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

D3.2 Assessment of certification procedures

D3.3 Assessment of options for monitoring and enforcement

Certification, monitoring and enforcement

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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.

PROMINENT aims 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 at further decreasing the energy consumption and carbon footprint of IWT. This is an area where IWT performs better than road transport.

Work Package 3 explores the technical options for certification, monitoring and enforcement procedures for inland vessel engines emissions, suitable for a range of 'greening technologies' and to comply with stringent legislation.
This is a combined report for the deliverables D3.2 and D3.3. The objectives are respectively: the assessment of certification procedures (D3.2) and the assessment of options for monitoring and enforcement (D3.3).

In this study a close look into the requirements for effective emission certification, monitoring and enforcement is given. The only goal of 'stringent' legislation is low Real Sailing Emissions or low Real Driving Emissions, for ships and road vehicles respectively. The experience with road vehicles over the past decades shows that specific and stringent tests and requirements for Real Driving Emissions are necessary to reach this goal. The report focuses on recommendations for Type Approval and Real Sailing Emissions. Both for different scenarios such as new stage V engine systems as well as Retrofit Emission Control (REC) systems.

Test options for certification, monitoring and enforcement
The report presents an overview of test options for certification, monitoring and enforcement. Several types of tests were identified and they have been divided into three categories: lab tests, on-board tests and on-board monitoring.
An analysis is given of the on-board test procedures. They are evaluated for their suitability for Certification and Type Approval provisions as well as for Monitoring and Enforcement. A set of criteria have been chosen for the evaluation of the measuring methods. The following on-board measurement options are evaluated:

- Tests with Standard Reference Material (SRM), relatively high quality equipment used in laboratories. This includes the PEMS (Portable Emissions Measurement Systems) which was first developed for road vehicles. PEMS currently measures NO_x, CO,HC and CO_2. With SRM also gravimetric particulate matter can be measured.
- On-board tests with sensor based equipment.
  The emission measurements are usually limited to NOx and O_2. The sensors are developed for the automotive market. Therefore they are economically and widely available.

For on-board test the main difficulty is the measurement of engine power, fuel consumption and exhaust flow. These parameters are normally used to do the calculations for emissions in g/kWh. A work around, using the carbon balance method is acceptable, but still at least one of the three parameters is needed with sufficient accuracy. Fuel consumption and/or power are often available from the engine management system. It is fine to use those as long as the accuracy can be verified.

Retrofit Emission Control device (REC)
A type approval of REC for vessels is recommended in line with UNECE R132[1], including a validation of the emissions performance on board of each vessel. In order to be able to act quickly, a procedure under the umbrella of EC or interested member states is recommended (rather than a formal UNECE procedure).
To be economically viable the scaling of REC systems must be more flexible for IWT than required by R132. To tackle this issue the regulation must provide guidelines for the following subsystems: a) exhaust package, b) urea dosing package, and c) NOx Control Diagnostics (NCD)

Real Sailing Emissions (RSE)
RSE is especially important for engines which need to comply with stringent legislation such as Stage V. It is recommended to use the same procedure for RSE (Real Sailing Emission) for both OEM engines as well as for engines with REC, and to give this an official status. The proposed test consists of a simple test during the type approval in the laboratory[2], as well as a validation on board of each vessel. The on board test consists of the 'E3 cycle points', as well as some random points. The 'E3 cycle points' are on the actual propeller curve which generally deviates from the theoretical propeller curve. It is proposed to present emissions in both g/kWh and g/kg CO_2[3].

Monitoring and Enforcement
For In Service Conformity (ICS) monitoring, the same procedure is recommended for OEM Stage V engines as well as engines with REC, namely the on-board RSE test procedure.
Independent on-board testing can be performed with the following recommended options, with:
- SRM / PEMS equipment - similar to road vehicles;
- Sensor based equipment - as an economic option;
- Sensor based Environmental Performance Monitoring (EPM) – as an option for continuous monitoring on board, which includes energy consumption and CO_2 emissions.

These options will be further investigated in WP5 'real life pilots'.

Environmental Performance Monitoring (EPM),
Environmental Performance Monitoring (EPM), is defined as a voluntary continuous monitoring of environmental parameters on board of a vessel with a daily wireless (GPRS) data transmission to a central database. It is based on a NOx sensor and parameters available on the vessel. EPM includes NOx, fuel consumption, CO_2 emissions, engine load pattern and vessel parameters like location, route and speed. Apart from NOx in g/kWh, NOx and CO_2 performance are reported in g/km, g/ton.km or g/trip. EPM is also meant to evaluate the powertrain efficiency and navigation efficiency.

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[1] UNECE R132 was specially developed for Retrofit Emission Control devices for road vehicles and land based NRMM (feb. 2015).
[2] This test with random point(s) within the engine control area was already proposed in the discussion paper from the delegated act working group, March 2016.
[3] NOx in g/kg CO_2 can directly be derived from exhaust gas composition. It eliminates the uncertainty associated with engine power and exhaust flow needed for the g/kWh calculation. g/kg CO_2 emissions can be correlated easily with laboratory tests.

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2 Introduction

2.1 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."

2.1.1 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. For more information on these innovations, the reader is referred to other PRMINENT reports, including reports D1.2 and D3.1.

2.1.2 PROMINENT objectives

PROMINENT aims 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 at further decreasing 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.

2.1.3 Targets of PROMINENT

The goals of PROMINENT are:

1. Developing cost-effective solutions and standardised applications (reducing required investment costs):
   - ➔ 70%+ coverage – Developing solutions that are applicable to at least 70% of the European inland fleet and their operating areas.
   - ➔ 30% costs reductions – Reducing implementation costs of innovative greening solutions by 30%.
2. Involving all relevant actors concerned in the research and innovation process
   - ➔ 100% inclusive - All stakeholders 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
   - ➔ Visible and physical results by 2017 – 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. Setting up a roll-out strategy which is geared towards producing the required full impacts by no later than 2020.

2.1.4 PROMINENT WP3.1, scope and definition

Work Package 3 explores the technical options for certification, monitoring and enforcement procedures for inland navigation vessel engines emissions, suitable for a range of 'greening technologies' and to comply with stringent legislation. Key aspect is the demonstration of effectiveness in practice. This is referred to as Real Sailing Emissions, the equivalent of Real Driving Emissions of cars and trucks.
New stringent emission limits require the drastic reduction of harmful emissions of NO_x and PM by up to 80 - 95%.

Certification for inland vessel engines can learn from certification of road vehicles. However, there are some important differences:
- a much longer lifetime of vessels and their engines;
- engines are replaced by new engines or rebuilt engines during the lifetime of a vessel;
- a larger need to clean up existing vessels, because of the lifetime;
- a larger need for retrofit solutions or clean fuel options (clean diesel, LNG, etc.);
- also a possible wish to separately purchase a new engine and the emission control systems;
- large differences in engine load for inland vessels, due to upstream and downstream sailing and other waterway characteristics.

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 vessel 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 inland navigation vessels and their organisations (e.g. Euromot, AECC, CESA and national organisations)
- vessel owners/ operators and their associations
- clients of transport such as shippers and multinationals interested in the environmental performance of their transport operations.

The following table shows the deliverables of WP3.

Table 1.1: Deliverables of Work Package 3

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

This report presents deliverables D3.2 and D3.3 combined.

2.2 Objectives of certification, monitoring & enforcement

The main objective of WP3, certification, monitoring and enforcement is:
- To develop options for certification procedures for new engines and retrofit solutions for compliance with strict air pollutant emission limits (Stage V), both for laboratory and on-board certification.
- To evaluate certification & monitoring options to secure low Real Sailing (Pollutant) Emission (RSE, equivalent to Real Driving Emissions, or RDE, for trucks).

The objectives of D3.2 and D3.3 are to evaluate a range of measurement and monitoring options for this purpose. The measurement options vary from a test in a laboratory, to specific on-board measurements and to continuous on-board monitoring. All these options will be evaluated for Certification (D3.2) as well as for Monitoring and Enforcement (D3.3).

More specific goals for certification and monitoring & enforcement are:

- The goal of certification is to check if an engine with advanced emission control system (new or retrofit) or with an alternative or clean diesel fuel, complies with the emission regulations, to secure low Real Sailing Emissions and to facilitate monitoring and enforcement.
- The goal of monitoring and enforcement is to collect data on the Real Sailing Emissions and to verify if the engine complies with the certification. Presentation of emissions both in g/kWh as well grams per ton.km (CO_2, NO_x, PM).

2.3 Definitions and list of abbreviations

Certification
Certification according to the European Directives 97/68/EC and 2004/26/EC, 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 tests are normally carried out in an engine laboratory, however for retrofit systems also on-board certification tests are carried out. The tests must be accurate and reproducible. 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 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.

Type approval
Type approval of engines and after-treatment systems means that only one system must be tested for all the same systems to have the certificate. When the to-be-certified system meets the type-approval emission requirements all these systems are automatically approved. Therefore type-approval tests happen before the market introduction of the system.

Compliance
Compliance is about actually meeting the requirements. It is about true agreement to regulations meaning compliance deals with the situation after a system's market introduction. The relation with certification and monitoring is that these can both be ways to show compliance to the rules. Enforcement on the other hand is a way to ascertain and investigate in-use compliance.

Retrofit
Retrofit refers to adding technology or features to an existing system. In the automotive industry this can be interpreted as any type of emission after-treatment system (e.g. SCR, DPF). For vessels, retrofitting is a much broader concept. Retrofitting can be any type of (large) change to a vessel and does not always relate to emission after-treatment systems. Elongation of a vessel, turning a tanker into a bulk carrier, changing the deck house of a bulker into a moveable superstructure so that the vessel can also carry containers: these are all examples of retrofits. These changes are fairly common in the inland navigation industry due to the long lifetime of vessels.

COP **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.

ISC **In Service Conformity**
IUC **In-Use Compliance**
ISC and IUC refer to investigations whether engines in practice comply with the emissions legislation.

According to [EC-CION 2016] these tests should be done for non-road mobile machinery engines.

RSE **Real Sailing Emissions**
RSE Factor

RSE is a new word in the context of NRMM, engines for Inland Waterway Transport. It is the equivalent to RDE, Real Driving Emissions for Road Vehicles. For HD vehicles and cars, specific RDE test procedures are in place. This is necessary to obtain a better correlation between type approval emissions and emissions in practice. Main differences between type approval and real life include the difference in load pattern and difference in ambient conditions (weather conditions).
Real sailing emissions are the average emissions in g/kWh during normal sailing (in the engine control area). The RSE factor is applied to the official limit values based on standard test cycles (E3, E2).

ECU **Engine Control Unit**

ECU's are electronic systems which are in place to control a combustion engine and its auxiliary systems. ECU's for example control the air-fuel mixture and ignition timing.

OBD **On Board Diagnostics**
NCD **NOx Control Diagnostics**
DTC **Diagnostic Trouble Codes**

OBD and NCD are basically the same. They are diagnostics securing compliant engine emissions during normal operations. If the OBD finds anomalies or problems it shows Diagnostic Trouble Codes. DTC will be stored electronically and an amber light will indicate the skipper that there are emissions problems.

EPM **Environmental Performance Monitoring**
OBM **On-Board Monitoring system**

Environmental Performance Monitoring uses an on-board monitoring system for the transmission of data on the environmental performance of a vessel to a central database and the relevant stakeholders. Data may include the performance of NO_x, CO_2, fuel consumption, power and location of a vessel to be used for several purposes. The stakeholders may be an independent authority.

SRM **Standard Reference Material**
PEMS **Portable Emissions Measurement System**
SEMS **Smart Emissions Measurement System**

Standard Reference Material (SRM) is measurement equipment used in tests like those which are performed by SGS. SRM must be used for type approvals in a laboratory. PEMS was specially developed for road vehicles for measurement of Real Driving Emissions (RDE), an official part of the type approval. SRM, PEMS and SEMS can be used to test emissions in on vehicles, ships and machines in their real application. These 'portable laboratories' have analysers and equipment to measure the environmental performance of engines in real sailing conditions.

