Sustainable, safe and
economically feasible
energy concepts and
technologies for European
Inland Shipping

D 3.1 State-of-the-Art Report

Certification, monitoring and enforcement

Grant Agreement:	633929
(Sub)Work package:	WP3
Deliverable No:	3.1
Author:	TNO
Version (date):	January 17, 2016

Document history

Document version (date)	Comments (changes compared to previous version)	Authorised by
0.1 (4th of November 2015)	Additional elements to be incorporated	Gerrit Kadijk
0.2 (22nd of November 2015)	Editorial Changes	Jaap Gebraad
0.3 (30th of November 2015)	Editorial Changes	Gerrit Kadijk
0.4 (9th of December 2015)	Editorial Changes	Gerrit Kadijk
0.5 (9th of December 2015)	Editorial Changes	Jaap Gebraad
0.6 (11th of January 2016)	Editorial Changes	Gerrit Kadijk
1.0 (17th of January 2016)	Editorial Changes	Jaap Gebraad

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Summary

PROMINENT is a multiannual research- and implementation program for the inland navigation industry which is funded by Horizon 2020. PROMINENT focusses on researching, testing and introducing alternative energy concepts and technologies for the European industry of inland navigation which are economically viable, safe and environmentally friendly.

The European IWT (Inland Waterway Transport) fleet consists of approximately 18.000 vessels (and 40.000 crew members) and plays a crucial role in major transport chains. The sector has a large potential to become more environmentally friendly (i.e. reduction of Green House Gases and pollutants) and transport chains can also be improved by shifting more cargo to the IWT sector, which reduces congestion on the European roads.

PROMINENT is aimed at providing solutions to make inland navigation as competitive as road transport in terms of air pollutant emissions by 2020 and beyond. In parallel, PROMINENT aims to the further decrease the energy consumption and carbon footprint of IWT.

PROMINENT consists of 7 work packages. Work package 3 explores the technical options for improved certification, monitoring and enforcement procedures regarding emissions and operational profiles, and prepares their pilot testing. This report summarizes the current available methods for certification of engines of inland waterway vessels, monitoring of real sailing emissions and enforcement. In addition it describes needs for improved certification procedures.

Inland Waterway Transport certification lags behind on other sectors:
Before 2002 no IWT emission legislation was valid and these engines have no emission certificate. In 2002 the CCNR introduced emission regulations for engines of inland waterway vessels and in 2007 these regulations became mandatory for all EU member states since Directive 97/68/EC Stage IIIA came into force; these are still valid. In 2020 it is planned to set new EU Stage V limit values. With current EU Stage V proposals emission requirements for inland waterway engines still lag behind HD engines (road transport) and on other engine categories for Non Road Mobile Machinery.

Development of certification test procedures are needed:
With road transport and with certain categories for Nor Road Mobile Machinery, stringent emissions limits were already introduced during the past decades. This also lead to adaptations and expansion of the certification test procedures. These adaptations are necessary in order to cope with the development in engine performance and in emission control technologies. The overall objective is that the certification test procedure is representative for real world emissions. The adaptations included adaptation of test cycles themselves (load pattern), an additional stationary or transient test cycle and emissions tests on the road.

Real sailing emissions may deviate strongly from type approval emissions:
Current type approval directives and regulations for inland ships do not guarantee low real sailing emissions: Directive 97/68/EC defines test procedures and emission limit values for engines of inland waterway vessels. This type approval test result does not represent the engine emission behaviour in the real world because operating conditions are mostly different. Furthermore monitoring and enforcement of the real emission performance of the engine are not been carried out. Consequently real sailing emissions might deviate strongly from the type approval emissions according to the test cycle under laboratory conditions.

Dedicated test procedures are needed to secure real sailing emissions:
A good certification test procedure and enforcement are the key activities to realize real sailing emissions in line with the limit values of certification. To comply with future legislation, advanced emission control systems such as oxidation catalysts, SCR catalysts and diesel particulate filters and new fuels will be applied. More advanced test procedures and enforcement activities are needed to secure low real sailing emissions, because emissions control systems can be tuned to the test cycle or can even be switched off or removed in practise.

On board certification procedures are needed for retrofit emission control systems:
Current engine type approval procedures are relatively expensive and complex:
As result of more emission standards and incentive schemes promoting clean vessels, it is expected that many existing engines of IWT vessels will be equipped with after treatment technology in order to reduce emissions of NOx and PM. Moreover, also new engines might be equipped with after-market emission reduction systems in order to comply with more strict emission limits. In order to measure the emission performance of these vessels with retrofit devices at reasonable costs, there is a need for developing on board certification tests. Simple and affordable additional certification test requirements and on board monitoring of emissions are marked as two key elements for future emissions legislation, both for entirely new engines as well as for retrofit solutions. Suitable options for this will be further investigated within PROMINENT (Deliverable 3.2 and 3.3).

On Board Monitoring is a very promising technology:
On Board Monitoring can play a key role in securing real sailing emissions. It can be applied for both OEM and retrofit certification as well as in regional incentive programs. It requires the development of a digital infrastructure and summarized reporting of emissions data to the different stakeholders for different functionalities such as certification and sustainability.
In The Netherlands on board monitoring is already accepted by regional governments and the shipping branch as a good way to go.

List of Abbreviations

AIS	Automatic Identification System
BTL	Bio-To-Liquid
CCNR	Central Commission for the Navigation of the Rhine
CESNI	Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure
CI	Combustion Ignition
CNG	Compressed Natural Gas
CO	Carbon Monoxide
COP	Conformity of Production
CRT	Continuously Regenerating Trap
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
EC	European Commission
ECA	Emission Control Area
ECE	UN Economic Commission for Europe
ECU	Electronic Control Unit
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency
GHG	Green House Gas
GTL	Gas-To-Liquid
HDV	Heavy Duty Vehicles
HILS	Hardware In the Loop System
IMO	International Maritime Organisation
INEA	Innovation & Networks Executive Agency
IMO	International Maritime Organization
ISC	In Service Conformity
ISM	In Service Monitoring
ISO	International Standardisation Organization
IUC	In Use Compliance
IWT	Inland Waterway Transport
LDV	Light Duty Vehicles
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LNT	Lean NOx Trap
MEPC	Marine Environment Protection Committee
NRMM	Non-road Mobile Machinery
NRTC	Non-Road Transient Cycle
NTE	Not To Exceed value
OBD	On Board Diagnostics
OCE	Off Cycle Emissions
OEM	Original Equipment Manufacturer
PEMS	Portable Emission Measurement System
PM	Particulate Matter
PN	Particulate Number
RDE	Real Driving Emissions
RPM	Rounds per minute
SCR	Selective Catalytic Reduction
SI	Spark Ignition
THC	Total Hydro Carbons
VOS	Vignet Olie Scheepvaart
WHSC	World Harmonized Stationary Cycle
WHTC	World Harmonized Transient Cycle
WP	Work package

Contents

1 Introduction to PROMINENT

PROMINENT is a multiannual research- and implementation program for the inland navigation industry which is funded by Horizon 2020. PROMINENT focusses on researching, testing and introducing alternative energy concepts and technologies for the European industry of inland navigation which are economically viable, safe and environmentally friendly.

Previous projects are, amongst others, PLATINA and PLATINA-II. These projects support the European Commission with the implementation of NAIADES and NAIADES-II. The NAIADES II programme will facilitate long-term structural changes in the inland waterway transport sector. It also includes short term actions currently being undertaken by the Commission to address the difficult economic situation of the sector. Regarding new directives the European Commission is aware of the complexity of the existing market and makes [NAIADES IIa] & [NAIADES IIb] a few statements regarding emissions.

"The approach to be adopted on emission limits should be strictly technology neutral from the perspective of engine technology and fuel choice. Due to this, it is assumed that the technology with the best cost/benefit characteristics would prevail".

"When defining new emission limits for the IWT engines, it may be necessary to differentiate between small and large vessels and between existing and new engines because of the technological and economic limitations that existing engines and small vessels face. The Commission is also aware that sufficient time must be allowed for the sector to adapt to more ambitious emission limits."

"Although IWT emits much less CO_2 than road transport, the external costs of its emissions to air (air pollutants and CO_2) are roughly equal to those of road transport. This is due to the higher cost of IWT air-pollutant emissions."

1.1 Innovations improving the environmental performance of IWT

The European IWT fleet consists of approximately 18,000 vessels (and 40,000 crew members) and plays a crucial role in major transport chains. The sector has a large potential to become more environmentally friendly (i.e. reduction of Green House Gases and pollutants) and transport chains can also be improved by shifting more cargo to the IWT sector, which reduces congestion on the European roads. During the last years, the European Commission and the partners of the PROMINENT consortium have been investing in the promotion of (technological) innovations in the inland navigation industry.

1.2 PROMINENT objectives

PROMINENT is aimed at providing solutions to make inland navigation as competitive as road transport in terms of air pollutant emissions by 2020 and beyond. In parallel, PROMINENT aims to the further decrease the energy consumption and carbon footprint of IWT. This is an area where IWT performs better than road transport.

For inland waterway vessels, the current engine emission standards are CCNR Stage II and EU NRMM Stage IIIA. More stringent (future) emission standards like EU NRMM Stage IIIB and the proposed Stage IV/V for inland vessels will require reductions of NOx and PM emissions between 60 and 90%. PROMINENT aims to support the widespread implementation of innovative and environmentally friendly solutions in IWT to improve the sector's economic competitiveness and environmental performance. In addition to the development of "hardware" solutions, PROMINENT will focus in particular on improving the "orgware". In other words, PROMINENT will also focus on improving the framework conditions, which are primarily responsible for the current stagnating innovation levels in the IWT sector. This will be done by setting clear and achievable targets.

1.3 Targets and work packages of PROMINENT

The goals of PROMINENT are:

1. Developing cost-effective solutions and standardised applications (reducing required investment costs):
   - ➔ <u>70%+ coverage –</u> Developing solutions that are applicable to at least 70% of the European inland fleet and their operating areas.
   - ➔ <u>30% costs reductions</u> – Reducing implementation costs of innovative greening solutions by 30%.
2. Involving all relevant actors concerned in the research and innovation process
   - ➔ <u>100% inclusive -</u> All stakeholders who are required for the full coverage of the innovation cycle from initial concept to real-life deployment are to be taken on board.
3. Actively addressing and removing current implementation barriers by 2020
   - ➔ <u>Visible and physical results by 2017 –</u> Producing results on the ground during the project lifetime

PROMINENT has 2020 as ultimate time horizon. With respect to this time frame, another goal is:

4. <u>Setting up a roll-out strategy</u> which is geared towards producing the required full impacts by no later than 2020.

1.4 PROMINENT WP3.1 objectives, scope & definitions

Work package 3 explores the technical options for certification, monitoring and enforcement procedures regarding emissions and operational profiles, and prepares their pilot testing.

New stringent emission limits require the drastic reduction of harmful emissions of NOx and PM by up to 80 to 95%. The differences between inland vessels and trucks are so large that the same emission control systems cannot be used. Inland vessels have engines with longer lifetimes, they have a greater variety of technical configurations, and they can be retrofitted with after-treatment systems, and so on. There is a need for specific solutions for the IWT industry.

The focus of WP 3 is to develop and test well-designed procedures for the certification, monitoring and enforcement of emission limits in the near future for a range of different vessel types, different operating profiles and different types of situations (new engine, engine overhaul, retrofit). This includes certification, (real life) verification, portable on-board measurements and continuous on-board monitoring. The options for collection of on-board monitoring results in a central database will be investigated. This is done for the enforcement of air pollutant emissions (NOx, PM) as well as for the creation of incentives for the ship owner to benchmark and demonstrate its vessel's environmental performance. For this latter purpose, on-board monitoring data will be combined with open-source data such as AIS data and data on the waterway characteristics.

Already during this phase of technical research and development, the views and opinions of stakeholders will be taken into account, including those of:

- the European Commission
- national and regional authorities
- providers of technical services
- classification societies
- manufacturers of engines, systems and ships and their organisations (e.g. Euromot, AECC, CESA and national organisations)
- ship owners/ operators and their associations
- clients of transport such as shippers and multinationals who are interested the environmental performance of their transport operations.

The following table shows the deliverables of WP3.

Name / sub WP	Main Deliverables
3.1 Improved certification, monitoring & enforcement	D3.1, State-of-the-art report
	D3.2, Assessment of certification procedures
	D3.3, Assessment of options for monitoring and enforcement
3.2 Prepare and Evaluate real life testing	D3.4, Design and project plan for the real-life testing
	D3.5, Ex-ante cost/benefit analysis of systems for certification, monitoring and enforcement

Table 1: Deliverables of Work package 3

In order to reach the overall objective of improving emission performance of the sector one should be aware of 'total solution' which lowers real sailing emissions. Therefore new regulations, stringent limit values and ***enforcement activities*** are needed.

Objectives and scope of this WP 3.1 study and definitions

This report on the 'state of the art' summarizes the current available methods for certification of engines of inland waterway vessels, monitoring of real sailing emissions and enforcement. Furthermore, future needs for improved certification procedures are described.

This study is limited to the exhaust gas emissions of combustion engines of inland waterway vessels.

The following definitions are used in this report:

Certification

Certification is the technical and formal determination of exhaust gas emissions according to a prescribed procedure of every new type of combustion engine with or without an exhaust after treatment system. Certification contains an administrative and technical part. The emission test must be carried out in a test laboratory or in the field and must be reproducible and repeatable. In the type approval documents and emission certificates the specification of the engine and the emission test, results are reported.

Monitoring

Monitoring is the collection and storage of on board 'real' sailing emissions[1] and/or operating data. The monitoring system which contains sensors and a data logger is (permanently) installed on board and collects and stores continuously all the real time engine operating parameters and emission data.

Enforcement

Enforcement deals with activities which are dedicated to in-use compliance of combustion engines and aims to secure emission levels which are set in the classification phase. The enforcement activities are related to administrative and technical issues. It must contain test procedures and criteria to check the engine configuration and to criticize the measured engine emission.

[1] Real sailing emissions are produced in daily operation of IWT

2 Overview of current emission legislation relevant to IWT

This chapter presents the existing and planned legislative instruments with respect to IWT engines. In 2003 the CCNR introduced the first engine emission legislation for the Rhine and in 2007 legislation for all EU member states came into force. Furthermore legislation of other sectors and standardization are studied.

NRMM (Non-Road Mobile Machinery) engines cover a large variety of combustion engines. These NRMM engines are installed in machines ranging from small handheld equipment, to construction machinery, generating sets, railcars, locomotives and inland waterway vessels. These NRMM engines significantly contribute to air pollution and account for roughly 15% of the nitrogen oxide (NOx) and 5% of the particulate matter (PM) emissions in the EU. The overview in this chapter contains both international and some country specific regulations.

Apart from engine certification every new vessel must be classified. The classification can be marked as a type approval of that particular vessel and describes its total lay out. During the lifetime of a vessel the authorities may check the current status of the vessel in the view of enforcement of the regulations.

The state-of-the-art emission legislation for inland vessels must be placed into its historical context. Figure 1 shows three major international regulatory authorities and their emission legislations. They are discussed one by one in this chapter. First, the chapter describes the regulations related to IWT, then regulations from other fields of transport, and it ends with a section on standardization efforts.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021 ...
CCNR				CCNR I				CCNR II														
EU								EU STAGE IIIA													EU STAGE V	
IMO	IMO TIER I											IMO TIER II					IMO TIER III					

Figure 1: Timeline of emission legislation

2.1 Inland Waterway Transport

Central Commission for Navigation on the Rhine (CCNR)

The first organisation to be discussed is the CCNR. The CCNR is the oldest intergovernmental organization in the world. It was created in 1815 at the Congress of Vienna. This consortium was created to ensure the freedom of navigation on the Rhine. The first meeting took place on 15 August 1816 in Mainz. Later, in 1831, the Convention adopted first laws regarding the Rhine navigation. Its role was strengthened by the 1868 Mannheim Document, which extended its terms of reference to include ensuring the prosperity of navigation on the Rhine and through Europe, and a high level of safety for navigation and its environment. The document was the precursor to the setting up a free common market for transport, brought about by the EU to a large extent a hundred years later. The headquarters of CCNR is currently located in Strasbourg. The Central Commission contains five member states (The Netherlands, Germany, France, Belgium and Switzerland), but there are a number of observer states which are also involved with its work.
The Central Commission is an up-to-date international institution with an administration that enables it to address effectively all the issues concerning inland navigation. It promotes the development of close cooperation with the other international organisations working in the field of European transport policy and with non-governmental organisations active in the field of inland navigation.

The CCNR regulations concerning pollutant emissions are comprised in the Rhine Vessel Inspection Regulations RVIR. The history of the CCNR's emission regulations is as follows:

Date	Regulation
2002	CCNR I
2007	CCNR II

Table 2: CCNR emission regulations

A specific chapter „Emission of gaseous and particulate pollutants from diesel engines" presents: definitions and fundamental principles. This chapter applies to all engines with a rated power P(N) equal or greater than 19 kW installed on board of the vessels or on board of machines which are not already covered by the European Community directives on the issue of gas and air-pollutant particles.

The emissions of carbon monoxide (CO), hydrocarbon (HC), nitrogen (di)oxide (NOx) and particle matter (PM) emissions from these engines shall not exceed, depending on the rated engine speed n, the following values:

P (N) [kW]	CO [g/kWh]	HC [g/kWh]	NOx [g/kWh]	PM [g/kWh]
37 ≤ PN < 75	6.5	1.3	9.2	0.85
75 ≤ PN < 130	5.0	1.3	9.2	0.70
PN _> 130	5.0	1.3	$n \geq 2800\ min^{-1} = 9{,}2$ $500 \leq n < 2800\ min^{-1} = 45 * n^{-0.2}$	0.54

Table 3: CCNR I emission limit values

P (N) [kW]	CO [g/kWh]	HC [g/kWh]	NOx [g/kWh]	PM [g/kWh]
19 ≤ PN < 37	5.5	1.5	8.0	0.8
37 ≤ PN < 75	5.0	1.3	7.0	0.4
75 ≤ PN < 130	5.0	1.0	6.0	0.3
130 ≤ PN < 560	3.5	1.0	6.0	0.2
PN ≥ 560	3.5	1.0	$n \geq 3150$ min-1 = 6,0 $343 \leq n < 3150$ min-1 = $45\ n^{-0.2} - 3$ $n < 343$ min-1 = 11,0	0.2

Table 4: CCNR II emission limit values

2.1.1 European Union (EU)

Existing EU legislation and ISO standards in this area are grounded in the strategies and action plans laid out by international cooperation bodies such as the Kyoto Protocol, or the International Maritime Organization (IMO) through its Marine Environment Protection Committee (MEPC) and Market-Based Measures Expert Group (MBM-EG) that specifically address the topic of gaseous emissions from ships. More information on the IMO is presented further in this chapter.

Directive 97/68/EC
The first legal instrument in the EU that has addressed emissions produced by engines installed in NRMM, is the Directive 97/68/EC of 16 December 1997. It deals with the emission of gaseous and particulate pollutants from internal combustion engines. Since its introduction, Directive 97/68/EC has been amended for 5 times. The next table shows the contents of these amendments.
A complete overview of the changes to the European regulations, is included in Appendix B.

