst the tests only take several days. Therefore these figures are indicative only are no guarantee of absolute long term performance. Also good storage conditions in the customer tank are critical to achieving long shelf life for GTL Fuel.

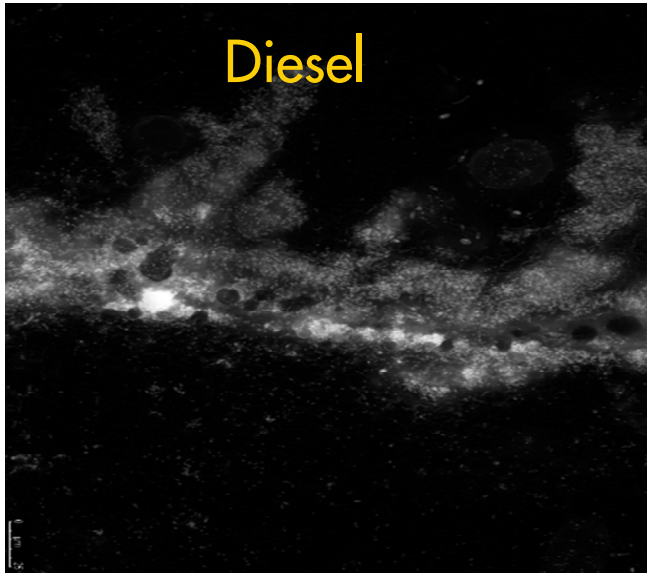


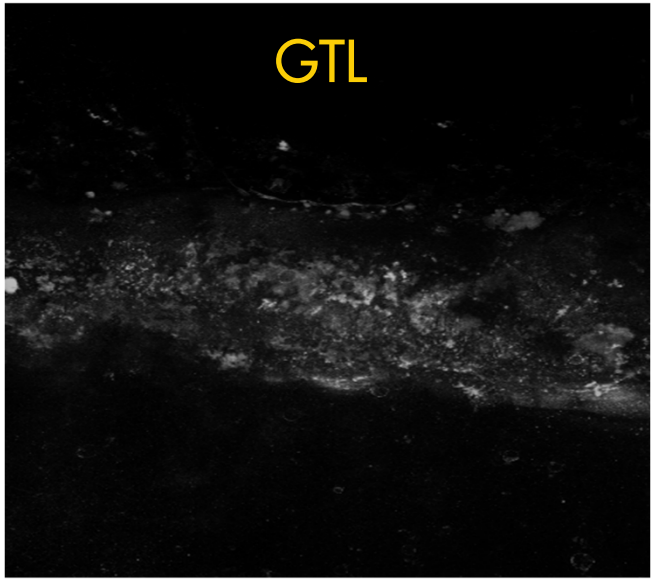
Source: Tec4Fuels analysis

RISIKO MIKROBENWACHSTUM MINIMIERT

- Microbial growth in fuels can severely influence diesel engine operations (e.g. **slimy sediments in fuel tanks, filter clogging**), product quality (HC molecules are broken down, leading many **physical/chemical properties to deteriorate**) and harm to equipment (e.g. formation of acids that lead to **corrosive attack of tanks and engines**)
- Microbial growth can be an issue specifically in **hot climate areas**
- The pictures below give an impression of the amount of material from microbial growth (picture of the test coupon from the fuel/water interface)
- The pictures show clearly that much **less microbial material is present when GTL is applied**, demonstrating the very **positive effect of GTL to advantageously reduce microbial growth**

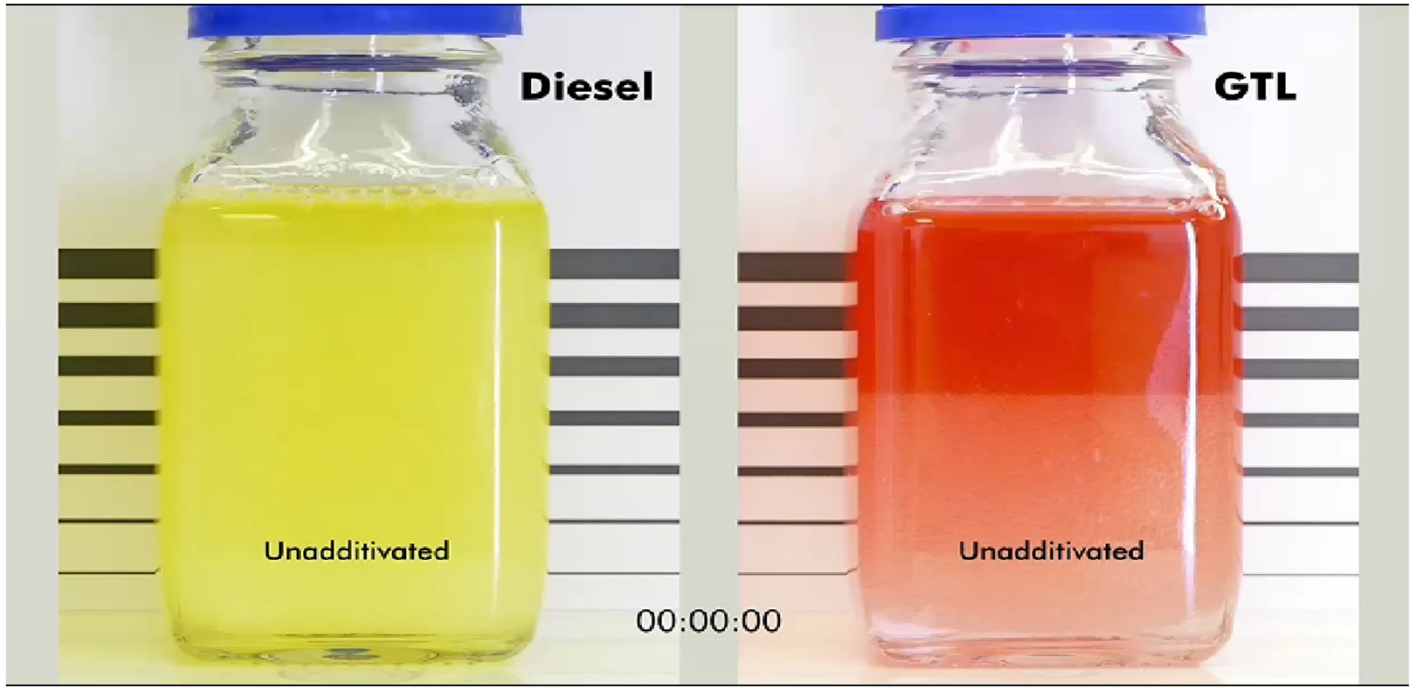






SCHNELLERE UND VOLLSTÄNDIGERE WASSERABSCHEIDUNG

- GTL Fuel and diesel have been mixed with an identical amount of water and intensively shook
- The video (showing a period of 1 hour) demonstrates how quickly water separates from GTL
- The video demonstrates also that even tiny water droplets are shedding from GTL, as haziness of the fuel disappears quickly

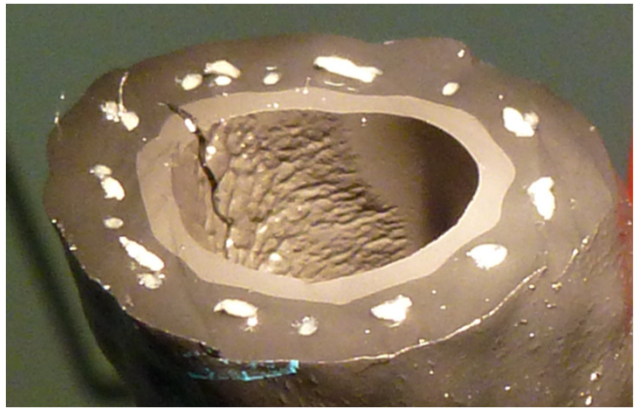


ELASTOMERVERTRÄGLICHKEIT

✓ Undichtigkeiten Dichtungen und Schläuche
Wechselwirkung **<u>veränderte Kraftstoffzusammensetzung</u>** und spröde Elastomere

➢ Austausch des betroffenen Bauteils behebt das Problem nachhaltig

Nicht in allen Fällen sind Undichtigkeiten kraftstoffbedingt



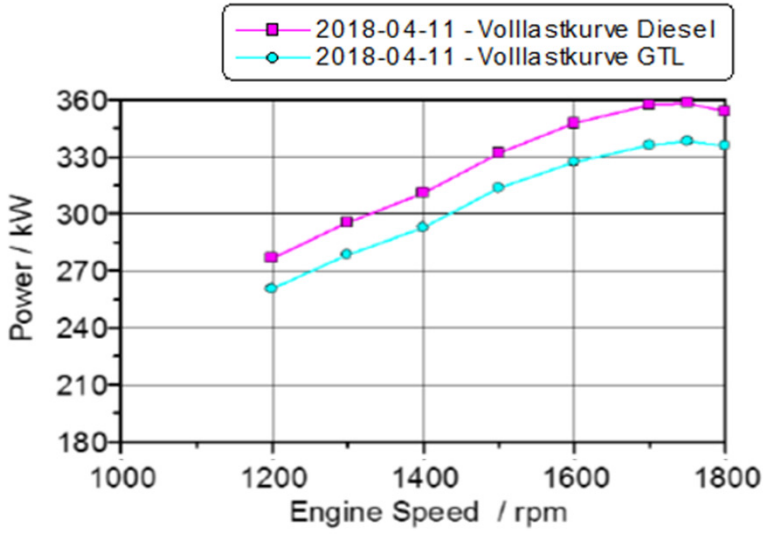
Motorenleistung

✕ Maximale Motorenleistung reduziert

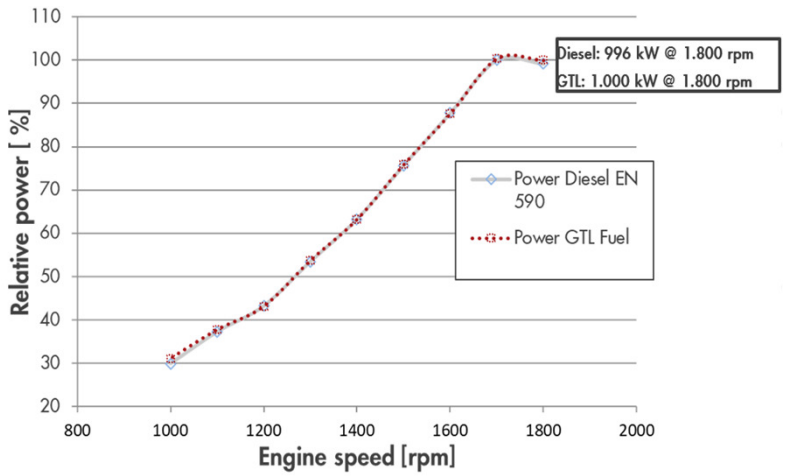
Auswirkung des geringeren volumetrischen Energieinhalts (3-5%) auf Regelung des Einspritzsystems

➢ Anpassung der Einstellungen an der Einspritzpumpe technisch möglich aber bei Motoren ab CCR1 nicht zulässig

Beispiel: Motor mit Reiheneinspritzpumpe (PLD)



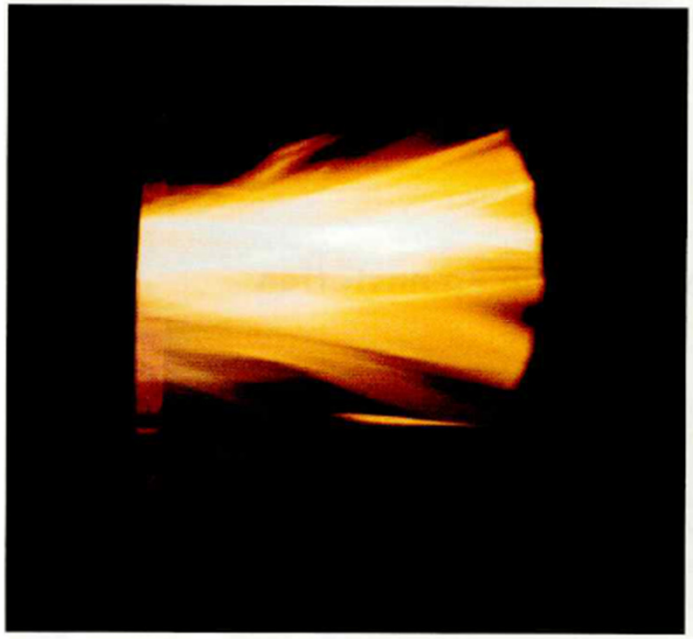
Beispiel: Motor mit CR Einspritzung



FLAMMENÜBERWACHUNG BRENNER

✓ Optische Flammenwächter erkennen die transparentere Flamme von GTL nicht

➢ Adjustierung (Empfindlichkeit) oder Austausch gegen modernen Flammenwächter in vielen Fällen möglich

