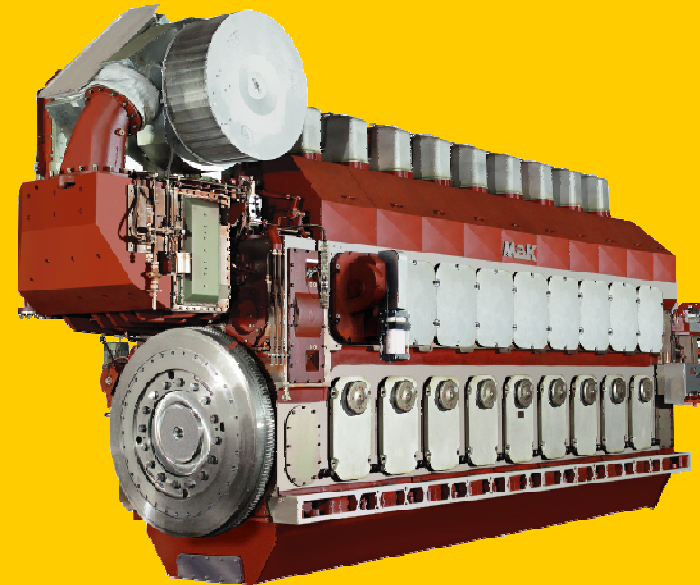




Emissions Reduction for MaK Engines

Today and Tomorrow



Klaus Wirth

Engineering Manager Caterpillar Motoren GmbH & Co. KG

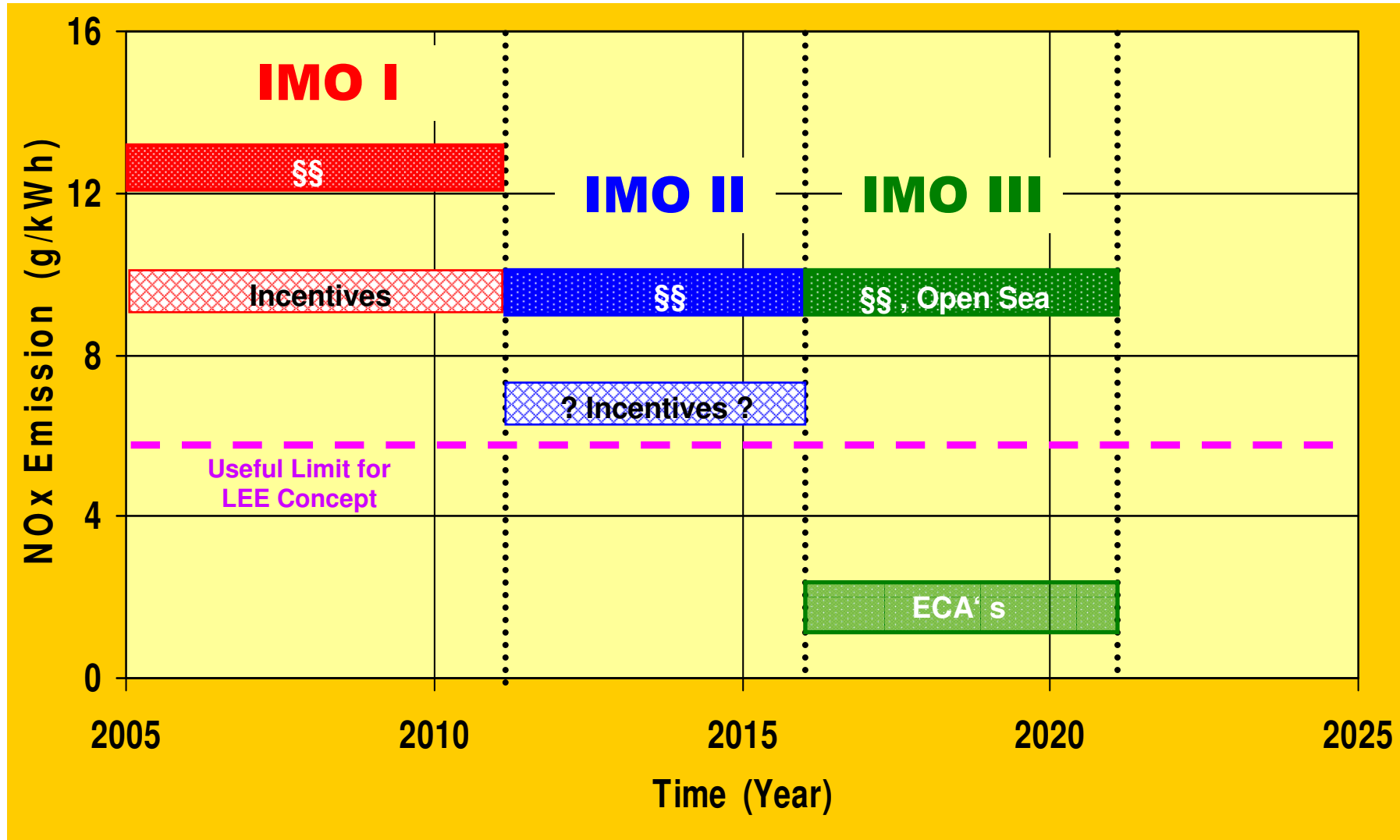
International Conference on Ship Efficiency, September 28 - 29, 2009



