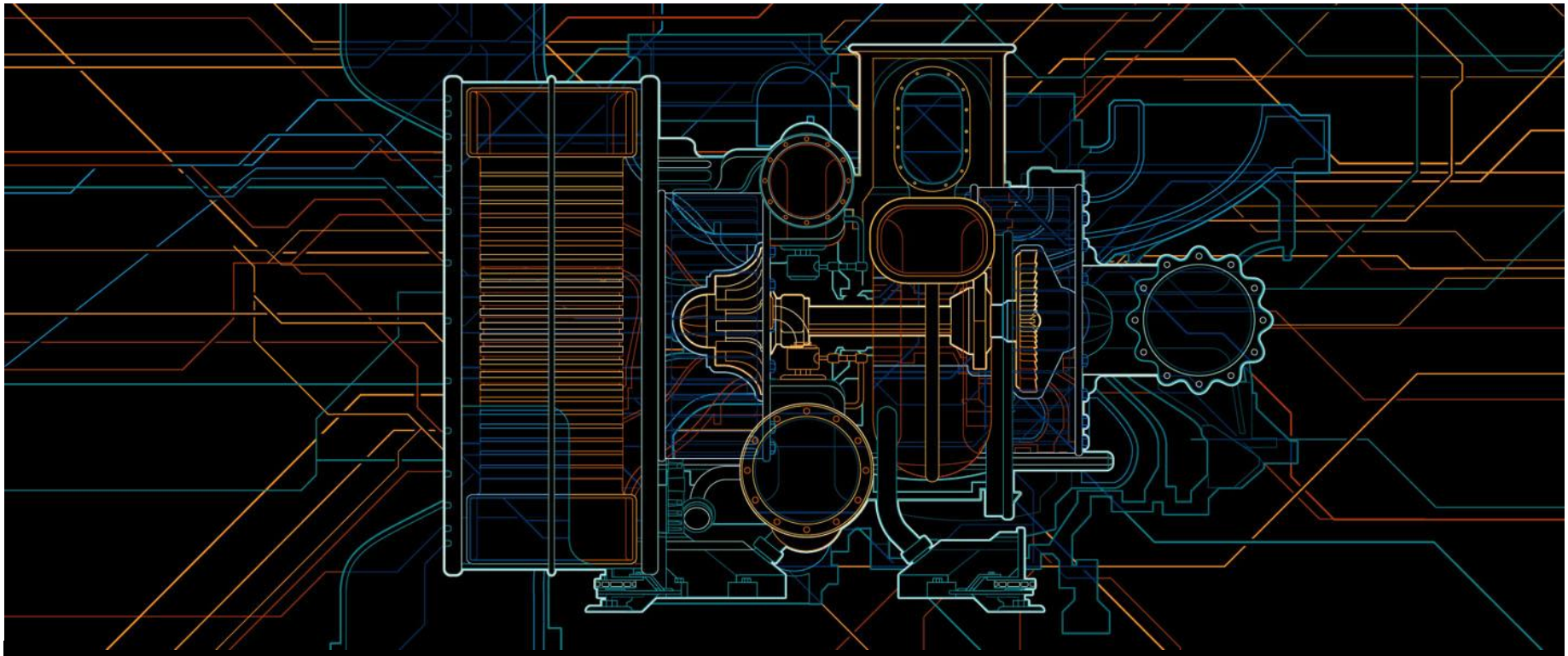


CIMAC Circle @ SMM / Hamburg; 2016-09-08

Medium Speed DF Marine Engines
Potential Performance Enhancement

Power and productivity
for a better world™

Medium Speed Dual Fuel Marine Engine
Typical «State-of-the-art» engine platform

Diesel – basic engine:

- Moderate Miller (IMO II)
- Simple variable valve timing (VVT)
- 1-stage turbocharging
- Optimized at around 85% load
  (EWG open at higher loads)

Gas fuel operation compatible:

- … lower compression ratio
- … reduced scavenging
- … reduced power density
- … l control with exhaust waste gate (EWG) or compressor bypass (CBP)
  (limited var. speed capabilities)

Dual Fuel consequences:

