X-DF :
General Methane emission

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Winterthur Gas & Diesel Ltd.
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Simply a better different

The shift to LNG is happening!

1819-1910 (about): Coal

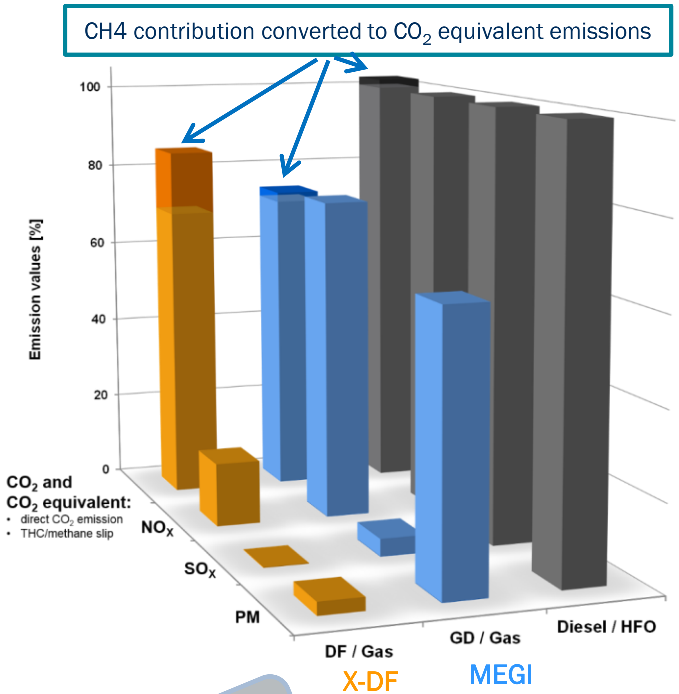
1897 – Today: liquid fuel

TODAY onwards: LNG!

- **Trendsetting: 9 x 22'000 TEU C/V with 12X92DF**
- **Largest environmental benefits for the largest ships**

2-s DF Overall Emission Picture

Low pressure vs. high pressure



NO_x Tier III (2016) & SO_x level in ECA (2015) are fully met !

- **PM further reduced** by the DF technology with lean-burn Otto combustion with pre-chamber ignition
- **Close to zero SOx** due to clean natural gas
- Unlike CO2, methane disappears over time. It's short term effect is 28 times stronger as a green house gas *)
- 'Methane slip' = THC emissions (Total Unburned Hydrocarbons). Included in total CO2 equivalent
- Potential to further reduce methane slip on the 2-s DF
- This results in approx. **-15~20% CO_2 equivalent compared to the diesel engine.**
- 2-s DF Otto process contributes positively to reduce the total emission scope compared to any engine operating in the Diesel process

*): *IPCC report 'Climate Change 2013'*

The keys to low methane slip

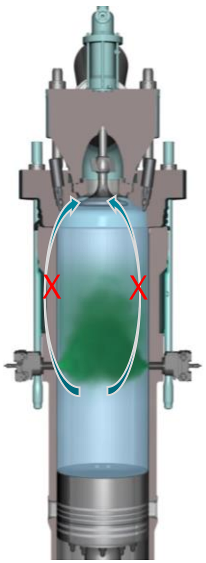
Reason of Methane emission

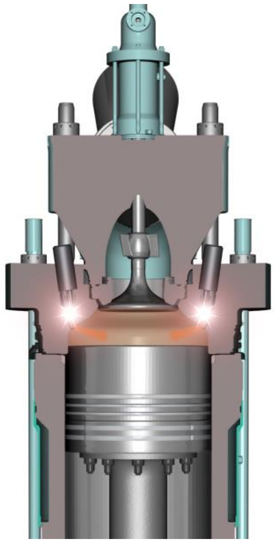
Reason of Methane slip which is reduced by :

- **Gas slip during valve overlap period**
  ✓ Remedy – Minimize valve overlap, ‘Direct’ methane slip can be avoided by correct gas admission valve timing

- **Incomplete combustion**
  ✓ Remedy – optimize combustion space and process, use of pre-chamber technology to have complete combustion, optimized lambda control incl. gas injection pattern and optimized combustion of the gas/air mixture

- **Crevices in combustion chamber**
  ✓ Remedy – Optimized combustion space and minimize ‘dead volumes’





Continously
Minimized Mathane
slip

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Measures for low methane emission

General status in international regulations

- The guaranteed weighted methane slip is below the industry standard of 6 g/kWh. 1.5~3.0g/kWh is being recorded but which will be further optimized and less which is depended on engine bore
- For the bigger bore DF engines, lower CH_4 slip would be expected.
- Any methane slip is to be included in the published brake specific gas consumption (BSGC) figures.

