TFTEI

Under the Convention on Long Range Transboundary Air Pollution

Technical work on shipping emissions (SO_2, NO_x, PM and BC)

TFTEI technical secretariat
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Ship Maneuvering out of Port
StLouis du Rhone, near Marseilles

TFTEI informal technical session
October 21, 2020

Summary of the presentation

- Objectives of the technical document
- Organisation of the work
- Evolution of maritime shipping and its emissions
- International legislation for abating SO_2 and NO_x
- Primary reduction measures :
  fuel switches, slow steaming, etc.
- Secondary reduction measures :
  SO_2 scrubbers, NO_x EGR and SCR and PM filters
- Conclusions and next steps

Summary of the presentation

- Objectives of the technical document

Objectives of the technical document

- Provide to the Parties of the UNECE Convention on the Long Range Transboundary Air Pollution (CLRTAP) guidance in identifying the best abatement options for shipping emission sources and assist them in meeting their obligations for SO_2, NO_x, PM and black carbon

- Emphasis given both on primary techniques (actions on fuel characteristics or combustion processes) and secondary ones (exhaust gas treatments)

- Cost estimation review for each presented techniques

- In this draft, main focus on maritime shipping emissions

Summary of the presentation

- Objectives of the technical document
- Organisation of the work

Organisation of the work

- A first draft of technical document developed by the technical secretariat (September 2020)
- A drafting group set up
- A first meeting with the drafting group on October 1st
- A second meeting scheduled on November 9th to finalize the report for early December
- It was agreed during the first meeting to focus on shipping emissions from maritime traffic and inland waterway navigation
- Other sources will be covered in 2021 for the review of annex VIII

Composition of the drafting group

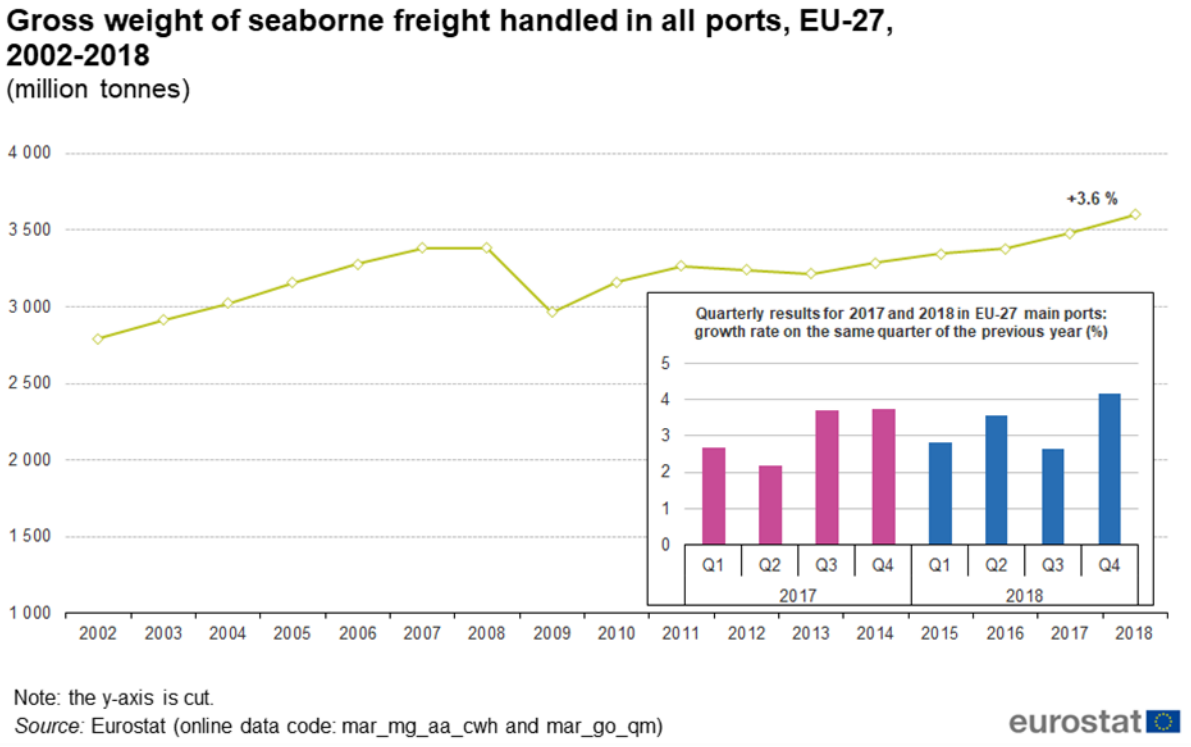
- Tiziano PIGNATELLI, co-chair of TFTEI,
- Christer AGREN, Airclim,
- Thomas BAUER, Solvay,
- Clea HENRICHSEN, Ministry of Environment and Food of Denmark (+ IMO),
- Heikki KORPI, Wartsila,
- Ralf OLDENBURG, MAN Energy Solutions SE,
- Peter SCHERM, Euromot,
- Jens BORKEN-KLEEFELD, IIASA,
- Christian LANGE FOGH, Ministry of Environment and Food of Denmark,
- Peter MEULEPAS, Flemish Government,
- John MURLIS, EFCA