- Diesel Mode
  IMO II
  … higher bsfc* due to low compression ratio
  … higher thermal load due to reduced scavenging
  … higher p_c** due to operation with closed EWG
- Gas Mode
  IMO III
  … poor TC exploitation due to high p_c** in Diesel Mode (DM)

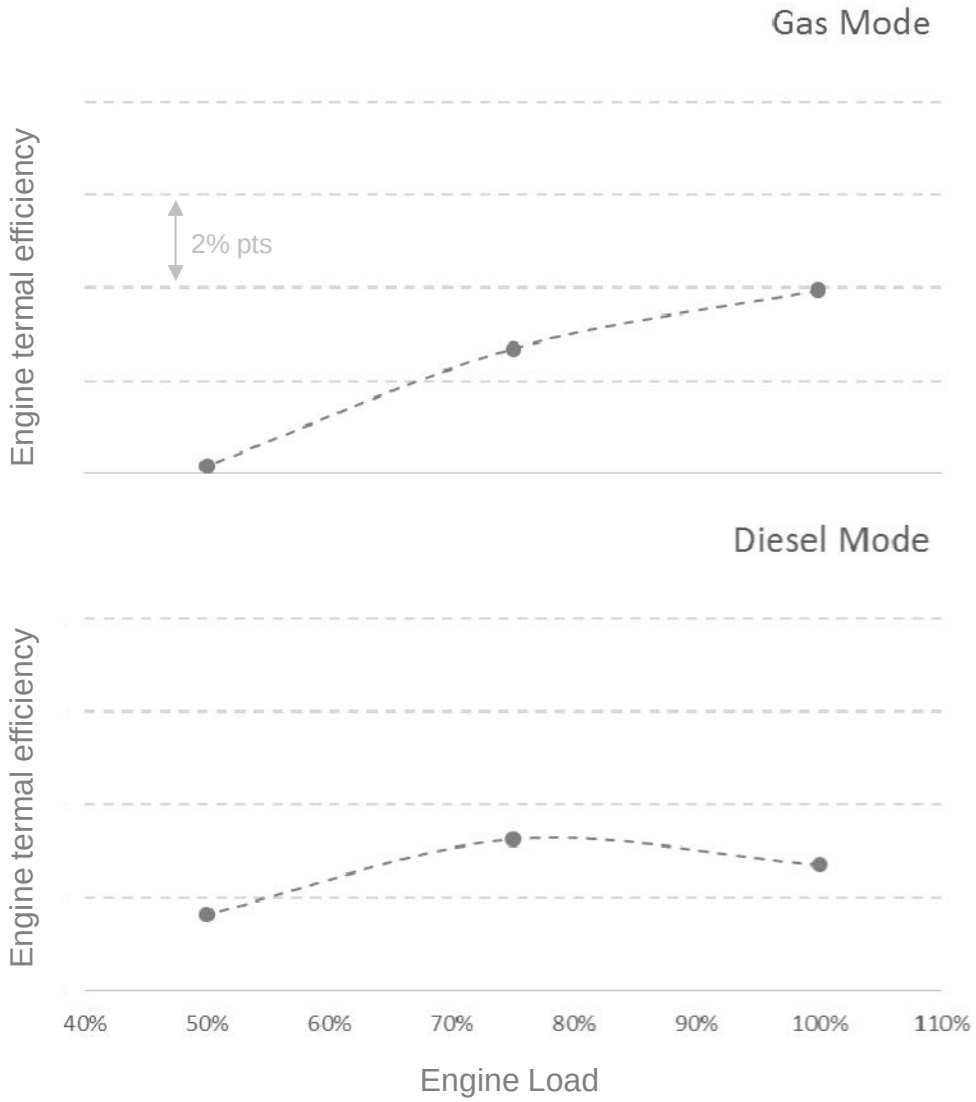
* bsfc: specific fuel consumption; **p_c: compressor pressure ratio

Medium Speed Dual Fuel Marine Engine
Typical «State-of-the-art» engine platform

Performance

Basic DF engine:

- Large bore (> 400 mm)
- 24 bar bmep*
- 1-stage turbocharging
- compression ratio = 12
- l control in Gas Mode with EWG



