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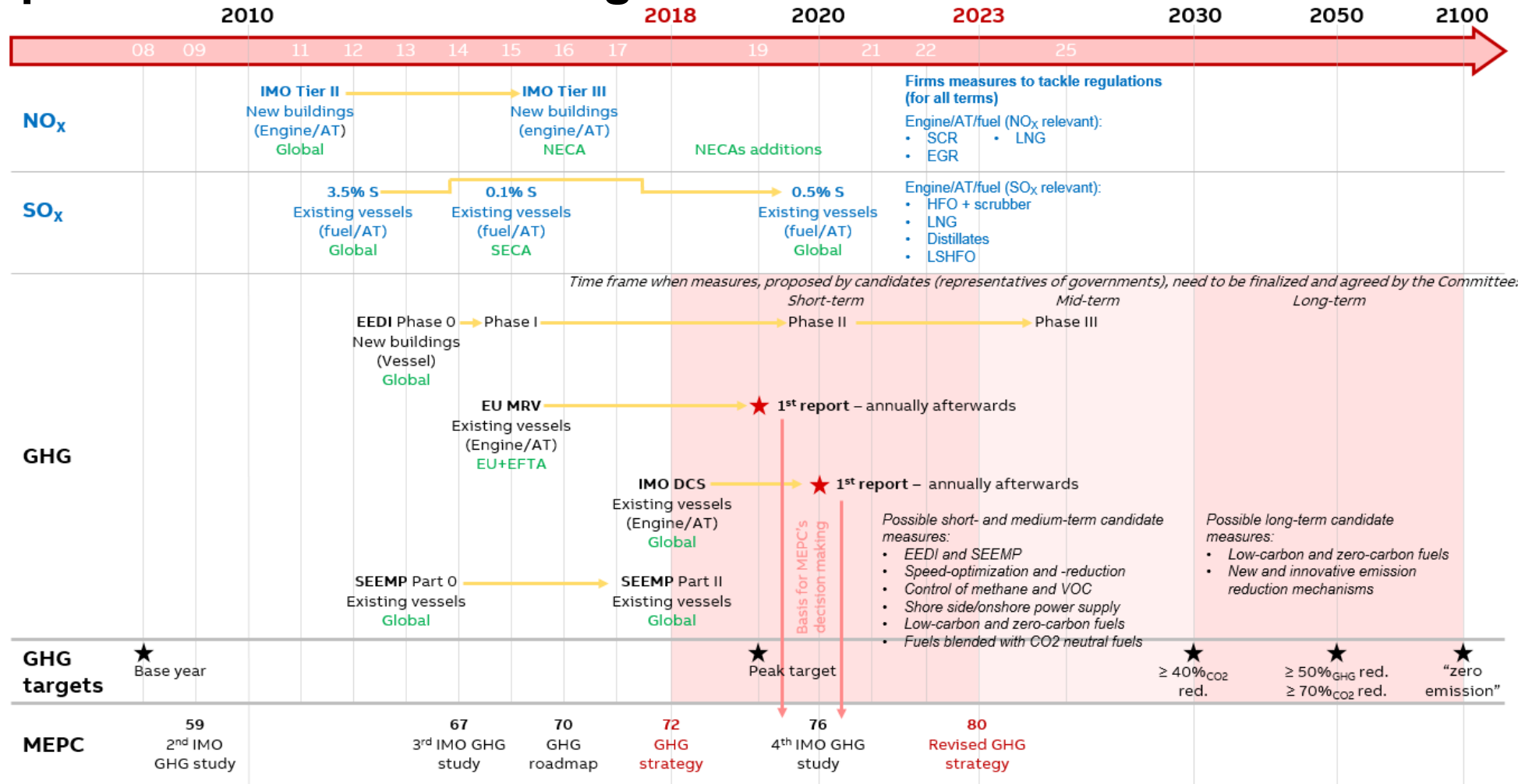
Turbocharging technology as an enabler for lower emissions

Greener Shipping Summit 2019 - At the Door of 2020 and Moving Fast to 2050

Stamatis Achillas, Head of Product Management Low-Speed Turbocharging



Landscape of marine emission legislation



AT: After treatment; DCS: Data Collection System; EEDI: Energy Efficiency Design Index; GHG: Greenhouse gas; MEPC: Marine Environment Protection Committee; MRV: Monitoring, Reporting, Verification; NECA: NO_x Emission Control Area; SECA: SO_x Emission Control Area; SEEMP: Ship Energy Efficiency Management Plan.