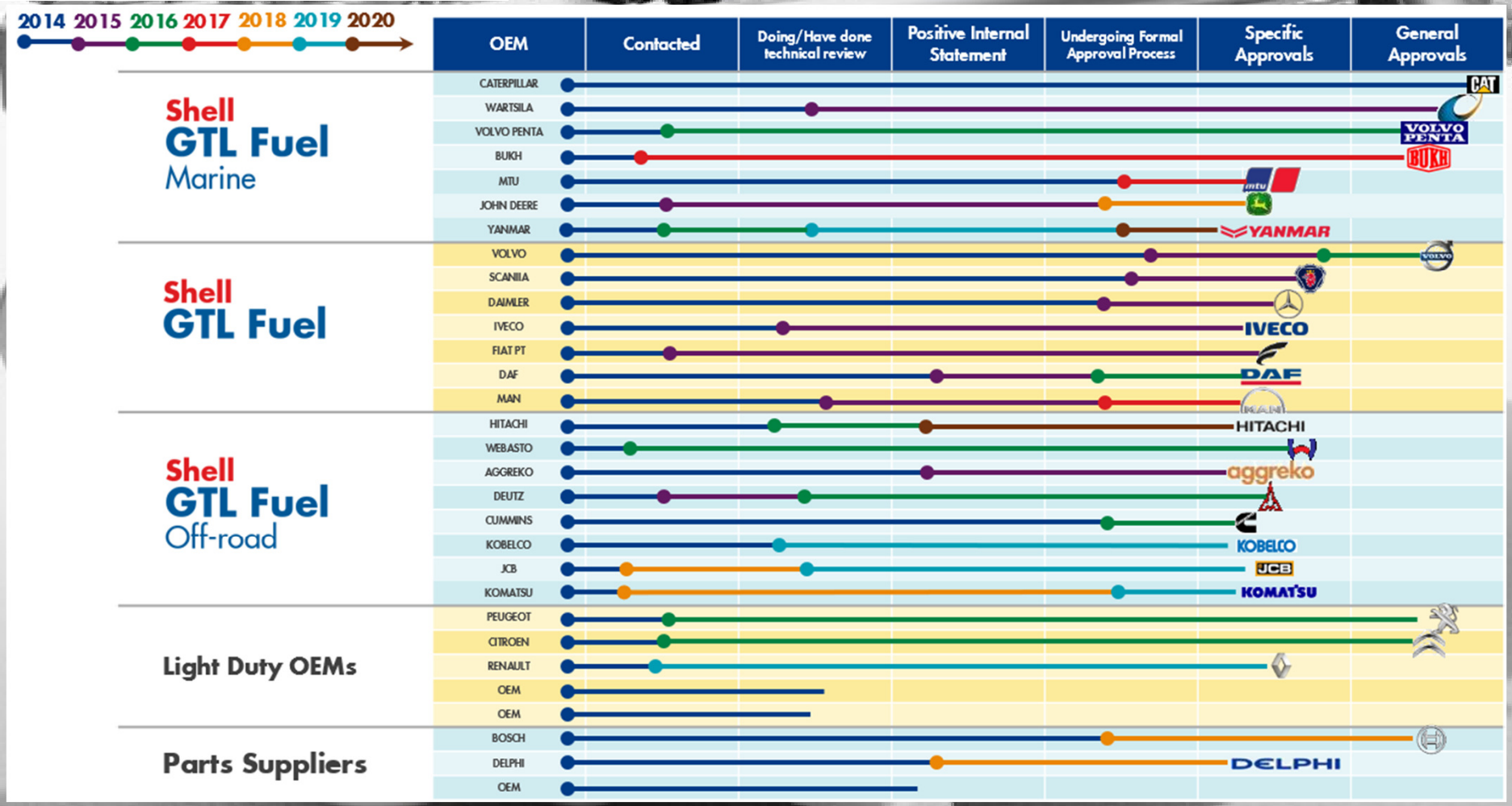


Flammenbild HEL/DIESEL

Flammenbild GTL Fuel

Bilder: Weishaupt

HERSTELLERFREIGABEN



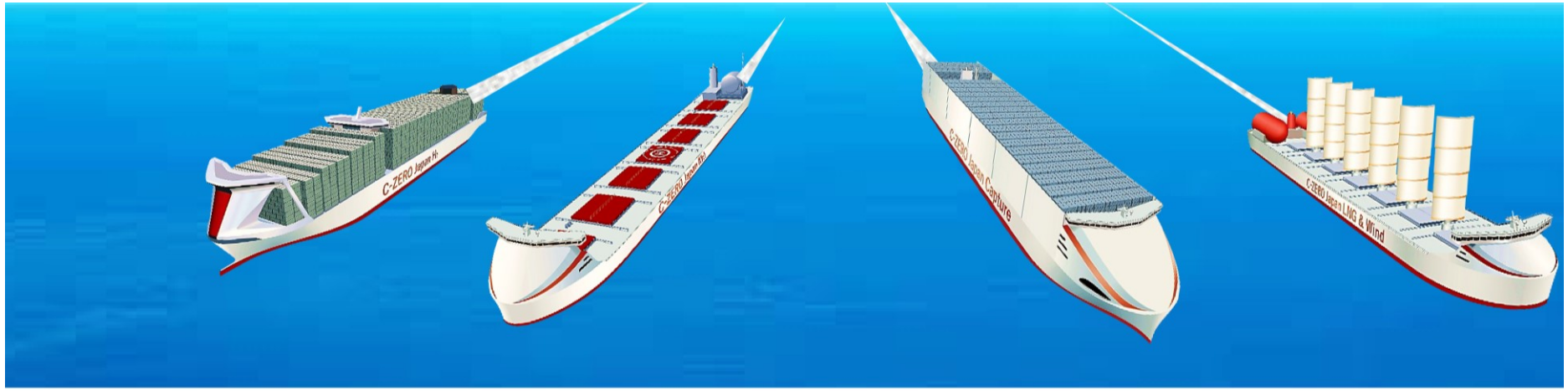
Vielen Dank für Ihre Aufmerksamkeit

Review and prospect of 'marine fuels' (Marine-Kraftstoffe: Rückblick und Ausblick)

Koji TAKASAKI**, Prof. (Emeritus), Dr., Kyushu Univ. **JAPAN

***Part 1**: Experiences in ship operation using **V**ery **L**ow **S**ulphur **F**uel **O**il (**VLSFO**) from 2020, related to combination with cylinder **L**ub. **O**il*

Part 2**: Combustion studies on alternative fuels, **natural gas** & **methanol



Part 1: *Experiences in ship operation using **VLSFO** : **V**ery **L**ow **S**ulphur **F**uel **O**il*

*(Residual Fuel Oil with less than 0.5 % Sulphur) related to combination with cylinder **L**ub. **O**il*

- *Fuel shift from high-sulfur heavy fuel to VLSFO has been promoted almost smoothly.*
  - *A mainstream in the market ・・ High-paraffinic VLSFO*
  - *Paraffinic fuels burn better than aromatic ones.*
- *However, just after the fuel change in 2020, more frequent **tribological troubles** for low-speed two-stroke main engines than before ・・ unexpectedly reported.*

(Photo left)
*Piston is seen from a scavenging port and piston rings part looks **dirty,** filled up by the **black deposit.** piston-rings **stick** in the ring grooves.*

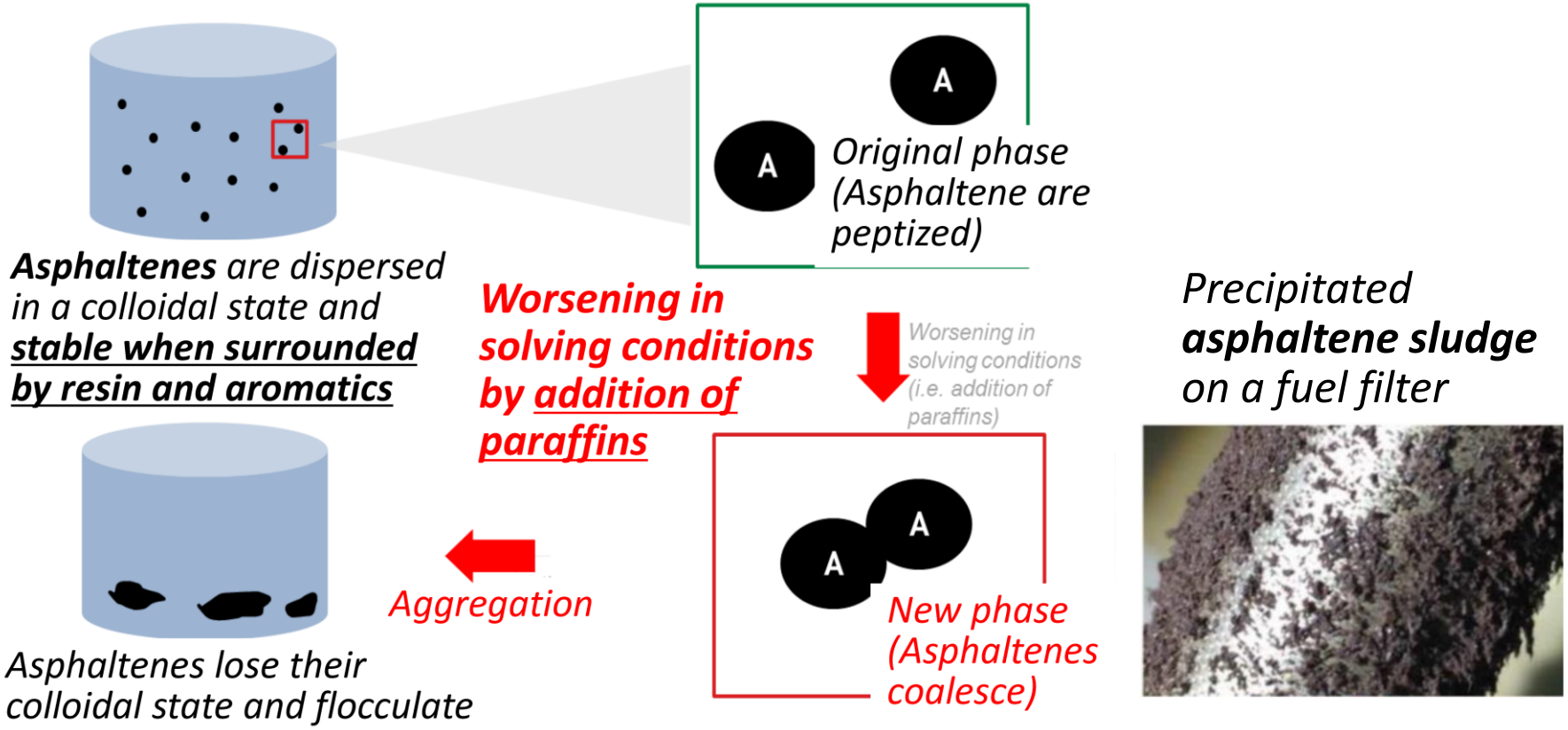
(Photo right)
*Ring is **broken**, maybe by sticking, would result in the liner scuffing.*

