



Caterpillar Marine

BUILT FOR IT.

Technologies for Reducing Black Carbon From Marine Engines

George Lin

Global Regulatory Affairs Technical Manager

Caterpillar Inc.

MAK



CAT

Caterpillar Marine Products



3500 Series
8, 12, 16
cylinder
526 – 2525 kW

C32
12 cylinder
492 – 1417 kW

C18
6 cylinder
339 – 847 kW

C12
6 cylinder
254 – 526
kW

C9
6 cylinder
15 – 423 kW

C7.1
6 cylinder
100 – 190 kW

C 4.4
4 cylinder
93 – 123
kW

C280 Series
6, 8, 12, 16 cylinder
1730 – 5650 kW

710 Series
8, 12, 16, 20 cylinder
1400 – 4000 kW

M 20 C
6, 8, 9
cylinder
1020 – 1710
kW

M 25 C
6, 8, 9 cylinder
1900 – 3000 kW

M 32 C / E / DF
6, 8, 9 cylinder
2880 – 5000 kW

VM 32 C
12, 16
cylinder
6000 – 8000
kW

M 43 C
6, 7, 8, 9 cylinder
6000 – 9000 kW

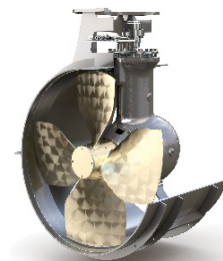
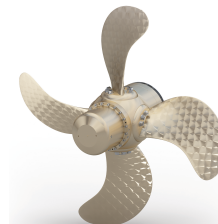
VM 43 C
12, 16 cylinder
12000 – 16000 kW

M 46 DF
6, 7, 8, 9 cylinder
5400 – 8100 kW

VM 46 DF
12, 16, 20
cylinder
10800 – 18000
kW



POWER PRODUCTS



September 07, 2016

CATERPILLAR®

Agenda

The following engine system technologies are available TODAY to reduce black carbon:

- FCT (flexible camshaft technology)
- Natural Gas Engines (& dual fuel engines)
- SCR (selective catalytic reduction)

Reducing PM also reduces black carbon

- In engine test cells, manufacturers measure PM (particulate matter) which includes both black carbon and non-black carbon components.
- The black carbon to non-black carbon ratio varies.
- Reducing PM with the technologies discussed in this presentation also reduces black carbon.

Flexible Camshaft Technology

- Normally, lower engine loads results in higher PM.
- FCT allows for PM reduction at low loads (e.g. operation under ice conditions in the Arctic) while maintaining optimum performance at high loads.
- At low loads, FCT retards intake valve timing while advancing start of injection (SOI) to reduce PM.
- Improves transient response at low engine loads (i.e low vessel speeds).
- Valve and injection timing return to normal when operating at higher loads.