* bmep: brake mean effective pressure

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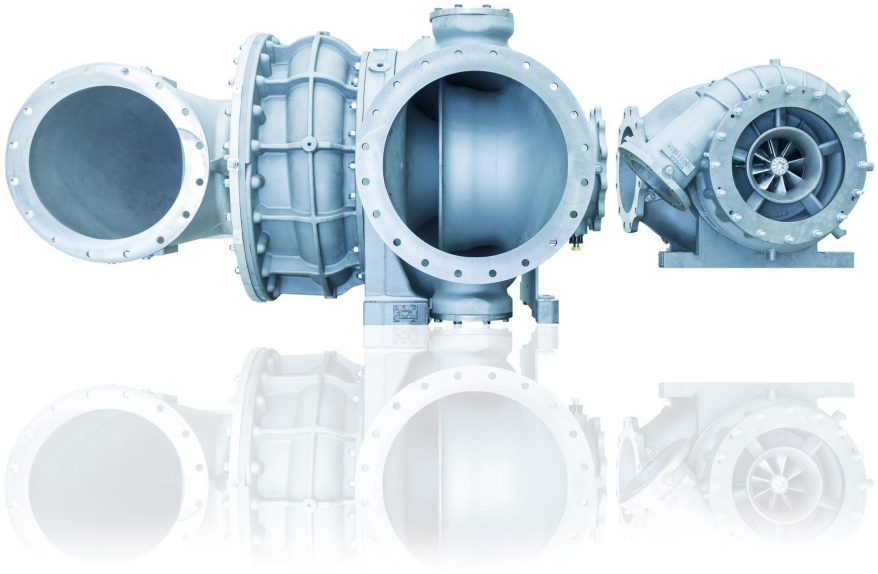
Key technologies

- 2-stage turbocharging Power2®
- Variable valve timing VCM®
- Variable frequency DE propulsion «Dynamic AC»



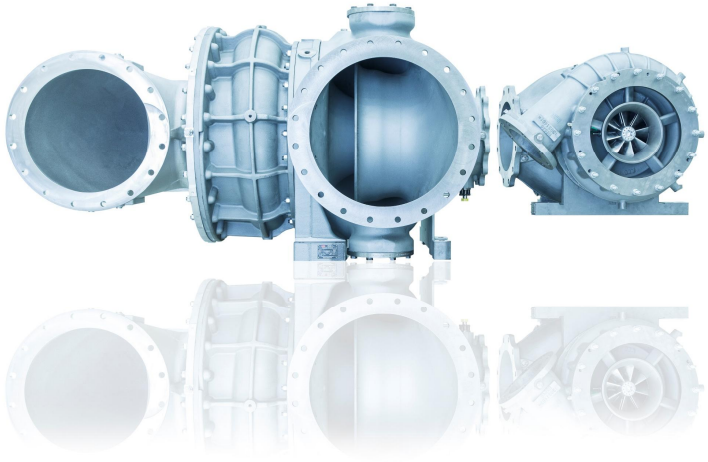
Blue: abb products to corresponding key technology

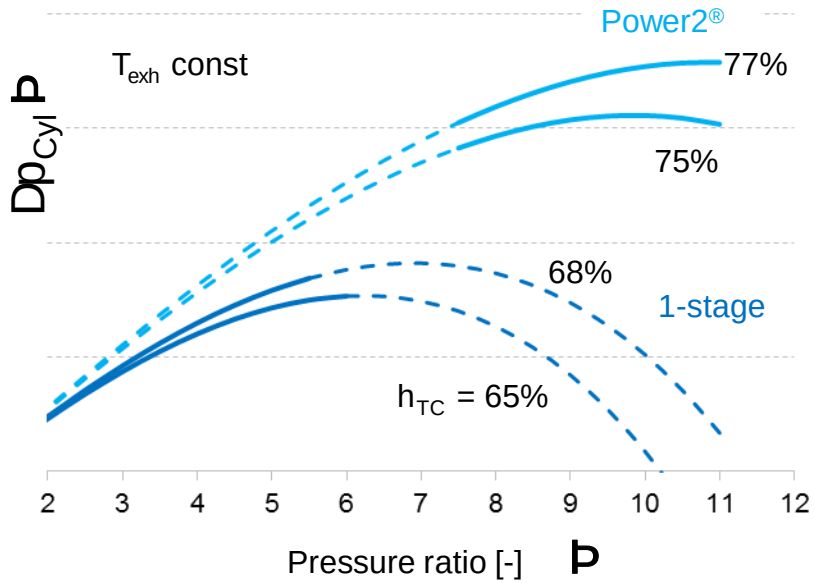
Medium Speed Dual Fuel Marine Engines
Potential performance enhancement