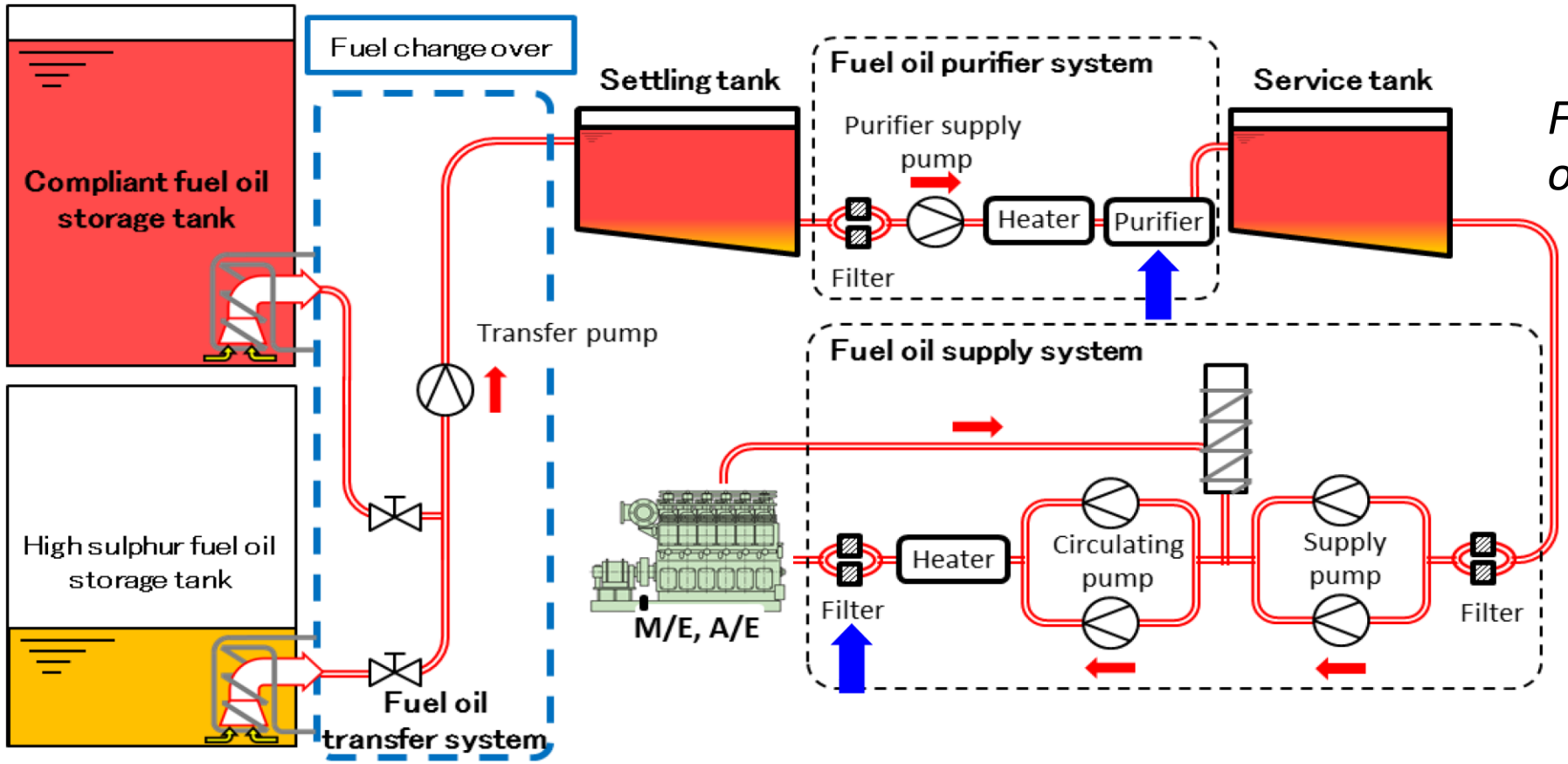
(Quoted from The MOTORSHIP – IMO 2020: A monumental change for the industry, 2020/4/17)

Two causes are considered, from the fuel side and from the Lub. Oil (LO) side.

- *It is considered as a cause in the fuel side that・・*
  - *・Too-high-paraffinic VLSFOs have lower compatibility, higher possibility to form the asphaltene sludge by mixing, in tanks and in pipes.*

If much paraffins are mixed ・・(quoted from CIMAC Guideline)





Fuel treatment system on board

Once sludge is formed, fuel treatment system in the figure, like purifier and filters should play the part to separate the sludge. But separating efficiency is not 100%.

So, even small amount, unseparated ***sludge particles*** *would be injected into the engine. Some of them would be* ***unburned*** *every cycle, and* ***deposit*** *in the piston ring part (・・A reasoning by the presenter).*

A possible cause in the cylinder Lub. Oil (LO) side

*Story・・Before 2020, cylinder LO with high-alkali (**BN70** or BN100) were used to neutralize sulfuric acid from high sulphur fuel.*

*・・After 2020, as a possibility of 'ash deposit' ('white deposit') formation with excess calcium by using too high-alkali LO for VLSFO was considered, LO was changed to lower alkali (**BN40**) in many cases.*

*By returning the LO from BN40 to **BN70**, cylinder troubles have been mitigated.*

*・・**BN70** LO has higher detergency than BN40 to disperse 'black deposit'.*

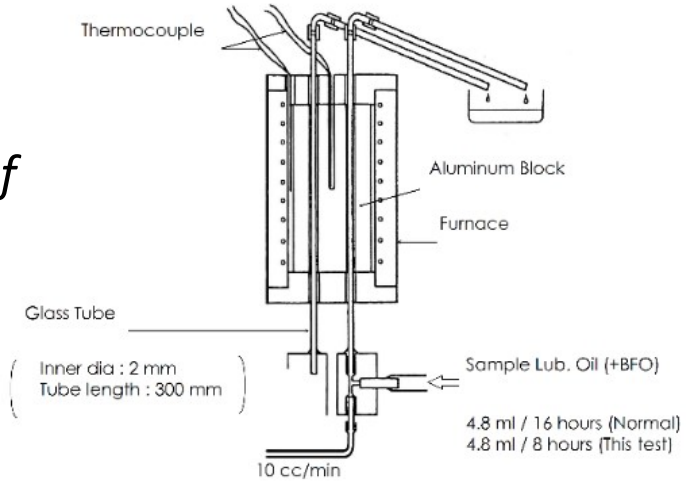
*・・**BN70** LO has higher anti-scuffing effect than BN40.*

***VLSFO + BN40** cylinder LO*

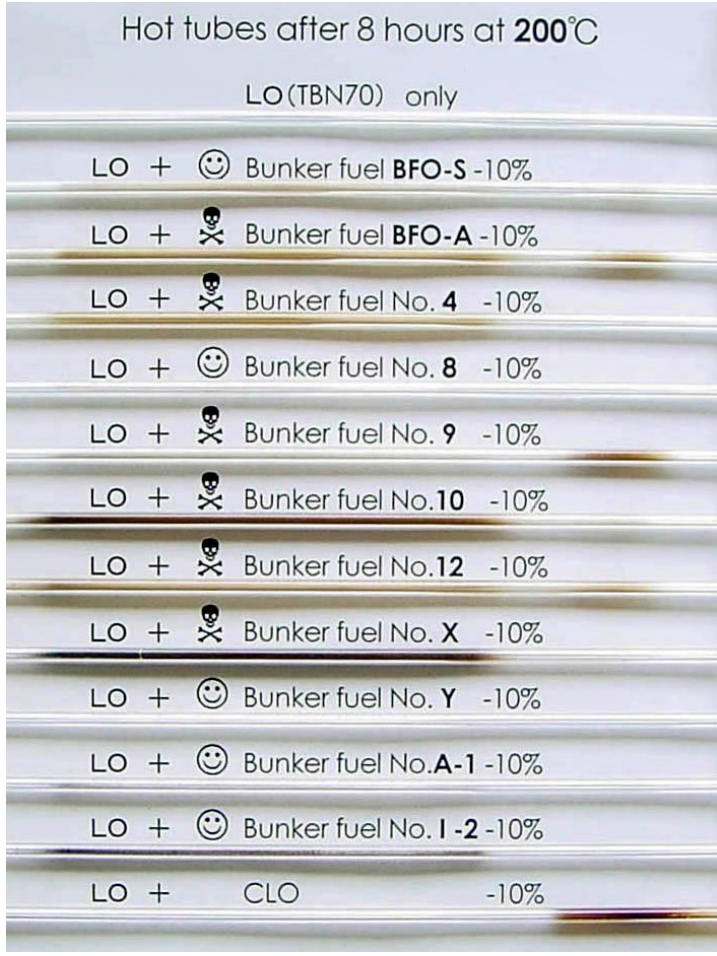
***VLSFO + BN70** cylinder LO*
(Black deposit on piston-land has been reduced)

As a history, during high sulfur and high aromatic heavy fuels were used for a long time, BN70 cylinder LO were well improved.

- *Reference :*
  An example of past fundamental research for BN70 LO
  - *(Right) HTT (Hot Tube Test) result of cylinder LO 90% + Bunker Fuel 10% simulating situation that unburned fuel portion is mixed to LO film on cylinder surface*
    (Takasaki, et al., CIMAC 2004).



Apparatus for Hot Tube Test (HTT)

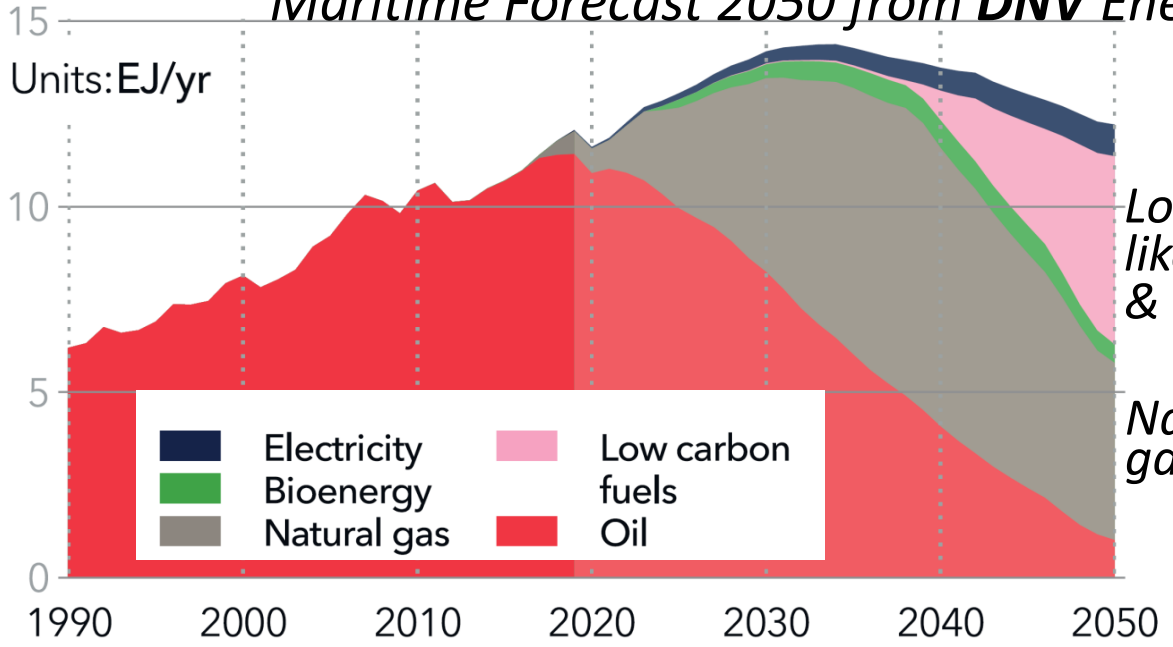


- *For VLSFO, new BN40 LOs (category 2) are expected*
  - *whose detergency and anti-scuffing effect should be as high as BN70.*

Part 2 Combustion studies on alternative fuels

Reference : An estimation of marine fuels by 2050

*Maritime Forecast 2050 from **DNV** Energy Transition Outlook (2021)*



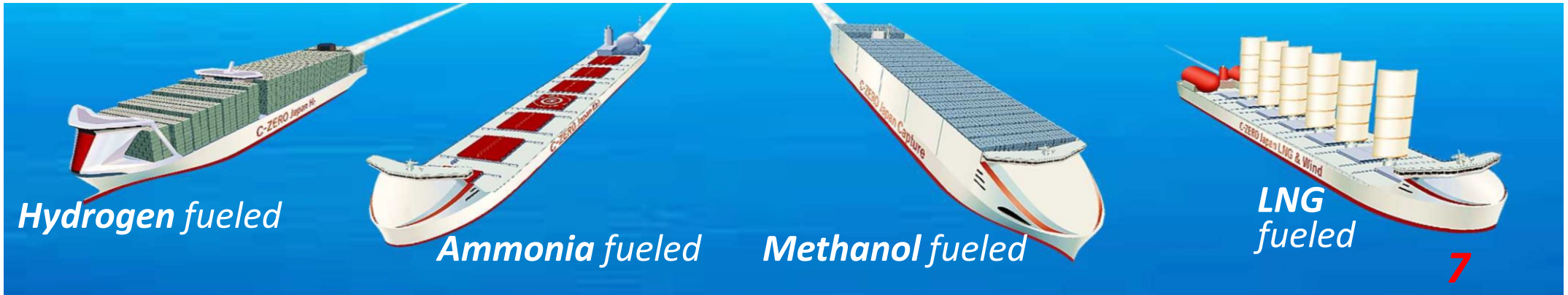
Low-carbon fuels like NH3, H2 & e-fuels

Natural gas

Target : GHG reduction to less than 50% of 2008 base at 2050

Concept ships using low-carbon fuels (Shipping GHG zero emission project, Japan)

https://www.mlit.go.jp/common/001354313.pdf



Studies on ammonia and hydrogen are in initial stage now and presented next year.
Today, combustion studies on the bridge fuels, like natural gas and methanol are introduced.

Reference: How many % CO2 can be cut by using the bridge fuels ?