NOx Emission Trend



CATERPILLAR
Motoren - KEC

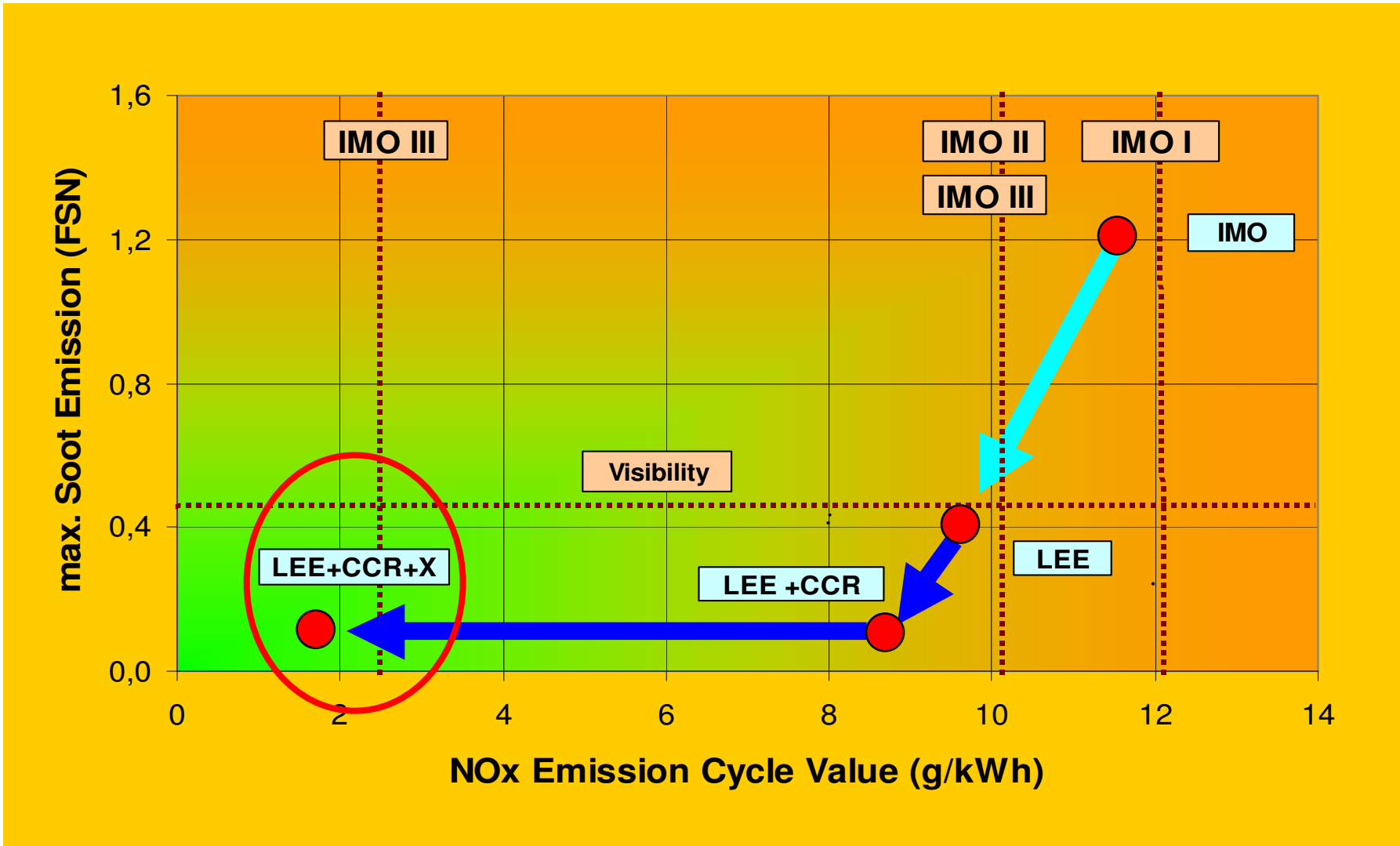




Scenario IMO III



CATERPILLAR
Motoren - KEC

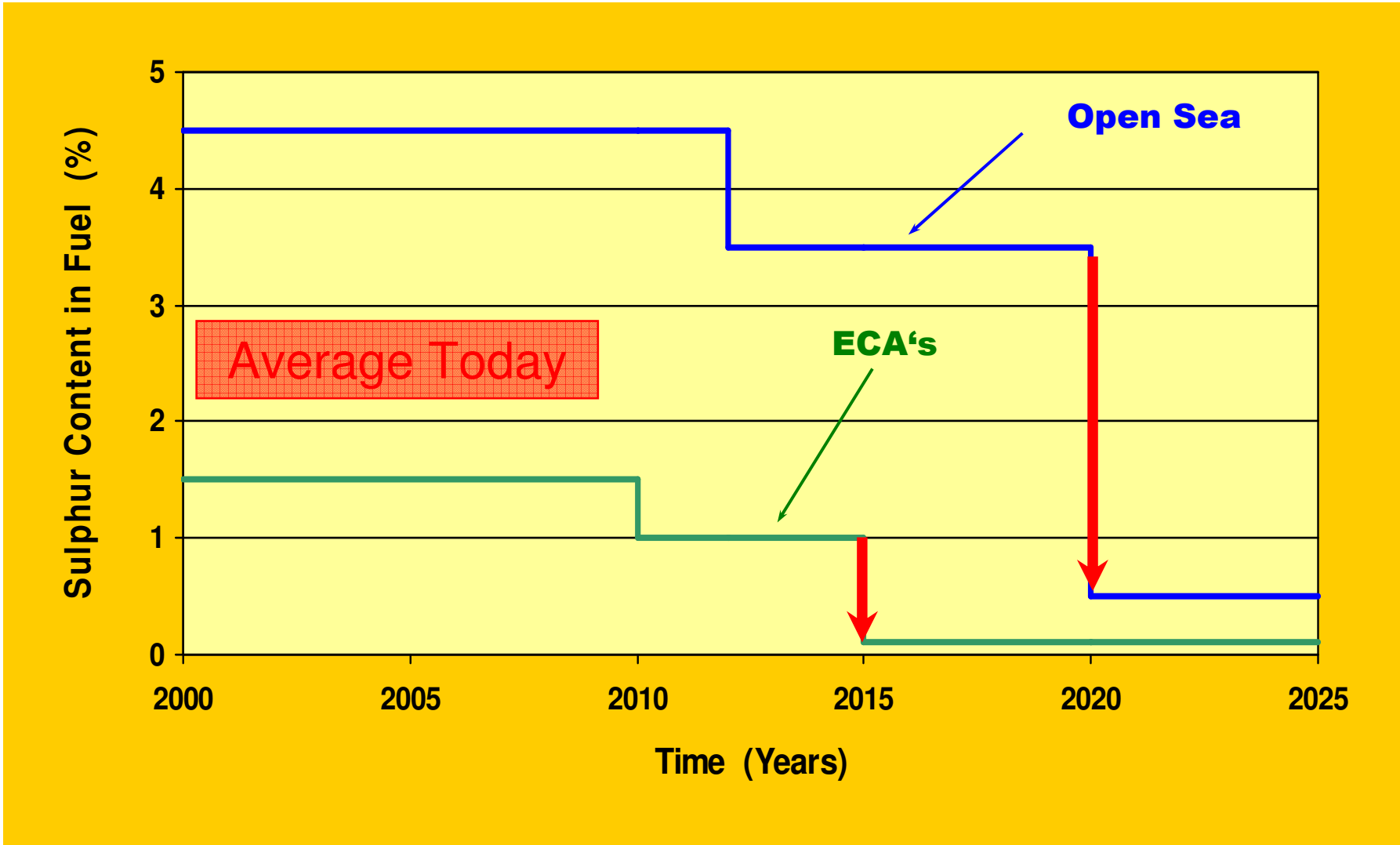




SOx Emission Trend



CATERPILLAR®
Motoren - KEC





Diesel Engine Scenarios



CATERPILLAR®
Motoren - KEC

Path	The Real Engine	Additional Features
Technology	<ul style="list-style-type: none">- Variable Valve Drive- Common Rail- Two Stage Turbo	<ul style="list-style-type: none">- SCR Catalyst *)- EGR System *)- Soot Scrubber- Water Injection
Achievable NOx Value	6 to 8 g/kWh	< 2 g/kWh

*) Enabled by Low Sulphur Fuel



Development Steps



CATERPILLAR®
Motoren - KEC

	IMO 0 < 2000	IMO I 2000	IMO II 2011	IMO III 2016
NOx Limit (g/kWh)	> 16	13	10	2
Compression Ratio	13	15	17	15
Miller Cycle	no	small	medium	strong
Secondary Feature	no	no	no	EGR
Turbo Stages	1	1	1	2
Valve Drive	no	no	yes	yes
Injection System	mech.	mech.	both	CCR



Gas Engine Scenarios



CATERPILLAR[®]
Motoren - **KEC**

Path	The Real Engine	Additional Features
Technology	<ul style="list-style-type: none">- Dual Fuel- Otto Gas	<ul style="list-style-type: none">- SCR Catalyst *)- Oxi Catalyst *)- EGR System *)
Achievable NOx Value	1 to 2 g/kWh	0,1 to 0,2 g/kWh

*) Only for extreme Low Emission Values



Gas Engine Types



	Otto Gas	Dual Fuel
NOx Limit (g/kWh) - ECA	> 2 (Gas)	> 2 (Gas)
NOx Limit (g/kWh) - non ECA	> 2 (Gas)	> 10 (HFO)
Compression Ratio	12	12
Miller Cycle	small	medium
Turbo Control System	Waste Gate	Waste Gate
Valve Drive	no	FCT
Ignition System	Spark	CCR