SEMS **Smart Emissions Measurement System**

SEMS is a smaller and simpler version of PEMS. SEMS combines data from the ECU with emission sensors to measure/compute the emission performance of engines in real sailing conditions.

DCU **Dosing Control Unit**

The Dosing Control Unit controls the dosing of reagent (urea, HC) in emission treatment systems like SCR catalysts.

Table 1.2 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	Compression Ignition
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CoP	Conformity of Production
DCU	Dosing Control Unit
DOC	Diesel Oxidation Catalyst
DM	Diagnostic Message
DPF	Diesel Particulate Filter
DTC	Diagnostic Trouble Codes
EC	European Commission
EGR	Exhaust Gas Recirculation
EPM	Environmental Performance Monitoring
GHG	Green House Gas
GTL	Gas-To-Liquid
IMO	International Maritime Organization
ISC	In Service Conformity
ISO	International Standardization Organization
IWT	Inland Waterway Transport
LNG	Liquefied Natural Gas
NCD	NOx Control Diagnostics
NRMM	Non-Road Mobile Machinery
NTE	Not To Exceed value
OBD	On Board Diagnostics
OBM	On Board Monitoring
OCE	Off Cycle Emissions
OEM	Original Equipment Manufacturer
PM	Particulate Matter
PN	Particulate Number
RDE	Real Driving Emissions
RSE	Real Sailing Emissions
REC	Retrofit Emissions Control device
RPM	Rotations Per Minute
SCR	Selective Catalytic Reduction
SEMS	Smart Emissions Measurement System

2. Needs for effective certification, monitoring and enforcement

This chapter looks into what is needed for effective emission certification, monitoring and enforcement. First, the issues related to the current situation are listed. These issues and attention points can be seen as the basis for ‘learning from the past’ and are used to identify the relevant criteria for the assessment of the various options.

2.1 Relation between certification, monitoring and enforcement

There is an inseparable relation between certification, monitoring and enforcement.
The only goal of ‘stringent’ legislation is low Real Sailing Emissions or low Real Driving Emissions, for respectively ships and road vehicles. The experience with road vehicles over the past decades shows that specific and stringent test and requirements for Real Driving Emissions are necessary to reach this goal, as discussed in Section 4.2 of the first PROMINENT report of certification, monitoring and enforcement (D3.1 the state-of-the-art)
So, it is very desirable that requirements for Real Sailing Emissions are included in the formal type approval. This does not have to be very complex as it will be shown in this report. Several options will be identified in this report.

For monitoring and enforcement, the possibilities for economical and independent testing on-board of vessels is very desirable. This will also be described in this report. The on-board test procedure described in section 4, can be used both as independent (in-use compliance) test as well as a test for retrofit emission control systems. Also the on-board monitoring, described in section 5, can be seen as an important option to secure low Real Sailing Emissions.
The history with trucks and cars proves that stringent legislation often does not lead to low Real Driving Emission. For diesel cars, NO_x emission in real world operation seems to be much higher than during the certification test cycle[4][5]. NO_x emissions of EURO V trucks under city driving conditions were typically a factor of three higher than the limit values[6]. For passenger cars the NO_x emissions are often 5 to 10 times higher. For trucks, the test procedures have been enormously improved with EURO VI, which has led to low real world NOx emissions, in line with the limit value[7].

2.2 Stakeholder considerations related to certification

The project team closely involved with this report represent already several types of stakeholders such as Technical Services, inspection and certification, after-treatment system supplier, research institutes and vessel owners. In-depth stakeholders’ consultation is planned in the ongoing PROMINENT project and will be included in Deliverable 5.6. Main stakeholders which can provide valuable input include EC (DG Growth, DG Move), CCNR/ CESNI, engine manufacturers and after-treatments system manufacturers.

[4] NO2-utslipp fra kjøretøyparken I norske storbyer: Utfordringer og muligheter frem mot 2025. Rolf Hagman, Karl Idar Gjerstad, Astrid H Amundsen. TØI rapport 1168/2011. November 2011. ISBN 978-82-480-1275-7 Electronic version

[5] TNO report MON-RPT-2010-02278 Verkennende metingen van schadelijke uitlaatgasemissies van personenvoertuigen met Euro-6 dieseltechnologie (exploratory measurements on pollutant emissions of Euro 6 diesel cars), W.A. Vonk en R.P. Verbeek, 8 september 2010

[6] Real-world NOx emissions of Euro V vehicles, Ruud Verbeek, Robin Vermeulen, Willar Vonk, Henk Dekker. TNO report MON-RPT-2010-02777, November 2010

[7] Robin Vermeulen, Jordy Spreen, Norbert Ligterink, Willar Vonk: The Netherlands In-Service Emissions Testing Programme for Heavy-Duty 2011-2013, TNO report : TNO 2014 R10641-2. May 2014

2.3 Criteria for assessment of certification and legislation

The following criteria are chosen for the evaluation of the measuring methods for certification and for monitoring & enforcement. Representativeness and accuracy are important for all purposes. However 'independent testing' and 'costs' are more important for (In Service Conformity, ISC) monitoring than for certification.

Table 2.1 Criteria for assessment of certification

Criteria	Clarification
Representativeness of real-world emissions or 'Real Sailing Emissions'	How good is the relation between emissions of the formal test and normal operation?
Accuracy / Reproducibility	Assessment of accuracy of all parameters used and the effect of inaccuracy on the end result
Cost of certification to end-user or manufacturer	Especially tests for retrofit systems should be low, because these are usually single systems. Also for OEM products costs should be relatively low due to the small market size.
Independent testing and quality check	The possibility for independent testing from the manufacturers is important for in-use compliance tests, for monitoring and for enforcement
Suitability for Certification	Is the quality of the test (measurement) high enough for certification? An accuracy of 5% to 10% could be sufficient in certain cases
Suitability for Monitoring & Enforcement	Especially the costs should be low. Accuracy is usually less important. The limit value can be increased with measurement uncertainty.

3 Overview of test options for certification, monitoring and enforcement

Certification of engines and after-treatment systems can be done in many ways. Certification always requires a test to check if the system is compliant to the regulations. Several types of tests can be identified. They can be categorized into three categories: lab tests, on-board tests and on-board monitoring. The following table shows the main options.
By checking a product against legal requirements by means of an approval granted by a member state authority the term certification is often replaced by the term Type Approval.

Table 3.1. Test options

1	**Laboratory tests**	**Section**
A	Original test cycle(s) E3, E2 and D2	4.1
B	Improved / additional formal test cycle(s)	4.2
2	**On-board tests**	
C	Vessel emission tests with PEMS or SRM	5
D	Vessel emission tests with SEMS	6
3	**On-Board Monitoring**	
F	Continuous sensor based monitoring	6

Laboratory tests
A. Laboratory tests are currently used in IWT for type-approval certification. Laboratory tests are tests which are carried out by installing the engine (and/or after-treatment system) on a test bed in a laboratory environment. Many parameters can be controlled and detailed emission data can be measured. These tests are done before an engine is installed on board respectively placed on the market.
B. Improved or additional test cycles similar to the E3 cycle, but with a more representative engine e.g. shifted propeller curve, lower average power and additional idle point. Additional not-to-exceed laboratory tests have a maximum emission value in g/kWh or g/kg CO_2 across the operating envelope of the engine.

On-board tests
On-board tests are currently already used for retrofit solutions. On board emission tests can be done with portable equipment. Nearly all emission tests that can be performed on a test bed in a laboratory environment can be performed on board as well. However, concessions must be made because less parameters can be controlled and the equipment is less accurate than lab equipment. Tests with SRM, PEMS and SEMS are carried out on board a vessel. Tests can be done after the installation of the engine and after-treatment system, either during operations or during testing-moments. SRM tests can measure almost all necessary emissions of the engine, where PEMS or SEMS focus on gaseous emission components.

Monitoring tests
Monitoring is inseparable from certification and type approval since monitoring can be used as a way to test compliance for certification purposes. This is not yet done this way in IWT. In road transport it is included: emission monitoring is a part of heavy duty emission legislation (but in solely responsibility of the engine / truck manufacturer). For on board-monitoring of vessels, the emission testing can be limited or extensive (from just smoke and NO_x to a broad set of parameters; PM, CO_2, and CH_4) but shall be under the control of an independent member state institution. Continuous on-board monitoring (OBM) or Environmental Performance Monitoring (EPM) would be the continuous monitoring of emissions. In contrast to periodic monitoring (or a single measurement), continuous monitoring would provide more information on the overall performance of the engine in practice.

This report focuses on on-board tests and on-board monitoring. The options are compared in the table below, with respect to the parameters that are measured and/or calculated.

Table 2.2. Comparison of on-board measurement options

	SRM / PEMS	**SEMS**	**EPM / OBM**
Technology	SRM analysers (official analysers)	Sensor based	Sensor based
NO_x	measured	measured	measured
PM	Gravimetric (SRM) or optional PN (PEMS)	Opt. PM/PN sensor[8]	Opt. PM/PN sensor
Emissions g/h calculation	Exhaust flow measurement usually not possible, so: • Fuel flow, or • Engine power, or • Air mass flow (calc. with carbon balance)	• Fuel flow, or • Engine power, or • Air mass flow (calc. with carbon balance)	Carbon balance method with fuel flow
CO_2 / fuel flow	optional	optional	Measured or from ECU
Power	Calc. optional or from ECU	Calc. optional or from ECU	Calculation via fuel flow or from ECU
GPS position	measured	measured	measured
Draught	n/a	n/a	Optional
OBM fault code	n/a	n/a	Via NCD
GPRS data transmission	optional	optional	Yes
Duration	1 day	1 day	≥ 1 month
Units	g/kWh g/km g/kg CO_2	g/kWh g/km g/kg CO_2	g/kWh g/km g/kgCO_2 g/tonkm optional

With EPM, fuel flow should always be measured, because energy consumption and CO_2 emissions are together with NOx the main continuous monitoring parameters.

[8] Only a level or number indication (not an official g/kWh value)

4 Laboratory test procedures

The laboratory test procedures are evaluated for their suitability for Certification as well as for Monitoring and Enforcement.

Since the revision 2004/26/EC of the European Directive 97/68/EC engines to be used in inland waterway vessels must comply with limit values for regulated pollutants. Such engines are tested in the test cycles E3, E2 and D2 of ISO 8178. The current version of Directive 97/68/EC is under revision at the moment. See for example [CION 2016]. For that reason there is an overlap between proposals for inland waterway vessels of the revision and the proposals in this report.

4.1 Original test cycle E3, E2, D2 and C1 (ISO 8178)

The E3 test cycle is used for propulsion engines intended to be used in inland waterway vessels. The E3 cycle is used for engines operated on a propeller curve. The cycle is designed to represent the operation points of engines for commercial marine applications. In the following table 4.1 the cycle modes are shown.

Table 4.1. ISO 8178 E3 cycle for vessel engines operating on the propeller curve

Mode Number	Engine Speed	Load	Weighting Factor
1	100% (Rated)	100%	0.20
2	91%	75%	0.50
3	80%	50%	0.15
4	63%	25%	0.15

The E2 test cycle is applied to fixed speed inland waterway propulsion engines with variable pitch or electrically coupled propellers. Those engines shall be tested on an engine dynamometer using the 4-mode steady-state cycle characterized by the same load and weighting factors as the above cycle but with the engine operated in each mode at rated speed (see table 4.2).

Table 4.2 ISO 8178 E2 cycle for constant speed vessel propulsion engines

Mode Number	Engine Speed	Load	Weighting Factor
1	Rated	100%	0.20
2	Rated	75%	0.50
3	Rated	50%	0.15
4	Rated	25%	0.15

Constant-speed auxiliary engines shall be type approved on basis of the D2 cycle, which is the 5-mode steady-state cycle (see table 4.3) and also the C1 cycle for variable speed and load of auxiliary engines (see table 4.4)
The load steps are defined as percentage values of the torque corresponding to the primary power output. The load speeds are defined as the maximum power available during a variable power sequence which is operated for an unlimited number of hours per year.