2014 GUIDELINES ON THE METHOD OF CALCULATION OF THE ATTAINED ENERGY EFFICIENCY DESIGN INDEX (EEDI) FOR NEW SHIPS, AS AMENDED

MEPC.1/Circ.866
30 January 2017

Type of fuel	Reference	Lower calorific value (kJ/kg)	Carbon content	C_F (t-CO_2/t-Fuel)
1 Diesel/Gas Oil	ISO 8217 Grades DMX through DMB	42,700	0.8744	3.206

MGO base・・ (per same heat)

Bridge fuels ***EEDI (CO2)*** *ratio calculated by Lower Calorific Value and* ***CF***

4 Liquefied Petroleum Gas (LPG)	Propane	46,300	0.8182	3.000
	Butane	45,700	0.8264	3.030
5 Liquefied Natural Gas (LNG)		48,000	0.7500	2.750
6 Methanol		19,900	0.3750	1.375

*Propane —**14%***

*Natural gas —**24%***

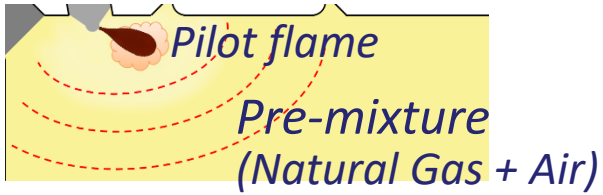
*Methanol —**8%***

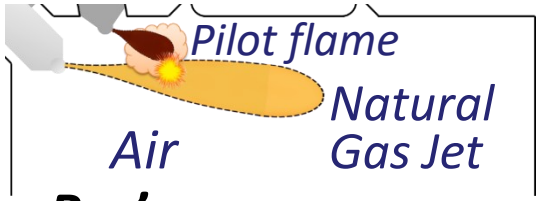
Net-zero fuels, like carbon-recycled methane instead of natural gas, bio-methanol and e-methanol are expected in the future.

2.1 Introduction of combustion studies on natural gas

Table: two types of natural gas engine

	Otto-cycle type gas engine Lean-burn (pre-mixed) (**low-pressure** gas supply)	**Diesel**-cycle type gas engine **GI** (Gas Injection) (**high-press.** gas injection)
Medium-speed 4-st.	Currently all	Possible but not yet applied
Low-speed 2-st.	Existing (X-DF, ME-GA)	Existing (ME-GI)





Pro's:

- Low pressure gas supply (≤1.6 MPa)
- Low NOx

Con's:

- Pme limited by abnormal combustion like pre-ignition (shown later) & knocking
- Higher methane slip

Pro's:

- Knocking-free, pre-ignition-free, any Methane Number is allowable
- Negligible methane slip

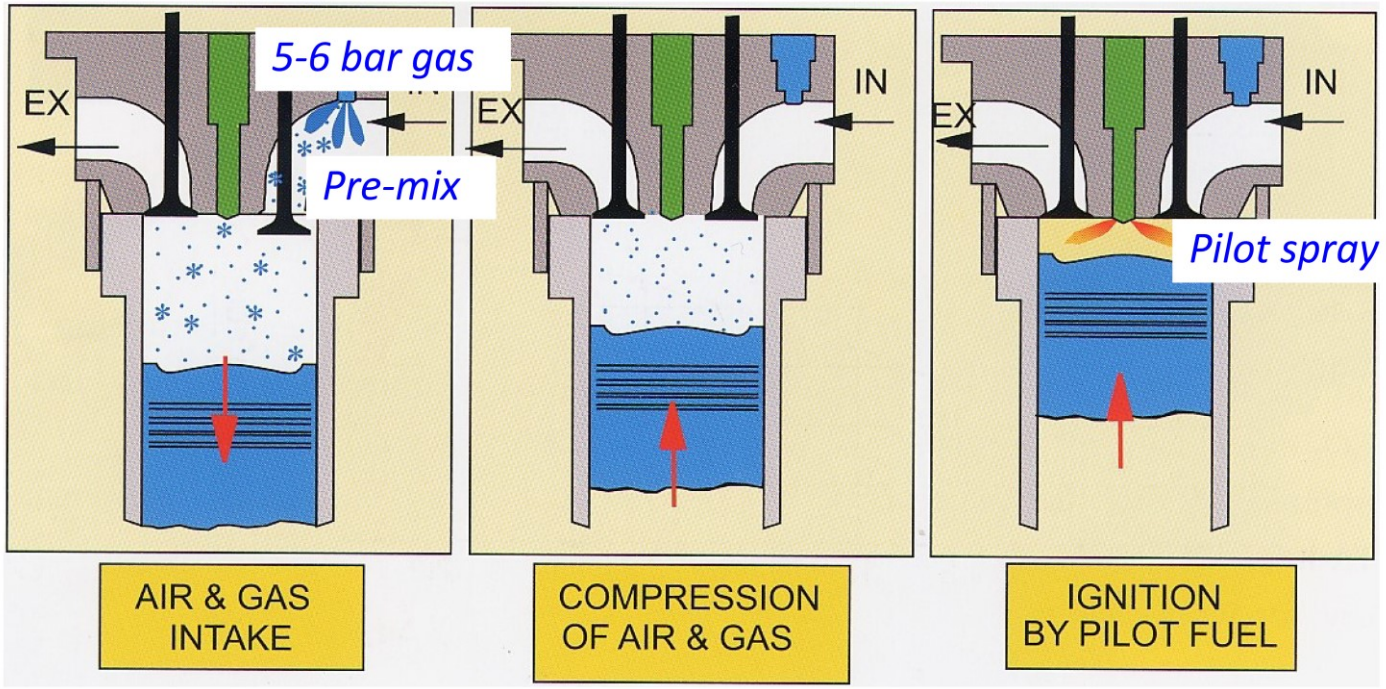
Con's:

- Higher NOx
- More expensive FGSS

2.1.1 **Otto-cycle** type natural gas pre-mixed lean-burn

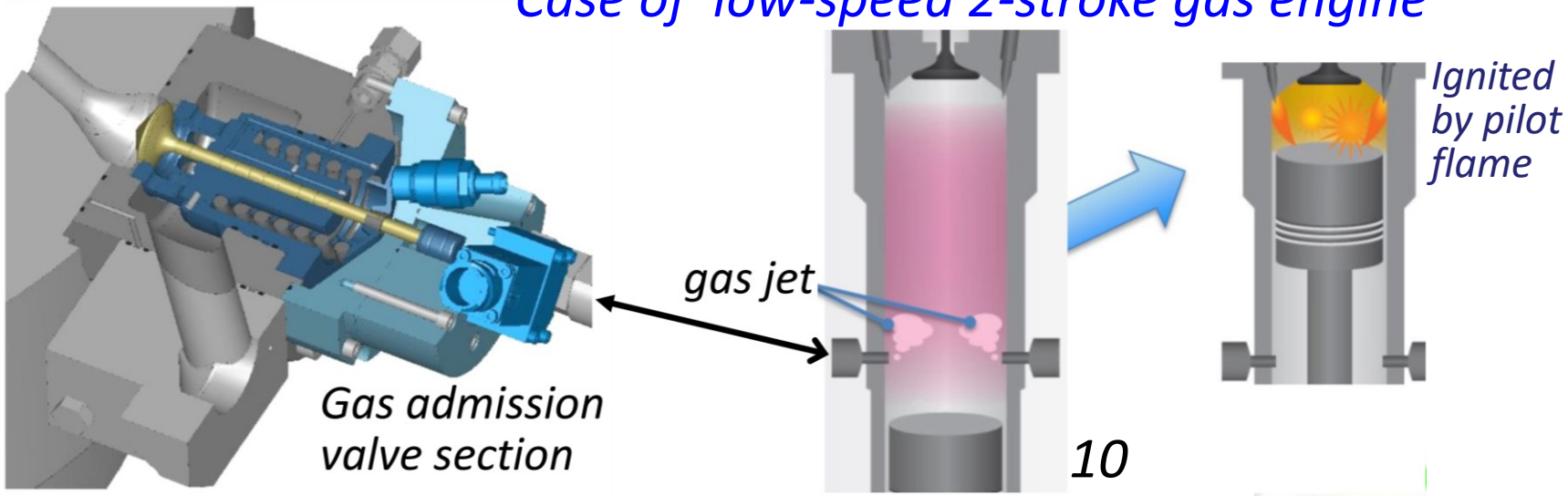
*How to make mixture (Natural gas + Air) for **Otto**-cycle type gas engine*

Case of 4-stroke gas engine

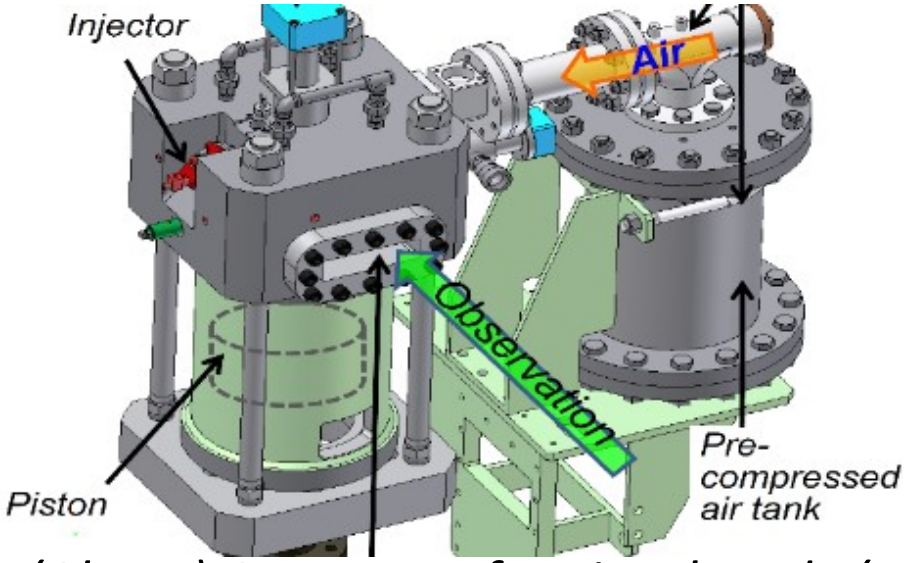


Natural gas is admitted into cylinder after scavenging timing through a nozzle drilled in cylinder-liner (Gas press. max 16 bar) (X-DF type)

Case of low-speed 2-stroke gas engine



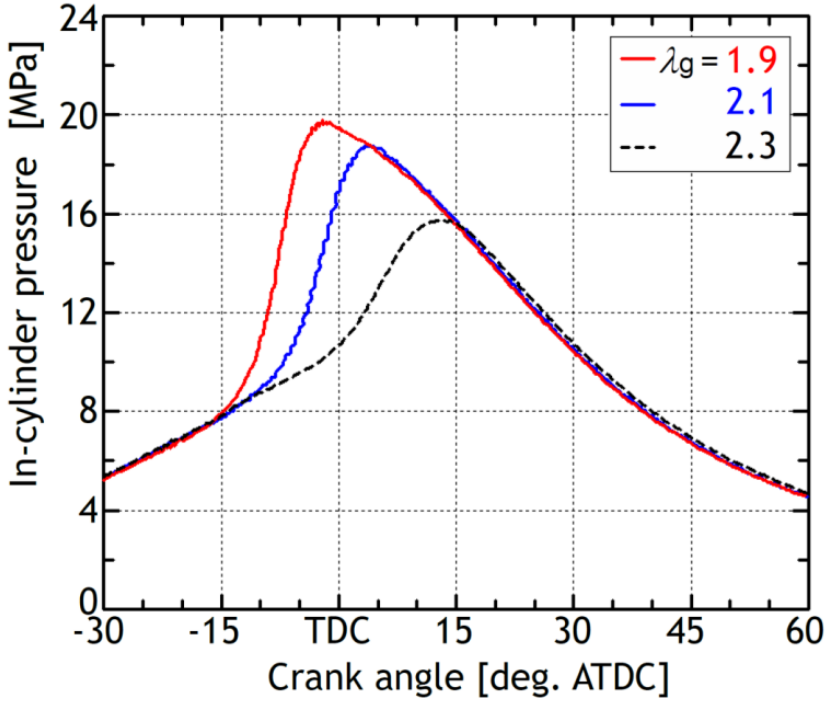
Quoted from CIMAC 2016 • Paper No.207 Takahiro Kuge (IHI Corporation, Japan), Study on Mixture Formation Process in Two Stroke Low Speed Premixed Gas Fueled Engine



An example of visual study on '<u>pre-ignition</u>'

