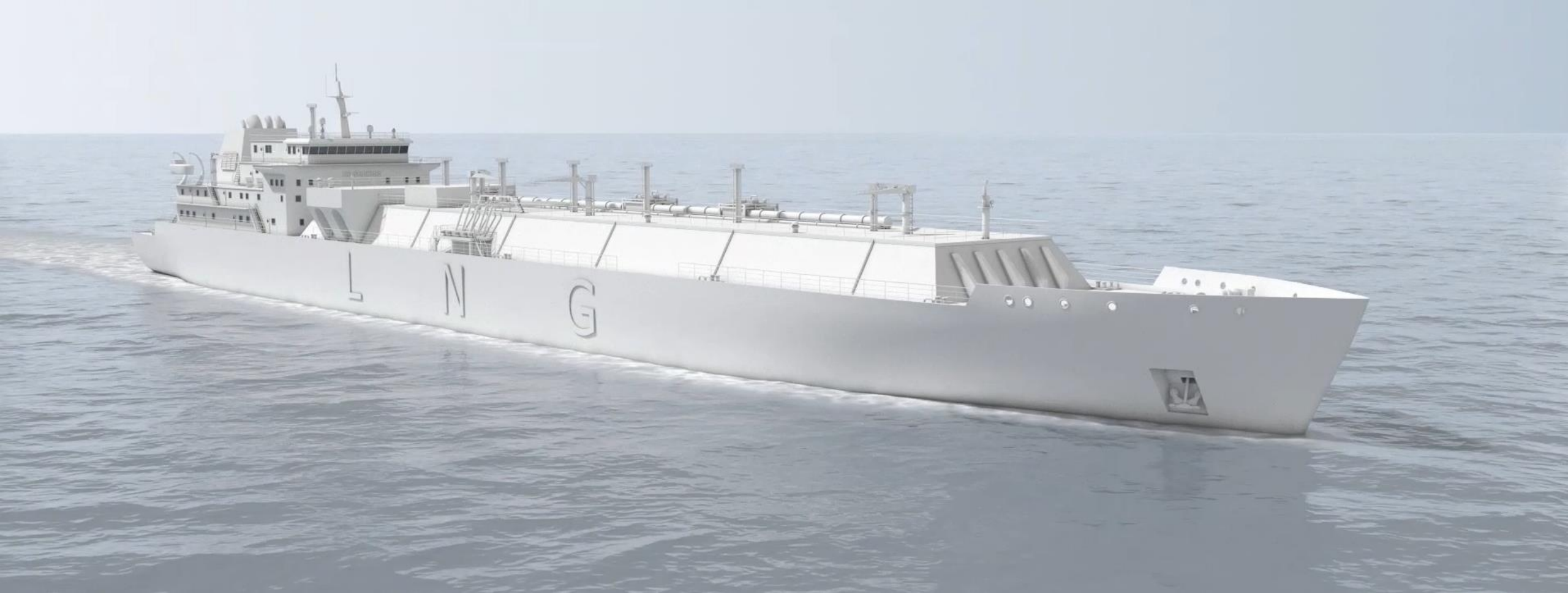


DFE+ (Dual Fuel Electric Plus)

The future of LNG vessel propulsion is electric

DFE+, A cooperation between MAN and ABB

Status and plans ahead

Status

- MOU between MAN and ABB signed at SMM in September 2022.
- Initial concept development and internal simulations completed.
- External simulations of the concept started with DNV January 2023.
- DNV simulation completed June 2023Launched the concept at Gastech 2023 in Singapore.
- Gave 2 presentations at Kormarine 2023 in Busan.
- Partnered up with selected shipyard in Q4 2023.

Plans ahead

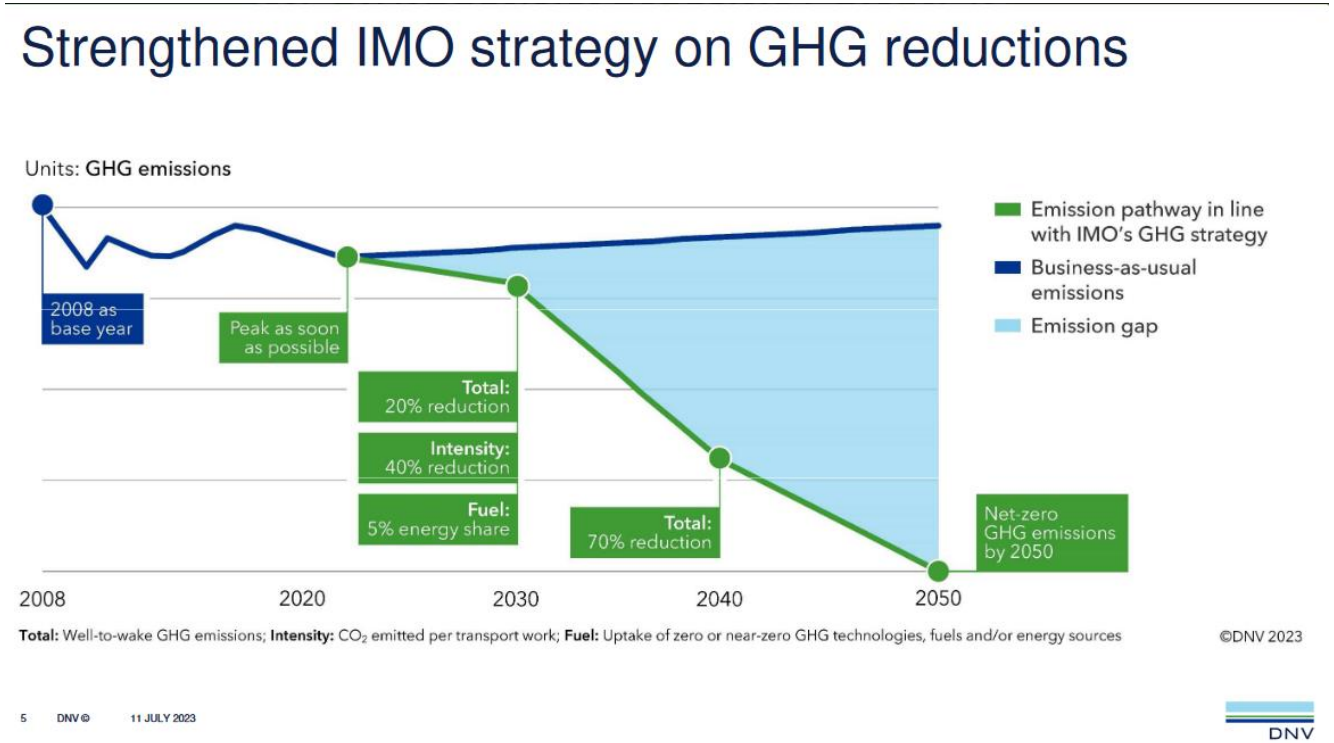
- Partner up with selected ship owners and charterers. **Q1 and Q2 2024**
- Together with the stakeholders start the detail development of the concept toward a commercial pilot project. **2024**
- Capture commercial pilot project. **2024.**

DFE+

The LNGC owner's challenges

A future with many uncertainties

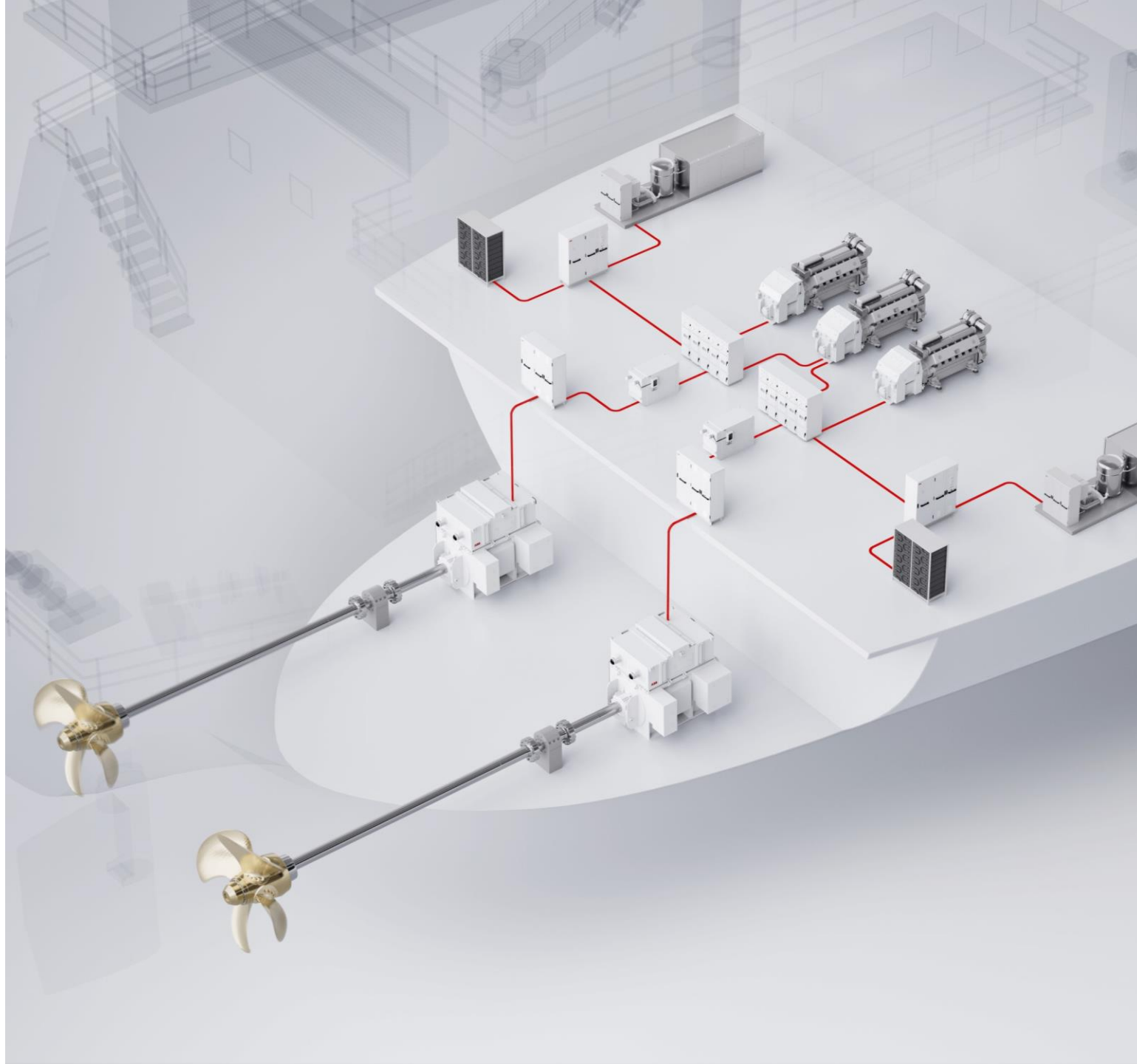
- New IMO and EU regulations in place. (CII, EEDI, ETS)
- Stricter future regulations, alternative fuels and power sources.
- Shifting trade patterns including need for FSRUs.