EU regulation	Contents of the changes
Directive 2002/88/EC of the European Parliament and of the Council of 9 December 2002	Directive 2002/88/EC extends the scope of Directive 97/68/EC to cover spark ignited engines (petrol engines) up to 18 kW for engines installed in handheld and non-handheld equipment. Stage I (and stage II) entered into force in August 2004.
Directive 2004/26/EC of the European Parliament and of the Council of 21 April 2004	Directive 2004/26/EC further extends the scope of 97/68/EC to include diesel engines from 19 kW to 560kW for common NRMM engines. The directive applies to both constant speed engines and to inland maritime engines **(inland waterway transport sector)**. An innovative feature of this Directive is that it establishes three further engine stages: • Stage III A refers to engines between 19 to 560 kW including constant speed engines, railcars, locomotives and inland waterway vessels. Stage III A entered into force on the 1st of January 2006. • Stage III B refers to engines between 37 to 560 kW. Stage III B entered into force on the 1st of January 2011. • Stage IV refers to engines between 56 and 560 kW. Stage IV entered into force on the 1st of January 2014. Directive 2004/26/EC also prescribes that engines introduced after a new stage comes into force must comply with the requirements of the previous stage. This directive is aligned with the US proposal TIER IV.
Commission Directive 2010/26/EU of 31 March 2010	Directive 2010/26/EU modifies type approval requirements for stages IIIB and IV. Directive 2006/105/EC brought changes to the provisions regarding the approval certificate numbering system (Annex VIII, point 1, section 1 of the Directive 97/68/EC).
Directive 2011/88/EC of the European Parliament and of the Council of 16 November 2011	Directive 2011/88/EU modifies the flexibility percentage for Stage IIIB engines.
Commission Directive 2012/46/EU of 06 December 2012	Directive 2012/46/EU refers to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in NRMM. Directive 2012/46/EU updated Directive 97/68/EC so as to reflect technical progress in various areas: • Symbols and abbreviations, specifications and tests, specification

	of conformity of production assessment and parameters defining the conformity of production (ANNEX I) • Type-approval process with reference to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery (ANNEX II) • Test procedures for combustion ignition engines (ANNEX III) • Analytical and sampling procedures for gaseous emissions tests (ANNEX IV) • Type approval certificate modifications (ANNEX VII) • Data sheet for type approved engines (ANNEX XI) • Recognition of alternative type approvals (ANNEX XII
Current developments	Directive 97/68/EC is currently being revised. The European Commission adopted a proposal for a new regulation for NRMM engines on 25 September 2014. This was transferred to the European Parliament and Council. The file is currently dealt within the ENVI Committee, with the IMCO Committee providing an Opinion. If the proposal is adopted by the European Parliament and the Council by end of 2015, the new regulation would enter into force beginning of 2016.

Table 5: Overview of EU regulations

Source: Directives on emissions from non-road mobile machinery, available at (http://ec.europa.eu/DocsRoom/documents/11209/attachments/1/translations/en/renditions/native)

The limit values of the abovementioned European regulations are quite complex. An extended overview is provided in Appendix B.

Directive 2006/87/EC: Installation requirements

There is another legal instrument addressing emissions produced by engines installed on IWT vessels. Directive 2006/87/EC of the European Parliament and of the Council of 30 December 2006 lays down technical requirements for inland waterway vessels and repeals Council Directive 82/714/EEC. This directive was amended later by the Commission Directive 2009/46/EC of 24 April 2009.

In order to secure the removal of all exhaust gas article 8.04 „Engine exhaust system” of the Directive 2006/87/EC prescribes that exhaust gases shall be completely ducted out of the vessel and all suitable measures shall be taken to avoid ingress of the exhaust gases into the various compartments. The segments of exhaust pipes passing through accommodation or the wheelhouse shall be covered by protective gas-tight sheathing. The gap between the exhaust pipe and this sheathing shall be open to the outside air.

Directive 2009/46/EC: Installation of the engine on board and emission testing:

The more recent Directive 2009/46/EC introduces Chapter 8a „Emissions of gaseous and particulate pollutants from Diesel engines” and prescribes the emission tests to be performed during installation, the recognized type-approvals and the technical services. After the installation of the engine on board, but before it is brought into service, an installation test shall be carried out. This test, which forms part of the initial inspection of the craft, or of a special inspection by virtue of the relevant engine having been installed, shall result either in the registration of the engine in the Community certificate to be issued for the first time or in the modification of the existing Community certificate.
Without prejudice to the requirements of the Directive 97/68/EC, the provisions of the Chapter 8a are applied to all engines with a rated power output higher than 19 kW installed on inland waterway

vessels or on the machinery on board such vessel. To apply this Directive, the engines must comply with the requirements of Directive 97/68/EC. According to the Directive 2009/46/EC, compliance to the exhaust gas emission limit values of the applicable stage shall be determined on the basis of a type-approval pursuant to the provisions of Art. 8a.03 „Recognized type-approvals".

2.1.2 Proposed European limit values in comparison to other segments

The European Commission has proposed stringent Stage V limit values (around 2020) for Inlet Waterway Transport (IWT) in 2014[2]. Consequently these were amended to much less stringent limit values in a new proposal in 2015[3]. The 2015 proposal follows exactly the USA Tier III and Tier IV limit values. For engines larger than 600 kW, these are reasonably stringent, but for engine up to 600 kW, the limit values are higher than Euro III of road vehicles.

In Figure 2 a comparison is made between several limit values, namely CCNR I and II, proposed Stage V (2015), Euro IV and V (HD vehicles) and USA EPA Tier IV. A more extensive comparison is presented in Appendix B, Table 20 and Table 21. It can be concluded that the emission limits for engines up to 600 kW are high, even somewhat above those of Euro III vehicles (entry into force in year 2000). It is not clear why limit values of inlet ship engines should lag more than 20 years behind on those of truck engines. They are also much higher than those of the category Non Road Equipment (NRE), refer to appendix B. Up to 560 kW, NRE limit values are similar to the very stringent Euro VI legislation for trucks. The main suppliers for marine engines up to 600 kW are: Mitsubishi, Volvo, Scania, Caterpillar and John Deere, which all have experience with advanced emission control systems. Most of these manufacturers also supply very similar engines for Non Road Equipment. So inland ship engines can benefit from the economy of scale of non-road equipment engines.

Reasonable stringent emission limits is especially important for engines up to 600 kW, because these engines are usually fitted in ferries and harbour ships, which often sail mostly in urban areas. Urban areas usually have issues with air quality. It is important to have clean OEM engines available for this. The same is the case with generator sets (auxiliary engines) of larger inland ships. They continue running when the ships are at quay in terminals etc. (where air quality is important).

The large difference between engines up to 600 kW and above 600 kW (Figure 2) in the 2015 Stage V proposal, is probably undesirable. If this will enter into force, in the future, engines smaller than 600 kW will probably be mounted in most inland ships, in order to take advantage of the higher limit values. This may also lead to a rise in diesel-electric powertrains or hybrid drivelines.

[2] Reference : COM(2014)0581-C8-0168/2014-2014/0268(COD))

[3] Reference: European Parliament, A8-0276/2015, 30.9.2015, Report RR\1074318EN.doc – PE557.123v02-00

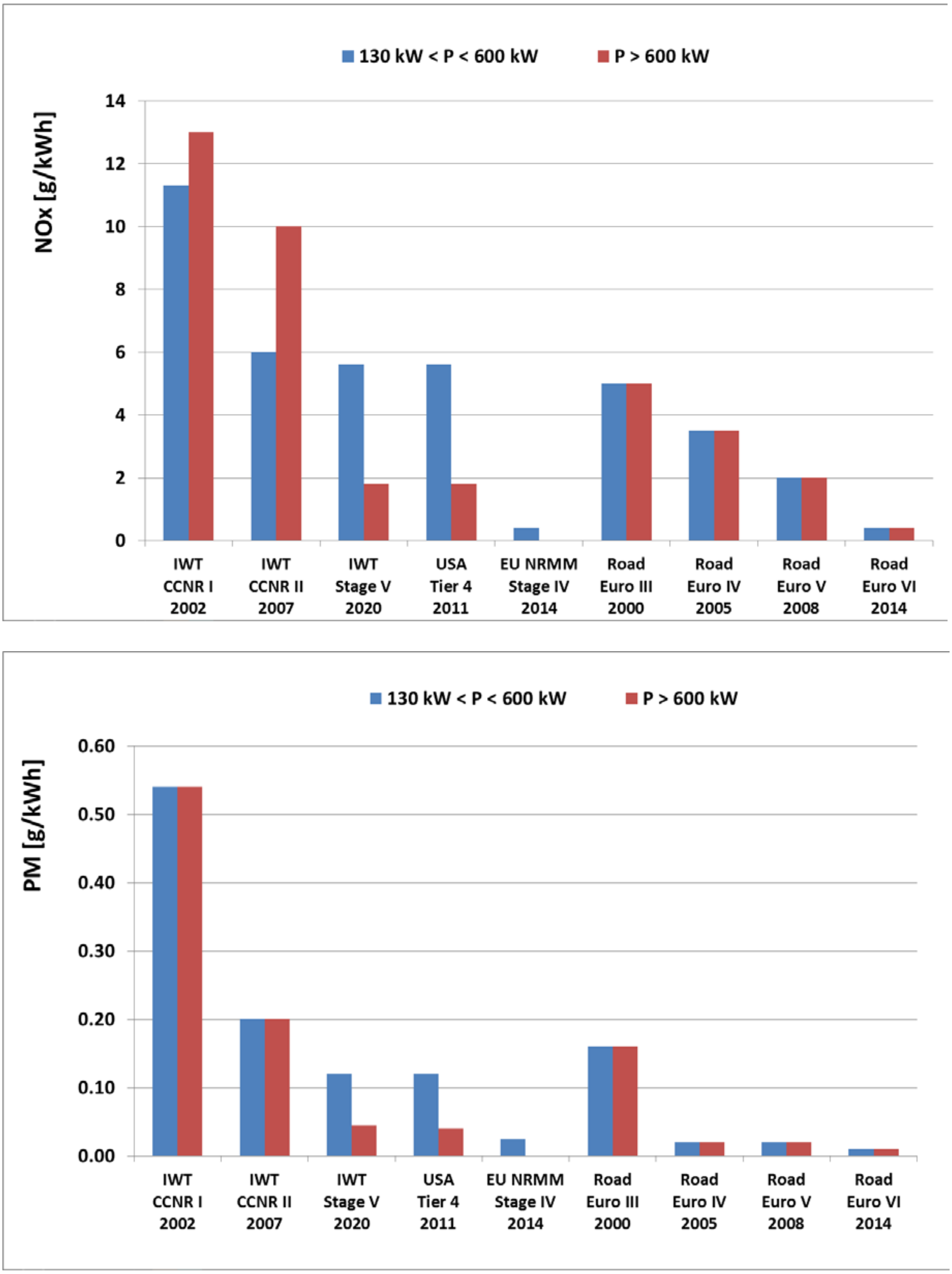

Figure 2: Comparison of limit values for inland ships: CCNR I and II, proposed Stage V (2015), Euro IV and V (HD vehicles) and USA EPA Tier IV: Top figure: NOx, below: PM – particulates emission

2.1.3 Country specific regulations

Apart from the international efforts in the regulation of emissions of waterborne transport, national or local authorities may also have their own emission requirements. National emissions regulations are available in different countries of Europe and they are in line with the European Directives, CCNR regulations, IMO and ISO regulations in regard to the gaseous and particulate matter emission limits. However there are some particularities which do not exceed the European Directives and regulations of various European and international bodies. This particularities of the national regulations offer in case of some countries incentives and discounts for ships having their gaseous emissions under certain limits while in other countries penalties are foreseen if the ships do not comply with certain limit values.

<u>Netherlands and Belgium</u>

In Netherlands and Belgium port dues differentiation is applied on basis of the Green Award. The Green Award is a voluntary measure which takes into account different aspects of the vessel. The Green Award distinguishes between three performance levels: Bronze, Silver and Gold [Green2015]. The levels are defined on the basis of the environmental performance of the main engine, auxiliary engines and additional measures taking into account both environmental performance (diesel-electric or hybrid propulsion, Fuel measure, Energy saving rudder, Environmental Plan in place, etc.), as well as safety measures. A points system is used to combine all measures to a certain total. Refer to http://www.greenaward.org/greenaward/452-inland-shipping.html ; downloads.
In order to receive a "Gold" performance level, the main engines of the vessel should be at least 60% cleaner than the CCNR II standard for NOx and PM. The 60% is based on a weighing between main and auxiliary engines and the delivered energy in kWh. The low emissions level has to be proven by an emissions measurement on board of the ship and an official report and/or the official certification of the engine supplier. On board emission tests are already developed in other sectors and described in ISO 8178-2 and MARPOL 73/78 Annex VI procedures. These test procedures are also the basis for Green Award field certification of inland waterway vessels and are already applied by a few service providers of emission tests. The application for a Green Award has to be submitted by the ship owner. The Green Award certificate should be renewed every three years with a yearly check; in this enforcement procedure no emission tests or checks are defined. In order to improve the quality of the Green Award durability criteria and enforcement procedures must be defined.

Thirteen Dutch and three Belgium harbours offer a discount of 5% to 30% on harbour fees, for inland ships with a green award. Usually the discount is around 15%. Only Amsterdam currently distinguishes between the three levels bronze, silver and gold (respectively 5, 10 and 15% discount). Another advantage of the green award is a discount on the interest rate of certain loans.
The Port of Antwerp, for example, applies a discount on port dues on the basis of the environmental performance of the vessel. The port distinguishes between two types of discounts. A discount of 7% is awarded if the ship complies with CCNR II:

- Ships built after 2007 automatically apply for 7%
- Ships built before 2008 must submit the required details (notification) before entering the port

Another discount of 15% is applied to certain engine types:

- Diesel-electric main engine, for which the diesel engine complies with CCRII
- LNG or Dual fuel engine
- Hydrogen engine

Technical information attesting the compliance with the specified engine types needs to be submitted by the ship owner.

Other Countries: the USA

In the USA, emissions from marine diesel engines (compression ignition engines) have been regulated by the EPA since 1999 for different engine categories. Certain overlap also exists with the regulations for mobile, land-based non-road engines, which may be applicable to some types of engines used on marine vessels. Marine engines below 37 kW (50 hp) are subjected to Tier 1-2, but not Tier 4 of non-road standards. The emission limit values are thus related to the engine power rather than the type of application.

Table 6 shows the major regulatory acts which establish emission standards for marine engines.

In Table 7 the EPA TIER 1-4 NOx emission limit values are shown.

Regulation	Description
1999 Marine Engine Rule	On 23 November 1999, the EPA signed the final rule "Control of Emissions of Air Pollution from New Compression Ignition Marine Engines at or above 37 kW" The adopted Tier 2 standards for Category 1 and 2 engines are derived from the land-based standard for non-road engines, while the largest Category 3 engines were expected—but not required by the rule—to comply with IMO MARPOL Annex VI limits.
2002 Recreational Engine Rule	Diesel engines used in recreational vessels are covered in the "Emission Standards for New Non-road Engines—Large Industrial Spark-ignition Engines, Recreational Marine Diesel Engines, and Recreational Vehicles" regulation.
2003 Category 3 Engine Rule	The decision to leave the largest Category 3 engines unregulated triggered a law suit against the EPA initiated by environmental organizations. A court settlement was reached that required the EPA to develop NOx emission limits for Category 3 engines. The final rule "Control of Emissions From New Marine Compression-Ignition Engines at or Above 30 Litres Per Cylinder signed by the EPA in January 2003—establishes Tier 1 emission standards for marine engines virtually equivalent to the IMO MARPOL Annex VI limits.
2008 Category 1/2 Engine Rule	A regulation signed on 14 March 2008 introduced Tier 3 and Tier 4 emission standards for marine diesel engines. The Tier 4 emission standards are modelled after the 2007/2010 highway engine program and the Tier 4 non-road rule, with an emphasis on the use of emission after treatment technology. To enable catalytic after treatment methods, the EPA established a sulphur cap in marine fuels (as part of the non-road Tier 4 rule). The Sulphur limit of 500 ppm became effective in June 2007, sulphur limit of 15 ppm in June 2012 (the sulphur limits are not applicable to residual fuels).
2009 Category 3 Engine Rule	On 18 December 2009, the EPA signed a new emission rule for Category 3 engines (published 30 April 2010), which introduced Tier 2 and Tier 3 standards in harmonization with the 2008 Amendments to IMO MARPOL Annex VI.

Table 6: EPA emission standards for marine engines in the USA

Source: US Marine Emissions

TIER	Date	HC + NOx	NOx
		[g/kWh]	
1	2004	9.8 – 17.0	
2	2007	7.5 – 11.0	
3	2012-2014	6.2 – 11.0	
4	2014-2017	-	1.8

Table 7: Short overview of EPA emission limit values (Category 1 and 2)

2.2 Maritime transport

The CCNR and EU's efforts at the level of emissions reducing legislation for inland ships can also be related to the IMO's emission requirements for sea shipping. This explains why IMO regulations have been mentioned in the previous sections. What is the IMO and which emission regulations do they have?

The IMO is as specialized agency of the United Nations. Since its establishment in 1948, the IMO developed, operationalized and maintained a comprehensive regulatory framework for the shipping sector. The main priorities targeted through this regulatory framework are: safety, environmental issues, legal matters, technical co-operation, security and efficient shipping. Among these priorities, safety and environmental issues should to be considered in any new regulation introduced by IMO or by other international standards.

The shipping activity is responsible for various types of pollution (air emissions, acoustic effects, oil spillages and toxic residue discharges), as documented by a wide range of scientific reports. IMO adopted in 1997 specific regulations to curb the level of shipping related emissions: the MARPOL 73/78 Protocol – Annex VI Regulations for the Prevention of Air Pollution from Ships. Since then, the MARPOL protocol has become the main international convention to govern the issue of preventing the pollution of the marine environment by ships, as a result of operational or accidental causes. The scope of the Protocol is set to include all the environmental issues associated with the shipping activity (see above). The MARPOL Annex VI Regulation for the Prevention of Air Pollution from Ships has been ratified by 53 countries. Altogether these countries represent approximately 81.88% of the gross tonnage of the world's merchant shipping fleet.

Although IMO MARPOL may not be directly related to IWT, these emission levels can provide some perspective and are therefore shown in Table 8.

TIER	Date	NOx limits [g/kWh]		
		n < 130	130 ≤ n < 2000	n ≥ 2000
I	2003	17.0	$45 \cdot n^{-0,2}$	9.8
II	2011	14.4	$44 \cdot n^{-0,23}$	7.7
III	2016	3.4	$9 \cdot n^{-0,2}$	1.96

N = rated engine speed [rpm]

Table 8: Overview of IMO emission regulations

Appendix C presents more information on the efforts of the IMO with respect to emissions reduction.

2.3 Standardisation

Apart from the regulations issued by national governments, European authorities and international cooperation bodies, there is also standardization that concerns the measurement and reduction of emissions levels. ISO is the most important international standardization organization which defines guidelines on all kinds of subjects. Technical requirements and emission test procedures from engines are one of the themes the ISO works on.

<u>ISO 8178-1:2006</u>

In the same year the Directive 2006/87/EC was issued, ISO elaborated a standard dedicated to internal combustion engines: ISO 8178-1:2006 "Reciprocating internal combustion engines - Exhaust emission measurement". ISO 8178 is an international standard for the measurement of exhaust emissions produced by a number of non-road engine applications. It is used for emission related certification and/or type approval testing in various countries, including: the United States, European Union and Japan. Depending on the legislation, the test cycle can be defined by referring to the ISO 8178 standard, or else by specifying a test cycle equivalent to ISO 8178 in the national legislation (as it is the case with the US EPA regulations).

ISO 8178 is a comprehensive standard, whose 11 parts cover topics such as:

- test-bed measurement of gaseous and particulate exhaust emissions;
- measurement of gaseous and particulate exhaust emissions at site;
- definitions and methods of measurement of exhaust gas smoke under steady-state conditions;
- test cycles for different engine applications;
- test fuels;
- reporting of the measuring results and the test;
- engine family determination;
- engine group determination;
- test cycles and test procedures for test bed measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions;
- test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions, and
- test-bed measurement of gaseous and particulate exhaust emissions from engines used in non-road mobile machinery under transient test conditions.

Moreover, ISO 8178 includes a collection of steady-state engine dynamometer test cycles designed for different classes of engines and equipment, see Table 9. Test cycles of type E concern marine applications. Each of these cycles represents a sequence of several steady-state modes with different weighting factors.

Cycle	Application
E1	diesel engines for craft less than 24 m in length
E2	heavy-duty constant speed engines for ship propulsion
E3	heavy-duty marine engines (propeller law)
E4	pleasure craft spark ignition engines for craft less than 24 m in length
E5	diesel engines for craft less than 24 m in length (propeller law).

Table 9: categories of marine test cycles

2.4 Fuel specifications

Certification of CCNR I and II engines must be carried out with a reference fuel (i.e. CEC-RF-06-99) which represents an average market automotive fuel quality. The parameters of the reference fuel (i.e. Sulphur content) are specified in a relatively narrow band. However in Europe there is no overall quality specification for inland waterway gasoil market fuels; the sulphur content is the only parameter which is specified in directives 93/12/EEC, 98/70/EC, 1999/32/EC, 2005/33/EC and 2009/30/EG. Currently the maximum Sulphur content of IWT-fuel is 10 ppmm, this limit value was introduced in January 2011. In most countries the characteristics of inland waterway gasoil on the market are comparable the characteristics of off-road diesel or heating gasoil.