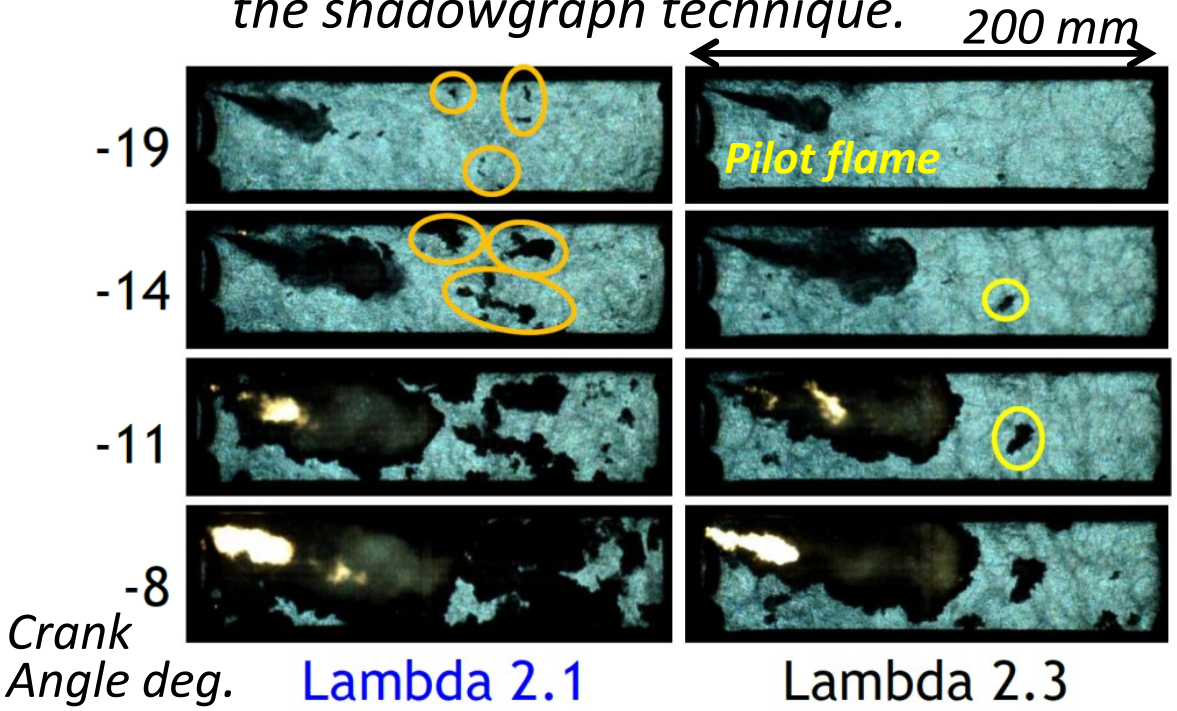
- *It is possible that natural gas + air mixture would be pre-ignited during compression stroke by cylinder **<u>L</u>ubricating <u>O</u>il** (**<u>LO</u>**).*

Pre-ignition causes higher Pmax and excessive cycle-to-cycle variation for cylinder pressure (below: from black to blue & red)



(Above) Apparatus for visual study (RCEM)

(Below) <u>Burning area of mixture looks black</u> by the shadowgraph technique.

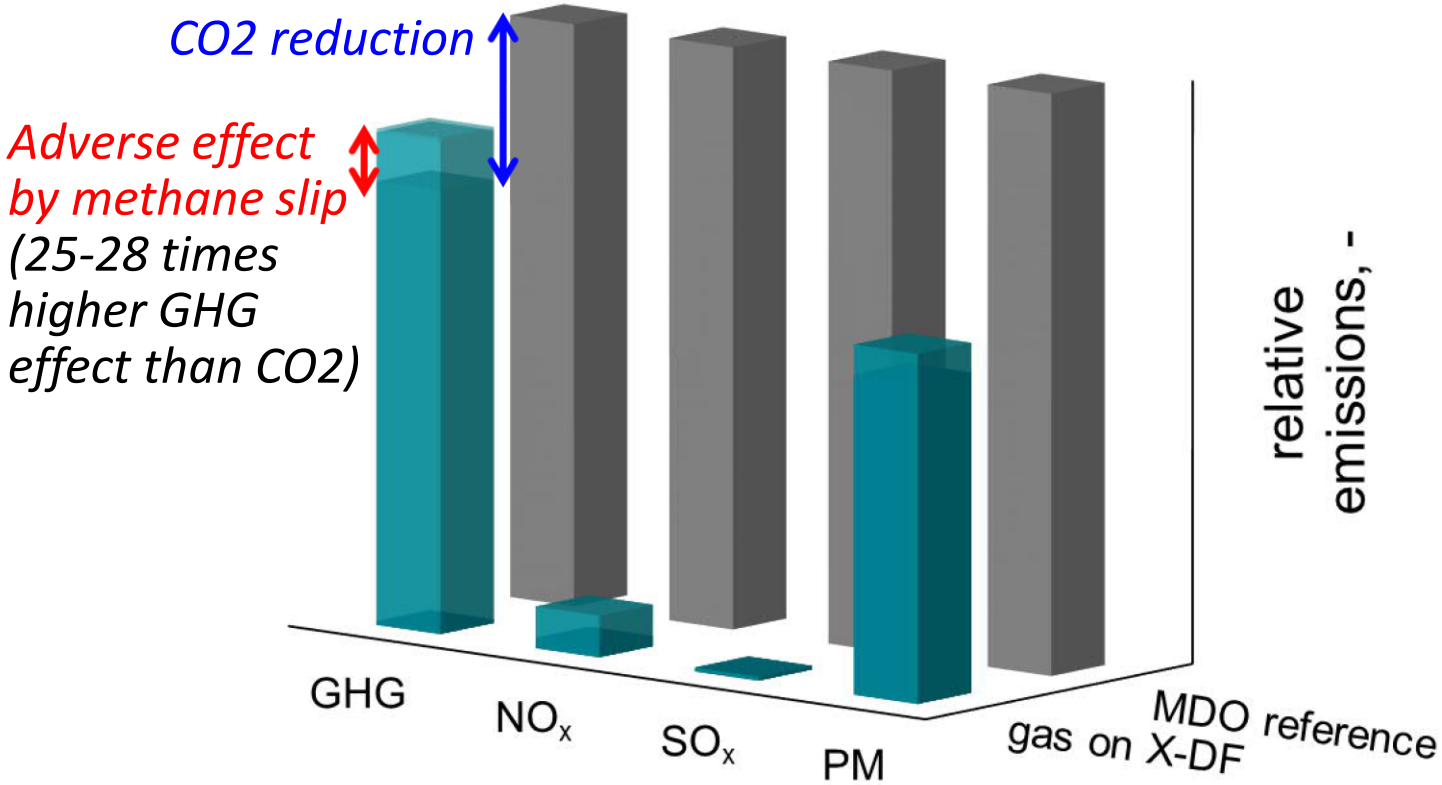


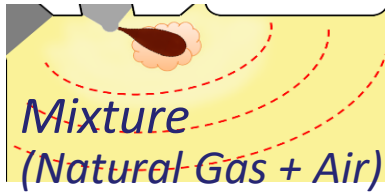
Photos left : Typical pre-ignition

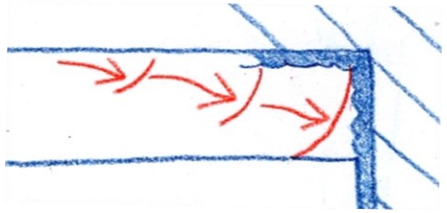
Small flames of self-ignited Lub. Oil (in circle) appear and pre-ignite surrounding mixture during compression stroke.

Another issue to be solved for Otto-cycle natural gas engine is ***'methane slip'***

An example of comparison of exhaust emissions between from an Otto-cycle natural gas engine and an MDO (Marine Diesel Oil) burning diesel engine (Case of low-speed 2-stroke)







An origin of methane slip

(unburned mixture layer near combustion chamber wall (blue part) is emitted every cycle.)

CIMAC 2019, Paper No.426,

Greenhouse Gas (GHG) Emissions from LNG Engines, Review of the Two-Stroke Engine Emission Footprint (WinGD, Switzerland)

A measure to mitigate both pre-ignition and methane slip (by WinGD and MAN)

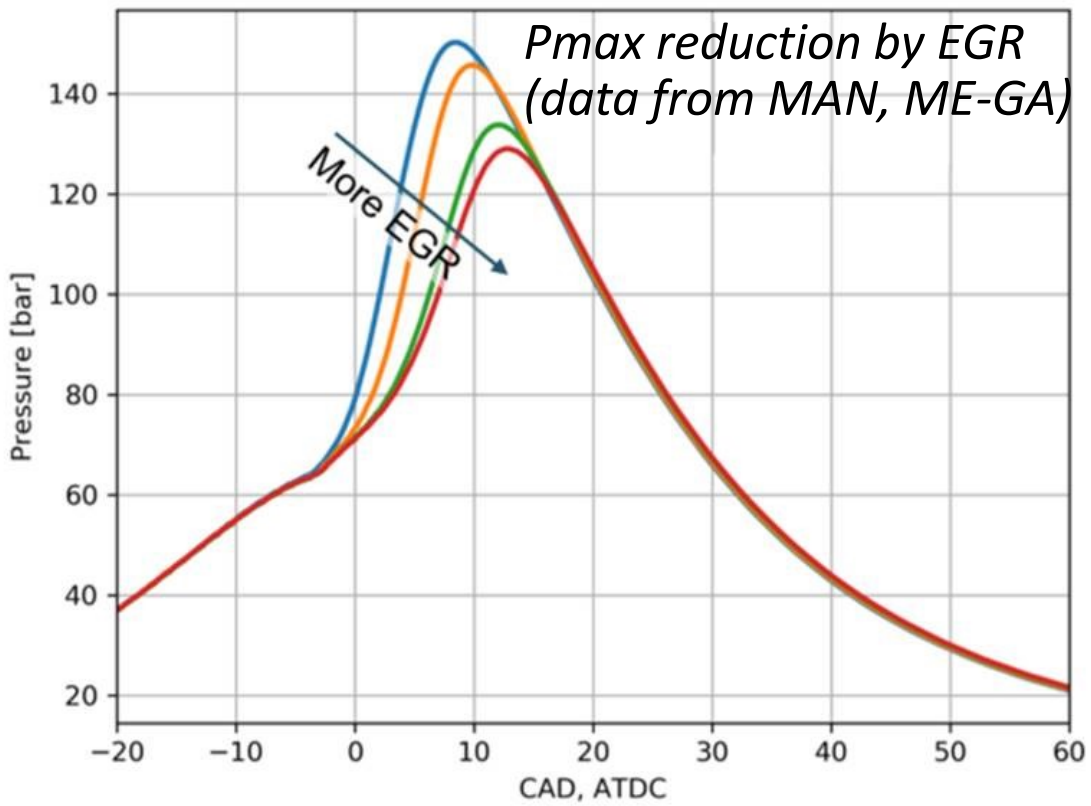
・・High rate of EGR (Exhaust Gas Re-circulation) (already applied to new engines)

・Pre-ignition and methane slip are absolutely unrelated phenomena each other.
but high rate of EGR is a common measure for them.

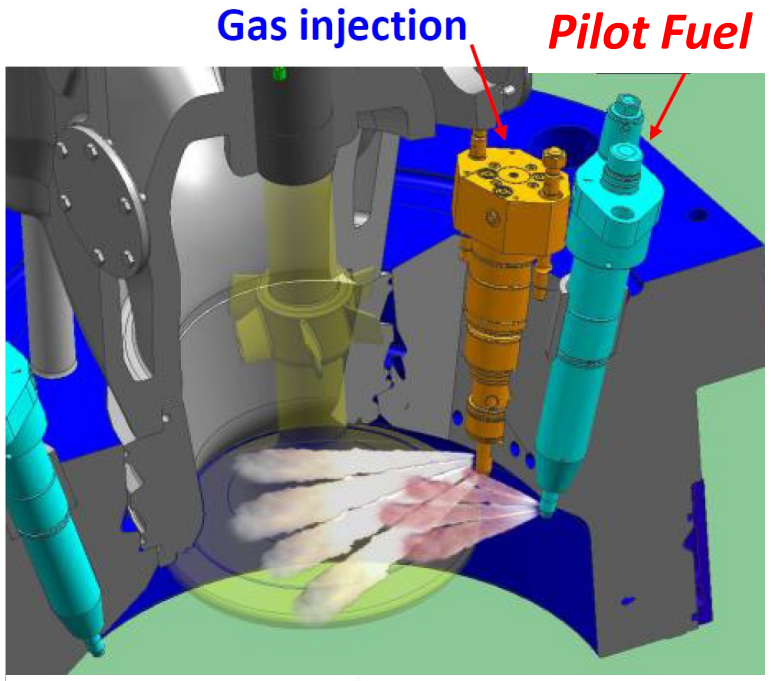
- Prevention of pre-ignition: EGR gas moderately reduces activation of mixture
- Effect to reduce methane slip
  : Re-burning of unburned methane in EGR gas

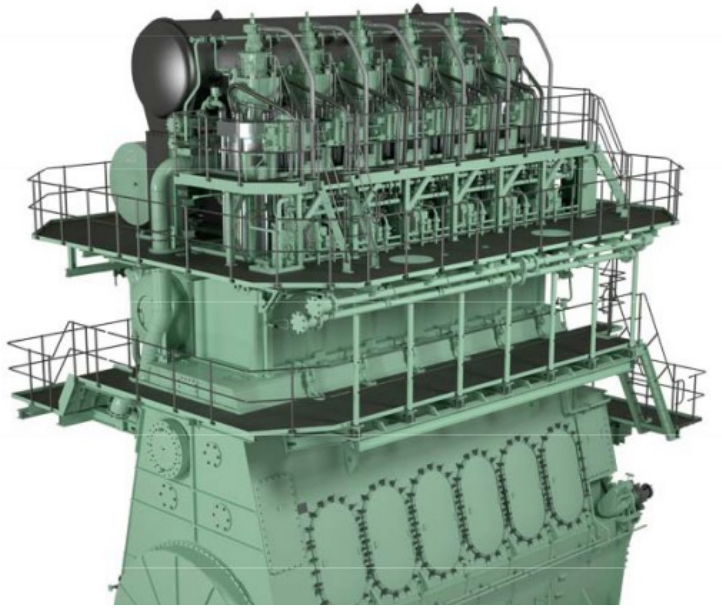
- Engine builders announce the following effects by EGR up to 50%
  - 3% energy consumption reduction in gas mode (Mitigation of pre-ignition allows setting of higher compression ratio.)
  - ・Up to 50% reduction of methane slip

