Engine developments to meet emissions & efficiency regulations

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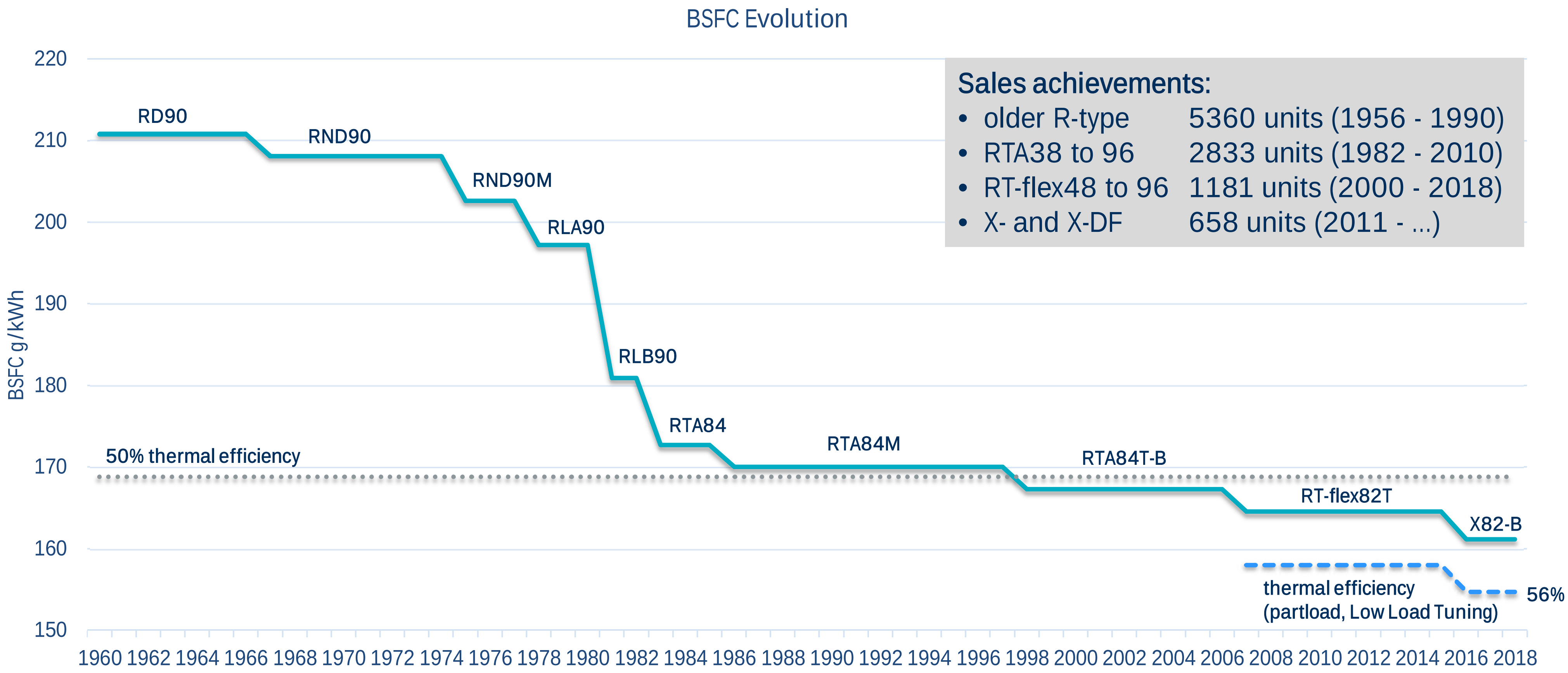
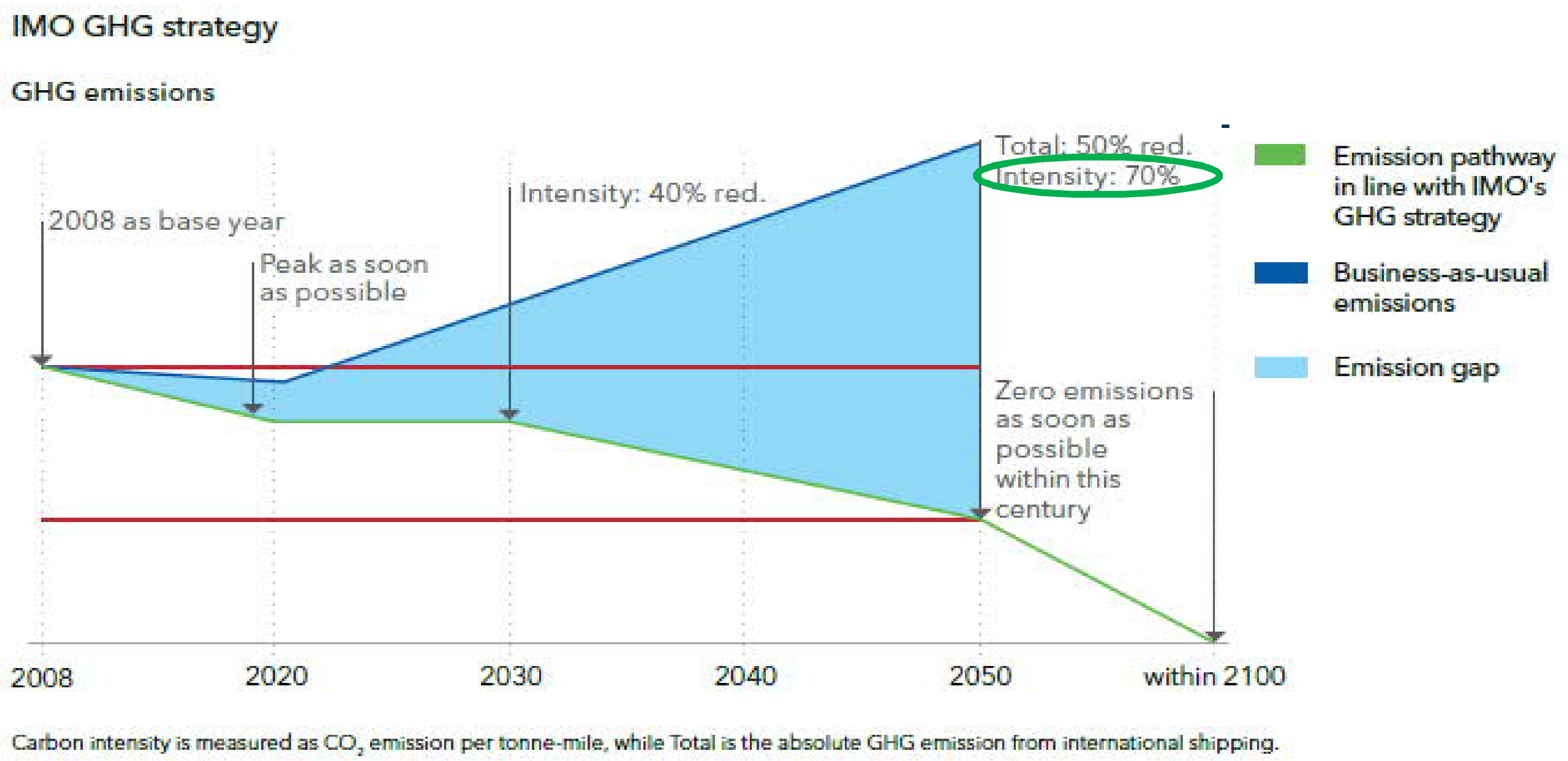
Reducing fuel consumption has always been driving us...

GHG is the current and future challenge



IMO GHG Strategy

Vessels meeting the 2050 requirement will look entirely different



...and will have to run to some extent on non fossil fuels!

The question is:
what will be the future fuel ?
...not what is the energy converter to propel the ships!

?

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Energy source for Ocean Shipping

The challenges replacing residual and Diesel fuels.....

Energy Storage type		Specific energy MJ/kg	Energy Density MJ/L
HFO	Chemical	40,5	35
MDO	Chemical	42,7	36
Liquefied natural gas (LNG -162 °C)	Chemical	50	22
LPG (including Propane / Butane)	Chemical	42	26
Hydrogen (liquid -253 °C)	Chemical	142	10
Methanol	Chemical	18	15
Ammonia (liquid -33 °C)	Chemical	18,6	12,5
Coal (anthracite or bituminous)	Chemical	~30	~38
Coal dust	Chemical	22	8.8-17.6
Lithium metal battery (Li-Po, Li-Hv)	Electrochemical	1,8	4,3
Lithium-ion battery	Electrochemical	0,8	2,6
Lead-acid battery	Electrochemical	0,2	0,6

Tank volume increases from HFO to LNG:

LNG: x 1.6 times ; + insulation

From LNG to Hydrogen (cryogenic):

Hydrogen: x 2.2 times and more insulation

Same Tank size = less then ½ endurance!

