A global cap-and-trade scheme for maritime transport

SNAME and the Marine Board Symposium, 16-17 February 2010

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CE Delft

- Independent, not-for profit consultancy, founded in 1978
- Based in Delft, the Netherlands
- Transport, Energy, Economy
- 15+ years of experience with environmental policies for shipping
- Clients include UNFCCC, IMO, European Commission, national governments, ports, NGOs

Outline

- How does a cap-and-trade scheme for maritime transport work?
- What are the obligations for ship owners, operators, charterers, flag states and port states?
- Which impacts will cap-and-trade have on the shipping sector?
- How does cap-and-trade compare to other policy instruments?
- Conclusions

Cap-and-trade in Maritime Transport

Basic setup

- Cap emissions – ensures environmental effect
- Allocate emission rights (‘allowances’) to emitters
- Allow emitters to trade allowances

- Scarcity of allowances creates a price
- Price acts as an incentive to reduce emissions

Cap-and-trade in Maritime Transport

- Global scope, including all ships above a certain size threshold: minimises carbon leakage
- Open system: reduces price volatility
- Cap: historical emissions and reduction path
- Responsible entity: ship or ship owner
- Accounting entity: ship – non compliant ships can be denied entry to ports by PSC
- Initial allocation: auction allowances, perhaps combined with partial free allocation in a start-up phase
- Global administrator to:
  - Distribute allowances.
  - Manage allowance registries for ships.
  - Monitor compliance.
  - Manage the fund in case of full or partial auctioning of allowances.

Cap-and-trade in Maritime Transport

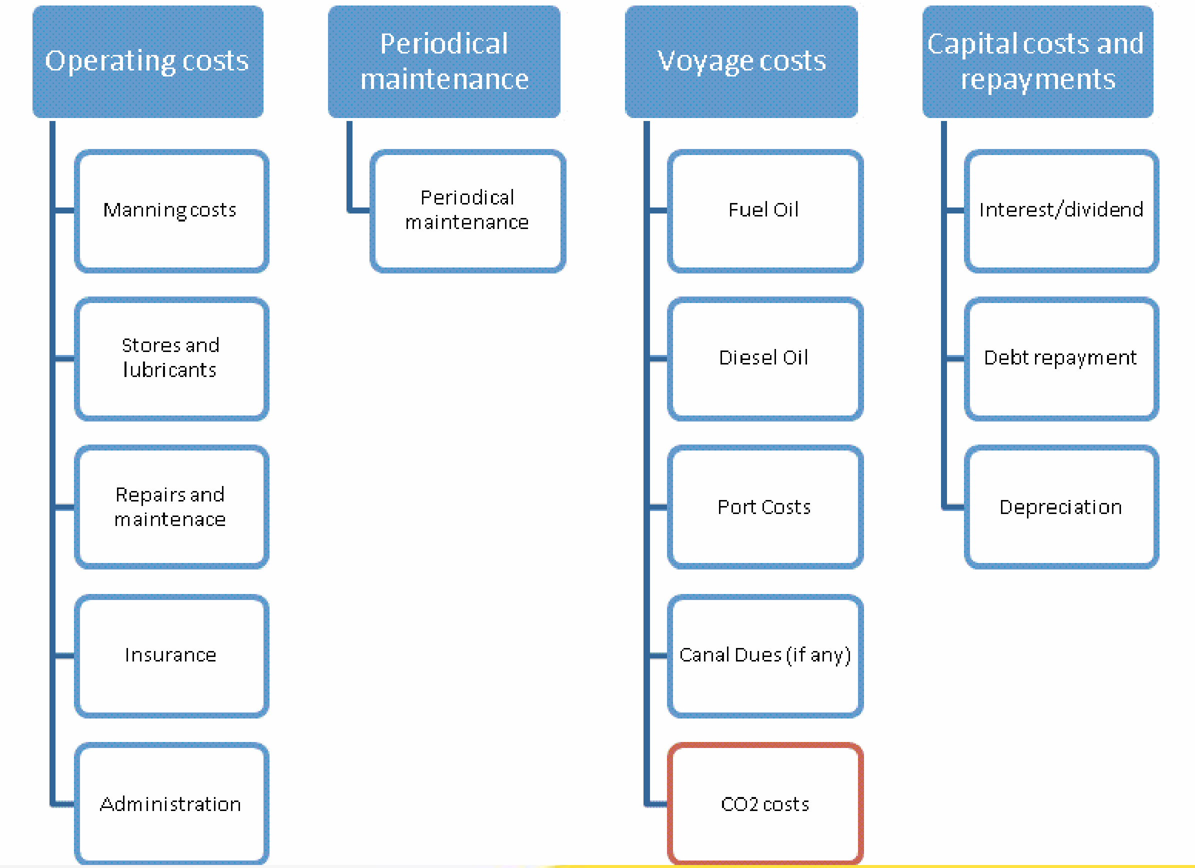
- Obligations on the ship owner
  - Monitor and report CO_2 emissions to administrator
  - Surrender allowances equal to the emissions reported to administrator
- Obligations on the administrator
  - Receive and administer emission reports.
  - Receive and administer surrendered allowances.
  - Maintain records of compliance status of all ships.
  - Sends statement of account to Flag State on yearly basis.
- Obligations on flag states
  - Annual survey: control of account balance.
  - Enforcement of requirements of ships flying the flag of that state.
- Rights of port states
  - Inspect ships and inform about a ship's compliance status.
  - Take action against a ship that is not in compliance.

Impacts of a maritime cap-and-trade scheme

- Emitting CO2 becomes costly
- Additional incentive to reduce emissions / increase efficiency
  - Technical abatement options, e.g. low friction paints, kites, …
  - Operational abatement options, e.g. slow steaming, increased maintenance, …
  - Demand reduction, e.g. substitute imports by domestic production
- Increase in costs of shipping
- Increase in import values

Impacts of a maritime cap-and-trade scheme

- Emitting CO2 becomes costly



Operating costs
- Manning costs
- Stores and lubricants
- Repairs and maintenace
- Insurance
- Administration

Periodical maintenance
- Periodical maintenance

Voyage costs
- Fuel Oil
- Diesel Oil
- Port Costs
- Canal Dues (if any)
- CO2 costs

Capital costs and repayments
- Interest/dividend
- Debt repayment
- Depreciation

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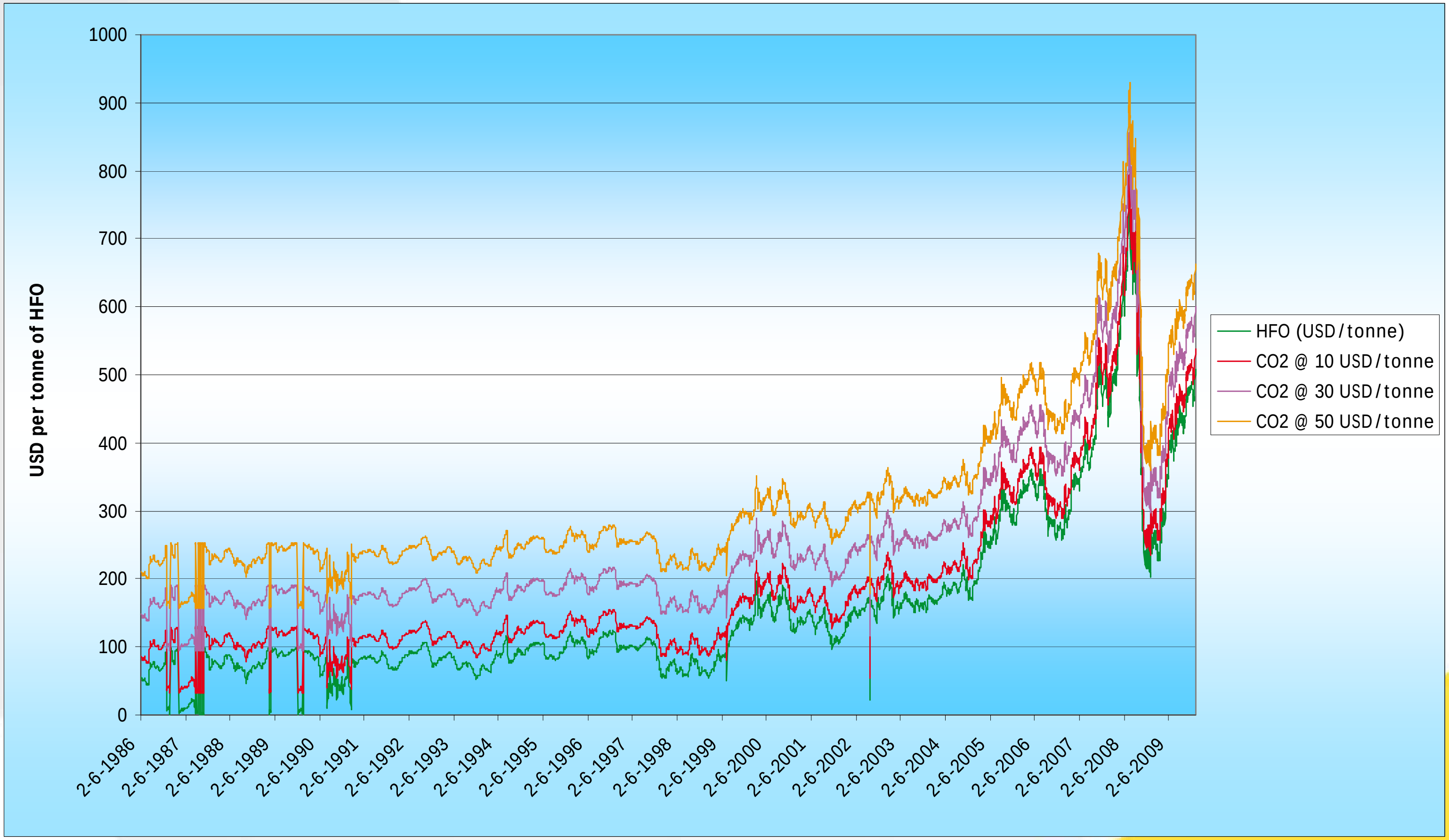
Impacts of a maritime cap-and-trade scheme

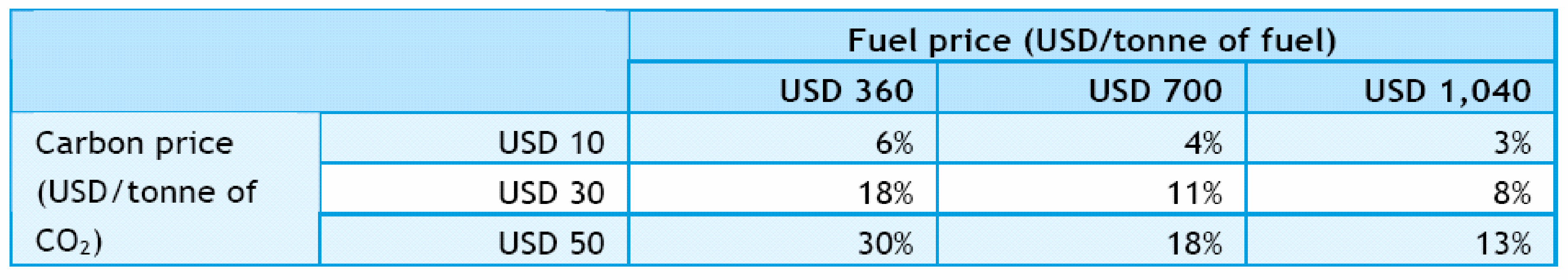


Source: EIA

Impacts of a maritime cap-and-trade scheme

- Revised MARPOL Annex VI:
  - Low sulphur fuel: 0.5% S m/m, 0.1% in ECAs
  - Price increase estimates 25% - 72% (IMO)

- Cap-and-trade:

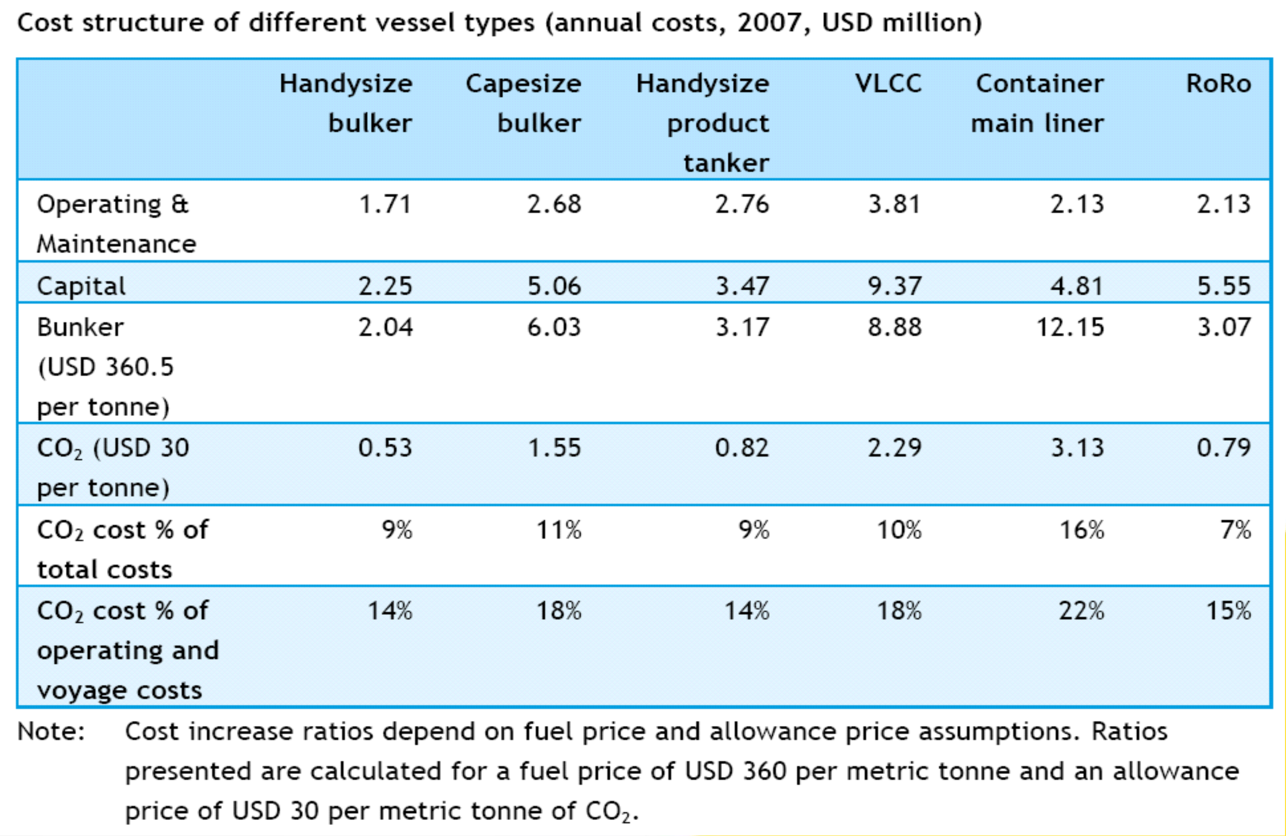


		Fuel price (USD/tonne of fuel)		
		USD 360	USD 700	USD 1,040
Carbon price (USD/tonne of CO_2)	USD 10	6%	4%	3%
	USD 30	18%	11%	8%
	USD 50	30%	18%	13%

Source: CE Delft et al., 2010

Impacts of a maritime cap-and-trade scheme

Maximum cost increase (assuming no improvement in fuel efficiency)



Cost structure of different vessel types (annual costs, 2007, USD million)

	Handysize bulker	Capesize bulker	Handysize product tanker	VLCC	Container main liner	RoRo
Operating & Maintenance	1.71	2.68	2.76	3.81	2.13	2.13
Capital	2.25	5.06	3.47	9.37	4.81	5.55
Bunker (USD 360.5 per tonne)	2.04	6.03	3.17	8.88	12.15	3.07
CO_2 (USD 30 per tonne)	0.53	1.55	0.82	2.29	3.13	0.79
CO_2 cost % of total costs	9%	11%	9%	10%	16%	7%
CO_2 cost % of operating and voyage costs	14%	18%	14%	18%	22%	15%

Note: Cost increase ratios depend on fuel price and allowance price assumptions. Ratios presented are calculated for a fuel price of USD 360 per metric tonne and an allowance price of USD 30 per metric tonne of CO_2.

Source: CE Delft et al., 2010

Impacts of a maritime cap-and-trade scheme

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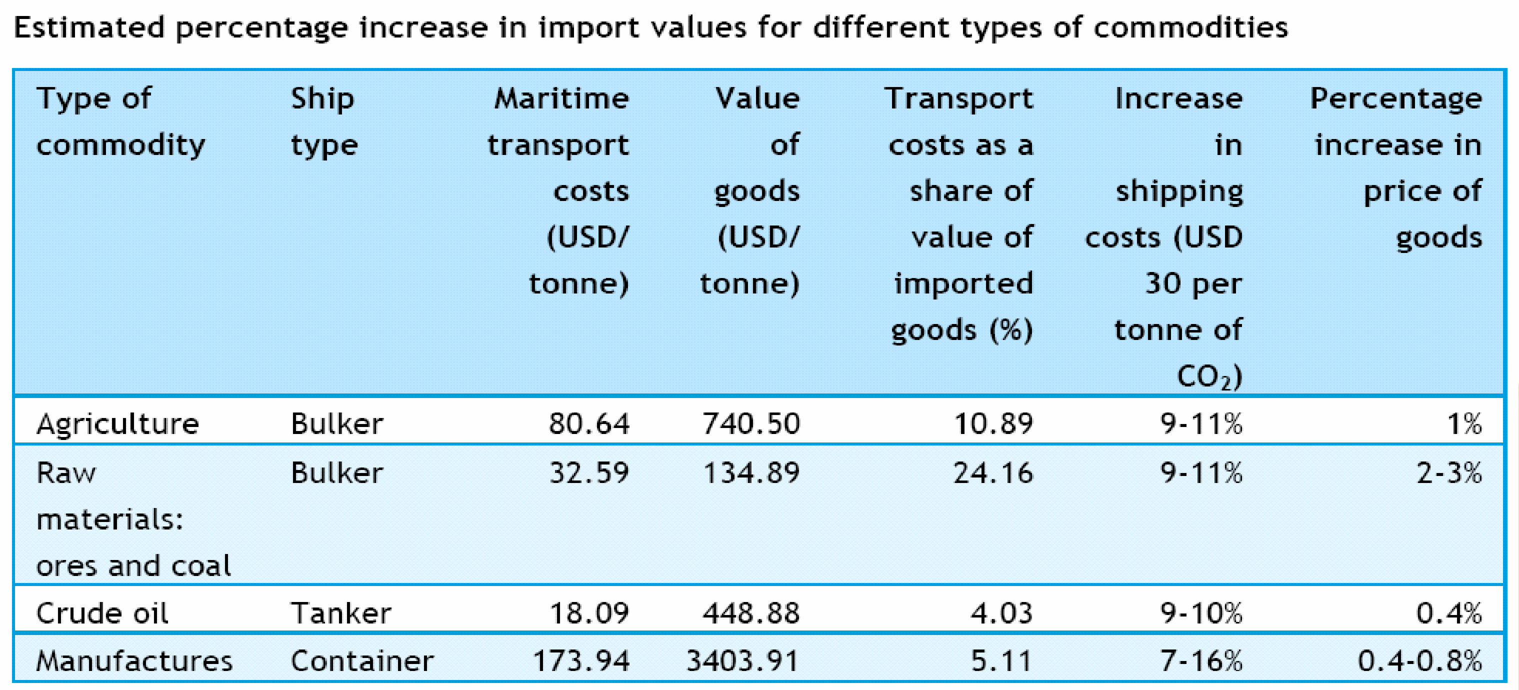
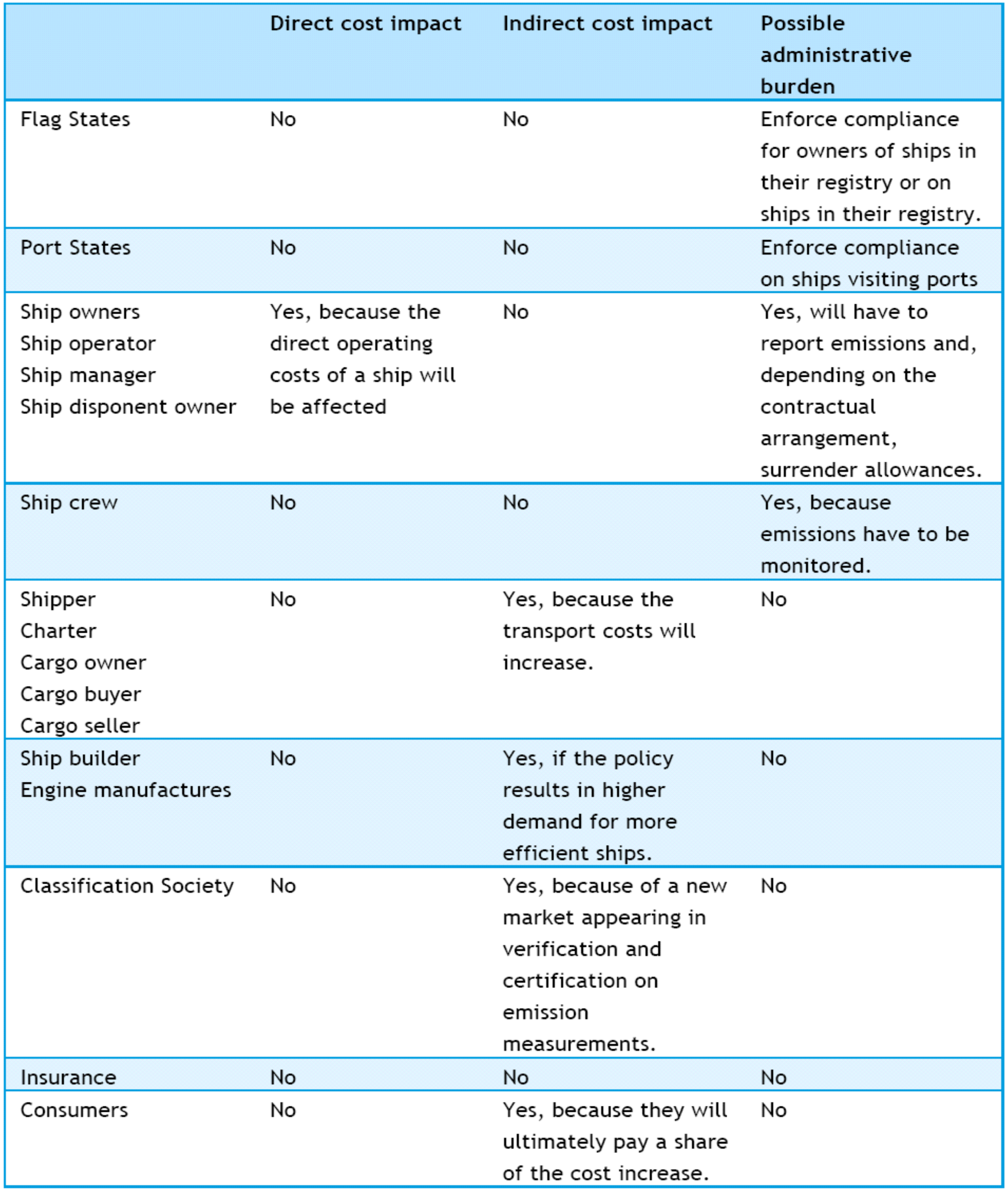


