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AIR POLLUTION AND ENERGY EFFICIENCY

Final report of the Correspondence Group on Assessment of Technological Developments to Implement the Tier III NO_x Emission Standards under MARPOL Annex VI

Submitted by the United States

SUMMARY

Executive summary:	This document provides final report on the work of the Correspondence Group on Assessment of Technological Developments to Implement the Tier III NO_x Emission Standards under MARPOL Annex VI. The collated comments for the Correspondence Group, a list of ships with installed SCR systems, and a list of ships with liquefied natural gas-fuelled engines, are submitted in document MEPC 64/INF.10.
Strategic direction:	7.3
High-level action:	7.3.2
Planned output:	7.3.2.1
Action to be taken:	Paragraph 16
Related documents:	MEPC 62/24; MEPC 64/4/16, MEPC 64/INF.8 and MEPC 65/INF.10

Introduction

1 Regulation 13.10 of MARPOL Annex VI calls for a review of the status of technological developments to implement the 2016 Tier III NO_x emission limits. At MEPC 62, the Committee established a Correspondence Group (CG) to carry out this review (MEPC 62/24, paragraph 4.24).

2 The Terms of Reference (ToR) provided by the Committee directs the CG to consider what information and data are pertinent for the review and how that information and data should be collected and analysed. In addition, the ToR directs the CG to use this data and any other information to determine the status of technological developments to

implement the Tier III NO_x limits set forth in regulation 13.5.1.1 of MARPOL Annex VI. The ToR call on the CG to consider the following specific points:

.1 range of technologies (engine fitting, material, appliance, apparatus, other procedures, alternative fuels or compliance methods) that may be used to comply with the Tier III NO_x standards;

.2 the current use of these technologies on marine diesel vessels with a view towards characterizing the introduction and demonstration of these technologies in real world applications;

.3 progress of engine and after-treatment manufacturers towards developing such technology and expectations for bringing Tier III NO_x technologies fully to market by 2016;

.4 identification of any subsets of marine diesel engines where there will not be technologies available to comply with the Tier III standards;

.5 where relevant, the global availability of consumable products used by a certain technology to reduce emissions to the required standard in Tier III, including supply chain issues, e.g. restrictions on import, export and sale;

.6 recommend whether the effective date in regulation 13.5.1.1 of MARPOL Annex VI should be retained or, if adjustment is needed, reasoning behind that adjustment; and

.7 provide an interim report to MEPC 64 and submit a final report to MEPC 65 in 2013.

Participants

3 The correspondence group membership covered a broad spectrum of the marine transportation industry, including governmental representatives, shipowners, and manufacturers. The participants in the correspondence group are as follows:

IMO Member States:

CANADA
DENMARK
ESTONIA
FINLAND
FRANCE
GERMANY
IRELAND
JAPAN
LIBERIA
NETHERLANDS
NORWAY
SWEDEN
UNITED KINGDOM
UNITED STATES

Observers from intergovernmental organization:

EUROPEAN COMMISSION (EC)

Observers from non-governmental organizations:

INTERNATIONAL CHAMBER OF SHIPPING (ICS)
INTERNATIONAL ASSOCIATION OF PORTS AND HARBORS (IAPH)
BIMCO
INTERNATIONAL ASSOCIATION OF CLASSIFICATION SOCIETIES (IACS)
OIL COMPANIES INTERNATIONAL MARINE FORUM (OCIMF)
INTERNATIONAL ASSOCIATION OF DRILLING CONTRACTORS (IADC)
INTERNATIONAL COUNCIL OF MARINE INDUSTRY ASSOCIATIONS (ICOMIA)
INTERNATIONAL ASSOCIATION OF INDEPENDENT TANKER OWNERS (INTERTANKO)
CRUISE LINES INTERNATIONAL ASSOCIATION (CLIA)
EUROPEAN ASSOCIATION OF INTERNAL COMBUSTION ENGINE MANUFACTURERS (EUROMOT)
INSTITUTE OF MARINE ENGINEERING, SCIENCE AND TECHNOLOGY (IMarEST)
INTERNATIONAL PETROLEUM INDUSTRY ENVIRONMENTAL CONSERVATION ASSOCIATION (IPIECA)
WORLD SHIPPING COUNCIL (WSC)
CLEAN SHIPPING COALITION (CSC)

and representatives from the following expert organizations on the invitation of the Coordinator as agreed by the Committee (MEPC 63/23, paragraph 4.51):

INTEGER RESEARCH
INTERNATIONAL ASSOCIATION FOR CATALYTIC CONTROL OF SHIP EMISSIONS TO AIR (IACCSEA)

Method of work

4 The final report is set out in the annex and is a record of the results of the Tier III NO_x technology review. Consistent with the ToR, the final report is submitted to MEPC 65.