Ammonia and Methanol:

Challenge on tank volume increase

Challenge in weight increase

...and both are toxic!

Batteries compared to HFO:

Volume increase: x 8 times

Weight increase: x 22 times

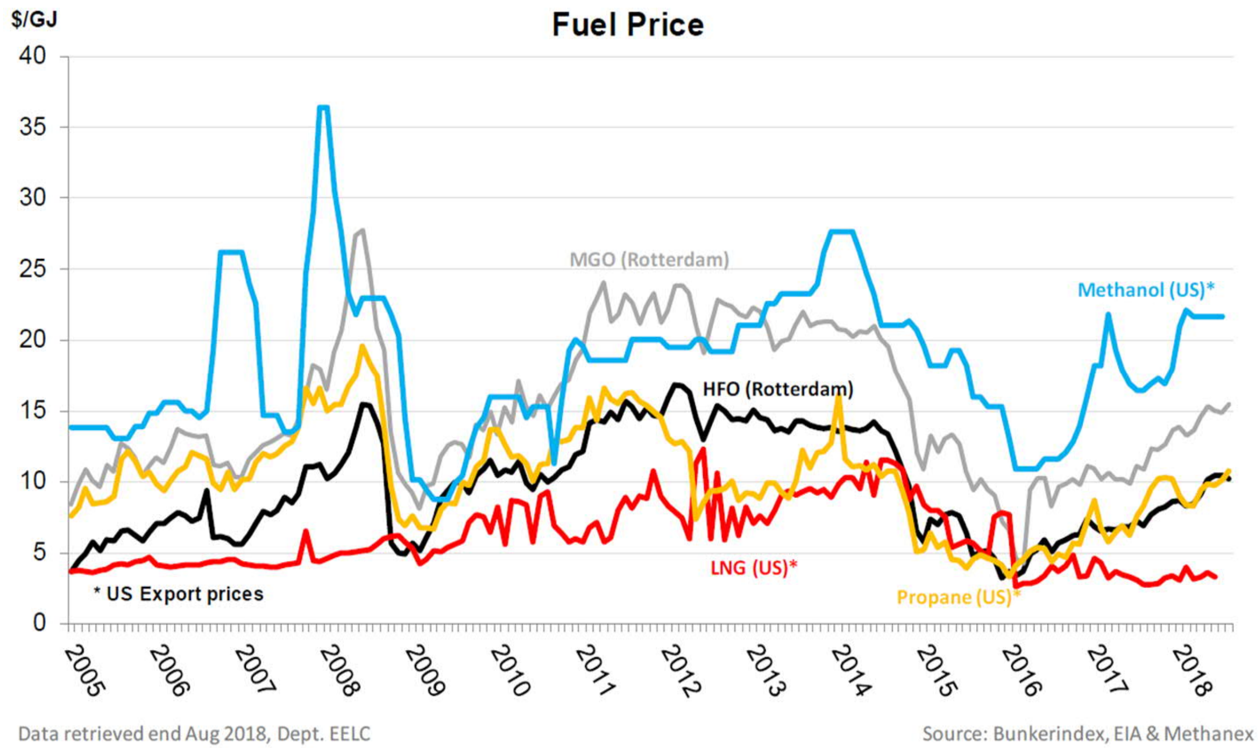
Development of fuel prices

LNG as most competitive fuel

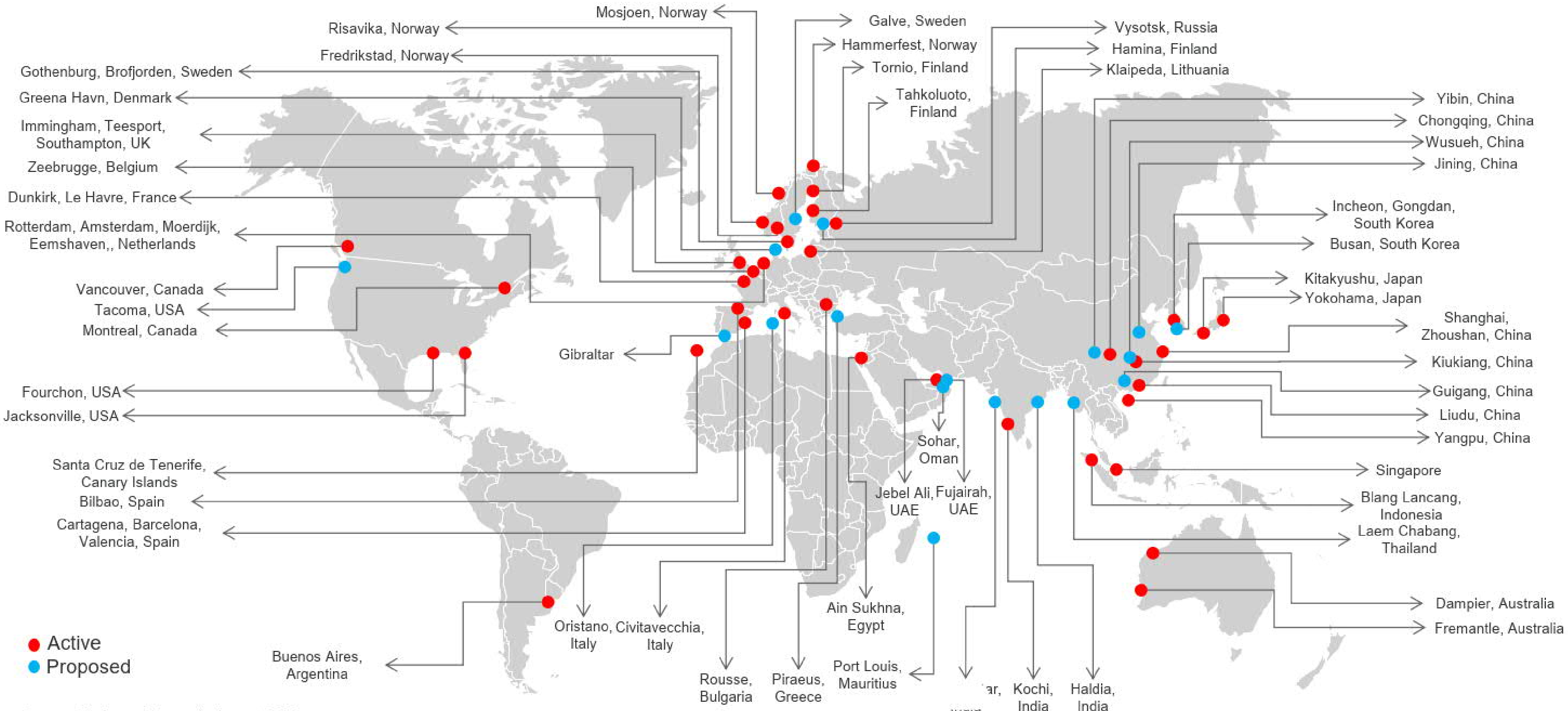
- Development of LNG pricing is supporting business cases to go for LNG as fuel
- Worldwide LNG production capacities are growing quickly

→ LNG price expected to remain very competitive

- What about liquid fuel prices post 2020??
- LNG bunkering infrastructure is developing quickly
- No other fuel is commercially competitive



Ports with LNG bunkering capabilities



Source: Clarksons Research, August 2019.

LNG is not the fuel of the future – it's the fuel of today!