Summary of the presentation

- Objectives of the technical document
- Organisation of the work
- Evolution of maritime shipping and its emissions

Evolution of international shipping transport

- International shipping transport: ~ 80% of world trade volumes
- Intensifying activities: +3.6% in 2018, higher than pre-crisis levels of 2009
- Growing fuel consumptions: from 217 Mt in 2004 to 300 Mt in 2012



Emissions of pollutants from maritime shipping

- Emissions of pollutants and GHG due to fuel combustion
- About 2.6% of world CO_2 anthropogenic emissions
- ~ 60,000 yearly premature deaths near EU and Asia coastlines due to PM from ships

- Significant contributions observed in Europe:

Pollutant	Contribution to total emissions [%]
SO_2	0-80
NOx	0-30
NMVOC	0-5
CO	0-18
NH_3	-
TSP*	0-3
PM_{10}*	0-4
$PM_{2.5}$*	0-5

Note
* = values from EMEP (http://webdab.emep.int/) which correspond to official emissions for 2004, from country submissions in 2006.
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions reported

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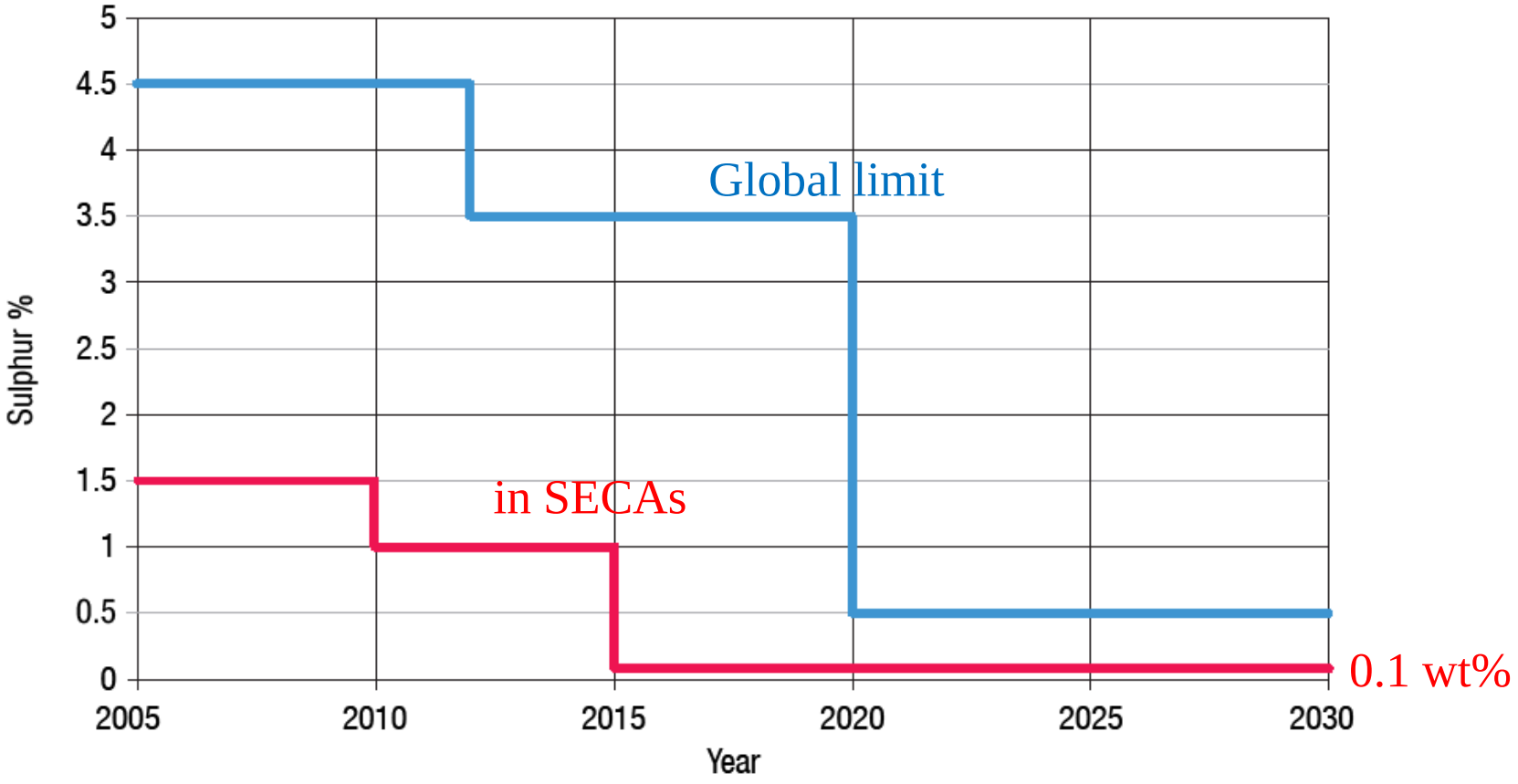
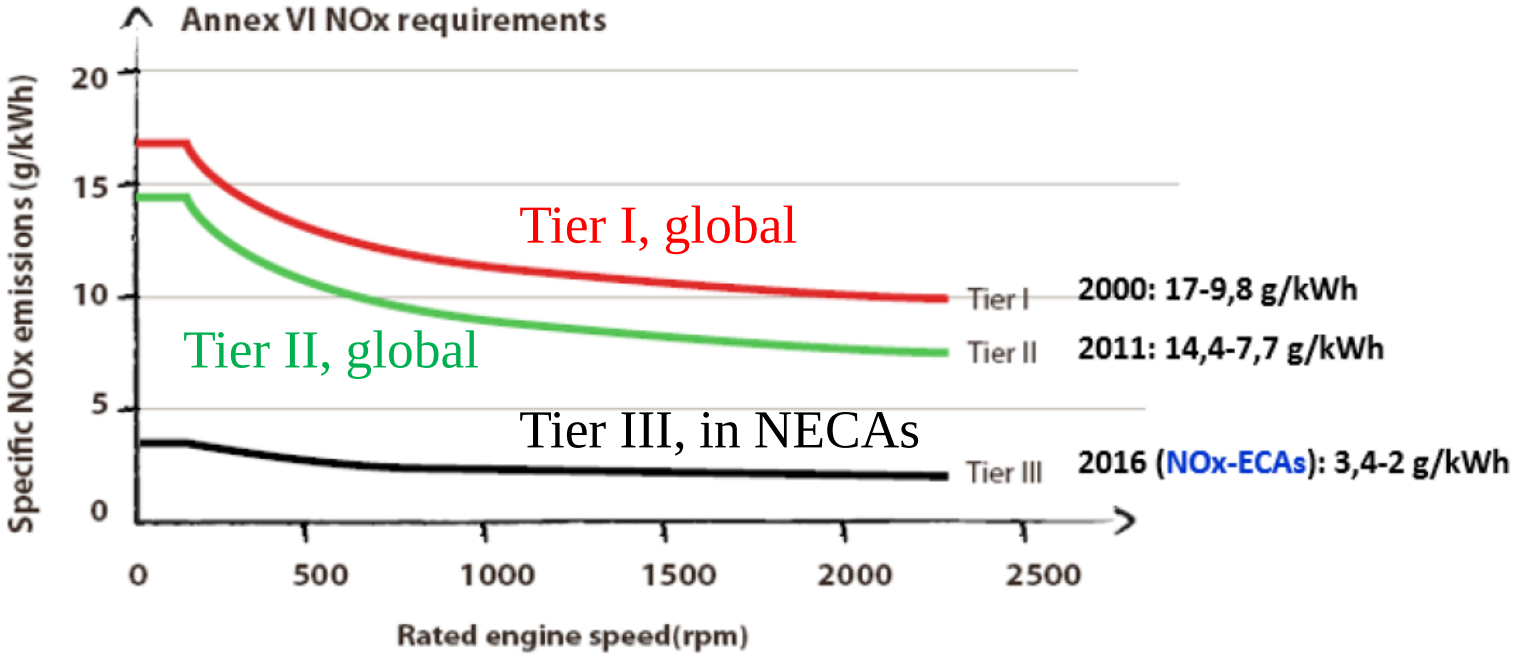
Fuel sulphur content limits (in wt%) according to Marpol Convention Annex VI