DFE+
Highlights

- Overall energy consumption improvement 6% to 7.5%
- Flexible; maintaining efficiency throughout the speed range.
- Extra space for cargo (~ 6%*)
- Redundancy with 3 - 4 engines and a battery.
- Prepared for easy installation of alternative power sources like fuel cells and others in the future.
- Can easily be prepared for future FSRU operation.

*174kcbm^3 ⇒ 185kcbm^3



DFE+
Main components

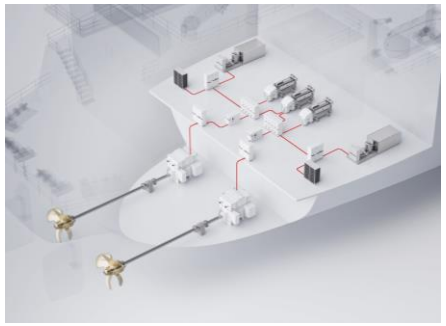
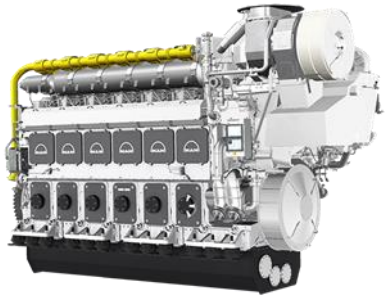
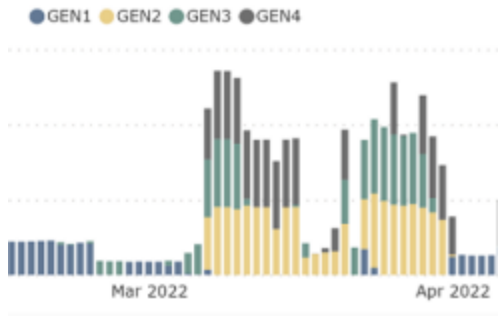


ABB Dynamic AC (DAC)



The new MAN 4-stroke Machine



Improved and optimized PEMS

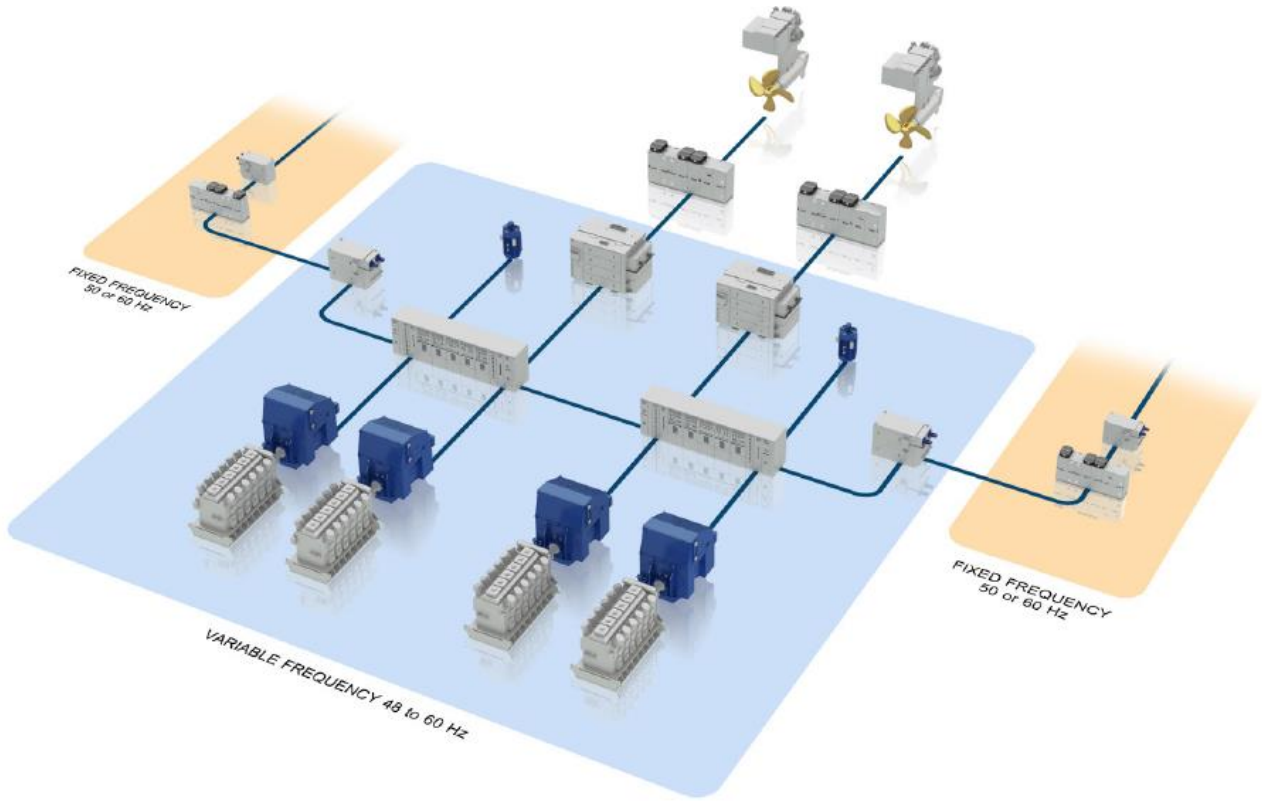
Batteries

Permanent magnet motors

Azipod® propulsors as an alternative

DFE+

Dynamic AC (DAC), Optimized utilization of power plant



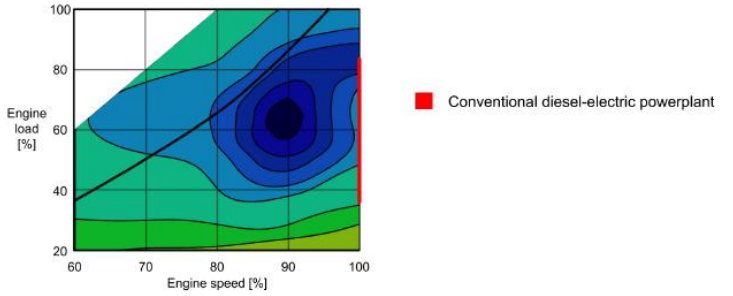


Figure 3: Example of specific fuel oil consumption (SFOC) diagram for an internal combustion engine

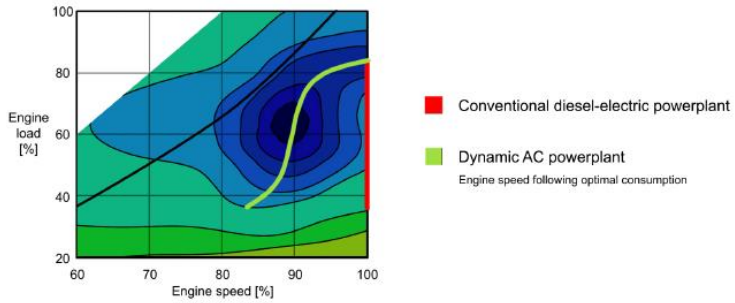


Figure 4: Comparison of SFOC between constant and adjustable speed power generation