In a report from a DG-ENV consultant dated November 2001 the inland marine gasoil volume is calculated to be in the order of 20 to 25% of the total off-road gasoil volume [EC2001]. When compared with the automotive diesel volume this is in the order of 4%. This means inland waterway fuels represent a small segment for gasoil companies. This is why inland marine gasoil is often derived from mean grade qualities like heating gasoil or agricultural grades. This reduces the costs of segmentation, risk of contamination and tax fraud. Altogether, most inland marine gasoil delivery specifications are not dedicated to the specific purpose of inland waterway transport.

To be able to meet the future stringent emission requirements the marine engine technology must be optimized regarding exhaust gas emissions. The emission targets can only be fulfilled by combining engine technology with an appropriate and constant fuel quality. For that reason, for modern engines latest fuel quality requirements like the EN 590 specification are prescribed by the engine manufacturers. The need for fuel requirements can also be observed by some examples of self-regulation within the industry of gasoil for inland ships.

CEN EN 590 automotive gasoil specification:
European standards are established by the European Committee for Standardization CEN (fr. Comité Européen de Normalisation). The standards developed by CEN are known as European Norm (EN). The CEN EN 590 is the European standard for automotive gasoil (diesel). It specifies the minimum requirements and test methods. The sulphur limit, set by a European Directive 2005/33/EC is specified maximum 10,0 mg/kg (= ppmm).

VOS specification
In the Netherlands a series of fuel quality incidents in inland marine during the late 80's triggered a request by the sector for a better defined gasoil specification. The Dutch oil wholesale association NOVE took the initiative to start negotiations with the national oil refiners and establish the so called VOS specification (Vignet Olie Scheepvaart). By modifying their individual customer gasoil specification the oil refiners fulfilled the VOS specification so preventing the creation a new refinery gasoil pool. Later on when the German gasoil pool according to DIN 51603-1 became more important, alignment of the VOS spec with this grade was sought for by the refiners.
The 2007 VOS specification[4] is now almost fully aligned with the German DIN 51603-1 specification. VOS includes some additional requirements for acid number, cetane index (min. 45) and a slightly higher flashpoint to be fulfilled in case of deliveries to seagoing vessels.
The drawback of the VOS specification is that it has no international status as established and maintained by the Dutch wholesale association.
The Sulphur limit, set by the 2008 VOS specification is specified maximum 1000 ppmm and the 2011 VOS specification is specified maximum 10 ppmm.

EN590, VOS and DIN 51603-1 fuel specifications are reported in Appendix E.

[4] VOS specification; http://www.stichtingvos.nl/

2.5 Future emission legislation for inland vessels

The European Union plans to adopt a new legal instrument for NRMM engines that should soon enter into force, but it still is under discussion. So far this legal text is known under the name of "Proposal for a Regulation of the European Parliament and of the Council on requirements relating to emission limits and type-approval for internal combustion engines for non-road mobile machinery". This regulation establishes the emission limits for gaseous pollutants and particulate matter, as well as the administrative and technical requirements relating to EU type-approval for all engine types and engine families. The requirements for the market surveillance of engines to be installed or intended to be installed in non-road mobile machinery, which are subject to EU type-approval are also regulated in this proposal.

This proposal targets the following engines categories:

Category	Description
NRE	Engines for mobile non-road machinery, suited to move or to be moved, that are not included in any of the points below
NRG	Engines above 560 kW used in generating sets
NRSh	SI engines below 19 kW exclusively for use in hand-held machinery
NRS	SI engines below 56 kW that are not included in category NRSh
IWP	Engines above 37 kW used for the propulsion of inland waterway vessels
IWA	Auxiliary engines above 560 kW for use in inland waterway vessels
RLL	Engines for the propulsion of railway locomotives
RLR	Engines for the propulsion of railcars
SMB	SI engines used in snowmobiles
ATS	SI engines used in all terrain and side-by-side vehicles

Table 10: categories of engines which are targeted by the NRMM proposal

The essential changes brought by this proposal are considered to be the exhaust emission requirements for EU type-approval and the monitoring of emissions of in-service engines. The proposed regulation also covers the EU-type approval procedures, as well as the administrative provisions.

The main objective of this proposal is to reduce the emission of gaseous and particulate emissions (NOx, HC [Hydrocarbons], PM, CO [Carbon Monoxide]) of engines used in NRMM.
A range of options is considered when it comes to the stage V of NRMM. One of these would be a step towards road sector ambition levels, for the most relevant emission sources. The main reference for this option would be the Euro VI emission standard for heavy duty vehicles, although consideration would be given to the technical and regulatory differences between heavy goods vehicles and NRMM when setting limits. Limited differentiation would be allowed in accordance with the cost-benefit analysis for different engine power classes.
Two sub-options are considered in relation to inland waterway vessels (IWV): Option 3A aligning with forthcoming regulations on NOx and HC, but additionally introducing a PN emission limit; Option 3B would set in addition more ambitious emission reduction targets for NOx and HC.
Another objective of the proposal would be to bridge the gaps affecting the overall effectiveness in limiting the exhaust emissions of NRMM stage IV directive. Currently there is no legislation at the EU level regulating compression ignited (CI) engines with less than 19kW and more than 560kW and spark ignited (SI) engines above 19kW. The current legislation also fails to apply to stationary engines, engines installed in all-terrain vehicles and in snowmobiles, and engines that run on alternative fuels such as Liquefied Natural Gas (LNG).

3 Emission control technologies and certification test methods for inland vessel engines

Progress in developing engine technologies and exhaust after treatment systems led to the achievement of PM and NOx reduction rates of up to more than 90 percent of the levels delivered by the engine technology available at the beginning of exhaust emission regulation. For application cases with shorter lifecycle times than that of inland shipping, the renewal of system brings this progress into fleet faster.
To improve the emission behaviour of the inland shipping fleet, the use of retrofit technologies beyond the normal renewing cycle is a necessary option. In Europe, all engine systems and, of course, all retrofit systems need to have a type approval before entering the market.

This chapter deals with different emission control technologies of engine systems and after treatment systems and with the adapted approval methods, if there are any. Then new possibilities of approval of retrofit systems, even for single applications, are addressed.
Furthermore this chapter gives an overview about technologies used in other application cases like Heavy Duty Vehicles and Non-road Mobile Machinery and addresses the burdens for transferability to inland vessel engines, especially for retrofit. A comparison of technologies leads to profiling the expected emission control technologies for inland ship engines (IWS) with the upcoming Stage V of NRMM regulation.

Emission control or ‘greening’ technologies are also investigated in Work Package 1, Deliverable D1.2. In D1.2 [VIA2015] an extensive description is given and a market analysis is done based on a set of criteria. In this section a short technical description is provided in the context of the various certification method options.

3.1 European type approval principle

The European way of approving engines is based on the type-approval principle. This implies that: a) the performance of the system to be certified is tested, and b) a detailed description of the tested system is provided. After a successful type approval, the owner of the type approval is allowed to produce and sell systems as described and tested. In accordance to most of the current emission regulations, a ‘system’ in this case refers to the combination of a combustion engine (or engine family) and an exhaust after treatment system (if needed).

A second way of obtaining the approval for a new engine is the “New Approach”, which is e.g. applied for recreational crafts with 94/25/EC. In that case, the manufacturer declares compliance with the regulations. Figure **2** highlights the differences between the two approaches, which basically come down to only the administrative steps of the approval procedure. Both approaches are based on the same technical standards.

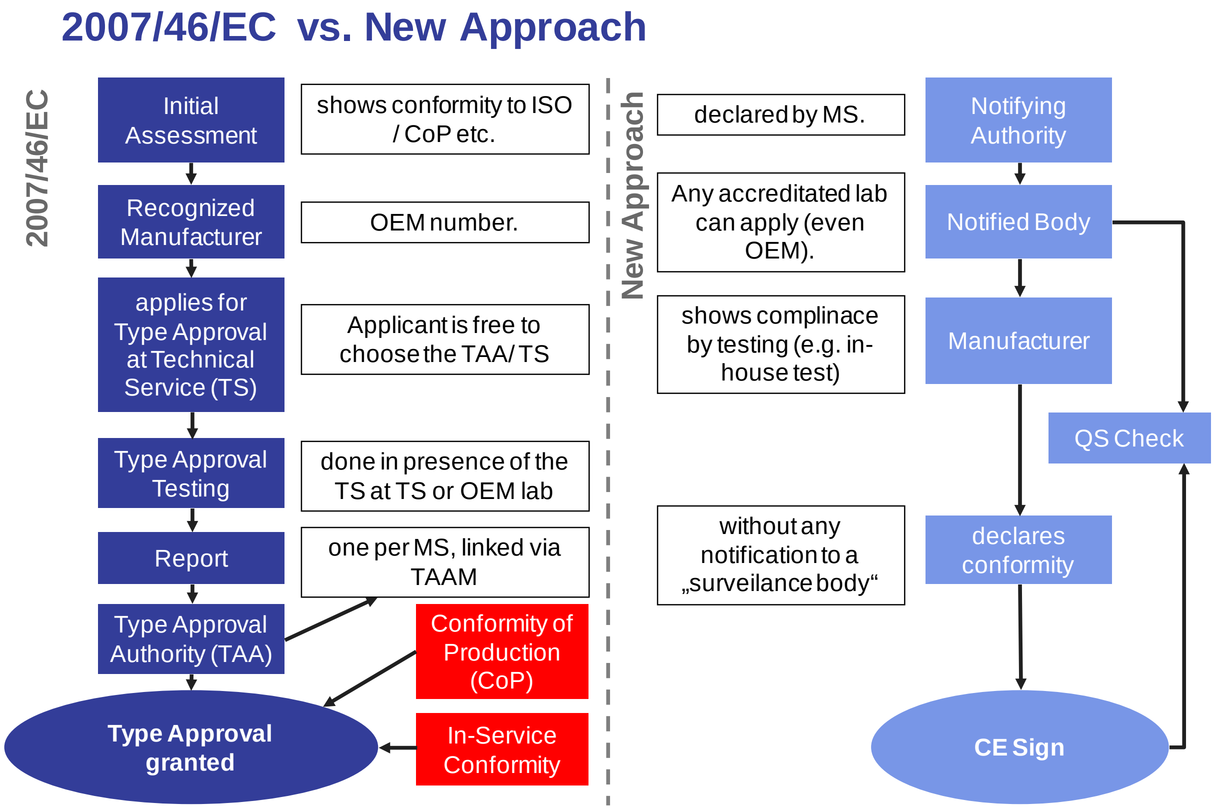

Figure 2: Comparison of Type Approval Approaches (e.g. 2007/46/EC) and the "New Approach"

Independent of the administrative way of approving a system for IWT purposes, the following three principal ways of approval in Table 11 must be linked to various technical solutions for emission control systems.

Approval of an engine (or an engine and an exhaust after treatment system) according to current regulations	This kind of approval is the normal way to go for new engine/engine family-types. 'Engine' in this case also refers to the combination of a combustion engine and an exhaust after treatment system, if the latter is necessary to meet the imposed requirements.
Approval of an exhaust after treatment system (efficiency check)	For retrofitting of existing engine systems with exhaust after treatment systems, only one regulation is available in Europe within the scope of Heavy Duty Vehicles (HDV), Non-road Mobile Machinery (NRMM) and agricultural and forestry tractors (ECE 132). In many EU member states, national regulations exist. However, this kind of approval does not deliver the absolute amounts of emissions of a retrofitted engine. It only shows the effectiveness of the after treatment system and does not specify the effect this system has on the engine emission out-performance.
Individual approval on a vessel by evaluating real world emissions	To modernize or retrofit the engines of inland waterway vessels, it must be assumed that system layouts may be very individual and not covered by any type approval. Furthermore, many vessel engines are so old, that no type approval was ever performed and no emission data is available. In order to evaluate the emissions output for this case, measurements on board of vessels must be performed with a portable emission measurement system (PEMS). For this way of approval, an approach is yet to be developed.

Table 11: The three principal ways of approval of a system

3.2 State of the art of emission reduction technologies

Several methods are used to reduce the amount of exhaust gas emissions. First, the ways to improve the environmental performance of stock engines is discussed. Next, this chapter goes into the methods to reduce the emissions output of existing engines. These are the retrofitting options.

Methods for stock engines

The way new engines are approved has had an impact on the strategies to reduce the emissions. Due to the rather late implementation of emission regulations with limit values depending on cylinder capacity, the majority of engines could meet the requirements by solely developing internal combustion strategies. This explains why most of these engines have no after treatment systems.

Depending on the age of the vessel and its engine, the technology features differ. Generally speaking, there are more and more medium speed engines in the IWT industry. Smaller vessels sometimes use engines that are originally created for road applications. These engines have speed levels of up to 2000 rpm. Typical methods to reduce the emissions of inland engines, include:

- Direct injection medium speed diesel engine
- Turbocharging

- Single stage turbocharging
- Sequential single stage turbocharging
- Two stage turbo charging
- Regulated two stage turbocharging
- Charge air cooling
- 4-Valve technology
- Common rail injection technology (single pump setup)
- Electronically controlled engines

For older engines, differences in injection technology (in-line fuel injection pump), supercharging (single stage turbocharger) and combustion layout with 2-Valve cylinder heads are typical.

Methods for retrofit devices

To improve the emission behaviour of stock engines mounted on vessels, various retrofit devices are available. Depending on the retrofit emission control principle, an existing type approval of the engine may be considered or not, notwithstanding the influence of a retrofit system on tailpipe emissions. Independent from the engine type approval, the vessel classification must be checked after any retrofitting.
Despite the question of a valid engine approval after retrofitting, the question of vessel emissions output with a retrofit system will be of interest. The different possibilities of retrofit devices are discussed below.

Modification of engine settings

Perhaps the easiest way of retrofitting an existing combustion engine setup to influence the engine's emissions output is the modification of the engine settings (like injection timing). A disadvantage of this method is the trade-off with another emission component. The reduction of NOx-emissions by late injection timing, for example, leads to higher particulate emissions and a higher fuel consumption. Another disadvantage of changing the engine settings is that the nonconformity has to the described and engine system needs to be tested if it was type approved.

Long or short route Exhaust Gas Recirculation (EGR)

The possibility of reducing NOx-emissions from internal combustion engines by using EGR is well-known. Figure 3 shows the influence an EGR system can have on the NOx-Emissions: it can reduce the NOx emissions by 90%. EGR-systems are either High Pressure (Short route) EGR or Low Pressure (Long route) EGR. Also combinations of both are known: see the system setups shown in Figure 4.

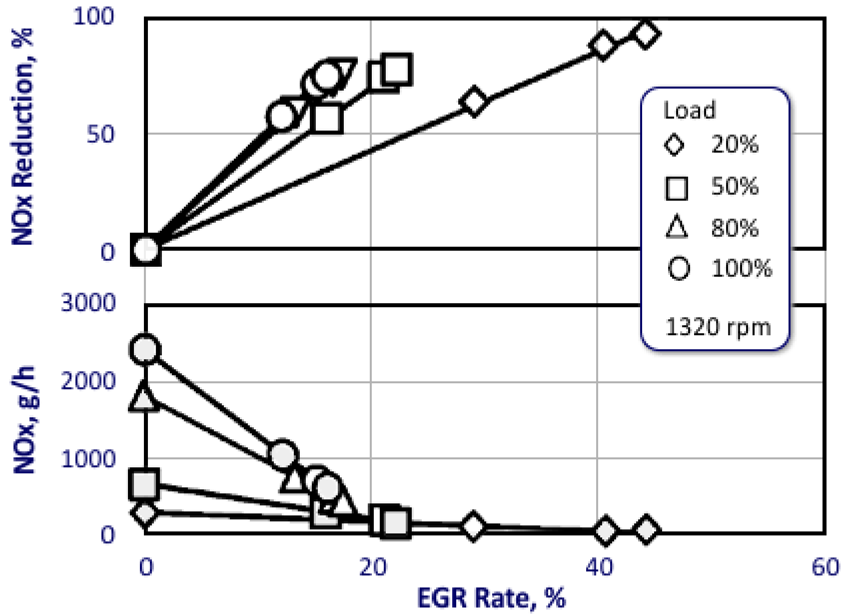

Figure 3: Influence of EGR on NOx emissions

https://www.dieselnet.com/tech/engine_egr_performance.php

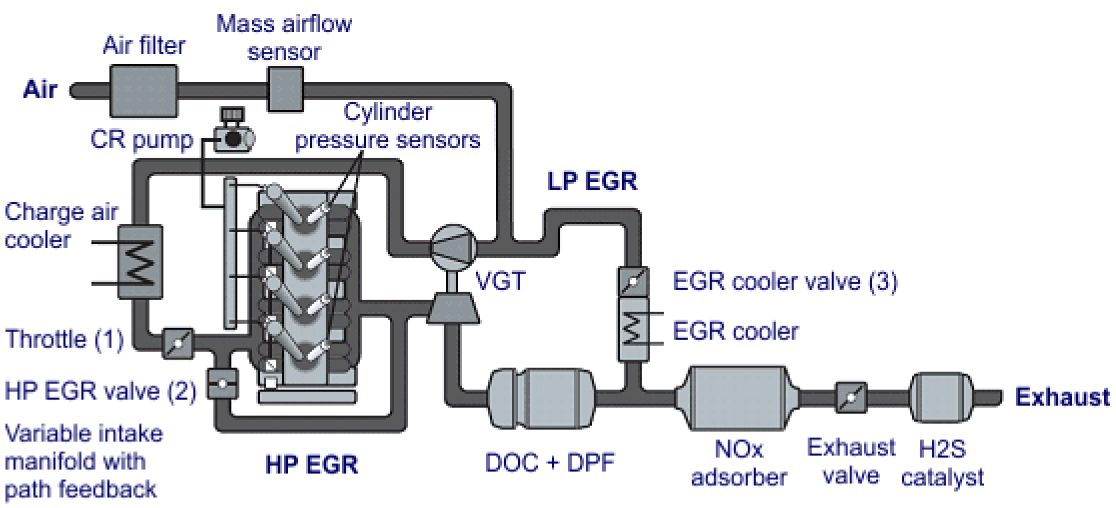

Figure 4: Example for a low pressure or long route and high pressure or short route EGR system

https://www.dieselnet.com/tech/engine_egr_sys.php#issues

EGR Systems do not belong to exhaust after treatment devices but are part of the internal layout of the combustion engine. Therefore any retrofit application of an EGR-System on an engine requires a new type approval. Because of very high application efforts for EGR retrofit systems, it is not very often used in marine applications. When it is used however, a very important lesson to be learnt from the automotive industry is that it should be ensured the EGR system is functioning properly in real-world operations. This measure is necessary because switching off the EGR system improves the operational performance of the engine – as contamination in the intake air circuit of the engine is avoided, and may therefore be considered by ship operators.

Diesel Oxidation Catalyst (DOC)

A Diesel Oxidation Catalyst is a catalytic converter, which will be fitted to the engine's exhaust system. It converts mainly HC, CO and some particulate mass, which are absorbed hydrocarbons on the soot. Figure shows the working principle of a DOC. The definition of "engine" in the description document for type approval normally ends with the outlet flange of the turbine of the turbocharger and the information about the maximum allowable backpressure at this point. A DOC is a passive component. If the increase of exhaust back pressure is within allowable limit values, the existing engine type approval is still valid.

It must be noted that bunkering fuels containing sulphur will poison the DOC, reducing its performance. This means that enforcement must be able to evaluate the performance of the DOC systems.