→ Basis for MEPC → Evolution steps

Non-IMO Measures and Indexes

Will any of these emerging benchmarks influence newbuilding decisions in the future?

Poseidon Principles – Annual Efficiency Ratio (AER)

The Poseidon Principles Association, founded in June 2019, aims to assess climate alignment of a vessel by comparing its AER (carbon intensity metric) with the decarbonization trajectory of the vessel's type and size class. The Poseidon Principles signatories comprise so far financial institutions.

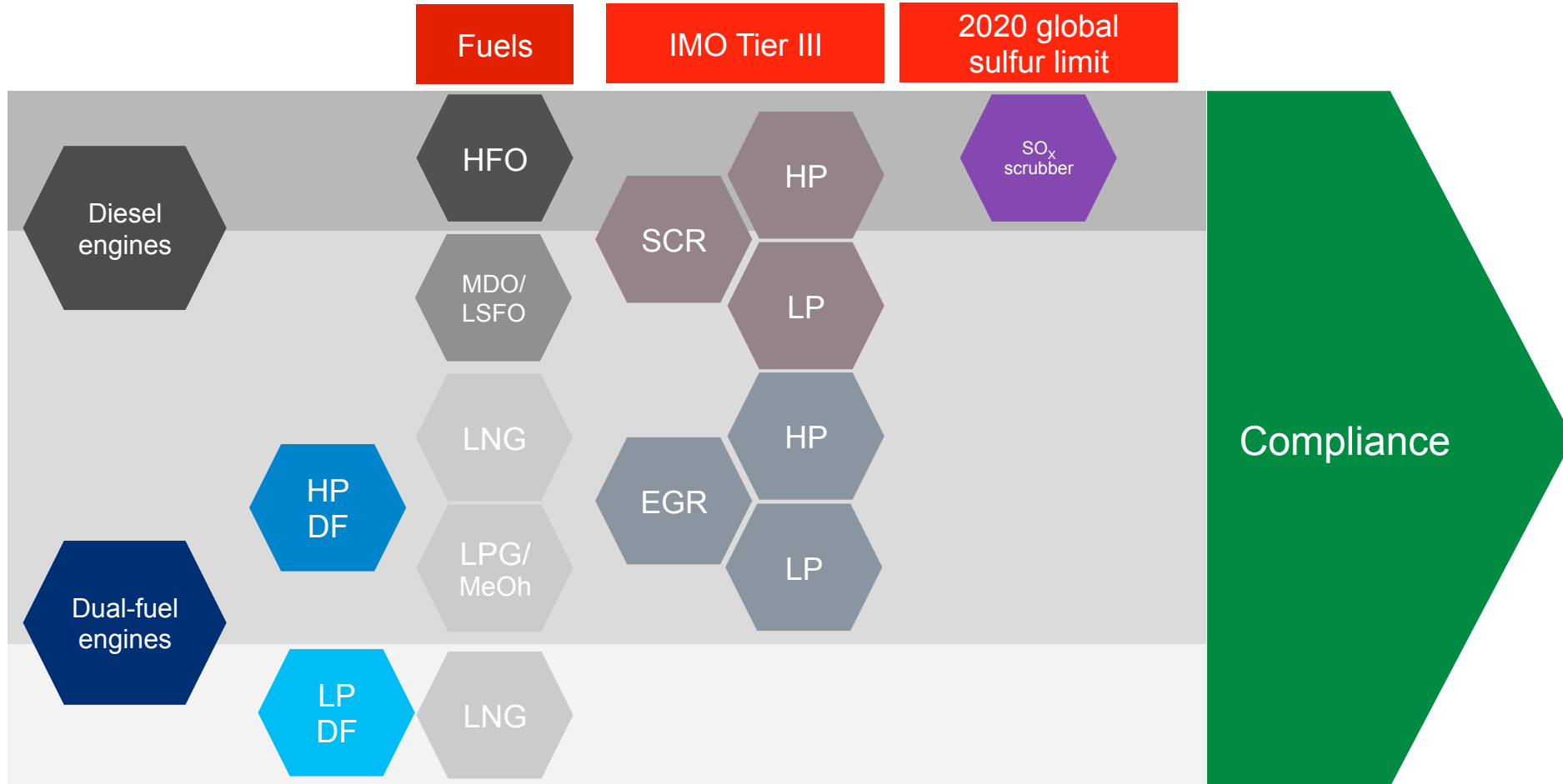
Clean Cargo Working Group