2-s DF : typical exhaust gas emission data

T.HC, NMHC, MHC

Gas operation

IMO Tier III NOx compliant (E3 cycle, max weighted average = 3,4g/kWh)

		100%	75%	50%	25%	weighted avg.
NOx	g/kWh	1.2	0.3	0.2	0.4	0.6
CO	g/kWh	0.8	1.1	1.4	2.2	
THC	g/kWh	2.0	2.1	2.6	2.9	
- CH4	g/kWh	1.6	1.7	2.1	2.3	
- NMHC	g/kWh	0.4	0.4	0.5	0.6	

Diesel operation

IMO Tier II NOx compliant (E3 cycle, max weighted average = 14,4g/kWh)

LFO operation

		100%	75%	50%	25%	weighted avg.
NOx	g/kWh	11.6	14.9	17.1	18.5	14.4
CO	g/kWh	0.3	0.2	0.2	0.4	
THC	g/kWh	0.1	0.1	0.1	0.2	
- CH4	g/kWh	-	-	-	-	
- NMHC	g/kWh	0.1	0.1	0.1	0.2	

1. Data shown for operation along fix pitch propeller curve under ISO conditions
2. Values are preliminary and for guidance only

- THC = NMHC + CH4.
- NMHC = is almost coming by chemical reaction during combustion
- **Unburned hydrocarbons** (**UHCs**) = guess that almost in the exh. gas flow ~ THC
  1. are the hydrocarbons emitted after petroleum is burned in an engine.
  2. When unburned fuel is emitted from a combustor, the emission is caused by fuel "avoiding" the flame zones.
  3. For example, in 2S engines, some of the fuel-air mixture "hides" from the flame in the crevices provided by the piston ring grooves.
  4. Further, some regions of the combustion chamber may have a very weak flame, that is, they have either very fuel-lean or very fuel-rich conditions and consequently they have a low combustion temperature.

2-s DF : typical exhaust gas emission data

X72-DF

Gas operation

IMO Tier III NOx compliant (E3 cycle, max weighted average = 3,4g/kWh)

		100%	75%	50%	25%	weighted avg.
NOx	g/kWh	1.2	0.3	0.2	0.4	0.6
CO	g/kWh	0.8	1.1	1.4	2.2	
THC	g/kWh	2.0	2.1	2.6	2.9	
- CH4	g/kWh	1.6	1.7	2.1	2.3	
- NMHC	g/kWh	0.4	0.4	0.5	0.6	

Tolerances:

		75%-100%	below 75%
NOx	g/kWh	±0.4	±0.1
CO	g/kWh	±0.2	±0.4
CH4	g/kWh	±0.1	±0.2
NMHC	g/kWh	±0.1	±0.2

RT-flex50DF

Gas operation

IMO Tier III NOx compliant (E3 cycle, max weighted average = 3,4g/kWh)

		100%	75%	50%	25%	weighted avg.
NOx	g/kWh	1.9	0.8	0.7	0.8	1.2
CO	g/kWh	0.8	1.1	1.4	2.2	
THC	g/kWh	2.6	2.9	3.3	4.0	
- CH4	g/kWh	2.1	2.3	2.6	3.2	
- NMHC	g/kWh	0.5	0.6	0.7	0.8	

Tolerances:

		75%-100%	below 75%
NOx	g/kWh	±0.7	±0.3
CO	g/kWh	±0.2	±0.4
CH4	g/kWh	±0.2	±0.3
NMHC	g/kWh	±0.2	±0.2

X-62DF

Gas operation

IMO Tier III NOx compliant (E3 cycle, max weighted average = 3,4g/kWh)