NO_x: Marpol Convention annex VI requirements

- ✓ **Tier I limits to be met globally** by all ships from January 1st, 2000
- ✓ **Tier II limits to be met globally** by all ships constructed after January 1st, 2011
- ✓ **Tier III limits to be met in NO_x Emission Control Areas** (NECA)
  - North America NECA: from January 1st, 2016
  - Baltic Sea, North Sea and English Channel from January 1st, 2021



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- Primary reduction measures :
  fuel switches, slow steaming, etc.

Primary reduction measures: switch to low sulphur fuels

- SO_2 emissions directly proportional to sulphur content of fuels
- HFO* at 3.5 wt% → MDO* at 0.5 wt% : reductions of SO_2 by 86%
  → MGO* at 0.1 wt% : reductions of SO_2 by 97%
- Reduction of TSP/PM emissions from 60% to 90% for distillate fuel use
  ➔ BC emission reductions from 0% to 80% (medium at 30%)
- HFO* at 2.7 wt% → MDO* at 0.5 wt% : TSP reductions by 68% [1]
  → MGO* at 0.1 wt% : TSP reductions by 78% [1]
- Simple and no investments related to the engine required, only the fuel price change

*HFO: heavy fuel oil ; MDO: marine diesel oil ; MGO: marine gas oil

[1]: Ineris - Citepa "ECAMED" (2019)

Primary reduction measures: switch to LNG

- In 2015, about 2.4% of the marine shipping consumption was LNG
- Very low sulphur content: SO_2 emissions almost negligible - reductions by 90-100%
- Other important pollutant reductions:
  - 90% for NO_x
  - 98% for PM
  - 75-90% for BC
- Limitations about additional space required (+3% TEU*) + CH_4 emission increase
- Significant investments related to engine, storage, piping, etc. but savings on operational costs due to lower fuel price

* TEU: twenty-foot equivalent unit

Primary reduction measures: switch to water-in-fuel emulsions (WiFE)