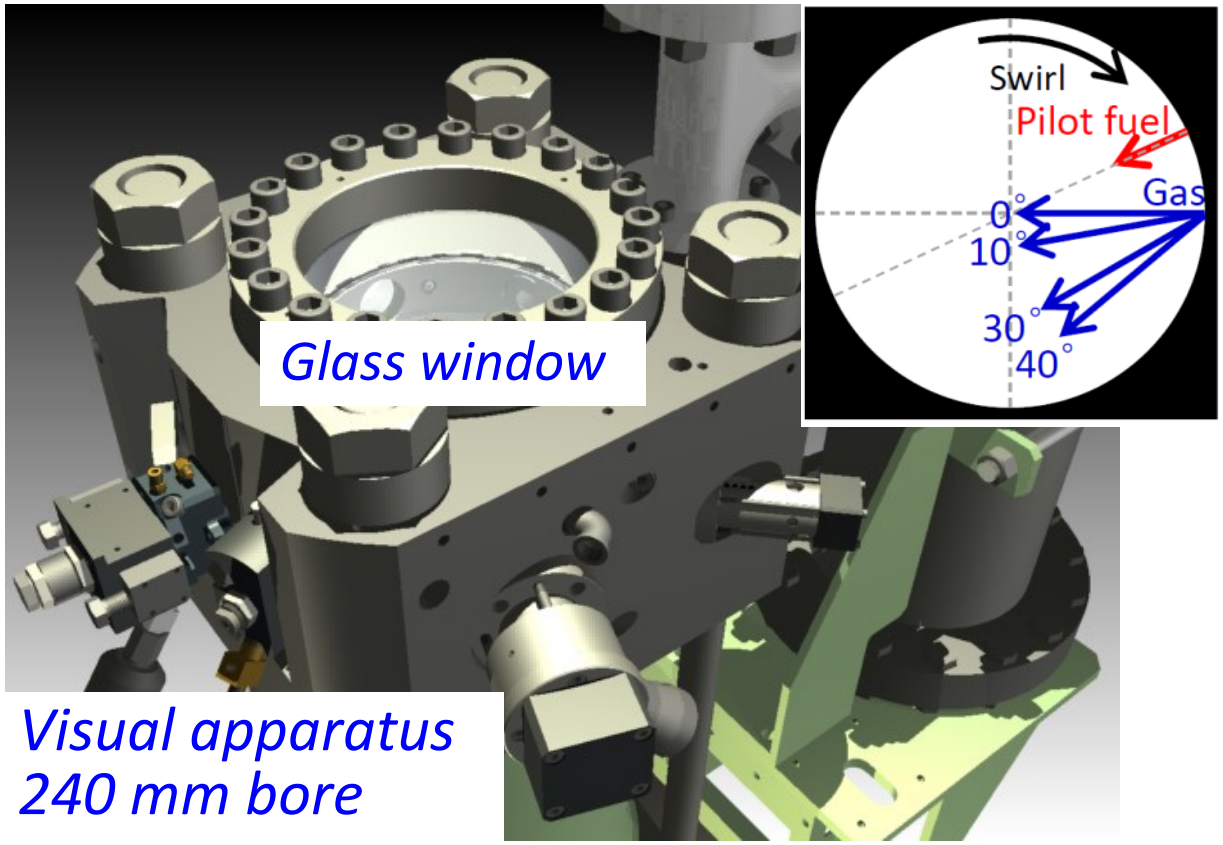
(Swiss engine designer, WinGD has confirmed that fuel savings achieved with its X-DF2.0 engine technology have surpassed initial expectations.
The MOTORSHIP 06/04/2022)



2.1.2 Diesel-cycle *type high pressure gas injection and combustion*



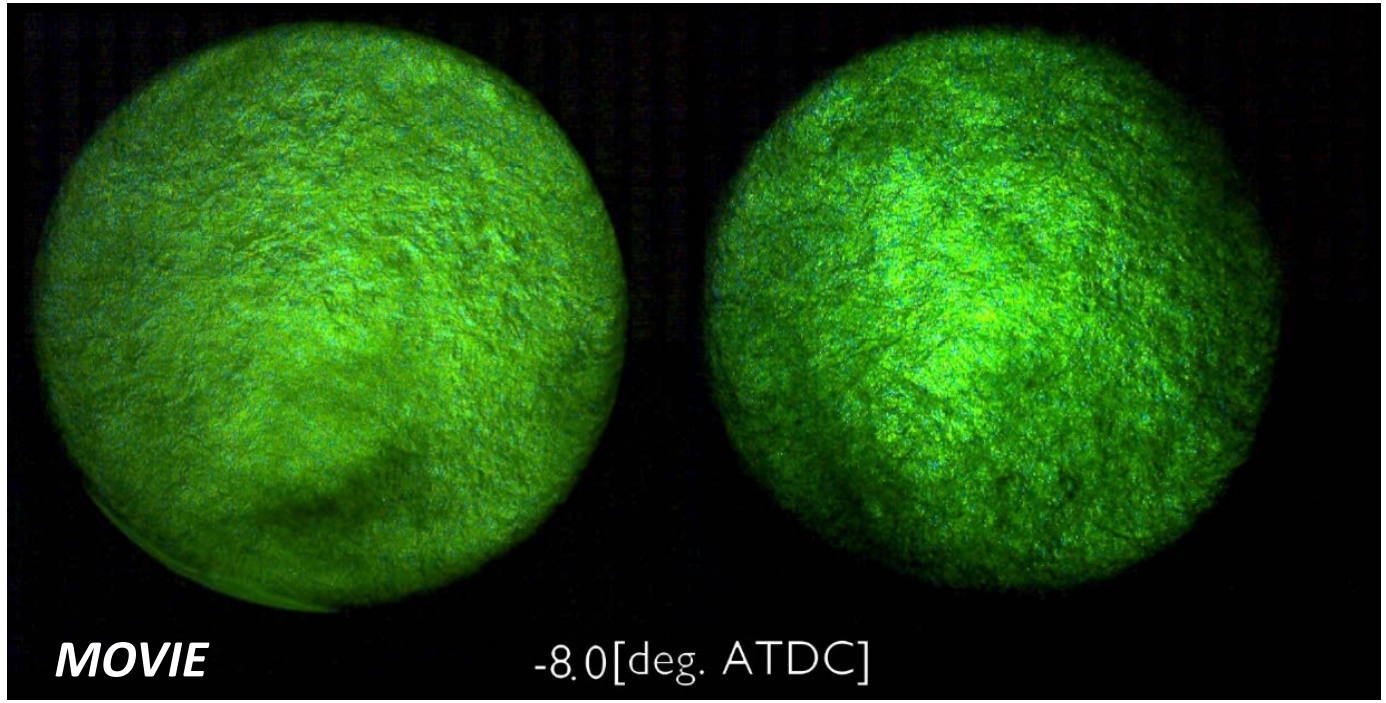


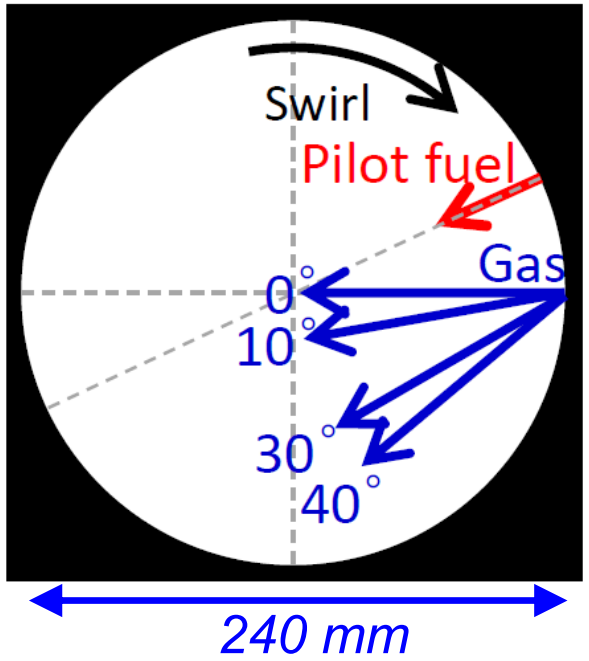


Visual apparatus
240 mm bore

A low-speed marine two-stroke ME-GI engine

Gas Oil *(Pinj.* ***135*** *MPa)* ***Methane CH4*** *(****32*** *MPa (Gas))*





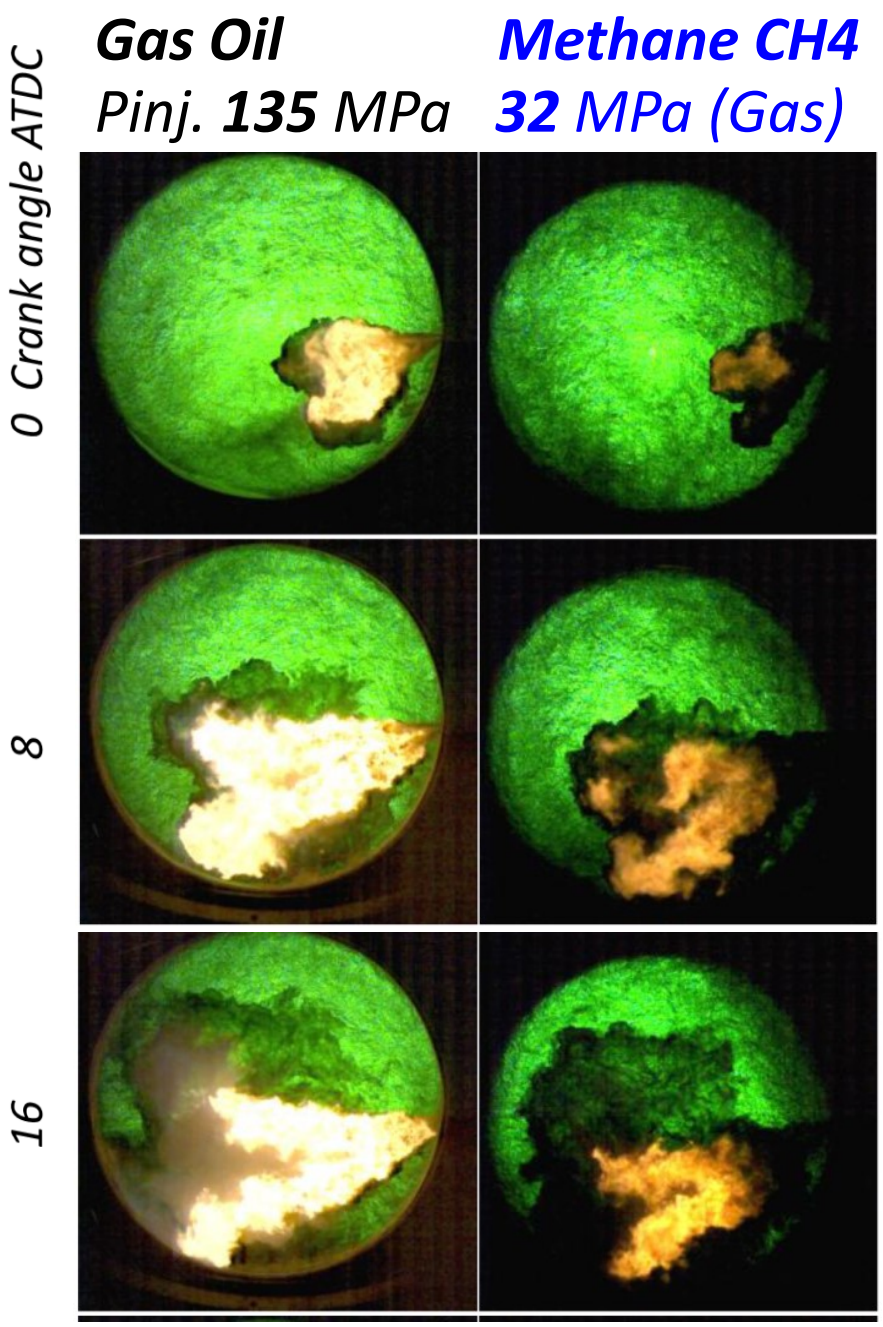
(Air : Pc 10 MPa, Tc 500℃)