5 The final report consists of a summary of the information and materials submitted by participants in response to three rounds of questions distributed by the CG coordinator. The questions are contained in the materials provided in this report. The first round of questions (Q1 through Q14) were developed by the Coordinator based on the ToR and reflect the following topics:

.1 the range of technologies that may be used to comply with the Tier III NO_x standards;

.2 the current use of these technologies; the progress of engine and after-treatment manufacturers towards developing such technologies;

.3 identification of subsets of marine engines where there will not be technologies available;

.4 global availability of consumable products used by certain technologies; and

.5 how information should be gathered, collated, and analysed.

Participants were requested to provide information and relevant support documents. Based on participant responses, a second round of questions (QII-1 through QII-9 and a third round of questions (QIII-1 through QIII-7) were sent to the members of the CG soliciting additional information. The collated comments are contained in a separate document MEPC 65/INF.10. A list of the support documents cited or submitted by the participants is also provided in that document.

Conclusion of technology review

6 The CG has completed its work in defining and evaluating technologies that are expected to be used to meet the regulation 13 Tier III NO_x standards. Specifically, the CG participants identified the following technologies that have the potential to achieve the 2016 and later Tier III NO_x limits, either alone or in some combination with each other:

.1 Selective Catalytic Reduction (SCR);

.2 Exhaust Gas Recirculation (EGR);

.3 Liquefied Natural Gas (LNG), either in a dual-fuel (diesel pilot injection with gaseous LNG as the main fuel) or alternative fuel arrangement; and

.4 Other technologies: direct water injection, humid air motor (HAM), scrubbers, treated water scrubber, variable valve timing and lift, Dimethyl Ether as an alternative fuel.

7 The majority of the CG discussions focused on the first three of these technologies: SCR, EGR, and dual-fuel LNG. There was broad agreement within the CG that SCR can meet the Tier III limits as a sole emission reduction strategy for most, if not all, marine engines and vessel applications. Some marine engine manufacturers are already marketing SCR-based Tier III compliant SCR engines. Overall, no significant concerns were raised concerning the availability of the reductant (urea) or catalyst materials used by these systems.

8 The use of EGR is expected to be used either as a sole emission reduction strategy or in combination with other technologies. The information available to the CG indicates that EGR likely will be used in a more limited number of engines and applications. More technical development appears necessary to expand the technology to a broader range of applications. Finally, the use of dual-fuel LNG technology for complying with the Tier III NO_x limits is expected to increase overtime as the necessary LNG distribution infrastructure expands.

9 The information assessed by the CG did not suggest a need to delay the 2016 implementation date of the Tier III NO_x standards contained in regulation 13 of MARPOL Annex VI.

10 With regard to ToR 4 (identification of any subsets of marine diesel engines where there will not be technologies available to comply with the Tier III standards) a concern was raised about the application of the requisite NO_x reduction technology, i.e. SCR systems, to at least some models of recreational yachts greater than 24 metres in length by the 2016 compliance date. One participant noted that the existing hull designs of these vessels represent a unique packaging challenge because they lack the physical space necessary to install SCR systems without substantial adverse effects on the ship's mission requirements or safety. The participant suggested that unconventional, compact SCR systems would be helpful in this respect, but expressed the concern that the number of

recreational yachts produced each year may not be enough to stimulate the development of these systems by engine manufacturers. Another participant addressed this issue by noting that in some cases, new innovative ways need to be developed to create space to install the extra equipment.

11 One participant also noted that it may not be economical to redesign recreational yachts to accommodate SCR systems or that special compact SCR systems may not be offered by engine manufacturers because of the low sales volumes associated with this market segment. Other participants believed that SCR systems were technologically viable for all large recreational vessels and that compliance by these vessel types was feasible by the current 2016 Tier III NO_x compliance date. One participant recommended that the Tier III NO_x implementation date be delayed a minimum of five years to provide additional time for the large recreational yacht industry to transition to the new standards, and that a technology review be conducted before that date to evaluate the progress being made by the industry toward that goal. This participant also stated that design and build decisions for these vessels will begin in 2013, therefore, any decision on relief for this market segment should be made quickly. The remaining participants generally expressed no opinion of this issue, except to either request that IMO restate its position on the NO_x compliance date for recreational yachts, or to note that SCR is a viable technology for all applications, including this market segment. However, the recommendation by one participant to delay the standards for these vessels was not supported by the rest of the group.