Table 4.3 ISO 8178 D2 cycle for constant speed vessel auxiliary engines

Mode Number	Engine Speed	Load	Weighting Factor
1	Rated	100%	0.05
2	Rated	75%	0.25
3	Rated	50%	0.30
4	Rated	25%	0.30
5	Rated	10%	0.10

Table 4.4 ISO 8178 C1 cycle for variable speed and -load auxiliary engines

Mode Number	Engine Speed	Load	Weighting Factor
1	100% (Rated)	100%	0.15
2	100%	75%	0.15
3	100%	50%	0.15
4	100%	10%	0.10
1	Intermediate	100%	0.10
2	Intermediate	75%	0.10
3	Intermediate	50%	0.10
4	Idle	0%	0.15

4.1.1 Presentation / overview

Aspect	**Characteristics of the option**
Where are tests carried out?	In a laboratory (either manufacturer lab in presence of a designated Technical Service or in the lab of a designated Technical Service)
When are tests carried out?	Generally prior to market release of new engine type. Individual engines can also be tested such as after an (emissions) upgrade or in the context of Monitoring & Enforcement
Which emissions are tested?	NO_x, HC, CO, PM, CO_2 (after revision of directive also PN, particulate number is limited for some engine categories as well as NH_3 for SCR systems)
Who carries out the tests?	Laboratory of applicant for type approval in presence of a Technical Service or the Technical Service directly
Which authorities give a certificate?	With respect to the European directive type approval is granted by the Type Approval Authority of a Member State
How long is the certificate valid?	As long as the engine type is produced / For the engine life. Engine must be installed according to the manufacturers specifications
What is certified: a type of engine/ a particular setup/ etc?	The complete engine system (combustion plus after-treatment) is type approved, including all emission control systems based on a parent engine representative for an engine family.

The parent engine is measured and it becomes representative for an engine family on an engine test bench before engines of that family are allowed to be placed on the market. The parent engine of the family shall be selected using the primary criteria of the highest fuel delivery per stroke at the declared maximum torque speed. In the event that two or more engines share these primary criteria, the parent engine shall be selected using the secondary criteria of highest fuel delivery per stroke at rated speed.

The parent engine as well as the family members must comply with the legal emission limits for the defined criteria pollution. An engine conforming to the engine type characteristics shall be submitted to the technical service responsible for conducting the approval tests. The technical service issues a test report about the outcome of the emission testing. The application for the engine type or engine family type-approval shall be submitted by the manufacturer to the approval authority of an EU Member State together with the Technical Report issued by the Technical Service. An application shall be accompanied by an information folder delivering all required information in accordance with the applicable Directive.

The Member State receiving the application from an engine manufacturer or its representative shall grant type approval to all engine types or engine families which are in conformity with the information folder and which meet the requirements of the Directive.

The engine tests are performed on an engine test bench complying with the requirements of Directive 97/68/EC in the applicable stage. The tests can be done on an engine test bed at the manufacturer's facility in presence of a Technical Service or directly in the lab of a Technical Service. The engine shall be equipped with an intake system within the manufacturer's specified value of ± 300 Pa for a new air cleaner at the engine operating condition in which according to information from the manufacturer gives the maximum air flow. The test engine shall be equipped with an exhaust system with exhaust back pressure within ± 650 Pa of the specified by the manufacturer at the engine operating conditions which results in maximum declared power. An engine cooling system with sufficient capacity, which makes it possible to maintain the normal operating temperatures of the engine as prescribed by the manufacturer shall be used.

The engine shall meet the limit values for the regulated exhaust gas components. For the time being the regulated gaseous criteria components are carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) and nitrogen oxides (NO_x) as well as the particle mass (PM). Methane emission CH_4 is not yet mentioned in the legislation (Directive 97/68/EC). It is planned to be added with Stage V.

4.1.2 Equipment review

In order to perform engine type approval testing, the identification of the performance data of the regulated exhaust gas components is prescribed. The engine test bench criteria are described in Directive 97/68/EC and ISO 8178-4.

An engine dynamometer with adequate characteristics to perform the required test cycles shall be used. The measuring equipment for torque and speed measurement shall allow the measurement of the power within the given accuracy limits. The accuracy of the measuring equipment must meet the maximum tolerances according to ISO 8178-4.

The regulated components to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearizing circuits is permitted.

- Carbon monoxide (CO) analysis
  The carbon monoxide analyser shall be of the non-dispersive infra-red (NDIR) absorption type.

- Carbon dioxide (CO_2) analysis
  The carbon dioxide analyser shall be of the non-dispersive infra-red (NDIR) absorption type.

- Hydrocarbon (HC) analysis
  The hydrocarbon analyser shall be of the heated flame ionization detector (HFID) type with detector, valves, pipe work, etc, heated so as to maintain a gas temperature of 463 K (190 °C) ± 10 K.

- Oxides of nitrogen (NO_x) analysis
  The nitrogen-oxide analyser shall be of chemiluminescent detector (CLD) or heated chemiluminescent detector (HCLD) type with a NO_2/NO converter, if measured on a dry basis. If

measured on a wet basis, a HCLD with converter maintained above 328 K (55°C) shall be used, provided that the water quench is satisfied. For both CLD and HCLD, the sampling path shall be maintained at a wall temperature of 328 K to 473 K (55°C to 200°C) up to the converter for dry measurement, and up to the analyzer for wet measurement.

- Particulate matter

  Particulate matter is determined by gravimetric weighing of the particulate matter load on a sampling filter. For that reason diluted exhaust gas is pulled through a sampling filter on which the solid material in the exhaust gas (mainly elemental carbon, hydrocarbon and small quantities of sulphate and adsorbed water, ash, metal and other solid parts) is sampled. Dilution may be accomplished by a partial or full flow dilution system. The additional weight on the filter represents the measured amount of particles by means of a differential weighing of the filer before and after the sampling.

The gaseous emissions sampling probes must be fitted at least 0.5 m or three times the diameter of the exhaust pipe - whichever is the larger - upstream of the exit of the exhaust gas system as far as applicable and sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (70°C) at the probe. In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a 'V'-engine configuration, it is permissible to acquire a sample from each group individually and calculate an average exhaust emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emissions calculation the total exhaust mass flow of the engine must be used. If the composition of the exhaust gas is influenced by any exhaust gas after treatment system, the exhaust sample must be taken upstream of this device in the tests of stage I and downstream of this device in the tests of stage II. When a full flow dilution system is used for the determination of the particulates, the gaseous emissions may also be determined in the diluted exhaust gas. The sampling probes shall be close to the particulate sampling probe in the dilution tunnel. CO and CO_2 may optionally be determined by sampling into a bag and subsequent measurement of the concentration in the sampling bag.

The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems, and maintain the temperature of the diluted exhaust gas between 315 K (42°C) and 325 K (52°C) immediately upstream of the filter holders. De-humidifying the dilution air before entering the dilution system is permitted, if the air humidity is high. Dilution air pre-heating above the temperature limit of 303 K (30 °C) is recommended, if the ambient temperature is below 293 K (20°C). However, the diluted air temperature must not exceed 325 K (52°C) prior to the introduction of the exhaust in the dilution tunnel.

The calibration of all measurement instruments shall be traceable to national or international standards and comply with the requirements listed in table 4.5.

Table 4.5 Accuracy requirements of equipment for test according to ISO 8178-4

No.	Measuring Instrument	Accuracy
1	Engine speed	± 2% of reading or ± 1% of engine's max. value whichever is larger
2	Torque	± 2% of reading or ± 1% of engine's max. value whichever is larger
3	Fuel consumption	± 2% of engine's max. value
4	Air consumption	± 2% of reading or ± 1% of engine's max. value whichever is larger
5	Exhaust gas flow	± 2,5% of reading or ± 1,5% of engine's max. value whichever is larger
6	Temperatures ≤ 600 K	± 2 K absolute
7	Temperatures > 600 K	± 1% of reading
8	Exhaust gas pressure	± 0,2 kPa absolute
9	Intake air depression	± 0,05 kPa absolute
10	Atmospheric pressure	± 0,1 kPa absolute
11	Other pressures	± 0,1 kPa absolute
12	Absolute humidity	± 5% of reading
13	Dilution air flow	± 2% of reading
14	Diluted exhaust gas flow	± 2% of reading

The response time determination shall be done with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0.1 second. The gases used for the test shall cause a concentration change of at least 60% FS. The concentration trace of each single gas component shall be recorded. The response time is defined as the difference in time between the gas switching and the appropriate change of the recorded concentration. The system response time (t90) consists of the delay time to the measuring detector and the rise time of the detector. The delay time is defined as the time from the change (t0) until the response is 10% of the final reading (t10). The rise time is defined as the time between 10% and 90% response of the final reading (t90 – t10). For time alignment of the analyser and exhaust flow signals in the case of raw measurement, the transformation time is defined as the time from the change (t0) until the response is 50% of the final reading (t50). The system response time shall be ≤ 10 seconds with a rise time ≤ 2.5 seconds for all limited components (CO, NO_x, HC) and all ranges used.

The test engine shall be mounted on the test bench. Prior to the test the engine power curve is measured. Following the measurement equipment are calibrated and turned on. At least one hour before the test, each filter must be placed in a petri dish for a number of hours conditioning in the weighing chamber. At the end of the stabilization period, each filter shall be weighed and the weight shall be recorded. The filter shall then be stored in a closed petri dish or sealed filter holder until needed for testing. The filter shall be used within eight hours of its removal from the weighing chamber. The tare weight shall be recorded.

4.1.3 Performance on Criteria

Table 4.6 Evaluation laboratory test on performance criteria

Criteria	Characteristics of the option	Assessment
Representativeness of real-world emissions or Real Sailing Emissions	The standard test cycles and standard weighting factors do not necessarily reflect the real operating characteristics of the engine.	Poor /Average
Accuracy / Reproducibility	The accuracy and reproducibility on the engine test bench is good to very good.	Good
Cost of certification to end-user or manufacturer	The applicant for Type Approval has to bear the costs	Average
Independent testing and quality check	Independent testing and quality control is useful, but after the installation of engines on a vessel, it is not possible to test it again on a test bench. For the independent testing and quality check, a portable emission measurement regime is considered being essential (refer to section 4).	Poor
Suitability for Certification	New OEM systems Retrofit systems (if engine is available for test bench) Clean(er) fuels (if engine is available for test bench)	Good Good Good
Suitability for Monitoring & Enforcement	New OEM systems Retrofit systems Clean(er) fuels	Poor Poor Poor

4.2 Improved/ additional test cycle

4.2.1 Additional test points

Vessel engines are not solely operated on the given propeller curve. Therefore it is useful to measure the operating points next to the propeller curve or on the curve. The various routes of the vessels will not always allow that the required engine power is the same as on the theoretical propeller curve. Usually the design point of the engine-propeller combination includes a power safety margin of 10% to 15%. Consequently the real propeller curve is 10% to 15% below the theoretical power curve. In addition, the environmental conditions (wind, wave, tidal current, water flow, etc.) can have a more or less important influence on the motor power requirement.

To improve the testing procedure one can consider to test more than the points on a particular (most likely not representative) propeller curve but also points of different engine-propeller combinations. Figure 4.1 below shows an already considered improvement to this situation for vessel engines operating on the propeller curve (E3 cycle)[9]. The revision of the current state of Directive 97/68/EC will consider additional random points below and above the considered propeller curve. During the type approval testing the Technical Service shall randomly select two additional load and speed points in which the criteria pollutants are measured. Each test point shall meet the limit values as they will be defined in the future Non-Road Mobile Machinery Directive.

Depending on the purpose of the inland water vessel, it could be useful to measure the idling emissions of the engine during the emission test. Vessel engines, e.g. while waiting at a lock or waiting at loading / unloading, are occasionally operated at engine idle speed. As future task the determination of inland waterway vessel idling time shall be considered.