		100%	75%	50%	25%	weighted avg.
NOx	g/kWh	1.8	0.5	0.3	0.5	0.7
CO	g/kWh	0.8	1.1	1.4	2.2	
THC	g/kWh	2.4	2.9	3.0	3.4	
- CH4	g/kWh	1.9	2.3	2.4	2.7	
- NMHC	g/kWh	0.5	0.6	0.6	0.7	

Tolerances:

		75%-100%	below 75%
NOx	g/kWh	±0.6	±0.2
CO	g/kWh	±0.2	±0.4
CH4	g/kWh	±0.2	±0.2
NMHC	g/kWh	±0.2	±0.2

- All DFs are in compliance with IMO Tier III.
- As shown, bigger bore will be less THC and methane slip.
- CH4 will be less than current values on X-82DF and X92DF due to relatively smaller combustion space compare to total volume ratio.

Newsflash

IMO Agrees to CO2 Emissions Target

Delegates at MEPC 72 (IMO)

- MEPC 72th, 9-13 April 2018, at IMO Headquarters in London.
- ***Highlights of particular interest to media include:***
  - Reduction of greenhouse gas emissions from ships
  - Implementation of sulphur 2020 limit
  - Ballast water management treaty implementation
  - Measures to reduce risks of use and carriage of heavy fuel oil as fuel by ships in Arctic

- **Reduction of greenhouse gas emissions from ships**
  - At least a 40% reduction in carbon intensity by 2030 and pursuing efforts towards a 70% reduction by 2050, both compared to 2008 levels.
  - Announced agreed on a target to cut the shipping sector's overall GHG output by 50 percent by 2050.
  - Interim report to MEPC73 (Oct 2018)
  - Final report to MEPC74 (Spring 2019) and reduction rate for EEDI phase III

Table 1. Candidate measures included in IMO's initial GHG strategy.

Type	Years	Measure	Target	Current status
Short-term	2018-2023	New Energy Efficiency Design Index (EEDI) phases	New vessels	-10% in 2015 -20% in 2020 -30% in 2025
		Operational efficiency measures (e.g. SEEMP, operational efficiency standard)	In-service vessels	SEEMP planning required
		Existing fleet improvement program	In-service vessels	-----
		Speed reduction	In-service vessels	-----
		Measures to address methane and VOC emissions	Engines and fugitive emissions	-----
Mid-term	2023-2030	Alternative low-carbon and zero-carbon fuels implementation program	Fuels/new and in-service vessels	-----
		Further operational efficiency measures (e.g. SEEMP, operational efficiency standard)	In-service vessels	SEEMP planning required
		Market-based Measures (MBMs)	In-service vessels/fuels	-----
Long-term	2030+	Development and provision of zero-carbon or fossil-free fuels	Fuels/new and in-service vessels	-----

Exhaust gas emission & fleet status

1) CO_2 (g/kWh) = BSFC x C_F

2) SO_2 (g/kWh) = BSFC x YS x 1,998
YS = mass fraction of sulphur content in %

3) No_x (g/kWh)
Weighted average of 25,50,75 and 100%
EIAPP / Technical File

.1 C_F is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content. The subscripts $_{MEi}$ and $_{AEi}$ refer to the main and auxiliary engine(s) respectively. C_F corresponds to the fuel used when determining SFC listed in the applicable EIAPP Certificate. The value of C_F is as follows:

Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-Fuel)
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.75	2.750000

Reported number of vessels equipped with selected technology. Percentages basis world fleet/orderbook (100+ GT).

Technology		No.	m. GT
SOx Scrubber	Fleet *(% Total)*	525 *(0.6%)*	35.0 *(2.6%)*
	Orderbook *(% Total)*	403 *(11.5%)*	33.8 *(24.2%)*
LNG Capable	Fleet	429 *(0.5%)*	32.8 *(2.5%)*
	Orderbook	268 *(7.7%)*	15.3 *(11.0%)*
LNG Ready	Fleet	97 *(0.1%)*	11.7 *(0.9%)*
	Orderbook	96 *(2.7%)*	11.6 *(8.3%)*
BWMS	Fleet	6,750 *(7.1%)*	324.8 *(24.5%)*
	Orderbook	2,134 *(61.0%)*	127.0 *(90.9%)*
NOx SCR/ EGR	Fleet	434 *(0.5%)*	8.0 *(0.6%)*
	Orderbook	270 *(7.7%)*	18.3 *(13.1%)*
HVSC	Fleet	406 *(0.4%)*	20.6 *(1.6%)*
	Orderbook	29 *(0.8%)*	0.2 *(0.2%)*