12 Although outside of the scope of the ToR for the CG, the group considered the ability of pure, gaseous LNG, compressed natural gas (CNG), and liquefied propane gas (LPG) to meet the Tier III NO_x standards. Currently, these engines are not covered by the regulation 13 NO_x limits, which apply only to diesel engines and dual fuel engines that operate on diesel pilot fuel. The broad conclusion of the group was that single-fuelled engines using these purely gaseous fuels should be required to meet the same air pollution requirements as other engine types with regard to NO_x emissions.

Recommendations

13 The effective date of the Tier III NO_x standards in regulation 13.5.1.1 of MARPOL Annex VI should be retained.

14 Member States and observer organizations are invited to submit documents to MEPC 65 regarding the application and timing of the Tier III NO_x limits to recreational yachts greater than 24 metres in length.

15 The Committee also may wish to consider applying the Tier III NO_x standards contained in regulation 13 of MARPOL Annex VI to marine engines fuelled solely by gaseous fuels by a future date, e.g. pure LNG.

Action requested of the Committee

16 The Committee is invited to consider the final report set out in the annex and the information provided in document MEPC 65/INF.10, and take action as appropriate.

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ANNEX

ASSESSMENT OF TECHNOLOGICAL DEVELOPMENTS TO IMPLEMENT THE TIER III NO_X EMISSION STANDARDS UNDER MARPOL ANNEX VI – CORRESPONDENCE GROUP FINAL REPORT

Overview

1 This final report is a record of the current status of the Tier III NO_x technology review. Consistent with the ToR, this report is being submitted to MEPC 65.

2 This final report is organized as follows:

.1 the range of technologies considered by the CG;

.2 the information received with respect to the NO_x control technologies: SCR, EGR, LNG; and other technologies, respectively; and

.3 the conclusions and recommendation of the CG.

The following supporting information is provided in document MEPC 64/INF.10: the collated comments on the first two rounds of questions and other information that was received from the participants as part of this review; a list identifying the ships with installed SCR systems; and a list identifying ships with engines fuelled by LNG.

3 It should be noted that, as set out in regulation 13.10, the purpose of this report is to "review the status of the technological developments to implement the Tier III standards". Therefore, the review is not intended to conclusively demonstrate the availability of all or any specific NO_x technology for every marine application conceivable, nor be prejudiced toward the use of any particular technology. It is ultimately up to each engine manufacturer to determine the technology that will be used to certify an engine to the Tier III NO_x standards. Thus, the goal of this technology review is to evaluate whether manufacturers are making progress toward certifying Tier III engines by the stated effective date of 2016, or if additional time is needed.

Range of Tier III NO_X Technologies

4 The ToR calls on the CG to identify the "range of technologies (engine fitting, material, appliance, apparatus, other procedures, alternative fuels or compliance methods) that may be used to comply with the Tier III NO_x standards" (ToR 1).

5 The participants identified the following technologies that may be used to achieve the Tier III NO_x limits:

.1 Selective Catalytic Reduction (SCR);

.2 Exhaust Gas Recirculation (EGR);

.3 Liquefied Natural Gas (LNG), either in a dual-fuel or alternative fuel arrangement; and

.4 Other Technologies: direct water injection, humid air motor (HAM), scrubbers, treated water scrubber, variable valve timing and lift, Di Methyl Ether as an alternative fuel.

6 For this Interim Report, the CG discussions focused on the first three of these technologies, SCR, EGR, and LNG. The vast majority of comments and materials received were associated with SCR. This reflects the interests of the participants and should not be interpreted as a statement about the likelihood of manufacturers to use this or any other technology to achieve the Tier III NO_x limits for all engine models or all ship types. It is expected that the final report will contain more information about the other possible NO_x reducing technologies.

Selective Catalytic Reduction (SCR)

Description of SCR Technology

7 Selective Catalytic Reduction (SCR) is an emission reduction method that reduces NO_x emissions through after treatment technology. An SCR device uses a catalyst to chemically reduce NO_x to N_2 and water by using ammonia (NH_3) as the reducing agent. The most common method for supplying ammonia to the SCR catalyst is to inject an aqueous urea ($(NH_2)_2CO$ in H_2O) solution into the exhaust stream. In the presence of high-temperature exhaust gas (greater than 250ºC), the urea hydrolyses to form NH_3 and CO_2; the NH_3 reacts on the surface of the SCR catalyst where it is used to complete the NO_x reduction reaction. In theory, it is possible to achieve 100 per cent NO_x conversion if the NH_3-to-NO_x ratio (α) is 1:1 and the space velocity within the catalyst is not excessive (i.e. there is ample time for the reactions to occur). The urea dosing strategy and the desired α are dependent on the conditions present in the exhaust; namely gas temperature and the quantity of NO_x. However, given the space limitations in packaging exhaust after treatment devices for mobile and marine applications, an α of 0.85-1.0 is often used to balance the need for high NO_x conversion rates against the potential for NH_3 slip (where NH_3 passes through the catalyst unreacted).