- Mixture of water, emulsifiers and fuel oil (HFO or diesel)
- Lower combustion temperatures → lower NO_x formation (-1% per % added water)
- NO_x emission reductions achievable up to 50-60%
- Other reductions achievable: up to 20-90% for PM, up to 45-85% for BC
- Limits for retrofits for maintaining same power level while running injection system
- Investments related to installation, maintenance and fuel penalty (~1-2%)

Primary reduction measures: switch to biofuels or methanol

- **Biofuels:** PM reduced by 12-37% ; BC by 38-75% compared with HFO
- CO_2 reductions, but higher fuel consumption : 8-11% lower energy content

- **Methanol or DME:** 95-100% CO_2 reductions if made from biomass, none if made from natural gas
- no sulphur (no more SO_2) ; other reductions: 35-55% NO_x, 99% in PM compared with diesel but 9% drop in fuel efficiency
- Poor information about investments, higher fuel prices even for methanol from NG
- Limitations of cost and availability for biofuels and methanol made from biomass

Primary reduction measures: slow steaming

- Reducing the sailing speed to achieve fuel savings (up to 50%)

- Environmental benefits, reductions by:
  - 13-50% SO_2,
  - 21-64% NO_x,
  - 18-69% PM and 0-30% BC
  - CO_2 reductions, proportional to fuel savings
  - but, potential negative impacts on CO at lower load factors

- Limits about delivery efficiency (eventual increased ship fleet required, e.g. about 33% more ships for a 25% speed reduction)

- Investments for engine tuning but savings related to lower fuel consumption

Summary of primary measures

Reduction techniques :	SO_2	NO_x	PM	BC	fuel penalty	Investments costs (€/kW)	Operation & maintenance costs
Primary measures:							
- Switch to low sulphur fuels	up to 97%[1]	-	60-90%	30-80%	-	-	88-223 €/t fuel
- Switch to LNG	90-100%	90%	98%	75-90%	- 5-10%	219-1603	- 43 €/t fuel (+ fuel savings)
- Switch to water-in-fuel emulsions	-	1-60%	20-90%	up to 85%	+ 0-2%	11-44	33-271 k€/year[5]
- Switch to biodiesel and biofuels	-	-	12-37%	38-75%	+ 8-11%	-	-
- Switch to methanol	100%[3]	55%	99%	97%[2]	+ 9%	-	10-15 €/MWh
- Slow steaming	13-50[4]%	21-64%	18-69%	0-30%	- 15-50%	71	- 42-77% (fuel savings)[6]

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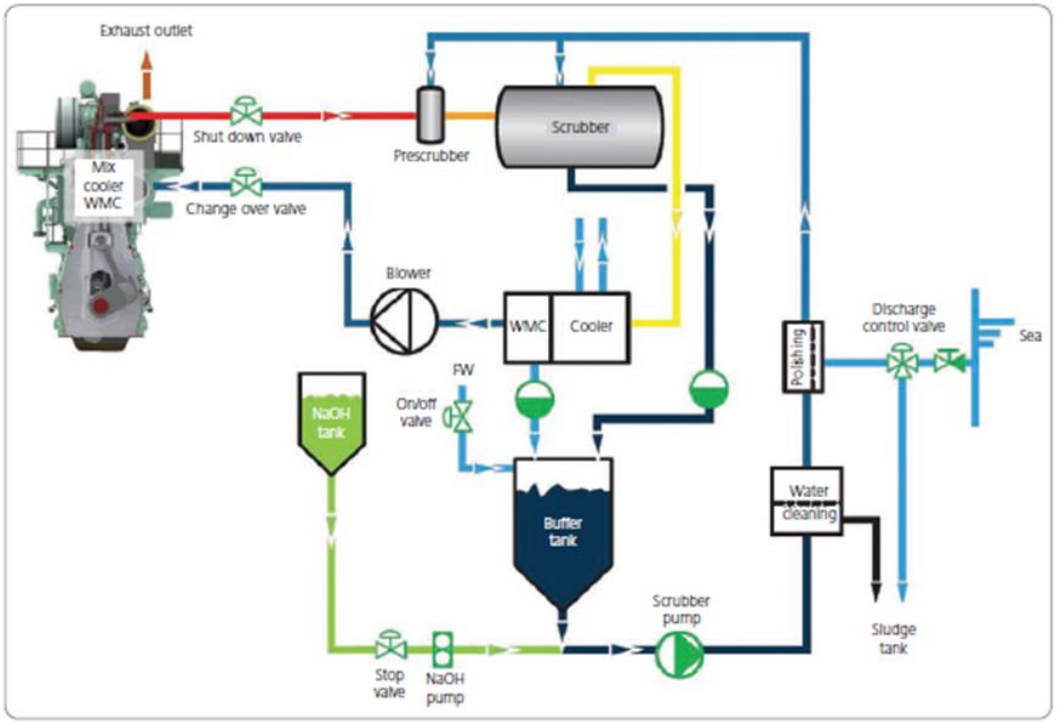
Secondary reduction measures: EGR

- Recirculation of exhaust gases into the combustion chamber: decrease combustion temperature, pressure and oxygen content → lower NO_x formation
- Exhaust gases need to be cleaned to prevent corrosion (coupled w/ DPF or scrubber) and water neutralized with NaOH solution
- Pollutant reductions : 25-80% NO_x, 0-20% BC and PM due to gas cleaning