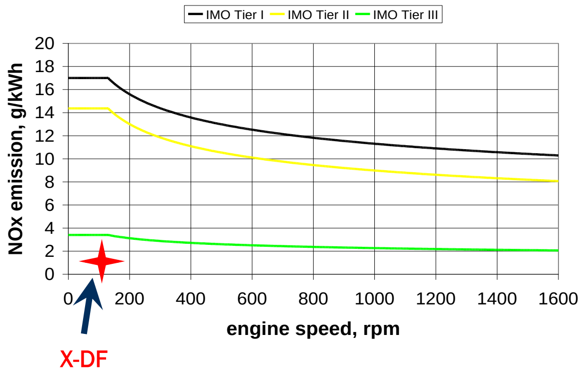
Source: Clarksons Research Services, fleet status as per 22nd Aug 2018

GHG
Very aggressive,
GWP of 300

Most prominent

Table 1. Nitrogen Oxides (NOx) (7 compounds)

Formula	Name	Nitrogen Valence	Properties
N_2O	nitrous oxide	1	colorless gas water soluble
NO N_2O_2	nitric oxide dinitrogen dioxide	2	colorless gas slightly water soluble
N_2O_3	dinitrogen trioxide	3	black solid water soluble, decomposes in water
NO_2 N_2O_4	nitrogen dioxide dinitrogen tetroxide	4	red-brown gas very water soluble, decomposes in water
N_2O_5	dinitrogen pentoxide	5	white solid very water soluble, decomposes in water



The number of vessels equipped with environmental technologies is slowly but constantly growing. The data in the table are provisional and based on reported equipment in the merchant fleet; this will underestimate the total size of the market

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X-DF:
Greenhouse gas emissions and total emission footprint

Winterthur Gas & Diesel Ltd.

September 2018

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Main greenhouse gas (GHG) types

Carbon dioxide (CO_2), Methane (CH_4) and their global warming potential (GWP)

- CO_2 is defined with a Global Warming Potential (GWP) of 1
  - According to the Intergovernmental Panel on Climate Change (IPCC) report *Climate Change 2014, AR5*

- CH_4 has a GWP of 28-86 according to the definition:
  - CH_4 has the same global warming potential as 28-86 g (CO_2), depending on the considered time frame (100 or 20 years) and depending on whether the 'climate-carbon feedback' (cc fb) is included. According to the IPCC report *Climate Change 2014, AR5*
  - IPCC recommends a 100 year time frame for GWP considerations as a 'general scientific practice' without 'climate-carbon feedback'.
  - As per the above definition, **WinGD follows IPCC recommendation** and applies **GWP of 28 for CH_4**

- **N_2O and Black Carbon Particles** are also emission components with an effect on global warming.
  - These components are being discussed e.g. in IMO and IPCC and are not included in this review

- **Particulates Matters (PM), NO_X and SO_X** represent a serious hazard to human health
  - Accordingly, they are also to be considered when comparing different technologies.

Methane emissions

Sources of methane emissions

- CH_4 (Methane) is the second most common GHG after CO_2
- Methane is emitted into the atmosphere through both, natural (~40 %) and man-made (anthropogenic, ~60 %) sources
- Production and distribution of fossil fuels accounts for about 20 % of anthropogenic methane emissions; see figure 1.
- Stationary and mobile sources (transportation, including shipping) contribute approximately 1 % of anthropogenic methane emissions; see figure 1.

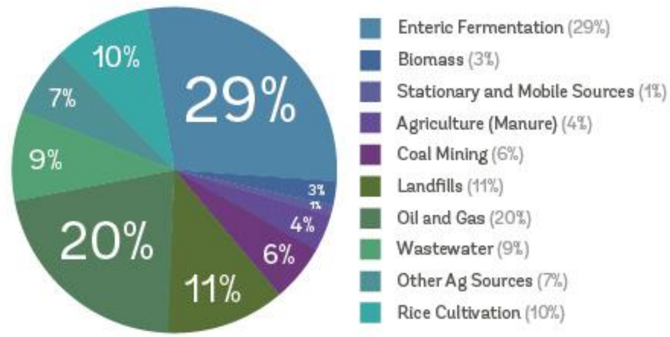

Fig. 1: Estimated global anthropogenic methane emissions by source, 2010. Source: Global Methane Initiative