Local Segmentation



CATERPILLAR®
Motoren - KEC

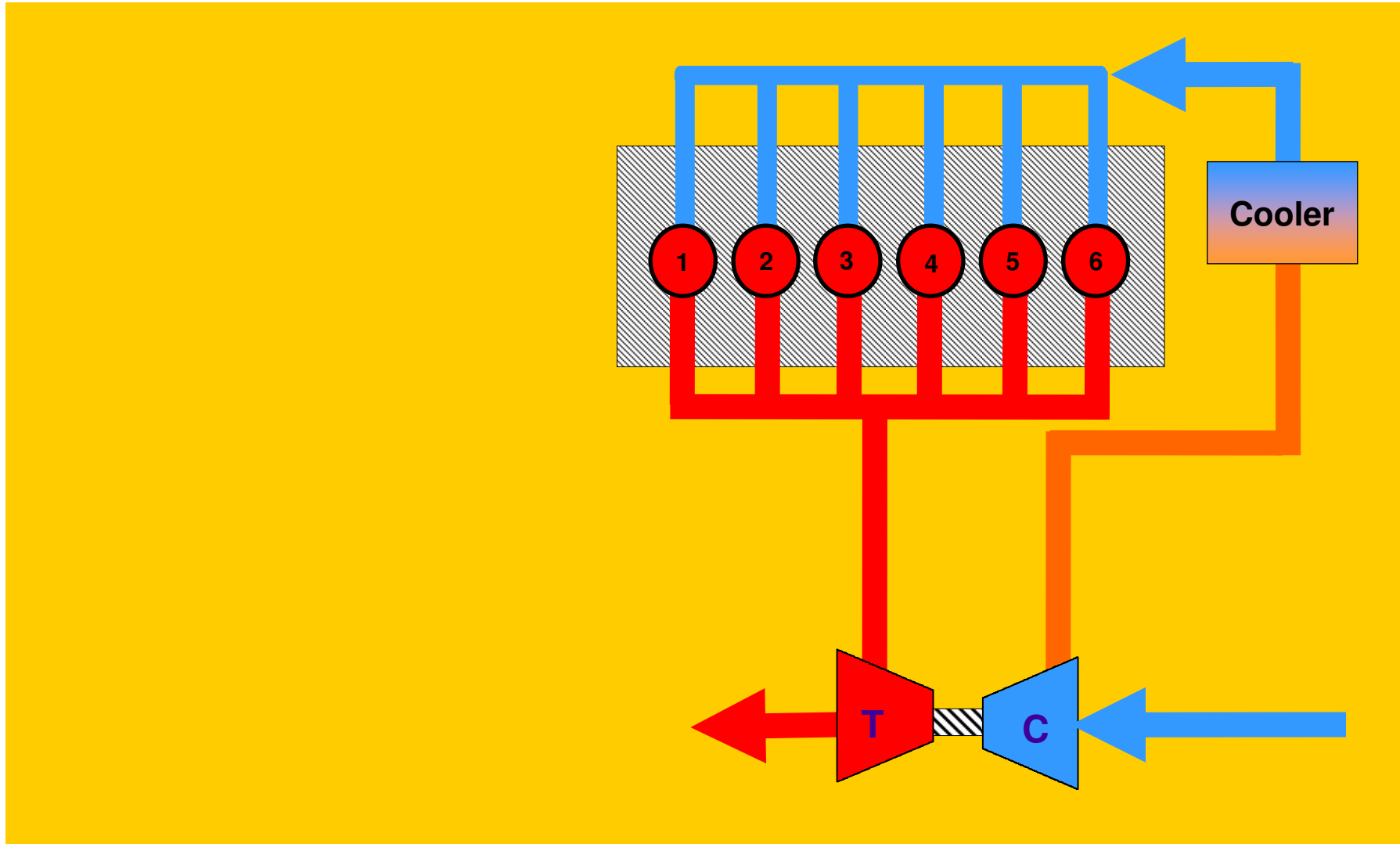
Operation Area	Inside ECA's	In and Outside	Outside ECA'S
Concept	Fixed Parameters	Variable	Fixed Parameters
Solutions	LEE Engine After Treatment Gas Engine	LEE Engine After Treatment Dual Fuel Engine	LEE Engine