[9] An engine control area will be defined similarly for vessels with constant speed engines (E2, D2 cycle),

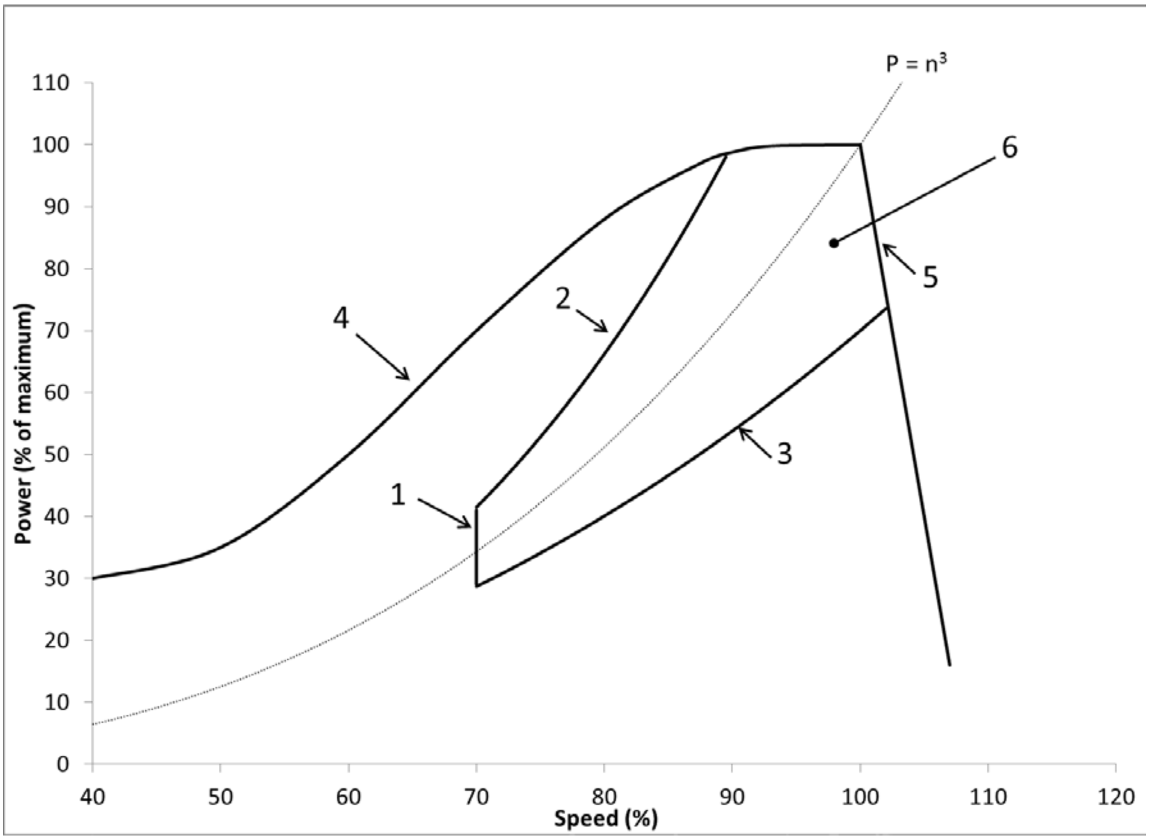

Figure 4.1: Control area for engine tested on E3 cycle

	Key
1	Lower speed limit
2	Upper boundary curve
3	Lower boundary curve
4	Full load power curve
5	Governor maximum speed curve
6	Engine Control Area

4.2.2 Weighing factors of E3 and E2 test cycles

In table 3.1, the weighting factors of the E3 and E2 test cycles are presented. This weighing is very much focussed on the 75% power point. Additionally 20% weighting for the maximum power points and in total 30% weighting for 50% and 25% power. The weighted average power is about 63%.
The operation profiles were investigated in the WP1 report: 'D1.1 List of operational profiles and fleet families'. In section 3.2, it can be seen that the power profiles are different from the E3 cycle. Depending on the vessel type, two characteristic patterns are seen. Refer to the figures below (both on the Rhine). The first one is a relatively even distribution across the power profile, the second one is more bi-model with a time peak at about 75% power and one at about 25% power. The first one is characteristic for upstream sailing and the other one for downstream sailing. From

this assessment, it can be concluded that an E3 or E2 test cycle with a more even distribution of the weighing factors would be more in line with the real sailing characteristics and will therefore give a more realistic average emission value.

In WP5 of PROMINENT, the operation profiles and the engine operating characteristics will be extensively investigated for a substantial number of vessels for Rhine, Danube and other waterways. This will give more insight for both the operational area in the engine map, as well as possibly improved weighting factors of individual load points.

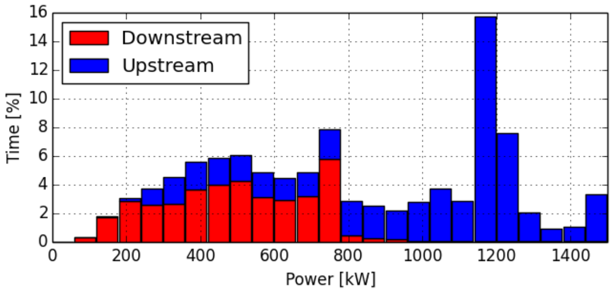

Figure 4.2. Operational Profile for Journey 03 (135m MTS, Rotterdam - Karlsruhe, Crude Oil)

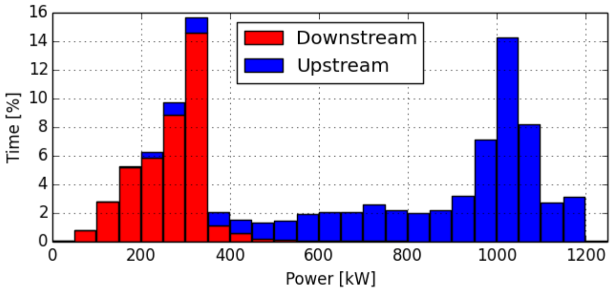

Figure 4.3. Operational Profile for Journey 10 (135m MVS, Antwerp - Mainz, Containers)

4.2.3 Presentation

The main purpose of the extended test cycle is to improve the representativeness of the laboratory test procedure for the Real Sailing Emissions (RSE). Several options will be considered.

There are two options for the additional engine test points to the E3 cycle.

- **As random points within a Not to Exceed (NTE) area (also referred to as engine control area);**
- **As fixed value in the E3 cycle table**

To set fixed values in the cycle table for E3 test is not effective. The engine can be designed for these operating points and cannot verify outside of the fixed points. When introducing a NTE area, the engine emissions can be checked on random operating points within the NTE area. The emissions must comply with the emission limits in each point. The technical service selects the additional points within the NTE area. The precise limit value for the individual points should be further investigated and agreed upon with all stakeholders.

4.2.4 Equipment review

For the tests on an engine test bench with the extended test procedure, no new measurement instruments are required. Existing measurement equipment to be used. Refer to 4.1.2.

4.2.5 Performance on Criteria

Table. 4.6 Evaluation laboratory test with improved test cycle on performance criteria

Criteria	Characteristics of the option Test cycle: adapted E3, E2, D2	Assessment
Representativeness of real-world emissions or Real Sailing Emissions	There are additional engine load points tested that can occur in real sailing mode. The additional engine load points are fixed test points.	Average
Accuracy / Reproducibility	The accuracy and reproducibility on the engine test bench are very good because there are no disturbing influences.	Good
Cost of certification to end-user or manufacturer	The applicant for Type Approval has to bear the costs.	Average

Table 4.7 Evaluation laboratory test with improved test cycle including selected additional points within the engine control area on performance criteria

Criteria	Characteristics of the option E3, E2, D2 + NTE	Assessment
Representativeness of real-world emissions or Real Sailing Emissions	There are additional engine load points tested that can occur in real driving mode. The additional engine loads are selected by the Technical Service and are within the range of propeller curve.	Good
Accuracy / Reproducibility	The accuracy and reproducibility on the engine test bench are very good because there are no disturbing influences.	Good
Cost of certification to end-user or manufacturer	The applicant for Type Approval has to bear the costs.	Average
Independent testing and quality check	Independent testing and quality control is useful, but after the installation of engines on a vessel, it is not possible to test it again on a test bench. For the independent testing and quality check SRM or PEMS portable emission measurement equipment is essential.	Poor
Suitability for Certification	New OEM systems Retrofit systems Clean(-er) fuels	Good Good Good
Suitability for Monitoring & Enforcement	New OEM systems Retrofit systems Clean(-er) fuels	Poor Poor Poor

5 On-board measurements with SRM / PEMS

The on-board test procedures are evaluated for their suitability for Certification and Type Approval provisions as well as for Monitoring & Enforcement.

5.1 Emission testing on board of a vessel

The tests are carried out with Standard Reference Material (SRM). This is relatively high quality equipment also used in laboratories. For this purpose the systems are made portable. PEMS systems (Portable Emissions Measurement Systems) were first used for road vehicles. The system is also considered for application on board of vessels. PEMS usually measures the gaseous components NO_x, CO and HC. Often dual NO_x analysers are used, such that NO and NO_2 can be measured in parallel. Separate modules for PM (particle mass) and PN (particle number) measurement are available.

5.1.1 Presentation / overview

Table 5.1 Characteristics of on board measurements with SRM and PEMS equipment

Aspect	Characteristics of the option
Where are tests carried out?	On board
When are tests carried out?	Whenever tests are needed. After refit. In order to check the after-treatment.
Which emissions are tested?	SRM:O_2, CO_2, CO, NO_x, C_xH_y / CH_4, PM, NH_3 (for SCR systems) PEMS: O_2, CO_2, NO_x, CO, HC, optional PM, PN and NH_3
Who carries out the tests?	Independent ISO 17025 accredited Laboratory in case of certification on board (when using SRM).
Which authorities give a certificate?	Depends on purpose of measurements. Local administration or (Dutch) Green Award
How long is the certificate valid?	Depends on demands of local administration
What is certified: a type of engine/ a particular setup/ etc?	Engine plus after-treatment system

5.1.2 Equipment review

According to the standard ISO 8178, emission measurements should be performed with measuring equipment with the following measuring principles:

- **Oxygen: paramagnetic**
- **Carbon dioxide: non-dispersive Infra Red**
- **Carbon monoxide: non-dispersive Infra Red**
- **Nitrogen oxides: (heated) chemiluminescense**
- **Hydro carbons: heated Flame Ionisation Detector**
- **Particulate matter: dilution tunnel**

The emission measuring equipment to be used is stated in ISO 8178-1 and / or ISO 8178-11. Other systems or analysers may be accepted if it is found that the yield equivalent results or if parties involved agree to the use of such a system or analyser.

When measuring the gaseous components (O_2, CO_2, CO, NO_x, C_xH_y / CH_4) with alternative measuring principles, the proper functionality shall be demonstrated by the use of calibration gases as well.

The SRM for measurement of PM is the dilution tunnel (full flow or partial flow). PM from diesel engines consists of a condensable part and a non-condensable part. With the use of the dilution tunnel the exhaust gas is cooled down quickly to a temperature between 315 K (42 °C) and 325 K (52 °C) in order to capture the condensable part of the exhaust gas. The ratio condensable – non condensable is unknown, but can vary between a factor of 2 and 5. Therefore, both have to be measured. Also the emission limit values for PM are based on condensable plus non-condensable.
PEMS equipment usually does not include the gravimetric PM measurement. Separate modules for PM (particle mass) and PN (particle number) measurement are available as options.