Estimated percentage increase in import values for different types of commodities

Type of commodity	Ship type	Maritime transport costs (USD/ tonne)	Value of goods (USD/ tonne)	Transport costs as a share of value of imported goods (%)	Increase in shipping costs (USD 30 per tonne of CO_2)	Percentage increase in price of goods
Agriculture	Bulker	80.64	740.50	10.89	9-11%	1%
Raw materials: ores and coal	Bulker	32.59	134.89	24.16	9-11%	2-3%
Crude oil	Tanker	18.09	448.88	4.03	9-10%	0.4%
Manufactures	Container	173.94	3403.91	5.11	7-16%	0.4-0.8%

Source: CE Delft et al., 2010

Impacts

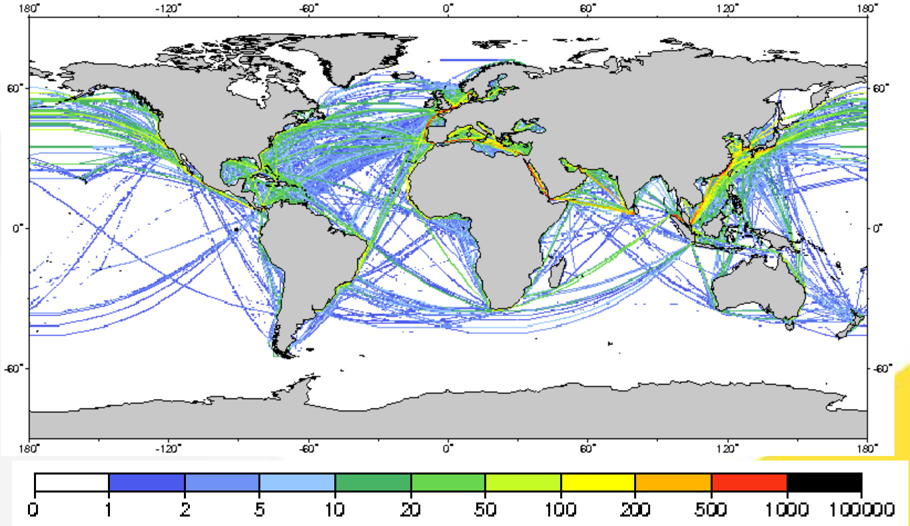


	Direct cost impact	Indirect cost impact	Possible administrative burden
Flag States	No	No	Enforce compliance for owners of ships in their registry or on ships in their registry.
Port States	No	No	Enforce compliance on ships visiting ports
Ship owners Ship operator Ship manager Ship disponent owner	Yes, because the direct operating costs of a ship will be affected	No	Yes, will have to report emissions and, depending on the contractual arrangement, surrender allowances.
Ship crew	No	No	Yes, because emissions have to be monitored.
Shipper Charter Cargo owner Cargo buyer Cargo seller	No	Yes, because the transport costs will increase.	No
Ship builder Engine manufactures	No	Yes, if the policy results in higher demand for more efficient ships.	No
Classification Society	No	Yes, because of a new market appearing in verification and certification on emission measurements.	No
Insurance	No	No	No
Consumers	No	Yes, because they will ultimately pay a share of the cost increase.	No

Source: CE Delft et al., 2010

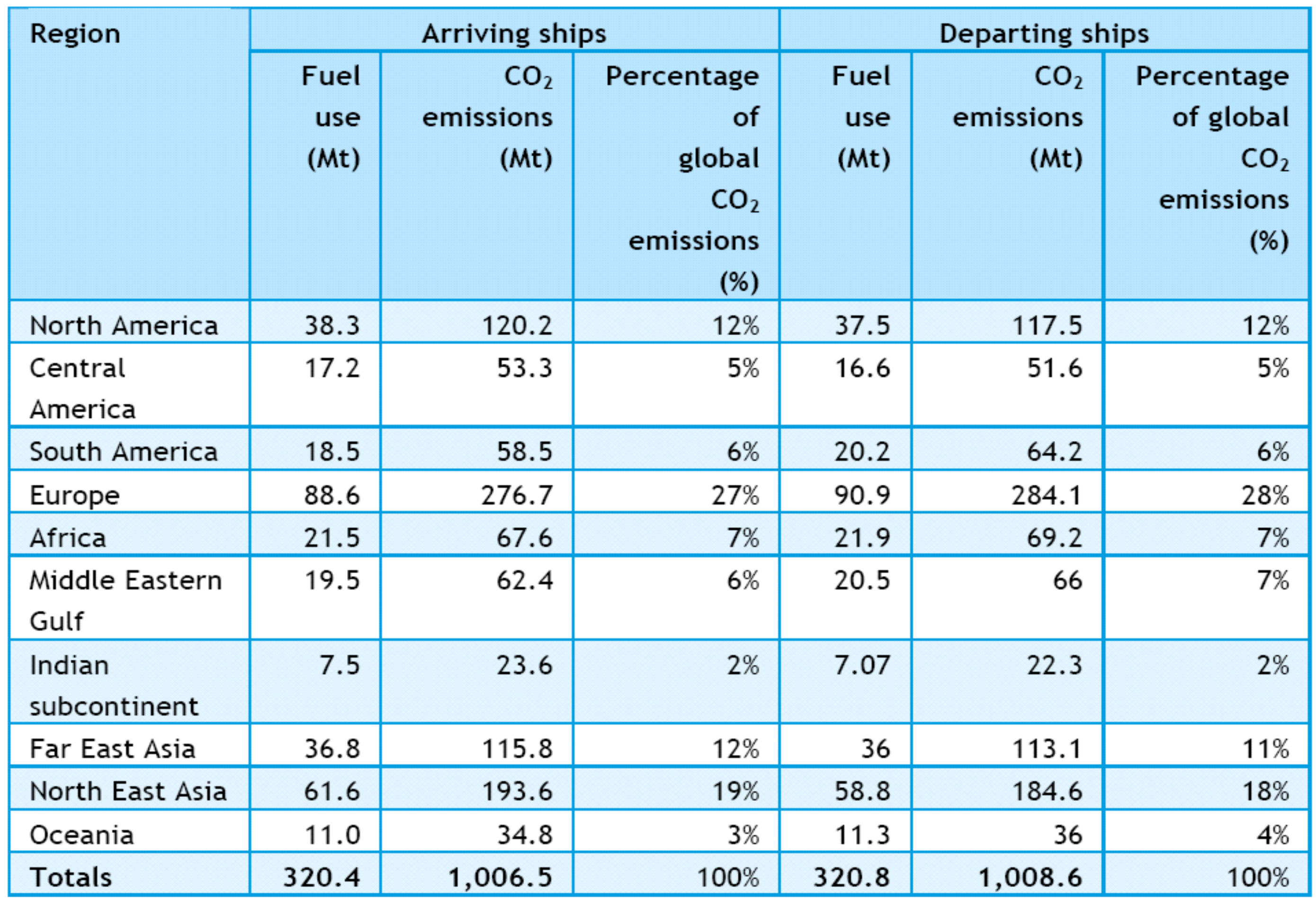
Impacts of a maritime cap-and-trade scheme

- Impacts on economies
- Assumption: main impact through higher import prices
- Assumptions: trade patterns, ship fuel efficiency and import quantities are constant (worst case)



Source: CE Delft et al., 2010

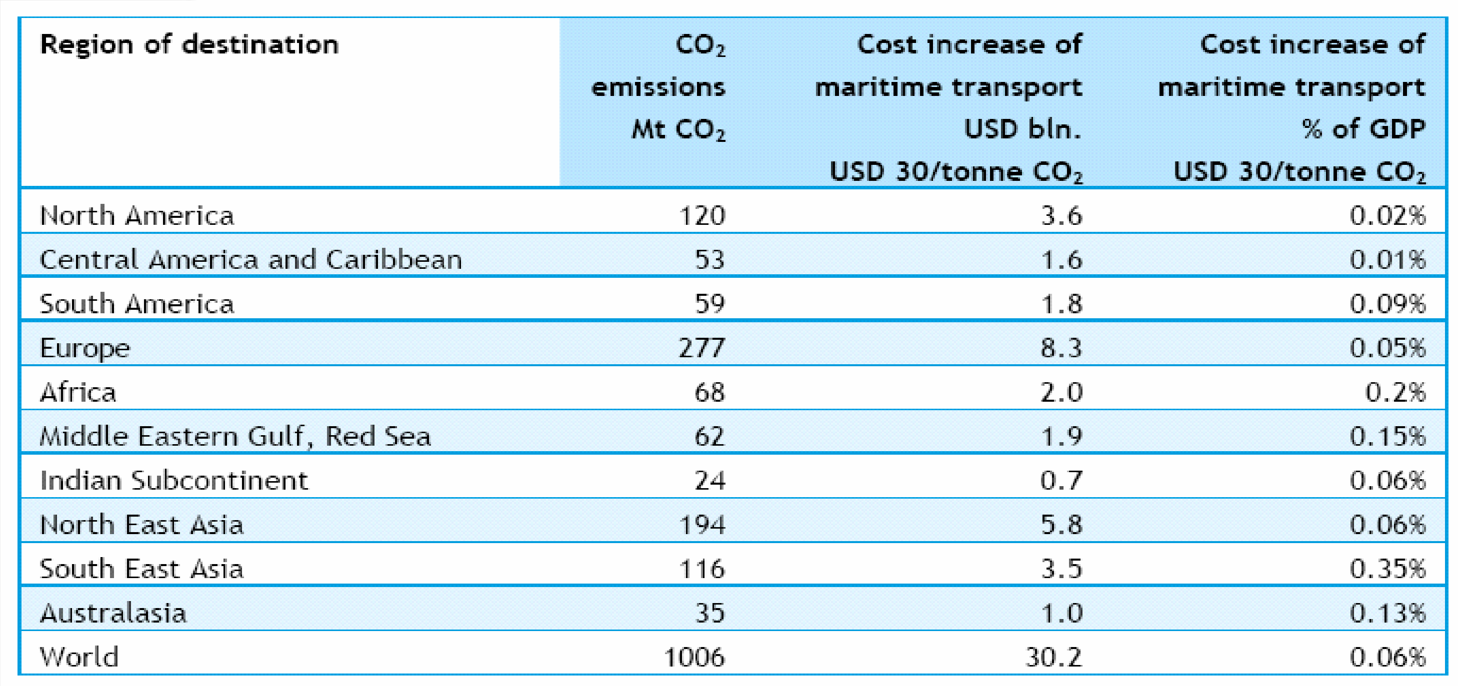
Impacts of a maritime cap-and-trade scheme



Region	Arriving ships			Departing ships		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of global CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of global CO_2 emissions (%)
North America	38.3	120.2	12%	37.5	117.5	12%
Central America	17.2	53.3	5%	16.6	51.6	5%
South America	18.5	58.5	6%	20.2	64.2	6%
Europe	88.6	276.7	27%	90.9	284.1	28%
Africa	21.5	67.6	7%	21.9	69.2	7%
Middle Eastern Gulf	19.5	62.4	6%	20.5	66	7%
Indian subcontinent	7.5	23.6	2%	7.07	22.3	2%
Far East Asia	36.8	115.8	12%	36	113.1	11%
North East Asia	61.6	193.6	19%	58.8	184.6	18%
Oceania	11.0	34.8	3%	11.3	36	4%
Totals	**320.4**	**1,006.5**	100%	**320.8**	**1,008.6**	100%

Source: CE Delft et al., 2010

Impacts of a maritime cap-and-trade scheme



Region of destination	CO_2 emissions Mt CO_2	Cost increase of maritime transport USD bln. USD 30/tonne CO_2	Cost increase of maritime transport % of GDP USD 30/tonne CO_2
North America	120	3.6	0.02%
Central America and Caribbean	53	1.6	0.01%
South America	59	1.8	0.09%
Europe	277	8.3	0.05%
Africa	68	2.0	0.2%
Middle Eastern Gulf, Red Sea	62	1.9	0.15%
Indian Subcontinent	24	0.7	0.06%
North East Asia	194	5.8	0.06%
South East Asia	116	3.5	0.35%
Australasia	35	1.0	0.13%
World	1006	30.2	0.06%

Source: CE Delft et al., 2010

Comparison with other instruments

Three types of policy in the IMO debate

- Technical policy options, aimed at improving the design efficiency of the fleet
  - Mandatory EEDI limit value
  - Baseline-and-credit trading based on EEDI (US proposal)
- Operational policy options, aimed at improving the operational efficiency of the fleet;
  - Voluntary actions: SEEMP
- Market-based policy options instruments addressing CO2 emissions directly
  - Emissions trading
  - Fuel levy ('International Fund for Greenhouse Gas Emissions from Ships')

Comparison with other instruments

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Comparison with other instruments

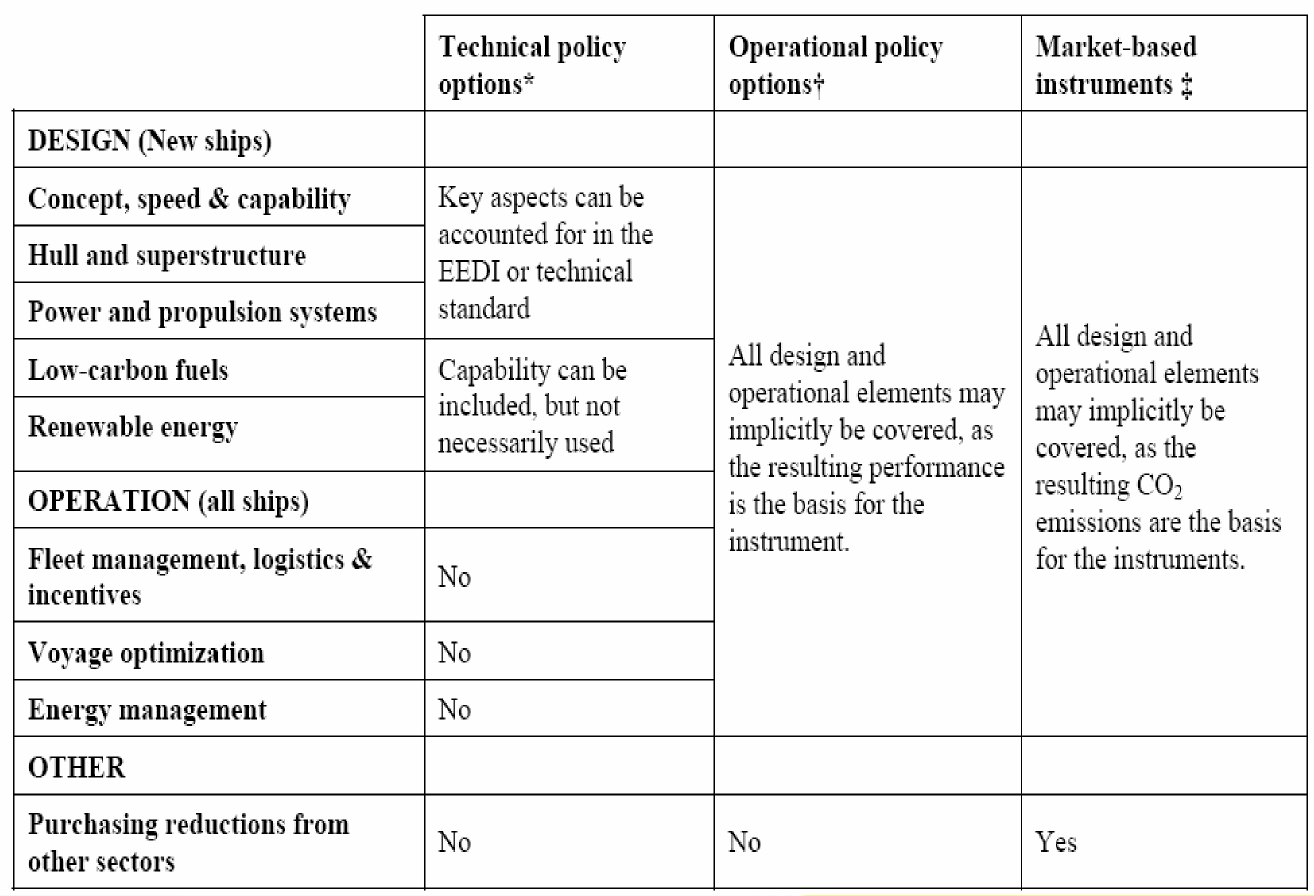
Assessment of policy options

- Environmental effectiveness
- Cost-effectiveness
- Incentive to technological change
- Practical feasibility