- LNG is the commercially most attractive fuel today and in foreseeable future
- It complies with all existing and upcoming emission legislation – if burned in an Otto-process engine
- Proven technology with excellent safety record
- Bunkering infrastructure is developing faster than for any other fuel
- Fully replaceable by bio- or synthetic NG with the same infrastructure
- Therefore, investments in LNG are future-proof

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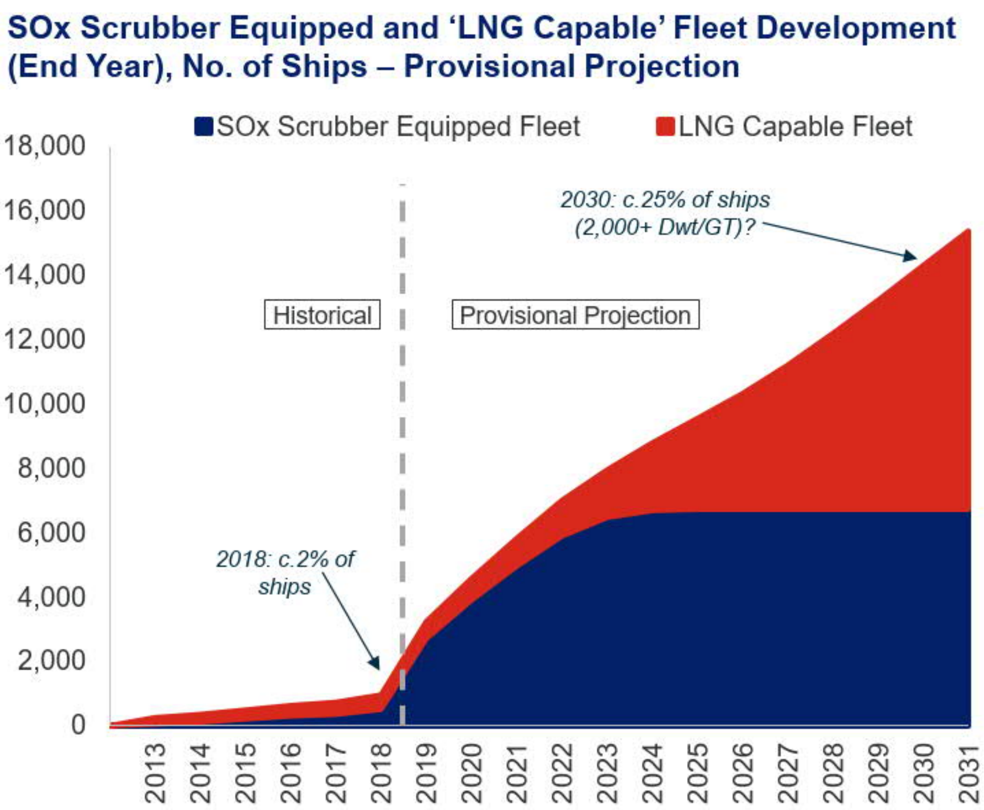
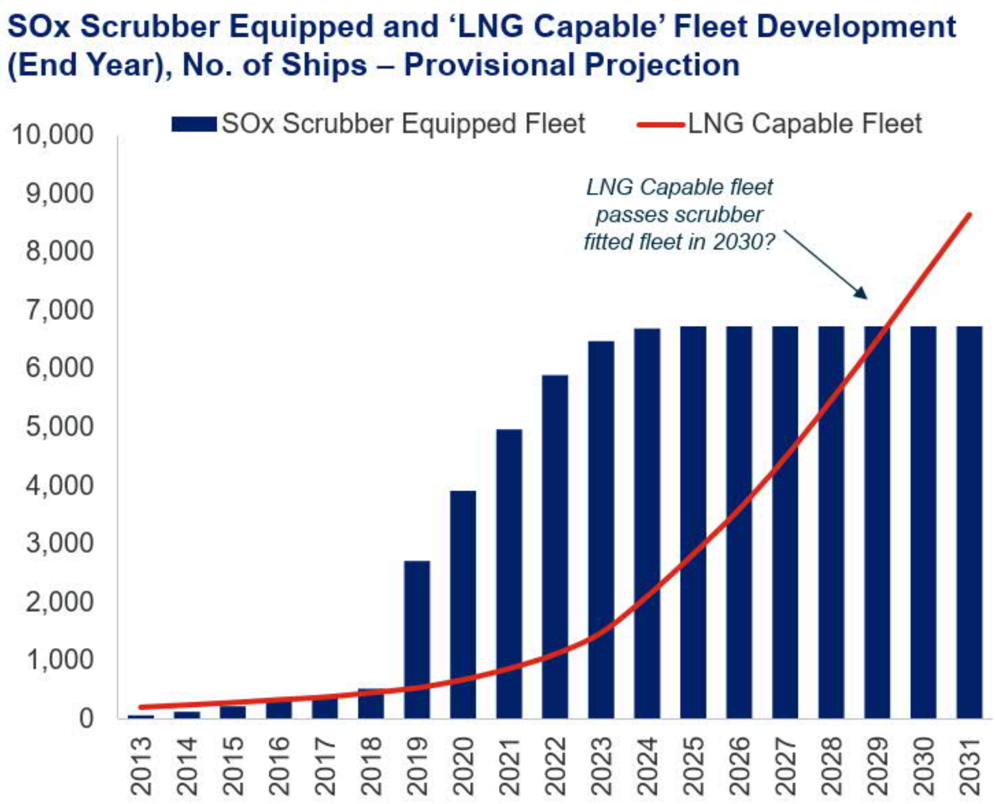
Projection of fleet equipment

Large growth in LNG-capable fleet expected (source: Clarksons Research)



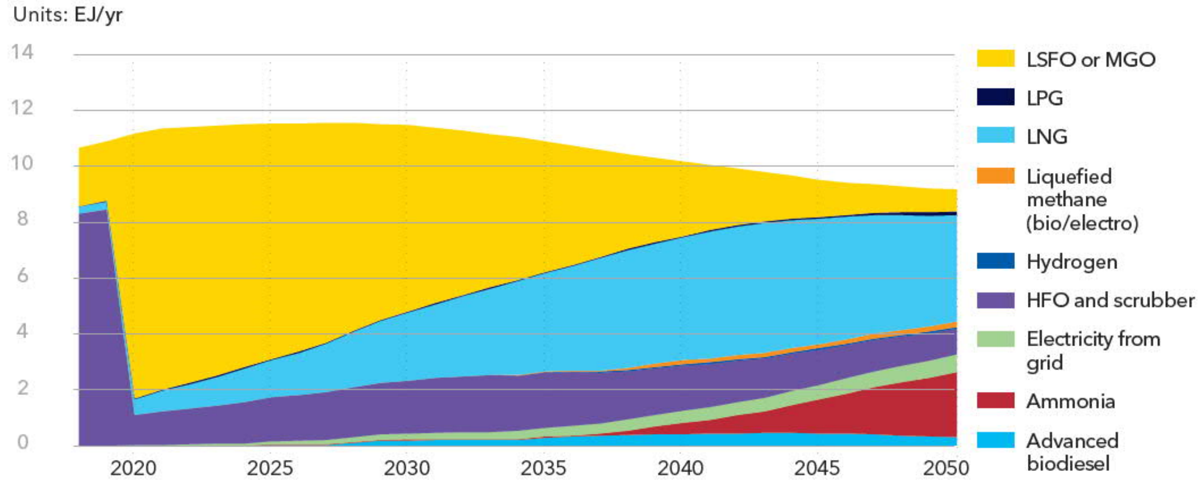


Projected fuel mix – long term outlook

Growth of LNG, followed by Ammonia (source: DNV GL Energy Transition 2019)

- Energy use shown – lagging behind newbuilding orders
- Largest growth of LNG, where technology, fuel and infrastructure is available today
- (Green) Ammonia may become a viable option after 2035
- Synthetic drop-in fuels expected to play a major role in decarbonization of shipping