Parameters / components to be measured during testing

The following parameters have to be measured during emission testing on test beds:

- Engine speed
- Torque or power
- Fuel consumption
- Air consumption
- Exhaust gas flow
- Temperatures at several locations around the engine
- Pressures at several locations around the engine
- (Gaseous) emission components
    - O_2 (oxygen)
    - CO_2 (carbon dioxide)
    - CO (carbon monoxide)
    - NO_x (nitrogen oxides)
    - C_xH_y (unburned hydrocarbons)
    - PM (particulate matter)

In order to ensure the results, the deviations and calibration periods as shown in table 5.2 must be taken into account:

Table 5.2 Deviations and calibrations periods

Number	Parameter	Permissible deviation (± values based on max. values of engine)	Permissible deviation (± values according to ISO 3046)	Calibration frequency (months)
1	Engine speed	2%	2%	3
2	Torque	2%	2%	3
3	Power	2%	3%	Na
4	Fuel consumption	2%	3%	6
5	Specific fuel cons.	na	3%	Na
6	Air consumption	2%	5%	6
7	Exhaust gas flow	4%	Na	6
8	Cooling liquid temperature	2 K	2 K	3
9	Oil temperature	2 K	2 K	3
10	Exhaust gas pressure	5% of maximum	5%	3
11	Under pressure intake manifold	5% of maximum	5%	3
12	Exhaust gas temperature	15 K	15 K	3
13	Combustion air	2 K	2 K	3
14	Barometer pressure	0.5% of reading	0.5%	3
15	Relative humidity	3%	Na	1
16	Fuel temperature	2 K	5 K	3

For the gaseous components the following demands have to be taken into account:

Table 5.3 Accuracies of the measurements' range

Item	Accuracy
Measuring range	15 – 100% of the scale
Measuring accuracy	5% of reading / 3.5% of full scale ± 4 ppm at concentrations < 100 vppm
Repeatability	± 1% at concentrations > 155 vppm ± 2% at concentrations < 155 vppm
Noise	2% of full scale
Drift	2% of the measuring range

The emissions have to be tested using the below mentioned measurement principles:

Table 5.4 Measurement principles

Component	Measuring principle
Carbon monoxide	Non Dispersive Infra Red
Carbon dioxide	Non Dispersive Infra Red
Hydro carbons	Heated Flame Ionisation Detector
Nitrogen oxides	Chemiluminescent detector (when dry sampling) Heated chemiluminescent detector (when wet sampling)
PM	Partial dilution with 1 or more filters, isokinetic sampling, filter temperature less than 325 K
Oxygen	Paramagnetic

The analysers have to be calibrated and / or adjusted using calibration gases.

Validity of the tests

The tests on a test bench are valid when the requirements below are met:

- The atmospheric factor: $0.98 < f_a < 1.02$ (or when due to technical reasons this can't be met: $0.93 < f_a < 1.07$ (and correction of the PM)
- The drift of the emission measuring equipment between two calibrations is less than 2%
- Measurement time is at least 10 minutes

Emission testing on board of a vessel

ISO 8178: "Reciprocating internal combustion engines – exhaust emission measurement – Part 2: Measurement of gaseous and particulate exhaust emissions under field conditions" specifies the measurement and evaluation methods for gaseous and particulate exhaust emission from reciprocating internal combustion engines (RIC engines) under steady-state and transient conditions for field testing.

This part of ISO 8178 is applied when RIC engines used in off-road vehicles, marine installations, generating sets, diesel rail traction or similar applications need to be measured under field conditions or at site in order to determine the in-use compliance, or when it is not possible to take the measurements under test-bed conditions or to use the test-bed measurement results.

Field measurements shall be conducted only when one or more of the following requirements and conditions exist:

a) When test-bed measurement for type approval is not appropriate because site conditions cannot be duplicated.

This test is a substitution of test-bed measurement, therefore the test should be conducted using the test cycle in ISO 8178-4. In this case, this part of ISO 8178 is only applicable to those engines which can reproduce at site measuring points specified in ISO 8178-4, such as marine engines at sea trials, initial installation of engines for driving generators and diesel electric locomotives.

b) When measurement at site is necessary to evaluate actual and local pollution.

This should be made under actual or simulated operating conditions. Engine operation under a test cycle defined in ISO 8178-4 is not always possible, but the test procedure should be as close as possible to that procedure. Therefore, values measured in this case may not be directly comparable with test-bed results because measured values are very much dependent on test cycles.

c) When site measurement is agreed between the parties involved.

Values obtained represent only a specific engine under specific site conditions and do not necessarily represent average or typical values. Measured values cannot be compared with test-bed results in most cases because measured values are very much dependent on test cycles.

d) When measurement at site is necessary to check the conformity of used or rebuilt engines to a standard.
e) When in-use compliance testing is required for off-road vehicles covered in ISO 8178-4:1996, 8.3 (mobile C cycle applications).

If field measurement cannot reproduce exactly the same operating conditions as the test-bed conditions, the emission values will not be identical to the values obtained on the test bed. Therefore, specific methods shall be available for the determination of compliance. Such methods are not covered by this part of ISO 8178, but are subject to the respective legislation or to agreement between the parties involved.

Parameters / components to be measured during testing

The following parameters shall be measured, calculated or recorded:

- Specific fuel consumption
- Engine speed during the test
- Turbo charger speed, if applicable
- Air pressure after the charge air cooler
- Uncorrected brake power during test
- Fuel rack position of each cylinder, if applicable
- Air temperature after the charge air cooler, if applicable
- Coolant temperature, inlet
- Coolant temperature, outlet
- Lubricating oil temperature

The emission measuring equipment to be used is stated in ISO 8178-1 and / or ISO 8178-11. Other systems or analysers may be accepted if it is found that the yield equivalent results or if parties involved agree to the use of such a system or analyser.

The determination of system equivalency shall be based on a seven-sample pair (or larger) correlation study between the system under consideration and one of the accepted systems of this part of ISO 8178. This testing shall be done under laboratory conditions. “Results” refers to the specific cycle-weighted emissions value. The correlation testing is to be performed at the same laboratory and test cell, and on the same engine, and is preferably run concurrently. The test cycle to be used shall be the appropriate cycle as found in ISO 8178-4 or in ISO 8178-11. The equivalency of the sample pair averages shall be determined by *F*-test and *t*-test statistics in accordance with ISO 8178-1:2006, Annex D, under the laboratory conditions and engine conditions described above.

The instrumentation for torque and speed measurement shall enable the measurement of the shaft power to be within the given limits.

The accuracy of the data to be measured is given in the table below.

Table 5.5 Accuracy of the recorded parameters

Number	**Parameter**	**Permissible deviation (± values based on max. values of engine)**	
1	Engine speed	± 2%	
2	Torque	± 5%	
3	Power	± 5%	
4	Fuel consumption	Diesel: ± 4% Residual fuel oil: ± 6%	
5	Air consumption	± 5%	
6	Exhaust gas flow	± 5% calculated	
7	Coolant temperature	±2 K	
8	Lubricating oil temperature	± 2 K	
9	Exhaust gas pressure	± 5% of max.	
10	Inlet manifold depressions	± 5% of max.	
11	Exhaust gas temperature	± 15 K	
12	Air intake termperature	± 2 K	
13	Atmospheric pressure	± 0.5% of reading	
14	Intake air humidity	± 3 %	
15	Fuel temperature	± 2 K	
16	Dilution tunnel temperatures	± 1.5 K	
17	Dilution air humidity	± 3 %	
18	Diluted exhaust gas flow	± 2% of reading	
Number	Component	Accuracy	Precision
19	Gaseous emissions vppm mg/m_0^3 g/kW	 ± 5% of reading ± 7% ± 9%	 ± 1% of reading ± 5.1% ± 7.4%
20	PM emissions mg/m_0^3 g/kW	 ± 6.5% ± 8.5%	 ± 6.5% ± 8.5%

Issues with on board testing

In practice it is often impossible to measure the fuel consumption at site / on board. In such cases, especially those concerning heavy fuel, an estimation with a corresponding estimated error has to be made. The consequences of such an error on the final emissions shall be calculated and reported with the results of the emission measurement.

The engine shall be operated with the torque and speed sequence applied according to the typical field conditions or, if applicable, to the relevant test cycles described in ISO 8178-4. In cases where the relevant test cycle is not possible, e.g. due to the characteristic of the load or because of the torsional vibration of the plant, the required test point shall be replaced by a point as close as possible, by agreement with all parties involved.

5.1.3 Performance on Criteria

Table 5.6. Evaluation of SRM / PEMS test on board of a vessel on performance criteria

Criteria	Characteristics of the option	Assessment
Representativeness of real-world emissions or Real Sailing Emissions	On board measurements can be performed while sailing an E2/E3 cycle, On board measurements can be performed during normal sailing	Average Good
Accuracy / Reproducibility	- SRM/PEMS in combination with accurate Power / fuel consumption measuring devices - SRM/PEMS in combination with ECU Power and fuel consumption	Good Average
Cost of certification to end-user or manufacturer	For on board validation of new OEM systems, Retrofit systems (REC), Clean(er) fuels	Average
Independent testing and quality check	SRM/PEMS testing is carried out by independent company	Good
Suitability for Certification (on board Validation)	New OEM systems , Retrofit systems, Clean(er) fuels - SRM in combination with accurate Power / fuel consumption measuring devices - SRM in combination with ECU Power and fuel consumption	 Good Average
Suitability for Monitoring & Enforcement	New OEM systems , Retrofit systems, Clean(er) fuels	Good

6 On-board measurements with sensor based equipment

On board sensor based measurements are considered for two purposes:

1. For (independent) validation of the REC (Retrofit Emission Control device), as a 1 day measurement on board of the vessel. An example of such a system is the TNO SEMS system. Refer to [Vermeulen 2012] and section 3
2. For Environmental Performance Monitoring, EPM[10]. This is a system which permanently stays on the vessel and monitors continuously fuel consumption, CO_2 and NO_x emissions. Refer to section 6 and 9.

6.1 Continuous sensor based Environmental Performance Monitoring

Emissions, fuel consumption and performance parameters of a vessel and its engines can be measured using relatively simple sensors and algorithms. Most of the sensors used to continuously measure emissions are developed for the automotive market. Therefore they are widely available and very well engineered.

In order to verify compliance of all emissions of a vessel engine a low-cost EPM system needs to measure the legislated emissions in the required units. In practice these are NO_x, CO, HC, PM all in g/kWh, and ammonia slip in ppm. Additionally, the monitoring system can be used to monitor the total amount of emissions of a vessel.

The most important sensors are the NO_x, O_2 and fuel flow sensors in combination with the strategy to determine exhaust flow. All emission component sensors placed in the exhaust measure concentrations. The precision of the determination of the exhaust flow is therefore of critical importance to the precision of the EPM system. The CO_2 or O_2 in the exhaust gasses can be used to calculate fuel consumption or the inverse, when power, exhaust gas flow or combustion air flow is known. Alternatively CO_2 or O_2 combined with fuel consumption, can be used to calculate power and exhaust flow.

PM cannot be quantified with a direct measurement. For low PM engines there are sensors which allow the user to verify if the PM emissions indicatively, for example if they are below a given threshold. These sensors are considered ‘OBD-sensors’. For road transport, these sensors are especially promoted to determine whether the diesel particulate filter (DPF) is working correctly. For engines without DPF, an estimation of PM could be done when an engine map of the PM exists or can be obtained by on board measurements. Because the sailing profile of an engine is rather flat (mostly stationary and on the propeller curve), the calculated PM emissions will give a realistic idea of the order of magnitude of emitted PM.

Modern engines are often equipped with an ECU which can provide detailed data on air/exhaust mass flow, fuel consumption and even power (amongst other engine parameters). The results for the named values are not measured by the engine system but the calculations programmed in the engine software dependent on fuel rack, engine speed settings and engine characteristics. This information would greatly improve the accuracy of the emission measurements, especially when these parameters are validated during the Type Approval test of the engine or during pass off tests of the engine on board of the vessel.

The sampling frequency of the sensors is generally in the order of 10-100 Hz or higher. This resolution of emission data is not opportune in practice. Since the emissions of the engine are measured later than the delivery of the power, an average over time is preferred. The precision of the results increases with the averaging times. The accuracy of the EPM data mostly depends on the accuracy of the exhaust mass flow measurement.

[10] EPM is also referred to as On-Board Monitoring (OBM) in earlier PROMINENT reports

Data processing and storage is done by a data-logger. This unit is able to read the different inputs and convert these into the required emissions. The unit also stores the values until they can be downloaded as a report, as with DM2[11] in automotive OBD systems, or broadcasted to a central storage point. In PROMINENT the information is broadcasted over GPRS.