DFE+

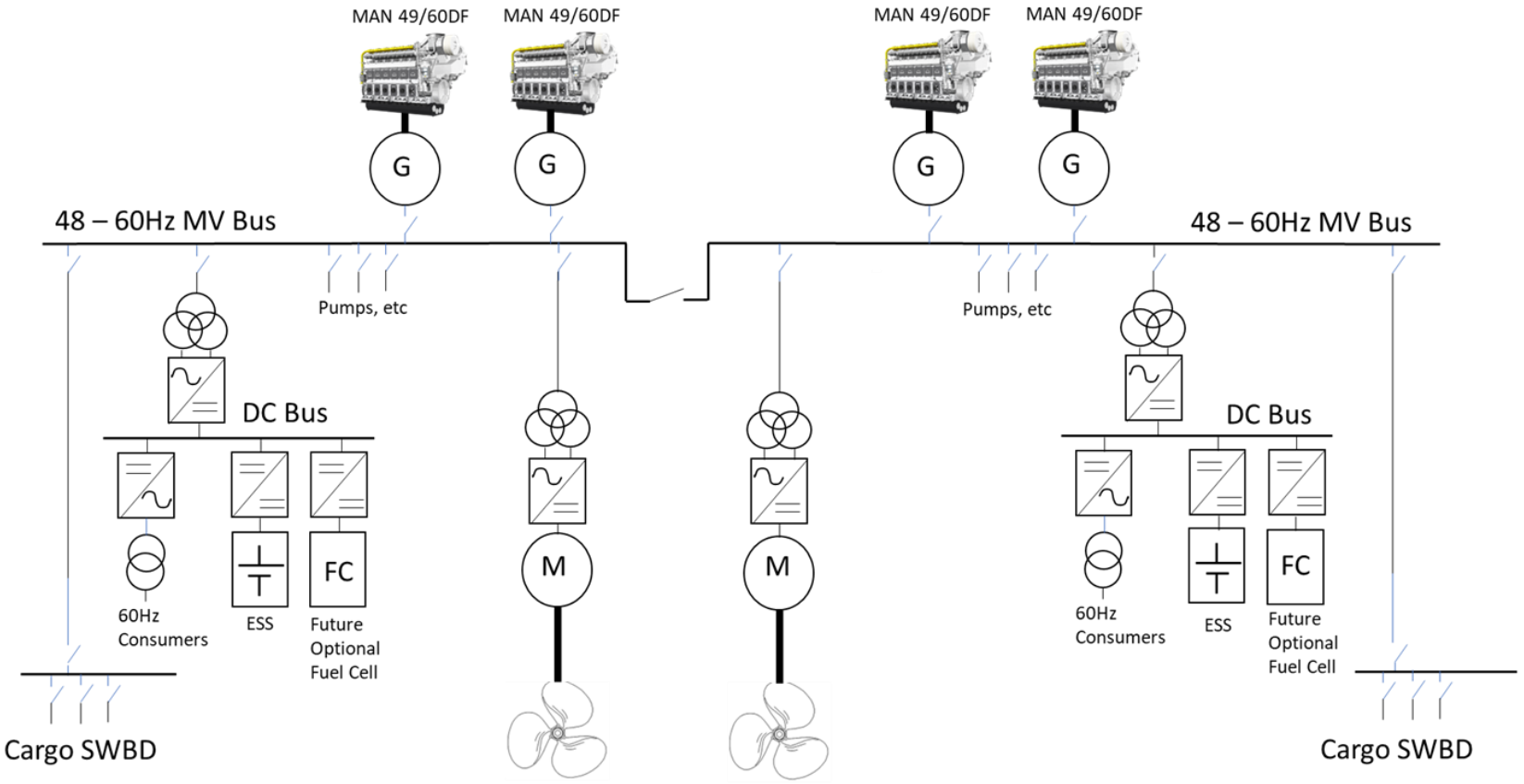
Single Line Diagram

Additional Equipment:

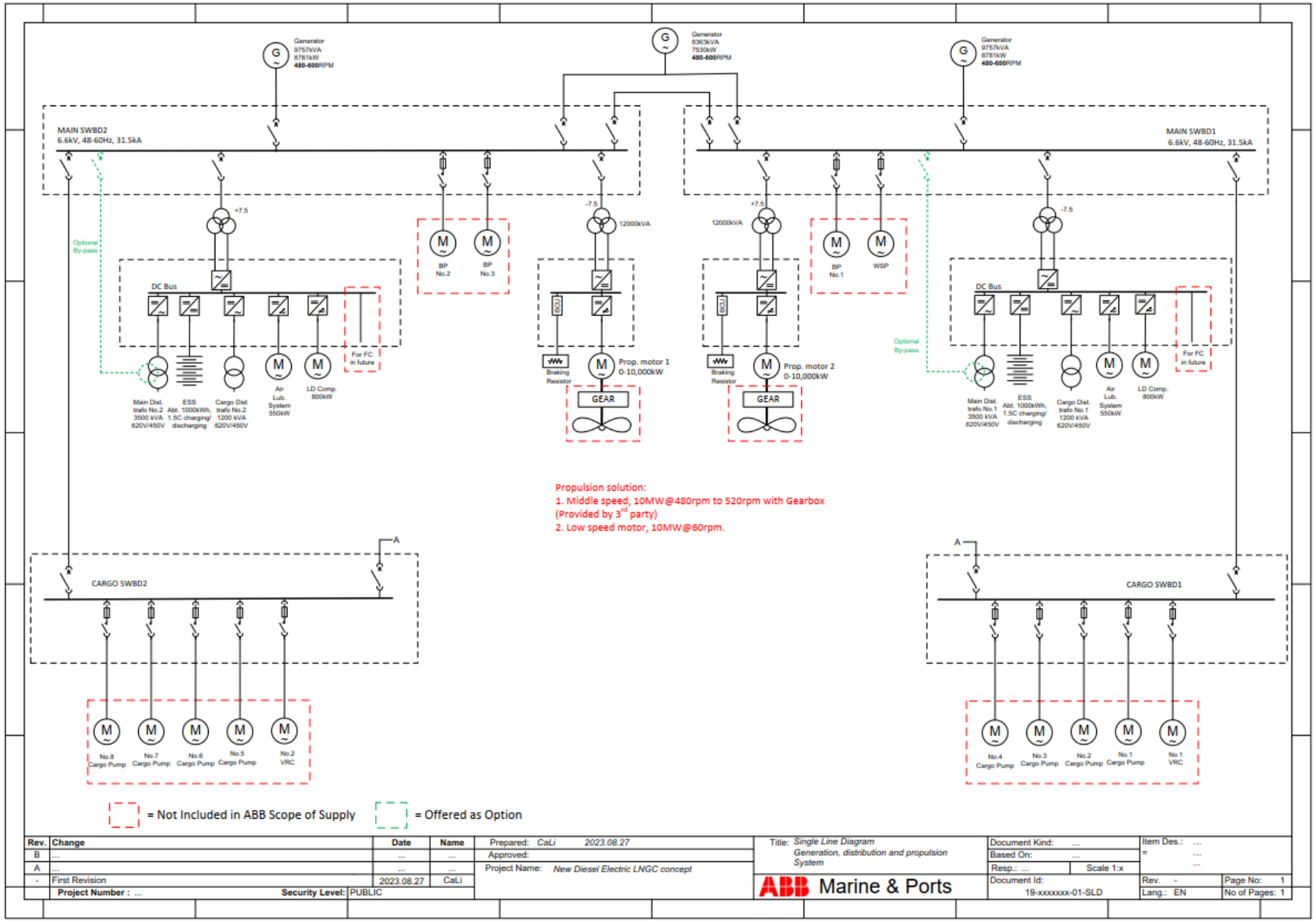
- VFDs for FGCs
- Island converters for dist systems
- Transformers for Island converters

Changes in Equipment:

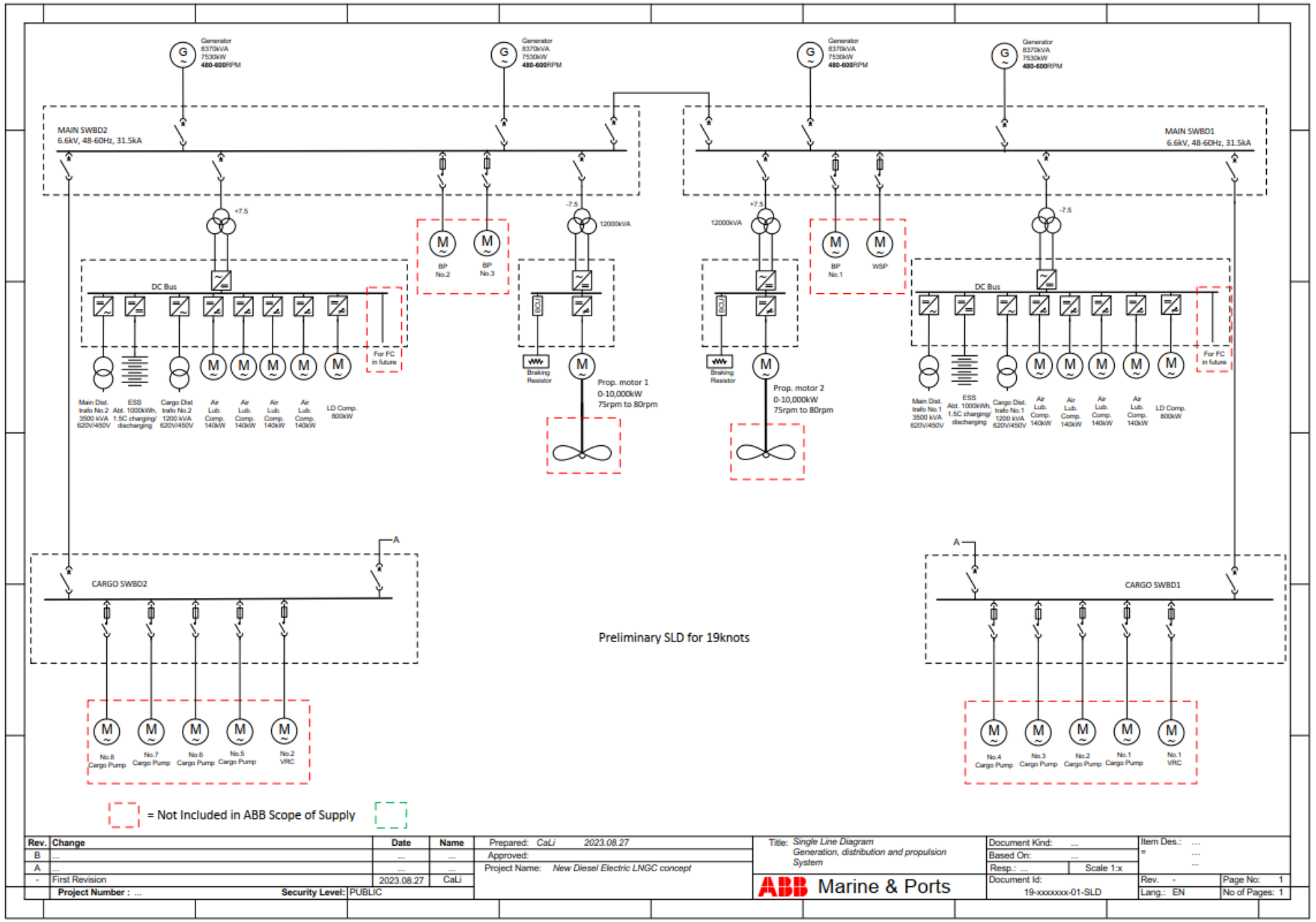
- Generators designed for 48-60Hz
- Drive transformers designed for 48-60Hz
- 6.6kV Switchboard designed for 48-60Hz