Visualized flame (by shadow graph technique)

・*Green-coloured area is only air. Black part (including yellow flame) represents burning area. Burning area of Methane (right) spreads almost similarly to one of Gas Oil.*

・*Less-luminous (less-bright) yellow flame of Methane means a combustion with less soot formation (less black carbon).*

・*Such a diffusive flame of methane burn almost perfectly like diesel spray combustion, that leads to negligible methane slip.*



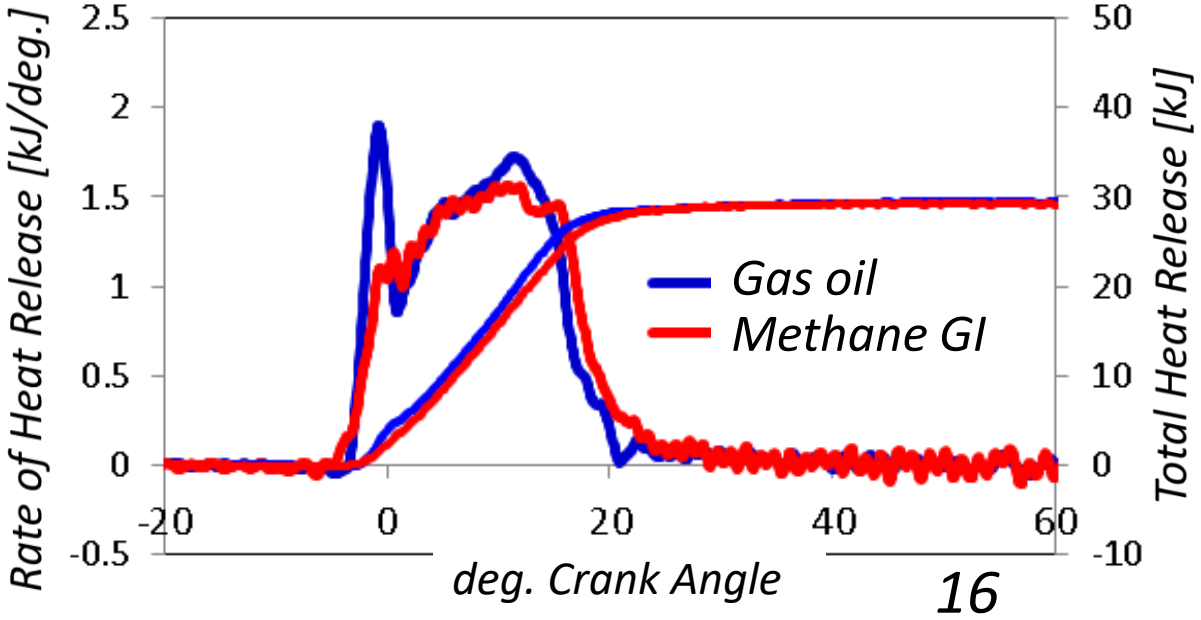
(Air: Pc 9.5 MPa, Tc 500 ℃)

Visualized flame (by shadow graph technique)

- Green-coloured area is only air. Black part (including yellow flame) represents burning area. Burning area of Methane (right) spreads almost similarly to one of Gas Oil (left).
- Less-luminous (less-bright) yellow flame of Methane means a combustion with less soot formation (less black carbon).
- Such a diffusive flame of methane burn almost perfectly like diesel spray combustion, that leads to negligible methane slip.

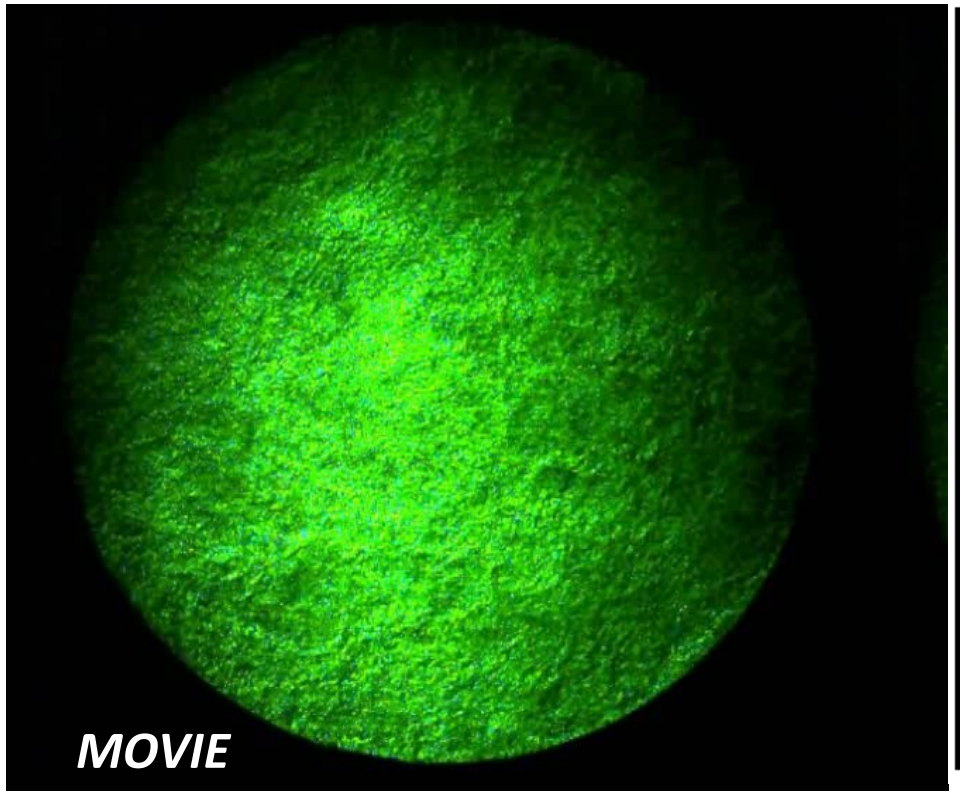
Combustion rate (below)

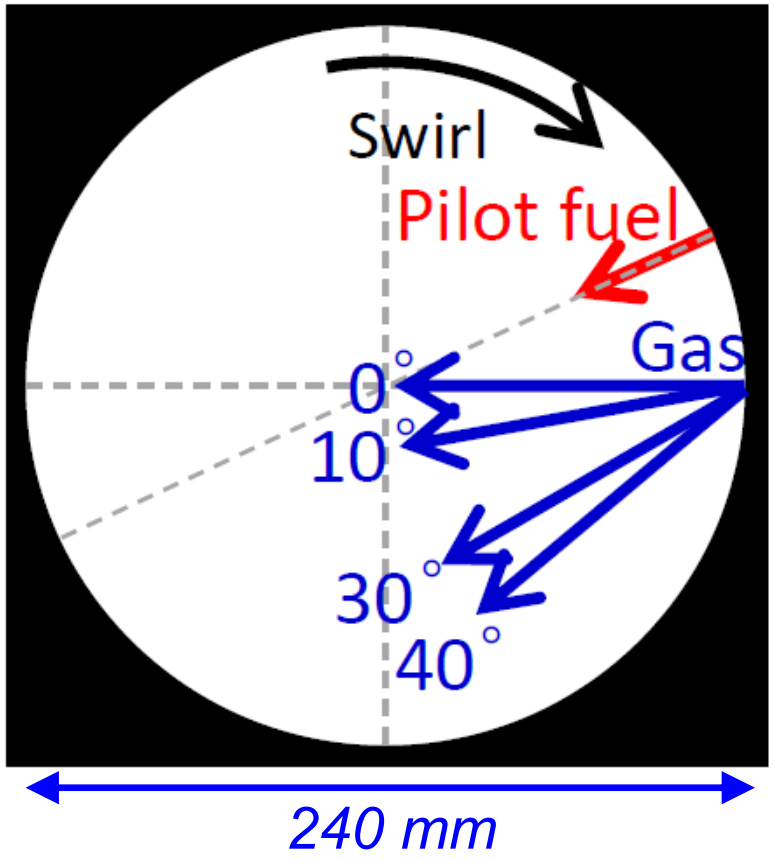
- Methane shows a similar combustion state as Gas Oil.



Ignition by pilot diesel fuel in detail

(Pilot mass is equivalent to 5% of total heat in this experiment)





2.2 Methanol spray combustion

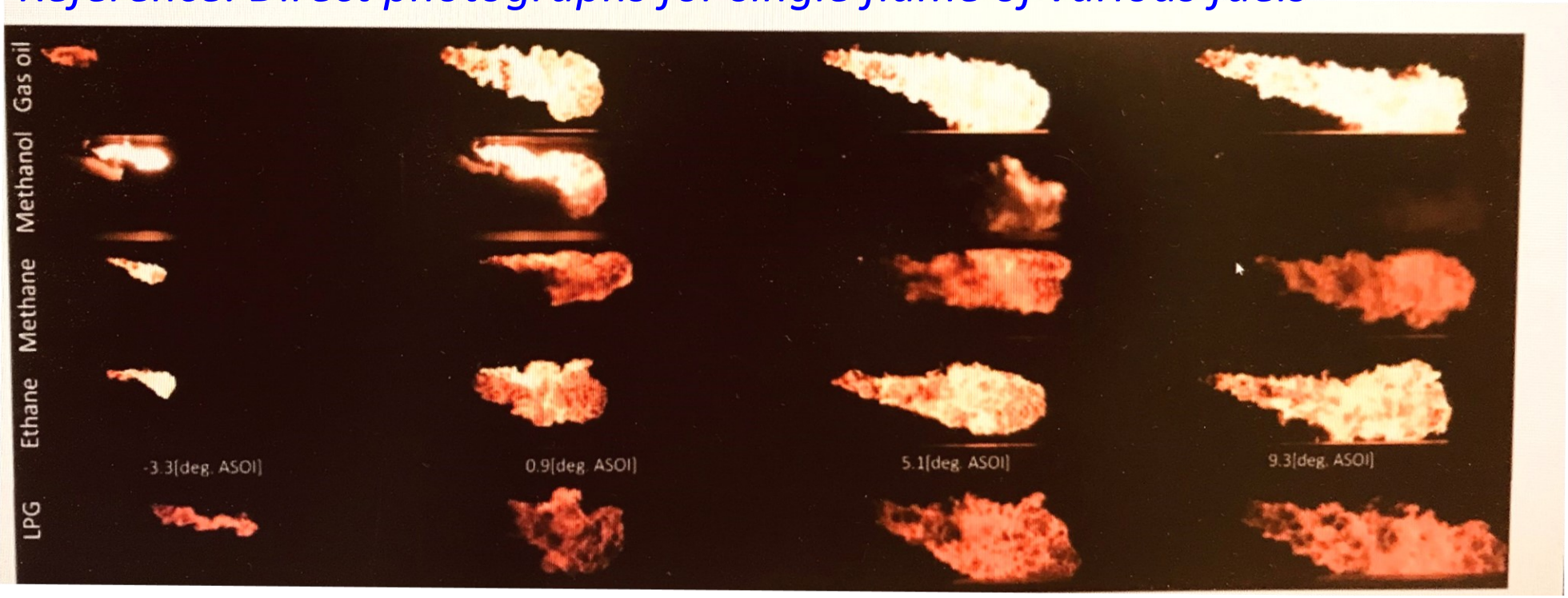
*Reference: Properties of **methanol** compared with gas oil*

	Unit	Gas Oil (Cetane)	Methanol
Formula		**C16H34** (Cetane)	**CH3OH**
Molecular Weight	kg/kmol	226 (Cetane)	32
Density	kg/m3	835 @288K (GO)	793 @293K
Boiling Point	deg. C	**287** (Cetane)	65
Latent Heat of Vaporization	kJ/kg	229 (Cetane)	1101
Flash Point	deg. C	45～70 (GO)	11
Ignition Point	deg. C	250 (GO)	450
Lower Calorific Value (LCV)	MJ/kg	**43.1** (GO)	**19.9**
Theoretical Air/Fuel Ratio	kg/kg	14.5 (GO)	6.5

Higher ignition point of methanol
- *Pilot fuel injection is necessary*

Lower calory of methanol
- *Two times more mass must be injected to get the same heat as gas oil*