An EPM system should be certified as an independent monitoring device. The installation of this system can be ratified by an on-board measurement using a procedure as described in section 5.1. Ideally, this would be done in combination with the pass-off test of a new engine. As mentioned before, the precision of the exhaust flow measurement is the main criteria for a precise EPM system. TNO has estimated a precision of 20% for the NOx emissions in g/kWh. It is expected that the accuracy of the EPM system could be improved to 10% (bandwidth), when the OBM system is calibrated during an independent on board test with SRM/PEMS equipment or with a test on an engine bench. This accuracy evaluation is scheduled for WP5, real life pilots, within PROMINENT.

There are different scenarios on how the EPM data can be used. It can be used by the vessel owners to optimise the operations of their fleet and to optimise the drive train configuration (for new vessels or with rebuilds of existing vessels). The parameters include engine load pattern, sailed distance, fuel consumptions, emission data as a function of diverse parameters such as location, velocity, type of waterway, etc. This can also be used to demonstrate their environmental performance; energy consumption, CO_2 emissions and pollutant emissions to their customers.

Secondly EPM can be used to demonstrate compliance of pollutant emissions to the authorities (such as sometimes required for incentive programs). In that case the authorities should determine the content and format of the information they want to obtain. It is proposed that this rather aggregated information which reports the NO_x performance in line with the type approval and (future) RSE requirements. The accuracy is lower than with SRM measurements, but the advantage is that NOx is monitored permanently.

A number of scenarios is given for the use of an EPM system for proof of environmental performance to authorities:

- Only feedback to the skipper
  - Only the skipper is warned when his vessel engine is no longer compliant and only he is able to consult the outputs of the OBD system
  - The hardware required for this option will be implemented in all scenarios
  - The feedback provided to the skipper will be applied in all scenarios
  - There is limited requirement to store the OBM data. The number and/or date of non-compliancy events can be stored.
  - This scenario is comparable to OBD for modern on-land applications (trucks EURO VI, machines stage IV), but with as major difference that on marine vessels the implementations of effective inducements is not accepted (such as power reduction)
- Part of recurring checks done by authorities and harbours
  - EPM data must be stored on-board for a certain amount of time.
  - A standard report can be produced allowing authorities to evaluate the compliancy of the vessel and other EPM variables
  - Reports are shared when asked upon
- Formal periodic report to authorities
  - Extension of scenario 2
  - Skipper has to regularly file the periodic reports to authorities. These reports can contain summarised and processed variables reducing the amount of data.
- Direct reporting of (non-)compliancy to the government
  - Same features as in scenario 1

[11] DM2 = history / logged diagnostic messages. DM1 = current messages

    - Broadcast non-compliancy in a standardised format (comparable to AIS but without public access)
    - Does not require long term on-board storage of OBM data
    - This can be an addition to scenario 2 and 3
    - In case of non-compliancy the authorities can request the skipper to provide OBM data of the period of non-compliancy
- Continuous reporting of EPM data to authorities
    - Same features as scenario 1
    - Broadcast EPM data in a standardised format (comparable to AIS but without public access)
    - Does not require long term on-board storage of EPM data
    - Large data storage and processing capacities required on authority side

6.1.1 Presentation

The different scenarios described in the previous paragraph all make use of the same sensors and DAQ system. They differ in the way data is processed and communicated with authorities.

Aspect	**Characteristics of the option**
Where are tests carried out?	In situ operational measurements. Sensors are placed directly into the exhaust system, on the engine and fuel lines. With modern engines, certain parameters can be directly obtained from the engine ECU.
When are tests carried out?	Continuous measurement of a NO_x, O_2, engine mass flow. If available: read-out of engine ECU data
Which emissions are tested?	NO_x is measured directly precision better than 20% CO_2 is calculated with precision better than 20% PM threshold can be validated with OBD-sensor in low PM environment, alternatively PM production can be estimated by specified routines based on the engine specifications or on-board mapping of PM emissions
Who carries out the tests?	Continuous and automated testing Installed by certified contractor
Which authorities give a certificate?	Not yet defined.
How long is the certificate valid?	System type-rating is valid for the period of the OBM legislation When combined with on-board ratification, a periodical renewal is advisable In order to check PM emissions periodical on-board measurements are required
What is certified: a type of engine/ a particular setup/ etc?	An OBM system should be type rated. Setup of sensors, DAQ-system and data storage and reporting system are type certified.

1. Only feedback to the skipper

How is compliancy checked by authorities?	Authorities are not aware of non-compliancy
How is measurement data stored	Data is not stored or storage of non-compliance events with data and duration

2. Part of recurring checks done by authorities and harbours

How is compliancy checked by authorities?	Compliancy is checked when checking paperwork
How is measurement data stored	Data is not stored on-board for a given period

3. Formal periodic report to authorities

How is compliancy checked by authorities?	Compliancy is evaluated at moment of reporting
How is measurement data stored	Phase 1: data is stored on-board Phase 2: data is filed to authorities which can add valuable parameters to their databases

4. Direct reporting of (non-)compliance to the authorities

How is compliancy checked by authorities?	Option 1: A message confirming compliancy is constantly broadcasted to authorities Option 2: When the vessel is not long compliant a message is broadcasted to authorities
How is measurement data stored	Option A: Data is not stored Option B: Report of non-compliancy is stored Option C: Identical to scenario 3

5. Continuous reporting of OBM data to authorities

How is compliancy checked by authorities?	Option 1: A message confirming compliancy or not compliant is constantly broadcasted to authorities Option 2: When the vessel is not compliant a message is broadcasted to authorities
How is measurement data stored	Data is stored by authorities. Requires vast amounts of process and storage capacity on authorities' side.

6.1.2 Equipment review

Table 6.1 Measurement equipment review

Sensor	**Manifold air pressure (MAP) sensor**
Output	MAP, Manifold air temperature
Derived variables*	Exhaust mass flow, engine Power, fuel consumption
Measuring principle	Automotive sensor Pressure measurement
Accuracy	MAP: 5% (affected by position) Manifold air temperature: <1 °C
Precision	MAP: 2% Manifold air temperature: ±3 °C
Response time	1 s
Cost	
Correction factors	none
Preconditioning/calibration	none

Sensor	NO_x sensor
Output	NO_x [ppm], O_2 [vol%]
Derived variables*	NO_x [g], engine Power, fuel consumption
Measuring principle	Automotive sensor
Accuracy	NO_x [ppm]: spec sheet: offset: ±10 ppm, gain: ±10 % (0-500 ppm). NO_x [ppm] can be improved to ± 2% by calibration with span-gas. NO_x [g/kWh]: ±10 %, dependent on accuracy fuel consumption, power or exhaust flow O_2: <1 %
Precision	NO_x [ppm] in SCR system: ±10 % (affected by position, especially in SCR systems) NO_x [ppm] in non-treated exhaust gas: none
Response time	5 ms
Cost	
Correction factors	NO_x: aging is compensated by sensor electronics
Preconditioning/calibration	Self-calibrating sensor

Sensor	**OBD PM sensor (for systems with PM filter)**
Output	PM compliancy status
Derived variables*	None
Measuring principle	Automotive sensor The sensor is loaded with PM and consecutively regenerated. The duration of this sequence is monitored in order to evaluate changes in the performance of the soot filter.
Accuracy	na
Precision	na
Response time	na
Cost	
Correction factors	na
Preconditioning/calibration	Sensor has to be calibrated for the system / different loads of the engine

6.1.3 Performance on Criteria

The suitability of sensor based on board measurements is judged for two applications:

1. **For (independent) validation of the REC (Retrofit Emission Control device), new OEM engine or clean fuel, as a 1 day measurement on board of the vessel.**
2. **For Environmental Performance Monitoring, EPM.**

Table 6.2 Performance on criteria

Criteria	Characteristics of the option	Assessment
Representativeness of real-world emissions or Real Sailing Emissions	Emissions are measured in real-sailing conditions and therefor fully representative. If following automotive, limit values for RSE would be higher than limit value for the official test cycle (E3, E2). In this report referred to as RSE factor.	Good
Accuracy / Reproducibility	-Both accuracy and reproducibility are strongly related with sampling time. -Long term: Average values calculated over multiple months have a very high precision (<1 %), average accuracy (<10 %) and good reproducibility. -Short term: Emissions calculated on short timescales (1 h) have an estimated accuracy below ±10 %. -Reproducibility is average for constant sailing (low for dynamic operation / manoeuvring)	Average
Cost of certification to end-user or manufacturer	for on board validation of new OEM systems , Retrofit systems (REC), Clean(er) fuels	Average / good
Independent testing and quality check	Certification of the EPM system is required. Option 1: Certification of stand-alone OBD system. Requires to prove that the system preforms well on different engine types. Option 2: Certification of OBD system for a certain engine family. Option 3: On board certification of OBD system.	Good Average Poor
Independent testing and quality check	Certification of the OBD system is required Relative low cost system which can be mounted on a vessel Possible future expansion with a PM sensor	Good
Suitability for Certification (on board validation)	New OEM systems Retrofit systems Clean(er) fuels	Average / good
Suitability for Monitoring & Enforcement	New OEM systems Retrofit systems Clean(er) fuels	Good Good Good

7 Recommendations Type approval and Real Sailing Emissions (MUL)

7.1 Introduction type approval

A type approval is granted to a product that meets a minimum set of regulatory, technical and safety requirements. The set of requirements becomes usually more stringent over time, dependant of the impact the product can generate on human health, nature, environment, complexity and safety. Consequently the product providers must improve, test and validate their products to keep their access to the market. When speaking about engines for the inland waterway transportation, it is clear that new rules are needed to make this transportation method more sustainable.

From road transport it has been proven that Real Driving Emissions (RDE) of trucks became acceptable after the implementation of the stringent legislation (Euro VI). Especially the RDE test procedure part is important because the engine is tested across the actual load pattern of the truck with also varying ambient conditions.
Whereas for over the road transportation economics of scale exists, with IWT the market volumes are very small. This means that the costs of Type Approval, including RSE testing should be as low as possible. Another important difference to consider between IWT and Road transportation is the economic lifecycle; a vessel engine is used for 50,000 to 80,000 hours before its replacement whereby the life cycle for a truck engine is roughly 20,000 to 25,000 hours.

7.2 Type approval requirement's for new Stage V Engine systems

It is recommended to consider the following items to be included in the new engine type approval regulations:

- Focus on RSE to improve the environmental sustainability of IWT
- Responsibility at the engine manufacturer to place emphasis in the subject
- Durability validation to improve long-term emission related performance
- Family building in order to reduce burden of testing and administrative work
- Engine OEM to deliver proper documentation of strategies and calibrations (similar to the EPA TIER 4F approach)

7.3 Type approval requirements for REC systems

7.3.1 The basis: UNECE R132

The UNECE R132 was made for Retrofit Emission Control devices (REC) to be applied to heavy-duty road vehicles and land based NRMM. It offers a strong basis for inland navigation to start from because it was written with the following purposes:

- Rules for a type approved REC system
- Obtain an equal standard for all REC providers
- Offer a quality guarantee for REC devices
- Increase roll out scale to fit road vehicles with a Retrofit Emission Control devices
- Increase roll out scale to fit NRMM with a Retrofit Emission Control devices

In R132 four REC classes are defined, depending on which emission components are meant to be reduced:

- Class I: Only PM reduction, with no increase of NO2
- Class IIA or IIB: Only PM reduction, with increase of NO2 lower than a certain amount

- Class III: Only NOx reduction.
- Class IV: PM and NOx reduction.

NOx consists of NO and NO_2. NO_2 is considered as the more toxic.
For class I the NO_2 incremental may not be higher than from the baseline. For class II the NO_2 incremental increase must be lower than 20%. For class III and IV, the NO_2 value in g/kWh may not be higher, than from the baseline. For inland navigation a similar strategy could be chosen. Specific NO_2 requirements currently do not exist to OEM engines.
PEMS system for road vehicles are often equipped with dual NOx analysers. NO and NO_2 can than be measured in parallel.