DFE+



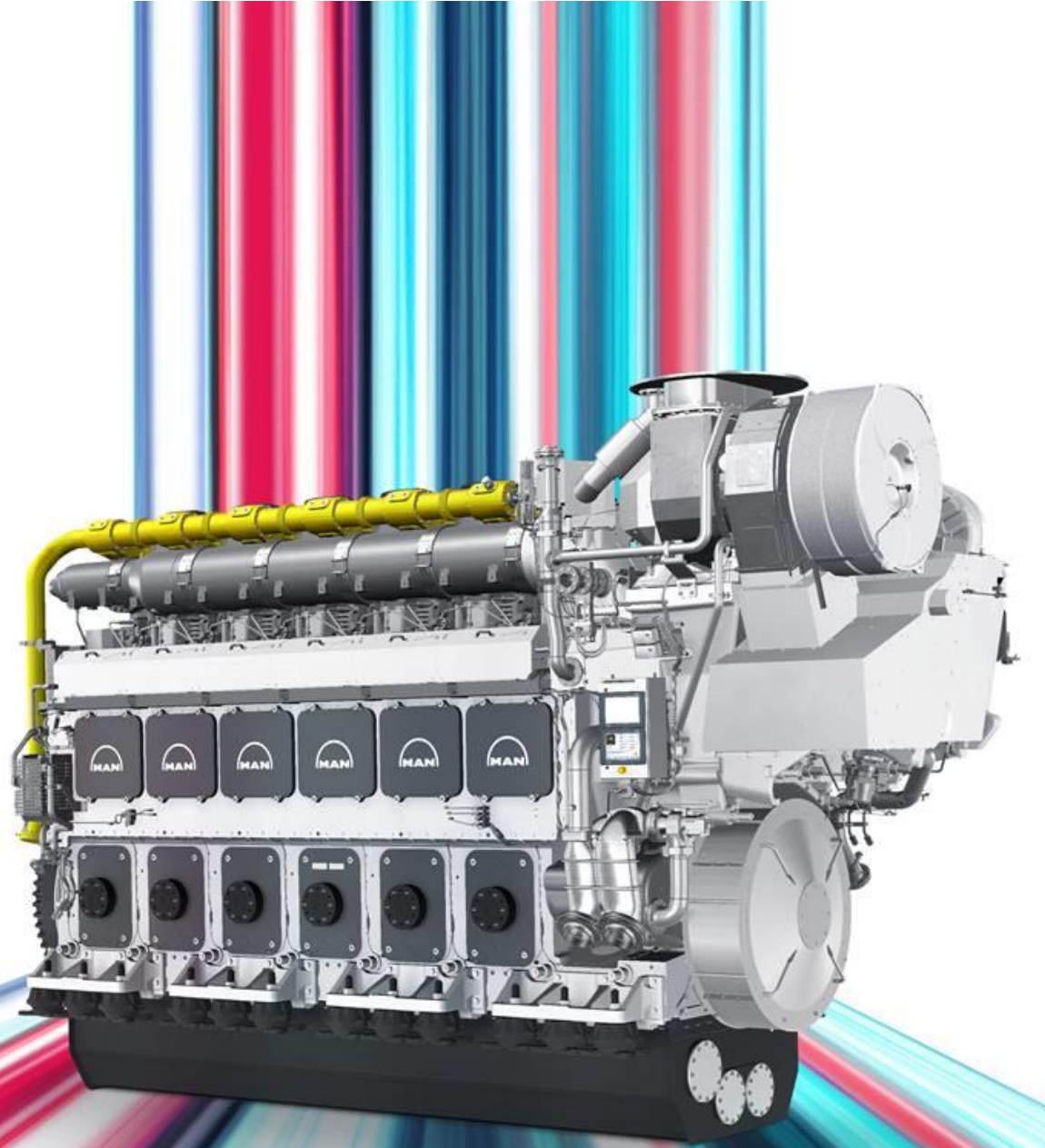
DFE+



MAN Energy Solutions
Future in the making

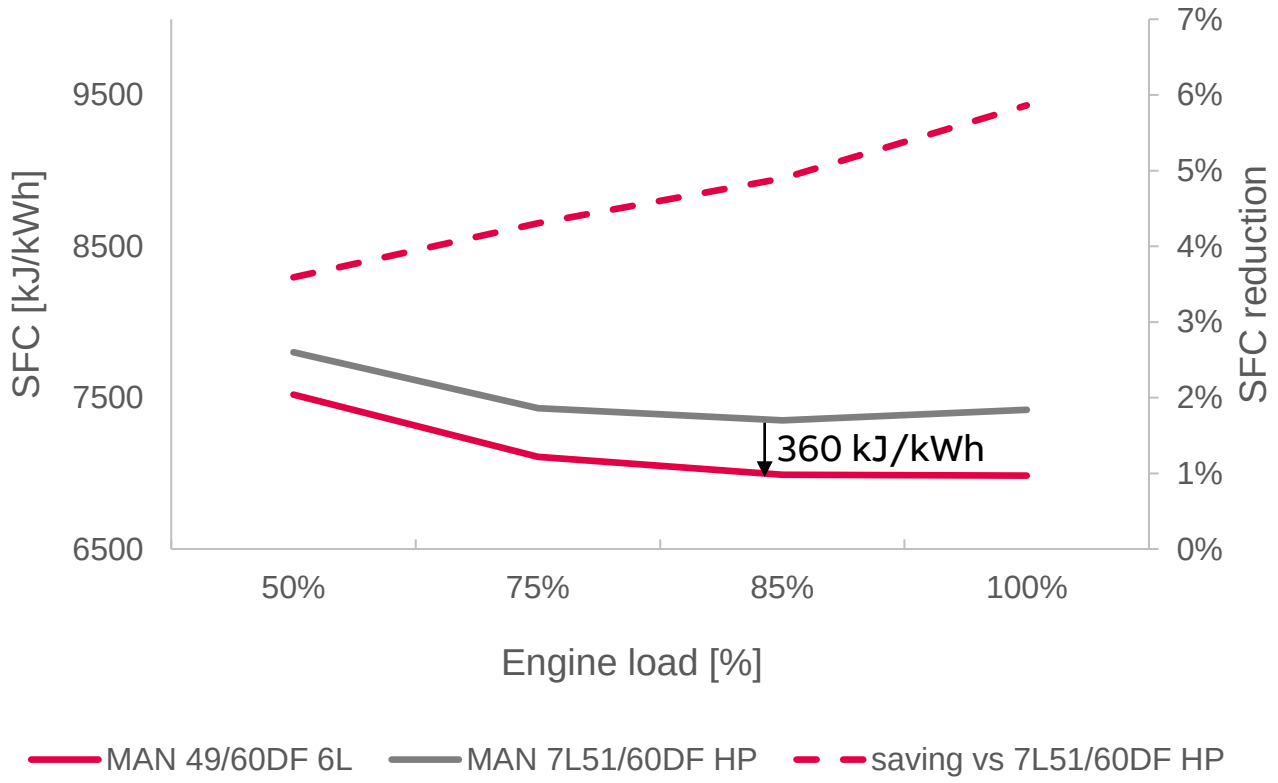
Future-proof in multiple ways

The new MAN 49/60 engine family

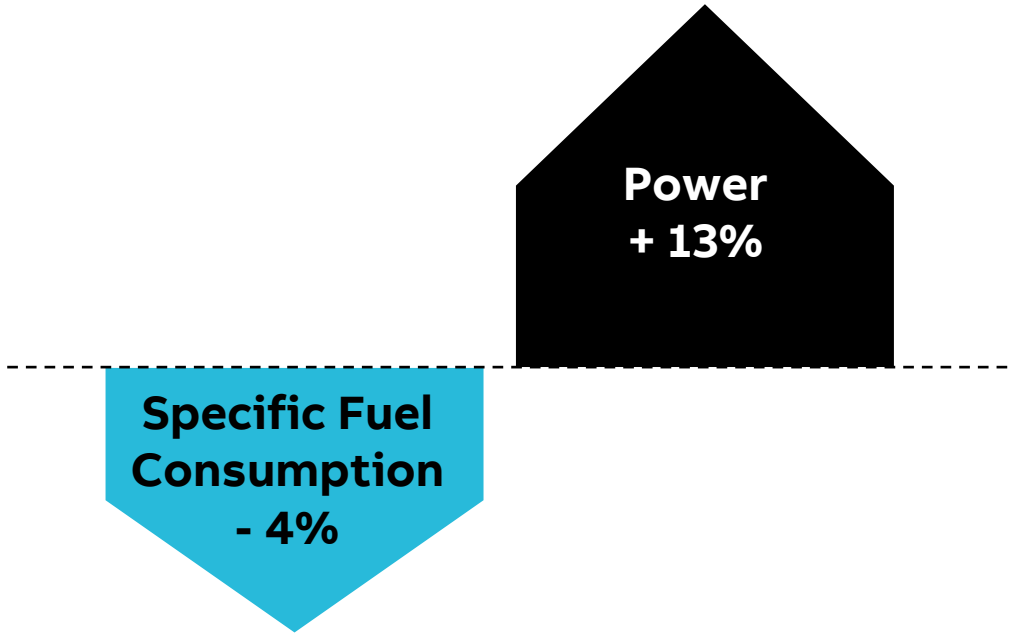


Specific Fuel Consumption – Gas Mode

MAN 49/60DF facts and performance



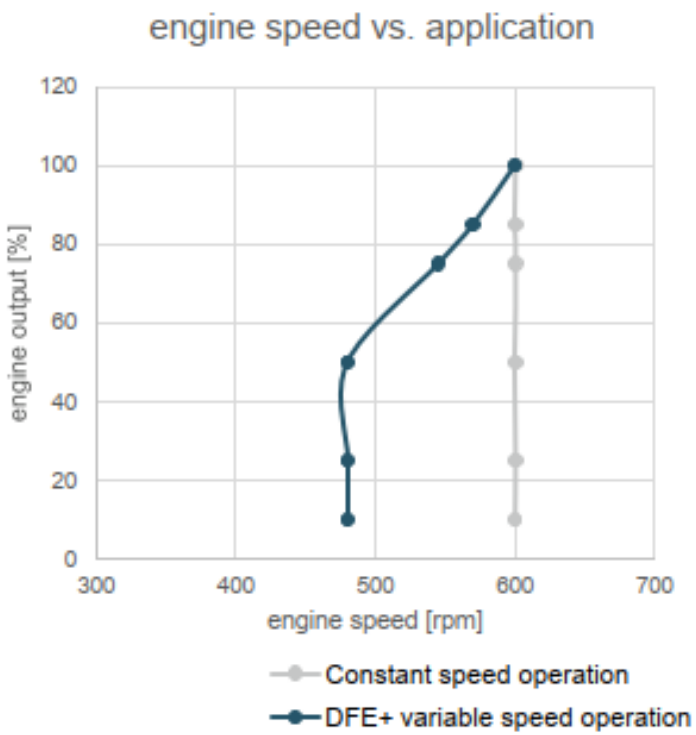
MAN 49/60DF advantages vs. MAN 51/60DF

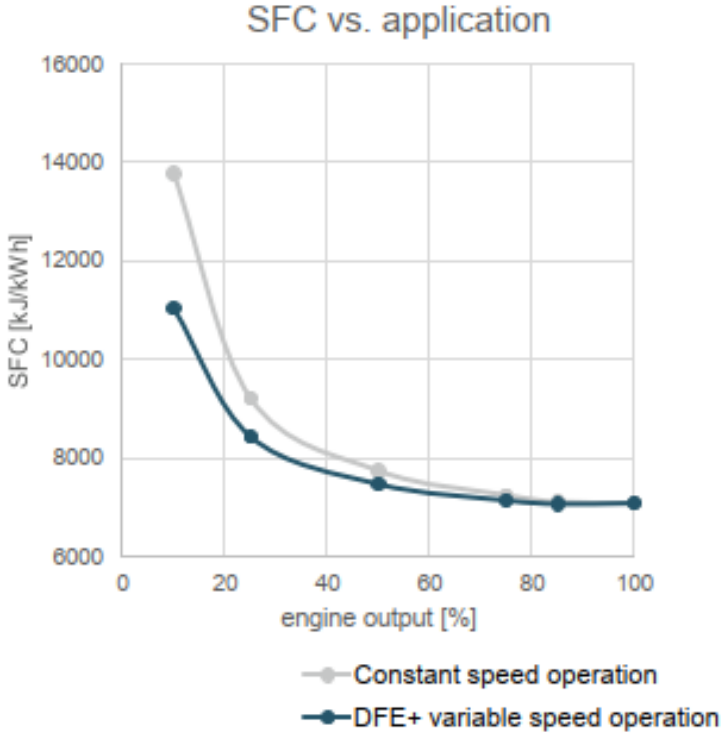


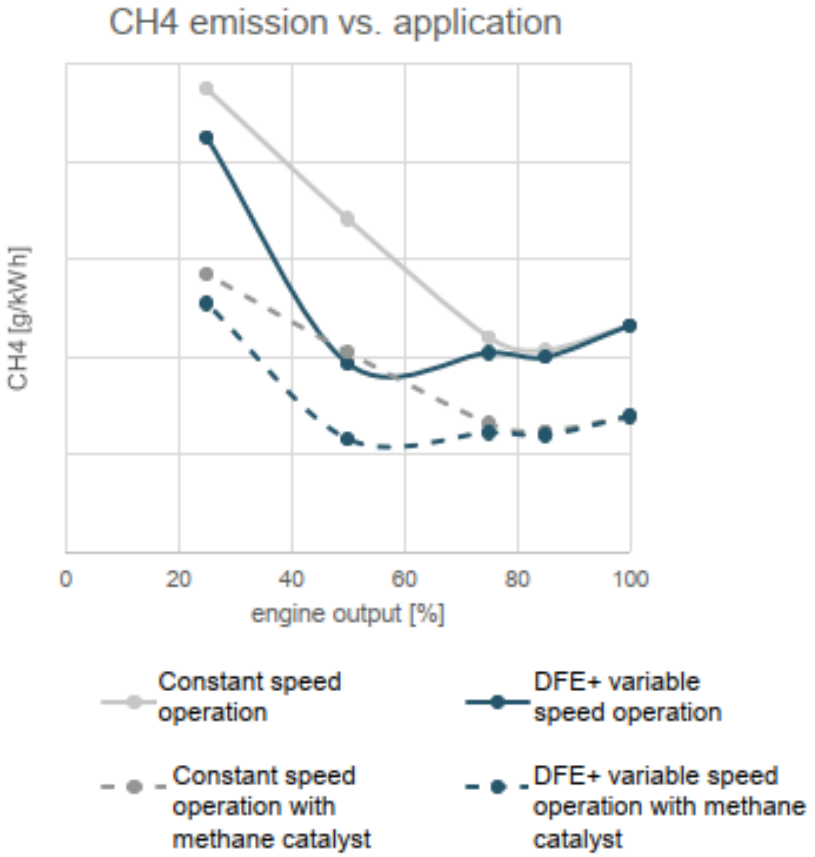
* Diesel-electric, const. speed. Including pilot fuel oil, without attached pumps, E2/D2 cycle, ISO conditions, Tier III in gas mode, MN>= 80, pilot fuel DMA with NCV of 42.700 kJ/kg, 50mbar exhaust gas backpressure, +5% tolerance.