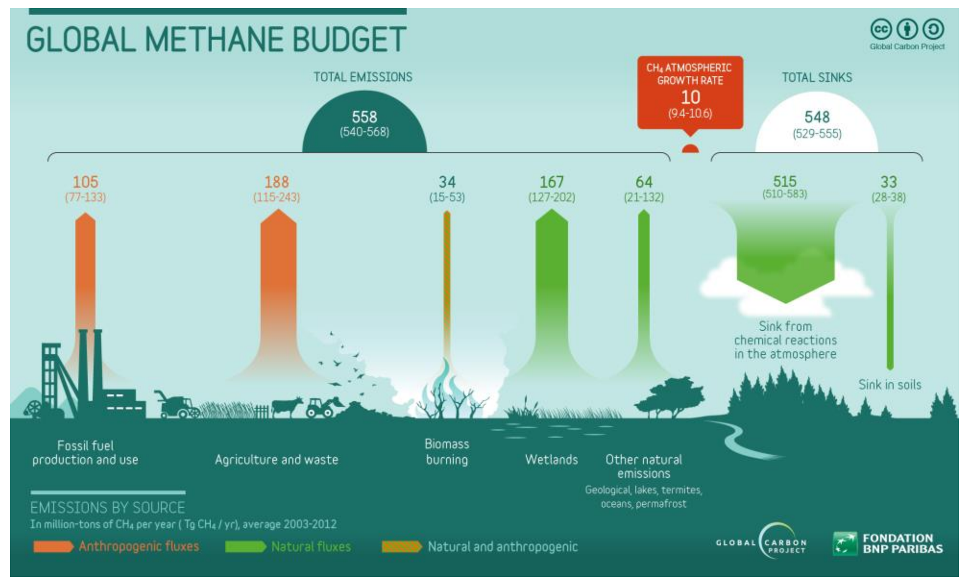

Fig. 2: Estimated methane emissions, natural and anthropogenic Source: www.climate.gov, global methane budget

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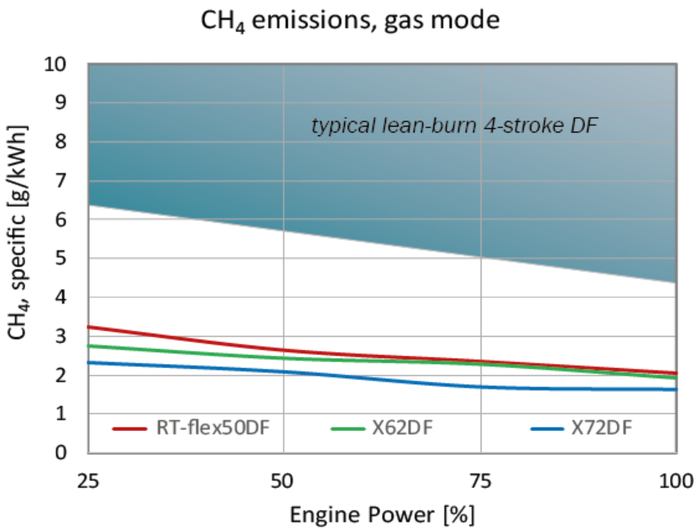
Measured T. HC / CH_4 emissions

X-DF technology features the lowest methane figures in the industry

- The measured THC emissions on production engines are between 2 - 3 g/kWh (IMO weighted avg.)
  - typically 80 % of the THC is CH_4

  → CH_4 emissions 1.6 – 2.4 g/kWh depending on bore size
- Figures remain low in part-load operation
- This unburned gas is included in the published brake specific gas consumption (BSGC) figures
- **X-DF engine GHG emissions are approx. 15 % - 20 % lower than diesel engines running on HFO**
- Anticipated CH_4 emissions for larger bore engines (e.g. X82DF and X92DF):

  → below 1.5 g/kWh IMO weighted avg.