Clean Cargo aims to establish itself as a global standard for benchmarking CO₂ emissions in the container shipping sector. It invites companies who wish to showcase their commitment to reducing their environmental impact.

World Ports Sustainability Program – Environmental Ship Index (ESI)

A measure used to identify vessels with emissions performance above and beyond current international (IMO) legislation. The ESI considers NO_x, SO_x, and GHG emissions.

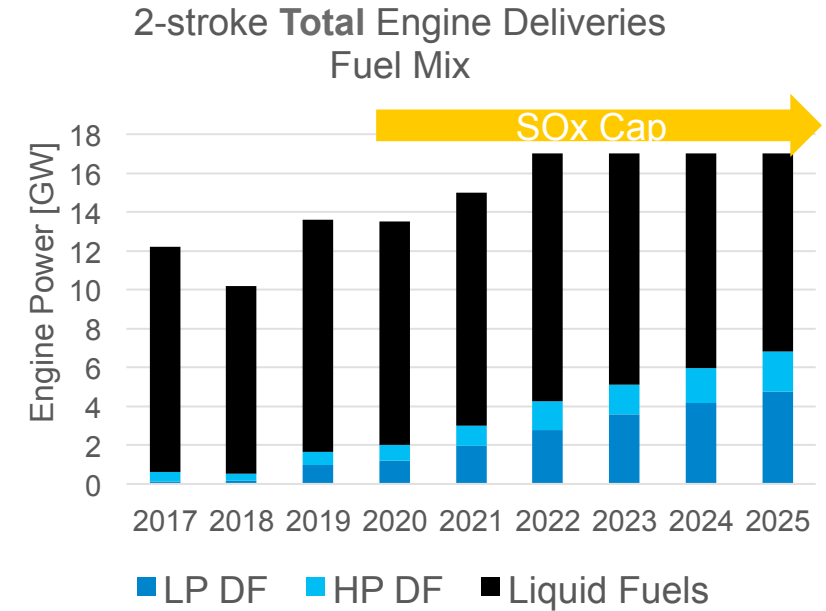
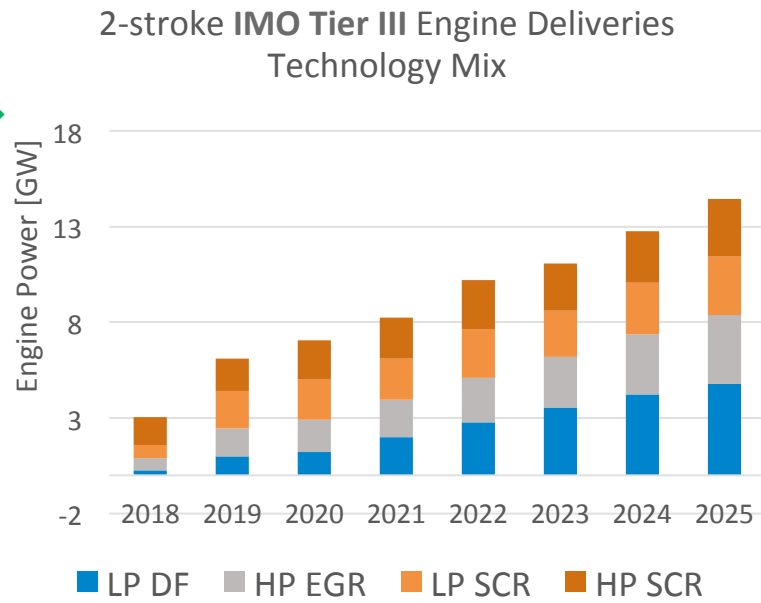
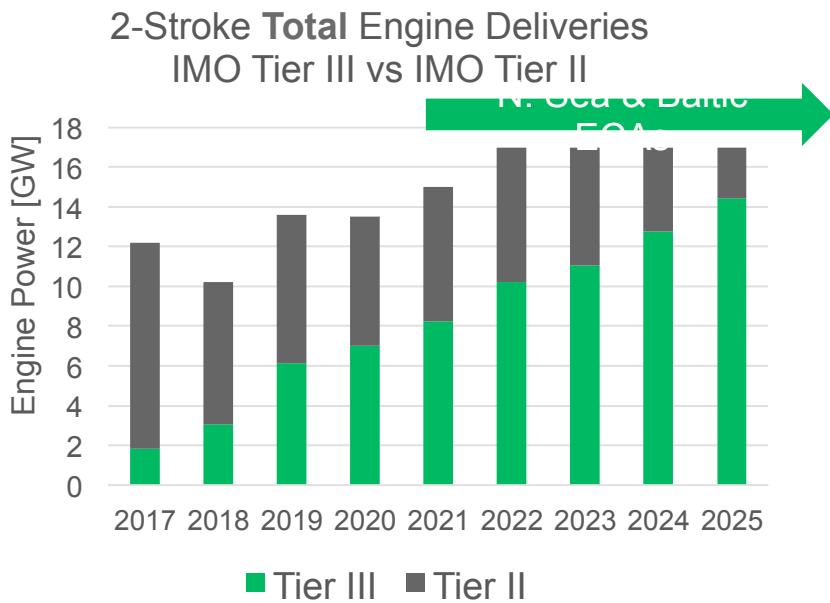
NO_x and SO_x compliance: A complex matrix of solutions