SCR Emission Reduction Potential

8 There was broad agreement by the CG participants that SCR technology can be used to achieve the 80 per cent emission reduction required by the Tier III NO_x limits. One commenter cited SCR's NO_x reduction capability as being over 80 per cent efficiency even when used with high sulphur fuels such as heavy fuel oil (HFO) and even coal. Others noted reduction potentials of over 90 per cent. The reference materials indicate that engine manufacturers also acknowledge SCR's high NO_x reduction potential.[1,2,3,4]

9 There was also broad agreement by the CG participants that SCR technology is available to comply with the IMO Tier III NO_x standards. One commenter submitted material from an engine manufacturer asserting that SCR presently appears to be the only stand alone technology for meeting the Tier III NO_x standards.[5] Other participants also

1 MAN, *Selective Catalytic Reduction,* No date.
2 MAN, Tier III Compliance, Low Speed Engines, 2010.
3 Wärtsilä, 32/44CR Cracks Tier III with Selective Catalytic Reduction, 2010.
4 Wärtsilä, Wärtsila Introduces New More Powerful Version of its Wärtsilä 32 Engine, 2010.
5 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.

observed that SCR would likely be the preferred technology to meet the requirements. Several reasons were cited, including: SCR is an on/off technology that can be used only in ECA[6] areas;[7] it is the most economically attractive strategy available at this time; it is the most cost-efficient way to meet the standards;[8] and it provides greater engine design flexibility to avoid adversely affecting fuel consumption.[9]

Current Use of SCR Technology

10 Participants noted that SCR is a proven emission reduction technology. A number of commenters noted that SCR has been widely demonstrated in highway vehicles and stationary source applications. One commenter stated that within their country, stringent NO_x standards have been established for a wide range of non-highway mobile sources and that SCR will soon be used in non-road applications such as locomotives, farm and construction equipment, and marine ships.[10]

11 A number of commenters noted that SCR has been widely used in marine applications (see list of vessels with installed SCR systems in document MEPC 65/INF.10). Two commenters mentioned that this was especially true for 4-stroke engines; experience with low-speed, 2-stroke engines was expanding and current demonstration projects look promising. Two participants noted that over 500 ships have been equipped with these systems over more than 20 years and one of these commenters provided a list of over 340 ships with SCR systems, including six passenger/ferry ships. Another participant submitted the results of testing, including onboard trials, using SCR on low, medium, and high speed marine engines in commercial service that demonstrated the efficacy of this technology on these types of engines.[11] According to the report, the trial of the SCR system for the low speed diesel engine, which was set after the turbocharger with an exhaust gas minimum temperature of 250ºC and using 25 per cent ammonia water as the reducing agent, was carried out on the ship in service with a successful result. General comments were also received noting that shipowners and manufacturers have gained experience with SCR systems over the last 10-15 years.

12 In the reference material provided to the CG, one engine manufacturer notes that SCR reactors have been used in power plant applications since the late 1970s. This manufacturer was involved in one of the first marine SCR applications in 1989, and they have been focused on developing Tier III SCR for their entire 2-stroke engine line since 2009.[12] Literature from another engine manufacturer states they have long and wide experience with SCR with a total of about 400 systems installed in a large variety of applications. That same engine manufacturer notes that they first installed SCR on 2-stroke marine ships in 1999/2000 with three roll-on/roll-off vessels in operation for over 10 years that have been certified with NO_x values below 2 g/kWh. This manufacturer stated that they offer and deliver SCR systems for high sulphur applications.[13] The reference material also states

6 The reference to Emission Control Areas (ECA) in this document refers only to those areas established to limit NO_X emissions and not those that were established to limit SO_X (and PM) emissions.

7 Caterpillar, *Caterpillar Poised to Reach IMO III Requirements for MaK Marine Engines*, 1 August 2010.

8 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.

9 MAN, *Technology for Ecology – Medium Speed Engines for Cleaner Air.*

10 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.