- Based on criteria set by MEPC 57

Comparison with other instruments

Environmental effectiveness and cost-effectiveness

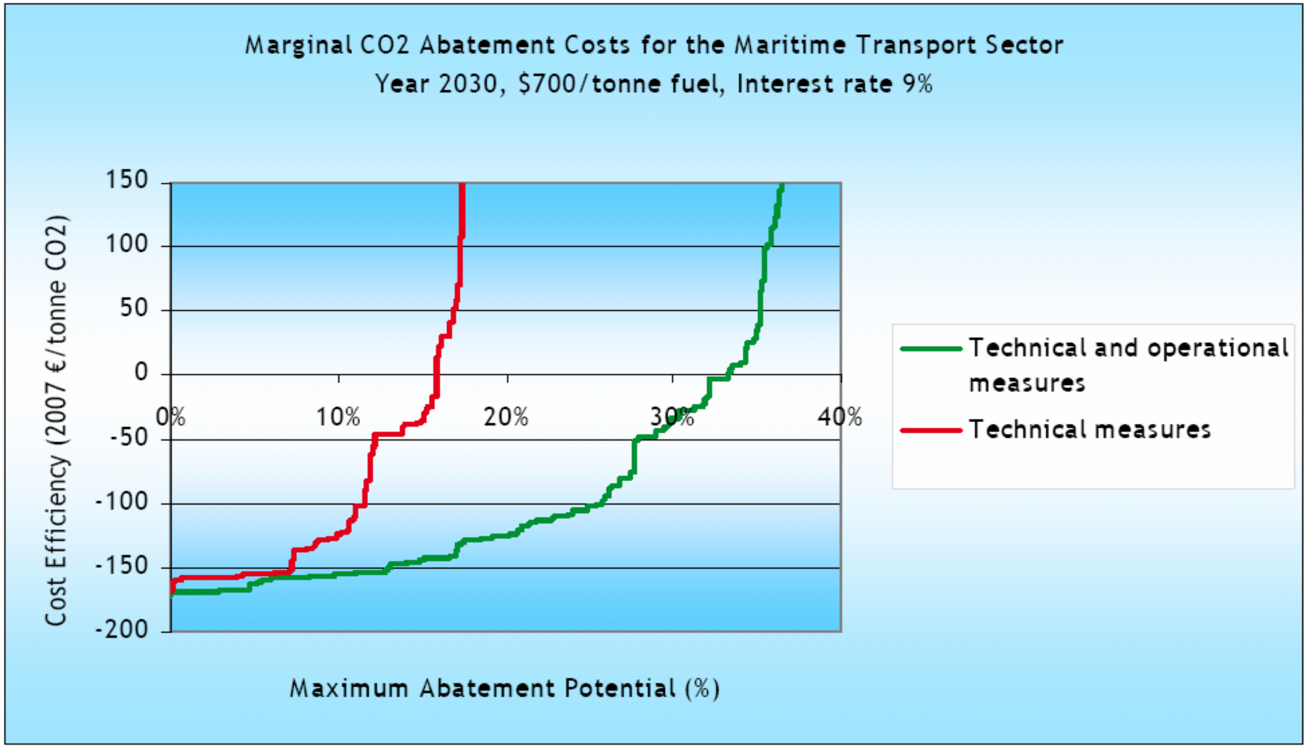


	Technical policy options*	**Operational policy options†**	**Market-based instruments ‡**
DESIGN (New ships)			
Concept, speed & capability	Key aspects can be accounted for in the EEDI or technical standard	All design and operational elements may implicitly be covered, as the resulting performance is the basis for the instrument.	All design and operational elements may implicitly be covered, as the resulting CO_2 emissions are the basis for the instruments.
Hull and superstructure			
Power and propulsion systems			
Low-carbon fuels	Capability can be included, but not necessarily used		
Renewable energy			
OPERATION (all ships)			
Fleet management, logistics & incentives	No		
Voyage optimization	No		
Energy management	No		
OTHER			
Purchasing reductions from other sectors	No	No	Yes

Comparison with other instruments

Environmental effectiveness and cost-effectiveness

MACC curves for all measures and for technical measures only, 2030, 9% interest rate and fuel price of US$ 700 per tonne



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Comparison with other instruments

- Market-based policy options
  - Largest environmental effectiveness – all possible measures rewarded, offsets
  - Most cost-effective if administrative burden can be kept low - all cost-effective measures rewarded
- Operational policy options
  - Large environmental effectiveness – many measures rewarded
  - Most cost-effective if administrative burden can be kept low - all cost-effective measures rewarded
- Technical policy options, aimed at improving the design efficiency of the fleet
  - Smaller environmental effectiveness – only technical measures rewarded
  - Less cost-effective - many technical measures are expensive
  - Low administrative burden

Comparison with other instruments

- Combination of policies?
  - Lead to higher admin burden
  - Reduce cost-effectiveness when markets are functioning well
  - Could be beneficial when market failures exist

- Example
  - Market based instrument to reduce emissions, stimulate innovation in ship operation and retrofit
  - Mandatory EEDI to create more transparency in newbuilding, second-hand and charter market, stimulate innovation in shipbuilding

Comparison with other instruments

- International Fund for Greenhouse Gas Emissions from Ships, submitted by Denmark (MEPC 59/4/5)
    - Levy on fuels bunkered
    - Levy depends on difference between actual emissions and emissions target
    - Ships have to bunker from a fuel supplier that pays the levy or pay the levy themselves
    - Levy feeds into fund and is spent on offsets, adaptation, R&D
- Global Emission Trading Scheme for International Shipping, submitted by France, Germany and Norway (MEPC 59/4/25)
    - Emissions cap for global shipping
    - Ship owners monitor emissions and surrender sufficient allowances
    - Allowance trading possible between shipping companies and with participants in other systems
    - Revenue from auctioning feeds into fund

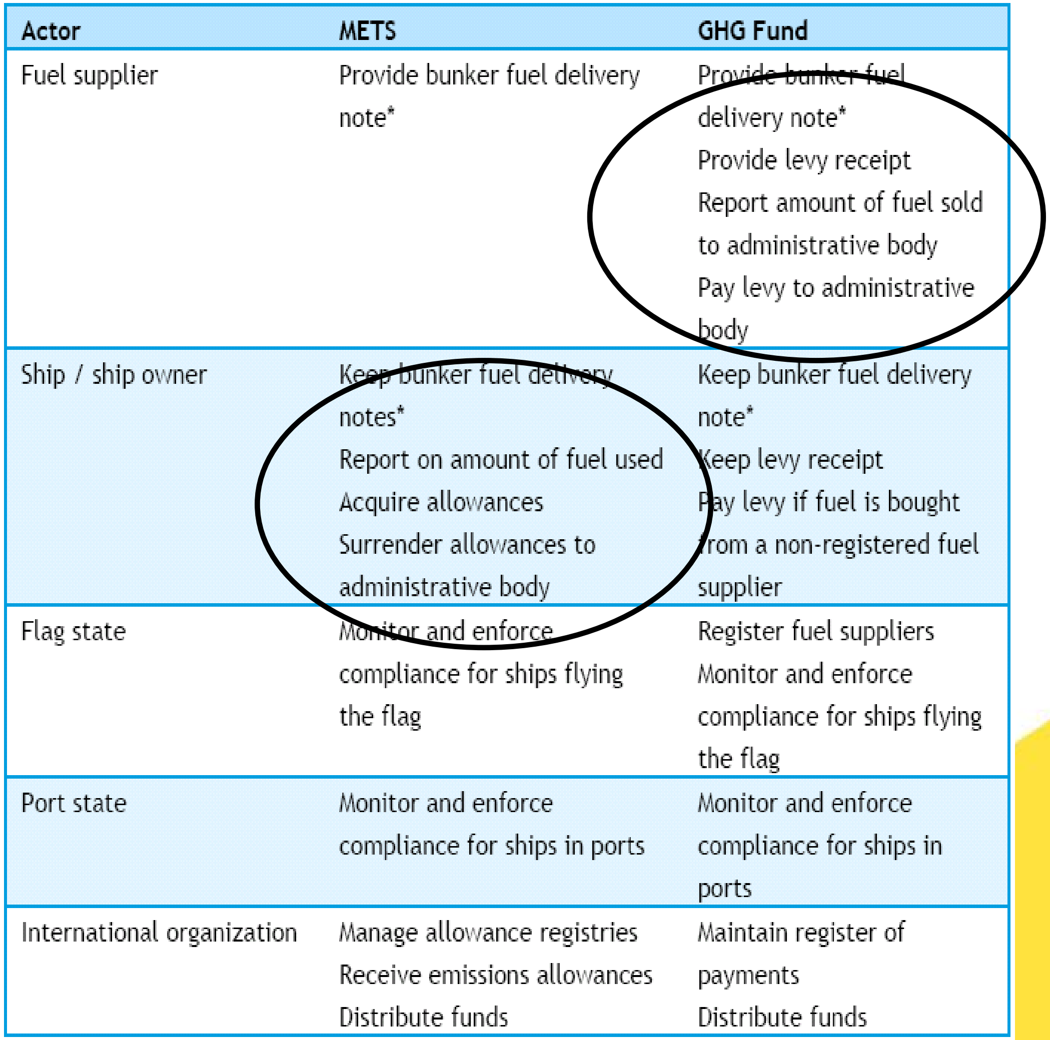
Comparison with other instruments

- Environmental effectiveness
  - METS: set by cap, depends on effectiveness of enforcement and carbon leakage
  - International Fund: depends on availability and price of offsets, quality of offsets, level of the levy

- Cost-effectiveness
  - International Fund initially lower costs to sector, but this reverses as the emissions target becomes more ambitious
  - METS lower costs to society as a whole, as more emission reduction measures are taken in the sector

Comparison with other instruments

Admin burden



Actor	METS	GHG Fund
Fuel supplier	Provide bunker fuel delivery note*	Provide bunker fuel delivery note* Provide levy receipt Report amount of fuel sold to administrative body Pay levy to administrative body
Ship / ship owner	Keep bunker fuel delivery notes* Report on amount of fuel used Acquire allowances Surrender allowances to administrative body	Keep bunker fuel delivery note* Keep levy receipt Pay levy if fuel is bought from a non-registered fuel supplier
Flag state	Monitor and enforce compliance for ships flying the flag	Register fuel suppliers Monitor and enforce compliance for ships flying the flag
Port state	Monitor and enforce compliance for ships in ports	Monitor and enforce compliance for ships in ports
International organization	Manage allowance registries Receive emissions allowances Distribute funds	Maintain register of payments Distribute funds

Source: CE Delft 2009

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Comparison with other instruments

Increase of costs

- Emissions trading
  - Full auctioning: high direct costs
  - Part auctioning , part free allocation: lower costs
  - Price of allowances determined by supply and demand
  - Costs may be volatile and unpredictable (cf fuel)
- GHG fund
  - Costs lower than full auctioning
  - Level of the levy determined by price of offsets
  - Or by a political decision
  - Costs are predictable over a 4-year period

Conclusions

- It is feasible to implement a cap-and-trade scheme in maritime transport
  - Ship owners need to monitor emissions and surrender allowances
  - Flag states will inspect ships and port states may deny entry to non-compliant ships
- While the impacts on the cost of shipping are significant, the impacts are comparable to the impacts of air pollution policies and smaller than historical fuel price increases
- The impacts on import values are small
- The economic impacts are small for most world regions
- A cap-and-trade scheme is a cost-effective way to reduce emissions in the shipping sector

Thank you!

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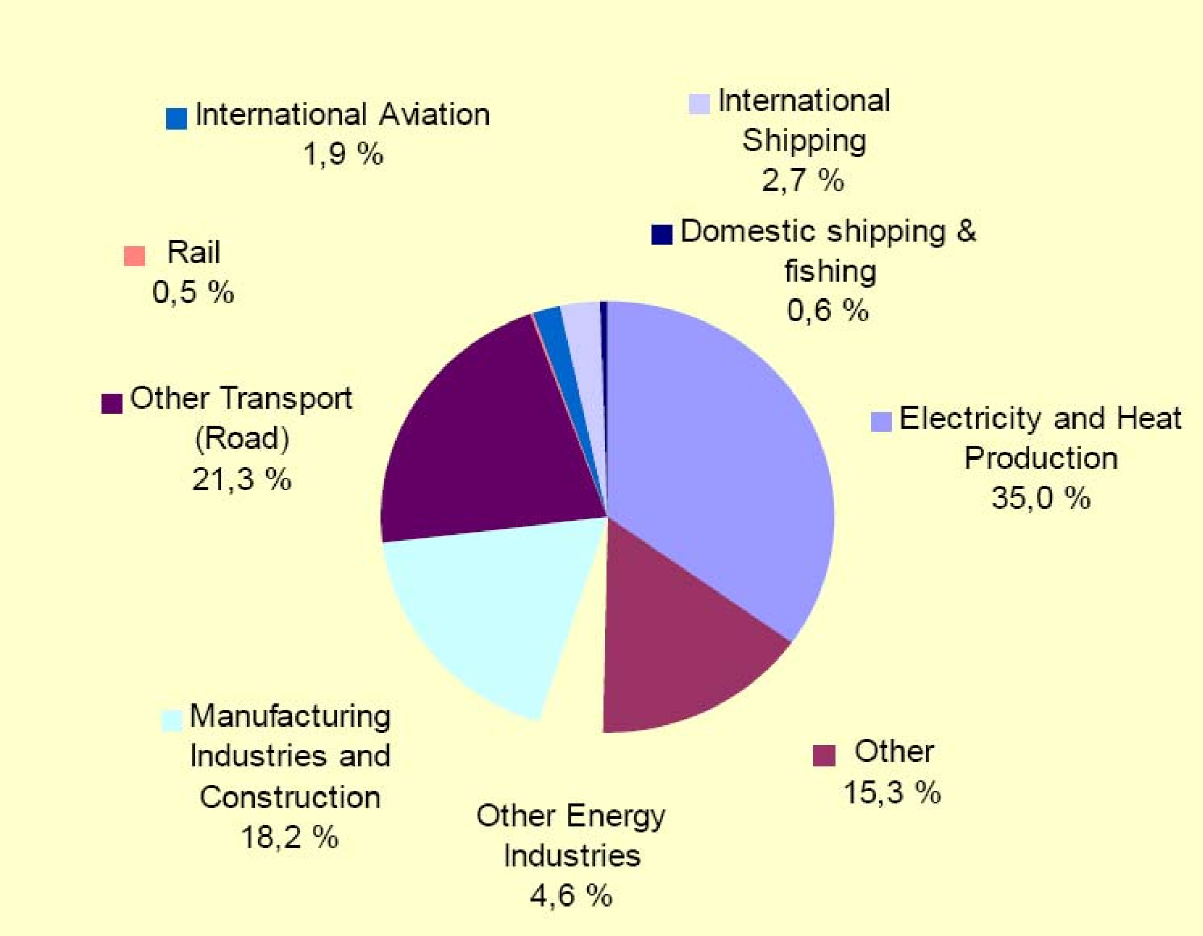
Climate change and shipping emissions

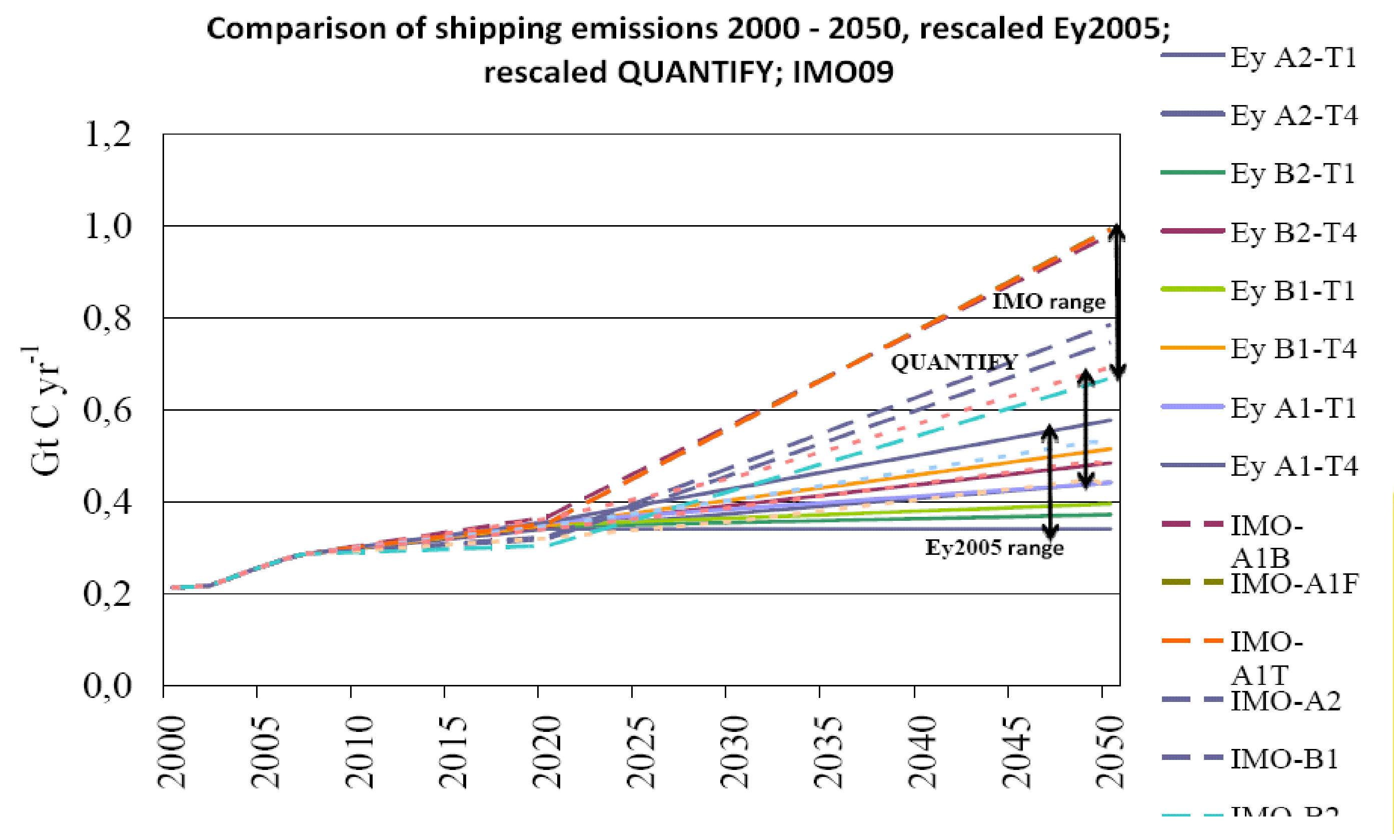
Shipping accounts for 3.3% of global emissions



Source: Buhaug, Faber et al., 2nd IMO GHG study 2009

Climate change and shipping emissions

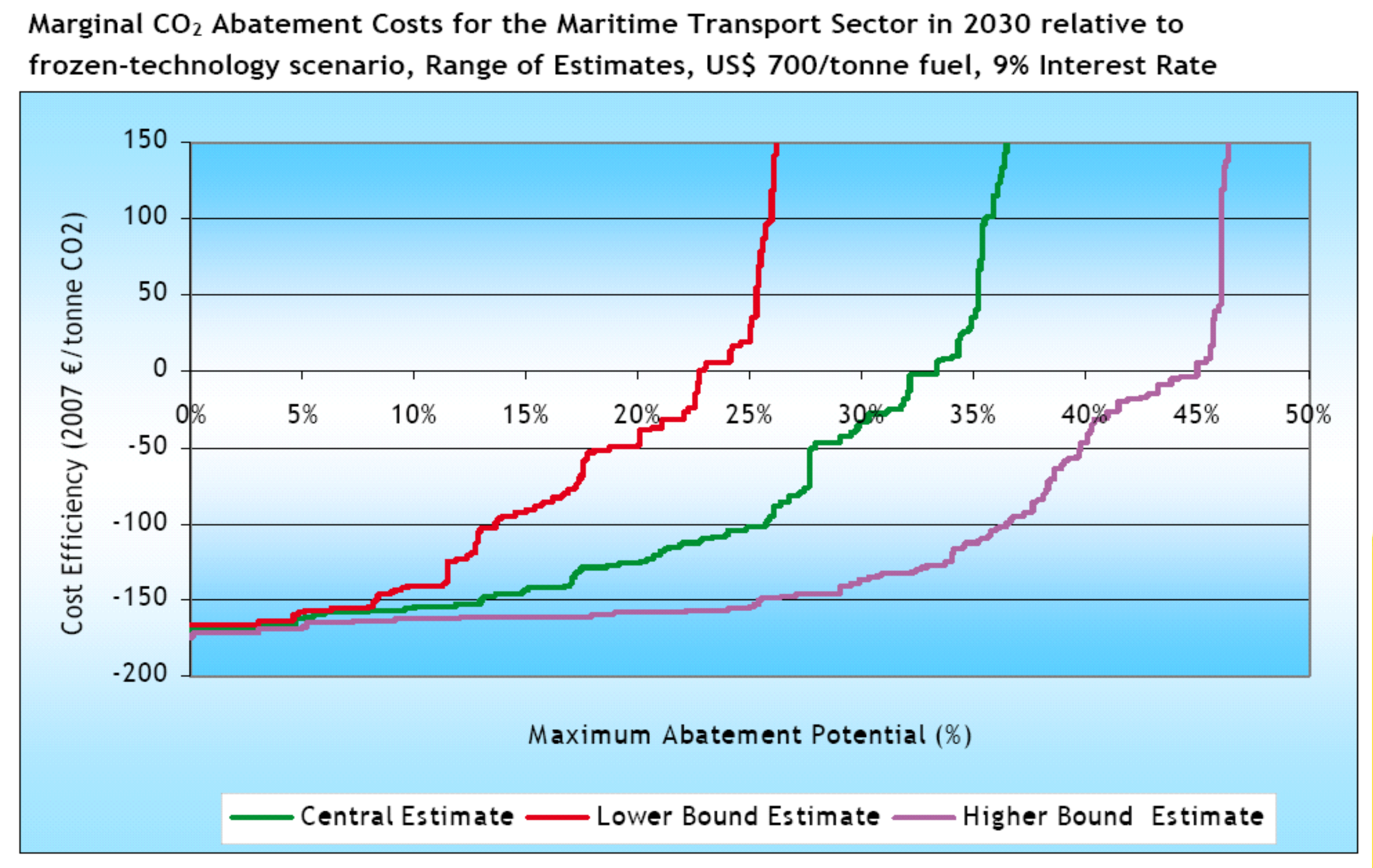
Emissions are projected to increase two- to threefold in the next decades, using up the available carbon budget at an increasing rate