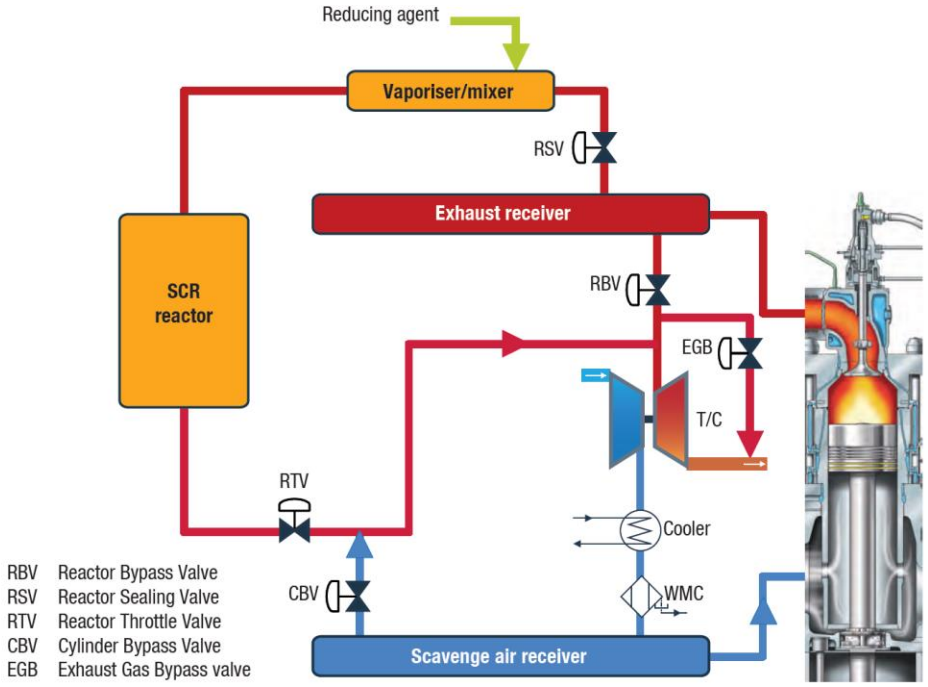
EGR for 2-stroke engine

Source: Lloyd's Register (2012). Understanding exhaust gas treatment systems.

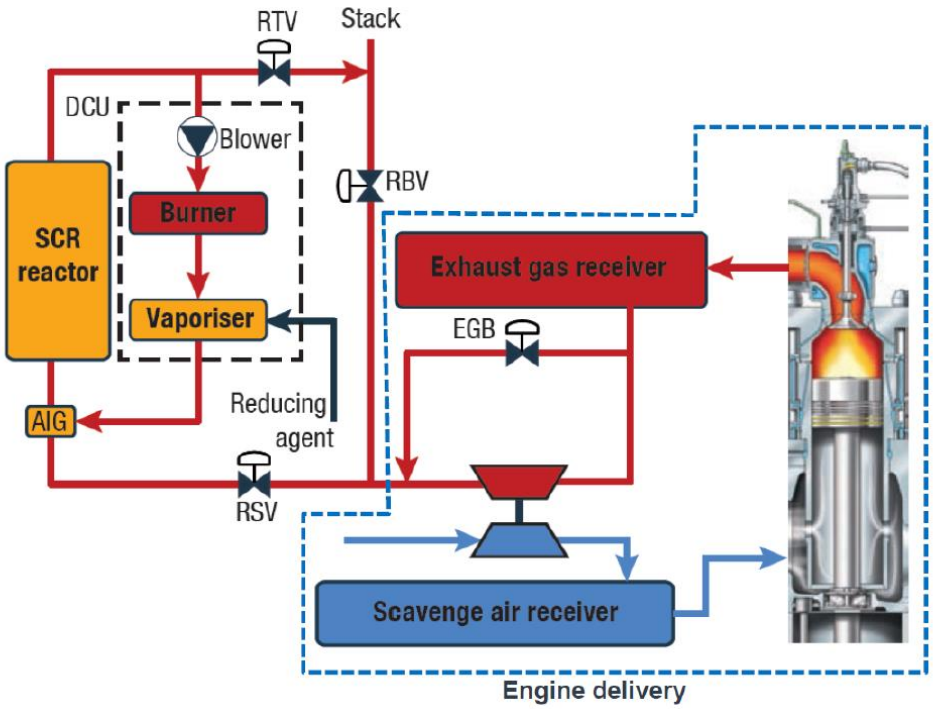
Secondary reduction measures: SCR

- Chemical reaction with ammonia solution or urea (NH_3) to neutralize NO_x and form N_2 and H_2O

High pressure



Low pressure



Source: Man 2018 – NOx reduction – Tier III solutions

Secondary reduction measures: SCR

- Advantage : can be retrofitted on existing engines and switched off while cruising outside NECAs

- Risk of ammonia solution leakage
  + risk of ammonium bisulfate formation at low T° (> 300°C w/ HFO)

- Pollutant reductions :
  - 70-95% NO_x,
  - BC emissions to some extent,
  - but, risk of NH_3 emission increase

  if an oxidation catalyst is present, potential reductions of :
  - 20-40% for PM,
  - 50-90% for CO and VOC,

  suitable with fuels with low sulphur content only.