IMO I Engine



CATERPILLAR®
Motoren - KEC

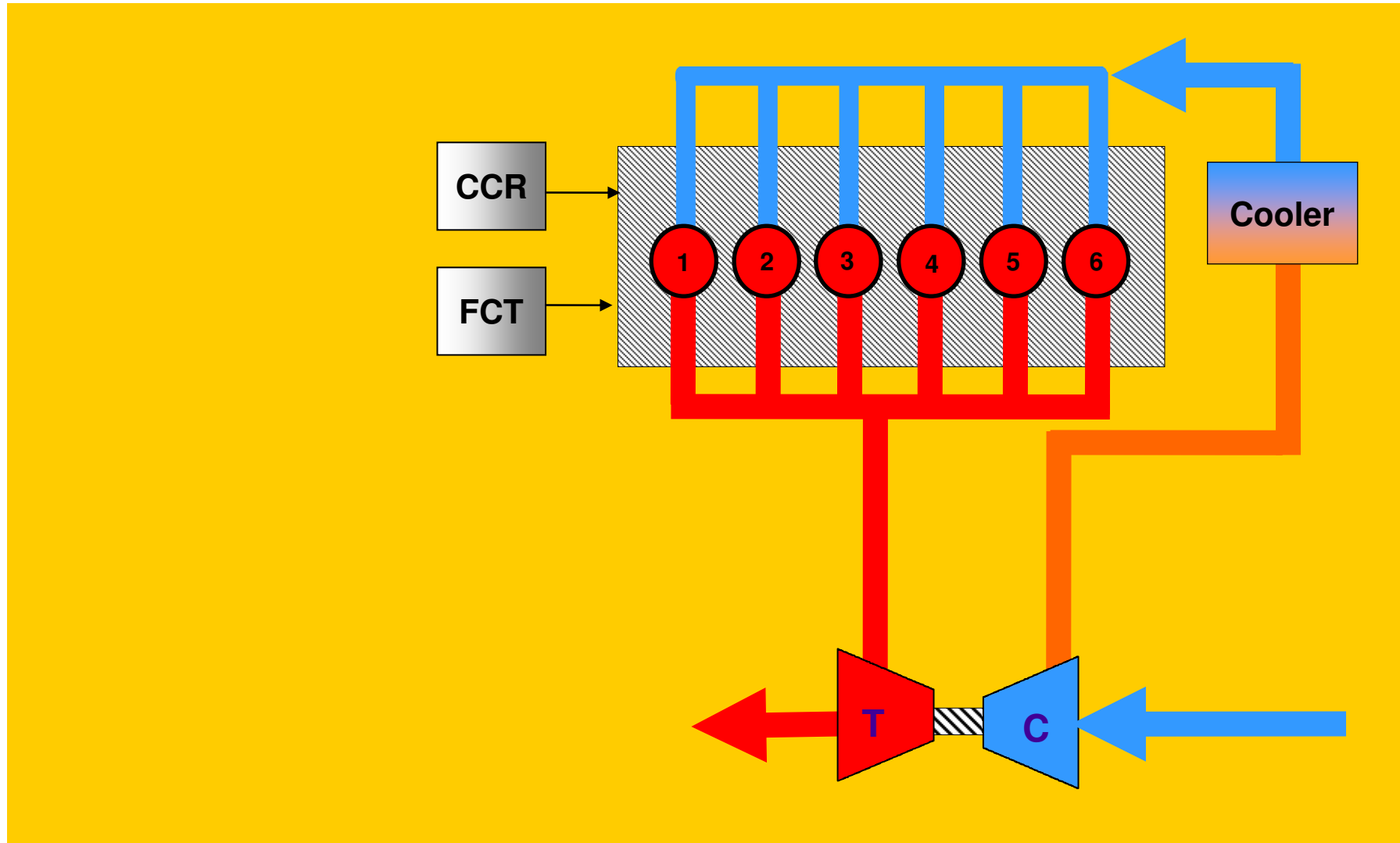




IMO II Engine



CATERPILLAR®
Motoren - KEC

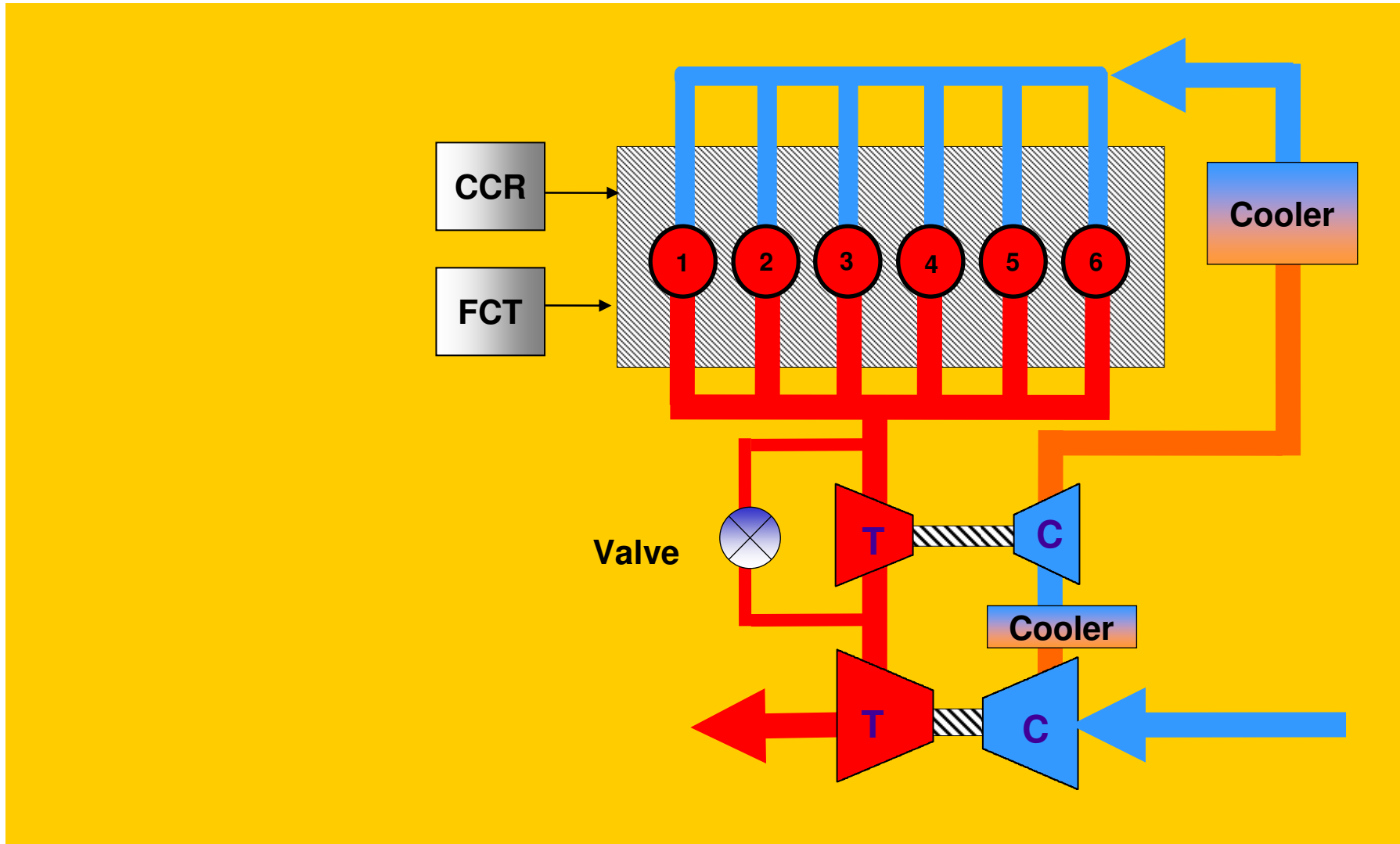