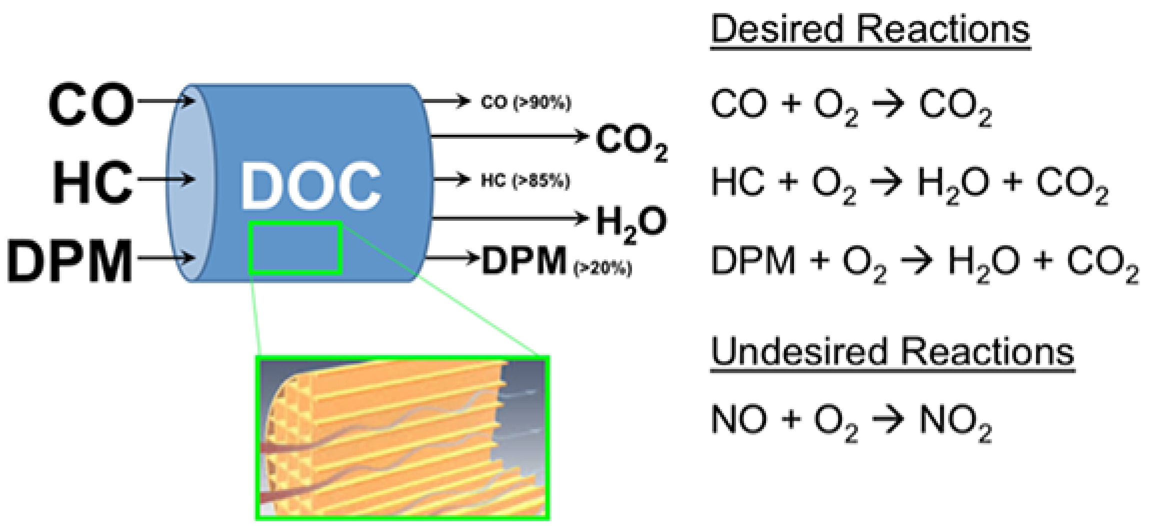

Figure 5: Diesel oxidation catalyst

http://www.airflowcatalyst.com/new/wp-content/uploads/2014/11/tech2.png

Diesel Particulate Filter (DPF)
Diesel particulate filters are components used to reduce particulate emissions. DPFs are available in various designs, substrates and working principles. Up to now, the main relevant systems are wall flow filters with very high efficiency (>95%). These filters need to be regenerated periodically or, if possible, continuously. The regeneration process needs a certain level of exhaust temperature depending on the regeneration principle. A very popular principle is a CRT regeneration (Continuously Regenerating Trap) in combination with a DOC upstream the filter in which NO is converted into NO_2. Regeneration of a DPF with NO_2 occurs above 250 °C and is in general continuous. This way of regeneration is also called passive regeneration. For active regeneration, exhaust gas must be heated up to 550 °C, which can be achieved through different strategies. Heating is obtained with a) late fuel injection, b) an additional burner in the exhaust system or with c) fuel injection into the exhaust system in combination with an oxidation catalyst. Figure 6 shows the principle of a wall flow filter.

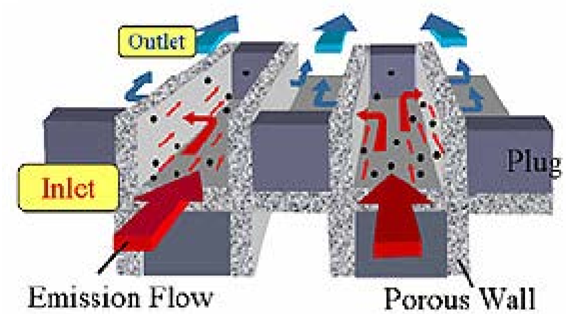

Figure 6: Principle of a wall flow particulate filter

http://www.atzonline.com/cms/images/f2008-06-058.jpg

The application of a particulate filter on an existing engine system needs the clarification of regeneration conditions. The possibility of applying a passive or continuously regenerating filter system must be checked in terms of operation profile, particulate mass in raw exhaust, exhaust temperature profile (e.g. 30 percent of operation time above 250°C) and exhaust backpressure. If a passive regenerating system is not applicable, an active or periodically regenerating trap must be foreseen with an adapted strategy of regeneration.
Depending on the regeneration strategy, the emission behaviour of an engine fitted with a particulate filter system varies. Therefore test procedures for type approval need to demonstrate continuous regeneration for passive systems during test cycles and emission behaviour over a “loading and regeneration cycle” for periodically regenerating traps. Testing procedures for this emission behaviour are known and implemented in different regulations. In case of remaining within the limits for the exhaust backpressure as specified by the engine manufacturer, the existing type approval of the engine is not influenced in the same way as described for DOC.
Nevertheless the implementation of a filter system in the vessel body needs a check of classification regarding different items. Filter regeneration is an exothermal reaction that creates the risk of increasing surface temperatures. There are also security items to be considered as e.g. engine stop because of blocked filter with emergency strategies. The next figure shows the application of a DPF on a MTU series 4000 engine.

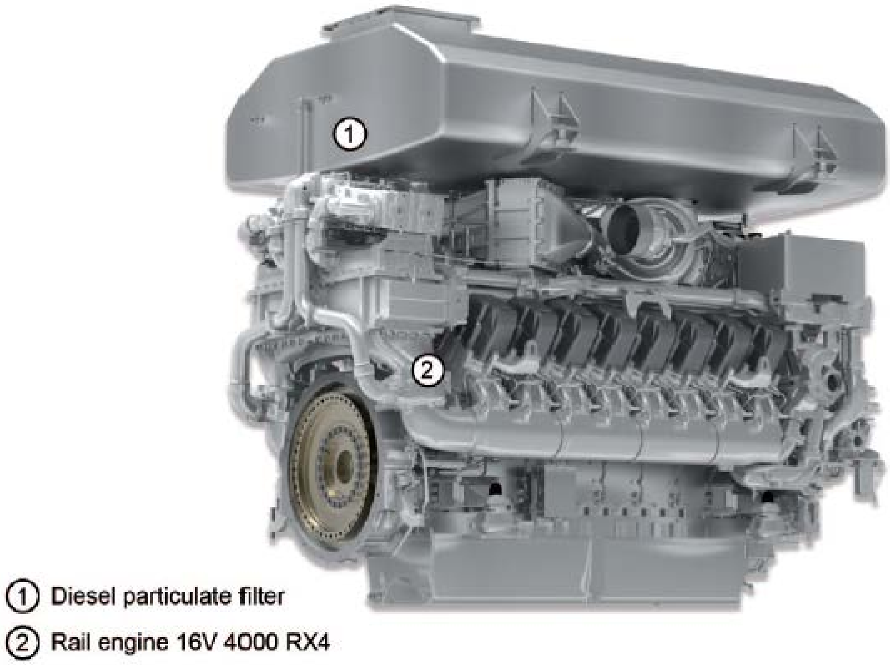

Figure 7: Example of a diesel particulate filter

With respect to enforcement of DPF's, the presence of the filters must be regularly checked. It may be tempting for ship operators to remove the filters because they require additional maintenance. Consequently unannounced periodic checks are necessary.

SCR catalyst

A Selective Catalytic Reduction Catalyst is designed to reduce NOx in the air excess of diesel exhaust using NH_3 as reagent. With a SCR system, high efficiencies (>70%) are possible but depend on operating conditions and engineering parameters. An ambitious task is the dosing of the reagent. Using an aqueous urea solution (AdBlue®) is the established way. To produce NH3 out of an urea solution, hydrolysis or thermolysis is necessary, which needs a minimum temperature level of 150 – 200°C.

Figure shows a typical SCR setup with a) an oxidation catalyst that converts NO into NO_2 (necessary for high SCR efficiency at low temperatures) and oxidises HC and CO, b) a hydrolysis catalyst for formation of NH_3, c) the SCR catalyst and d) the NH_3 slip catalyst to prevent ammonia emissions. [EMT2010]

(http://www.emitec.com/fileadmin/user_upload/Bibliothek/Vortraege/2010_SCR_Emicat_Temp_Strat_TU_DA_Umicore.pdf)

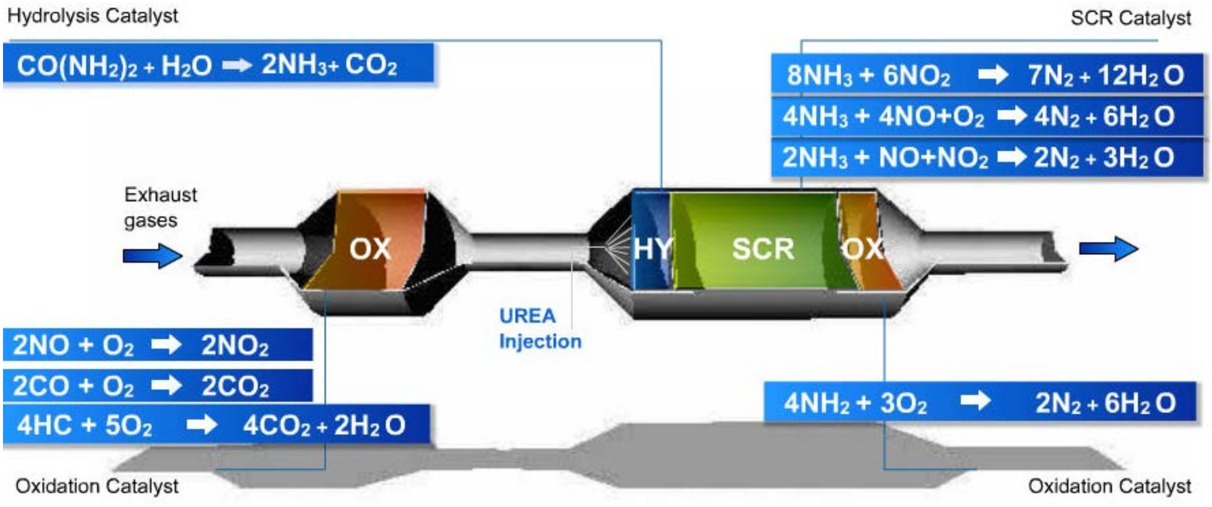

Figure 8: typical SCR catalyst setup

https://www.lubrizol.com/assets/0/294/1090/5069/5248/3f917b7e-c1fb-4170-b7be-98529d8ebc23.jpg

To control the functionality of a SCR system, a dedicated Adblue injection system is needed. The input parameters of this system are exhaust mass flow (speed and load), NOx mass flow rate of the engine and SCR-catalyst temperatures. SCR systems are available as a standalone solution, independent from the engine management system. Because of large number of implementation boundaries, each application of a SCR system on a vessel may be an individual task. Misapplications may lead to the blocking of the catalyst. In the case of a retrofit SCR system, the same engine type approval boundary conditions are valid as those described for DOC.
In type approval test procedures, SCR technology requires specific attention. Ammonia slip measurements must be part of the test procedure and the preconditioning must secure the absence of historical effects in the SCR-catalyst.
The consumption of AdBlue will increase the voyage expenses of vessel. This means there will be an interest to switch off the SCR catalyst or to reduce the amount of injected AdBlue. Enforcement regulations must ensure than there is a way to control the continuous operation of the SCR system.

DPF and SCR catalyst
To prevent emissions of the two most critical exhaust components particulates and NOx, the combination of a DPF and a SCR system is a usual setup. Because of the common need for an oxidation catalyst, a typical setup has the particulate filter substrate downstream of the oxidation catalyst, which in turn is upstream of the urea dosing. Sometimes setups are used where the filter substrate is catalytic coated and combines the functionality of an oxidation catalyst and a particulate filter. Figure 9 shows two variants of system setups for a vessel. All other boundaries are the same as those described for DPF and SCR systems.

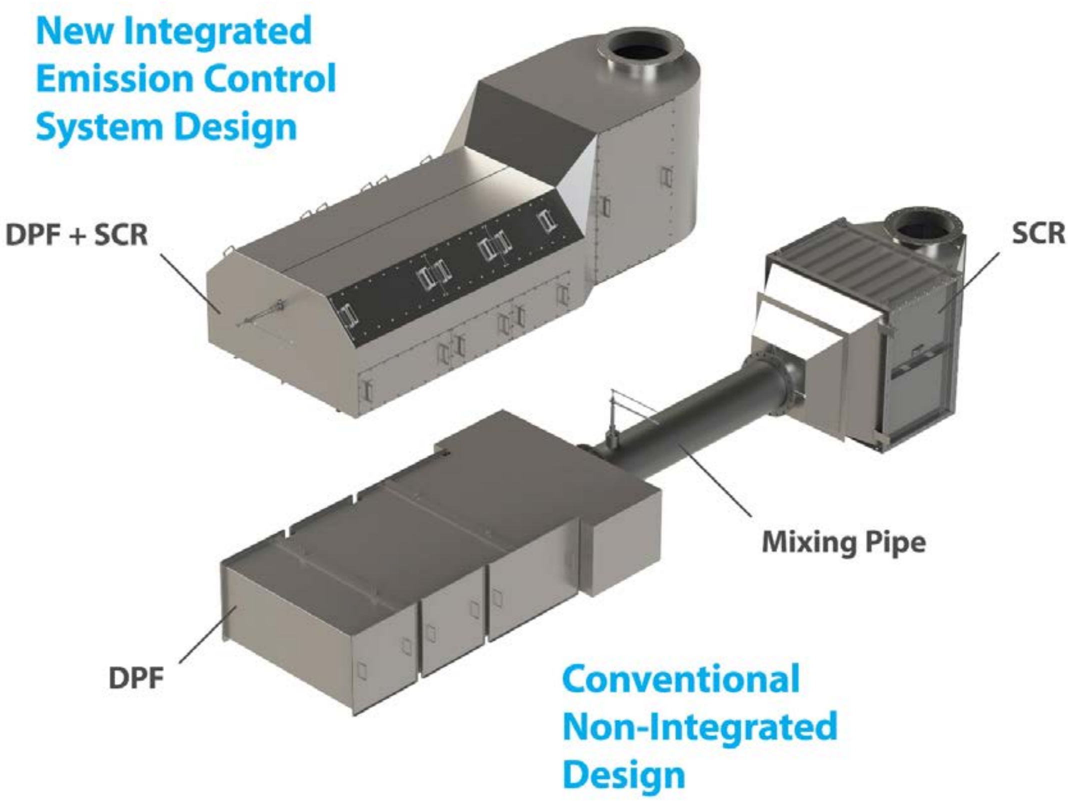

Figure 9: DPR+SCR in a conventional and an integrated setup

http://www.marinelink.com/images/maritime/Johnson_Matthey_Int_SCRT_System-24475.jpg

NOx storage catalyst

The technology of a NOx-storage catalyst in diesel exhaust gas stores NO_2 on a Barium oxide during conditions with high air-fuel ratios. Once the LNT-catalyst is saturated, it needs to be regenerated under conditions with low air-fuel ratios. Because of this functionality principle, a NOx storage catalyst needs to be integrated into the engine management system to realize short periods of combustion events with low air-fuel ratios. These are abnormal conditions for diesel engines. Usually this technology is found in passenger cars with an engine displacement of up to about 2 litres. These boundary conditions and especially the needed system integration does not recommend NOx storage technology for vessel application or as a vessel retrofit device. Figure 30 shows the working principle of a NOx storage catalyst.

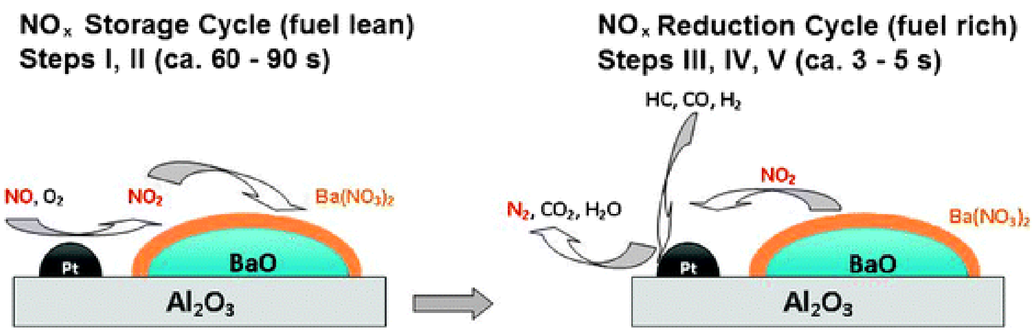

Figure 30: Principle functionality of a NOx storage catalyst [PUB2011]

If LNT technology does penetrate the IWT market, emission regulations must focus on real sailing emissions because regenerations of a LNT might be deactivated.

3.3 Certification possibilities for retrofit devices

As aforementioned, the certification or approval of retrofit systems for vessel applications is not covered by any European regulation. Currently only an approval of the engine with the exhaust after treatment system is possible. Beside the existing procedure, additional procedures to approve any kind of retrofit on vessel engines would be desirable. These additional procedures should cover an approval of exhaust after treatment system families or components and an approval of a single application.

Certification of new engines

The common certification of a new engine type (engine family type) together with a retrofit system is described in current regulations such as 97/68/EC or the CCNR regulations. The approval yields the emission results for the tested engine/exhaust after treatment system. The owner of the approval (normally the engine manufacturer) is responsible for the complete type-approved system including the exhaust after treatment system.

For inland waterway transport, another constellation is conceivable: the manufacturer of exhaust after treatment systems would like to get a type approval for the combination of an engine (engine family) and an exhaust after treatment system. This approval also delivers emission results for the tested setup. There is one challenge of this constellation, namely that the manufacturer of the exhaust after treatment system as owner of the type approval will be forced to become engine manufacturer of the used engine type with all duties of a type approval, which means CoP (Conformity of Production), duration warranty and so on. This enforcement is not a convenient solution but provides the opportunity to get a type approval for the combination of a non-type-approved engine with an exhaust after treatment system.

Certification of retrofitted systems

Due to the fact that an exhaust after treatment system may be designed for stand-alone use, independent from the control system of a combustion engine, the possibility to have a system type approval for retrofit systems should exist. For Europe there is just one regulation (ECE R132), dealing with the approval of retrofit exhaust after treatment systems. A lot of member states do have national solutions, but for many applications, as for inland shipping, an adequate legal framework is missing. The common target, to improve the emission situation for inland waterway shipping will stimulate the development of a regulation for retrofit exhaust after treatment systems on vessel applications. This may be realized for example as an amendment to ECE R132 or with solutions for its own. All tools as test cycles (ISO 8178-4), measurement equipment, test procedures and family concepts are basically known and must only be tuned to vessel applications. Compared to type approvals of engines and engine/after treatment systems, which result in an emission value for one engine or engine family, an approval of an exhaust after treatment system will always result in a reduction efficiency of the system regarding the different limited components. That means that the emissions of a type approved engine, retrofitted with an approved exhaust after treatment system can be determined by just multiplying the engine results with the approved efficiency of the after treatment system. This will be an approximate value.
The advantage of a type approval for retrofit systems, which contains a detailed description of the after treatment system and its characteristic parameters as it is required for example in ECE R132,

is the possibility of retrofitting as many vessel engines as defined in the range of use of the type approval without additional certification work (except classification issues).
Even if the described way of type approval will help to retrofit a great number of vessels, there are a high number of vessels (especially the older ones) which will not be covered by such approvals. Very old engines on vessels without any approval regarding emissions will not be present in ranges of use. Furthermore, even if retrofitting these engines is possible from the technical point of view, such a solution will not get a certification. For this situation, it would be very helpful to have a procedure that allows certification to be granted on basis of real world emission measurements. This is a new challenge, because until now no approvals based on real world emission measurements only exist.

A possible tool to aid in the creation of on-board certification procedures is PEMS (Portable Emission Measurement System). This technology and the procedures for PEMS measurements, described in various regulations (ECE R49; EU 595/2009 with 582/2011), have not yet been used for type approval tests. For Euro VI Heavy Duty Vehicles real world measurements are used for ISC (In Service Conformity), which is a confirmation of regulation compliance of customer cars. Currently, a procedure for passenger cars called RDE (Real Driving Emissions) is under development. This procedure will look at vehicles emissions under real driving conditions.
Outside of the regulatory scope, PEMS technology is used also for emission measurements on vessels. Obtaining precise data about the power output of the engine is one of the problems that occur in measurement setups on a vessel. The determination of the engine's exhaust mass flow is another challenge. Given these problems, it seems necessary to develop a measuring procedure using PEMS on vessels in order to realize a certification of any kind of retrofit by measuring real world emissions.

3.4 Future technologies and fuels for IWT

Beside the new developments of diesel technology and the well-known exhaust after treatment systems, trends are observed at the level of future technologies for vessel propulsion. Nearly all activities in this area deal with the optimization of combustion engines concepts. One key issue is fuel.