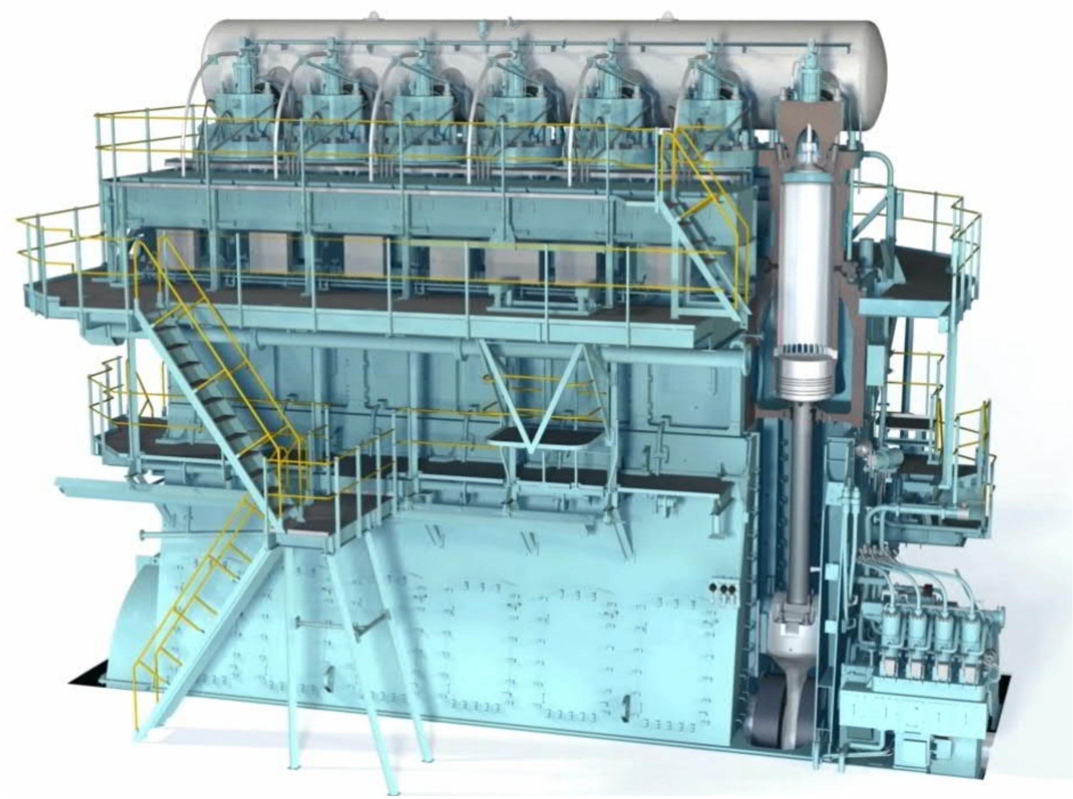
Energy use and projected fuel mix 2018-2050 for the simulated IMO ambitions pathway with main focus on design requirements



LSFO, low-sulphur fuel oil; MGO, marine gas oil; LPG, liquefied petroleum gas;
LNG, liquefied natural gas; HFO, heavy fuel oil;
Advanced biodiesel, produced by advanced processes from non-food feedstocks

WinGD's solution: X-DF low-pressure technology

Maximum simplicity



The Principle

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

The main merits with low gas pressure < 13bar

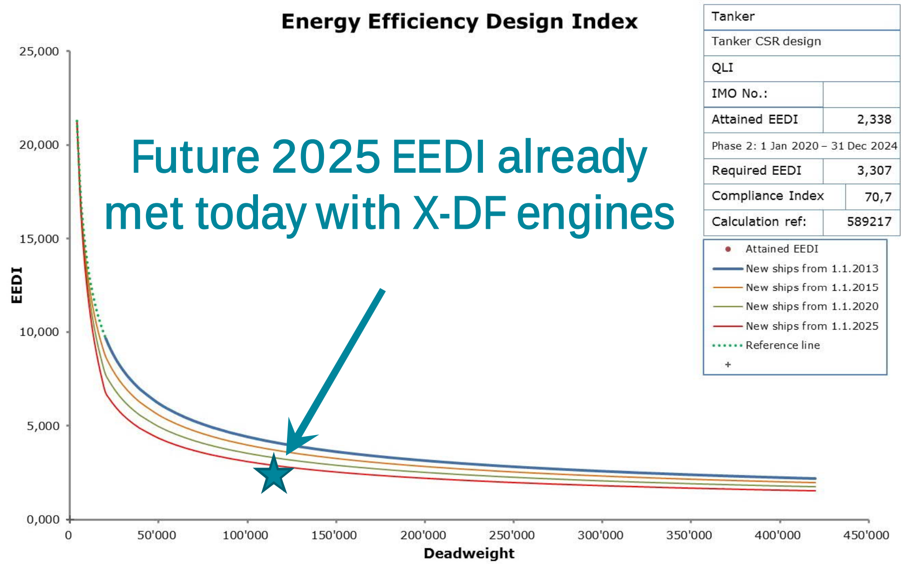
- Simple and reliable gas supply system
- Simple gas sealing
- Wide selection of proven compressors / cryogenic pumps

Lean Burn 'Otto' combustion means

IMO Tier III compliance:

- Permanent operation with Tier-III compliance, without additional equipment (EGR/SCR)
- Without additional fuel consumption
- Without compromised component reliability

Meeting future EEDI targets with X-DF (Aframax)



• **Owner:**	Sovcomflot	AET
• **Charter:**	Shell	Shell
• **Main engine:**	7X62DF	6X62DF
Power:	13 800 kW / 86 rpm	11 200 kW / 81 rpm
• **Fuel gas tank:**	Type C: 2 x 850 m3	Type C: 2 x 850 m3 → approx. 6000 nm
• **Vessel:**	Ice 1A	no ice class
• **Seatrials:**	July 2018	Oct 2018

LNG as fuel - positive emission effect for shipping

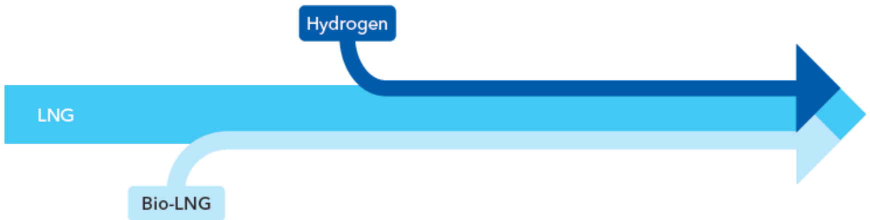
Emission reduction with LNG as fuel and WinGD X-DF Engines

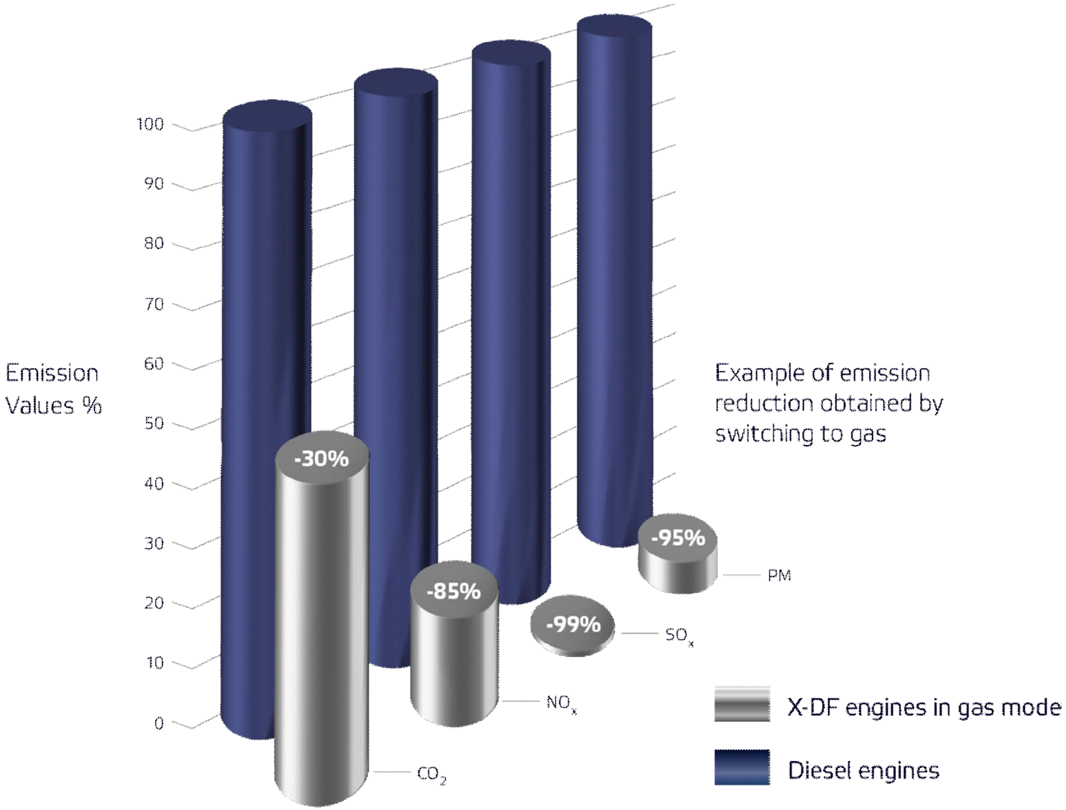
Beside the 20% reduction in GHG with LNG as fuel major other pollutants can be tackled:

- Sulphur -99%
- Nitrogen oxides -85%
- Particulates/black smoke -95%

Reducing GHG further will need drop in e-fuels like synthetic natural Gas (SNG)

Adding Bio- or synthetic LNG is a promising solution and is tested in small scale today





Conversion efficiency of E-Fuels

Hydrolyses technologies enable feasible figures in the coming decades

- Synthetic natural Gas (SNG) can be generated with efficiency of up to 65% out of electricity
- The conversion efficiency is only 10 to 12% percentage points lower then for pure Hydrogen.
- SNG can then easily be liquefied and used as a drop in fuel in existing LNG distribution network.
- Efficiency for Synthetic Ammonia is on similar level then SNG. The benefit of Ammonia is the absence of carbon during combustion.
- Disadvantage of Ammonia is the absence of a distribution network, no drop in possibility and the complex handling as it is toxic. Further, since it is a nitrogen-based fuel, combustion results in large NOx production → SCR needed

Fuel	Efficiency	Conditions
Pathway: Electricity→Gas		
Hydrogen	54–72 %	200 bar compression
Methane (SNG)	49–64 %	
Hydrogen	57–73 %	80 bar compression (Natural gas pipeline)
Methane (SNG)	50–64 %	
Hydrogen	64–77 %	without compression
Methane (SNG)	51–65 %	

Source: Frauenhofer Institute

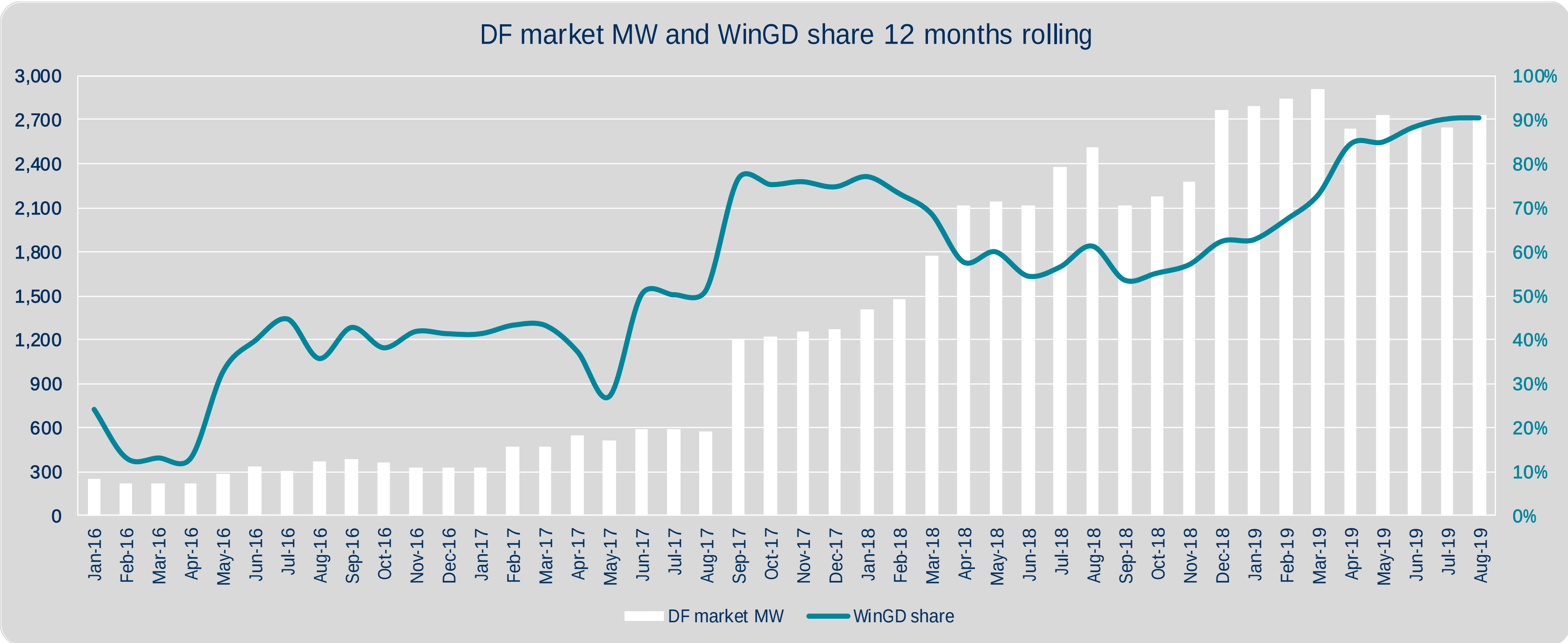
X-DF engines reference list (September 2019)

X-DF engine type	Vessel type		Orders
X40DF	9’500 cu.m. LNGC		1 engine
RT-flex50DF	15K dwt Product Tankers 1-2K TEU Feeder CVs 14-20K cu.m. LNG Carriers 3’600 vehicles PCC 5’800 lane m Ro-Ro	 	33 engines
X52DF	125K dwt Shuttle Tanker 7’000 vehicles PCC	 	6 engines
X62DF	115K dwt Crude Oil Tankers 180K cu.m. LNGC/twin screw 174K cu.m. LNGC/twin screw	 	35 engines
X72DF	174k cu.m. LNGC/twin screw 180K dwt Bulk Carriers	 	186 engines
X92DF	22K TEU Post-Panamax CVs 15K TEU Neo-Panamax CVs	 	14 engines
TOTAL	**275 DF engines (ca. 4.9 GW)**		

LNG as fuel approaching 3.000 MW/annum

About 27% of 2-stroke engines ordered in 2019 are DF engines!

X-DF holds >90% share of this!



Source: Clarksons Research Services, WinGD internal data

The orders changing the future of Container shipping: 9 x 22'000 TEU + 5 x 15'000 TEU C/V

Press Release of Nov. 7, 2017
http://www.cma-cgm.com/news/1811/world-innovation-cma-cgm-is-the-first-shipping-company-to-choose-liquefied-natural-gas-for-its-biggest-ships