HP: High-Pressure | LP: Low-Pressure | DF: Dual-Fuel | SCR: Selective Catalytic Reduction | EGR: Exhaust Gas Recirculation

2-Stroke Marine Engines Market

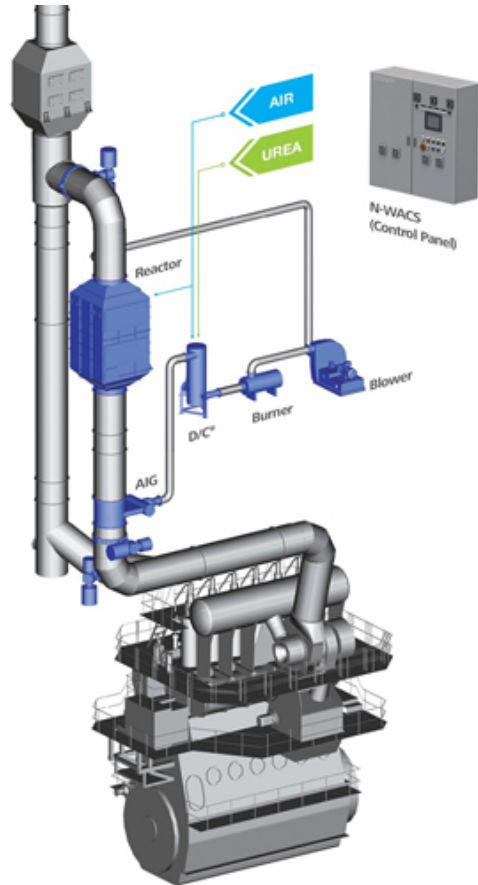
Fuels and Technologies Selection for Emissions Compliance



- ❖ Strong Dual-Fuel (LNG) market penetration – 12% in 2019 2-stroke engine deliveries by engine power
- ❖ SOx scrubbers 33% of new building orderbook – 50% for Tankers & Containerships (Clarksons)
- ❖ Alternative fuels (e.g. ammonia, hydrogen, e-fuels) will have no significant presence in new buildings by 2025, but might enter the new building fuel mix by 2030.