Diesel-Water Emulsion

Diesel/Water-Emulsions are being researched because of their theoretical potential to simultaneously reduce NOx and particulate (soot) emissions. Investigations on a test bed and measurements on a vessel show a potential to reduce soot emissions by up to 90% and NOx by up to 45%. For a retrofit application of a Diesel/Water Emulsion system on an engine, some key issues need to be researched:

- The substitution of fuel by water leads to a loss of power. To keep the engine on a same maximum power output, the fuel injection device must be able to compensate the water volume by a higher fuel delivery per stroke. This may be possible by using capability reserves or modifying the injection devices.
- Safety issues like engine restart after a shut down during emulsion operation need to be tested and certified during a classification check.
- Long term durability performance of in-service engines seems to –still- be an issue with diesel-water emulsion technology.

Because fuel is mixed with substantial amounts of water, this technology could be seen as a change of the fuel. Such a change severely affects the engine performance and emissions output, which in turn means it is necessary to perform type-approval tests for engines running on diesel-water emulsions.

LNG-technology

LNG (Liquefied Natural Gas) provides new possibilities to store and transport natural gas. Given the relative high density (compared to CNG) and the volumetric energy content, the attractiveness of natural gas for mobile applications increases with LNG.

Engine concepts for LNG use are developed for various applications. These are working as SI-engines (Spark Ignition), which have advantages in terms of emissions reduction of about 20% CO_2, 80 – 90% NO_x and nearly 100% of particulates. Due to the relative high fuel consumption it is not expected that stoichiometric LNG engines will be adopted by IWT.

Compression ignition engines can be modified for diesel-lng operation (dual fuel) but there is a big concern regarding methane emissions. In future emission legislation methane limit values must be also taken in to account. Currently the maximum allowed proposed THC limit value for certain LPG /CNG/LNG applications is 6.19 g/kWh. In case of a specific engine fuel consumption of 200 g/kWh, this implies a waste of fuel of 3%. Special attention must be given to long term methane emissions because there are some concerns of the durability of methane slip catalysts.

It is expected that the number of LNG propelled vessels will increase. One indication is the EU masterplan for LNG (2012-EU-18067-S) for Rhine, Main and Danube, which is installed to promote LNG infrastructure along the waterways.

Figure 11 shows the inland waterway tanker “Greenstream” with LNG-Electric propulsion.

Figure 11: Tanker “Greenstream” with LNG-electric propulsion [IWN2013]

This technology will be established for new ship developments and seems not be economically feasible in case of re-motorisation or retrofit application.

Alternative fuels, CNG and LPG

CNG (Compressed Natural Gas) is stored as a gas and transported under high pressure to increase density and reduce storage volume. LPG, a result of crude oil refining, is a liquid mixture of propane and butane. The development of engine technologies for LPG follows a similar path to that of LNG. Because of the EU masterplan LNG, which promotes LNG as favourite fuel, CNG and LPG are possible technologies, but will remain a niche product or interim solution.

To find alternatives to conventional crude oil based fuel, the development of alternative fuels has intensified over the last years. A lot of commercially available fuels such as GTL or BTL can be typically used in diesel engines without any modification of the engine. The paraffinic fuel structure and high cetane numbers will lead to substantial CO, THC and PM10 emission reductions. This brings advantages especially for CO, HC (up to 80%) and PM emissions (up to 30%) [5]; In general, the NOx emissions reduces slightly (0-12%).

Introducing these alternative fuels to inland waterways shipping will largely depend on the availability of necessary infrastructure and the price evolution of the various conventional and non-conventional fuel types.

Dual fuel applications

Due to the cost advantage natural gas holds against diesel, the demand for the former use led to the development of dual fuel applications (i.e. diesel-LNG) for different uses. Dual fuel applications need hard- and software modifications, which result in a change of the engine emission behaviour. In this case, methane emissions in particular should be monitored: diesel combustion at low loads is relatively cold, which may lead to high methane emissions because a good combustion of methane requires a relative high combustion temperature level.

Hybrid applications

Hybrid application entails the combination of at least two principles in a powertrain, i.e. a diesel engine and an electric engine with separate energy storages. For hybrid applications, various setups are possible (in series or parallel). Basic system setups for hybrid applications are currently state of the art in a number of markets e.g. HDV. For new vessels, hybrid applications are used to optimize the point of operation of the combustion engine. Approval of hybrid systems for NRMM - including vessel applications - has not yet been discussed, but the solution used for Heavy Duty Hybrids, which is a HILS (Hardware in the Loop) approach, may be a guide for future NRMM discussions.

Future technologies and certification

For all future technologies, the question of approval is to be discussed. It must be checked whether a technology is covered by existing regulations or how regulations must be changed for future applications. The main parameters to be discussed are:

- Are existing testing procedures applicable to new technologies?
- Are the boundaries of a new technology covered by current regulations or are there parameters which need to be adapted (like definitions of new fuels)?
- Is it possible to transfer operation strategies of new technologies to a representative test bed procedure?
- Are costs of type approval reasonable for small serial production to be expected for new technologies for vessel applications?

[5] http://infohouse.p2ric.org/ref/46/45872.pdf

- Is there a need for an easier approval approach due to costs and administrative efforts for small manufacturers and single applications?

Possibilities with current regulations
A lot of future technologies like alternative fuels and new combustion principles - like dual fuel applications, are not covered by the actual state of current regulations, but in many cases, the regulations for type approval could be modified in the necessary way through some amendments.

All future technologies based on the exclusive use of fuels other than diesel (EN590), are covered by existing regulations if the fuel is described as reference fuel. This is also valid for spark ignition engines. The draft for amendments of 97/68/EC contains Diesel fuel (B7), Ethanol (ED95) for compression ignition engines, Petrol (E10), Ethanol (E85), LPG and methane/Bio-methane fuels.
For heavy duty on road vehicles (EU 595/2009), the use of other fuels, listed as a reference fuel, is possible, if the manufacturer will show compliance with the regulation by use of this fuel. This feature of the regulation opens the possibility to use different fuels, if they are described e.g. in a normative regulation. Such a solution would also be appropriate for NRMM engines, including vessel engines.

Dual fuel applications are not covered by the current NRMM regulations but it is planned to be included in the future Stage V legislation. For heavy duty on road vehicles the testing procedure for approval of dual fuel engines (diesel and natural gas) is described in ECE R49.06. This regulation should be transferred to NRMM regulations.

Hybrid applications require adapted test procedures. All tasks mentioned before are also valid for engines in hybrid applications. An additional task, which is not so easy to define, is the implementation of the hybrid operational strategy into the test procedure. Even for on road applications for heavy duty vehicles, this task is not solved yet for European or ECE regulations. The favourite approach is HILS (Hardware in the Loop), where the hybrid part is simulated to calculate a combustion engine load cycle.

On board certification is needed. All possibilities of approval described before are for type approvals of new engines or engine/after treatment system combinations; nevertheless system setups of stock engines in combination with future retrofit concepts are conceivable. Especially for older engine types and single applications, there should be a possibility to get an approval on basis of an on board real world emission measurement. For NRMM regulations, PEMS measurements on mobile machinery are in discussion for In Service Monitoring (ISM).

3.5 Specifications of measurement equipment and accuracies of test results

In emission tests the next parameters determine the accuracy of the total test results:

- Accuracy of measuring equipment
- The possibility to measure parameters directly or indirectly
- The ability to set and control engine speed & load
- Load and operating conditions of auxiliaries and powertrain elements
- The repeatability of the test (ambient conditions and river flow patterns may not be stable)

In an engine laboratory all required basic parameters can be measured in an accurate way and this yields very accurate test results. However on board tests have restrictions, some parameters cannot be determined or must be derived. For every future candidate test procedure the total accuracy of the test result must be determined.

In **Table 12** an example of an overview of measurement parameters to be judged is given.

Parameter	Unit	Example Engine test bed Accuracy
Fuel mass flow rate	g/s	1-2 %
Air mass flow rate	g/s	1 %
CO	ppm	1 %
CO2	%	1 %
THC	ppm	1 %
NOx	ppm	1 %
PM10 mass	mg	0.1 %
Temperatures	°C	1.0 °C
Absolute humidity	G H_2O/ kg air	1 %
Engine Torque	Nm	1 %
Engine speed	Rpm	0.5 %
Auxiliaries	kW	
Powertrain devices	kW	

Table 12: Example parameters and accuracies of test equipment

4 Potential improvements of emission certification

The European directives 97/68/EC & 2004/26/EC are currently the basis for certification of engines of inland waterway vessels. In the near future more stringent emission limit values will be set and new technologies will be implemented in existing vessels. Therefore certification procedures must be adapted and improved.

4.1 Why are improvements of current certification procedures needed?

In the near future, besides new and updated engine technologies, exhaust after treatment systems will be implemented in (existing) inland waterway vessels. The function, nature, behaviour and needs of these after treatment systems are different from combustion engines and more complex; real sailing emissions may deviate strongly from type approval emissions. In order to secure their emission performances and emission levels in daily operation certain additional requirements in certification procedures are needed.

In the next enumeration the different subjects for possible improvements of certification are listed:

- Kind & type of certification*
- Administrative procedures
- Number of engine types per certificate
- Test procedures*
- Conformity of production*
- In-use compliance *
- Representativeness & Real sailing emissions*
- Waterway worthiness *
- Monitoring*
- Enforcement*

*In the view of the scope of this Work package the certification subjects which might be improved are further explained in this chapter.

4.2 Which lessons can be learnt from other sectors?

In the last twenty years real world emissions of road transport vehicles deviate more and more from their type approval emissions. Despite good emission performance of road transport diesel vehicles in type approval tests real driving NOx emissions of most diesel vehicles are 3-10 times higher and exceed by far the type approval limit values.

USA

Severe problems with discrepancies between real driving emissions and type approval limit values were first experienced in USA with HD trucks. This was at the end of the nineties. The truck engines used a kind of 'dual mapping'. During type approval a low NOx map was used, while on the road predominantly a high-NOx, low fuel consumption map was used. The problem led to enormous fines (hundreds of millions, up to some $10,000 per engine supplied) for all HD engine suppliers.

The problem also led to a simple and effective adaptation of the certification test procedure, which mainly consisted of:

- The addition of the European Stationary test Cycle; ESC (!). This in additional to the US-HD transient test cycle.

- The addition of a Not to Exceed (NTE) area in the engine map. The NOx emissions were not allowed to exceed a max value (in g/Bhph) for each point in this area, which covered a large part of the engine map.

Diesel cars

The problems with high NOx emissions of Volkswagen diesel cars in 2015 (diesel-gate) is due to 'defeat software' which would recognise laboratory conditions and then lower the emissions. This is basically very similar to the dual mapping of the nineties described above.

Europe

In extensive in-use compliance programs of the Dutch Ministry of Infrastructure & The Environment real driving emissions of Euro 5 LD-vehicles [TNO2012], Euro 6-vehicles [TNO2015a], Euro 5 Light Commercial Vehicles [TNO2015b] and Euro V and VI HD- vehicles [TNO2010] are reported. These results have been summarised in an overall report [TNO2015c].

Except Euro VI trucks all diesel trucks have relatively high real driving NOx emissions, see Figure 4. These elevated NOx emissions are part of the standard engine calibration and settings and result in lower operational costs (lower fuel and AdBlue consumption). On the contrary Euro VI trucks perform very well; their real world emissions are in line with type approval emissions. The main reason for these low real world emissions is the Euro VI legislation which regulates and limits real driving emissions effectively.

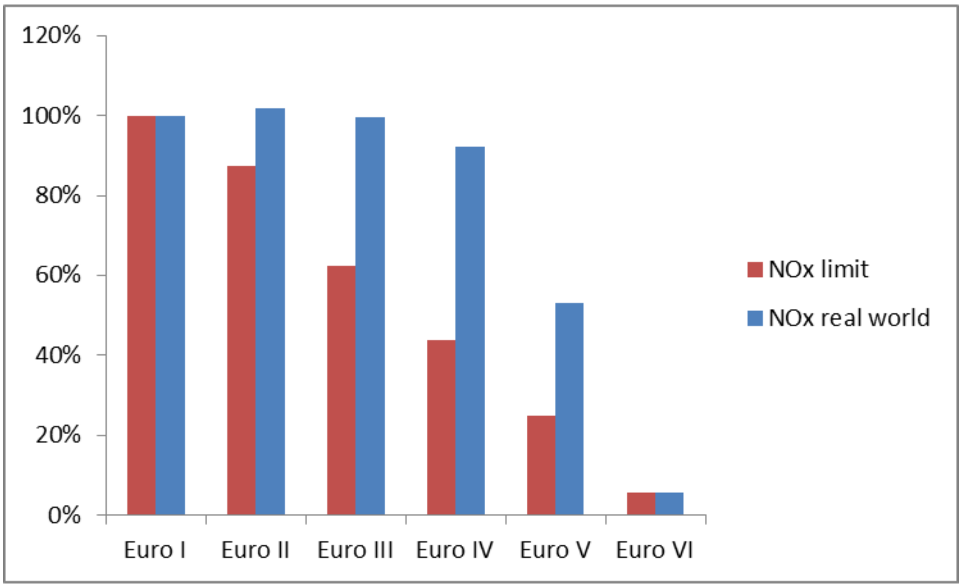

Figure 4: Relative NOx limit values and real world emissions of HD vehicles

In Figure 5 the emissions of diesel passenger cars are shown. In most cases the real world emissions are 5-10 times higher than the type approval emissions. This legislation doesn't contain requirements for Real Driving Emissions. Again low fuel consumption and less operational costs are the main drivers for these emission characteristics.

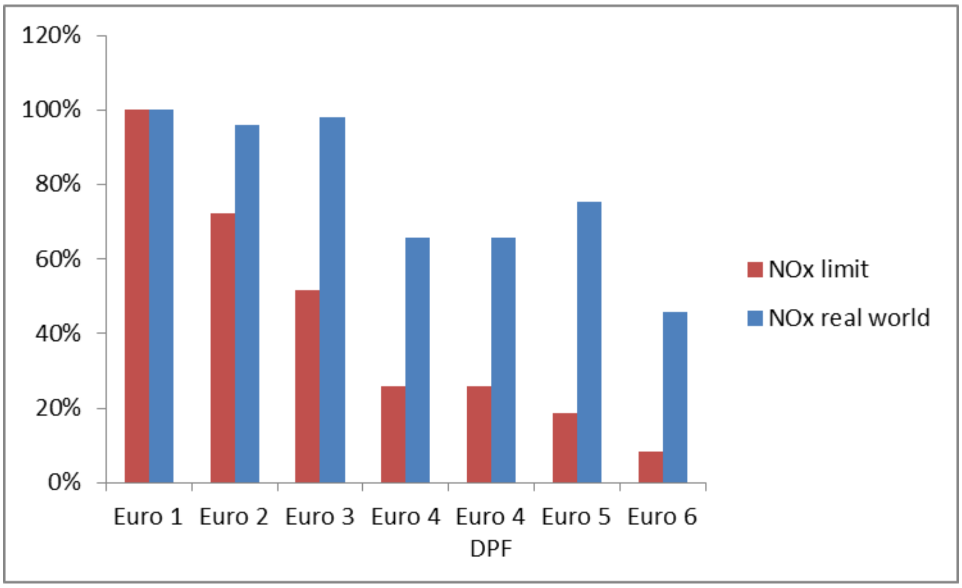

Figure 5: Relative NOx limit values and real world emissions of LD diesel vehicles

From these research and monitoring activities it is clear that real driving NOx emissions may deviate strongly from type approval emissions. The implementation of modern technologies which are controlled by micro-processors may facilitate this emission gap. It can be concluded that dedicated real driving emission legislation is needed to avoid high real world emissions.

On the contrary the implementation of closed diesel particulate filters in Euro 5 passenger and commercial vehicles and Euro VI trucks is an example of effective implementation of technology. This technology has a passive character (no adjustments are possible) and this results in very high PM filtration efficiencies in all engine conditions. As long as the diesel particulate filters are mounted and well maintained the PM-emissions of these engine are near zero.

What can be learned from the road transport sector?
Without specific real sailing legislation the inland waterway transport sector might follow the road transport sector. Than it can be expected that real sailing emissions will be relatively high because stakeholders will optimise on costs (i.e. low fuel consumption). It can be concluded that the quality of emission legislation heavily determines the real sailing emissions of IWT.

4.3 Development of type approval procedures in other sectors

For other applications as e.g. on road transportation, emission regulations were developed very detailed according to the impact of the application to the overall emissions. Engines of heavy duty vehicles and high powered non-road mobile machinery are more similar to vessel engines regarding engine technology than other applications. Especially the heavy duty vehicle regulations (EU 595/2009 or ECE R49) for EURO VI vehicles are upfront and include some features, which led to low real world emissions as shown in a lot of investigations.

Heavy Duty Vehicles

The test procedures for heavy duty vehicles contain different tests on engine test benches and emission measurements under real world conditions as

- WHTC (Worldwide harmonized Heavy duty Transient Cycle), which is a transient test cycle to represent urban, rural and motorway operation.
- WHSC (Worldwide harmonized Heavy duty Stationary Cycle), which is a test cycle of 13 speed/torque targets
- OCE (Off Cycle Emissions), which are tested on test bench by 15 random speed/ torque operating points (WNTE) ((Worldwide harmonized Not to exceed)
- Another part of OCE describes a vehicle trip under real word conditions, fitted with a PEMS (Portable Emission Measuring System) for confirming emission compliance with a conformity factor of 1.5 related to WHTC limits.
- OBD (On Board Diagnostic) which is a system, installed at the ECU of vehicles/engines for diagnostics of engine hardware and exhaust after treatment system functionality.

Overview

In Table 13 an overview is given about the development in certification test procedures for road vehicles and for Non Road Mobile Machinery.

Year	Category	Developments in test procedures
1998	HD trucks USA	US HD transient test European Stationary Cycle Not to Exceed
2000	Trucks Euro II, IV and V	New test cycles including transient test cycle: - European Stationary Cycle - European Transient Cycle - Linearity check and requirement
2010	Non Road Mobile Machinery, categories	ISO 8178 steady state mode test Non Road Transient Cycle (NRTC)
2014	Trucks Euro VI	New test cycles and Emissions test on the road: - World Harmonised Transient Cycle (WHTC) - World Harmonised Stationary Cycle (WHSC) - PEMS test on road (PEMS=Portable Emissions Measurement System)
2017	Euro 6 diesel cars	New test cycles and Emissions test on the road: - World Harmonised Light Duty Test procedure - PEMS emissions test

Table 13. Development in certification test procedures in order to cope with stringent limit values and secure low real world emissions

According to Table 13, the adaptations can be summarized as follows:
- Improved test cycle (stationary and/or transient test)
- The addition of a stationary of transient test
- The addition of a Not to Exceed area.

Table 14 shows the limits for Euro VI trucks (EU 595/2009). The NOx limit values are approximately 20 times lower and PM limits are 20-30 times lower than CCNR Stage II limit values.

Euro VI Emission Limits

	Limit values							
	CO (mg/kWh)	THC (mg/kWh)	NMHC (mg/kWh)	CH_4 (mg/kWh)	NO_x (1) (mg/kWh)	NH_3 (ppm)	PM mass (mg/kWh)	PM (2) number (#/kWh)
WHSC (CI)	1 500	130			400	10	10	$8{,}0 \times 10^{11}$
WHTC (CI)	4 000	160			460	10	10	$6{,}0 \times 10^{11}$
WHTC (PI)	4 000		160	500	460	10	10	(3)

PI = Positive Ignition.
CI = Compression Ignition.
(1) The admissible level of NO_2 component in the NO_x limit value may be defined at a later stage.
(2) A new measurement procedure shall be introduced before 31 December 2012.
(3) A particle number limit shall be introduced before 31 December 2012.'

Table 14: Emission limits for Euro VI Heavy Duty Applications

NRMM

The European emission regulation for Non-road Mobile Machinery (97/68/EC) has an engine scope from small handheld engines like motor saws or lawn mowers, to engines for generators, excavators or mobile cranes up to engines for inland shipping or rail traction. According to the emission impact, regulation amendments first deal with engines e.g. of construction machinery.

Table 15 shows the emission limit values of the latest amendments for engines for use in other applications than propulsion of locomotives, railcars and inland waterway vessels. Table 14 shows the limits for Non-road Mobile Machinery. The NOx limit values of NRMM are approximately 20 times lower and PM limits 10 times lower than CCNR Stage II limit values.