THC, IMO weighted	2 - 3 g/kWh
CH_4, IMO weighted	1.6 - 2.4 g/kWh
GHG comp. to HFO	20 % - 15 % less

Measures for Low methane emissions on X-DF engines

Innovative design features and ongoing developments:

<u>Reduction of methane emissions to a minimum through:</u>

- Application of basic design principles to the combustion chamber:
  - Reduction of dead volume and crevices compared to conventional diesel engines
- Engine tuning measures:
  - Lambda control, gas admission valve timings, etc.
  - Optimization of the gas admission valve position and gas injection pattern
- Pre-chamber ignition technology:
  - Optimized ignition and combustion of the gas/air mixture
- Low shaft-speed and long stroke
  - Resulting in a large time window for excellent, homogeneous gas/air mixing and complete combustion with a minimum of unburned fuel emissions.
- Ongoing developments and improvements implemented in production engines

GHG emission comparison: X-DF vs. ME-GI

Comparison fundamentals for fig. 3 page 7

- Published data for gas and pilot consumption (WinGD's GTD and MAN's CEAS)
- GWP factor of 28 for CH_4 (see page 2)
- Emissions of generating sets not considered **
- The facts that X-DF is always emitting very low NO_X emissions (when running in gas mode) and ME-GI with high pressure engines require additional auxiliary power to be IMO Tier III compliant is not reflected in this comparison
- Conventional Tier II diesel engine, operated on HFO, CO_2-emissions @ 100 % — Fig. 3 (1)
- Conventional Tier II diesel engine, operated on MDO — Fig. 3 (2)
- X72DF: weighted avg. CH_4 emissions 1.6 g/kWh as measured — Fig. 3 (3)
- G70ME-GI: weighted avg. CH_4 emissions 0.36 g/kWh as informed by MAN paper — Fig. 3 (4)

** It has to be noted that ME-GI plants have a higher electrical power demand compared to X-DF plants. This additional electrical power is produced by auxiliary generating sets, with typically higher methane emissions.

GHG emission comparison: X-DF vs. ME-GI

Example with X72DF

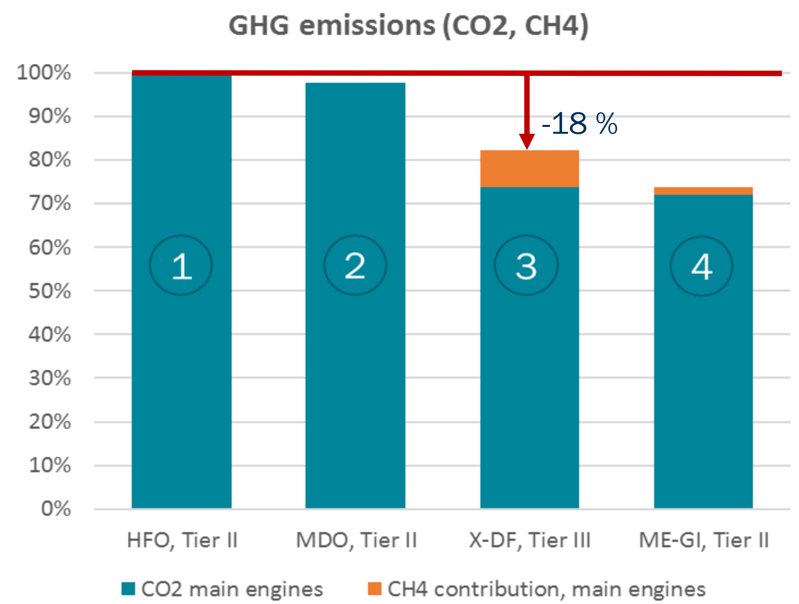


Fig. 3: GHG comparison: X-DF vs. ME-GI

- Diesel engine on HFO Tier II set as a reference (100 %) ❶
- Diesel engine on MDO Tier II emits slightly less CO_2 due to lower carbon intensity of MDO compared to HFO ❷
- Significant reduction in CO_2 emissions with gas as a fuel (approx. 25 % - 30 % less compared to HFO)
  Benefit is partly reduced by CH_4 emissions
- As a net effect, GHG emissions of X-DF are still 18% lower compared to a diesel engine on HFO ❸
- Solely considering main engines, ME-GI results in slightly lower GHG emissions. Including auxiliary power for gas compressors and Tier III compliance of the ME-GI, GHG emissions of X-DF and ME-GI are typically similar *(see following pages)* ❹