Secondary reduction measures: Diesel particulate filters (DPFs)

- Porous ceramic substrate to trap particles
- Particle burning or oxidation at appropriate T° to clear it (i.e. maintain efficiency)
- Important reductions:
  - 45-92% for PM,
  - 70-90% for BC
  - 60-90% for VOC and CO when oxidation catalyst present but suitable with fuels with low sulphur content only.
- Limits: - fuel with max. 0.5 wt% S required
  - possible fuel penalty of 1-4%
  - mostly short-term tests, doubts of efficiency on long term

Secondary reduction measures: scrubbers

- Chemical reaction with alkaline solution to neutralize SO_2
- Two types: dry or wet, and three configurations for wet types: open-loop, closed-loop or hybrid
- Dry scrubber: absorber unit brings exhaust gas with solid alkaline agent
- Wet scrubber: use of seawater or freshwater with added alkaline chemicals
- Dry scrubbers do not require washwater treatment systems
  → savings in power consumption (0.15-0.2%) compared with wet systems
- However, additional operational costs for dry scrubbers for waste management
- Similar reduction rates achieved: 90-98% for SO_2, up to 70-90% for PM and up to 25-70% for BC
- Fuel penalties of about 0.5-3%

Secondary reduction measures: scrubbers

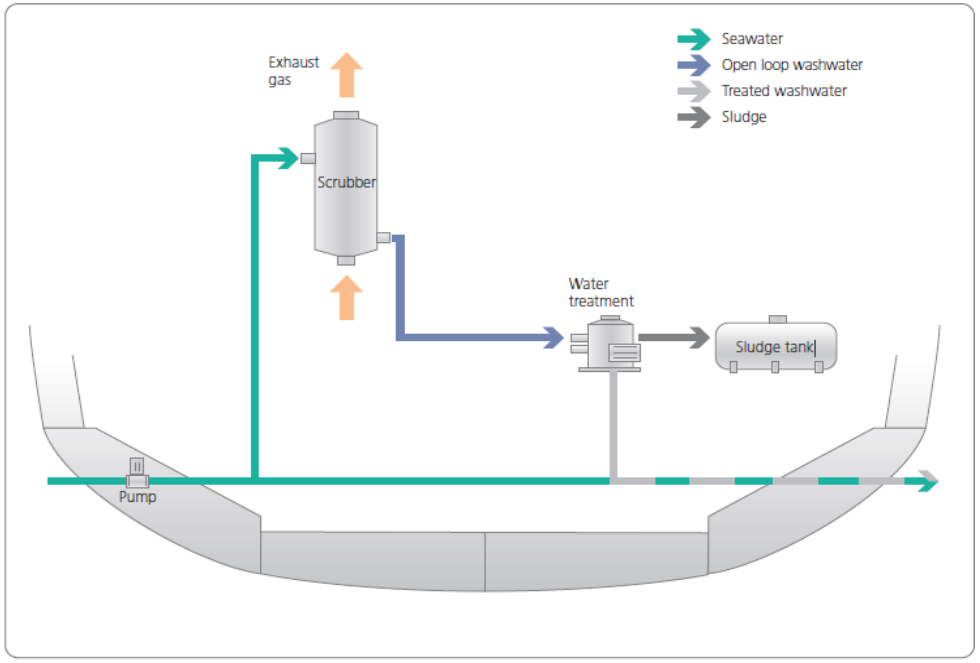
Open-loop scrubber:

Use of seawater, SO_2 removed by alkalinity of sea water to form sulphuric acid

Specially meant for seagoing ships as freshwater directly available

Efficiency decrease with higher seawater T°, requiring specific dispositions to keep it constant

Limit: discharge of washwater sometimes impossible in some areas



Source: Lloyd's Register (2012). Understanding exhaust gas treatment systems.