Low-Pressure Selective Catalytic Reduction (LP SCR)

Illustration of a Low-Pressure SCR installation

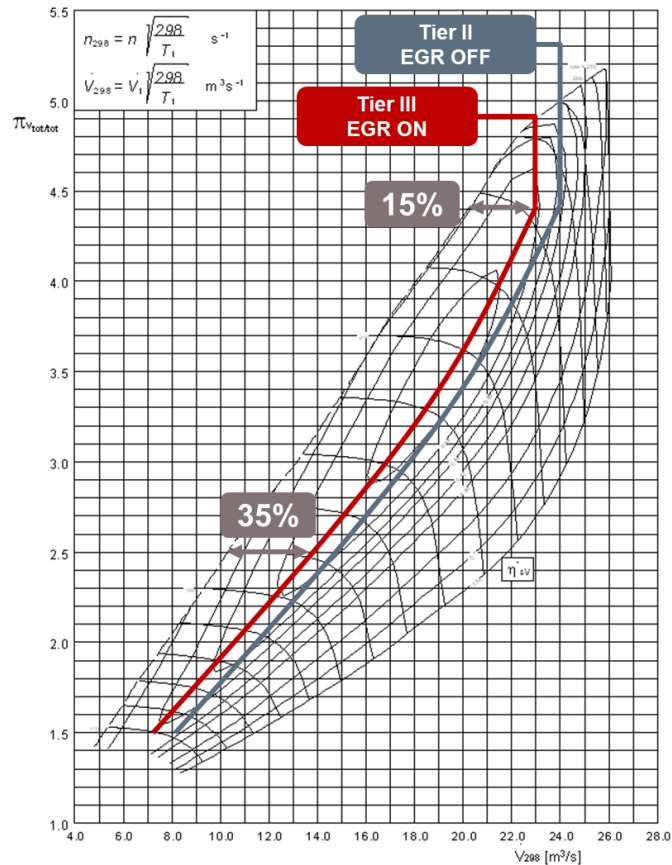


Key Takeaways

- ❖ Increased backpressure after the turbocharger calls for higher turbocharger efficiency
- ❖ Temperature management of exhaust gas requires lower turbocharger efficiency
- ❖ Flexibility in turbocharger specifications and application engineering know-how are of utmost importance for turbocharger matching.

High-Pressure Exhaust Gas Recirculation (HP EGR)