Source: Lee et al., 2010

Climate change and shipping emissions

Shipping has a large potential of cost-effective abatement options



Source: CE Delft et al., 2009

Agenda

Current Legislation

Exhaust Components

Overview Formation, Reduction, Control Technologies

Leading Engine Technologies

- Primary Wet / Dry Means
- Secondary Wet / Dry Means

Case Example

Value Mapping Analysis

Summary

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Formation & Reduction

Emission	What	Cause	Formation	Reduction
Nitrogen Oxide	Nitrogen and oxygen dissociation react forming nitric oxide.	Combustion zone dissociation reactions form Nitric Oxide NO.	Exponentially temperature dependent, also dependent on residence time	Lower peak combustion temperature.
"NO_2"		Flame region reactions yield Nitrogen Dioxide NO_2		Reduce combustion time duration. Inhibit dissociation.
Particulate Matter, Soot	Carbon soot mixture plus some volatile organic and sulfate compounds.	Later combustion oxidizes most carbon particles.	Temperature, combustion residency time, and oxidation availability.	Improve mixing. Reduce fuel sulfur content. Exhaust catalyst treatment. Shorten ignition delay. Remove crevices.
"PM"		Organic fraction from unburned fuel and lube oil consumption. Sulfate dependent upon sulfur proportion in fuel.	After-cooling and exhaust air dilution foster sulfate PM and volatile organic	
Hydrocarbon	Fuel and trapped lubricant.	Crevice traps in top ring land and injector sac promote incomplete combustion mixing.	Cold start white smoke.	Exhaust catalyst treatment. Shorten ignition delay. Remove crevices. Reduce sac volume. Eliminate secondary injections.
"HC"		Excessive swirling promote fuel related overmixing during ignition delay.		

Emission engineering first principle fundamentals form root basis

Control Technologies

What	How	Means	Target	Effectiveness
Charge Air Cooling	**Low temperature cooling "LT"**	**Lowers manifold air temperature to reduce combustion temperature and improve charge air density.**	**NO_X**	**Lower NO_X 5% - 7% NO_X per 10C chilling intake air, improved fuel economy.**
Fuel Management	**Rate Shaping**	**Brief initial fuel charge restrains rapid pressure rise and promotes stable controlled flame.**	**NO_X**	**Improved NO_X – fuel consumption trade-off**
	Multiple Injections	**Electronic controlled high pressure multiple burst injections key delay preceding final pulse and duration.**		**Improved NO_X – fuel consumption trade-off**
	Common Rail	**Sustained ultra high fuel pressure removes compromises; expands operational range.**		**Improved NO_X – fuel consumption trade-off**
Injection Timing Retard	**Delay Combustion start.**	**Aligns heat release to expansion stroke facilitating lower combustion temperatures**	**NO_X**	**Lower NO_X. Negatives; higher fuel consumption, HC, CO, and PM.**
	Shorter premix phase.	**Concurrent with lower combustion temperature and pressures.**		

Engineering fundamentals drive target technologies

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Control Technologies

What	How	Means	Target	Effectiveness
Exhaust Gas Recirculation	**Reintroduces exhaust gases to cylinder.**	**Increased presence carbon dioxide and water vapor reduces combustion temperatures.**	**NO_X**	**Lower NO_X Negatives: higher fuel consumption resulting from longer burn duration and pumping work.**
Induced Mixing Turbulence	**High Injection Pressure**	**Boosts fuel spray velocity for improved coverage**	**HC, PM, Smoke**	**Tradeoff: increased NO_X for gains elsewhere**
	Multiple Split Injection	**Added dwell significantly reduces particulates and breaks up soot.**		
	Enhanced Swirl	**Improved intake valve and piston bowl designs extend swirl time.**		
Selective Catalytic Reduction "SCR"	**Catalytic Reduction**	**Reducing agent (ammonia, urea) injected into exhaust is channeled through a catalyst.**	**NO_X**	**Lower NO_X to 90%, effective over narrow power range; durability requires low sulfur fuel**
Water Injection	**Fuel Emulsification**	**Water emulsification to reduce combustion temperature.**	**NO_X**	**Lower NOX up to 50%**
	Direct Injection	**Parallel water and fuel injection into Cylinder – acts as diluent.**		
	Air Humidification	**Water injection into combustion air – acts as diluent.**		

Engineering fundamentals drive target technologies

Agenda

Current Legislation

Exhaust Components

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- Secondary Wet / Dry Means

Case Example

Value Mapping Analysis

Summary

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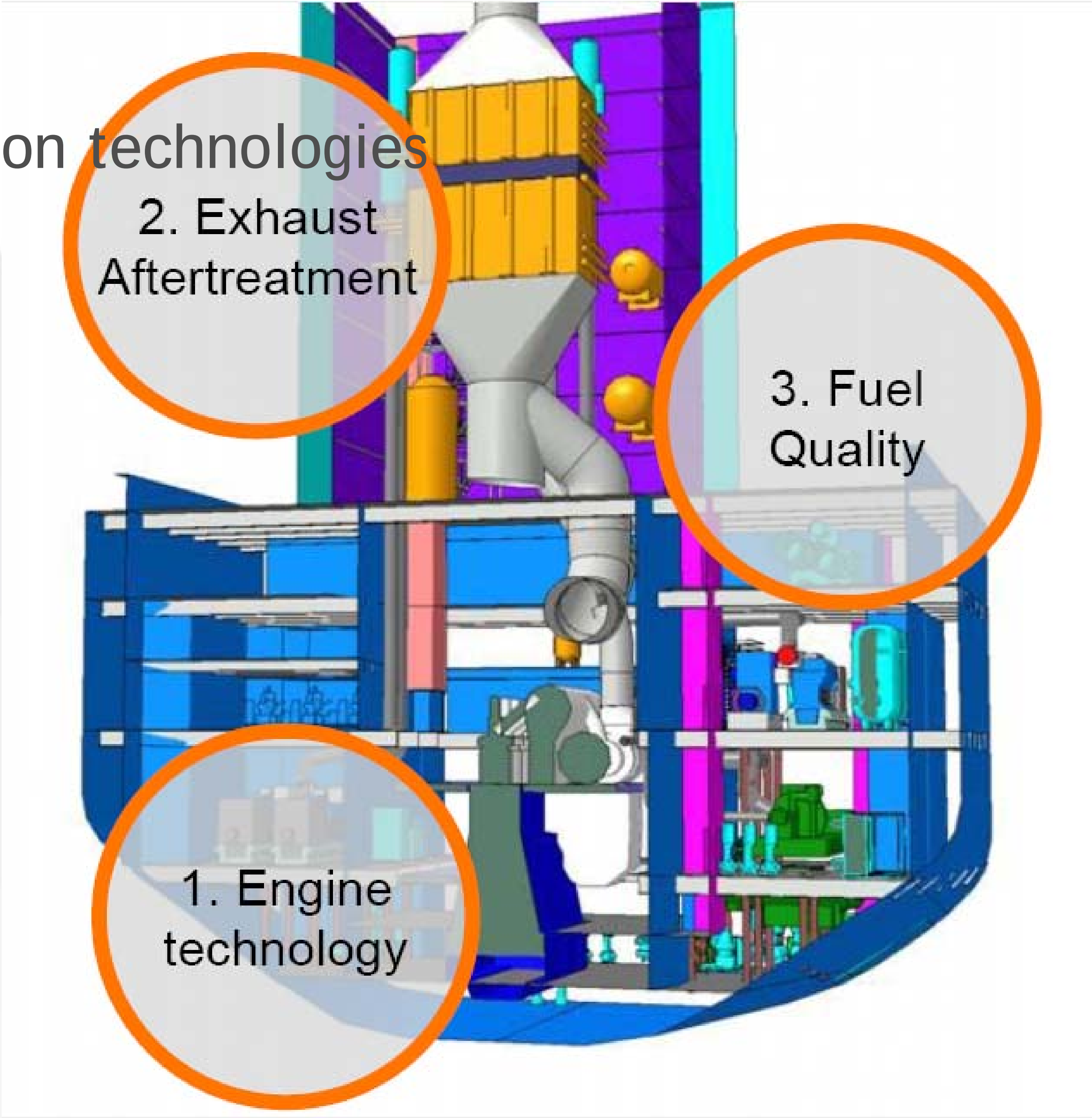
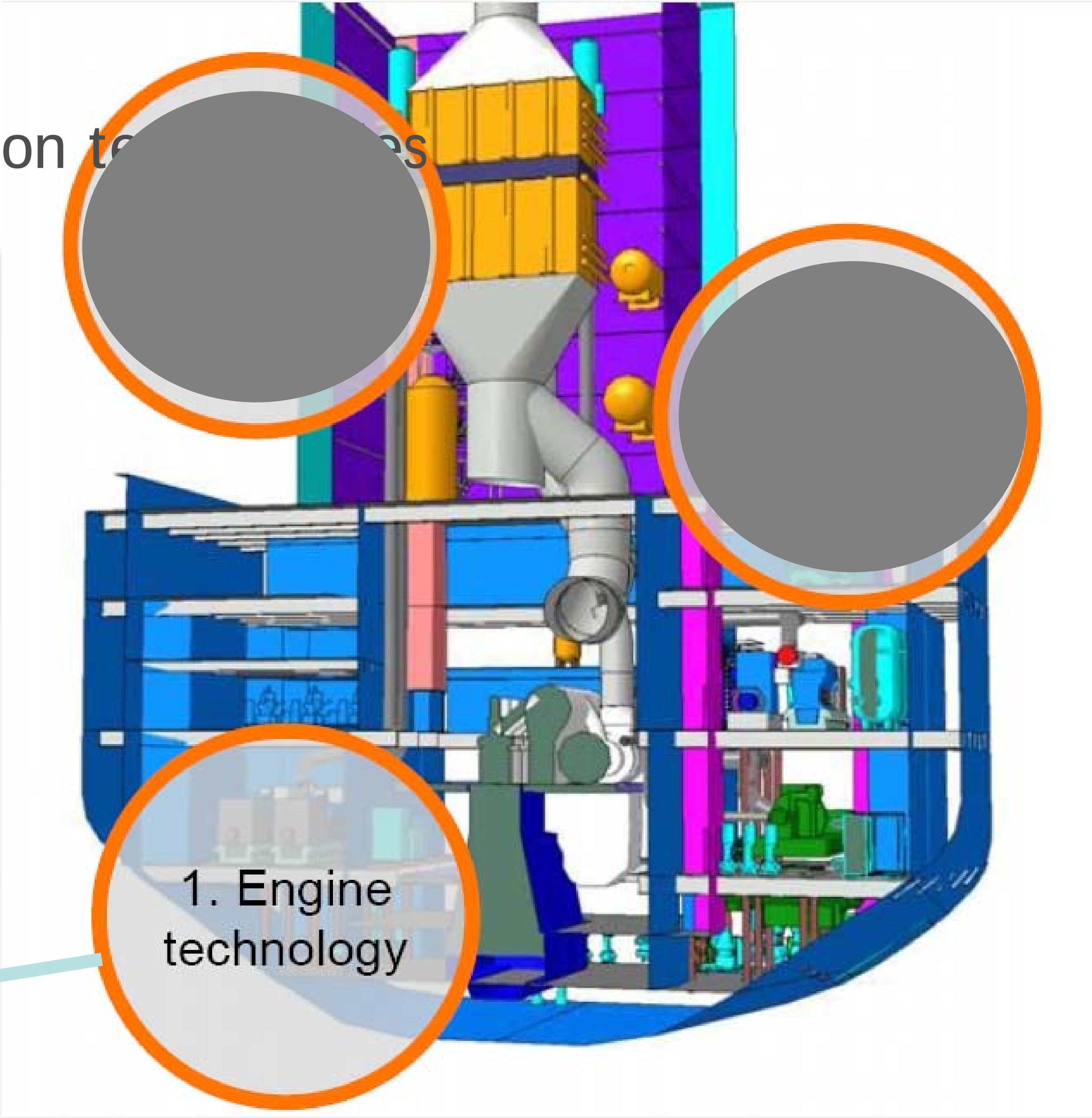
- NOx reduction technologies



Emissions Control T

			NOx	SOx	PM	Smoke
primary	dry	Low NOx tuning	★★			
		VIC ★★	★		★	★★
		Common Rail ★	★★		★	★★★★
	wet	WETPAC -H	★★★		★	
		WETPAC -DWI	★★★★		★	
		WETPAC -E	★★★		★	
secondary		SCR	★★★★		★	
		Scrubber	★	★★★★		★
		ESP	★		★★★	★
conv.		Switching to light fuel		★★★★	★	
		Conversion to gas	★★★	★★★★	★★★	★★

- NOx reduction te[illegible]es



1. Engine technology

DRY

NOx	SOx	PM	Smoke
★★			

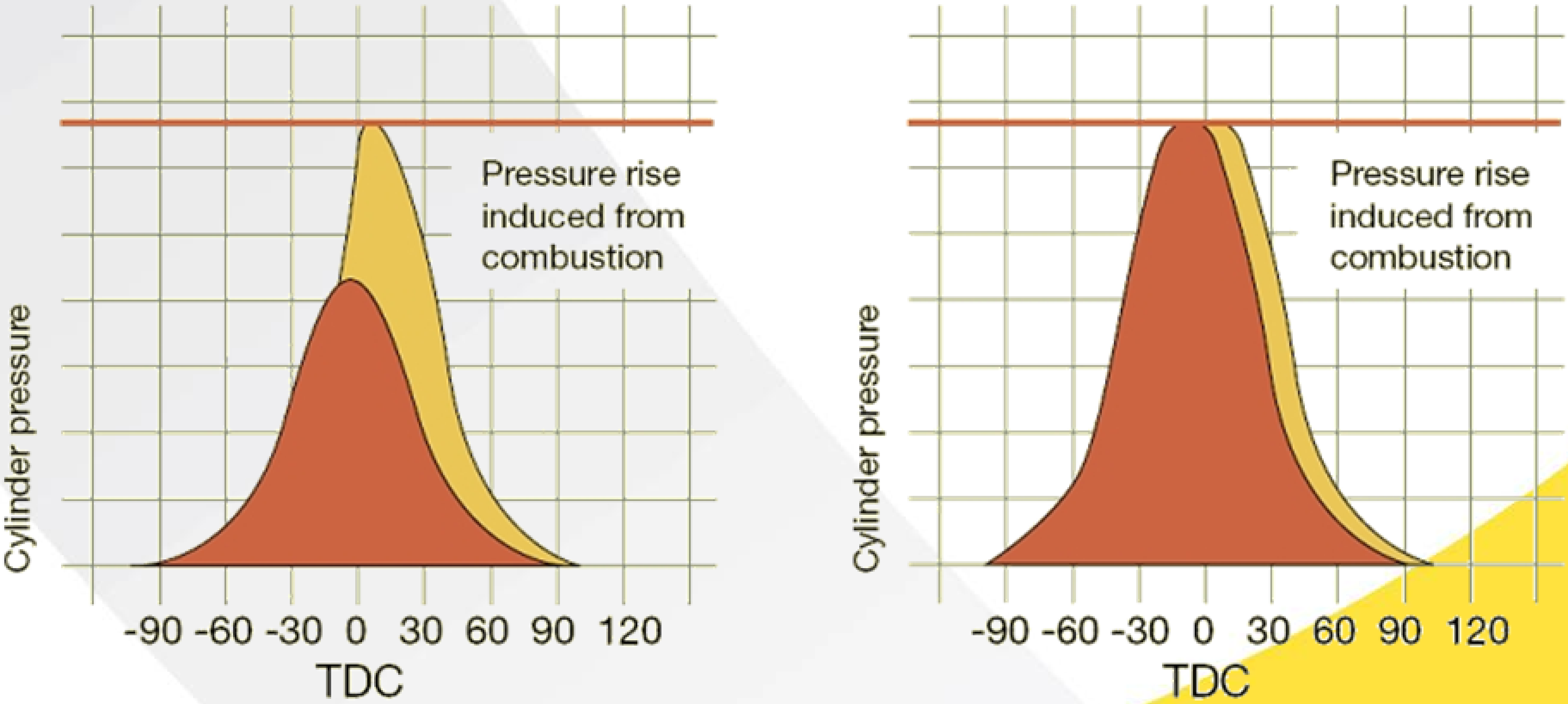
Low NO_X Engine Tuning

Application: All fuel types

NO_X reduction potential typically: 30-50%

Conventional design
Engine maximum firing pressure

Low NO_X design
Engine maximum firing pressure



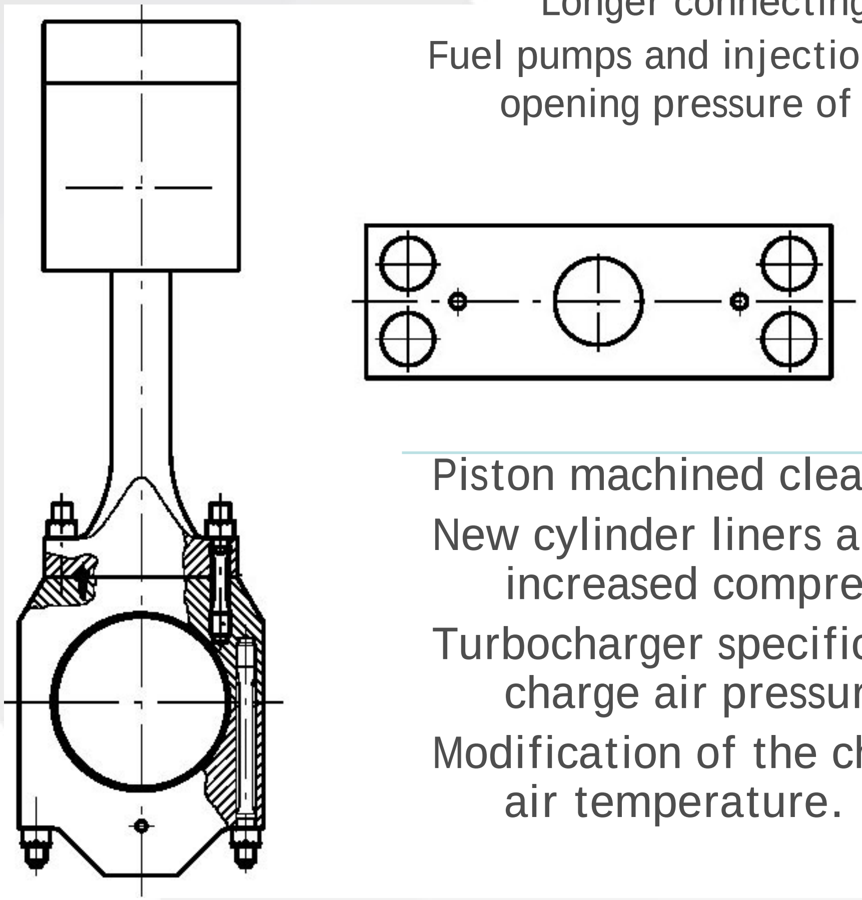
NOx	SOx	PM	Smoke
★★			

Low NO_X Engine Tuning

Increased Compression Ratio

Longer connecting rods or shims

Fuel pumps and injection valves settings to retard fuel injection & increase opening pressure of fuel injection.