11 Japan's Presentation: *On-board Denitration Trial of Engine with Low, Medium, and High-Speed Rotation, and Auxiliary Engine; (http://www. jsmea, or.jp/superclean.html, http://www.mhi.co.jp/technonogy/review/pdf/e473/e473048.pdf, http://www.mhi.co.jp/en/news/story/110622en.html, http://www.myk.com/english/release/1414/NE 110622.html.*

12 MAN Diesel & Turbo, *Tier III Compliance, Low Speed Engines*.

13 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.

that more than 300 SCR systems, developed by Argillon, Wärtsilä, Munters, and other companies, have been installed on marine ships. Some of these have been in operations for more than 10 years and have accumulated 80,000 hours of operation. Another reference states that over 1,000 ships were equipped with SCR in worldwide use as of 2011.[14] The reference material also states that these systems have been used in a wide range of ship types including ferries, supply ships, ro-ros, tankers, containerships, icebreakers, cargo ships, workboats, cruise ships, and foreign navy ships for both propulsion and auxiliary engines. Other reference materials provided to the CG also identify SCR systems that have been used on many of these ship types.[15,16,17,18]

13 All of the participants who commented on the issue indicated they expect SCR systems for marine ships to be commercially available on or before the 2016 compliance date. Several participants stated a general belief that Tier III compliant SCR systems will be available for all or most of the regulated ships in the 2016 time frame. One participant specifically stated that with the variety of ships, engines and fuels operating on SCR today in maritime and, considering the land-based industry and automotive experience, they do not see any specific segment where SCR cannot be applied. They also noted that SCR technology is suitable for yachts, fishing ships, barges, tugs, and inland waterway ships. However, a number of other participants suggested there may be limitations for installing SCR in some specific applications; these specific application-related concerns are discussed below.

14 The reference material also supports the general expectation regarding the commercial availability of SCR for Tier III NO_x compliance. Literature from one manufacturer generally states that SCR is the "panacea" for complying with Tier III and that they will have compliant systems ahead of the 2016 implementation date.[19] This manufacturer also notes that SCR provides greater design flexibility without degrading fuel economy.[20] They also specifically state that compliant SCR systems will be available for several of their engine lines that use HFO, with low-speed engines targeted for the end of 2012.[21] In their literature, another engine manufacturer considers SCR as a first, readily available approach for achieving compliance with IMO Tier III standards for their 2-stoke engines.[22]

15 Three participants stated, and the reference material specifically shows, that compliant SCR systems for marine ships are already commercially available. One engine manufacturer is marketing a medium-speed model, i.e. the 32/44CR, with a compliant SCR system and also suggests another model, i.e. the 20V32/44, is also available.[23] The same manufacturer has sold low-speed 2-stroke engine model, i.e. the 6S46MC-C8, which is

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14 www.integer-research.com, *AdBlue & DEF Monitor: AdBlue and DEF Suppliers Look to Maritime Selective Catalytic Reduction Applications*, Issue 13, April/May 2011.

15 Kvichah Marine, *M/v Scorpio*, 2009.

16 Motor Ship, *Propulsion in the New Millennium*, 1999.

17 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.

18 Manufacturers of Emission Controls Association, *Case Studies of the Use of Exhaust Emission Controls on Locomotives and Large Marine Diesel Engines*, 2009.

19 MAN, *SCR – Selective Catalytic Reduction.*

20 MAN, *Technology for Ecology – Medium Speed Engines for Cleaner Air.*

21 MAN Diesel & Turbo, *Tier III Compliance, Low Speed Engines*.

22 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.

23 MAN Diesel Turbo, *Diesel Facts: 32/44CR Cracks Tier III with Selective Catalytic Reduction* p3, April 2010.

Tier III NO_x compliant. A second engine manufacturer states that they have 40 sizes of SCR available for their entire 4-stroke engine line.[24] This includes all medium speed 4-stroke models which operate on MGO, MDO, and HFO (less that 1.0% sulphur), with options for higher sulphur content fuels available.[25] That same manufacturer is specifically offering a popular medium speed, 4-stroke engine model, i.e. model 32, with a compliant SCR system.[26] A third engine manufacturer is offering a generator set with an SCR system that is compliant with the United States EPA Tier IV NO_x standards, which suggests such engines could be IMO Tier III compliant.[27]

16 A few comments were received that cautioned against drawing conclusions from existing SCR installations and how that experience would apply to the introduction and demonstration of certified Tier III NO_x control technologies in real world applications. These participants noted that the majority of the current systems (and other technologies) in operation to date have not been assessed or certified against the NO_x Tier III standards. One of these participants specifically referenced the applicable testing regimes of the NO_x Technical Code, chapter 5 in this regard. That participant also noted that the first applications to be tested on a voluntary basis under the NO_x Technical Code requirements are expected in the near future. It should be noted that the current availability of SCR-equipped engine models from two engine manufacturers that are advertised as being compliant with Tier III NO_x standards, as described above, suggests that those engine models were developed and tested with the existing or likely certification requirements in mind.