Category: Net power (P) (kW)	Carbon monoxide (CO) (g/kWh)	Hydro-carbons (HC) (g/kWh)	Oxides of nitrogen (NO_x) (g/kWh)	Particulates (PT) (g/kWh)
Q: 130 kW $\leq$ P $\leq$ 560 kW	3,5	0,19	0,4	0,025
R: 56 kW $\leq$ P $<$ 130 kW	5,0	0,19	0,4	0,025

Table 15: Emission limit values for NRMM engines of category Q and R, stage IV

The test procedures of this regulation are based on different test cycles according to the engine use as described in ISO 8178-4. For some engine categories features like transient test cycles, NTE (Not To Exceed) or NCD (NOx Control Diagnostic) are realized. For future amendments ISM (In Service Monitoring) by use of emission measurements performed during real world operation with PEMS is foreseen.

4.4 Why can on board tests be relatively inaccurate?

The emissions of NOx and particles of vessels become more important as land sources are more reduced / eliminated. Therefore accurate measurement of real sailing emissions of vessels is needed.

General parameters must be measured

In order to determine the emissions of marine engines on board of ships, the following parameters have to be measured accurately:

- Engine power in kW
- Engine speed in rpm
- Fuel consumption in l/h or kg/h
- Oxygen content in the flue gases
- CO, CxHy, NOx contents in the flue gases
- Fuel analyses in order to determine the amount of C-H-O-N-S, calorific value and density.

All these parameters are needed to determine the emission results in g/kWh.

On-board operating parameters must be available, accurate and reliable

Most ships lack accurate equipment in order to determine the power output, engine speed and fuel consumption. If a ship is equipped with the mentioned equipment, the inaccuracy of the equipment is mostly not (accurate) determined, nor is the equipment calibrated.

The engine load differs widely at defined engine speeds

The results of the power output and fuel consumption on board at a certain engine speed of sailing ships are affected by several amendable parameters around the ship, like

- depth of the water under the ship and width of the waterway
- flow rate of the water in the river, sailing upstream or down stream
- wind speed and wind direction

The inaccuracy of measurement results

The inaccuracy of the emission test results is affected by the inaccuracies of all the parameters responsible for the results, not only by the emission measurement equipment.

The inaccuracy of the emission measurements with standardised measurement equipment in the exhaust pipe is known as the equipment, the calibration gases and the measurement location is tested conform several relevant European standards. In case the power output and fuel consumption is measured by the ships, the inaccuracies of this measuring equipment are mostly unknown.

Increased or decreased inaccuracy of the measurement results

Emission measurements can be performed with official, standardised test equipment or with non-standardised equipment. Regulation of emission on shore is based on results obtained with standardised test equipment conform official European / International agreed standards. European and / or international standardisation organisations require specific measurement principles as the results given by these specific measurement principles are the most accurate when used in a correct manner.

The non-standardised measurement equipment lacks generally extensive performance tests that have to be performed on the standardised equipment.

On most ships, the fuel consumption can be taken from the on board computer. Unlike the fuel consumption meters in official engine test benches, these meters on board are neither calibrated nor maintained. On test benches, the power output of the engine is measured with a water brake or Eddy Current brake or in a generator formation. On the test bench the engine performance or relation between fuel consumption and power output can be ascertained. Although the on-board engine performance depends on for example the propeller diameters, the power output on board is calculated from the engine characteristics and the fuel consumption. This automatically leads to an increased uncertainty.

Official, standardised fuel meters, strain gauges in full-bridge arrangement for determining the shaft torque can be used in ships to perform the fuel consumption and power output measurements on a relatively accurate manner.

In conclusion, the most accurate way to determine the emission performance of an on board engine is to use the official standardised instrumentation and adequately educated technicians. In case non-standardised equipment is used and/or technicians that are not trained properly and/or derivative calculations are used, the inaccuracy can increase severely.

4.5 How can the emission certification be improved?

Kind & type of certification:
The European directives 97/68/EC & 2004/26/EC describe certification procedures for combustion engines which can be equipped with an after treatment system. For technical and practical reasons, engines are certified as a product in an engine laboratory. Moreover the quality and accuracy of the test result is very high. In general this certification procedure fits new engines very well. However real sailing emission tests are not part of this procedure. If the procedure is extended with dedicated real sailing procedures, emission levels are better secured.

Existing vessels need on board certification procedures:
For upgraded engines or retrofit systems the certification procedure in a test laboratory is very complex and expensive because engines must be removed from the vessel, transported and prepared for laboratory testing. And after testing the engine must be placed back in the vessel. It is expected that a lot of future engine upgrades of inland waterway vessels are carried out on board and this creates a need for field certification procedures.
Field certification tests are already developed in other sectors and described in ISO 8178-2 and MARPOL 73/78 Annex VI procedures. These test procedures might be a basis for field certification of inland waterway vessels.

Certification of real sailing emissions requires a dedicated test procedure:
Once a certified engine runs on board of an inland waterway vessel currently no in-use compliance test is required. Consequently this lack of technical standards and testing creates a much undefined level of real sailing emissions. In order to secure real sailing emissions a dedicated test real sailing procedure is needed.

Current test procedures can be improved and need to be extended
Current certification procedures consist of fixed emission tests which cover partly daily operation. Test procedures which cover better real sailing practice must be developed for IWT. Probably a new test procedure consists of more emission tests. In the next list different types of potential tests which can improve the quality of an emission test procedure are reported:

- Engine (+ catalyst and/or DPF) certification on an engine test bed.
- Catalyst/DPF certification on an engine test bed.
- Emission tests under field conditions.
- In-use compliance tests.
- Real sailing emission tests.
- Waterway worthiness tests

In order to develop a feasible test procedure the next criteria for judgement must be taken in to account:

- Representativeness
- Administrative burden
- Applicability
- Feasibility
- Costs
- Acceptance of stakeholders

Conformity of production:
Engine manufacturers must apply in engine mass production emission conformity tests. In these tests some selected new produced engines are tested on an engine test bed and emission performances must be within a certain bandwidth. In the future this practice can be continued because it serves very well mass production purposes. However upgraded engines or retrofit equipment will probably be tested on board and the test possibilities of these individual engines differ per vessel. Due to this variety of test conditions the conformity of production methodology cannot be applied on board.

In-use compliance:
In-use compliance tests are not part of current IWT emission directives because execution of these tests is technically and economically not feasible. Especially the removal of an engine and installation of an engine on an engine test bed needs too much effort.

Representativeness & Real Sailing Emissions. How relate real sailing emissions to type approval emissions?
Real sailing emissions may deviate strongly from type approval emissions and in most cases they are higher. In fact the type approval test is a very well described procedure at some defined settings and conditions but these settings/conditions don't represent daily operation and practice very well.

What are the possible causes of high real sailing emissions?

In a type approval test only some fixed and well defined engine speed and load points are part of the emission test. Real sailing engine speed and load settings cover a wider range and mostly result in a different emission performance.

Due to different and more varied ambient and engine operating conditions and more dynamic use the emission performance of an engine may deviate in daily operation from type approval emissions. Moreover deterioration of engines may also yield higher emissions. I.e. for diesel engines PM-emission is very dependent on the engine condition.

Enforcement is a key issue

Lack of enforcement creates opportunities in daily operation to optimize engines on costs. I.e. engine adjustments (like fuel injection timing) may reduce the fuel consumption 3-5% but the NOx emission increases severely.

Furthermore during engine lifetime it might be modified or adjusted. Practically it is not possible to detect these modifications with a general optical survey. Detailed emission tests or monitoring of emissions are needed to measure the impact of engine modifications or adjustments on real sailing emissions.

What is (not) described in current legislation about real sailing emissions?

Current certification procedures are based on steady state tests in engine laboratories and real sailing emission tests or in-use compliance tests are not part of certification. This lack of real sailing emission test requirements is the basis of the potential gap between type approval and real sailing emissions.

Which real sailing emission test procedures are already available?

For field certification tests the ISO 8178-2 and MARPOL 73/78 Annex VI procedures describe (in-use compliance) test procedures. In general these tests are complicated and expensive because the installation of the prescribed test equipment on board is a technical challenge or even not possible. Measurements of engine torque and exhaust mass flows are on board often not possible.

Therefore according to ISO 8178-2 and MARPOL 73/78 Annex VI procedures more simple tests are allowed in which the determination of engine torque/power and exhaust mass flow rates are not measured but calculated from other parameters. Usually the carbon balance method is used[6]. In short, this means that emissions are directly related to CO2 (in exhaust) and fuel consumption. Engine power are then calculated from the fuel consumption. This should be accurate enough to check the type approval values and to determine the Real Sailing Emissions, especially if this calculation procedure is included in and validated during the type approval tests.

What is needed for improved real sailing emissions?

Current type approval test procedures only consist of fixed speed and load operating points which don't cover real sailing patterns. Therefore the directives must be extended with dedicated real sailing test procedures which should cover the a larger part of the engine speed and load map and cover load points weightings experienced in practise. In PROMINENT this will be further investigated and options will be described (deliverables 3.2 and 3.3). There is a strong preference of use of simple, low costs emission test equipment which yields a good indication of real sailing emissions; the developments of the last years of low-cost automotive NO_x and O_2 sensors and CAN-bus

[6] Real-time Fuel Consumption Measurement Using Raw Exhaust Flow Meter and Zirconia AFR Sensor, HORIBA Feature Article

technologies are a good basis. Furthermore continuous monitoring of operating data and emissions is a possible tool and a good basis for improvement of real sailing emissions.

Waterway worthiness

Currently inland waterway vessels have no periodic obligatory technical engine check which covers safety and environmental issues. On the contrary road transport vehicles have to pass regularly a roadworthiness test which contains also an environmental part; the CO-emissions of petrol engines are limited and diesel engines have to pass a smoke emission test.

Monitoring

Monitoring systems measure certain (emission) parameters like O_2 and NOx volume concentrations and engine and ship parameters and these data are logged. Additional calculations produce operating values, i.e. NOx and CO_2 mass flows as well as fuel consumption. The continuous availability of these monitoring data enables operators to secure emission levels and to optimise fuel consumption. Monitoring is a good instrument to ensure in-use compliance of engine emissions.

Enforcement

The current enforcement activities of engine emissions of IWT only deal with administrative issues. Emission tests are not a fixed part of the enforcement procedure but the inspector may decide to carry out an on-board emission test. In fact enforcement of emissions is very complex and expensive because emission levels must be measured, calculated and judged. Consequently certain specific technical knowledge is needed and dedicated inspectors must be trained.

Monitoring equipment might be a good and cheap alternative to serve the goals of enforcement and simultaneously secure the image of inland shipping as environmentally conscious sector.

Laboratory vs. on-board certification

According to directives 97/68/EC and 2004/26/EC the certification test procedure for engines of IWT must be performed with one parent engine on an engine test bed. In a steady state engine emission test (NRSC E3 test cycle) emission levels are determined in four defined operating points. This creates possibilities for optimisation of fuel consumption in other operating points which will mostly result in relative high NOx emission levels. On modern engines detailed optimisation of fuel consumption and emissions is possible because electronic sensors, systems and dedicated engine controllers are very sensitive and selective. These new technologies create a need for improved engine certification which covers better daily operation.
On-board certification is not part of the current certification procedure and might be needed to secure emissions in order to develop also an approach to certify existing engines with after-market emission control or alternative fuels systems in a cost effective way.

From the road transport sector it can be learnt that current IWT certification procedures need to be extended. This can include both improvements for the laboratory test procedure as well as tests with real sailing (on-board) emission tests and dedicated limit values. The laboratory test could include an improved test cycle (better fit to the normal operational profile as well as Not to Exceed requirements (specific requirements for any point in a specified area of the engine map). On-board tests represent daily operation better. However real sailing tests may be less accurate because measurements of engine torque and exhaust mass flow rates are very complicated and in some cases not possible.

For maritime vessels, Regulation 13 of Annex VI of the MARPOL Convention of 19 March 2005 refers to the NOx technical Code which describes guidelines of on-board verification procedures. These are:

- Engine parameter check method
- Simplified measurement method
- Direct measurement and monitoring method

This regulation is dedicated to verification of emissions and doesn't describe continuous monitoring.

Simple screening or indicative tests with automotive NOx and O_2 sensors which produce less accurate but repeatable results might be a good possibility for monitoring of real sailing emissions. This enables a dedicated approach which may result in a good view on real sailing emissions. Currently no PM sensors are available, so PM-monitoring might be done by a periodic check of opacity measurements. Possible scenarios for test procedures of certification of engine emissions are shown in Table 16.

	Scenario					
Activity	1	2	3	4	5	6
Certification test on an engine test bed.	x	x	x	x	x	x
Administrative checks of engine configuration.	x	x	x			
NTE-limit		x	x	x	x	x
IUC-test			x	x		
Waterway worthiness test				x		
Monitoring					x	x
Durability & Enforcement						x

Table 16: Six certification scenarios for future emission regulations

On-board type approval test procedures must be further developed

On board certification tests are an alternative for certification tests in an engine test laboratory. In general the on board test procedure is equal to the test procedure in the engine laboratory. This implies that all test equipment must be installed on board. However in most cases on board measurements of engine torque and exhaust mass flow is practically not possible, i.e. too much effort is needed or due to technical reasons the measurements cannot be carried out. Alternatively several methods to derive or estimate these parameters are described in ISO 8178-2 / maritime shipping and Regulation 13 of Annex VI of the MARPOL Convention of 19 March 2005 which describe on board certification. Consequently the test result is less accurate and deviations up to 15% can be expected.

In the last decade new automotive sensors and monitoring test equipment have been developed which enables manufacturers to measure emissions continuously at low costs. In the next years these technologies can be implemented in the Inland Waterway Transport sector. This development must be taken into account in the next deliverables of this project because it might be a used complementary to secure low real sailing emissions for retrofit after treatment systems or for all engine applications.

Furthermore simple periodic emission tests are needed to check the condition and performance of after treatment systems. Main attention must be paid to the condition of diesel particulate filters.

5 Monitoring and enforcement of engine emissions

Monitoring of engine emissions
The Inland Waterway Transport sector has a long tradition and in general vessels have a life time of 40-50 years. Propulsion engines are in operation for 15-30 years and consequently the renewal rate of the fleet is low. Furthermore, monitoring systems are at present only sporadically implemented in the fleet. However monitoring and logging of engine parameters and emissions might be attractive for ship owners because it creates the possibility to optimize daily fuel consumption, in addition to supporting the decisions and behaviour that should lead to reducing the emissions levels.

Currently available technologies already enable authorities and/or operators to monitor engine emissions. Probably monitoring contributes to lower average IWT fleet emissions because measuring data is available and consequently fleet operators have a measure to act upon. Furthermore on line fuel consumption data enables operators to optimise operational costs.

In order to develop options for implementation of monitoring technologies and procedures, the following elements must be taken into account:

- Frequency of monitoring
- Reporting method and frequency
- Feasibility for the whole fleet
- Engine on-board diagnostic systems (OBD)
- Technical complexity
- Quality & effectiveness
- Benefits and draw backs
- Reliability
- Privacy
- Ownership of measured data
- Costs (initial and periodic)
- Legal status and enforcement body
- Measures in case of non-compliance

The next monitoring methods can be identified:

- Monitoring with an on board data logger (Incl. GPRS data transfer)
- Waterway worthiness test (periodically)
- Remote emission sensing (i.e. test equipment in a sluice/ lock)

A detailed study and review of monitoring of emission data will be performed in task 3.3.3, and will be published in 2016.

Enforcement
Enforcement is a key activity to reach certain predefined emission levels of IWT. In order to run at required emission levels, vessels with after treatment systems (i.e. Diesel Particulate Filters or Selective Catalytic Reduction) must operate under specific conditions. Only then can these systems reach conversion rates of 90-95%.
In other sectors it is obvious that a lack of enforcement will lead to higher average emission levels because engine operation has been optimized on costs. It is expected that new emission standards only will work in combination with sufficient attention to enforcement.

In general, the following methods of enforcement can be identified:

- Administrative checks on board
- Reporting of waterway worthiness tests

- On-Board Diagnostic tests and measures of engine operational performance
- Periodic emission tests on board
- Continuous monitoring of emissions with emission monitoring systems (with or without GPRS data transfer)

It is important that the enforcement options to be developed include the assessment of Real Sailing Emissions and not only the certification procedure test. Limit values for RSE could be somewhat higher than those required for the certification cycle (e.g. 20% or more - dependent on the precise procedure).

Furthermore the next issues must be taken into account:

- Reports of continuous monitoring to authorities can be on a simple aggregated level, so that no privacy issues will be raised.

- Any chosen enforcement procedure contains an obligatory technical and administrative part for ship owners and a verifying part for a government.

- Governmental enforcement bodies are needed to verify the emission performance of vessels. In order to optimise the administrative load and enforcement costs, a detailed investigation of enforcement activities is needed. The tasks, enforcement methods, legal possibilities and penalties in case of non-compliance must be studied.

A detailed study and review of enforcement will be performed in task 3.3.3, and will be published (delivered) in 2016.

6 Conclusions

Work package 3 explores the technical options for certification, monitoring and enforcement procedures regarding emissions and operational profiles, and prepares their pilot testing.

This report on the 'state of the art' is the first deliverable and summarizes the currently available methods for the certification of engine emissions of inland waterway vessels, the monitoring of sailing emissions and the enforcement of the prescribed limit values. Furthermore, the current gaps in the certification procedures are described.

Before 2002, no IWT emission legislation was in force and IWT engines did not require any emission certificates. In 2002 the CCNR introduced emission regulations for the engines powering inland vessels and in 2007 these regulations became mandatory for all EU member states when Directive 97/68/EC Stage IIIA came into force these emission regulations are still valid anno 2015. In 2020 a revision in the form of new EU Stage V limit values is planned. However, emission requirements for inland waterway engines lag behind those imposed on automotive heavy duty engines (trucks) and on other engine categories for Non Road Mobile Machinery.

Some local or national additional measures are also reviewed. In Belgium and the Netherlands differentiated port dues are applied on basis of the Green Award Certificate. The Green Award is a voluntary program which takes into account different environmental and performance parameters of the vessel.

Current engine type approval procedures are relatively expensive and complex. On the long term it is expected that most of the existing engines of IWT-vessels will be equipped with after treatment technology. In order to measure the emission performance of vessels equipped with retrofit devices at a reasonable cost, dedicated simple on-board certification tests must be developed.

Current type approval directives and regulations do not guarantee reliable real sailing emissions: Directive 97/68/EC defines test procedures and emission limit values for engines of inland waterway vessels; one sample of an engine type is tested in an engine test laboratory in a steady state test with a few modes and the engine emission performance is measured. This type approval emission performance does not represent the engine emission behaviour in the real world because operating conditions are most of the time different. Furthermore, monitoring the technical status of the engine and the emission performance are currently not being carried out. Without proper monitoring, the enforcement of the prescribed limit values cannot be achieved. Consequently, real sailing emissions levels might significantly and even severely deviate from emission levels recorded in type approval tests.

As mentioned above, enforcement mechanisms are a key component in the quest to keep real sailing emissions levels under the limit value levels imposed by law. To comply with future legislation, advanced emission control systems such as oxidation catalysts, SCR catalysts and diesel particulate filters and new fuels will be applied. More advanced test procedures and enforcement measures are needed to secure low real sailing emissions levels, because emissions control systems can be tuned to the test cycle, or can even be switched off/ removed in practice.

Simple additional certification test requirements and on-board monitoring of emissions are marked as two key elements for future emissions related legislation, both for entirely new engines as well as for retrofit solutions.

7 Next steps within this work package of PROMINENT

This state-of-the art deliverable (3.1) is the basis for the next steps within WP3. In deliverable D3.2 an assessment of various certification procedures is made, and in D3.3 "The assessment of options for monitoring and enforcement" a set of proposals for the next steps to be considered within the industry will be developed. The two deliverables will discuss among others the following elements:

- Extended or revised laboratory certification tests
- Certification test procedures of retrofit devices
- On board certification
- NTE limit values
- Real Sailing tests and limit values
- Durability requirements
- Monitoring of vessel emissions
- Enforcement activities

These proposals will be the basis providing the input for the cost/ benefit calculations in sub-work package 3.5.
During the real-life pilot deployments of PROMINENT, to be performed in WP5, experience will be gained with the implementation of some of the after treatment options mentioned in this report.