IMO II Engine Power up



CATERPILLAR®
Motoren - KEC

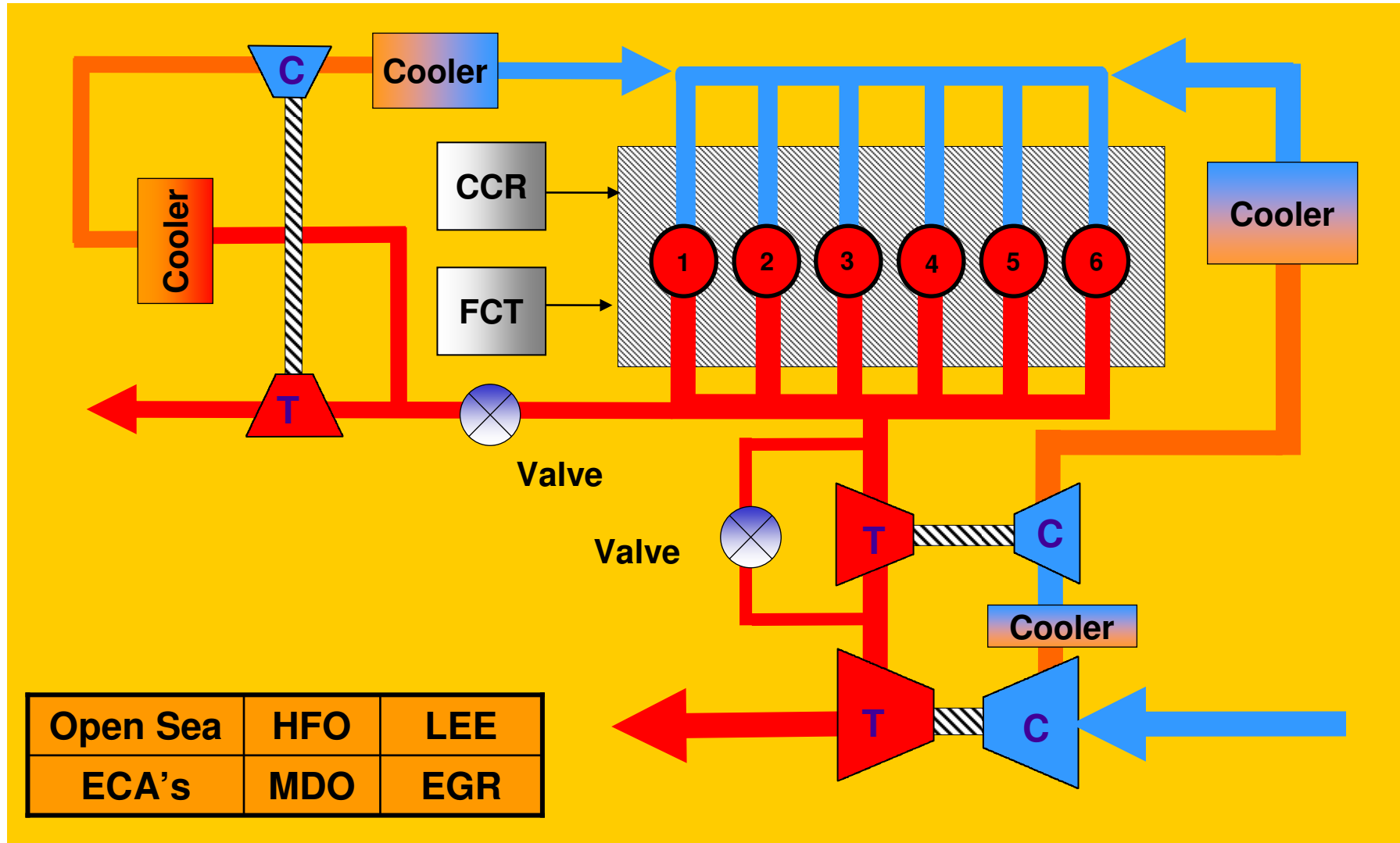




IMO III Engine



CATERPILLAR®
Motoren - KEC