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

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

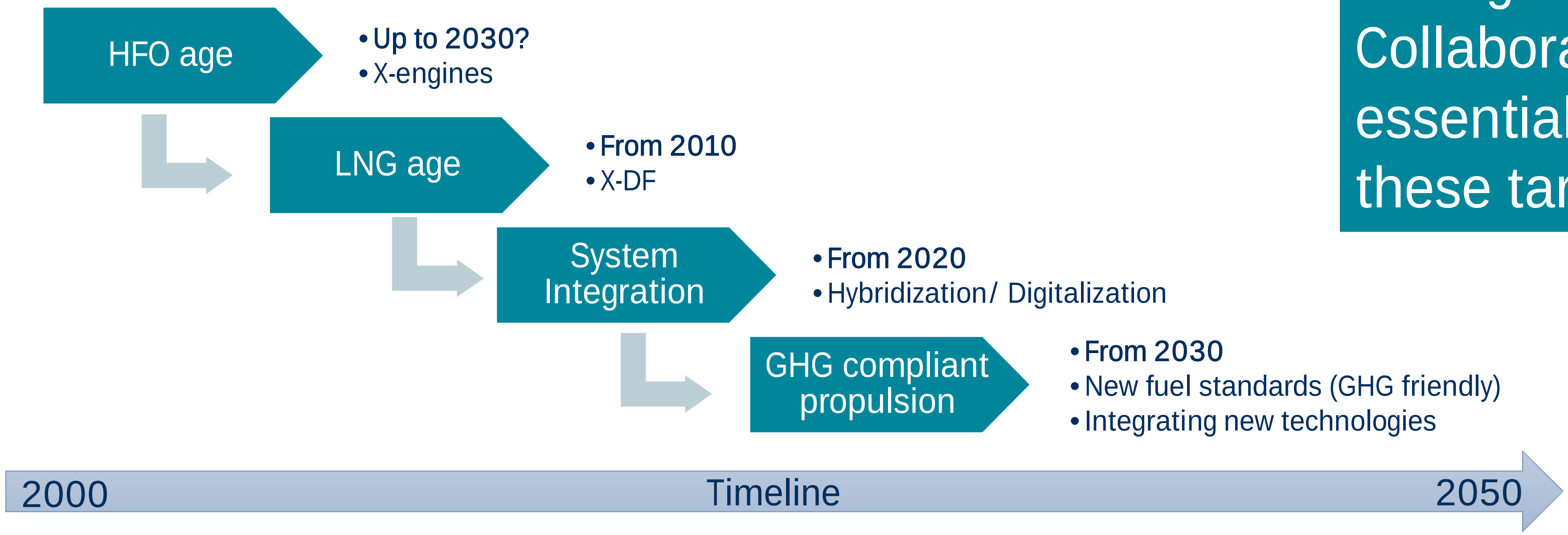
Gensets	
Wärtsilä	6 x L34DF

Fuel Gas Supply System
Wärtsilä

Fuel gas tank	
GTT	18 600 m3

Decarbonizing of shipping

Roadmap to IMO 2050

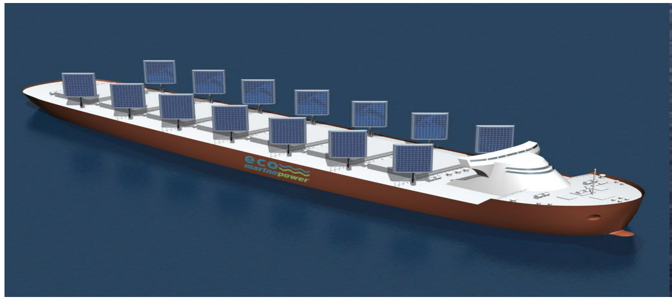


Strong Industry Collaborations essential to meet these targets!

...and yes back to the roots as well...

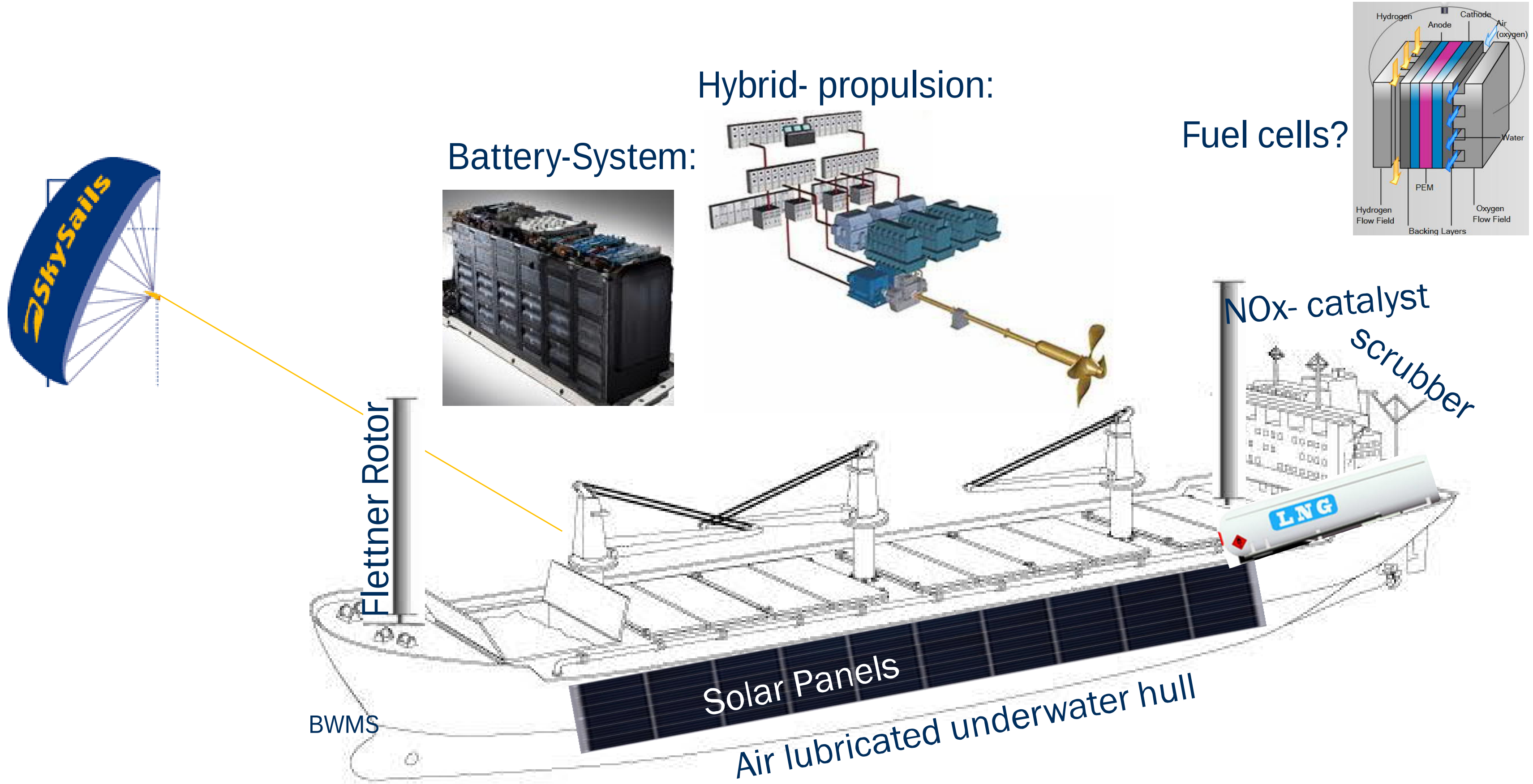
Windpower and Solar will play a role in reducing GHG intensity of shipping

Depending on the vessel type and the typical trade routes wind and solar can support propulsion and reduce The GHG intensity of shipping: <u>Potential 5 to 20% depending on vessel type</u>



Future Vessel Scenario to Reduce GHG Intensity by 70%

Increasing complexity by combining various technologies



Preparing for Hybridisation

Increased flexibility for FPP-based propulsion systems

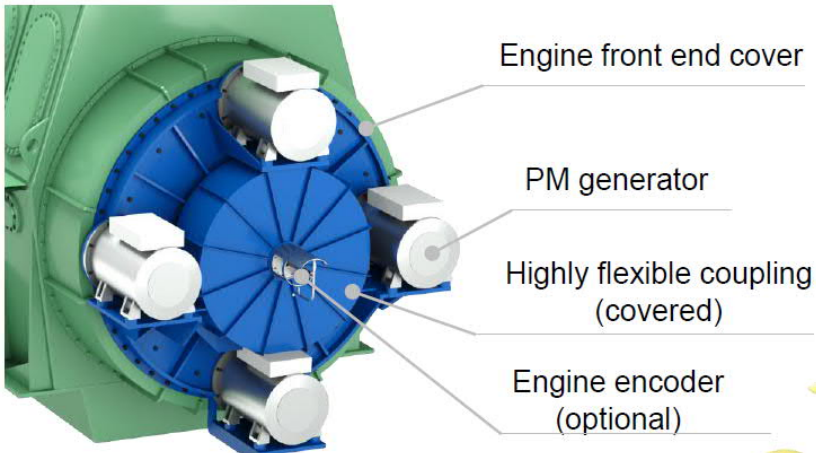
Integrated alternators for low-speed engines under development (e.g. Renk, Hyunday Electric)

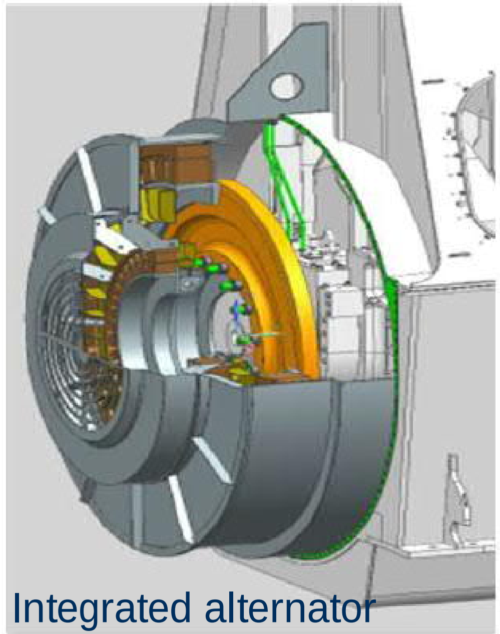
More efficient Power Take Off (PTO) at sea for on board consumption and battery loading.

Power Take In (PTI) possibilities:

- resolve minimum power requirement issues to meet future EEDI targets
- support acceleration of vessel in adverse sea conditions or shallow water

Hybrid solutions become more efficient!