IMO Tier II and Tier III modes with HP EGR

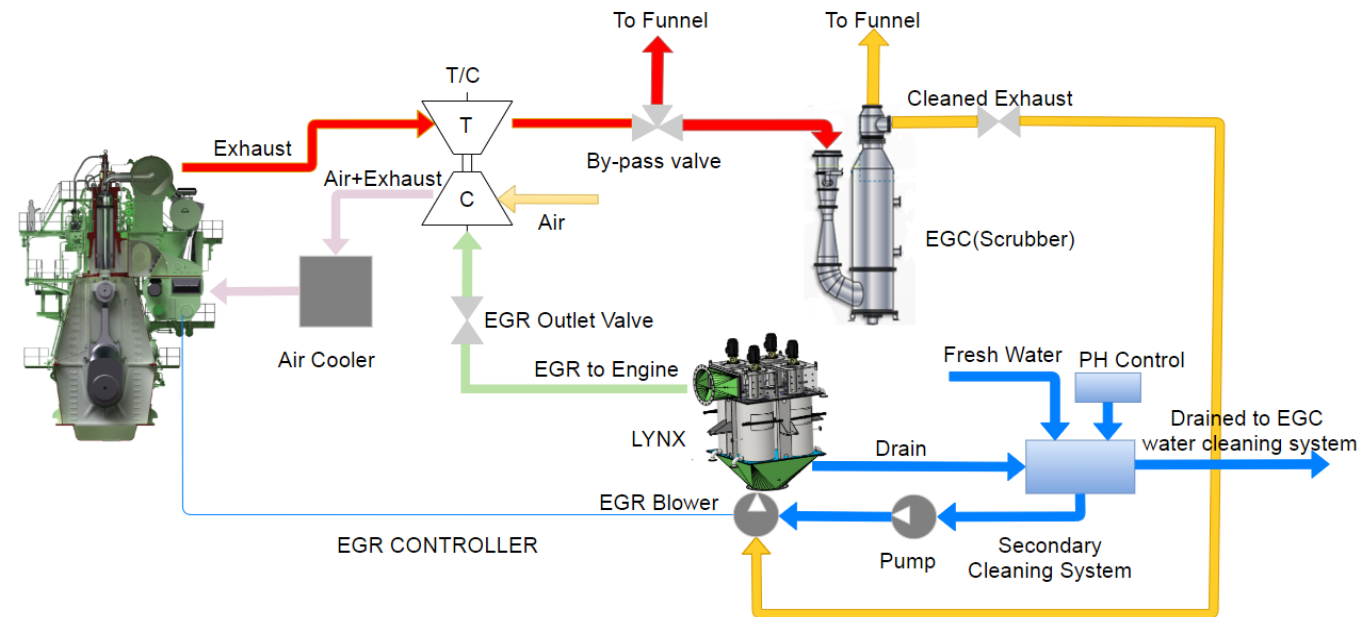


Key Takeaways

- ❖ Tier III mode is most demanding in terms of turbocharger efficiency and is used as reference for matching
- ❖ Tier II mode moves the operating line closer to choke
- ❖ A wide turbocharger compressor map is vital for stable operation at highest efficiency under all conditions

Low-Pressure Exhaust Gas Recirculation (LP EGR)