2-stage turbocharging Power2®

- Pressure ratios up to 12
- Turbocharging efficiencies (h_{TC}) above 75%

- With higher pressure ratio …
  - Þ … increase in h_{TC}
  - Þ … increase in Dp_{Cyl}*
  - Þ … more compact 2-stage system





* Dp_{Cyl}: pressure difference over cylinder head

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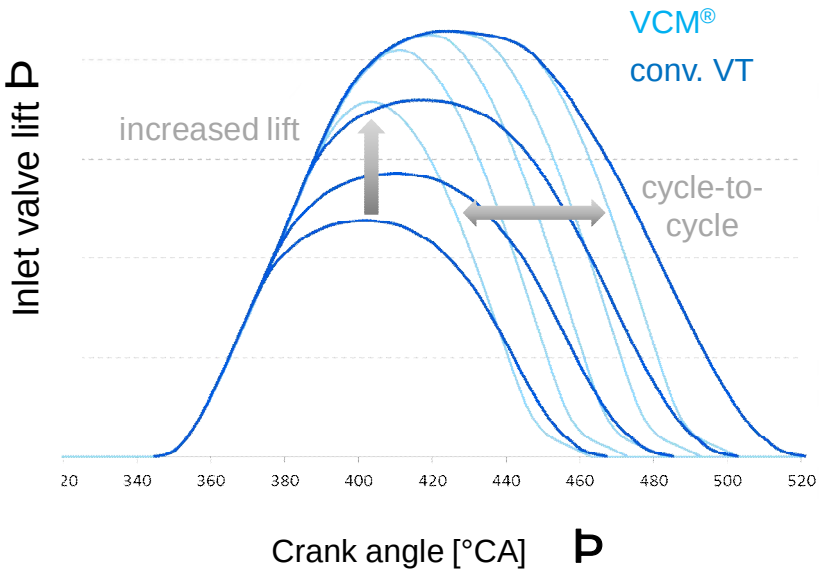
Variable valve timing VCM®

Conventional valve timing

- Red. valve lift with advanced Miller
  - increased throttle losses
  - limited inlet valve closure

Variable valve timing

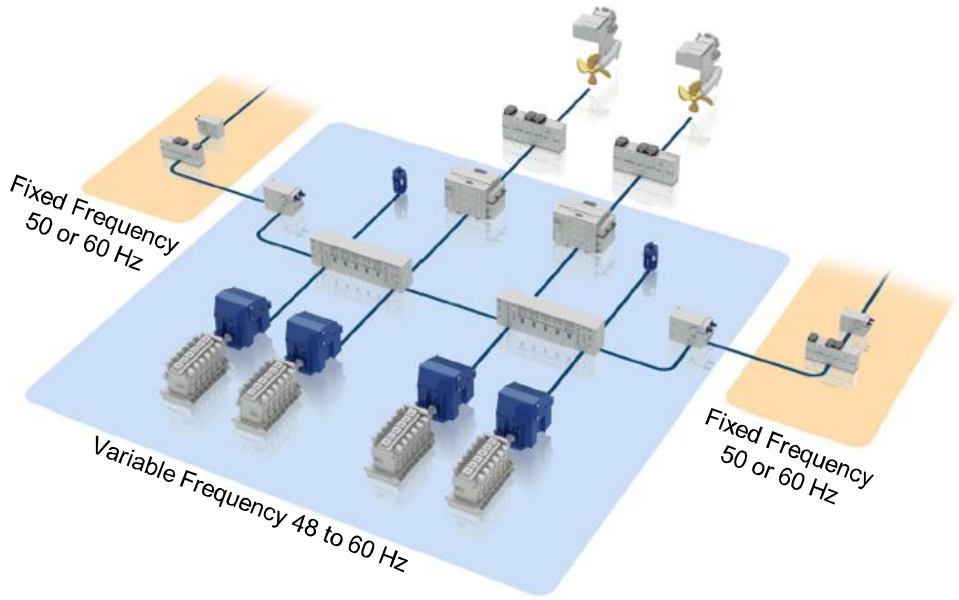
- Steep closing flanks
  - increased valve lift
  - advanced Miller timing
- Variation from cycle-to-cycle
  - replacing all conventional control elements