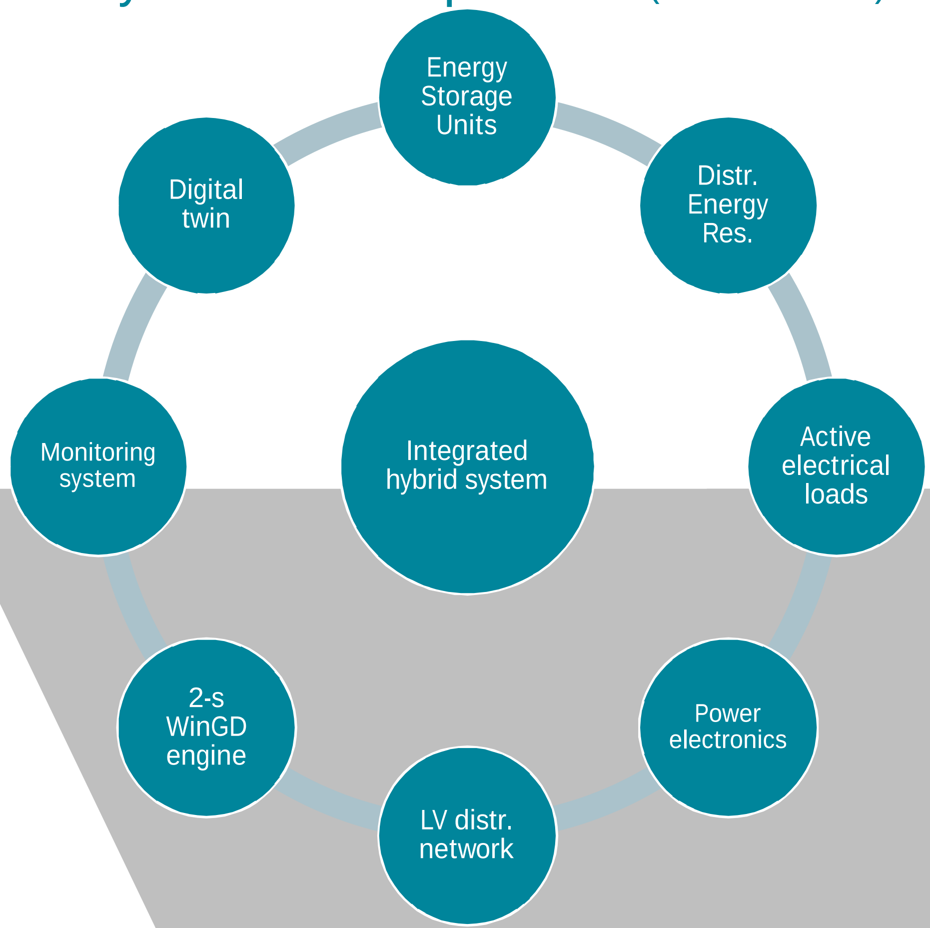




Integrated alternator

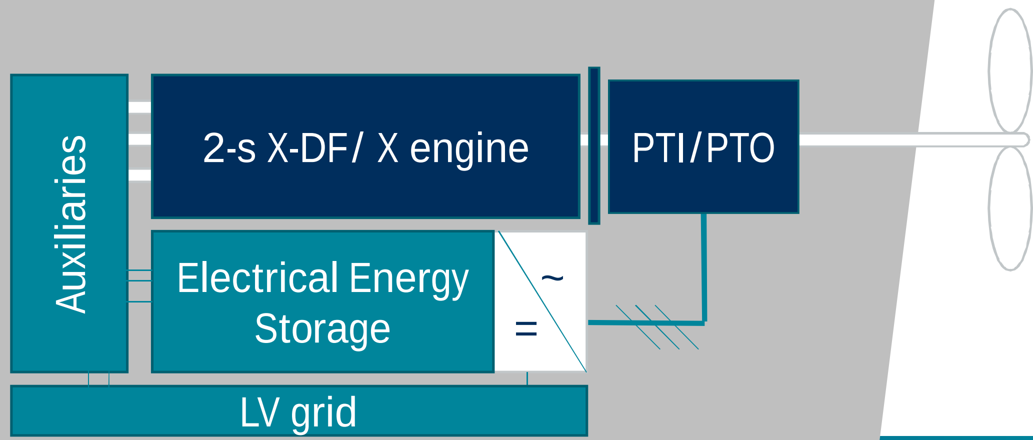
Towards more integrated systems

System decomposition (WinGD view)



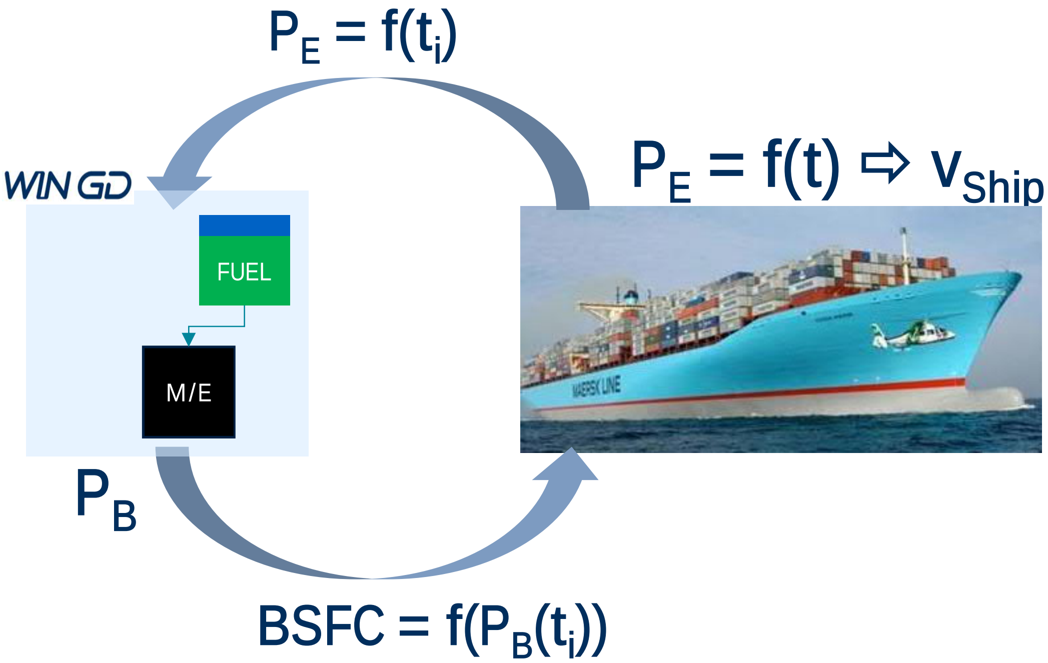
The "integration" is in 4 dimensions:

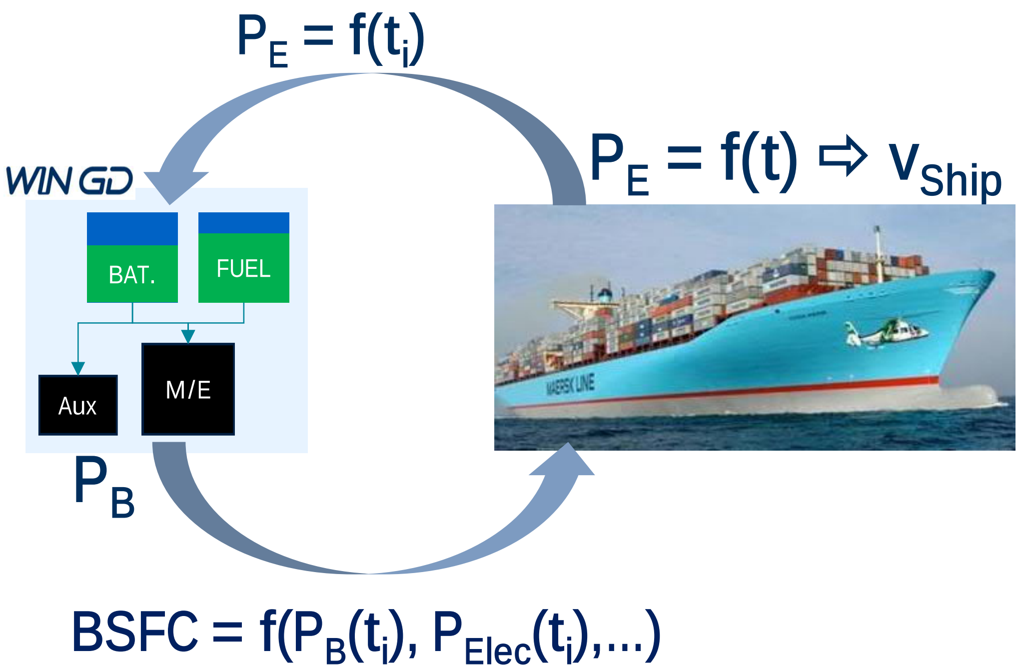
- Mechanical -> weight, physical size of the components
- Electrical -> conversion, protection, etc....
- Logical -> functionality, control
- Thermal -> manage the power loss