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Appendix A: Overview of the timeline of emission regulations

Date	Regulation	Amending	Define	Enter into force	Apply to	Implementation Timeline (depends on engines power)
1997	Directive 97/68/EC *Exhaust Emission*	-	STAGE I	31.12.1998	drilling rigs compressors construction wheel loaders bulldozers non-road trucks highway excavators forklift trucks road maintenance equipment snow plows ground support equipment in airports aerial lifts mobile cranes agricultural forestry tractors	01.01.1999-01.04.1999
			STAGE II	31.12.1998	drilling rigs compressors construction wheel loaders bulldozers non-road trucks highway excavators forklift trucks road maintenance equipment snow plows ground support equipment in airports aerial lifts mobile cranes agricultural forestry tractors	01.01.2001-01.01.2004
2002	2002/88/EC *Spark ignition*	Directive 97/68/EC *Exhaust Emission*	STAGE II (extended)	01.02.2005	Small utility engines Constant speed engines	

	engines up to 18 kW				Recreational crafts Vehicles Toys	
2004	2004/26/EC *Compression engines*	Directive 97/68/EC *Exhaust Emission*	STAGE III A	21.04.2004	All NRMM	01.01.2006- 01.01.2008
			STAGE III A	21.02.2005	agricultural forestry tractors	01.01.2006- 01.01.2008
			STAGE III B	21.04.2004	All NRMM	01.01.2011- 01.01.2013
			STAGE III B	21.02.2005	agricultural forestry tractors	01.01.2011- 01.01.2013
			STAGE IV	21.04.2004	All NRMM	2014
2010	2010/26/EU	2004/26/EC *Compression engines*	STAGE III B STAGE IV (further technical details on the testing and approvals)	2010	All NRMM	
2010	2010/22/EU	2004/26/EC *Compression engines*	STAGE III A	2010	agricultural forestry tractors	
2014	proposal		STAGE V	-	All NRMM	

Table 17: Overview of EU emission regulations

Appendix B: Emission limit values of EU Directive 97/68/EC

According to the Directive 97/68/EC and the subsequent amending Directives, the limit values for the various emissions are:

A. CI (compression-ignition) engines

a. for stage I, emission levels should not exceed the values in the table A4
b. for stage II, emission levels should not exceed the values in the table A5
c. for stage IIIA, emission levels should not exceed the values in the table A6
d. for stage IIIB, emission levels should not exceed the values in the table A7
e. for stage IV, emission levels should not exceed the values in the table A8.

Table A4. Limits for stage I

Net Power (P) (kW)	Carbon monoxide (CO) (g/kWh)	Hydrocarbons (HC) (g/kWh)	Oxides of nitrogen (NOx) (g/kWh)	Particulates (PT) (g/kWh)
130 ≤ P ≤ 560	5,0	1,3	9,2	0,54
75 ≤ P ≤ 130	5,0	1,3	9,2	0,70
37 ≤ P ≤ 75	6,5	1,3	9,2	0,85

Table A5. Limits for stage II

Net Power (P) (kW)	Carbon monoxide (CO) (g/kWh)	Hydrocarbons (HC) (g/kWh)	Oxides of nitrogen (NOx) (g/kWh)	Particulates (PT) (g/kWh)
130 ≤ P ≤ 560	3,5	1,0	6,0	0,2
75 ≤ P ≤ 130	5,0	1,0	6,0	0,3
37 ≤ P ≤ 75	5,0	1,3	7,0	0,4
19 ≤ P ≤ 37	5,5	1,5	8,0	0,8

Table A6. Limits for stage IIIA

a. engines for use in other applications than propulsion of inland waterway vessels

Net Power (P) (kW)	Carbon monoxide (CO) (g/kWh)	Sum of hydrocarbons and oxides of nitrogen (HC+NOx) (g/kWh)	Particulates (PT) (g/kWh)
H: 130 ≤ P ≤ 560	3,5	4,0	0,2
I: 75 ≤ P ≤ 130	5,0	4,0	0,3
J: 37 ≤ P ≤ 75	5,0	4,7	0,4
K: 19 ≤ P ≤ 37	5,5	7,5	0,6

b. Engines for propulsion of inland waterway vessels

Category: swept volume/net power (SV/P) (litres per cylinder/kW)	Carbon monoxide (CO) (g/kWh)	Sum of hydrocarbons and oxides of nitroger (HC+NOx) (g/kWh)	Particulates (PT) (g/kWh)
V1:1 SV ≤ 0,9 and P ≥ 560	5,0	7,5	0,40
V1:2 0,9 ≤ SV < 1,2	5,0	7,2	0,30
V1:3 1,2 ≤ SV < 2,5	5,0	7,2	0,20
V1:4 2,5 ≤ SV < 5	5,0	7,2	0,20
V2:1 5 ≤ SV < 15	5,0	7,8	0,27
V2:2 15 ≤ SV < 20 and	5,0	8,7	0,50
V2:3 15 ≤ SV < 20	5,0	9,8	0,50
V2:4 20 ≤ SV < 25	5,0	9,8	0,50
V2:5 25 ≤ SV < 30	5,0	11,0	0,50

Table A7. Limits for stage IIIB

(engines for use in other applications than propulsion of inland waterway vessels)

Category: Net Power (P) (kW)	Carbon monoxide (CO) (g/kWh)	Hydrocarbons (HC) (g/kWh)	Oxides of nitrogen (NOx) (g/kWh)	Particulates (PT) (g/kWh)
L: 130 ≤ P ≤ 560	3,5	0,19	2,0	0,025
M: 75 ≤ P ≤ 130	5,0	0,19	3,3	0,025
N: 56 ≤ P < 75	5,0	0,19	3,3	0,025

Table A8. Limits for stage IV
(engines for use in other applications than propulsion of inland waterway vessels)

Category: Net Power (P) (kW)	Carbon monoxide (CO) (g/kWh)	Hydrocarbons (HC) (g/kWh)	Oxides of nitrogen (NOx) (g/kWh)	Particulates (PT) (g/kWh)
L: 130 ≤ P ≤ 560	3,5	0,19	0,4	0,025
M: 56 ≤ P < 130	5,0	0,19	0,4	0,025

B. SI (spark-ignition) engines

a. for stage I, emission levels should not exceed the values in the table A9
b. for stage II, emission levels should not exceed the values in the table A10

Table A9. Limits for stage I

Class	Carbon monoxide (CO) (g/kWh)	Hydrcarbon (HC) (g/kWh)	Oxides of nitrogen (NOx) (g/kWh)	Sum of hydrocarbons and oxides of nitrogen (g/kWh)
				HC + NOx
SH:1	805	295	5,36	-
SH:2	805	241	5,36	-
SH:3	603	161	5,36	-
SN:1	519	-	-	50
SN:2	519	-	-	40
SN:3	519	-	-	16,1
SN:4	519	-	-	13,4

Table A10. Limits for stage II

Class	Carbon monoxide (CO) (g/kWh)	Sum of hydrocarbons and oxides of nitrogen (g/kWh)
		HC + NOx
SH:1	805	50
SH:2	805	50
SH:3	603	72
SN:1	610	50,0
SN:2	610	40,0
SN:3	610	16,1
SN:4	610	12,1

The NOx emission level for all engine classes must not exceed 10 g/kWh.

Stage III/IV provisions of the Directive 2004/26/EC only refer to new vehicles and equipment. Replacement engines to be mounted in already in use machinery - with the exception of the propulsion engines for railcars, locomotives and inland waterway vessels - should meet the limits that the engine to be replaced had to comply with when it was originally placed on the market. It is worth pointing out that Stage IV provisions introduced the NOx limit of 0.4 g/kWh, which resulted in a widespread use of NOx after treatment technologies.

Table A11. Emission Standards for Diesel Engines according to NRMM Stage IV

Category of Engine	Net Power	Date	CO	HC	NOx	PM
	[kW]		[g/kWh]			
Q	130 ≤ P ≤ 560	Jan. 2014	3.5	0.19	0.4	0.025
R	56 ≤ P < 130	Oct. 2014	5.0	0.19	0.4	0.025

Currently Stage V is under construction by the European Commission. The most important changes Stage V brings are:
An extension of the scope of regulated engines that now includes: CI engines below 19 kW and above 560 kW, SI engines above 19 kW, and other previously unregulated engine types.
More stringent limits for NOx and HC emissions are imposed for some engine categories, such as engines of 19-37 kW and engines powering inland waterway vessels.
Particle number (PN) emission limits are introduced for several CI engine categories.
On September 30st, 2015 the European Parlement voted in a plenary sitting for the latest proposals of amendments. A brief overview is given in tables A12 and A13.

Table A12. Proposed Stage V Emission Standards for Non-road Engines

Category of Engine	Ignition Type	Net Power	Date	CO	HC	NOx	PM	PN
		[kW]		[g/kWh]				[1/kWh]
NRE-v/c-1	CI	P < 8	2019	8.00	7.50[a,c]		0.40[b]	-
NRE-v/c-2	CI	8 ≤ P < 19	2019	6.60	7.50[a,c]		0.40	-
NRE-v/c-3	CI	19 ≤ P < 37	2019	5.00	4.70[a,c]		0.015	1×10^{12}
NRE-v/c-4	CI	37 ≤ P < 56	2019	5.00	4.70[a,c]		0.015	1×10^{12}
NRE-v/c-5	All	56 ≤ P < 130	2020	5.00	0.19[c]	0.40	***0.01***	***9×10^{11}***
NRE-v/c-6	All	130 ≤ P ≤ 560	2019	3.50	0.19[c]	0.40	***0.01***	***9×10^{11}***
NRE-v/c-7	All	P > 560	2019	3.50	0.19[d]	3.50	0.045	-

[a] HC+NOx
[b] 0.60 for hand-startable, air-cooled direct injection engines
[c] A = 1.10 for gas engines
[d] A = 6.00 for gas engines

Table A13. Proposed Stage V Emission Standards for Inland Waterway Vessels

Category of Engine with a certain displacement per cylinder	Net Power	Date	CO	HC[a]	NOx	PM	PN
	[kW]		[g/kWh]				[1/kWh]
Propulsion & Auxiliary Engines—Category IWP and IWA							
IWP-IWA-v/c-1, disp. < 0.9	P < 19	2019	6.6[1]	7.5		0.4	-
IWP-IWA-v/c-2, disp. < 0.9	19 ≤P < 37	2019	5.5	4.7		0.3[2]	-
IWP-IWA-v/c-3, disp. < 0.9	37 ≤P < 75	2019	5.0	4.7		0.3[2]	-
IWP-IWA-v/c-4, disp. < 0.9	75 ≤ P < 600	2019	5.0	5.4		0.14	-
IWP-IWA-v/c-5, 0.9< disp.<1.2	P ≤ 600	2020	5.0	5.4		0.12	-
IWP-IWA-v/c-6, 1.2< disp.<3.5	P ≤ 600	2020	5.0	5.6		0.10	-
IWP-IWA-v/c-7, 3.5< disp.<7.0	P ≤ 600	2020	5.0	5.8		0.10	-
IWP-IWA-v/c-8, all	P > 600	2021	5.0	0.19	1.8	0.045	-

[1] 8.0 g/kWh for < 8 kW
[2] Optionally, these categories may be certified to a NOx + HC level of 5.8 g/kWh and a PM level of 0.2 g/kWh
[a] For diesel-LNG applications the HC-limit value depends on the LNG rate and its maximum value is 6,19 g/kWh

Proposed limit values for Inlet Waterway Transport for Europe

A comparison of the proposed limit values for inland ships in Europe with US EPA limit values and limit values for HD vehicles.

	Proposal 1 EC		Proposal 2 EC		USA maritime		Proposal 2 EC	
	IWP – 2014		IWP, IWA - 2015		EPA – Tier 4		NRE -2015	
Power	NOx+HC	NOx	NOx+HC	NOx	NOx+HC	NOx	NOx+HC	NOx
[kW]	[g/kWh]							
<19			7.5		7.5*	-	7.50	
19 - 37			4.7		7.5 – 4.7*	-	4.70	
37 – 75	4.7		4.7			-	4.70 <56kW	0.40 >56kW
75 – 130	5.4		5.4-5.6-5.8		5.8*	-		0.40
130–300		2.10				-		0.40
300–600 (560)		1.20				-		
600-1000				1.8		1.8		3.5
> 1000		0.40		1.8		1.8		3.5

* EPA Tier 3 category 1

Table 18. Comparison of (proposals) of NOx emission limit values (EPA Tier 4 already implemented

	Proposal 1 EC		Proposal 2 EC		USA maritime		Proposal 2 EC	
	IWP – 2014		IWP, IWA - 2015		EPA – Tier 4		NRE-2015	
Power kW	PM g/kWh	PN #/kWh	PM g/kWh	PN #/kWh	PM g/kWh	PN #/kWh	PM g/kWh	PN #/kWh
<19		-	0.4	-	0.40	-	0.40	-
19 - 37		-	0.3	-	0.30	-	0.015	$1x10^{12}$
37 – 75 (56)	0.30	-	0.3	-		-	0.015	$1x10^{12}$
75 – 130	0.14	-	0.14-0.12-0.10	-	0.15-0.14-0.12-0.11*	-	0.01	$9x10^{11}$
130–300	0.11	-		-		-	0.01	$9x10^{11}$
300–600 (560)	0.02	$1x10^{12}$		-		-	0.01	$9x10^{11}$
600-1000			0.045	-	0.04	-	0.045	-
> 1000	0.01	$1x10^{12}$	0.045	-	0.04	-	0.045	-

* EPA Tier 3 category 1, dependent on engine displacement

Table 19. Comparison of (proposals) of PM/PN emission limit values (EPA Tier 4 already implemented

Appendix C: Emission regulations from the IMO

The International Maritime Organization (IMO) is as specialized agency of the United Nations. Since its establishment in 1948, IMO developed, operationalized and maintained a comprehensive regulatory framework for the shipping sector (see going vessels). The main priorities targeted through this regulatory framework were: safety, environmental issues, legal matters, technical co-operation, security and efficient shipping. Among these priorities, safety and environmental issues should to be considered in any new regulation introduced by IMO or by other international standards.

The shipping activity is responsible for various types of pollution (air emissions, acoustic effects, oil spillages and toxic residue discharges), as documented by a wide range of scientific reports. The IMO adopted in 1997 specific regulations to curb the level of shipping related emissions: the MARPOL 73/78 Protocol – Annex VI Regulations for the Prevention of Air Pollution from Ships . Since then, the MARPOL protocol has become the main international convention to govern the issue of preventing the pollution of the marine environment by ships, as a result of operational or accidental causes. The scope of the Protocol is set to include all the environmental issues associated with the shipping activity (see above). The MARPOL Annex VI Regulation for the Prevention of Air Pollution from Ships has been ratified by 53 countries. Altogether these countries represent approximately 81.88% of the gross tonnage of the world's merchant shipping fleet.

On the occasion of its 53rd session in July 2005, IMO's Marine Environment Protection Committee (MEPC) adopted the first amendments to MARPOL's Annex VI. Through these amendments, the provisions for two sets of emission and fuel quality requirements regarding SOx, PM, and NOx are laid down: a) a global requirement and b) more stringent controls in special Emission Control Areas (ECA). Later, a new chapter of the same MARPOL's Annex VI adopted in 2011 defines mandatory technical and operational energy efficiency measures aimed at reducing greenhouse gas emissions produced by ships.

The Annex VI amendments aim to achieve a progressive reduction of shipping related Sulphur oxide (SOx) emissions (see figure A1). In more specific terms, the global Sulphur cap is reduced to:

- 3.50% effective from 1 January 2012
- 0.50 % effective from 1 January 2020.

For the SECAs, the Sulphur oxide (SOx) emission should not be higher than:

- 1.00% beginning with 1 July 2010
- 0.10 % effective from 1 January 2015.

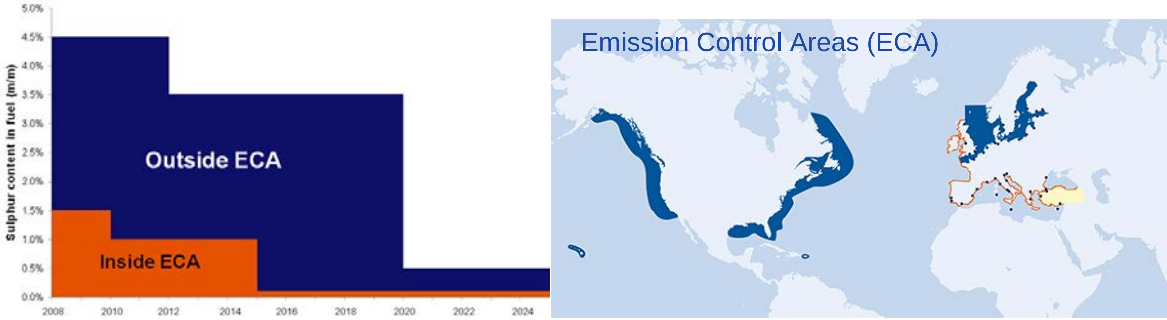

Fig. A1. Expected evolution of the sulphur content in marine fuel
Source: IMO MARPOL Annex VI, Regulation 14

A gradual reduction of the current level of nitrogen oxide (NOx) emission was also considered, with the most stringent limits to be imposed on Tier III engines (see figure A2).

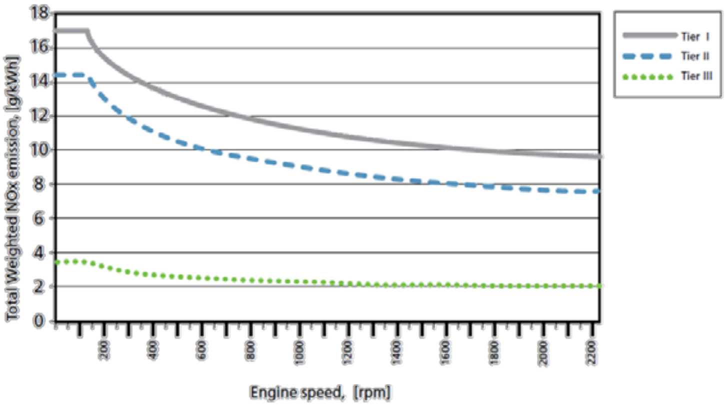

Fig. A2. Proposed Nox limits for steps TIER I, TIER II and TIER III (see Annex A)
Source: IMO MARPOL Annex VI, Regulation 14

Referring to the various types of air pollutant emissions associated with a ship, Annex VI defines requirements for the following areas:
a. Regulation 12 - Emissions of Ozone-depleting substances
b. Regulation 13 - NOx emissions from diesel engines
c. Regulation 14 - SOx emissions from ships
d. Regulation 15 - Volatile organic compounds emissions from cargo oil tanks installed on oil tankers
e. Regulation 16 - Emissions generated by shipboard incinerators

The limits prescribed by these regulations are:

A. The Sulphur content of any fuel oil used on board ships shall not exceed:
  a. 4.50% m/m prior to 1 January 2012
  b. 3.50% m/m on and after 1 January 2012
  c. 0.50% m/m on and after 1 January 2020

Moreover, in an ECA the Sulphur content of fuel oil used on board ships shall not exceed:
  a. 1.50% m/m prior to 1 July 2010
  b. 1.00% m/m on and after 1 July 2010
  c. 0.10% m/m on and after 1 January 2015

B. Nitrogen oxides

a. Limits from Tier I engines:

For diesel engines installed on ships built between the 1st of January 2000 and the 1st of January 2011, the allowed maximum levels for the total weighted NOx as a function of engine speed (n) are:

a. 17.0 g/kWh when n is less than 130 rpm
b. 45.0 × n(-0,2) g/kWh when n is 130 or more but less than 2000 rpm
c. 9.8 g/kWh when n is 2000 rpm or more

b. Limits from Tier II engines:

For diesel engines installed on ships built on or after the 1st of January 2011, the allowed maximum levels for the total weighted NOx as a function of engine speed (n) are:

a. 14.4 g/kWh when n is less than 130 rpm
b. 44.0 × n(-0,23) g/kWh when n is 130 or more but less than 2000 rpm
c. 7.7 g/kWh when n is 2000 rpm or more

c. Limits from Tier III engines:

Ships built on or after the 1st of January 2016 must comply with additional conditions when operating in an Emission Control Area (ECA). In the case of NOx emissions, no ECAs have yet been defined. It is expected however that both the Baltic Sea and the North Sea will become NOx ECAs before of the 1st of January 2016.