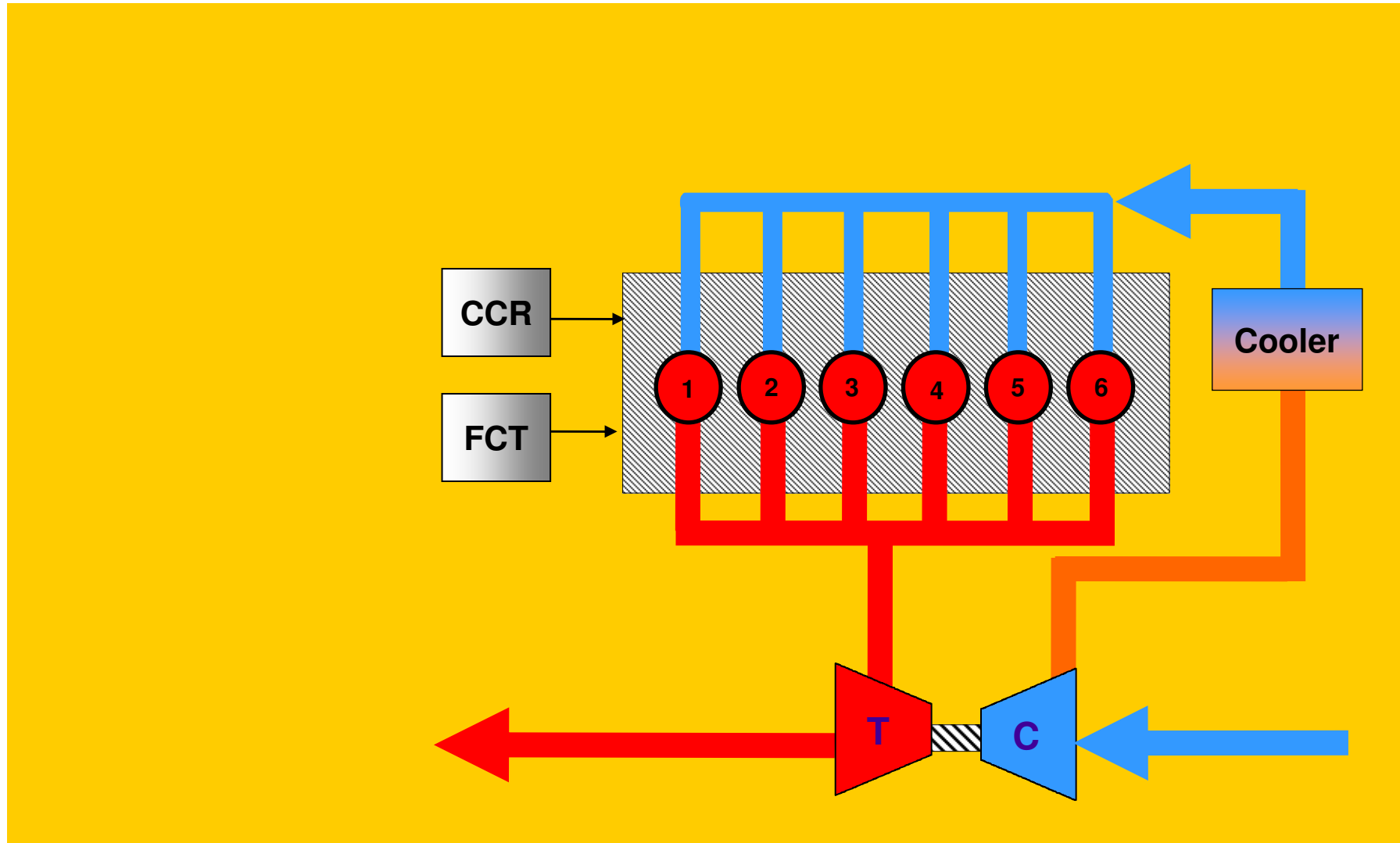




Diesel Engine (IMO II)



CATERPILLAR®
Motoren - KEC

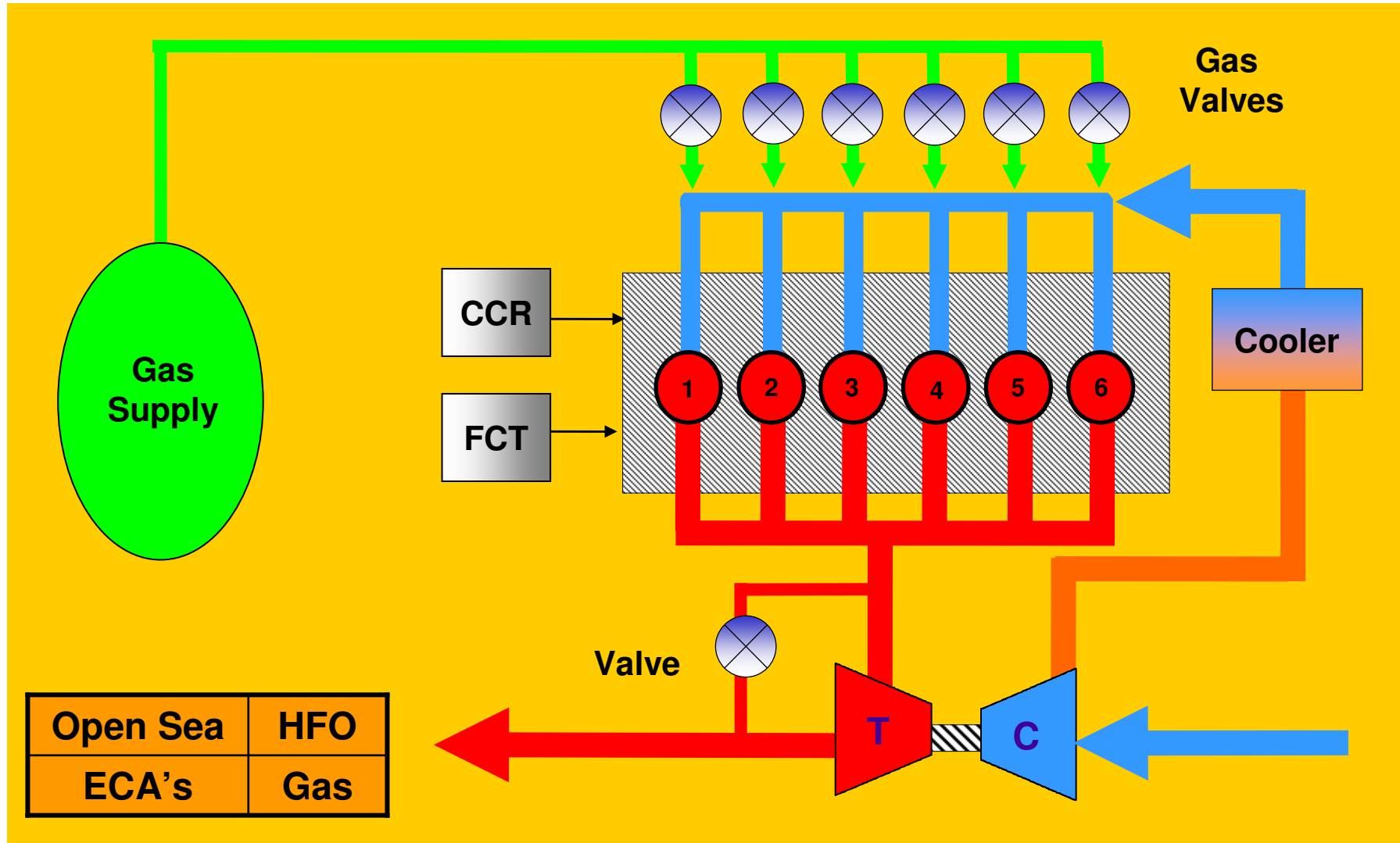




Diesel Engine (IMO III)