Reference: Direct photographs for single flame of various fuels



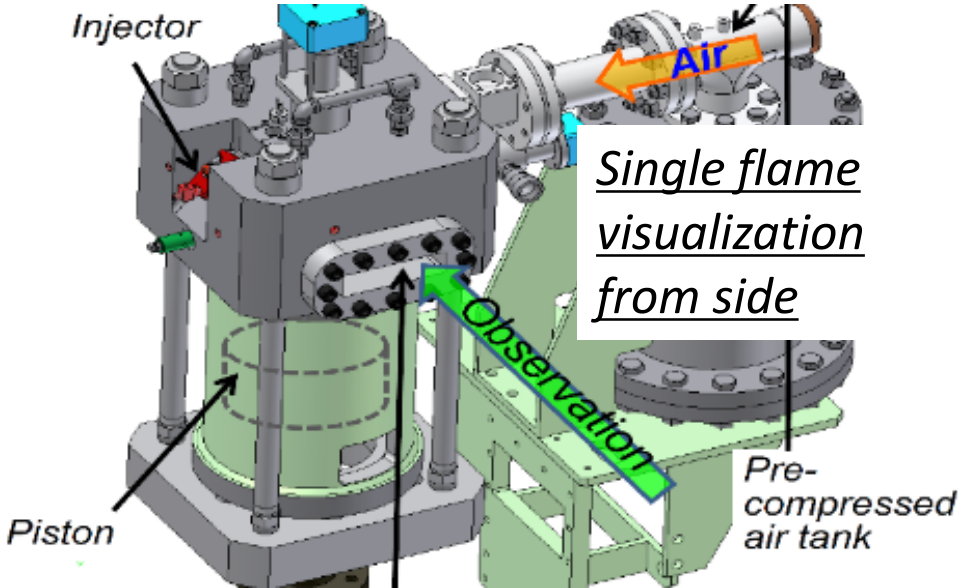
Gas oil

Methanol

Methane

Ethane

Propane



Single flame visualization from side

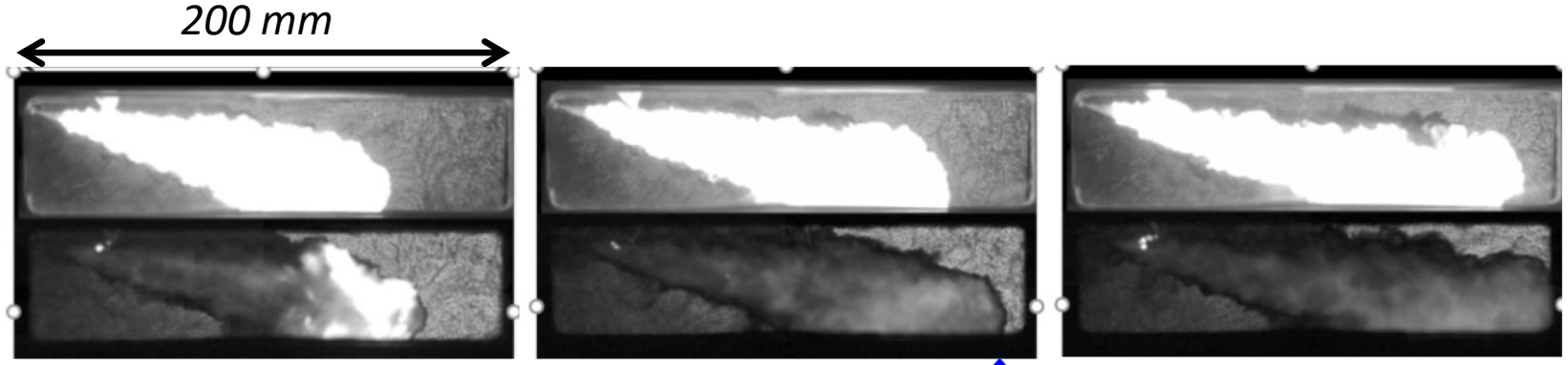
Methanol flame itself is almost invisible by the direct photos. (Only a pilot flame is visible)

- *Methanol shows the best combustion in the five fuels.*
  (Hard to self-ignite and pilot fuel is necessary. But once ignited, combustion state after that is the best. Less-luminous (less-bright) flame of methanol means a good combustion with less soot formation.)

Visualized methanol flame by shadowgraph technique

(a) **Gas Oil**
Inj. hole dia: 0.5 mm

(b) **Methanol CH3OH**
Inj. hole dia: **0.8** mm

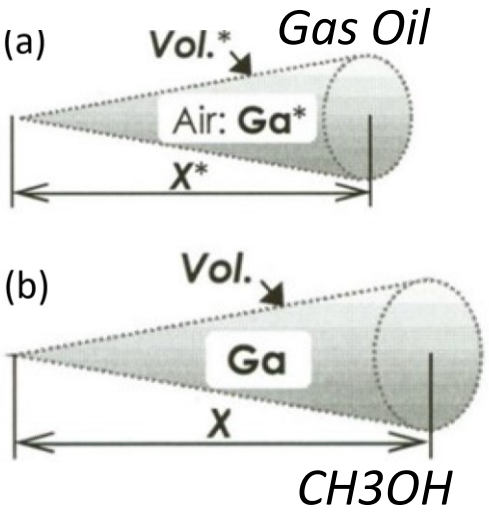


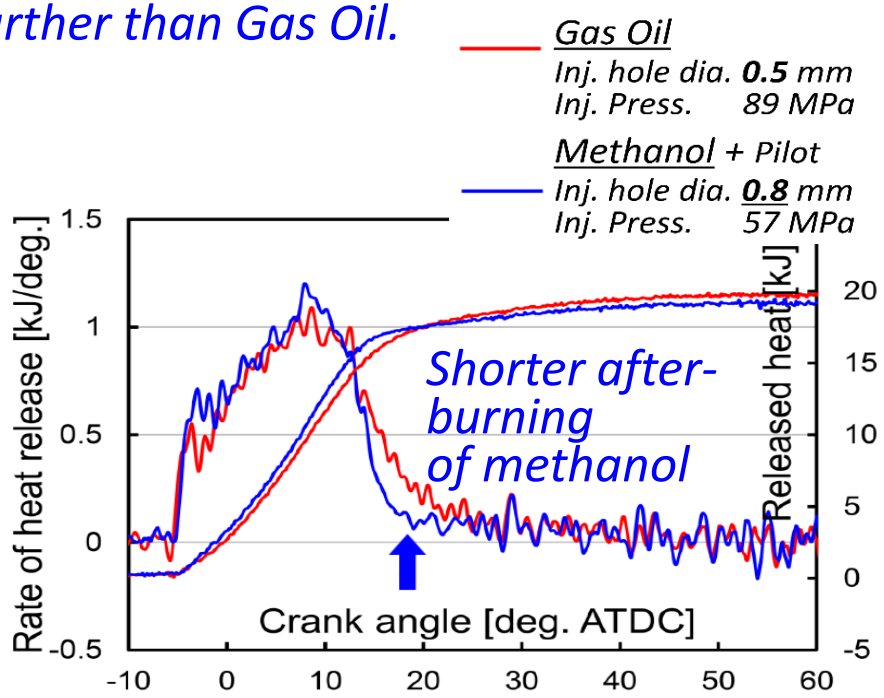
5 deg. 7.5 deg. 10 deg.

Methanol flame advances farther than Gas Oil.

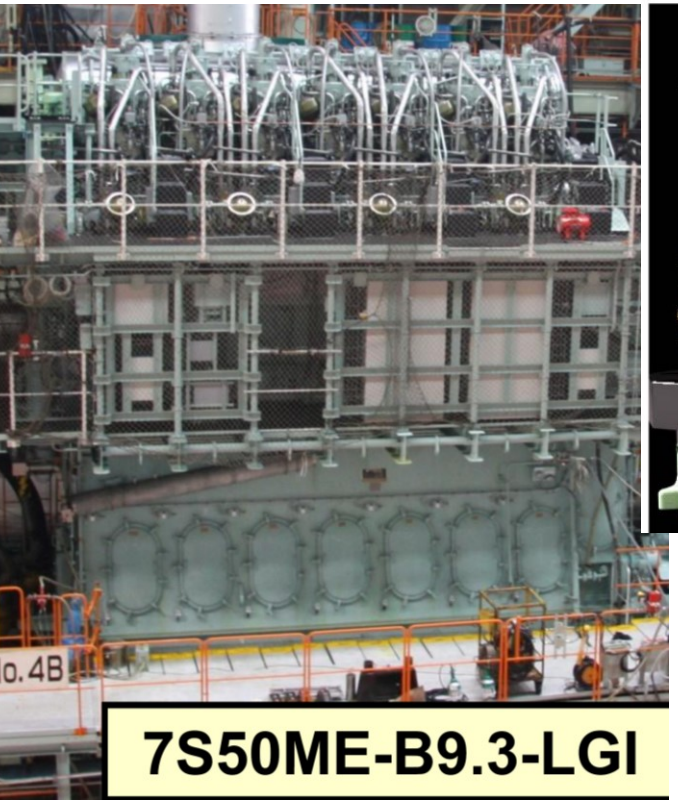
Two theories for the better combustion of methanol, **CH3OH**.

- Oxygen in methanol molecule has some good effect for combustion.
- Because of the lower calory, larger mass of methanol is injected from a larger hole than gas oil case.
  Larger momentum advances spray faster and forms bigger spray cone, air-richer condition for methanol.
  (The same effect as fuel-water-emulsion)

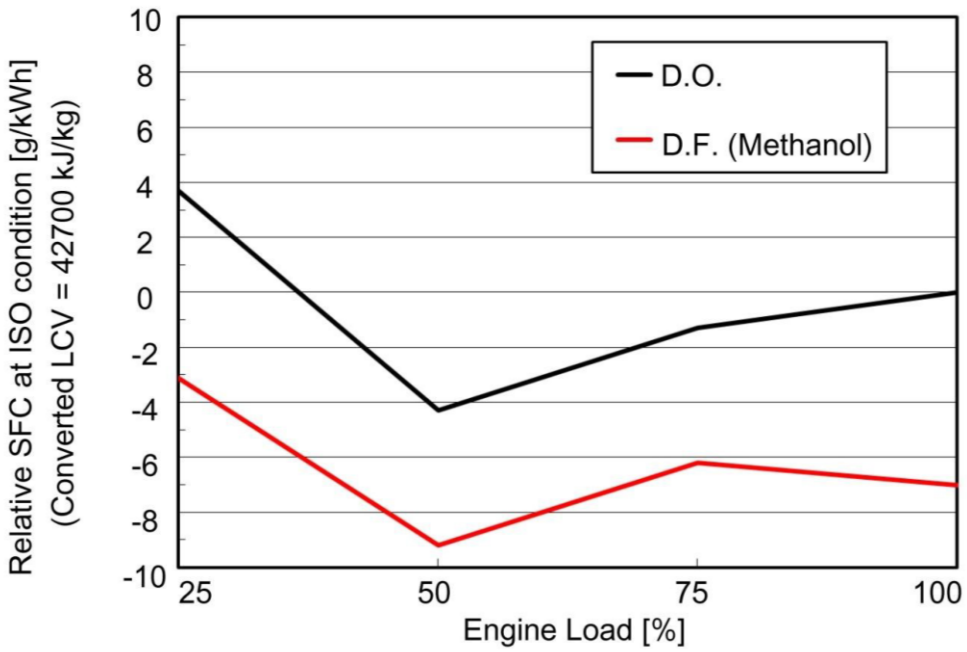


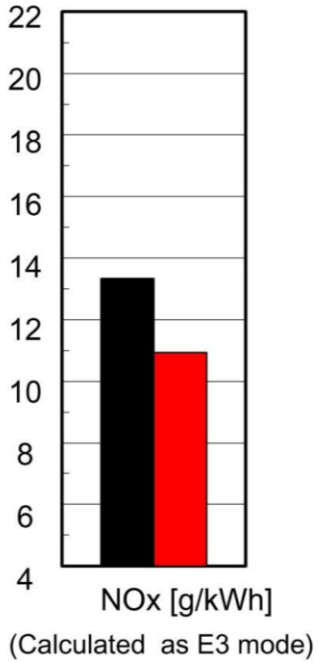


Methanol fueled (liquid CH3OH direct injection) low-speed 2-stroke engines are already in service.



Prototype test by MES, 2015





Improvement of thermal efficiency and NOx (by MAN E&S)

Cylinders	7
Bore	0.5 m
Connection rod	2.214 m
Stroke	2.214 m
Compression volume	16 l/cyl
Power	8,470 kW
MEP	16.9 bar
Speed	99 rpm
Max. pressure	185 bar

Recent news on green methanol: MOTOR SHIP 11/03/2022

A.P. Moller-Maersk has entered into strategic partnerships with six companies with the intent of sourcing at least 730,000 ton/year of green methanol by end of 2025 for the first 12 green 16,000 TEU container vessels currently on order.

Reference: on Lub. Oil for alternative fuels

At the end of the presentation, let's consider the performance requirements for cylinder LO for low-speed two-stroke engines using alternative (sulphur-free) fuels.

- *Lower BN but higher detergency for using VLSFO as shown in Part 1.*
- *(Excess calcium in LO precipitates as $CaCO_3$, white ash deposit.)*
  Ash should be softened by LO to prevent excessive wear of cylinder.
- *In case of Otto-cycle natural gas engine,*
  LO with higher self-ignition temperature is preferable to prevent pre-ignition of mixture.

- *On hydrogen and ammonia burning engines, not only combustion but also required feature for LO should be discussed.*

New studies on the zero-carbon fuels, ammonia and hydrogen will be introduced after next year.