7.3.2 Assessment of R132

An assessment of this regulation was made. On the positive side we see things that can remain as they are or requiring limited reviewing. On the other side, there are the points which should be adapted. These are points that are not relevant, not robust enough for IWT, therefore requiring specific marine approaches and thus some more in-depth work.

Positive
• Existing regulation covering all relevant topics related to Retrofit Emission Control devices (REC)
• Rules for retrofit systems: Needed for IWT because of the long lifetime of the vessels and their engines.
• Procedures similar to common practice used for engine type approval
• Documentation requirements similar to standards for engine type approval
• Procedures and technology validation protecting the end user (and also other stakeholders)
• Possibility to type approve an emission system rather than an engine => Scale of roll out is thereby increased
• REC BY-PASS forbidden but some options to be implemented for emergency reasons for IWT

To be adapted for IWT

Performance requirements to improve 1 step or multiple steps in emissions legislation

Our recommendation is to modify the approval possibilities to the schematic as shown below.

	Start			Goal
PM	Non certified	CCR1	CCR2	Stage V
NOX	Non certified	CCR1	CCR2	Stage V

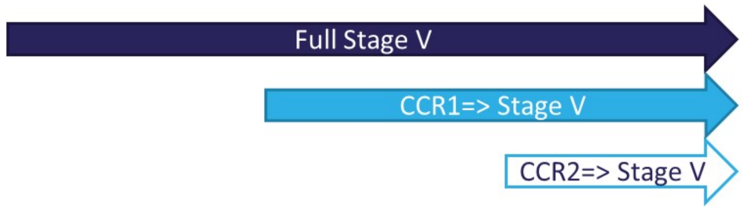

Figure 7.1 Performance requirements in emission legislation

- Exclusive focus is on Retrofit
- The vessel owner must get the same legal protection for a retrofitted Stage V as for a new engine Stage V. So product liability must be applied to both engine and REC manufacturer

- No rules for other technologies than REC for diesel engines; example GTL, LNG as clean fuels are not in the scope.

- Test cycles are transient.
- An extension towards the marine test cycles or convert to exclusive marine cycles should be possible. For marine the stationary ISO 8178 test cycles should be used, preferably including the random test points in the engine control area (NTE area)

- Durability requirement and validation is insufficiently defined for marine applications. It is recommended to:
- High Temperature validation required (could be done via artificial aging partly).
- 2800 hours like EPA TIER 4F as a safer approach

- Only of Type 3 (NO_X) and 4 (NO_X + PM) are relevant

- REC BY-PASS is forbidden in the R132 regulation but mandatory for some marine applications.
- We would suggest that a good back pressure monitoring system can also be used. This considers flow and can foresee problems. In combination with a partial by-pass it would be safe to operate an inland vessel engine without jeopardizing the full load capability under emergency conditions.

- Inducement strategies to be removed for safety reasons (full power capability at all time)
- We recommend to consider other inducement strategies than for road applications or NRMM, to secure maintenance and service on these systems.
- For example the OBD system can transmit a relevant DTC to controlling authorities as an alternative for inducement?

- System scaling options are not scoped for marine applications and must be reviewed

- The regulation does not foresee any verification after installation of the REC system.
- It is recommended to require an application validation on board of each vessel equipped with a REC. This is also to thoroughly check differences due to variations in scaling and in piping configurations. Refer to the picture below

- The regulation can only be used to type approve complete systems. System components or subsystems cannot be approved. An extension is needed for example to type approve the EPM (Environmental Performance Monitoring system).

7.4 Type approval, validation and RSE

It is recommended to implement a common procedure for type approval and RSE for new Stage V engines and for REC, see figure 7.2. The overall procedure includes the following steps:

- Type approval in an engine laboratory.
  This includes the random points for RSE and also the evaluation of the NOx Control Diagnostics (NCD).
- Validation of each system on board of the vessel.
  This includes again the random points for RSE and actual NOx measurements with SRM/PEMS or SEMS equipment.
  For a REC, it also includes the evaluation of all engine specific calculations. Refer to section 7.5.

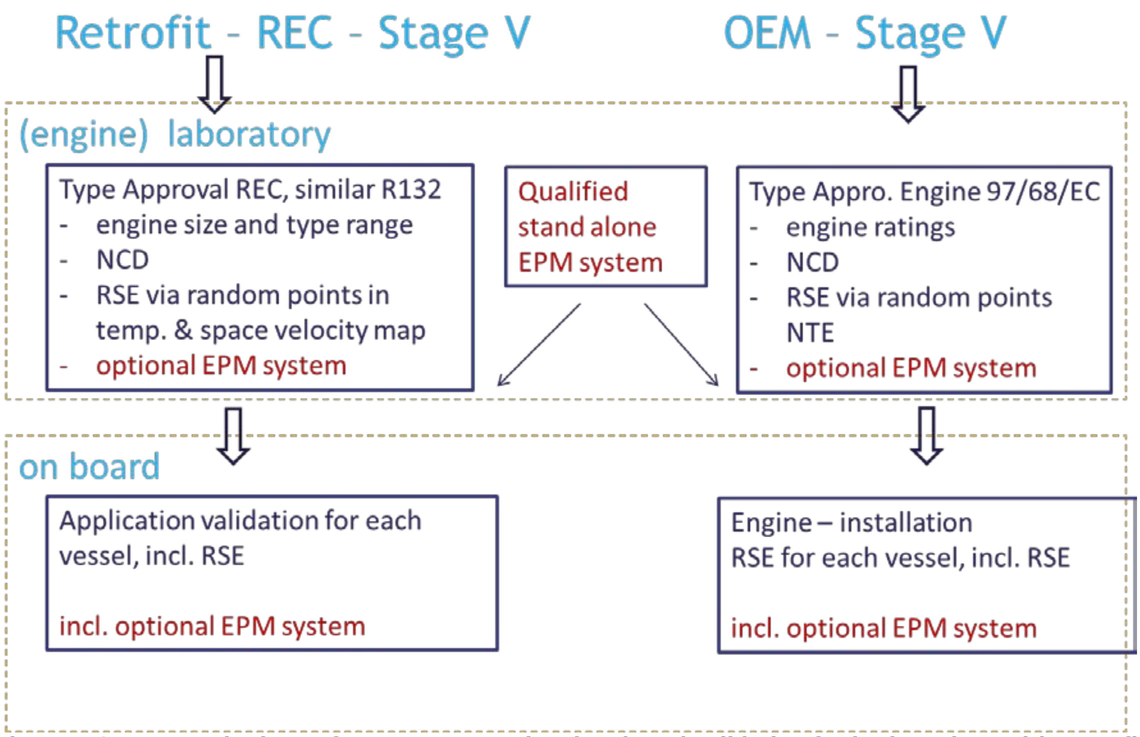

Figure 7.2. Proposed scheme for Type Approval and on board validation for both engines with Retrofit Emission Control device (REC) as well as for new OEM engines (Stage V).

An EPM (Environmental performance monitoring system) can help to ensure that the RSE of IWT can be made transparent to the operator of the vessel and to other stakeholders. Such a system can transmit the relevant data of the vessel's environmental performance to a central database of e.g. independent authorities of the member states. Also refer to 7.5.1.3.

7.5 Type approval requirements for REC system components

7.5.1 Subsystems requiring new scaling options for Type Approval

To be economically viable the scaling of REC systems must be larger for IWT than required by R132 for heavy-duty on-road and NRMM applications. To tackle this issue the regulation must provide guidelines for the following subsystems:

7.5.1.1 Subsystems exhaust package

- Catalyst and particulate filter

What can remain is the technical specification to be fulfilled for each building block as already specified in R132.
The additional requirement is to approve the package in function of minimum and maximum space velocity of exhaust gas per catalyst part (DOC, DPF, SCR, ASC) of the overall system and to allow REC providers (and OEM's) to scale systems to these calculations rather than to the engine swept volume per cylinder as a basis for approval.
The minimum and especially the maximum temperature exposure window must be type approved and well validated and documented. Typically Vanadium based SCR catalysts show to be sensitive over time for exhaust gas temperatures over 500°C when not correctly applied.
It must be possible for independent inspection services to verify based on the approval documentation that the system on board of a vessel is compliant and in conformity with the provisions to be applied for the engines on board.

Example: In the type approval documentation the maximum space velocity for

- *the DOC catalyst is described as 65000 (h^{-1})*
- *the DPF modules is described as 17000 (h^{-1})*
- *the SCR catalyst is described as 25000 (h^{-1})*
- *the ASC catalyst is described as 90000 (h^{-1})*
- *and the maximum exhaust gas temperature is defined as 540°C.*

It is easy for an inspector to verify based on the engine datasheet and the catalyst dimensions in the system if the catalyst package is compliant with the engine.

- Housing of the system & Urea mixing ducts

The concept of building the housing and exhaust package for an application must come with technical parameters demonstrating the quality of the system and mixing ducts
We hereby propose the following technical parameters that can be demonstrated by the REC provider and/or OEM.

  - Uniformity index for exhaust gas into the different sections of the system
  - Urea distribution into the SCR package
  - Velocity calculation methods
  - Urea mass range based on the NOx mass flow range

7.5.1.2 Subsystems urea dosing package

The dosing hardware of a urea dosing package is limited by a minimum and maximum flow rate. The system provider should demonstrate how the hardware can be scaled from the smallest to the biggest range. This should include NOx mass flow and urea mass calculations.

Example:
A system uses metering pump and an air assisted nozzle to inject urea into the system.
For a 400 kW engine one dosing package (dosing maximum 9 kg/h of urea) offers an overdosing capacity of 20% and is safe to use. Moreover the system has a good accuracy dosing urea at low

load conditions of the engine. For a 900 kW engine the dosing range is not sufficient because very accurate in the low load conditions but not capable of handling the high load conditions thus 2 or 3 dosing packages must be operated in parallel.

- *The REC provider must provide evidence of the* ***minimum and maximum*** *dosing range of the metering pump and injection nozzle.*
- *The REC provider must provide evidence and* ***proof capability to multiply*** *the same hardware within the same application.*

Calculation of urea flow requirement

The REC provider must be able to demonstrate for what engine technologies and types he is capable of scaling the computing for.
Elements of this computing or calculations are the correct amount of urea to be dosed, the DPF to be BP in function of exhaust flow to be monitored or the OBD to be accurate the calculation of engine power etc.

Example:
An engine is equipped with a mechanical injection system and no CANbus data for engine operational conditions are available. The REC provider must demonstrate and prove how the REC system can calculate the Exhaust mass Flow, the NOx mass flow, the required urea flow etc..
If the REC system provider also wants type approval for engines equipped with a CANbus system he must demonstrate his capability to read the relevant information from CANbus.

7.5.1.3 Subsystems EPM

Environmental Performance Monitoring - EPM is a systems which monitors continuously fuel consumption, CO_2 and NO_x emissions. It stays permanently on the vessel and transmits the data wireless, via GPRS, to a central database. From there it can be used for several purposes. Refer to section 9.
An EPM system can be an independent system or it can be a part of an REC or an OEM engine. In all cases an independent validation on board of the vessel is required.

The certification / type approval procedure of the EPM is proposed along the following pathway:

The European standard EN 14181 describes the quality assurance procedures needed to assure that an automated measuring system, AMS (installed to measure emissions to air) is capable of meeting the uncertainty requirements on measured values given by legislation, e.g. EU Directives or national legislation or more generally by competent authorities.

Three different quality assurance levels (QAL1, QAL2 and QAL3) are defined in this standard.

This quality assurance levels cover the suitability of and AMS for its measuring task, the validations of the AMS following its installation and the control of the AMS during its ongoing operation.

The suitability evaluation (QAL1) of the AMS and its measuring procedure are described in the European Standards EN 15267-3 and ISO 14956 where a methodology is given for calculating the total uncertainty of AMS measured values. This total uncertainty is calculated from the evaluation of all the uncertainty components arising from its individual characteristics that contribute.