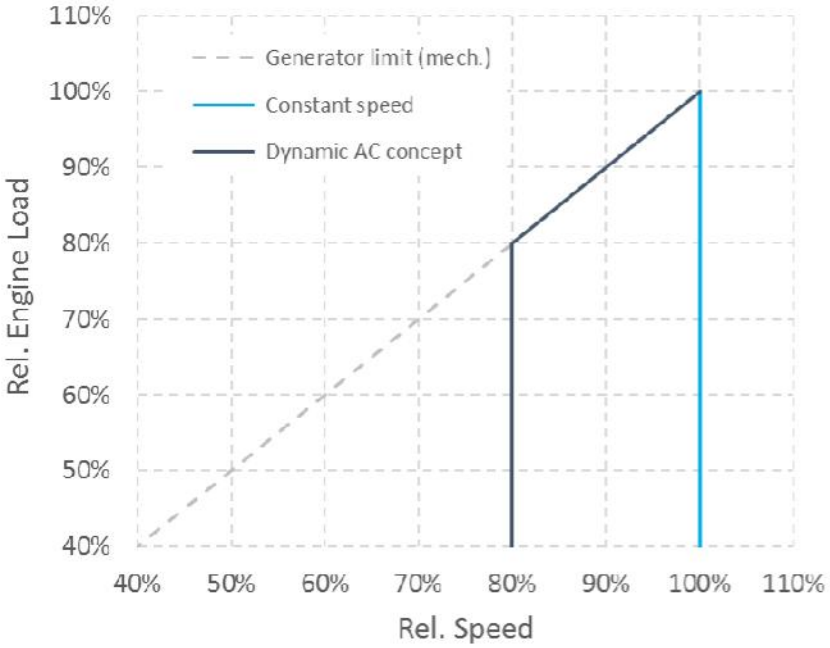


Medium Speed Dual Fuel Marine Engines
Potential performance enhancement

Variable frequency DE propulsion «Dynamic AC»

- Speed variation down to 80% of nominal speed considered





Medium Speed Dual Fuel Marine Engine
Potential performance enhancement

Performance

Base (slide 3)

Step 1:

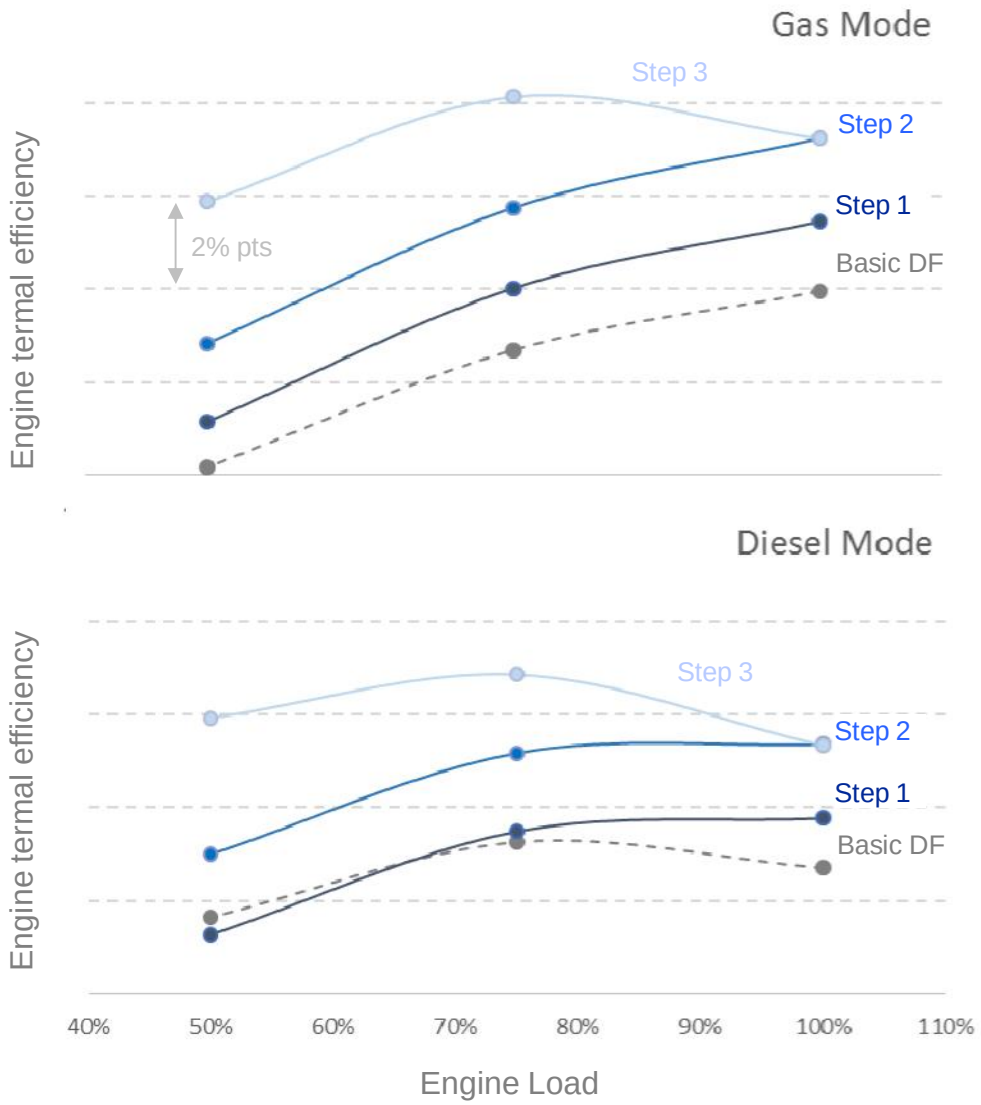
- 1-stage + EWG à Power2® + VCM®

Step 2:

- compression ratio = 12 à 15.5

Step 3:

- n = const à «Dynamic AC»

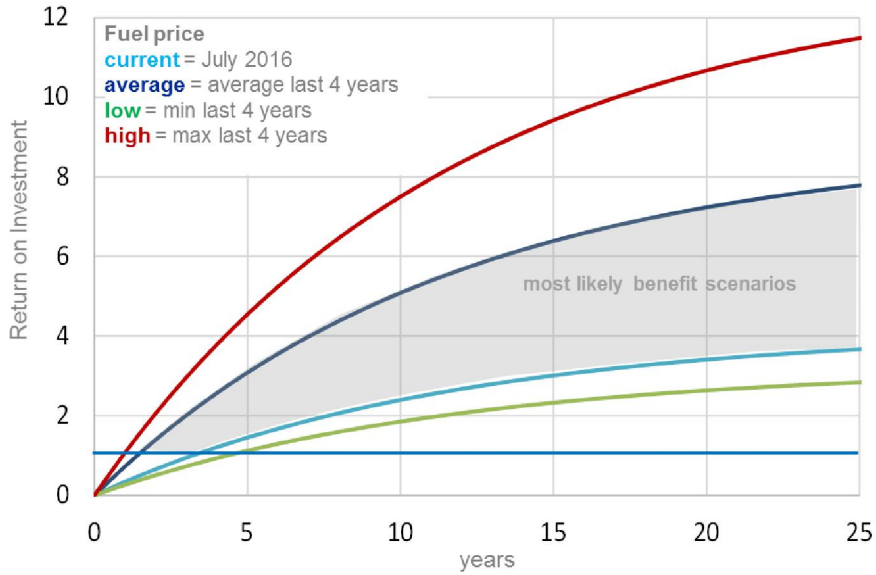


Medium Speed Dual Fuel Marine Engine
Potential performance enhancement

Case Study Cruise Vessel

Assumptions

- running hours: 5’000rhs/year
- operation time: 25years
- average engine load: 75%
- gas mode share: 70%
- fuel price: regional average*
- Dynamic AC cost taken into account
- discounting: 9%



Benefits

- Environmental compliance
- Fuel savings: up to 13% for gas; up to 10% for diesel
- For conservative approach (base assumptions + current fuel price)
  - OPEX** down 7%; ROI » 3 years
- Opportunities for engine builders

* Europe, US, Japan; ** Operational cost

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