17 One participant stated that current marine SCR installations are operated under highly controlled conditions, such as high quality fuels, high quality reductant and regular maintenance. Further, they may not be representative of the universe of marine engines in terms of the range of engine size and type. But another commenter noted that the characterizing current marine SCR installations as being unrepresentative of a broad range of engine size and type was incorrect. That commenter pointed out the use of SCR in land-based power generation applications, whose engines closely resemble their marine counterparts, have a successful record for the past two decades.

SCR Technological Concerns and Potential Solutions

18 While SCR is a proven technology for reducing NO_x emissions and is being employed in a variety of diesel applications, including marine applications, three technical issues were discussed by the participants. These were: operating the SCR system at low temperature; ammonia slip; and catalyst deterioration.

Temperature Concerns

19 With regard to temperature, if the exhaust gas temperature is too low, the reaction rate of the ammonia injected into the exhaust becomes insufficient to properly reduce the oxides of nitrogen. Because exhaust gas temperatures are correlated with the operating load placed on the engine, this concern is mainly for engines operating at low engine loads. A number of participants indicated that engine loads below 25 per cent, especially for extended periods of time, generate a suboptimal temperature environment and the SCR unit

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24 Wärtsilä, Wärtsilä Environmental Technologies: Wärtsilä Environmental Product Guide, March 2011.

25 Wärtsilä, *Wärtsilä NO_x Reducer – SCR System*, 2011.

26 Wärtsilä, *Wärtsilä Introduces New More Powerful Version of its Wärtsilä 32 Engine*, 30 Dec 2012, Article by Jocelyn Redfern.

27 Caterpillar, *Caterpillar Introduces 3516C-HD Tier 4 Interim Certified Diesel Generator Set*, 8 September 2011.

may not be able to achieve the desired NO_x emission reductions. (See paragraph 52 for a discussion the application of SCR to vessels such as Mobile Offshore Drilling Units.) Also at low exhaust temperatures, the ammonia can react with the sulphur in the fuel to create ammonia sulphates, which can foul the catalyst, further deteriorating the SCR system's ability to reduce NO_x. This condition may also adversely affect engine operation by increasing exhaust backpressure.

20 Some participants noted that the minimum temperature for good reactivity and the prevention of sulphate formation is dependent on the sulphur content of the fuel. The reference material generally identified a range of minimum temperatures versus fuel sulphur. For low-sulphur ECA fuels (1,000 ppm S) the minimum was approximately 270-300ºC. For higher sulphur fuel such as HFO, the minimum could be 300ºC or higher.[28]

21 Adequate exhaust gas temperatures can be addressed in a number of ways identified in the participants' comments and in the reference material submitted to the CG. One way is to properly position the SCR catalyst relative to the turbocharger. The exhaust gas temperature is always higher at the inlet (before the turbine stage) than at the outlet. When exhaust gases pass through the turbocharger, heat energy from the exhaust is converted into shaft work, where it is then used to compress the intake air. For 4-stroke engines the SCR catalyst can be mounted downstream of the turbocharger with a by-pass (or wastegate) installed in the exhaust before the turbocharger to divert hotter exhaust to the catalyst as the need arises.[29,30,31] For 2-stroke engines the catalyst can be mounted before the turbocharger where exhaust gas temperature is naturally higher than after the turbocharger.[32,33,34] This also allows for a smaller reactor to be used.[35] Other ways include reducing the level of charge air or modifying the injection timing; elevating exhaust temperatures by using burner systems during low power operations or some other method; or, on a ship with multiple propulsion engines, shutting down one or more engines such that the remaining engine or engines will operate at higher power.[36] One participant suggested using a heated urea dosing system to maximize SCR efficiency at low exhaust temperature conditions. Another noted that a degraded catalyst had almost recovered to the condition of a new catalyst after heating the unit at 300ºC for several hours. Two other participants stated that the regeneration temperature was 350ºC and more than 400°C (engine load factor >~80% of full load) for a period of time, respectively.