QAL1:
In order to calculate whether the EPM is feasible to measure the emission in g/kWh within the given uncertainties, European standard EN 15267-3 and ISO 14956 can be used.

QAL1 is a theoretically calculation of the uncertainties.

For QAL2 in the EN 14181 three day of testing is required. At each day at least five comparative measurements with SRM and AMS / EPM have to be performed. The results given by the EPM are corrected with a calibration factor determined during the QAL2 measurements. Once the factor is implemented, every 2nd, 3rd, 4th and 5th year an “annual surveillance test” (AST) has to be performed in order to check if the EPM is still in compliance with the uncertainty demands. During this AST at least 5 comparative measurements have to be performed.

For IWT EPM measurements quality assurance levels similar to the EN 14181 can be advised in order to assure the emission results when results have to be checked by the authorities.

8 Recommendations Monitoring and Enforcement

Monitoring in the context of the Non Road Mobile Machinery Directive, 97/68/EC, means that the EC or EC member states evaluate whether the emissions in practice corresponds to those during the Type Approval of engine. This can also be referred to as **'In-Service Conformity'**. In the proposal for Regulation 7795/16 article 18, 14 April 2016, monitoring is included as follows:
" the Commission will conduct monitoring programs to determine to what extent for every engine category, the emission from the test cycle correspond to the emissions measured in actual operation. Those programmes and their results shall annually be the subject of a presentation to the Member States and subsequently of a communication to the public".
In this report the emission in actual operation are referred to as **'Real Sailing Emissions, RSE'** in line with 'Real Driving Emissions, RDE' the official term used for road vehicles.

Enforcement needs to be carried out by Type Approval authorities, if for a certain engine type the emissions in actual operations deviated too much from the emissions during the type approval. The manufacturer of the engine or the Retrofit Emission Control system should be liable for these deviations. The regulation should describe in sufficient detail how the tests in actual operation can be carried out.

8.1.1 Monitoring and Enforcement test procedure

It is recommended to give the RSE test an official status for both OEM engines as well as for engines with REC. The test does not have to be carried out during the Type Approval of the engine, but should be carried out during the validation with the engine or REC installation in a vessel. Refer to section 7.

In particular the In Service Conformity / RSE test procedure should include:

- The **engine control area**, in the past also referred to as **Not To Exceed area, NTE**. For inland navigation vessels, the initial proposal is included in the proposal for Regulation 7795/16 (refer to section 4.2). In this proposal, the area is defined as a band width around the propeller curve in the engine map. Also the power range is limited from about 25% to 100% of maximum power. It should be noted that this may lead to relatively high NOx emissions at idle and low load operation. This may be high total NOx emissions for applications with a high share of idle and low load operations. For example for vessels such as ferries and work ships which may have a very low average load.

- Emission components and limit value:
  The relevant emission components are currently limited to NOx and NH3. It can be considered to add particulate mass (PM) or Particulate Number (PN) at some point in the future.
  The limit value for the NOx emissions, which is currently used can be defined as follows:

  NOx_{RSE} **<** RSE factor **x** Limit value Type approval (dimension g/kWh)

  RSE factor could vary from about 1.2 to 2. This includes than an allowance for measurement accuracy (on board) and ambient conditions. Recommended is an RSE factor of 1.5. Possibly with an initial value of 2.0 to build up experience with variations in practice.
  For NH3 the same RSE factor is recommended (but then based on a ppm limit value).

- The ambient conditions:
  NRMM regulation requires NOx control at ambient conditions between -7° and +35°C.

- Possible allowance for averaging (if any):
  According to the current proposal (proposal for regulation 7795/16??), every single point with the engine control area should comply with the RSE limit value. So no averaging across several points within the engine map. Averaging would be limited to several minutes.

8.1.2 Measurement equipment

It is recommend to allow a range of measurement options, as long as the labs are accredited for the particular measurement. In that way, volume of data can be collected in a costs effective manner.

Therefore, the options described above are all recommended for monitoring:
- SRM / PEMS: Standard Reference Material, which includes PEMS kind of systems currently used for road transport
- SEMS: Smart Emissions Measurement System. A general correlation should be available of SEMS with SRM or lab equipment, including the calculation procedure.
- EPM: the continuous sensor based monitoring could provide massive input for the understanding of Real Sailing Emissions. Proper working of each EPM system should be verified after the installation by an accredited organisation.

For an overview of the parameters for SRM/PEMS, SEMS and EPM, the reader is referred to Chapter 3 of this report.

9 Recommendations Environmental Performance Monitoring

Environmental Performance Monitoring - EPM, is defined as a voluntary continuous monitoring of environmental parameters on board of a vessel with a daily wireless (GPRS) data transmission to a central database. Originally EPM was referred to as On Board Monitoring (OBM), but this name would give the impression of obligatory monitoring of pollutant emissions in line with OBD (On Board Diagnostics).
EPM is wider, apart from NOx, it also includes fuel consumption, CO_2 emissions, engine load pattern and vessel parameters like location, route and speed.

EPM can be used for several purposes:

- Evaluate the performance of emission control systems
- Report NOx in g/kWh to regional or national authorities (if part of an incentive program or a voluntary program investigating In Service Conformity).
- Report NOx and CO_2 performance in g/km, g/ton.km or g/trip to clients
- Evaluate engine size, driveline configuration and efficiency of the overall energy system.
- Get insight and optimise the sailing pattern (efficient navigation)

9.1.1 Recommended parameters

It is recommended to monitor the following parameters with EPM.

One hour (average) values for propulsion engine(s):

- Average power (excluding idle)
- g/kWh NOx emissions (Power > 10%)
- g/kWh NOx emissions in accordance to 'In Service Conformity' ISC, emissions in Engine Control Area (probably only power larger than about 20-25%)
- l/h fuel consumption
- DTC: Diagnostic Trouble Codes

Cumulative per trip or during a longer period:

- Propulsion engine(s) idle time
- g/km NOx emission (including idle)
- litre/km fuel consumption
- kg/km CO2 emissions (based on fuel consumption)
- NOx and CO2 per ton.km emissions, based on nominal or actual cargo load
- Binned data: running time per power bin (10 power bins for 0-100%). Refer to example in the figure below.
- Binned data: average NOx in g/kWh per power bin (9 power bins 10% - 100%)

Axillary engines / generator sets per trip or during a longer period:

- running time for each generator set
- average (electric) power while running
- Calculation g/km emissions based on standard specific fuel consumption and emission factors (dependent on engine CCNR or EU Stage class)

Alternatively, for simplicity, for the auxiliary engines a default energy consumption and NOx emission can be taken into account. Default values are for example available from national emission factors for Non Road mobile machinery (including inland navigation vessels).

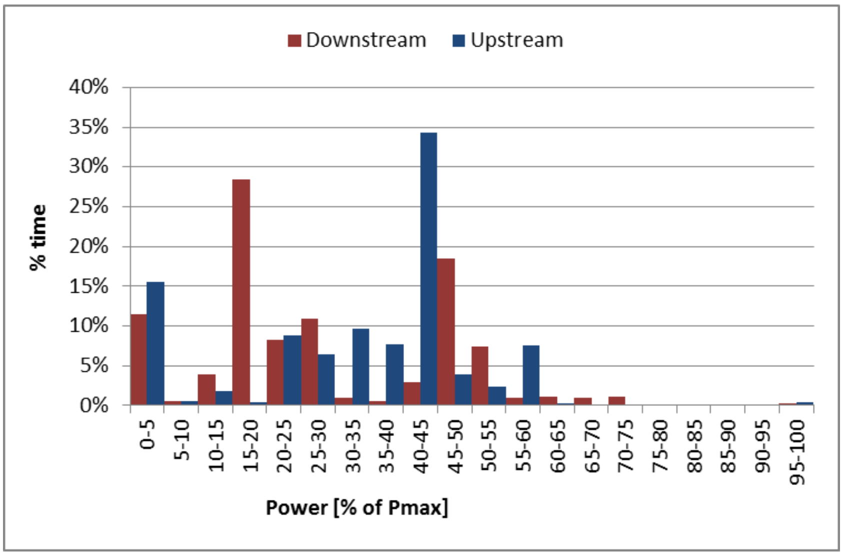

Figure 9.1. Engine power distribution for a container vessel, Rotterdam-Duisburg

9.1.2 Equipment

Currently, within PROMINENT, on-board data is recorded on a per second basis. Also experience is built up with transmissions of per second data to a central database. The load patterns of vessels are however fairly stationary. Engine speed and power can remain constant for hours. So in a later phase it can be decided to average data per minute, before sending it to the central database. From that further averaging can take place to parameters per hour and per trip.

Equipment for EPM monitoring is basically very compact digital equipment which fits in a shoe box. It uses an automotive NOx/O_2 sensor and a digital connection to the Engine Control Unit (ECU). Fuel consumption is obtained from the engine management or from a separate fuel consumption meter. A GPRS unit is used to transmit the data to a central database.

For a more detailed equipment and parameter description refer to section 6.

10 Conclusions

In this report an assessment of certification procedures has been performed for new engines and retrofit solutions for compliance with strict air pollutant emission limits (Stage V). This included certification and monitoring options to secure low Real Sailing Emission (RSE). This lead to the following conclusions.

1. Measuring methods

The laboratory and on-board measurement methods were evaluated based on criteria. The summary is provided in the table below. Main conclusions of this evaluation are: the lab based measurement excel in accuracy and are therefore very suitable for certification. The on-board measuring methods score better for representativeness of Real Sailing Emissions and are very suitable for on board validation of compliance with stringent standards (Stage V) and for In Service Conformity measurements.

Criteria	Laboratory tests		On-board tests with SRM or PEMS	On-board sensor based measurement
	Original ISO cycle	ISO cycle + additional test points		
Representativeness of real-world emissions or Real Sailing Emissions	poor / average	average / good	good (with additional points)	good (NOx) (with additional points or if continuous)
Accuracy / Reproducibility	good	good	good / average	average
Cost of certification to end-user or manufacturer	average	average	average	average / good
Independent testing and quality check	poor	poor	good	good
Suitability for Certification	good	good	average / good for on board validation	average /good for on board validation
Suitability for Monitoring & Enforcement	poor	poor	good	good

2. Retrofit Emission Control devices (REC)

A type approval of REC for vessels is recommended in line with UNECE R132[12], but with a validation of the emissions performance on board of each vessel. In order to be able to act quickly, a procedure under the umbrella of EC or interested member states is recommended (rather than a formal UNECE procedure).

The current practice regarding Retrofit Emission Control deals with a single engine test report which can be used as an incentive at national level due to the fact that the current practice has a few shortcomings such as quality variation, no check of OBD/NCD system, etc..

[12] UNECE R132 was specially developed for road vehicles and land based NRMM.

3. Real Sailing Emissions (RSE)

In terms of Real Sailing Emissions a very similar procedure for both engines with REC and OEM engines is recommended.

The proposed procedure consists of a set of measurements in random points in a laboratory (type approval, as to be implemented with stage V) and on-board measurements within the NTE area (validation). The on-board test procedure can be performed with laboratory quality equipment (SRM, e.g. PEMS), or with sensor based equipment (such as SEMS or EPM). For each test point within the NTE area the limit should be below the In Service Conformity (ISC) value in g/kWh or g/kg CO_2. The ISC value is defined as the RSE-factor times the Stage V limit value.

4. In terms of **monitoring and enforcement,** the same procedures for engines with REC and OEM engines should be applied. The ISC monitoring should be in line with land based NRMM. An independent testing with Real Sailing Emissions RSE test procedure on-board of vessels can be performed with the following recommended options:

- PEMS - similar to road vehicles;
- SEMS - as an economic option;
- EPM – as an option for continuous monitoring on board of vessels, which includes energy consumption and CO_2 emissions.
-

5. The main contributions of **PROMINENT** is related to the evaluation of:

- the load patterns of different types of vessels and different routes;
- the on-board measurement options SRM/PEMS – SEMS – EPM;
- EPM options for broad environmental performance.

Additionally, stakeholders' consultations (EC, national governments, manufacturers and end-users) will be conducted.

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