FCT major components

Valve drive



Cam shaft



Actuator

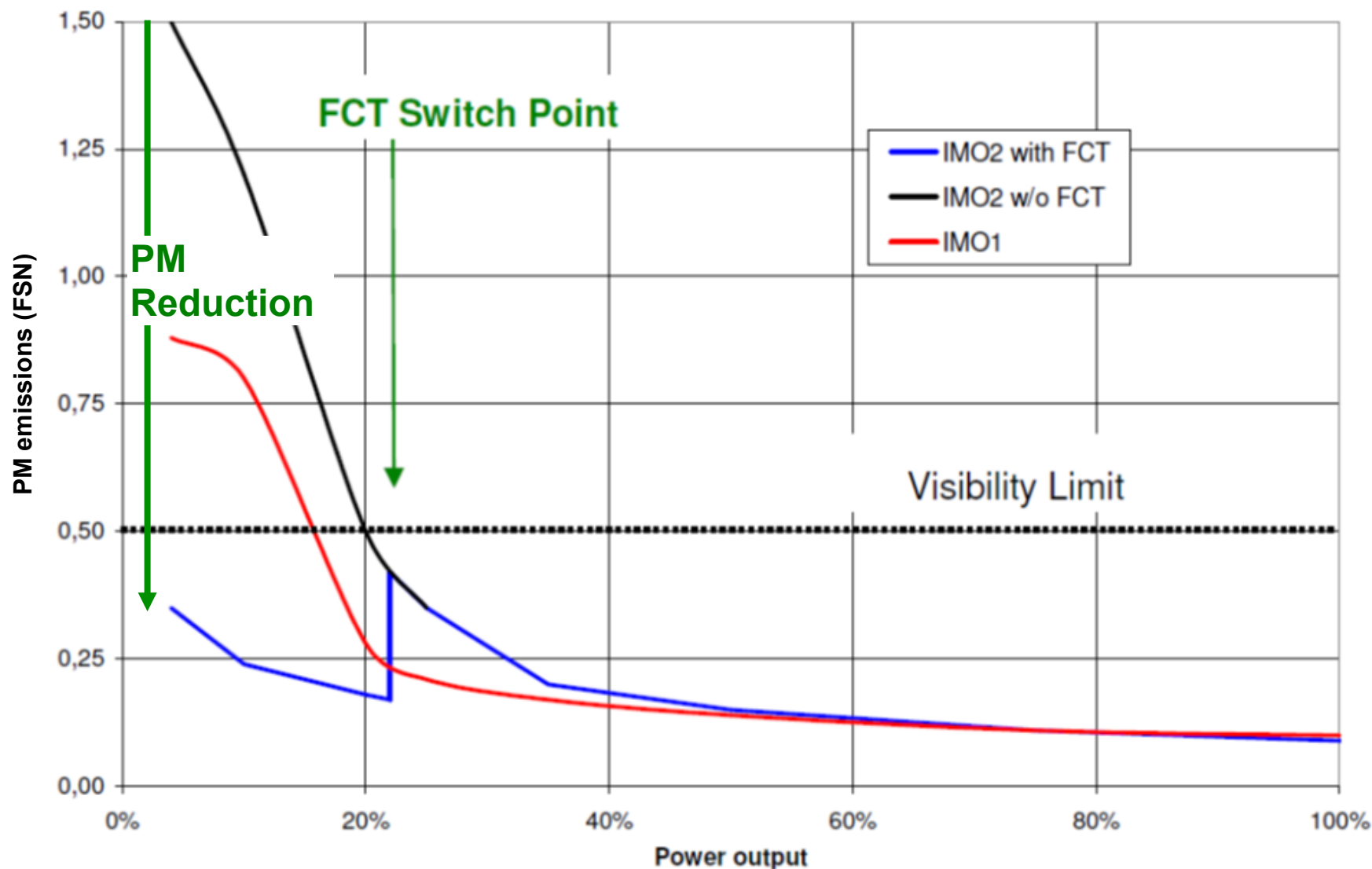


Controller

<https://www.youtube.com/watch?v=iL1nVAJdijU>



Example of FCT on a marine engine



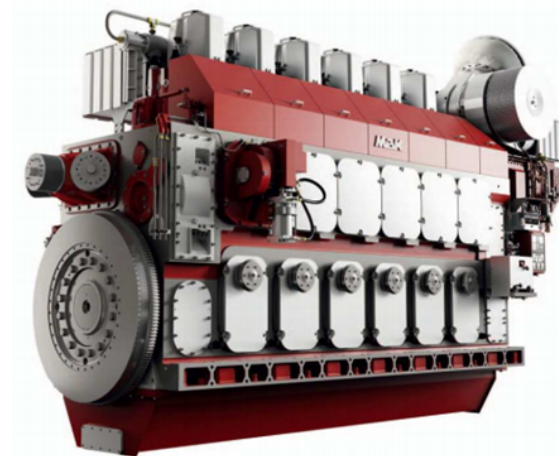
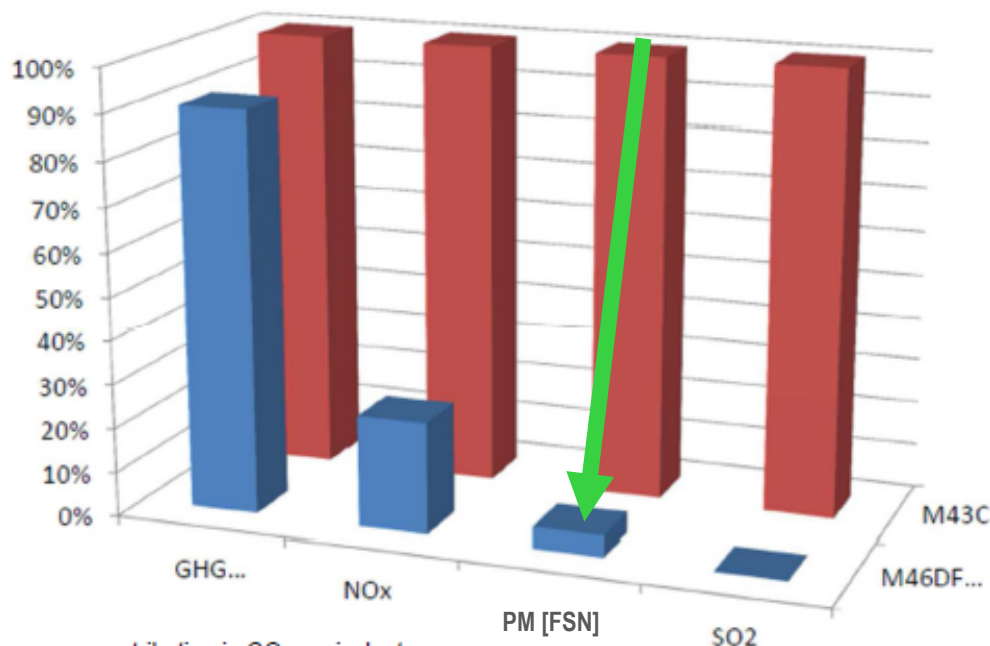
Natural gas fuel can reduce black carbon

- Natural gas and dual fuel (NG w/ diesel ignition) engines can be designed to have low PM.
- Dual fuel engines can lower emissions on a per-unit energy basis when compared with diesel (including lower CO₂ emissions).
- Dual fuel engines are available as new.
- Existing engines can also be retrofitted.

MaK M 46 DF

- Dual fuel engine can reduce PM by 90%.