Benefits of variable speed operation

MAN 49/60DF facts and performance

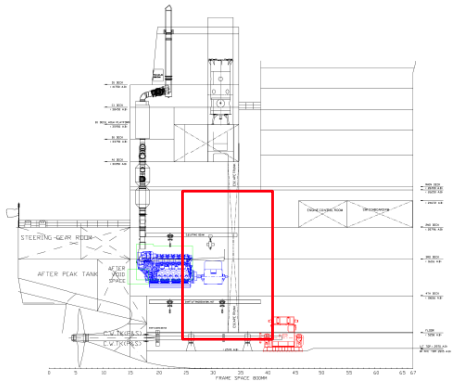




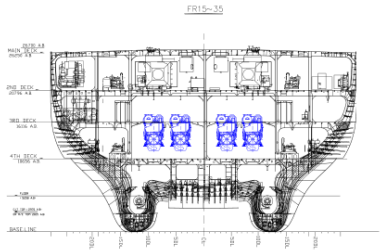


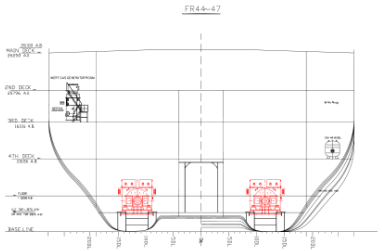
DFE+

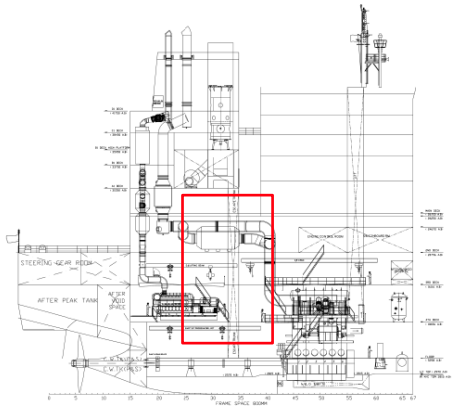
Example of space saving with DFE+



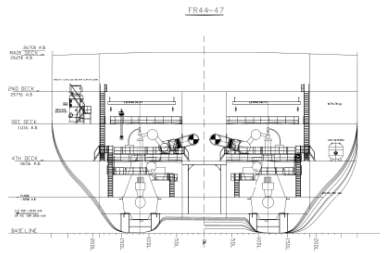
Four stroke: 6L49/60DF







Two stroke



DFE+
All the highlights.

Main highlights

- Flexible; maintaining efficiency throughout the speed range.
- Redundancy with 3 - 4 engines and a battery.
- Prepared for easy installation of alternative power sources like fuel cells and others in the future.
- Extra space for cargo.
- Can easily be prepared for future FSRU operation.

And then also featuring

- Low noise and vibration.
- Maintenance during vessel operation.
- Very stable operation in gas-mode.
- Future proof towards 2050.
- Reduced Methane-slip.
- ALS interface.

WHEN TRUST MATTERS

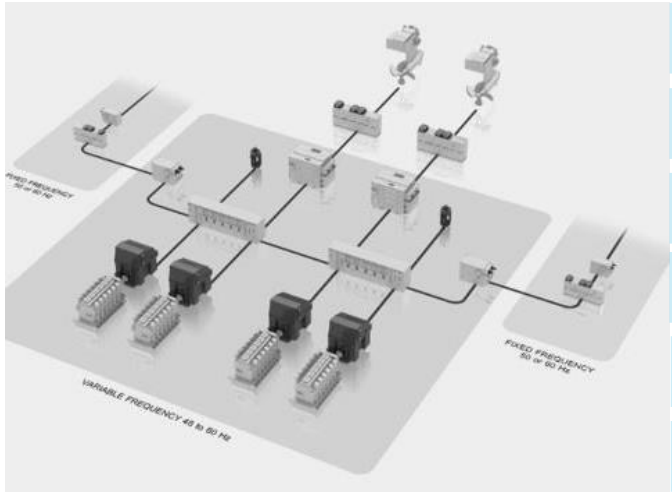
ABB – MAN ENERGY SOLUTIONS

DFE LNGC concept assessment

DNV Advisory
Version 01
Issued Date: 01/06/2023

Executive summary

Novel DFE+ Concept

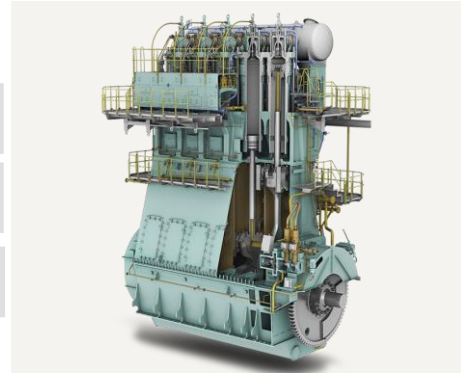


- Multi-engine arrangement based on the new MAN 49/60DF 2stage-TC
- Dynamic AC optimisation, generator variable frequency from 48 to 60Hz
- Permanent magnet motors for improved propeller matching at lower rpm
- Improved waste heat recovery potential
- Efficient ALS system using compressed air from engine turbochargers
- DF-electric concept with an at least 5% increase in cargo capacity

Comparative Assessment

State-of-art 2S-DFM (LP)

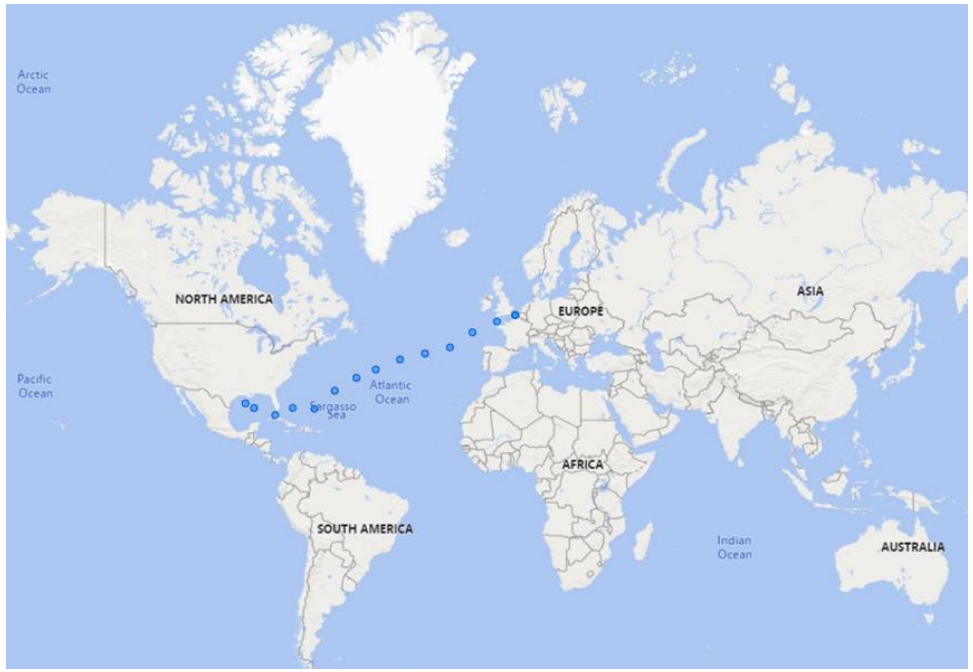
- Latest generation of XDF2.2 based LNGC propulsion
- Air lubrication system coupled with shaft generators
- Latest hull and machinery specifications for 174K cbm