For Tier III ships, operating in the NOx ECAs, the allowed maximum levels for the total weighted NOx as a function of engine speed (n) are:

a. 3.4 g/kWh when n is less than 130 rpm
b. 9.0 × n(-0,2) g/kWh when n is 130 or more but less than 2000 rpm
c. 2.0 g/kWh when n is 2000 rpm or more

Tier III limits will not apply to engines installed on ships measuring less than 24 meters in length when they are designed and used solely for recreational purposes. Neither will these limits apply to engines installed on ships with a combined nameplate diesel engine propulsion power of less than 750 kW if it is proved that these ships cannot comply with the Tier III limits because of design or construction limitations of the ship.

C. Volatile Organic Compounds - NA

The incineration of exhaust gas cleaning systems residues will always be prohibited on the ships subject to the provisions of Regulation 16 will be applicable.

Onboard incineration outside an incinerator is prohibited. As an exception to this provision, incineration of sewage sludge and sludge oil from oil separators in the main or auxiliary power plants and boilers is allowed when the ship is not in ports, harbors and estuaries.

Incineration of PVC's (polyvinyl chlorides) is prohibited except for the case when it is done in shipboard incinerators type approved according to resolutions MEPC 59(33) or MEPC 76(40).

During the past two years, IMO's Marine Environment Protection Committee (MEPC) brought various amendments to these rules. These changes are outlined below.

During the 66th session, held between the 31st of March - the 4th of April 2014, MEPC adopted:

- the proposed amendments to the NOx Technical Code 2008 concerning the use of dual-fuel engines and
- the Guidelines on the Approved Method process as required under regulation 13.7.1 of MARPOL Annex VI.
- a new standard specification for shipboard incinerators with capacities up to 4,000 kW per unit.

During the 67th session held between the 13th and the 17th of October 2014, the last session of

2014, MEPC modified the supplement to the IAPPC (International Air Pollution Prevention Certificate), by including a reference to gas as fuel and to gas-fuelled engines.

MEPC 67 adopted amendments to MARPOL Annex VI which extend the scope of the definition of a marine diesel engine as given by regulation to include gas-fuelled engines installed on ships constructed on or after 1 March 2016 and also such engines installed as additional or non-identical replacement engines on or after that date.
Gas-fuelled engines, where ignition is initiated by a spark plug or another external ignition device, are generally expected to readily meet the Tier III NOX emission limits and therefore it is possible that engine builders will seek only Tier III certification for such engines, irrespective of whether they are to be installed on ships which operate outside or inside Emission Control Areas (ECA) for NOX as described in regulation 13.6 of MARPOL Annex VI, currently the North American ECA and the United States Caribbean Sea ECA, both of which will take effect from 1 January 2016. In the case of dual fuel engines, those engines which use gas fuel in a pre-mix combustion process with the liquid fuel as the pilot ignition source (as opposed to gas-diesel engines which use high pressure gas injection directly into the combustion chamber) are expected to be certified to the Tier III NOX standards when operating in that arrangement. Consequently, the Technical Files for such engines will include the restriction that, when operating in the Tier III condition, the liquid fuel rate will be limited to the certified maximum liquid pilot fuel rate and those engines will undergo their Tier III Parent Engine test on that basis.1 These engines are expected to be certified to the Tier II NOX standards when operating on liquid fuel oil only. In these cases, the EIAPP Certificate would be completed for both Tier II (liquid fuel only) and Tier III (gas fuel with pilot fuel), with a single Technical File giving two different modes of operation.

In the 68th session, held between the 11th and the 15th May 2015, the GHG reduction target for international shipping was reconsidered by MEPC. This modification came as the result of a submission made by the Marshall Islands, calling for a quantifiable reduction target to be defined for greenhouse gas emissions produced by international shipping. The Committee accepted to advance the efforts to reduce emissions produced by ships by putting in place a data collection system. Moreover, MEPC looked forward to a successful UN climate change conference (UNFCCC COP 21 meeting) in Paris later this year.

During the same session, MEPC considered a number of amendments and revisions to existing guidelines and regulations targeting air pollution. These amendments are presented below.

- the 2009 Guidelines for exhaust gas cleaning systems (resolution MEPC.184(59)): here the amendments considered by the Committee relate to certain aspects of the emission testing, namely the measurement of the carbon dioxide (CO_2) and Sulphur dioxide (SO_2).
- NOx Technical Code 2008: here MEPC adopted the draft amendments to facilitate the testing of gas-fuelled engines and dual fuel engines for NOx Tier III strategy. MEPC also approved the 2011 Guidelines prescribing specific requirements for marine diesel engines fitted with Selective Catalytic Reduction (SCR) Systems (resolution MEPC.198(62)).
- MARPOL Annex VI: MEPC considered record requirements for operational compliance with NOX Tier III emission control areas and it approved the guidance on the application of regulation 13 concerning Tier III requirements for dual fuel and gas-fuelled engines;
- In terms of the applied Onboard NOX Verification Procedure, virtually all engines use the Parameter Check Method. In this, the Technical Files will provide that all replacements and adjustments to the listed components and settings which affect NOX emissions are to be recorded in a Record Book of Engine Parameters. This is also the case for engines certified to both Tier II and Tier III, with replacements and adjustments for both operating conditions

being listed. In addition, amendments to regulation 13 of MARPOL Annex VI approved at MEPC 68 also require that the tier and on/off status of an engine certified to both Tier II and Tier III or only Tier II on ships subject to regulation 13.5.1 of MARPOL Annex VI should be recorded together with the date, time and ship's position at entry into and exit from an ECA under regulation 13.6 of MARPOL Annex VI or when the on/off status changes within such designated area. It should be noted that prior to entry into an ECA, sufficient time must be allowed for the tier changeover, to ensure Tier III compliance upon entry into the ECA, and the Technical File should include a written procedure showing how the tier change-over is to be done.

- TIER III standards are expected to require dedicated NOx emission control technologies such as various forms of water induction into the combustion process (with fuel, scavenging air, or in-cylinder), exhaust gas recirculation, or selective catalytic reduction

A second group of IMO experts, namely the MBM-EG (Market-Based Measures Expert Group), worked in parallel with the MEPC on regulations addressing gas emissions produced by ships. In July 2011, IMO adopted mandatory technical and operational energy efficiency measures. The MBM-EG was tasked to focus on Market-Based Measures. Market-based measures include: emissions trading, emission related levies - charges and taxes, and emissions offsetting; all of which aim to contribute to the achievement of specific environmental goals, at a lower cost, and in a more flexible manner, than traditional command and control regulatory measures. An MBM would place a price on GHG emissions from international maritime transport. An MBM could thereby serve two main purposes: being an incentive for the industry to invest in more fuel efficient ships and to operate them more energy efficiently, and off-setting (in other sectors) of growing ship emissions. In addition, MBMs could generate considerable funds that could be used for mitigation and adaptation actions in developing countries. The two categories of measures came together to form the first mandatory global GHG reduction regulation applied to an entire international activity sector, namely commercial shipping. In force since 2013, it is expected to trigger a significant reduction in the amount of emissions produced by ships by stimulating a reduction in the quantity of consumed fuel: 200 million tons less CO_2 per year by 2020 and 420 million tons less CO2 by 2030.

The Expert Group on MBM (MBM-EG) was established with the aim of evaluating the ten submitted proposals and assessing the extent to which they could assist in reducing the quantity of GHG emissions produced by international shipping. IMO has been considering proposals from governments and observer organizations for Market-Based Measures (MBM). The MBM proposals continue to be further developed by their proponents and some proposals have been merged with others. The expert group modelled the possibilities to reduce the CO_2 emissions by applying a number of measures (see below). This exercise resulted in the proposal of the limit values presented in Table A1.

Table A1. Estimated limits for the CO_2 emissions

Ship type	Cut-off limit	Estimated CO_2 emissions (tonnes)	Contribution ratio from same ship type	Contribution ratio to total CO_2 emissions
Bulk carrier	10,000 DWT	175,520,816	98.52%	15.70%
Gas tanker	2,000 DWT	46,871,129	98.50%	4.19%
Tanker	4,000 DWT	213,145,106	95.72%	19.06%
Container ship	10,000 DWT	254,812,434	96.54%	26.07%
General cargo ship (Including combination carrier)	3,000 DWT	87,274,101	90.00%	7.80%
Refrigerated cargo carrier	3,000 DWT	18,767,755	97.64%	1.68%
Total coverage	---	796,391,341	96.11%	71.22%

The specific measures considered by the MBM-EG expert group are:

1. Environmental effectiveness
2. Cost-effectiveness and potential impact on trade and sustainable development
3. The potential to provide incentives for technological change and innovation
4. Practical feasibility of implementing market based measures (MBM)
5. The need for technology transfer to and capacity building within developing countries, in particular the least developed countries (LDCs) and the small island development states (SIDS)
6. The relation with other relevant conventions (UNFCCC, Kyoto Protocol and WTO) and the compatibility with customary international law
7. The potential additional administrative burden and the legal aspects to be considered by National Administrations when implementing and enforcing MBM
8. The potential additional workload, economic burden and operational impact for individual ships, the shipping industry and the maritime sector as a whole, generated by implementing MBM
9. The compatibility with the existing enforcement and control provisions under the IMO legal framework.

Appendix D: Overview of emission regulations

No.	Name	Code	Year of issue	Year of entering into force
INTERNATIONAL LEGISLATION				
1.	Reciprocating internal combustion engines. Exhaust emission measurement	ISO 8178-1:2006	2006	2006
2.	Directive 2006/87/EC of the European Parliament and of the Council of 30 December 2006 laying down technical requirements for inland waterway vessels and repealing Council Directive 82/714/EEC	2006/87/EC	2006	2007
3.	Commission Directive 2009/46/EC of 24 April 2009 amending Directive 2006/87/EC of the European Parliament and of the Council laying down technical requirements for inland waterway vessels	2009/46/EC	2009	2009
4.	Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery	97/68/EC	1997	1998
5.	Directive 2002/88/EC of the European Parliament and of the Council of 9 December 2002 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery	2002/88/EC	2002	2002
6.	Directive 2004/26/EC of the European Parliament and of the Council of 21 April 2004 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery	2004/26/EC	2004	2004
7.	Commission Directive 2010/26/EU of 31 March 2010 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery	2010/26/EU	2010	2010
8.	Directive 2011/88/EC of the European Parliament and of the Council of 16 November 2011 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery	2011/88/EC	2011	2011
9.	Commission Directive 2012/46/EU of 06 December 2012 amending Directive 97/68/EC on the approximation of the laws of the	2012/46/EU	2012	2012

	Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery			
10.	International Convention for the Prevention of Pollution from Ships (MARPOL)	MARPOL	1978	1978
11.	Marpol 73/78 Annex VI. Regulations for the Prevention of Air Pollution from Ships. Technical and Operational implications	Marpol 73/78 Annex VI	2005	2005
12.	Revised Annex VI adopted October 2008: MEPC.176(58) Amendments to the Annex of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (Revised MARPOL Annex VI)	MEPC.176(58)	2010	2010
13.	IMO policies and practices related to the reduction of greenhouse gas emissions from ships, Resolution A.963(23)	A.963(23)	2003	2003
14.	Instruments for measuring vehicle exhaust emissions -- Metrological and technical requirements; Metrological control and performance tests, ISO/PAS 3930:2009	ISO/PAS 3930:2009	2009	2009
15.	Reciprocating internal combustion engines. Vocabulary of components and systems. Part 12: Exhaust emission control systems, ISO 7967-12:2014	ISO 7967-12:2014	2014	2014

NATIONAL SPECIFIC LEGISLATION				
Belgium and The Netherlands				
1.	Port Dues of Antwerp	Tariefverordening op de binnenvaart	2014	2014
2.	Port Dues Differentiation based on Green Award	-	2014	2014
3.	Port of Rotterdam: Port Dues	Port of Rotterdam. General Terms and Conditions, including Port Tariffs 2015	2015	2015
4.	Port of Rotterdam: Denied access to the port	2010 Rotterdam Port Management Bye-Laws	2015	2025
Hungary				
1.	Decree of Ministry of Traffic and Water Management No. 2/2000	DM 2/2000	2000	2000
2.	Decree of Ministry of Traffic and Water Management No. 13/2001	DM 13/2001	2001	2001
Romania				
1.	Government Decision, HG 829/2012 amending and supplementing Government Decision no. 332/2007 establishing procedures for type approval of engines to be fitted to non-road mobile machinery and to secondary engines for vehicles for road transport of persons or goods and identify measures for limiting emissions of gaseous and particulate pollutants in order to protect the atmosphere	HG 829/2012	2012	2012
2.	Government Decision, HG 1197/2010 amending and completing HG 470/2007 regulates the use of certain liquid fuels, including marine fuels, to reduce sulfur dioxide emissions resulting from burning them in order to reduce the negative effects of these emissions on human health and the environment	HG 1197/2010	2010	2010
3.	Minister of Transportation Order, OMT 742/2009 transposing Directive 2009/46 / EC of 24 April 2009 amending Directive 2006/87 / EC of the European Parliament and of the Council establishing technical requirements for inland waterway vessels published in the Official Journal of the European Union no. L 109 of 30 April 2009.	OMT 742/2009	2009	2009
4.	Resolution no. 198/2011 MEPC.198 (62) - Guidelines of 2011 on additional aspects of the NOx Technical Code 2008 on the specific requirements of marine diesel engines fitted with selective catalytic reduction (SCR)	198/2011 MEPC.198 (62)	2011	2011

Appendix E: Fuel specifications

EN590 diesel specifications

Property	Unit	Specification	
		Min	Max
Year 2005 (2003/17/EC, EN 590:2004)			
Cetane number		51	-
Density at 15°C	kg/m^3	-	845
Distillation: 95% v/v recovered	°C	-	360
Polycyclic aromatic hydrocarbons	% m/m	-	11
Sulfur	mg/kg	-	50[a]
FAME	%, v/v	-	5[b]
Year 2009 (2009/30/EC, EN 590:2009)			
Polycyclic aromatic hydrocarbons	% wt.	-	8
Sulfur	mg/kg	-	10
FAME	%, v/v	-	7

a - 10 ppm S fuel must be available in the market
b - EN 590:2004 FAME limit; FAME not regulated by 2003/17/EC

STICHTINGVOS

VOS ULS 2011	Specificatie		Methode
	min.	max.	
Uiterlijk bij 20 °C		1*	Visueel
Kleur		Rood (2*)	Visueel
Dichtheid bij 15 °C, kg/m^3	820,0	845,0	EN ISO 12185
Viscositeit bij 40 °C, mm^2/s	2,00	4,50	EN ISO 3104
Cetaan Index (3*)	46,0		EN ISO 4264
Zwavelgehalte, ppm		10,0	EN ISO 20846 / 20884
Lubricity, µm		460	EN ISO 12156-1
Vlampunt , °C (6*)	55,0		EN ISO 2719
Fatty Acid Methyl Ester (FAME), % v/v		0,30 (4*)	EN 14078
CFPP (5*), °C			EN 116
Zomer (1 mei - 30 september)		- 5	(EN 590 grade C)
Winter (1 oktober - 30 april)		- 15	(EN 590 grade E)
Micro Carbon Residue			
na 10% destillatie, % m/m		0,30	EN ISO 10370
As, % m/m		0,01	EN ISO 6245
Koper strip corrosie (3 uur bij 50 °C)		Klasse 1	EN ISO 2160
Destillatie			EN ISO 3405
bij 250 °C, % vol		65	
bij 350 °C, % vol	85		
bij 95% destillaat, °C		360	
Water, mg/kg		200	EN ISO 12937
Totaal Contaminatie, mg/kg		24	EN 12662

1* - Helder en vrij van zichtbaar water en zichtbare verontreinigingen.

2* - Conform Douane voorschrift: Solvent Yellow 6.0 - 9.0 mg/l en rode kleurstof als herkenningsmiddel.

3* - Indien Cetaan Index < 46,0 dan Cetaan Nummer 51,0 (EN ISO 5165 / EN 15195).

4* - VOS streeft naar een nihil FAME-gehalte. Vanwege logistieke redenen kan een bepaald FAME-gehalte niet altijd voorkomen worden. Het maximum FAME percentage is gelijk aan de EN 590.

5* - CP (Cloud Point) wordt niet specifiek genoemd in de EN590 norm, met uitzondering van gebruik in Poolgebieden of strenge winters. Bij extreem winterse omstandigheden en/of brandstofopslag boven de waterlijn worden lagere waarden geadviseerd.

6* - Indien de brandstof gebruikt wordt in de zeevaart: vlampunt minimaal 60°C.

Produktspezifikation

Heizöl DIN 51603 – EL – 1 – Standard

TOTAL

Heizöl EL, Standard, gefärbt
(dyed standard light heating oil)

Nr.	Anforderung (requirements)	Grenzwert (limit) min.	max.	Einheit (dimension)	Prüfverfahren (method)
1	Äußere Beschaffenheit (appearance)	klar, frei von sichtbarem Wasser und festen Fremdstoffen (clear, free of visible water and solid matter)			visuell (visual)
2*)	Solvent Yellow 124 Roter-Farbstoff (red-colouring) Euromarker 2 (Solvent Yellow)	 5 7,3	 6 8,7	 mg/kg mg/kg	 DIN 51426 DIN 51426
3	Dichte bei (density at) 15 °C		860	kg/m³	DIN 51757 DIN EN ISO 12185
4	Siedeverlauf insg. verdampftes Vol. (destillation, total vaporized vol.) bis (up to) 250 °C bis (up to) 350 °C	 85	 < 65	 % (V/V) % (V/V)	 DIN EN ISO 3405 ASTM D 86 DIN 51751
5*)	Viskosität (viscosity) bei 20°C	2,5	6,0	mm²/s	DIN 51562-1
6*)	Flammpunkt (flashpoint)	57		°C	DIN EN 22719
7	Heizwert (H_u) (calorific value)	42,6		MJ/kg	DIN 51900 Teil 1 + 2 oder Teil 3 oder Berechnung[1)] (part 1 + 2 or part 3 or calculated[1)])
8	Schwefelgehalt (total sulphur)	> 0,0050 > 50	0,20 2000	% (m/m) mg/kg	DIN EN 24260 DIN EN ISO 8754 DIN EN ISO 14596
9*)	Neutralisationszahl (acid number)		0,20	mg KOH/g	DIN 51558-1
10	Koksrückstand von 10% Destillationsrückstand (carbon residue of 10% destillation residue)		0,3	% (m/m)	DIN EN ISO 10370 DIN 51551
11	Asche (ash)		0,01	% (m/m)	DIN EN ISO 6245
12	Gesamtverschmutzung (particle content)		24	mg/kg	DIN EN 12662
13	Wassergehalt (water content)		200	mg/kg	DIN 51777-1 DIN EN ISO 12937
14	Halogenkohlenwasserstoffe [angegeben als Chlor] (organic chlorine)		frei (<1)	 mg/kg	DIN 51577-3 DIN 51408-1 DIN V51408-2
15	Cloudpoint / CFPP	max. +3 und max. -12 max. +2 und max. -11 max. +1 und max. -10		°C	DIN EN 23015 / DIN EN 116

Heizöl EL entspricht der DIN 51603-1 und darüber hinausgehenden Anforderungen. (The heating oil conforms to DIN 51603-1.)

Heizöl EL entspricht nur dann den Anforderungen dieser Norm, wenn es oder seine Komponenten (Produktströme, die aus Mineralölverarbeitungsverfahren stammen) vorher zu keinem anderen Zweck eingesetzt worden sind. Heizöl EL darf keine anorganischen Säuren enthalten.

*) ergänzend zu/schärfer als DIN 51603-1 (in addition to DIN 54603-1)

1) Die Berechnung erfolgt mit der Formel (calculation with formula):

$$H_U = 52{,}92 - \frac{11{,}93 \times D_{15}}{1000} - 0{,}29 \times \omega(S)$$

D_{15}=Dichte bei (density at) 15°C in kg/m³
$\omega(S)$=Massenanteil Schwefel (mass content of sulphur) in %

Heizöl EL, Standard, gefärbt	erstellt: Hardtke, QA	geprüft: Dr. Stöckel, RPM	freigegeben: Dr. Behr, Q
	gültig ab: September 2003	Druck: 27.01.2005 11:12	Seite 1 von 1
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