Total Exhaust Gas Emission Balance LNG vs Diesel



https://youtu.be/_Xjj6KJ_Qr4?list=UU7nWdc4LnuDTSp4j2Clyid

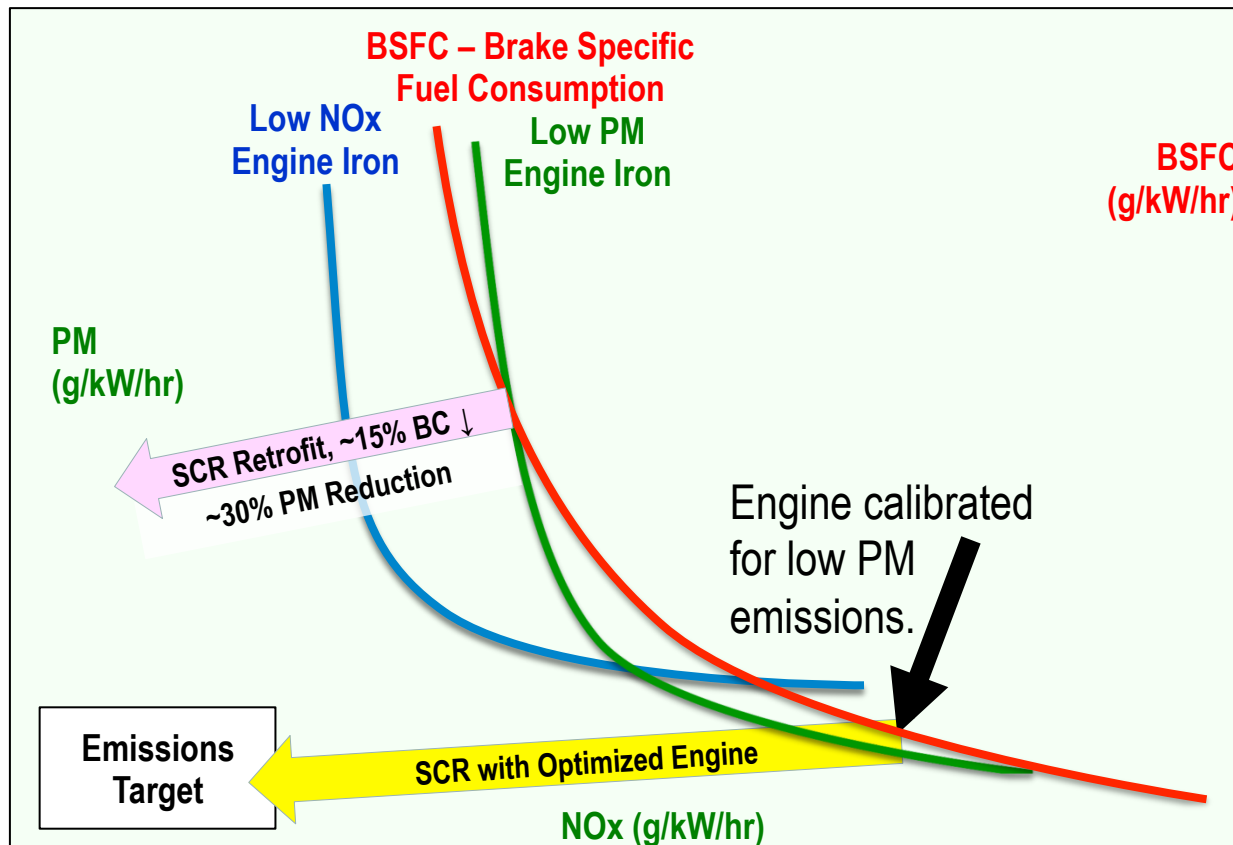
SCR systems lower both NOx and PM

- A study published by IMO in 2015 stated that *“There is sparse evidence that BC reductions can occur with SCR (up to 35%)”*
 - Study assumed SCR is retrofitted without any engine optimizations and does not account for in-cylinder PM reduction.
 - It is common for today’s SCR optimized engines to reduce PM by up to 80% over IMO II while improving fuel economy.
- SCR aftertreatment reduces NOx by +90%.
 - 15% BC reduction expected with Vanadia SCR.
- US EPA Tier 4 Marine and IMO Tier III engines utilizing SCR have significant reductions in PM.



Engine operation optimized for SCR

- Ideally, start with an engine designed for low-PM / BSFC.
- Calibrate engine for low PM emissions.



- This has the added benefit of reducing fuel consumption.
- SCR + urea is then used to reduce exhaust NOx down to a desired level.

Available Caterpillar / MaK SCR Systems

Key features:

- Complete marine certification society solution.
- Consists of SCR chamber, mixing tube, urea injection system and dosing cabinet.
- Urea transfer pump skid optional available.
- IMO Tier III certification.
- Optimized engine and SCR system.
- Application and installation support for every market segment and ship type.
- Available as a retrofit package.



MaK M 43 C

Summary

- Good options exist today to reduce black carbon, for both new engines and as retrofits for existing engines.
- SCR with optimized engine is an attractive solution because it also improves fuel economy (lowers CO₂) while reducing black carbon.
- US EPA Tier 4 Marine and IMO Tier III engines utilizing SCR have significant reductions in black carbon.