Optional

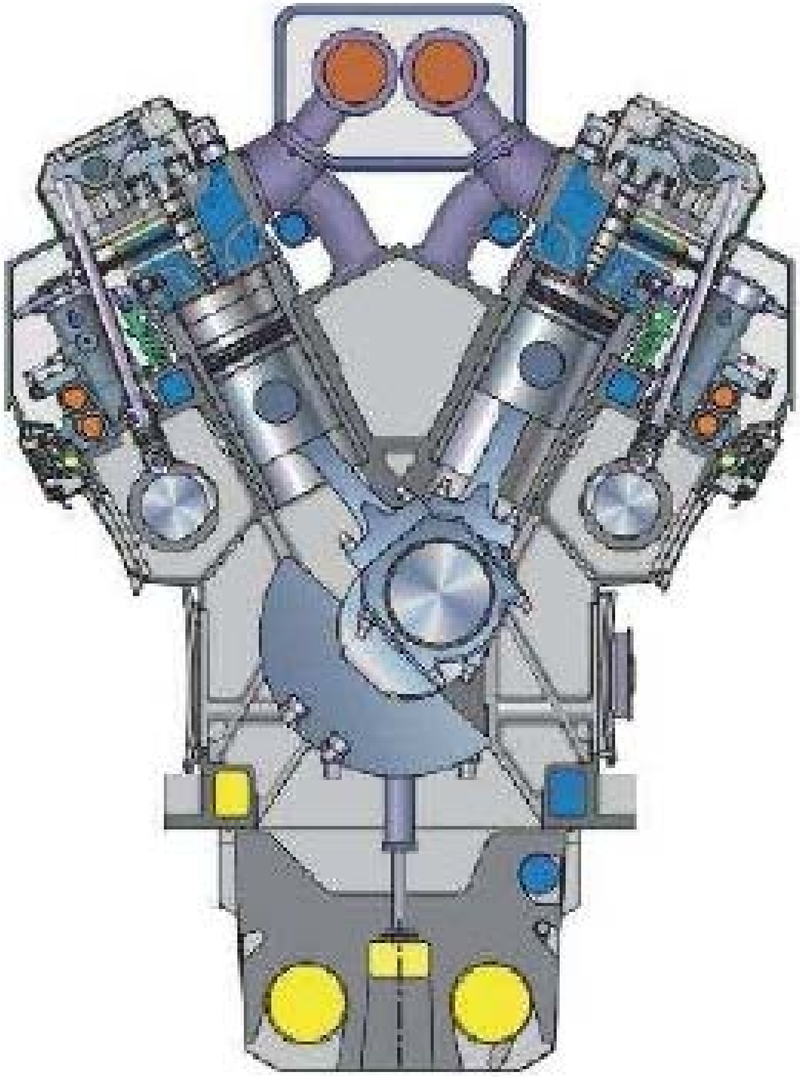
Piston machined clearance for inlet and exhaust valves.

New cylinder liners and anti/polishing rings matched to increased compression ratio.

Turbocharger specification with air waste gate to optimize charge air pressure.

Modification of the charge air cooling system to reduce charge air temperature.

NOx	SOx	PM	Smoke
★★			



Low NOx Technology

Later fuel injection start

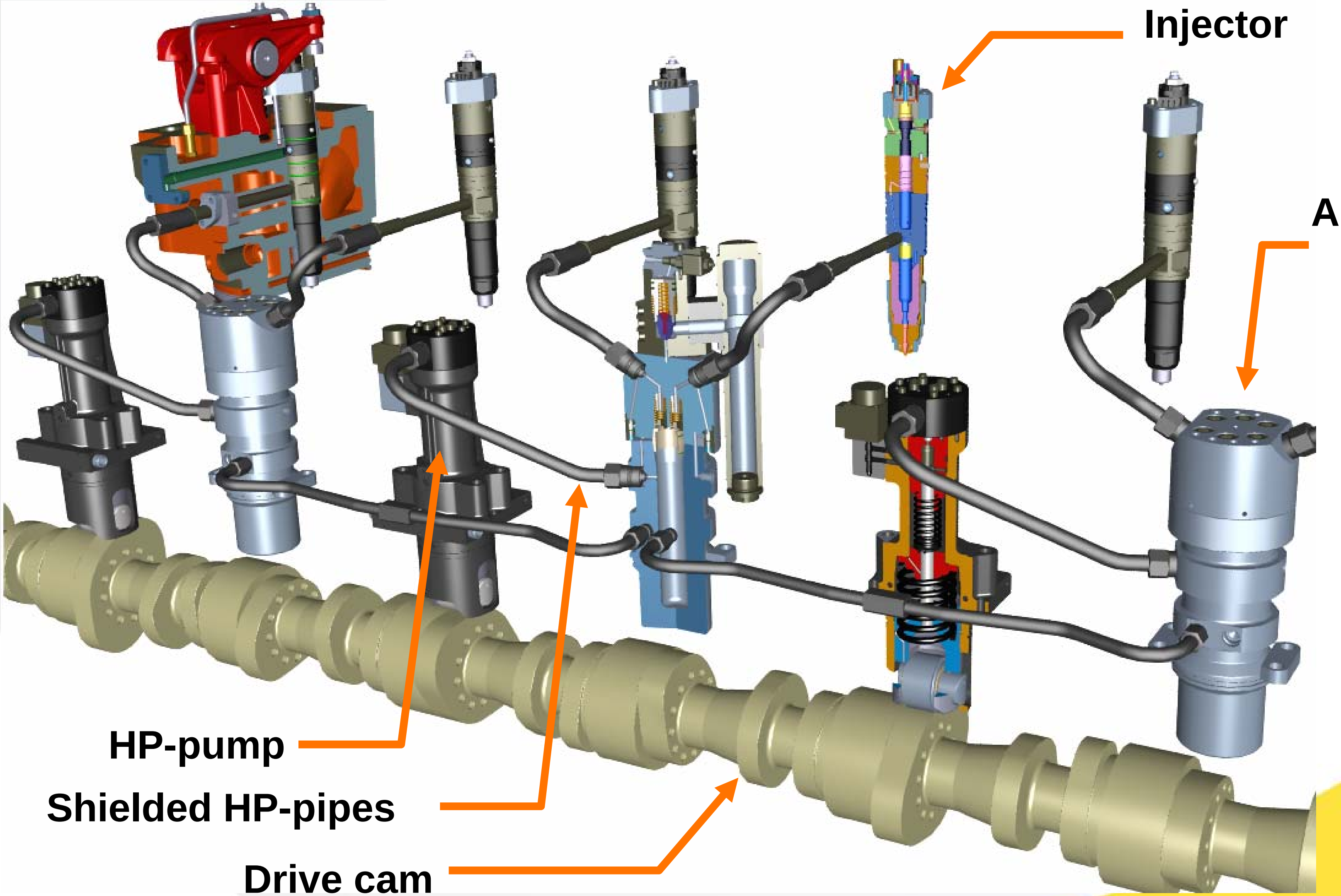
High compression ratio

Optimized combustion chamber

Fuel system:
- **4-stroke: Fuel rate shaping (CR Technology)**
- **2-stroke: Flexible fuel injection pattern (RT-flex Technology)**

Valve system
- **4-stroke: Early inlet valve closing (Miller timing)**
- **2-stroke: Flexible (late) exhaust valve closing (RT-flex Technology)**

NOx	SOx	PM	Smoke
★★		★	★★★★



Injector

Accumulator

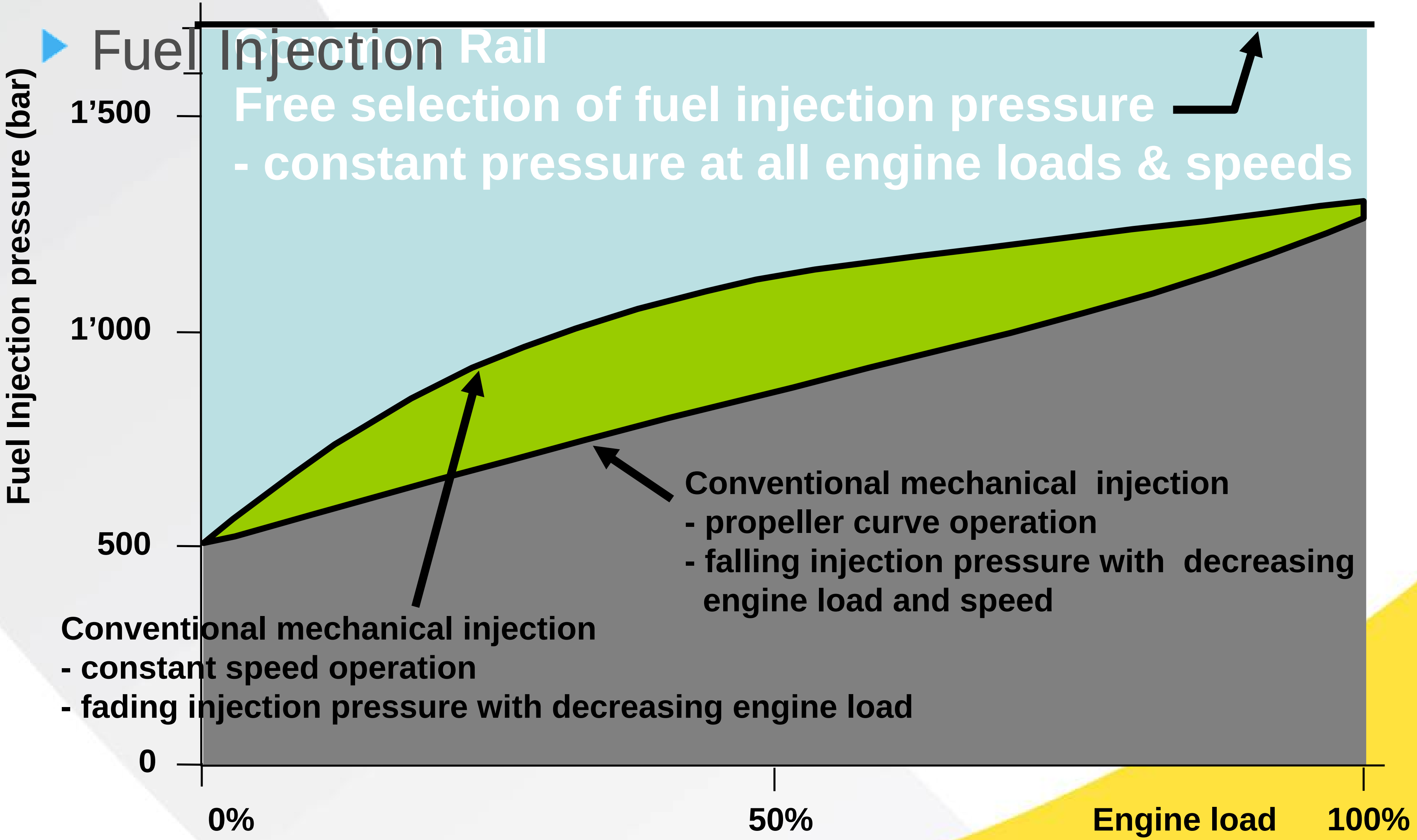
HP-pump

Shielded HP-pipes

Drive cam

NOx	SOx	PM	Smoke
★★		★	★★★★

Fuel Injection



Common Rail

Free selection of fuel injection pressure

- constant pressure at all engine loads & speeds

Conventional mechanical injection

- propeller curve operation

- falling injection pressure with decreasing engine load and speed

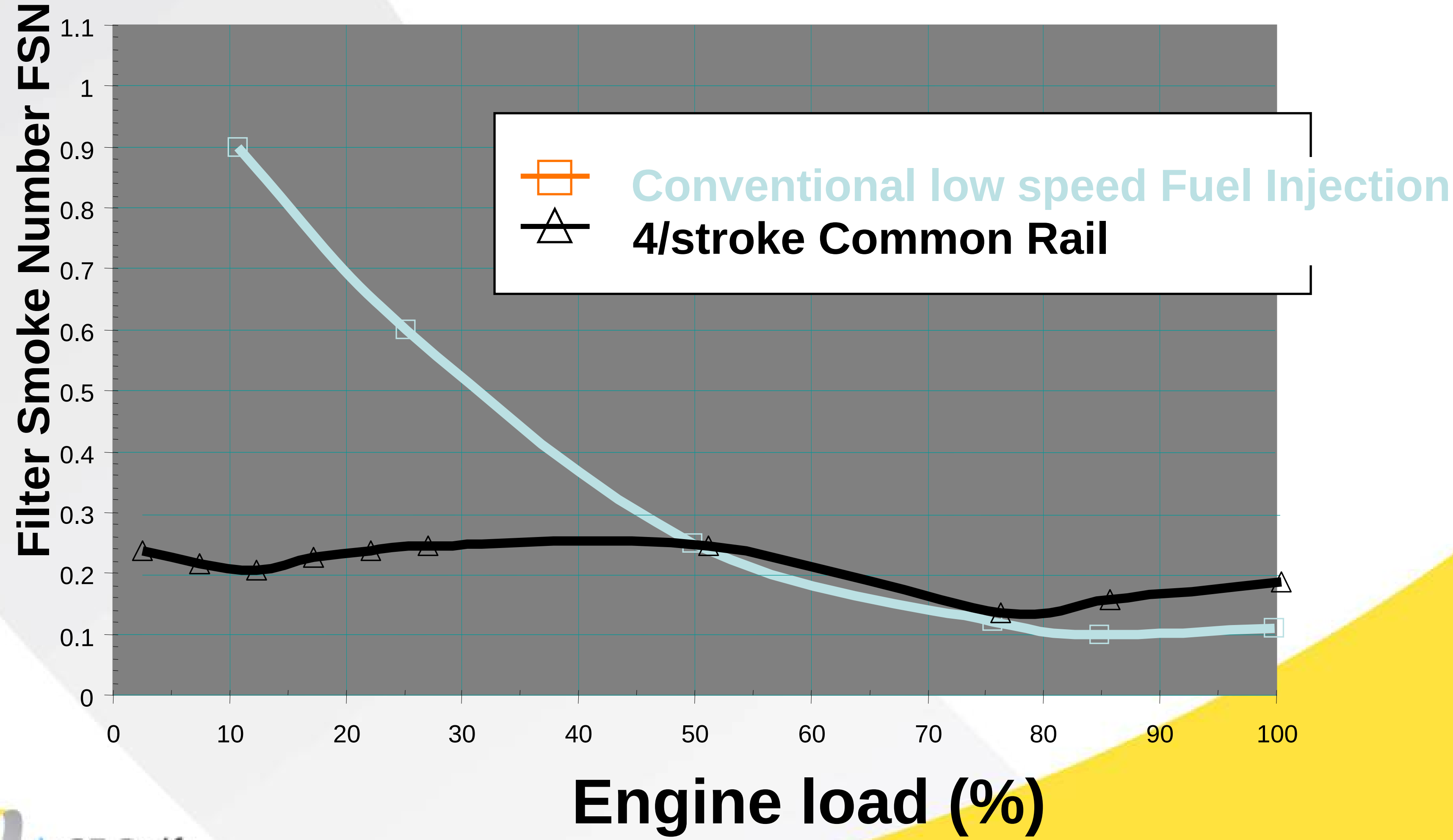
Conventional mechanical injection

- constant speed operation

- fading injection pressure with decreasing engine load

NOx	SOx	PM	Smoke
★★		★	★★★★

- Common Rail 4-stroke

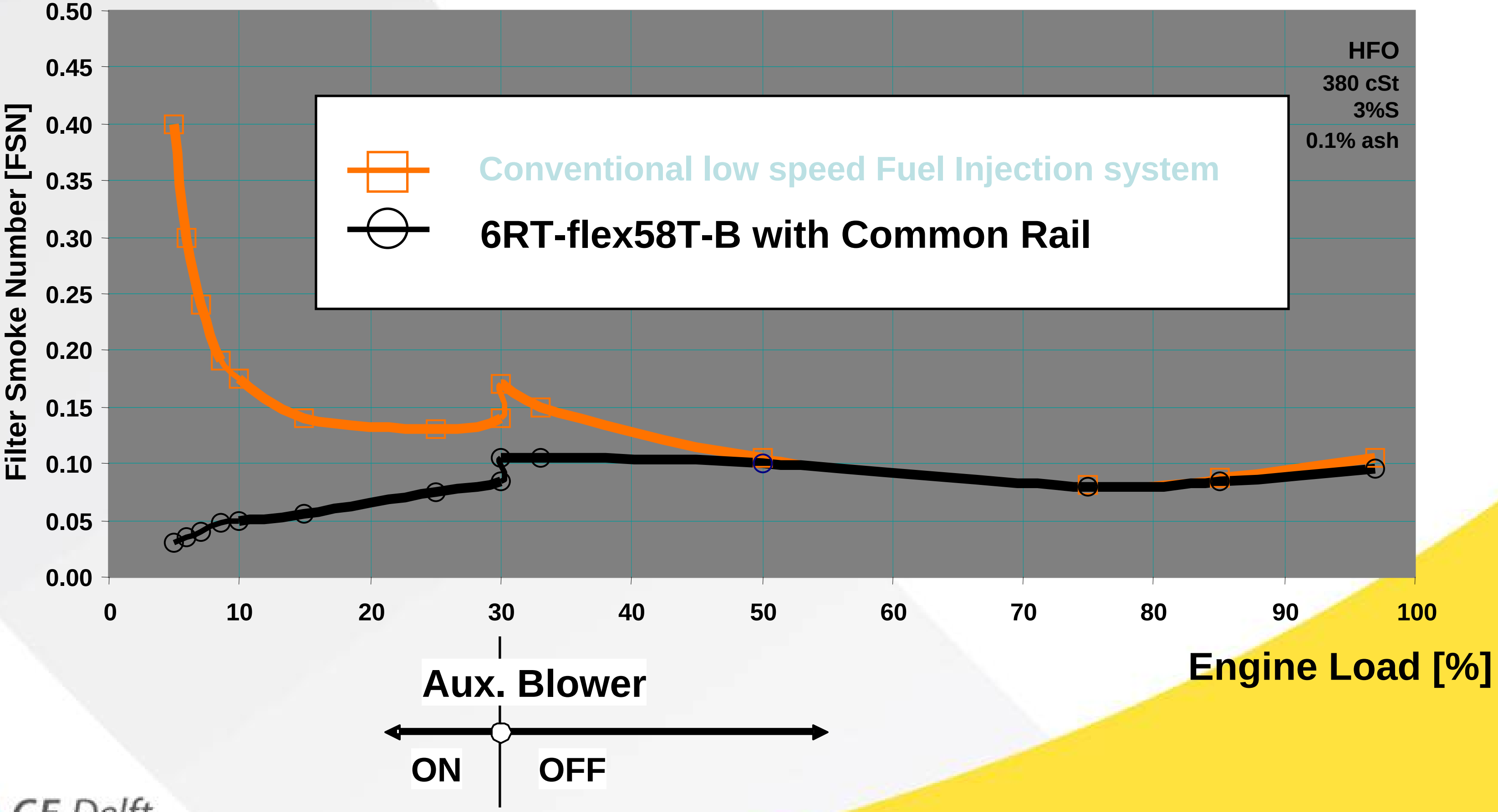


NOx	SOx	PM	Smoke
★★		★	★★★★

Common Rail, 2-stroke

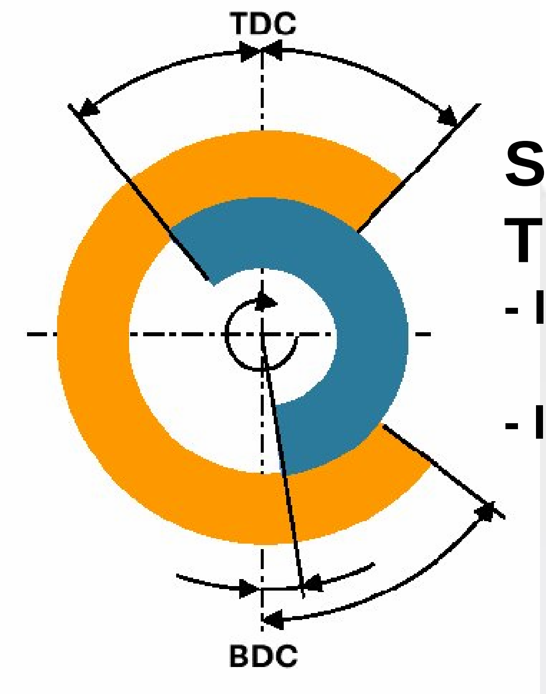
Near Smokeless operation throughout the load range