LNG-Carrier application comparison

Pre-conditions & assumptions for typical 174,000 cbm LNGC

Below, two machinery concepts are compared for laden and ballast operation at sea:

- WinGD: main engines 2 x 5X72DF (per engine: CMCR 11.350 kW) and 4s DF aux. engines for electric power generation (1 aux engine in operation with load 70 %)
- MAN: main engines 2 x 5G70ME-C-GI (per engine: CMCR 11.350 kW) and 4s DF aux. engines for electric power generation (2 aux. engines in operation with load 50 %)

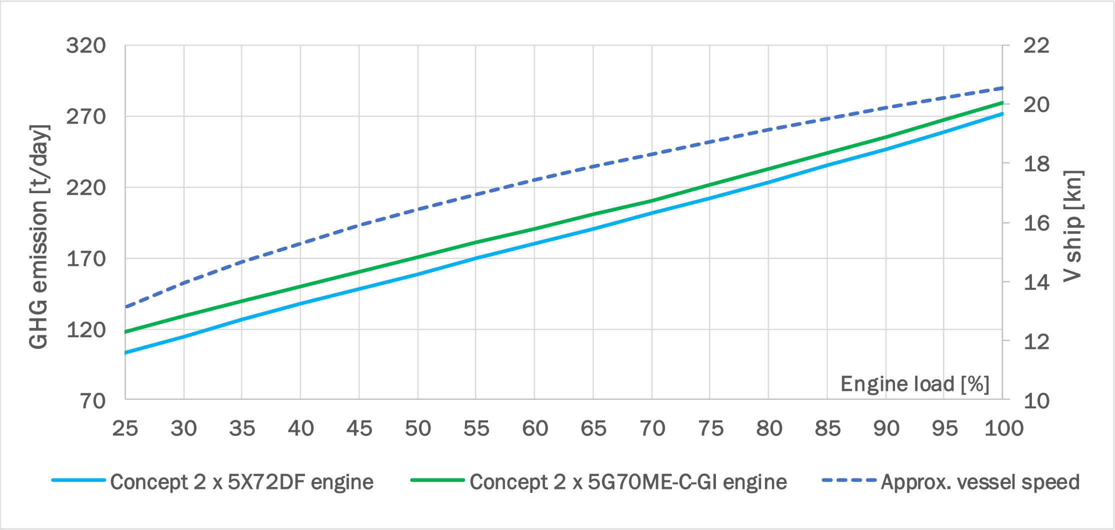
Electric power demand (assumed constant during load range) in relation to the machinery solution:

- Ship (WinGD or MAN): Hotel load - 2 000 kWe
- WinGD: Low pressure gas compressor - 800 kWe
- MAN: High pressure gas compressor - 1500 kWe
- TIER III (MAN): Exhaust Gas Recirculation (blower and water treatment system) – 150 kWe per ship

Unburned methane emission for machinery equipment:

	5X72DF	5G70ME-C-GI	4s DF Aux. engines
Load [%]	CH_4 [g/kWh]	CH_4 [g/kWh]	CH_4 [g/kWh]
100	1.61	0.35	3.6
75	1.68	0.35	4.5
50	2.08	0.41	7.1
25	2.32	0.5	15.1

LNGC machinery GHG emissions



	Machinery concept with 2 x 5X72DF engine	Machinery concept with 2 x 5G70ME-C-GI engine	Difference
Power [%]	GHG emission [t/day]	GHG emission [t/day]	GHG emission [t/day]
100	271.1	279.1	-8.0
95	258.5	267.1	-8.6
90	246.5	255.3	-8.9
85	234.9	244.1	-9.2
80	223.2	232.5	-9.2
75	211.7	221.2	-9.5
70	201.3	210.3	-9.0
65	190.7	200.4	-9.7
60	180.0	190.6	-10.5
55	169.4	180.6	-11.2
50	158.9	170.6	-11.8
45	148.1	160.4	-12.2
40	137.3	150.0	-12.7
35	126.2	139.4	-13.2
30	114.7	128.8	-14.1
25	103.0	118.0	-15.0