Catalyst Deterioration and Ammonia Slip

22 Methods to address catalyst deterioration (and potential ammonia slip) were also identified by the commenters or in the reference literature. Included in these techniques was prolonging the catalyst life by using SCR only in ECAs; using low-sulphur

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28 US EPA, *Regulatory Impact Analysis for Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder*, 30 April 2010.

29 Wärtsilä, *NOx Reduction Presentation*, 2004.

30 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.

31 MAN, *SCR – Selective Catalytic Reduction.*

32 Wärtsilä, *NOx Reduction Presentation*, 2004.

33 MAN Diesel & Turbo, *Tier* Wärtsilä, *NO_X Reduction Presentation*, 2004*III Compliance, Low Speed Engines*.

34 US EPA, *Regulatory Impact Analysis for Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder*, 30 April 2010.

35 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.

36 US EPA, *Regulatory Impact Analysis for Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder*, 30 April 2010.

fuel such as 1,000 ppm ECA or even lower sulphur fuels; using diffusion technology of the reductant into the catalyst; capturing ammonia at the back of SCR system; using ammonia instead of urea; heating the catalyst for several hours as mentioned previously; and turning off the system at predetermined low exhaust temperatures. Relative to this later approach, one commenter noted that the specific requirements of 3.1.4 of the NO_x Technical Code 2008 contain no provision for NO_x control below the 25 per cent operating point where low engine loads result in low reactor outlet temperatures such that the SCR does not operate properly. Therefore, the commenter concluded that it would be acceptable if the SCR unit did not function at this point, taking into consideration the auxiliary control device provisions of paragraph 9 in regulation 13 of MARPOL Annex VI. Soot blowing or infra-sonic cleaning was also noted by the participants. The former technology is discussed or incorporated into the current generation SCR designs of one engine manufacturer, as noted in the reference material.[37,38,39,40]

23 One participant noted that SCR catalyst performance will inevitably deteriorate over time, presumably by becoming poisoned or by the build-up of soot, ash, and ammonium sulphates. Three other participants suggested that catalyst manufacturers and SCR experts can factor deactivating mechanisms into their sizing programmes which means that deterioration can be considered at the design phase. One participant suggested that deterioration could be addressed by establishing a management programme that includes catalyst replacement. This was supported by an engine manufacturer's literature that was submitted to the CG.[41] Another participant stated that, at least relative to ammonium sulphate deposition, techniques are available that would circumvent the need to replace the catalyst. One participant addressed the relatively long useful life of SCR catalysts, noting that catalyst providers generally guarantee the operation of their product for a standard operating time such as 16,000 hours. This was supported by an engine manufacturer in the submitted material, i.e. 16,000 hours or two years.[42]

24 A number of participants addressed the potential deterioration of the SCR catalyst. Three participants noted that the exhaust stream could be monitored or controlled to actively manage the injection rate of the reductant. Two approaches were specific. The first approach identified was to monitor ammonia slip either continuously or at frequent intervals on ships with SCR systems. Relative to interval sampling, measurements would preferably be done as 15-30 minute average values. The grab sample method that is used for Swedish NO_x certificates is sensitive to sudden engine load changes, which may sometimes require several measurements before a true value is obtained. It was recommended that ammonia levels of less than 10 ppm in the exhaust were acceptable. The second approach was continuous monitoring of the NO_x emissions from the SCR catalyst outlet. That would guard against ammonia slip, as a properly functioning catalyst and dosing system will not slip ammonia above a 10 ppm limit, especially given the steady-state operating characteristics of marine engines. The commenter expressing this view argued that technologies were readily available today to measure NO_x on board a ship for comparison to measurements made during the certification of the engine or combined engine/SCR system. One participant mentioned that it would be important to have confidence that NO_x sensors will be ready and suitable for marine environmental conditions

37 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.

38 Wärtsilä, Wärtsilä Environmental Technologies: Wärtsilä Environmental Product Guide, March 2011.

39 Wärtsilä, *NO_x Reduction Presentation*, 2004.

40 Wärtsilä, *Wärtsilä NO_x Reducer – SCR System*, 2011.

41 Wärtsilä, Wärtsilä Environmental Technologies: Wärtsilä Environmental Product Guide, March 2011.

42 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.

which will be encountered in service. One participant specifically did not favour the first approach of monitoring ammonia, but did agree that an ammonia emission threshold of less than 10 ppm was appropriate. Another participant specifically noted that ammonia is not currently a controlled parameter under MARPOL Annex VI.