Sulzer 6 RT-flex58T-B M/V Gypsum Centennial



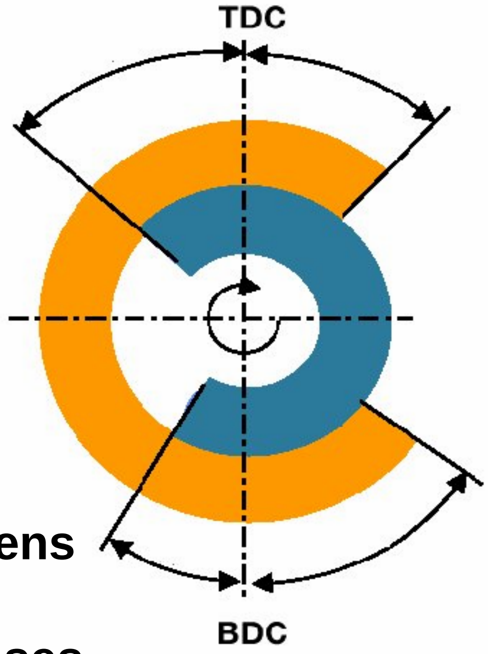
NOx	SOx	PM	Smoke
★		★	★★

et Valve Closing “VIC”



Standard Miller Timing

- Inlet Valve opens
  @ 35° bTDC
- Inlet Valve closes
  @ 16° ±1 bBDC



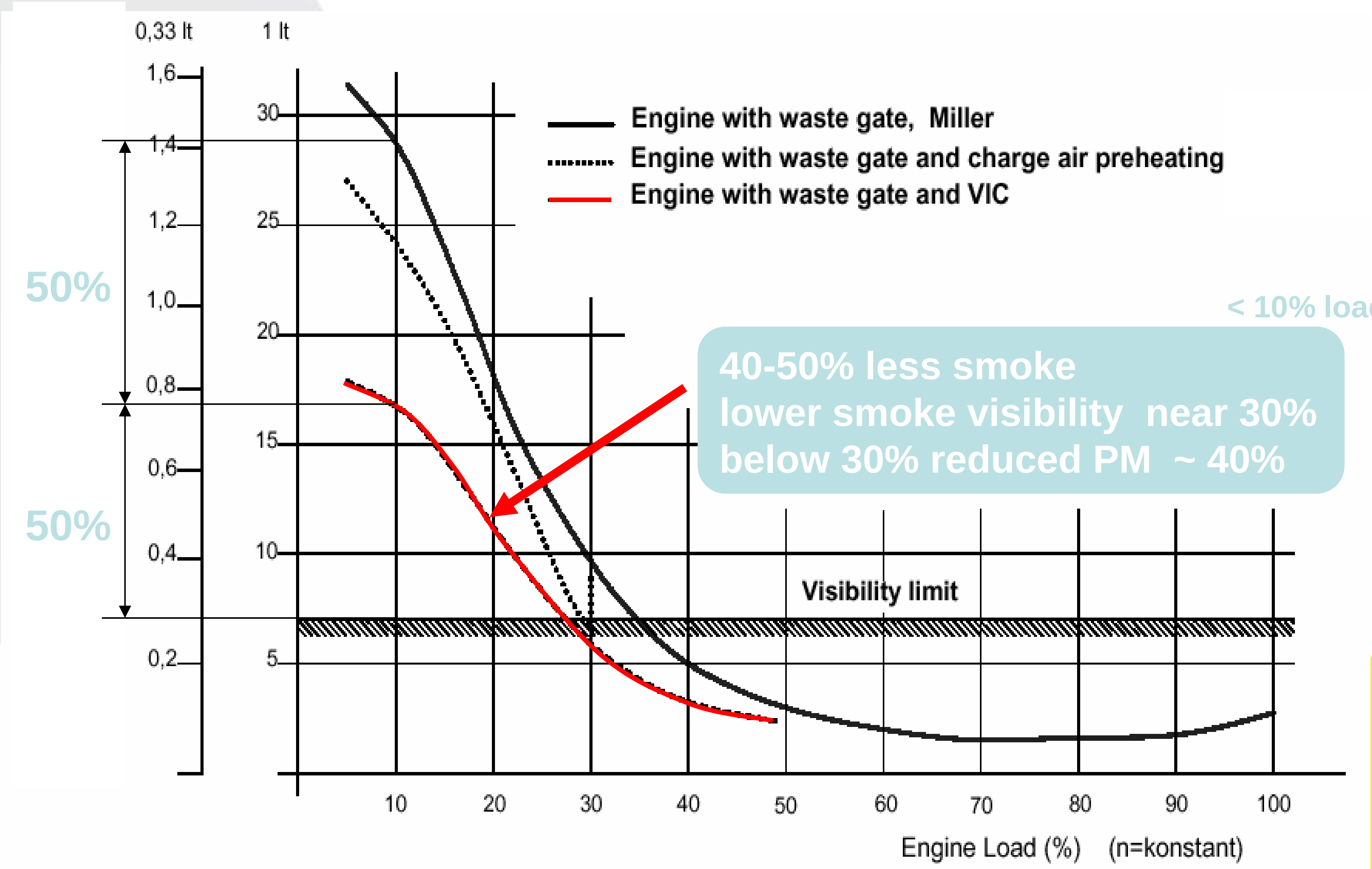
VIC Timing

- Inlet Valve opens
  @ 35° bTDC
- Inlet Valve closes
  @ 16° ±1 aBDC

Delay in Inlet Valve Closing → **Increase on air quantity & compression pressure** → **Better combustion process** = **LESS SMOKE**

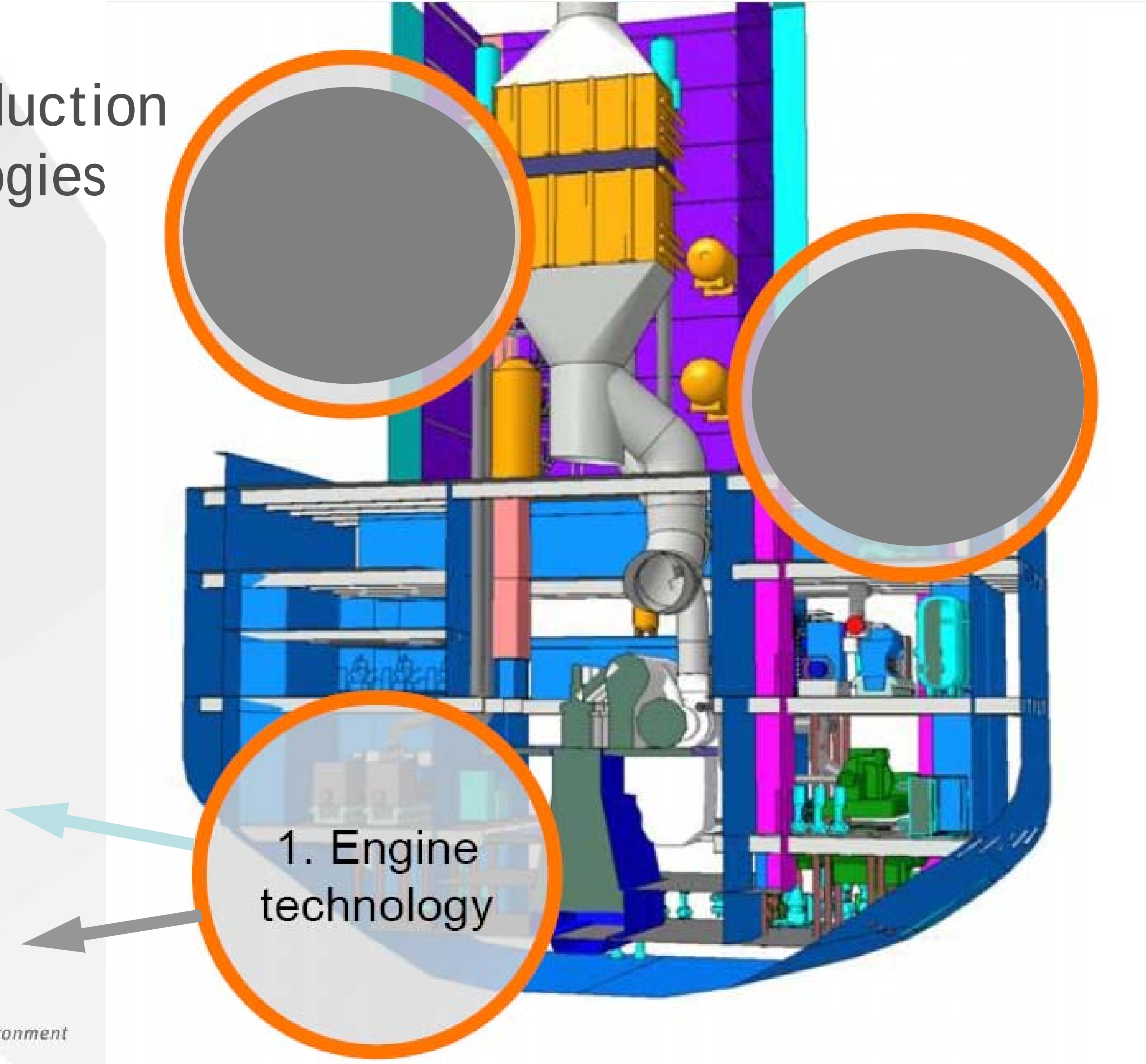
Delayed timing is actuated only below 50%load
Over 50% the system returns to standard Miller Timing

NOx	SOx	PM	Smoke
★		★	★★



40-50% less smoke
lower smoke visibility near 30%
below 30% reduced PM ~ 40%

- NOx reduction technologies



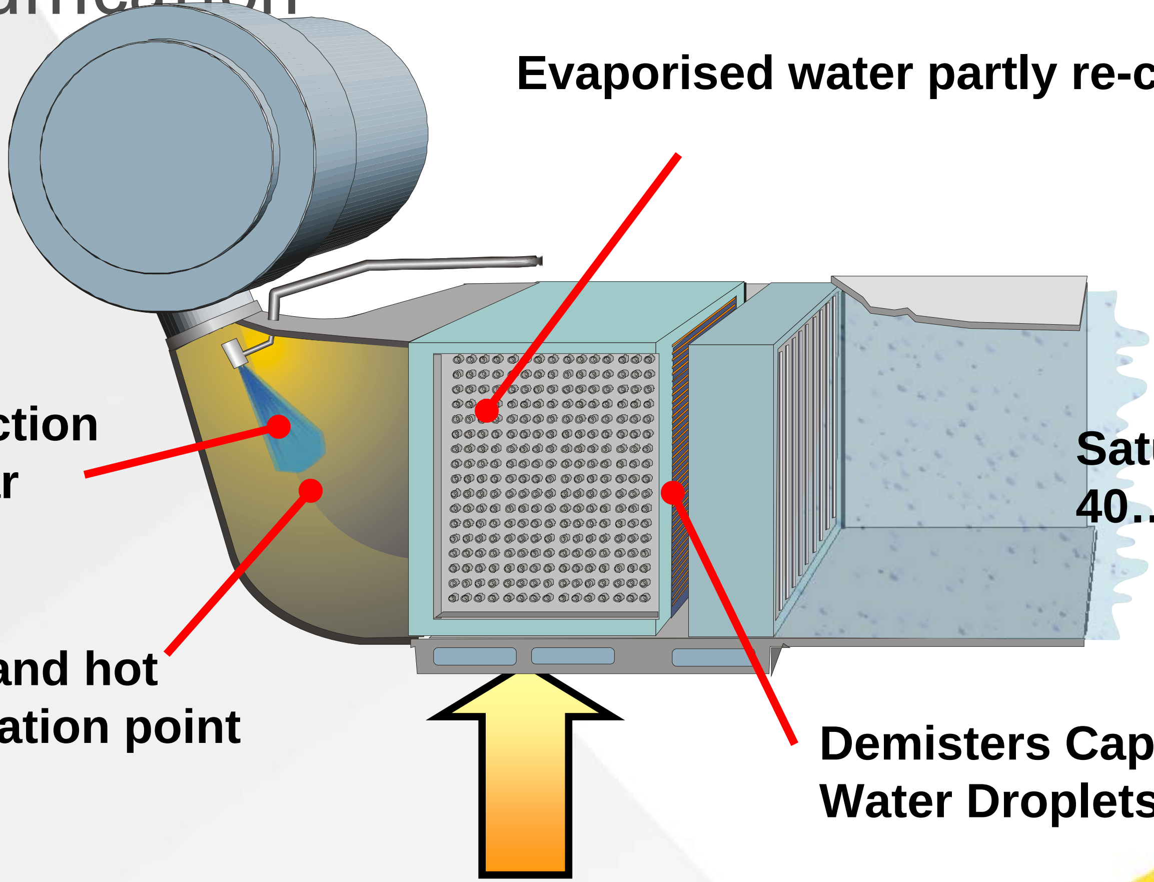
1. Engine technology

WET

DRY

NOx	SOx	PM	Smoke
★★★		★	

- Air Humidification



Compressor

Evaporised water partly re-condenses

Water injection
130-135 bar

Saturated air
40…70° C

Mist evaporates and hot
air cools to saturation point

Demisters Capture
Water Droplets

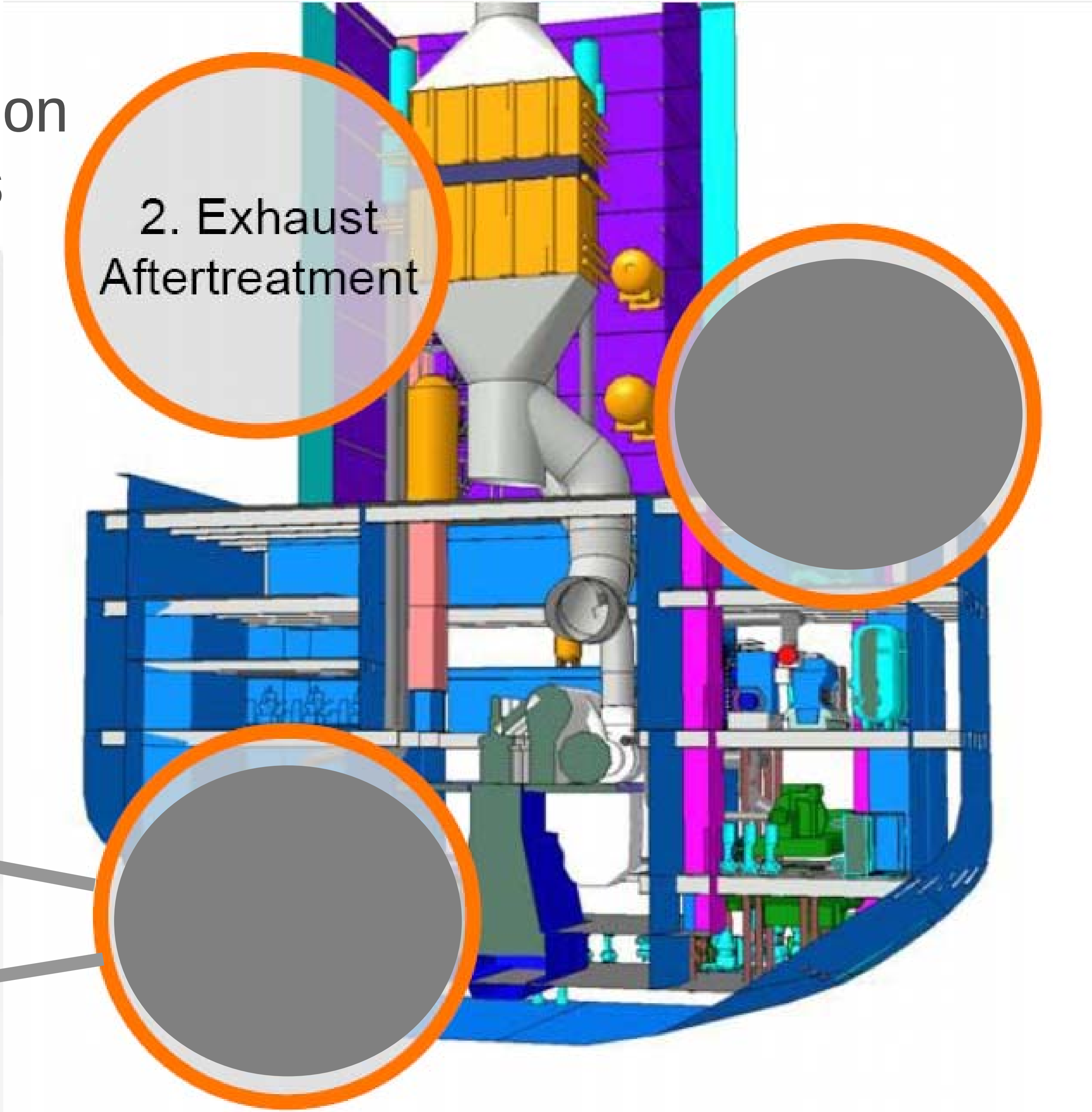
Re-condensing Extracts
Heat from Cooling Water

NOx	SOx	PM	Smoke
★★		★	

Combined Water Fuel Nozzle

- Direct Wa

- NOx reduction technologies



WET

DRY

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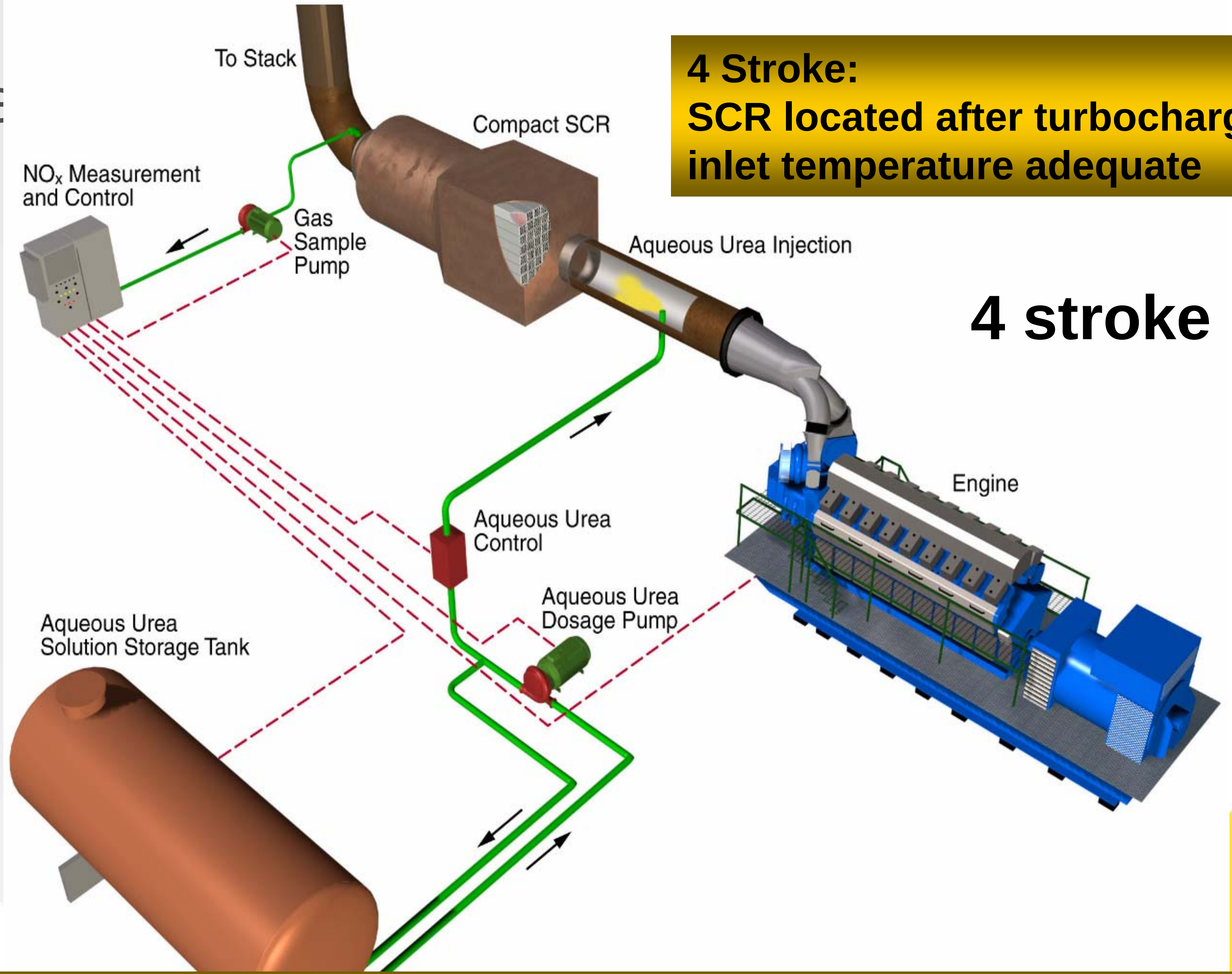
NOx	SOx	PM	Smoke
★★★★		★	