CATERPILLAR
Motoren - KEC

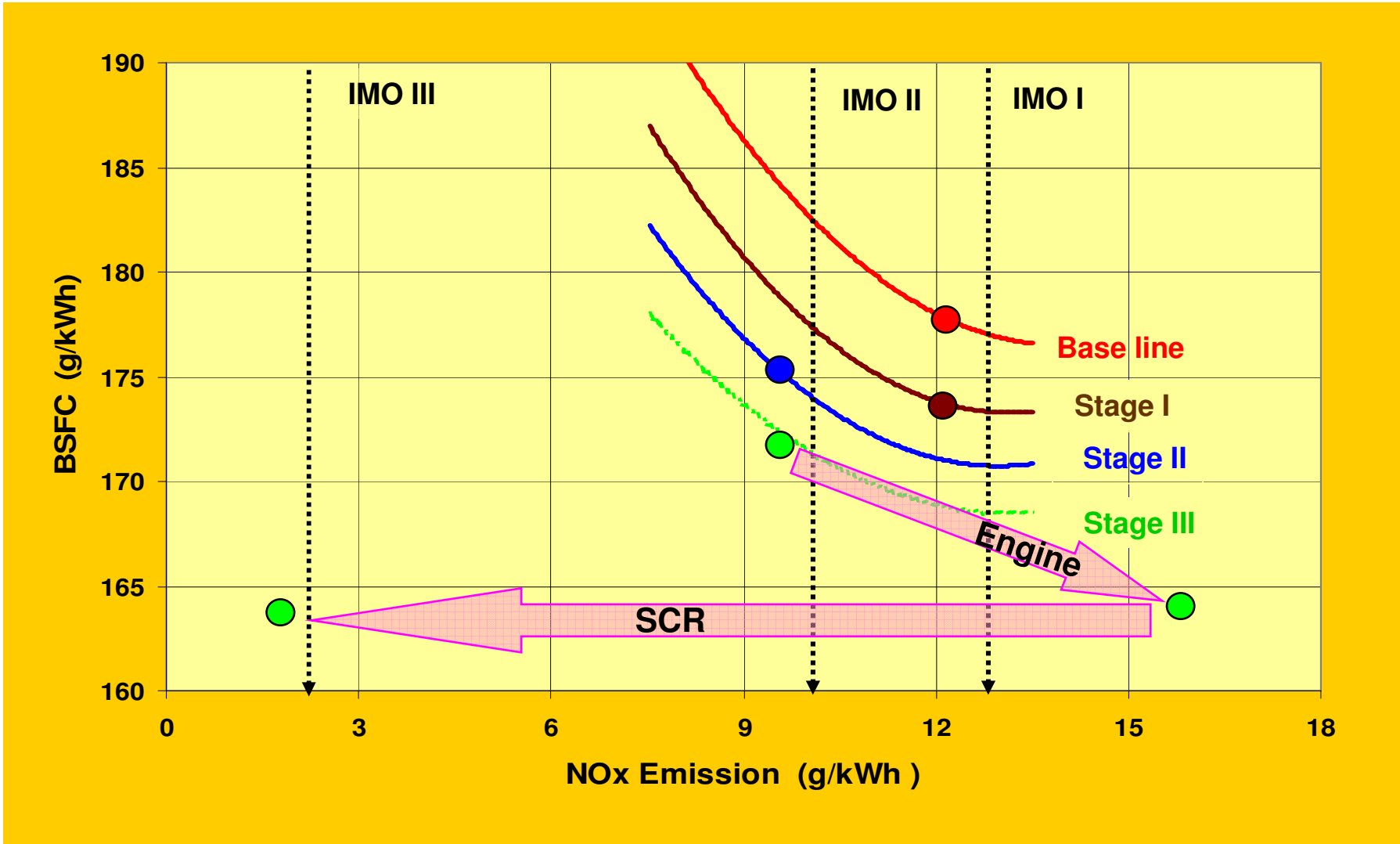




Emission Trade Off



CATERPILLAR
Motoren - KEC





Emission Trade Off



CATERPILLAR®
Motoren - KEC

Average Power: 5.000 kW, BSFC: 200 g/kWh, Operation Time: 6.000 h/Year

HFO @ 300 Euro/t, Urea @ 250 Euro/t

	NOx	BSFC	Fuel Cost	Urea Cost	Total Cost
	g/kWh	g/kWh	Mio€/Year	Mio€/Year	Mio€/Year
LEE	10	200	1,800	0	1.800
LEE+EGR	2	205	1,845	0	1.845
LEE+SCR	10→ 2	202	1,818	0,084	1,902
LEE+SCR	16→ 2	196	1,764	0,147	1,911



Summary



CATERPILLAR®
Motoren - KEC

The best solution for Diesel engines to fulfill IMO III emission regulations is not clearly visible today.

It depends on:

- **Availability of clean fuel**
- **Reliability of new technology**
- **Increase of fuel prices**
- **Local emission regulations**



CATERPILLAR®
Motoren - KEC

Thank you for your attention