Illustration of LP EGR installation

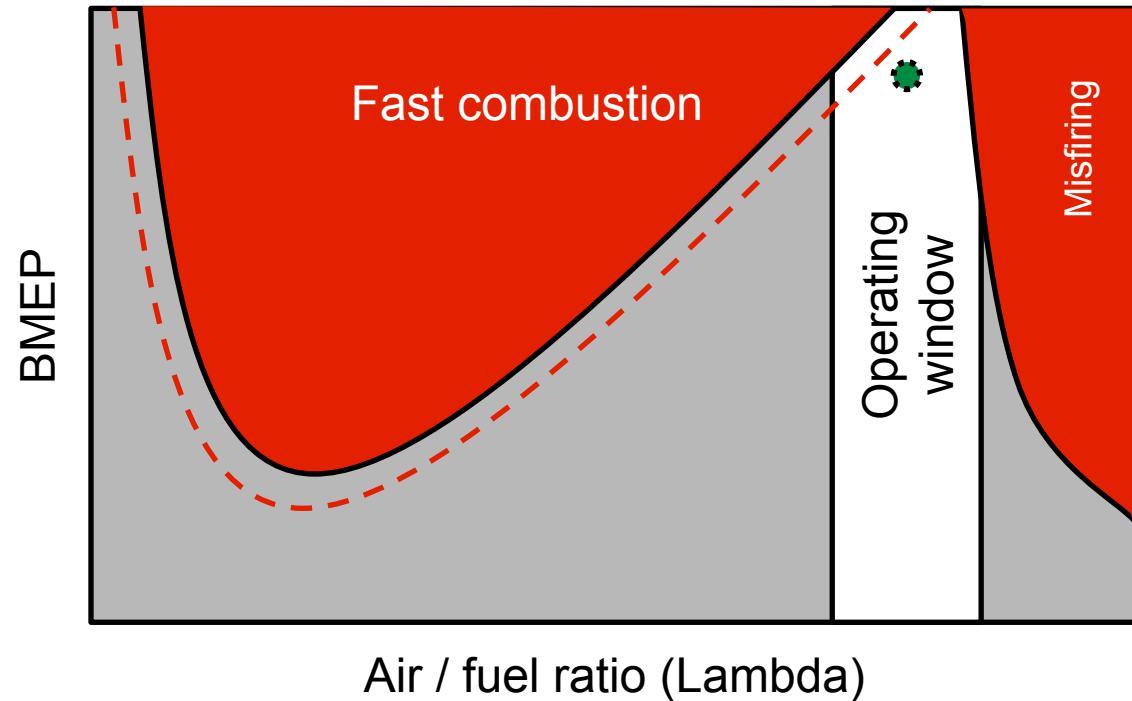


Key Takeaways

- ❖ Turbocharger compressor stage handles up to 40% exhaust gas flow throughput
- ❖ Mildly acidic environment, water vapor presence and soot content despite scrubbing
- ❖ Durable compressor stage materials and fouling-resistant design

Low-Pressure Dual-Fuel Technology on 2-stroke marine propulsion engines

Illustration of ideal operating area for LP DF in gas mode



BMEP: Break Mean Effective Pressure

Key takeaways

- ❖ A high and stable air/fuel ratio is vital for optimal combustion in a tight operating window
- ❖ Gas quality affects area of fast combustion and ambient conditions affect air mass flowrate
- ❖ Turbocharging efficiency, especially at high loads, is paramount for stable combustion

New A255-L and A260-L: the latest additions to our A200-L portfolio

Compact. Powerful. Efficient. – Available now



Key features

- ❖ Compact design based on reliable A200-L concept, delivers more power for its size, thus reducing maintenance costs
- ❖ Best in class efficiency, optimized for small bore two-stroke engines, enables lower fuel consumption and reduced emissions
- ❖ Compatible with all emission abatement technologies and all fuels

Best-in-class turbochargers for your applications

New A255-L and A260-L: propelling all two-stroke engines on vessels up to 40,000 DWT

**Small, handy tankers:
10,000 to 40,000 DWT**



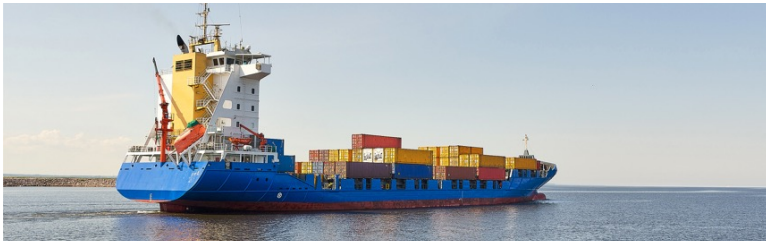
**Bulk carrier handysize:
10,000 to 40,000 DWT**



**Pure car carrier:
2,000 to 10,000 DWT**



**Container feeder:
<1,000 TEU**



**LNG carrier:
<40,000 CBM**



**General cargo:
+10,000+ DWT**



IMO 2030 & 2050 targets

Future turbocharger technologies as an enabler for lower CO₂ and Greenhouse Gas (GHG) emissions

Low-Pressure Dual-Fuel engines

Continuous optimization of turbocharger characteristics to enable:

- ❖ Stabler combustion at high loads and increased power density
- ❖ Further improved GHG footprint by reduced gas consumption and methane slip

Diesel engines: Trend to higher efficiency

More demanding turbocharging requirements to enable:

- ❖ Higher cylinder pressures and further improved scavenging
- ❖ Reduced fuel consumption and associated GHG emissions

Biofuels, e-fuels, ammonia, hydrogen and other alternative fuels

Potentially new requirements in terms of combustion characteristics and component materials



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