- Se



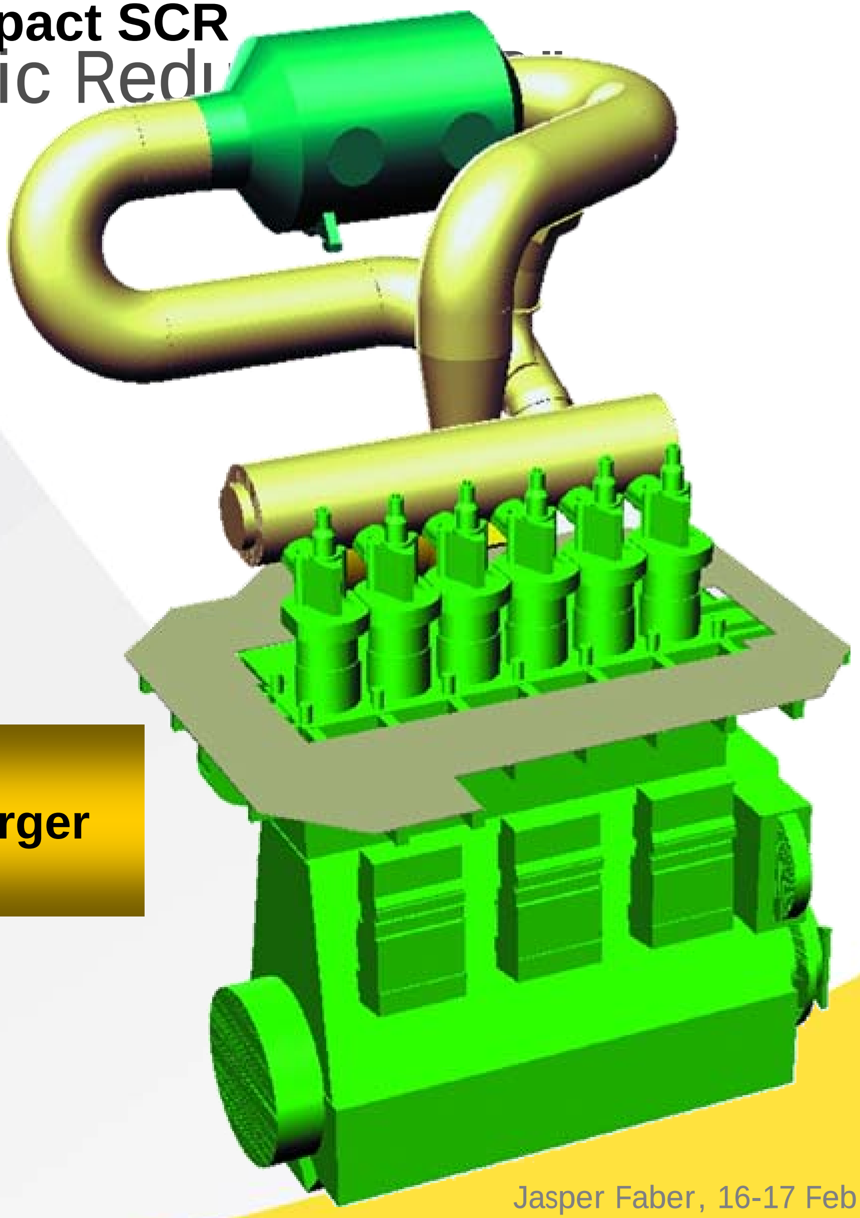
4 Stroke:
SCR located after turbocharger inlet temperature adequate

4 stroke

Agent deoxidizes NOx into nitrogen N2 + Water vapor H20

NOx	SOx	PM	Smoke
★★★★		★	

- Selective Catalytic Redu



Compact SCR

2 stroke

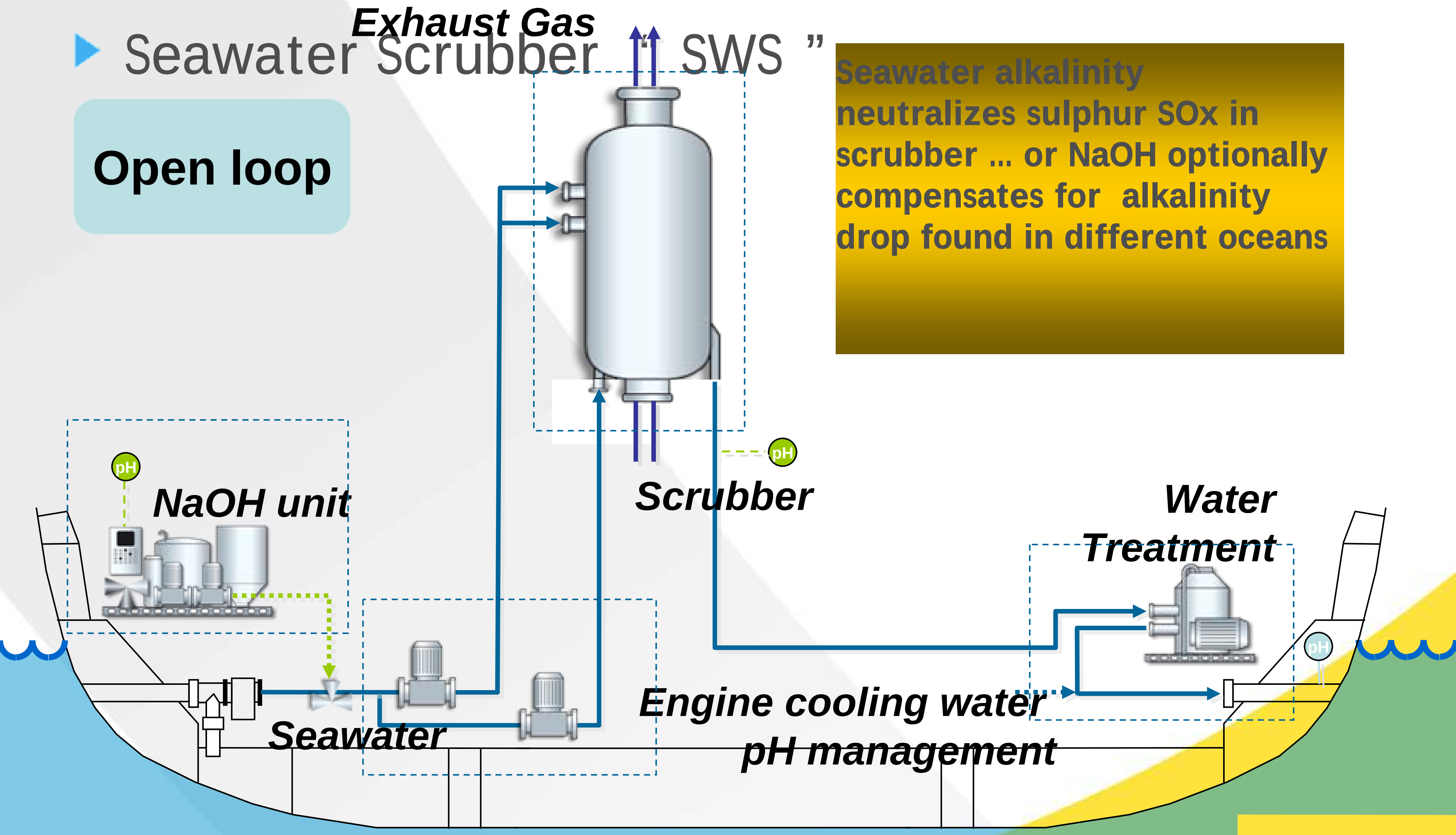
2 Stroke:
SCR located before turbocharger maintains inlet temperature

NOx	SOx	PM	Smoke
☆	☆☆☆☆	☆	

Seawater Scrubber “ SWS ”

Open loop

Seawater alkalinity neutralizes sulphur SOx in scrubber … or NaOH optionally compensates for alkalinity drop found in different oceans

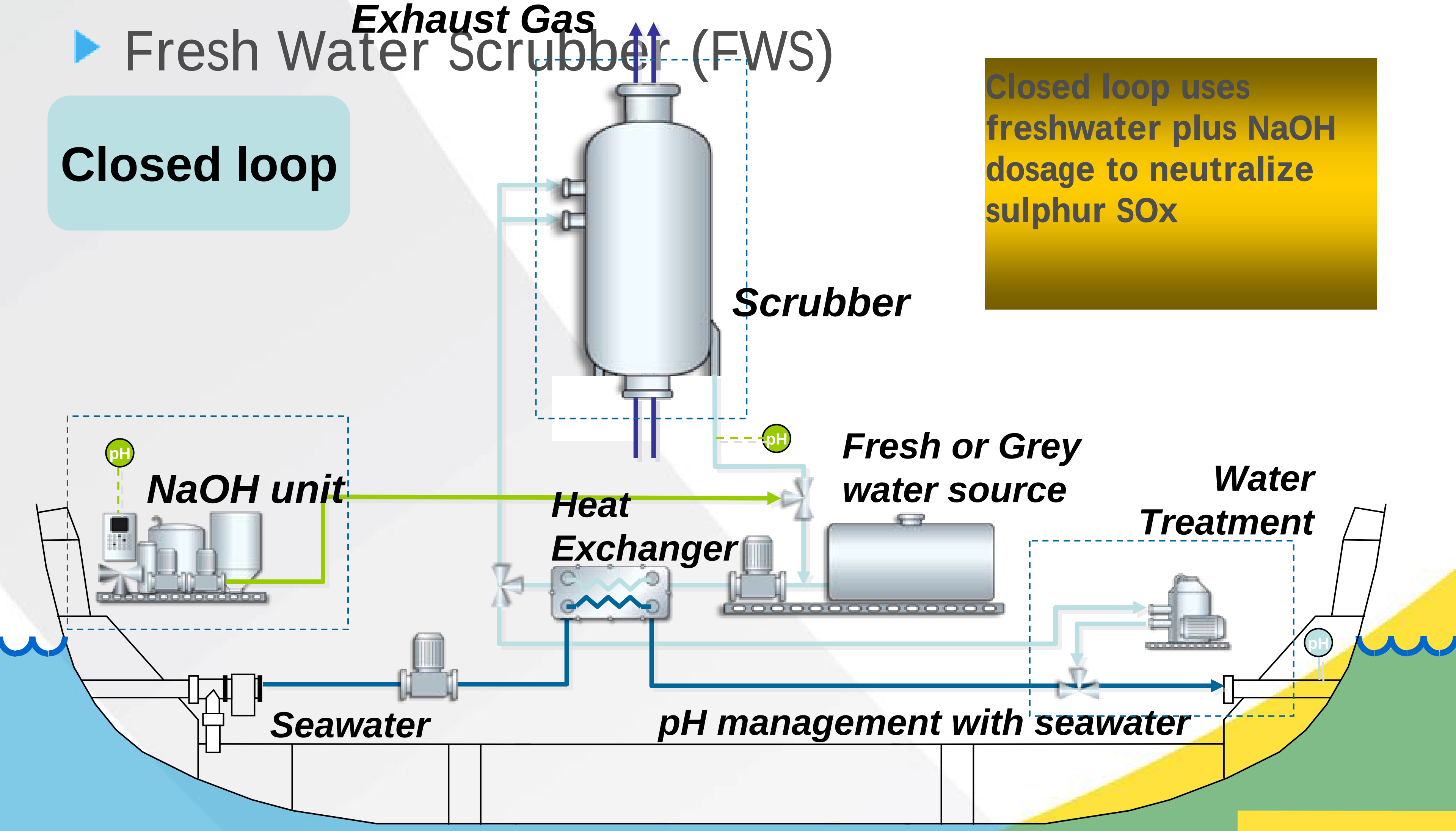


NOx	SOx	PM	Smoke
★	★★★★	★	

Fresh Water Scrubber (FWS)

Closed loop

Closed loop uses freshwater plus NaOH dosage to neutralize sulphur SOx



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Agenda

Current Legislation

Exhaust Components

Overview Formation, Reduction, Control Technologies

Leading Engine Technologies

- Primary Wet / Dry Means
- Secondary Wet / Dry Means

Case Example

Value Mapping Analysis

Summary

Emissions

Case Study Basis

4 Stroke Engine
Light Sulfur Fuel LSF
25 Year Life

Emissions Control Area ECA
Emissions IMO Tier 3

Crude oil = 90 $/bbl

Conservative may spike if ”crunch” between higher demand versus limited supply

HSFO = 485 USD / Mt €
≈ 350 € / Mt
Correlated to crude oil

LSF = 1.3 x HSFO price
(0.5% S) Correlated to HSFO

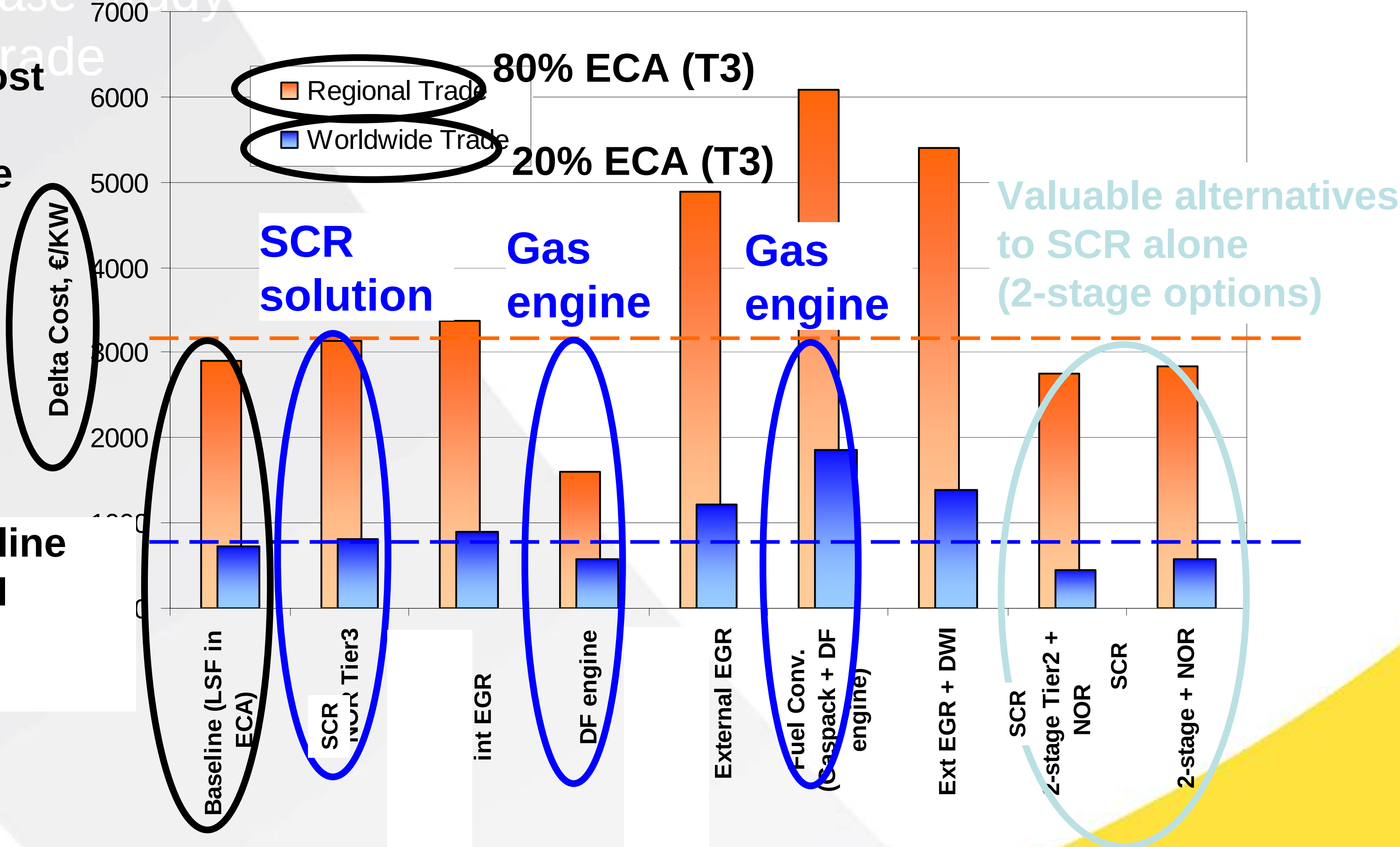
MGO = 1.8 x HSFO price
Correlated to HSFO

LNG = 1.4 x HSFO price Correlated to crude oil and HSFO

Baseline price multiple normalizes different energy content of fuels

Case Study Trade

Delta cost Tier II baseline



80% ECA (T3)

20% ECA (T3)

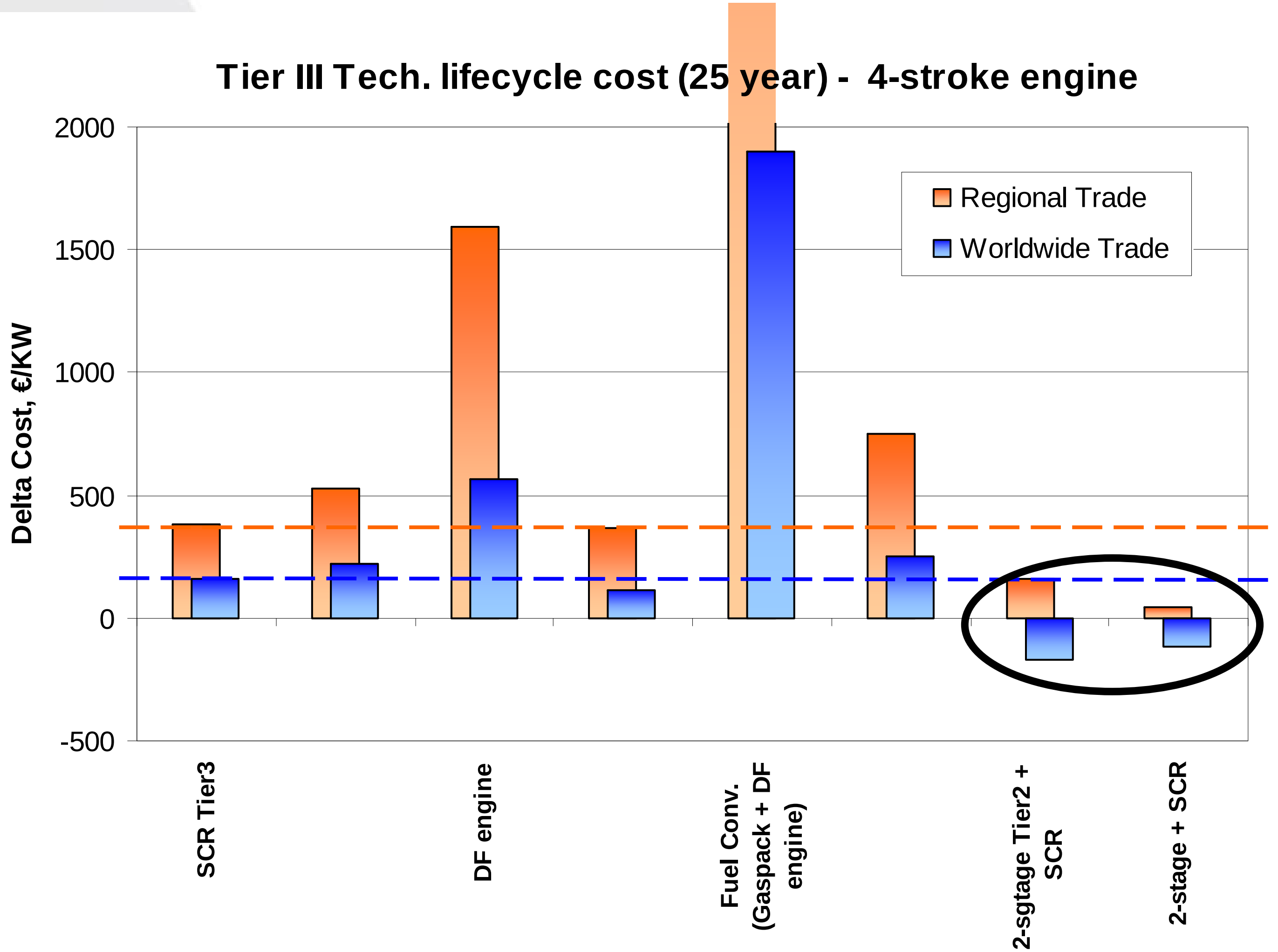
SCR solution

Gas engine

Gas engine

Valuable alternatives to SCR alone (2-stage options)