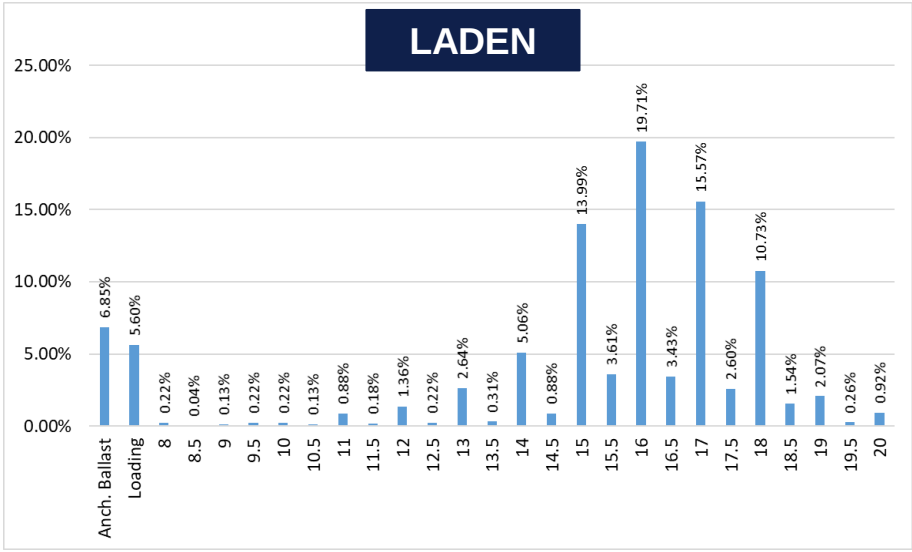
Operating profiles and trade routes

US – EUR 5200 nm

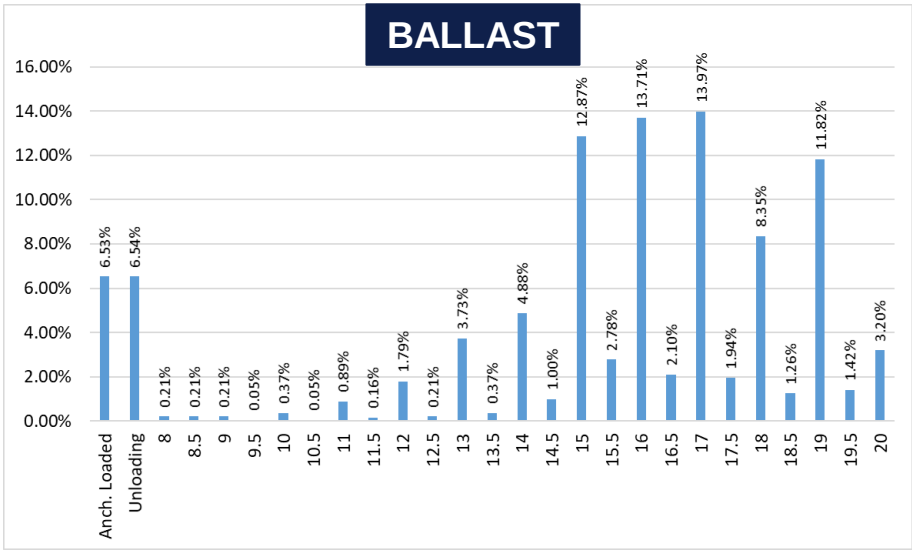
Sabine Pass - Zeebrugge



Frequency per voyage



Frequency per voyage

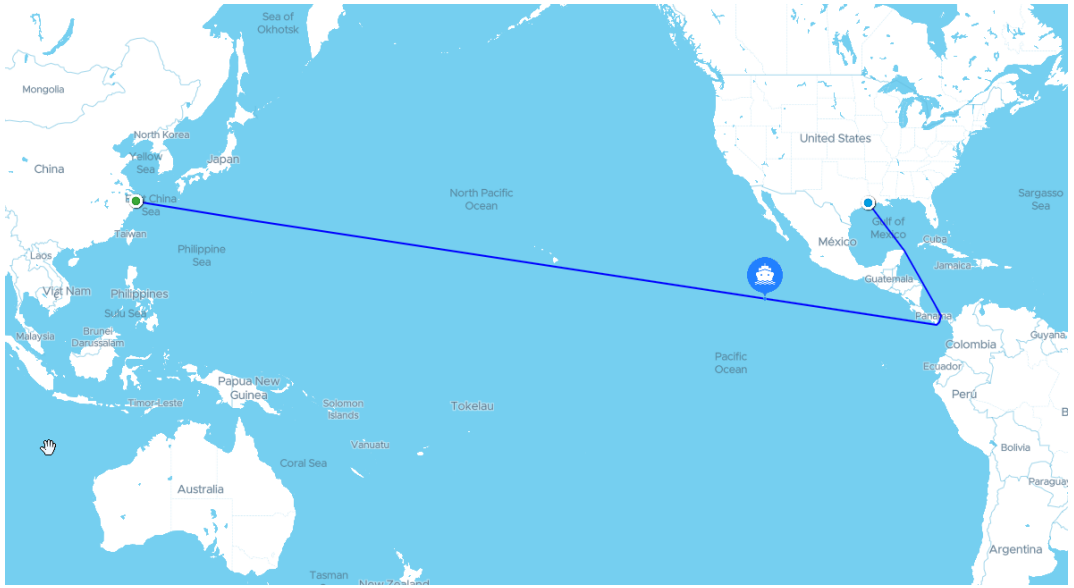


Speed

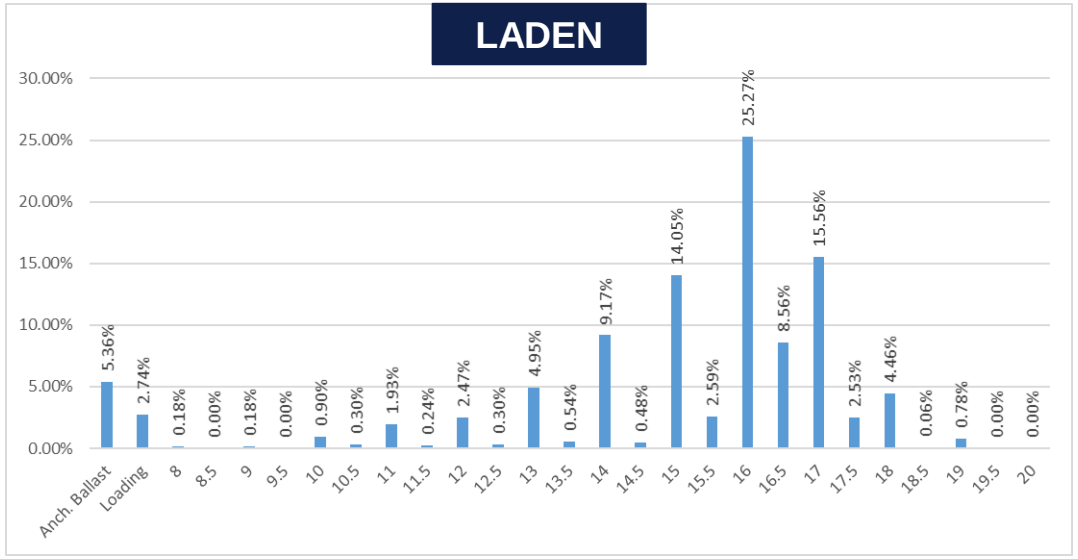
Operating profiles and trade routes

US – ASIA **10500 nm**

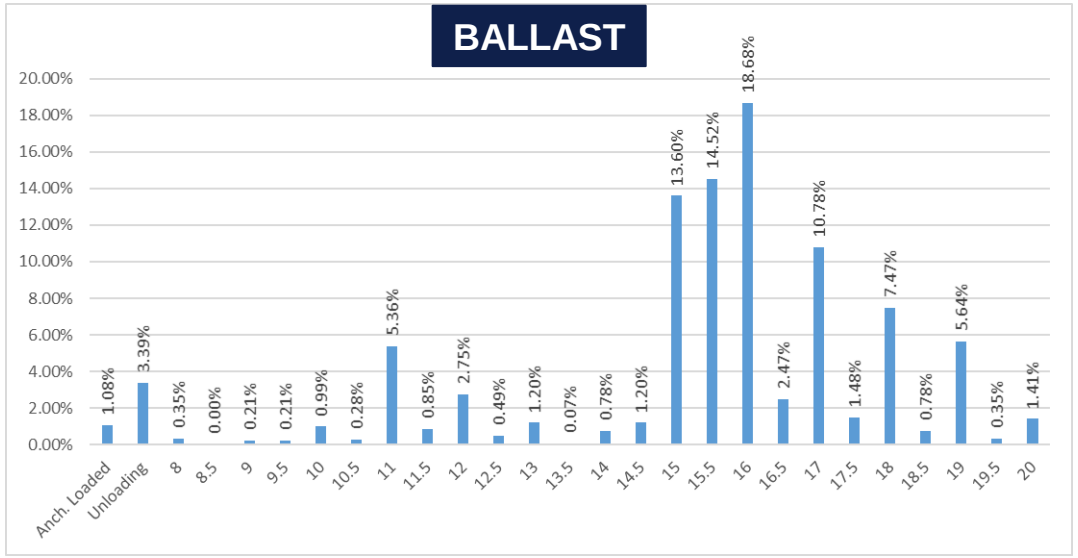
Sabine Pass - Tianjin



Frequency per voyage



Frequency per voyage

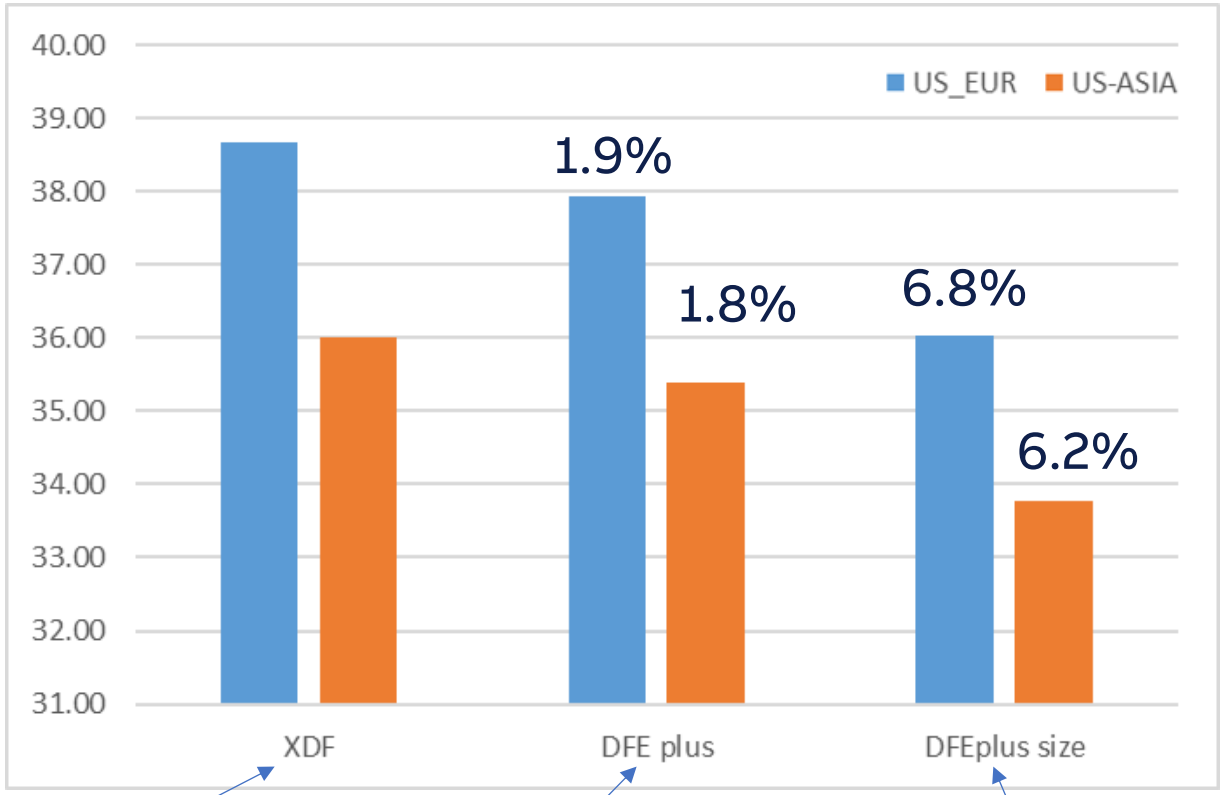


Speed

DFE operating profile optimisation results ALS results: compared to the original XDF and operating profile

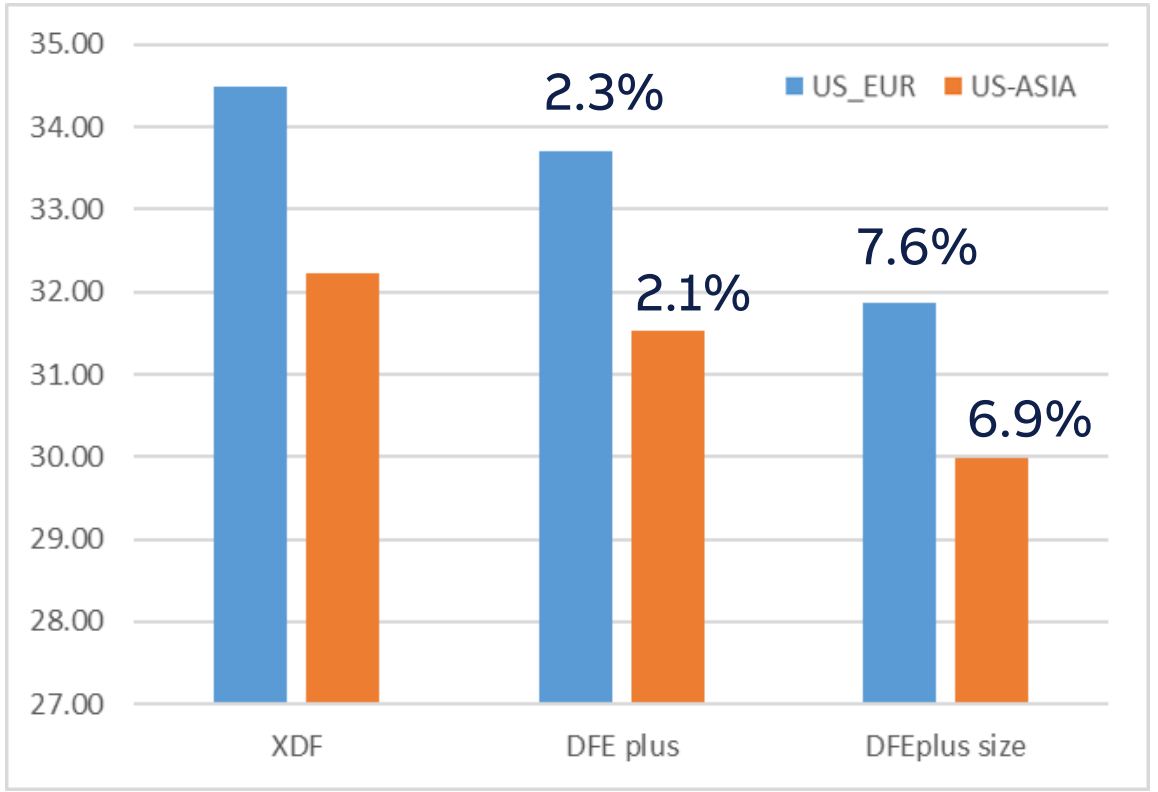
SM=21%

EFR round-trip (kJ / nm.cbm)



SM=0%

EFR round-trip (kJ / nm.cbm)



Benchmark vessel

DFE with the same cargo capacity as XDF

DFE with increased cargo capacity

DFE+

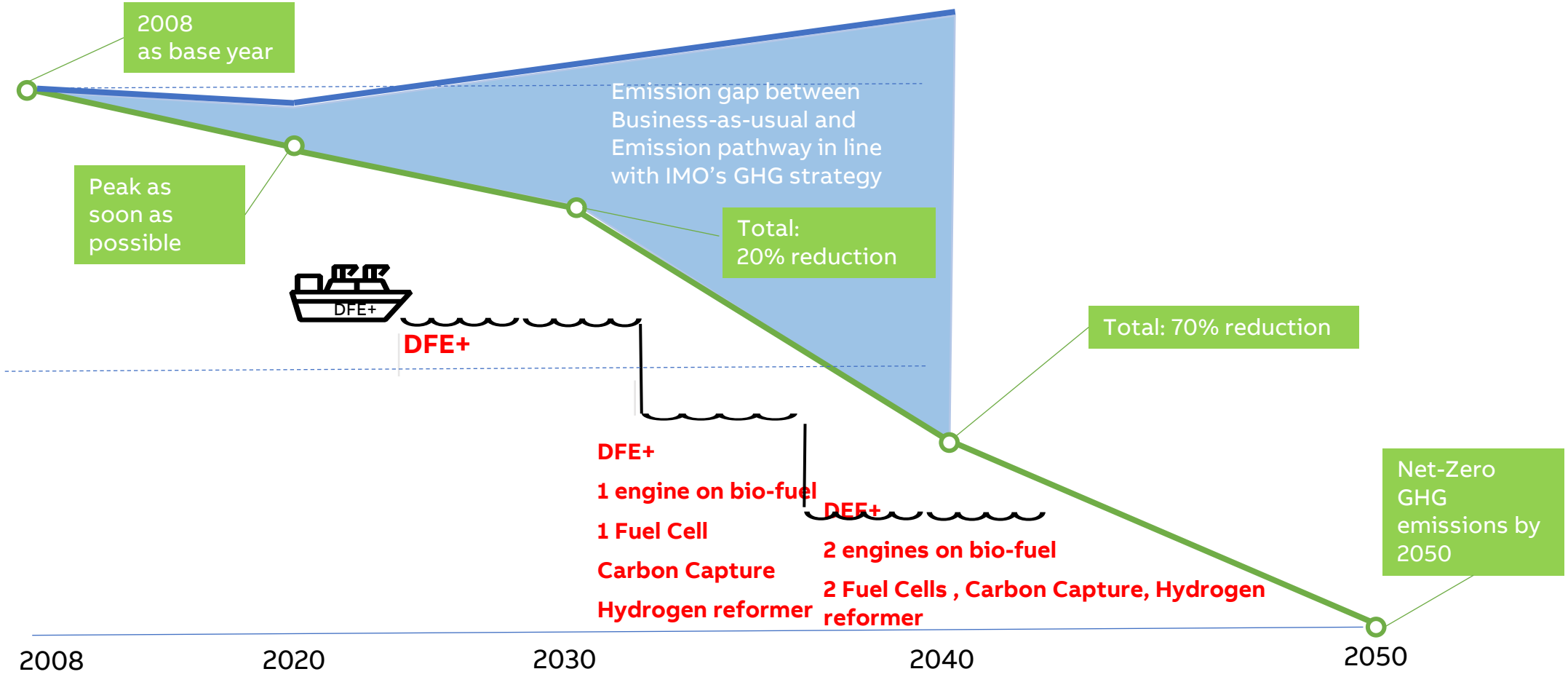
Key findings from the DNV simulation

Main highlights

- **The DFE proposed concept can be a competitive and more energy efficient alternative to the state-of-art 2-stroke DF LNGC propulsion designs.**
- **The most significant aspect of the DFE concept is the possibility to increase the cargo carrying capacity of the vessel by at least 5% without changing the main dimensions. This yields an energy efficiency benefit in terms of transport work performed on an annual basis.**
- **DFE+ has additional efficiency advantages at low speed / low demand (clean hull) and port stay modes. Due to the multi-engine arrangement avoiding pat loads.**
- **By the combination of all above improvements to the DFE concept (propeller matching, ALS, increased cargo capacity) the overall energy consumption improvement is between 6% to 7.5% compared to the 2SDF configuration.**

DFE+

Path towards 2050



DFE+
References

ABB has a long reference list from delivering power and propulsion systems to **143 LNG carriers** since 1995.

The new DFE+ concept is a natural continuation of this proud history.


ABB