Towards more System integration

Past vs. future

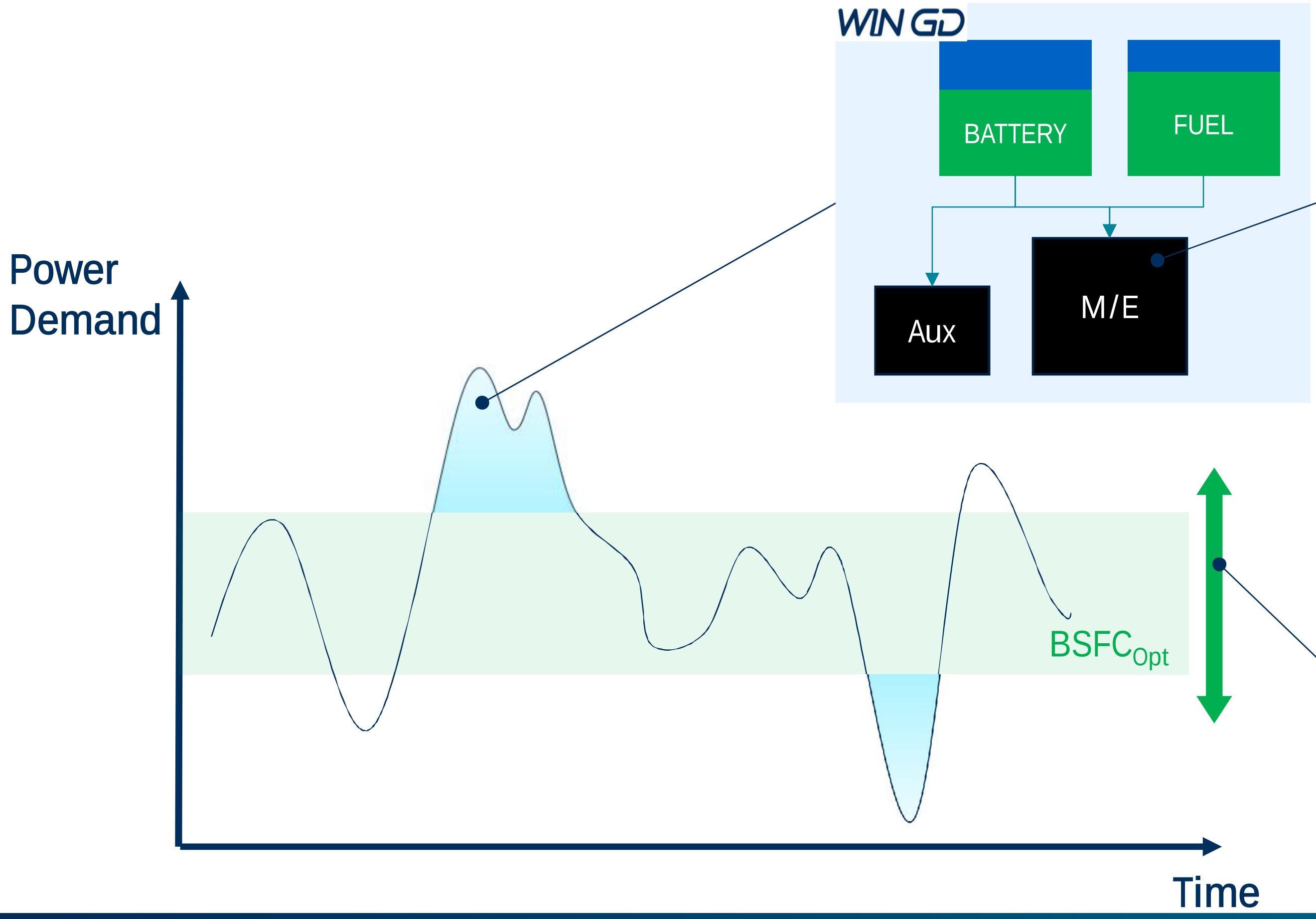




P_E ... Effective (Towing) Power
P_B ... Brake Power of M/E
P_{Elec} ... Power from electrical energy storage units
SOC... State of Charge

Towards more System integration

Use case example : peak shaving



Dynamic interaction between M/E and PTO/PTI

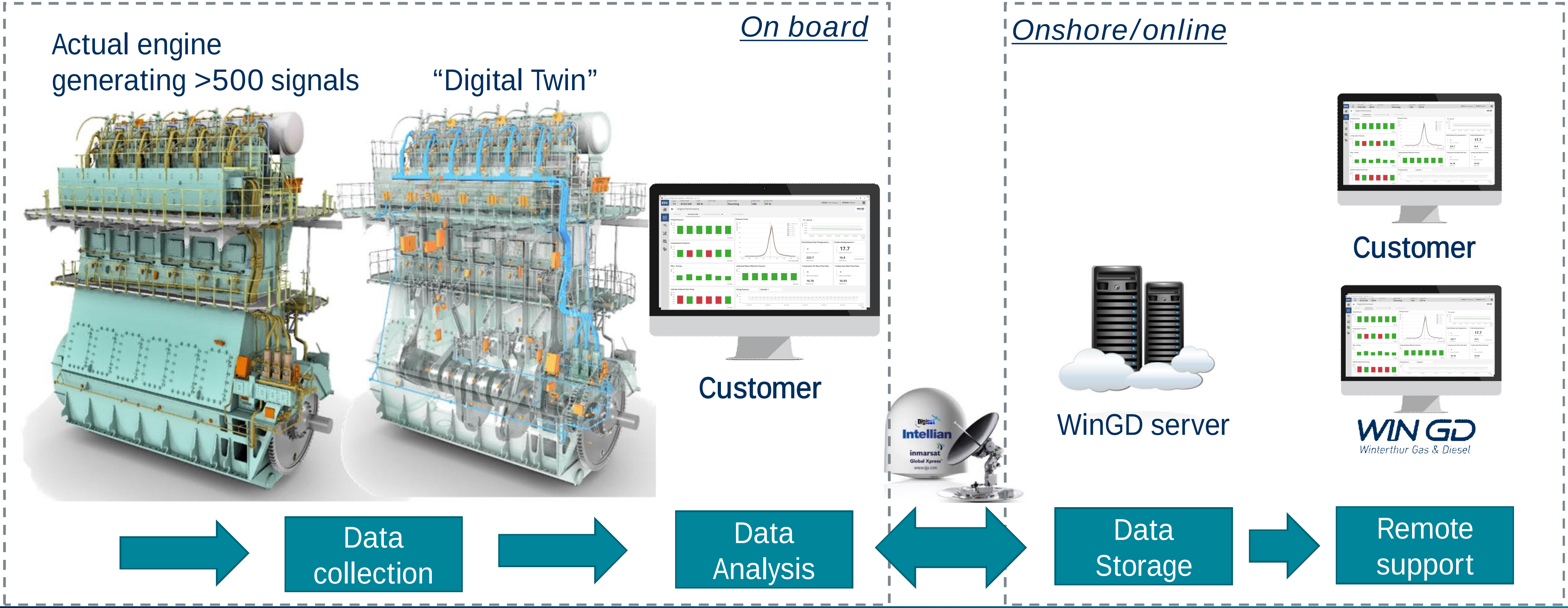
- Holding optimum operational range with PTO/PTI complementing
- Considering changing boundary conditions (e.g. ambient, EWG strategies, etc.)

Optimum BSFC Range depending on...

- Engine tuning
- Application of complementing technologies
- ...

Digitalization to reduce complexity - ‘WiDE’

“WinGD integrated Digital Expert” to improve performance, reliability, service



Take aways

- Major challenges regarding GHG regulations ahead
- Beyond 2030 non-fossil fuels will be needed
- Radical improvement of ship designs required
- The most feasible improvement today is LNG as fuel
- With X-DF, proven technology is available
- Hybridisation and system integration will play a mayor role

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