Secondary reduction techniques: scrubbers

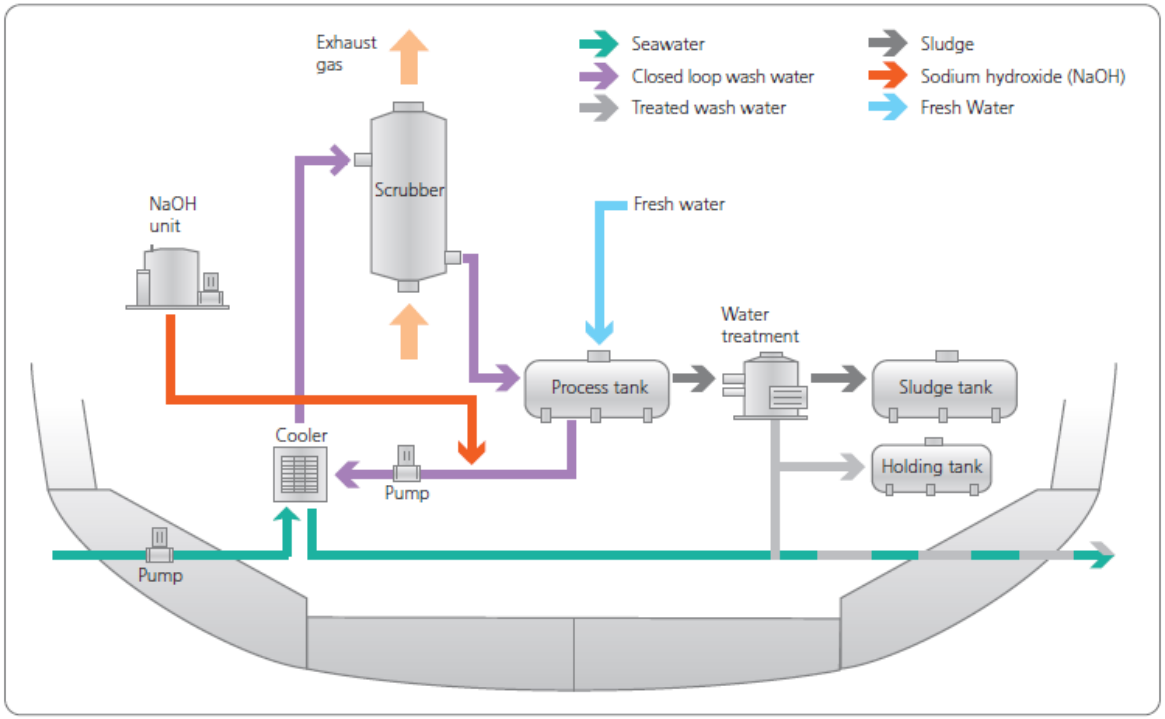
Closed-loop:

Fresh water used with caustic soda (NaOH) to form sodium sulphates

Washwater recycled after treatment in the scrubber

Average power consumption of 0.5-1% of the engine power

Useful in areas with low alkalinity seawater or if washwater discharge is not allowed



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Summary of results and conclusions

Reduction techniques :	SO_2	NO_x	PM	BC	fuel penalty	Investments costs (€/kW)	Operation & maintenance costs
Primary measures:							
- Switch to low sulphur fuels	up to 97%[1]	-	60-90%	30-80%	-	-	88-223 €/t fuel
- Switch to LNG	90-100%	90%	98%	75-90%	- 5-10%	219-1603	- 43 €/t fuel (+ fuel savings)
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- Switch to methanol	100%[3]	55%	99%	97%[2]	+ 9%	-	10-15 €/MWh
- Slow steaming	13-50[4]%	21-64%	18-69%	0-30%	- 15-50%	71	- 42-77% (fuel savings)[6]
Secondary measures:							
- Exhaust Gas Recirculation (EGR)	-	25-80%	-	0-20%	+ 1-2%	36-60	17-25€/kW
- Selective Catalytic Reduction (SCR)	-	70-95%	20-40%	-	-	19-100	3-10 €/MWh
- PM filters	-	-	45-92%	70-90%	+ 1-2%	16-130	+1-4% fuel penalties
- Scrubbers	90-98%	-	70-90%	25-70%	+ 0.5-3%	100-433	0,7[7]-12 €/MWh (~2% of capital investments)

Next steps

- Add information about reduction measures and their costs for ships at berth
- Include inland waterway navigation
- Take into account comments and information from the drafting group
- Another meeting scheduled early November with drafting group to finalize the report for early December
- The next year: another document for other water-borne navigation means (e.g. recreational crafts and others)

Main feedbacks/comments from drafting group

- Supplementary technical information about reduction techniques and their practical implementation
  + evaluation of the representativeness of the reduction efficiencies and costs,
- Comments on particular technical issues
- Providing of a recent report EMERGE (July 2020) with recent technical and cost data
- Include new technology similar to dry scrubber already tested on a pilot project,
- Include information on new fuel/propulsion systems (e.g., battery-electric, fuel-cell, hydrogen, ammonia, modern wind-propulsion),
- Add information about potential environmental impacts of scrubber washwater.

Thank you very much
for your attention!
Questions?

TFTEI Technical Secretariat

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DE LA TRANSITION
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Shipping sources covered by emission inventories (EMEP/EEA guidebook 2019)

1.A.3.d Water-borne navigation :

- Emissions from fuels used to propel water-borne vessels, including hovercraft and hydrofoils, but excluding fishing vessels.
- The international/domestic split should be determined on the basis of port of departure and port of arrival, and not by the flag or nationality of the ship

1.A.3.d.i International water-borne navigation (International bunkers) :

- Emissions from fuels used by vessels of all flags that are engaged in international water-borne navigation.
- The international navigation may take place at sea, on inland lakes and waterways and in coastal waters.
- Includes emissions from journeys that depart in one country and arrive in a different country.
- Excludes consumption by fishing vessels (see 1.A.4.c.iii - Fishing).

Definition of the different shipping categories according to the EMEP/EEA guidebook (2019)

1.A.3.d.ii Domestic water-borne navigation :

- Emissions from fuels used by vessels of all flags that depart and arrive in the same country (excludes fishing, which should be reported under 1.A.4.c.iii, and military, which should be reported under 1.A.5.b). Includes small leisure boats.
- Note that this may include journeys of considerable length between two ports in a country (e.g. San Francisco to Honolulu).

1.A.4.c.iii Fishing (mobile combustion) :

- Emissions from fuels combusted for inland, coastal and deep-sea fishing.
- Fishing should cover vessels of all flags that have refuelled in the country (include international fishing).