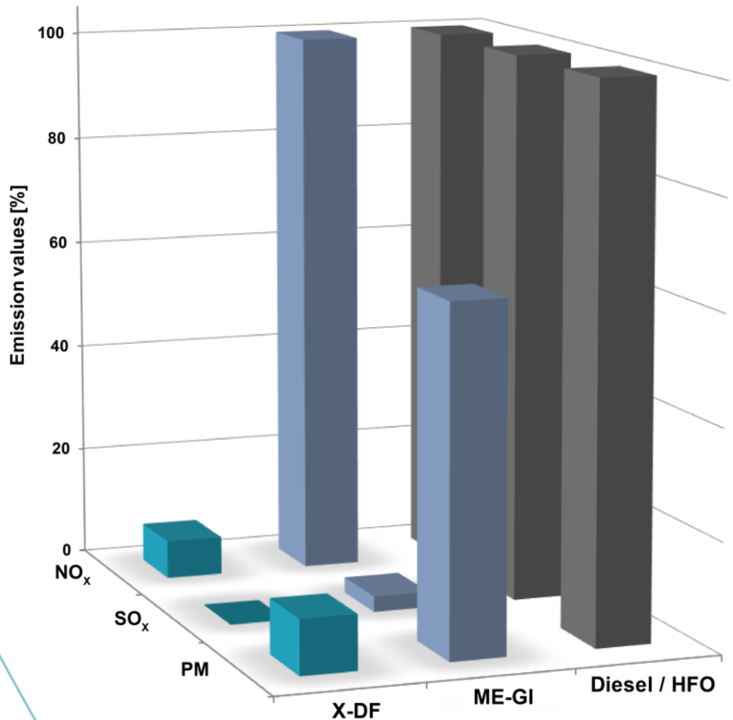
With methane emissions considered, X-DF machinery results in lowest GHG emissions

Calculation of GHG emissions with following conditions:

- TIER III operation
- ISO conditions
- BSFC and BSGC are without tolerances
- Main fuel (LNG) and pilot fuel (MDO)
- Global Warming Potential according to the IPCC report '*Climate Change 2014*: GWP100=28

What about non-GHG emissions?

Toxic emission components with different engine technologies



NO_X, SO_X and Particulate Matter (PM) are a serious hazard to human health and are most effectively reduced with X-DF propulsion!

Extract from the latest WHO report, 2018-05-02:
"In 2016, 91 % of the world population was living in places where the WHO air quality guidelines levels were not met.

Ambient (outdoor air pollution) in both cities and rural areas was estimated to cause 4.2 million premature deaths worldwide in 2016."

http://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

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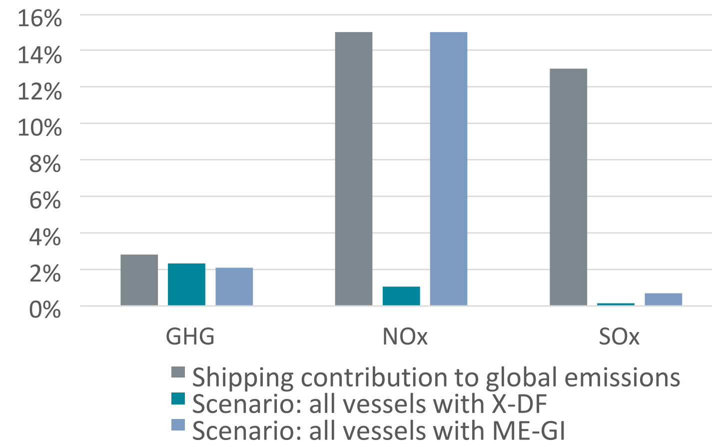
Conclusions

X-DF provides the Lowest overall emission footprint

- **Third IMO GHG study 2014:**
  - Shipping contribution to global emissions:
    - 2.8% of GHG emissions
    - 15% of NOx emissions
    - 13% of SOx emissions
- **X-DF engines significantly reduce emissions with toxic effect on human health (NO_X, SO_X, PM) to lowest level in the industry**
- **GHG emissions are reduced compared to conventional diesel engines**
- **Methane emissions of the X-DF have insignificant impact on the global GHG emissions**
- **X-DF engines provide the most environmentally sustainable total emission footprint currently available**
- **More environmental-friendly Otto cycle with X–DF when N2O is considered as GHG.**



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Simply a better different