Baseline Tier II LSF ECA



Lifecycle cost estimation is very sensitive to fuel and urea market price scenario. No option at this stage can be easily dropped out

Agenda

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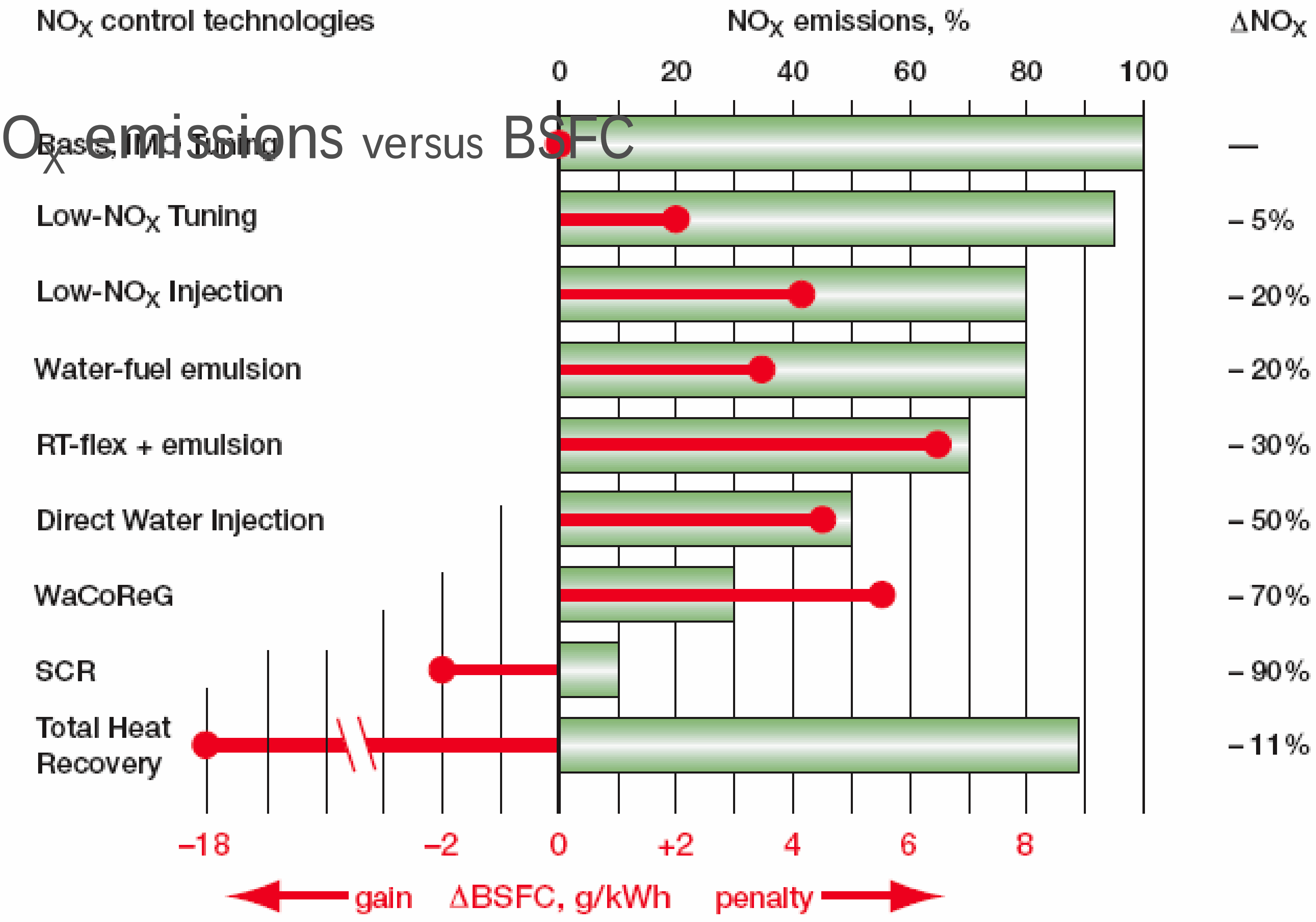
NO$_X$ emissions versus BSFC



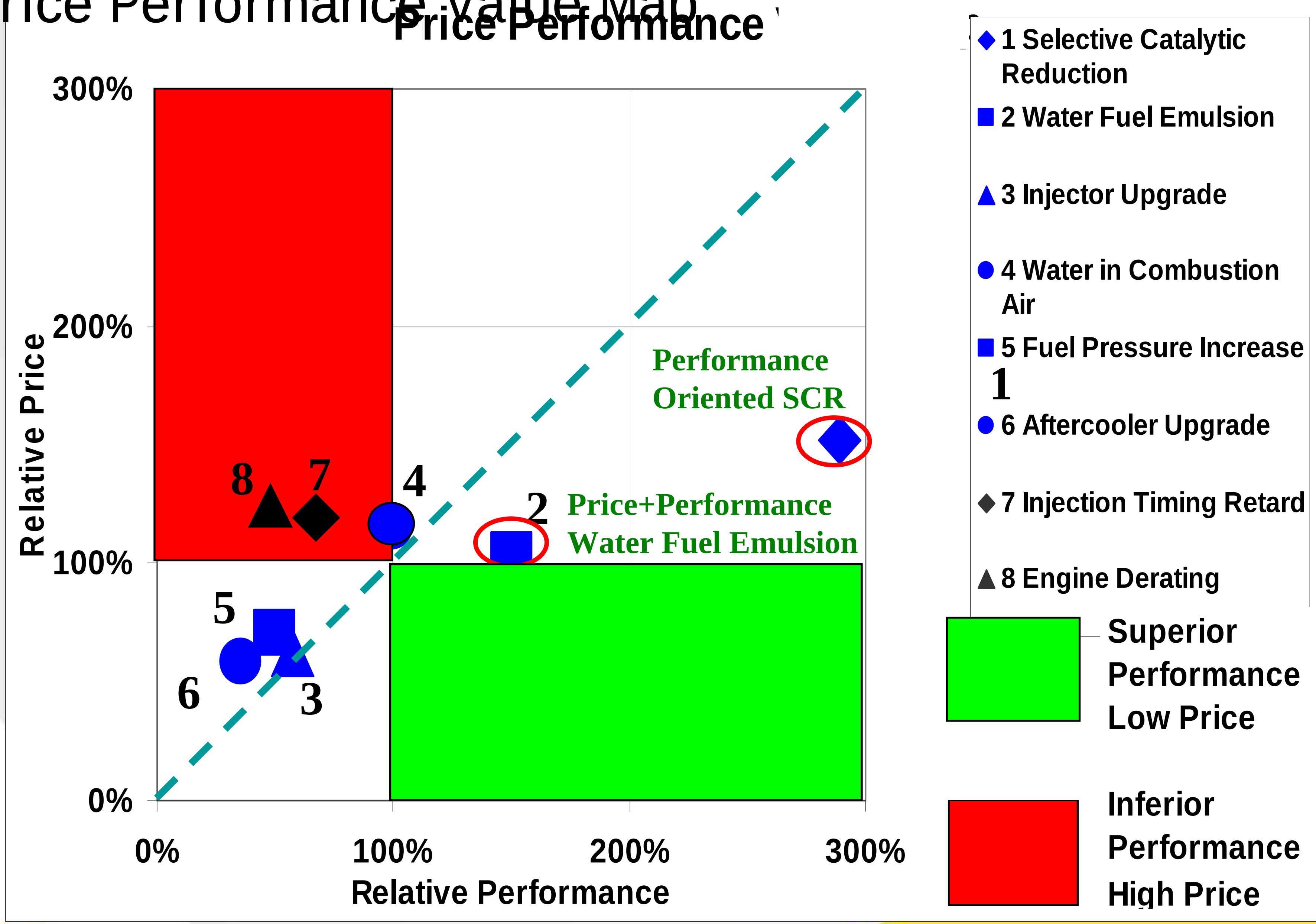
Many NO$_X$ reduction measures increase fuel consumption and particulates. Emissions optimization must balance several factors

EMISSIONS NET PRESENT VALUE

▶	Technology	% NOx Reduction	NPV CAPEX & Operating $
1	SCR	81	$477,000
2	Water Fuel Emulsion	42	$324,000
3	Injector Upgrade	16	$195,000
4	Water in Combustion Air	28	$364,000
5	Fuel Pressure Increase	14	$222,000
6	Aftercooler Upgrade	10	$185,000
7	Injection Timing Retard	19	$365,000
8	Engine Derating	14	$386,000

Spreadsheet Source: MARAD: Energy & Emissions Program, Daniel Gore, DEER Workshop August 26, 2002. NPV costs at 15% over 23 years.

Price Performance Value Map



SCR = Superior Price for Performance vs. Space and reductant complexity
Water Fuel Emulsion = Price + Performance: vs. Quantity water consumed.

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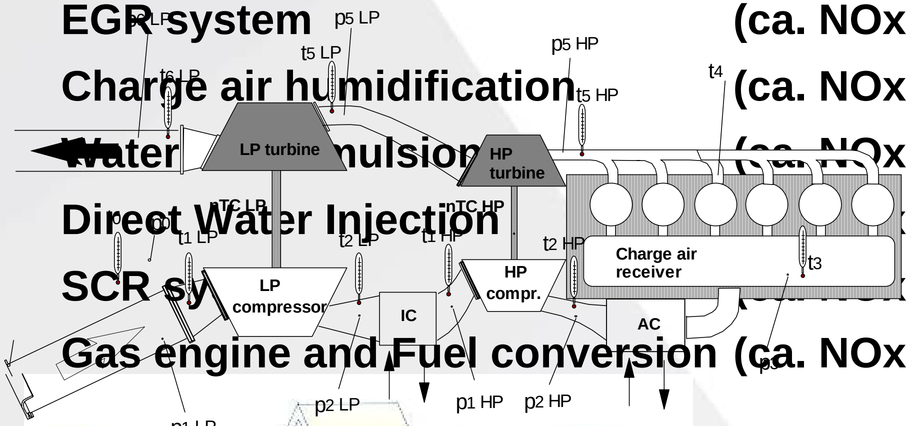
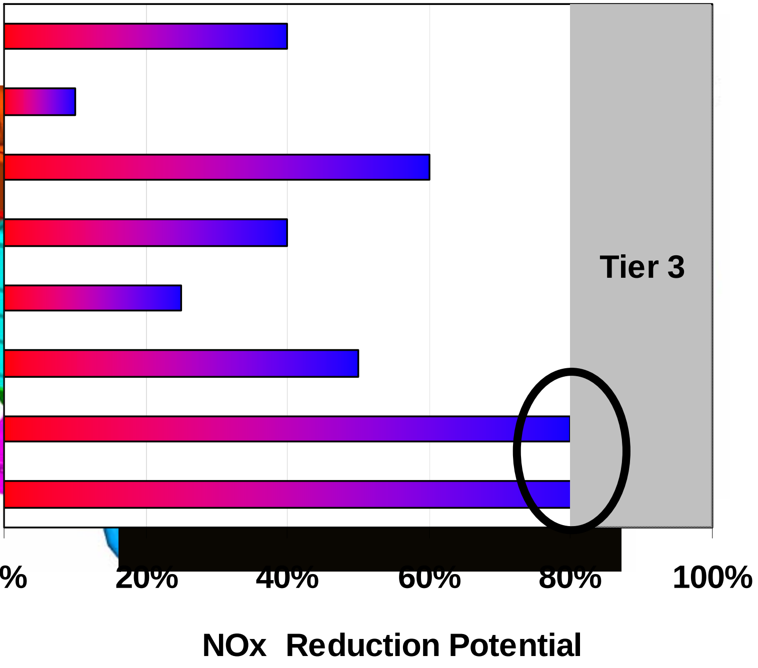
NOx reduc ies

- High pressure TC sys. (2-stage) (ca. NOx -40%)
- Low NOx combustion tuning (ca. NOx -
- EGR system (ca. NOx -
- Charge air humidification (ca. NOx -
- Water emulsion (ca. NOx -
- Direct Water Injection
- SCR sy
- Gas engine and Fuel conversion (ca. NOx -





Emissions Control Technologies

			NOx	SOx	PM	Smoke
primary	dry	Low NOx tuning	□□			
		VIC	□		□	□□
		Common Rail	□□		□	□□□□
	wet	WETPAC -H	□□□		□	
		WETPAC -DWI	□□□□		□	
		WETPAC -E	□□□		□	
secondary		SCR	□□□□		□	
		Scrubber	□	□□□□	□	□
		ESP	□		□□□	□
conv.		Switching to light fuel		□□□□	□	
		Conversion to gas	□□□	□□□□	□□□	□□

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☐ Upcoming IMO

Summary

3 principal control technologies

- ☐ **Engine technologies**
- ☐ **After treatment**
- ☐ **Fuels i.e. Gas**

☐ **Operation flexibility adapting to different emission areas will be a key future engine success**

☐ **Required fuel quality and quantity in ECA area will probably affect significantly lifecycle costs for operators, ushers in scrubber technology**

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Appendix

Comments

- Emission reduction regulations ultimate goal is to reduce Air Emissions, especially along sea shore where community leaves, but not to limit technologies to achieve the required levels.
- Regulating fuel isn’t a holistic approach as:
  - it will increase carbon foot print from land base production facilities and logistics chains
  - it only solves SO_X while having low or no effect on PM, and other harmful particulates
- Primary & Secondary technologies combination can achieve high emission reduction, also on non-regulated particulates, while minimising investment on land base infrastructure and having no negative impact on carbon foot print
- Emission trading, already in force for CO (Nordic countries) and NOX (US land base facilities) is an enabler with proven effect on global emission reduction.

Sources: SEAaT studies and
Lloyd’s Register Fairplay Event London 2005

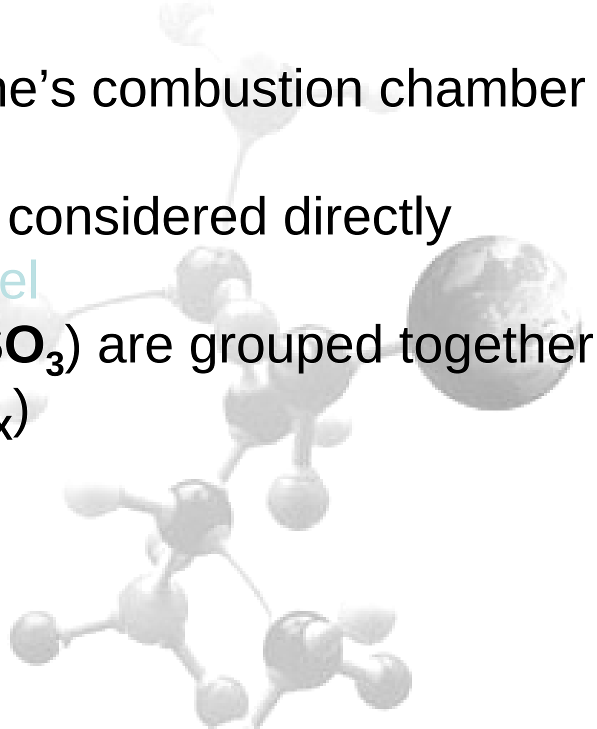
Nitrogen Oxides (NO$_X$)

- The formation of **NO$_X$** emissions in an engine is thermal; the primary source of nitrogen is the nitrogen in the combustion air
- The combustion temperature, the degree of fuel/air premixing and the duration of the fuel in the cylinder all strongly affect the formation of **NO$_X$**. It is highest with a high combustion temperature, low degree of premixing and long fuel duration
- **NO$_X$** formation in an engine is an extremely complex process comprising hundreds of different chemical reactions and many intermediate products
- The typical **NO/NO$_X$** ratio in a diesel engine's exhaust gases is 0.95
- The typical **NO$_2$/NO$_X$** ratio in a diesel engine's exhaust gases is 0.05
- After being released as exhaust into the atmosphere **NO** oxidizes into **NO$_2$** typically within a few hours.

Reducing Nitrogen Oxides (NO_x)

- Delayed fuel injection and ignition, which reduces the in-cylinder duration of the combustion gases at high temperatures
- In a diesel engine, lowering the fuel injection pressure reduces the formation of droplets and also the combustion efficiency and temperature
- Raising the degree of premixing, and in a gas engine increasing the amount of air
- Advancing the closing time of the inlet valve to lower the final combustion temperature (“Miller valve timing”)
- Reducing the temperature and pressure of the combustion air
- Optimizing the geometry of the combustion space
- Optimizing the compression ratio
- In a diesel engine, optimizing the fuel injection method
- Introducing water to the combustion space to reduce the temperature, e.g. using a water-fuel emulsion or saturating the intake air
- A Selective Catalytic Reduction (SCR) catalytic converter.

Sulphur Oxides (SO_X) and Reduction methods



Formation in engines

- The sulphur in the fuel oxidizes in the engine's combustion chamber into $\mathbf{SO_X}$.
- Hence, the emissions levels of $\mathbf{SO_X}$ can be considered directly proportional to the sulphur content of the fuel
- Sulphur oxide ($\mathbf{SO_2}$) and sulphur trioxide ($\mathbf{SO_3}$) are grouped together under the general term sulphur oxides ($\mathbf{SO_X}$)
- The typical ratio of $\mathbf{SO_2}$ to $\mathbf{SO_X}$ is 0.95
- The typical ratio of $\mathbf{SO_3}$ to $\mathbf{SO_X}$ is 0.05.

Emissions reduction methods in engines

- Using low-sulphur fuels, e.g. changing from heavy fuel oil with a high-sulphur content to low-sulphur heavy or light fuel oil.
- Secondary technology such as scrubbers
- Changing from fuel oil to natural gas.

Particulate Matters (PM) and Smoke

Particles form in the combustion space as a result of locally low quantities of excess air. Some of the particles do not have time to burn completely but pass out into the atmosphere in the exhaust gases.

The amount of particles in the exhaust depends on the amount of hydrocarbons in the fuel and lubricating oil and on the amount of sulphur and ash in the fuel.

- When using heavy fuel oil, typically more than 50% of particles in the exhaust come from the ash and sulphur components in the fuel
- When using light fuel oil, most of the particles consist of carbon or hydrocarbons and only a very small proportion comes from the ash and sulphur components in the fuel
- Particles smaller than about 0.4 μm are considered to be invisible. A proportion of the particles produced by an engine fall below this size.
- Gas engines have very low levels of particle emissions.

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Reducing Particulate Matters (PM) and Smoke

Primary technologies

- In diesel engines, raising the fuel injection pressure as this improves droplet formation and combustion efficiency
- Raising the temperature of the intake air
- Optimizing the geometry of the combustion space
- Optimizing the compression ratio, and the fuel injection method

Many measures taken to reduce particle emissions also tend to increase NO_X emissions.

High PM reduction with secondary technologies

Of the commercial technologies available today, only the electrostatic precipitator is suitable for diesel engine power plants but its investment costs are high.

Sometimes, in conjunction with desulphurization equipment, bag filters are used to reduce particle emissions.