1.A.5.b Mobile (water-borne navigation component) :

- All remaining water-borne mobile emissions from fuel combustion that are not specified elsewhere.

Definition of the different shipping categories according to the EMEP/EEA guidebook (2019)

Criteria for defining international or domestic navigation :

Journey type between two ports	Domestic	International
Departs and arrives in same country	Yes	No
Departs from one country and arrives in another	No	Yes

This table relates to all water-borne vessels, whether they operate on the sea, on rivers or lakes

Differences between rules for UNECE (pollutants) and UNFCCC (GHG)

- International sea traffic: emissions from bunker fuel sold for international sea traffic in the country of the reporting party. The emissions are to be reported to both UNFCCC and UNECE for information only.
- International inland shipping: emissions from bunker fuel sold for international inland shipping in the country of the reporting party. The emissions are to be reported to UNECE within national totals and to UNFCCC for information only.

Emissions of the different sources in the EU 28

EU28: 27.5.2020: 2018	*NFR sectors to be reported*			Main Pollutants (from 1990)				Particulate Matter (from 2000)			
				NOx (as NO_2)	NMVOC	SOx (as SO_2)	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC
NFR Aggregation for Gridding and LPS (GNFR)	**NFR Code**	**Longname**	**Notes**	**kt**	**kt**	**kt**	**kt**	**kt**	**kt**	**kt**	**kt**
G_Shipping	1A3di(ii)	International inland waterways		26,67	1,35	1,85	0,00	0,89	0,95	0,96	0,34
G_Shipping	1A3dii	National navigation (shipping)		339,18	46,37	48,14	0,07	16,89	17,92	18,07	3,86
I_Offroad	1A4cii	Agriculture/Forestry/Fishing: Off-road vehicles and other machinery		314,04	58,92	0,78	0,28	21,60	22,52	24,49	12,60
I_Offroad	1A4ciii	Agriculture/Forestry/Fishing: National fishing		101,26	5,07	3,37	0,01	2,61	2,72	2,75	0,97
I_Offroad	1A5b	Other, Mobile (including military, land based and recreational boats)		27,60	4,41	2,06	0,02	0,86	0,88	0,89	0,34
	NATIONAL TOTAL	**National total for the entire territory (based on fuel sold)**		7286,69	7014,42	2043,27	3858,92	1254,69	1988,69	3747,73	194,90
'MEMO' ITEMS - NOT TO BE INCLUDED IN NATIONAL TOTALS											
P_IntShipping	1A3di(i)	International maritime navigation		1825,33	62,27	570,78	0,80	104,59	111,08	114,06	15,86

https://www.ceip.at/status-of-reporting-and-review-results/2020-submissions NFR tables for the EU 28

Annex VIII of the Gothenburg Protocol

Annex VIII is based on EU directives for road vehicles and non road machineries

Table 9 : limit values (CO, sum of HC + NOx and PM) for engines for propulsion of inland waterway vessels

Table 10 : limit values (CO, HC, NOx and PM) for engines in recreational crafts

Annex VIII of the Gothenburg Protocol

- **Regulation (EU) 2016/1628 of 14 September 2016** on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery: including stage V emission limits for new engines used in inland waterway vessels ≥ 19 kW, excluding recreational and personal watercraft and sea going vessels

  Not yet considered in the annex VIII, but proposal for its inclusion to be made by TFTEI

- **Directive 2013/53/EU of 20 November 2013** on recreational craft and personal watercraft and repealing Directive 94/25/EC: stage II emission limits for new recreational craft and personal craft (compression and spark ignition engines) (stage II applicable from 2016)

  Inclusion in the annex VIII to be checked, but proposal for its inclusion to be made by TFTEI if not included

Do we need to have description of engines able to meet the requirements in the document?

Annex IV (SO2) of the Gothenburg Protocol

- Directive (EU) 2016/802 of 11 May 2016 relating to a reduction in the sulphur content of certain liquid fuels (codification of the substantially amended Directive 1999/32/EC);
- Commission implementing decision (EU) 2015/253 of 16 February 2015 laying down the rules concerning the sampling and reporting under Directive 1999/32/EC relating to a reduction in the sulphur content of certain liquid fuels: maximum S-content of liquid fuels, including for marine fuel used in sea going (international and national) ships (incl. inland waterway vessels and recreational craft when at sea, incl. fishing at sea); requirements on S-content of marine fuel for use outside/inside SECA (within MS territories, territorial seas, EEZs, pollution control zones), at berth in Union ports and by ferries

In the scope of the review of Annex IV (limit values for SO_2), inclusion of additional requirements will be assessed by TFTEI, in 2021

Annex VI (VOC) of the Gothenburg Protocol

- Commission implementing decision 2014/738/EU of 9 October 2014 establishing BAT conclusions, under Directive 2010/75/EU, for the refining of mineral oil and gas: vapour recovery at loading/unloading operations for sea-going vessels with an annual throughput ≥ 1 million m3/yr.

In the scope of the review of Annex VI (limit value for VOC), inclusion of additional requirements to be assessed by TFTEI,

Loading/unloading operations for sea-going vessels not yet included.

VOC reduction measures could be described in the technical document