25 Engine manufacturer literature supplied to the CG also recognized electronically monitoring NO_x concentrations as a viable approach to reductant management, and one manufacturer is offering it for sale on a Tier III compliant engine model.[43,44] Another approach that is less sophisticated, and therefore less sensitive to the precise management of the reductant as the catalyst ages, is to electronically control the urea dosage as a function of engine speed and load.[45,46,47,48]

26 Finally, one participant noted that the cost of ammonia itself would ensure that SCR manufacturers and engine builders can be expected to design systems that will not waste reductant. This participant stated that because ammonia slip represents poor usage of urea (a purchased commodity), there will in any case be commercial pressures to minimize waste. Also, it should be recognized that statutory control, such as MARPOL Annex VI, is not the only element influencing ammonia usage.

SCR Consumable Product: Urea

27 Two types of consumables were identified in the comments: urea and SCR catalysts. With one exception, all the comments from the participants focused on the availability of urea.

28 An aqueous urea solution was widely raised by the participants as being the most suitable and likely form of ammonia for SCR systems. All of the reference material submitted to the CG describing engine manufacturers' SCR system designs noted this form of urea is the most suitable reductant, and it was specifically mentioned as the reductant chosen for their product lines.[49,50,51,52] One engine manufacturer's literature specifically notes that urea was selected because of its safe handling characteristics.[53,54] One participant raised the possibility of making the reductant on board the ship from solid urea.

29 The topics related to urea that were reflected in the participants' comments, and the reference material submitted to the CG, also addressed a broad array of subjects including the concentration of ammonia in the aqueous solution, quality, cost, supply, transportation, and the storage, handling, and dispensing of the product. These topics are discussed below;

43 Wärtsilä, *NOx Reduction Presentation*, 2004.
44 Wärtsilä, *Wärtsilä NOx Reducer – SCR System*, 2011.
45 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2011.
46 Wärtsilä, Wärtsilä Environmental Technologies: Wärtsilä Environmental Product Guide, March 2011.
47 Wärtsilä, *NOx Reduction Presentation*, 2004.
48 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2010.
49 MAN, *SCR – Selective Catalytic Reduction.*
50 MAN, *Technology for Ecology – Medium Speed Engines for Cleaner Air.*
51 Wärtsilä, *IMO Tier III Solutions for Wärtsilä 2-Stroke, Engines – Selective Catalytic Reduction (SCR)*, 2010.
52 Wärtsilä, *Wärtsilä NOx Reducer – SCR System*, 2011.
53 MAN, *SCR – Selective Catalytic Reduction.*
54 MAN, *Technology for Ecology – Medium Speed Engines for Cleaner Air.*

the availability of urea as a consumable material is discussed separately in paragraphs 35 to 40.

30 Three participants specifically discussed the likely concentration of ammonia in urea. Two indicated they expected concentrations of 32.5 to 40 per cent. These concentrations are typical of the urea solutions used in land-based power plant and highway engines equipped with SCR, which closely resemble their marine counterparts. One of these participants also thought that 40 per cent urea solutions yielded better economy over the 32.5 per cent solution, and could be more readily used in marine applications where storage tanks would be located below the waterline and not susceptible to freezing like the 32.5 per cent solution used for vehicles, which has a lower freezing point for that purpose. The other participant expressed the expectation that marine SCR systems will have enough flexibility in design to adjust their reductant injection rate to account for different concentrations of urea in water solution. This can be done either by inputting the urea concentration into the SCR controller when delivery is taken on board or by actively monitoring NO_x reduction across the SCR catalyst and adjusting urea injection rates accordingly to ensure that the NO_x emissions are in compliance with the standard. The reference material identified two grades of urea that are currently being used in marine engines.[55] One of these is a 40 per cent concentration and the other is presumably a 32.5 per cent concentration product based on its commercial name.

31 Urea quality was addressed by several respondents. All agreed that urea for marine SCR applications must be of high quality, e.g. significantly better than the urea used for agricultural and industrial use and without impurities. The majority of these comments favoured creation of an international standard specifying urea quality before the Tier III implementation date. One commenter noted that an expert group in CEFIC has completed a joint proposal for an International Organization for Standardization (ISO) standard for a maritime urea solution. This proposal was presented to ISO with the objective to establish a marine application ISO approved urea solution standard within 2012/2013. Until then, this commenter recommended that the proposed specification AUS40 should be used as a quality recommendation. Another commenter suggested an ISO standard similar to AUS32 for a 40 per cent urea solution. Two participants recommended that ISO and IBIA be invited to comment on this question.

32 Two participants submitted information relating to the demand and price of fertilizer. None of the information indicated that the price of urea would affect the commercial availability of SCR for complying with the Tier III NO_x standards.

33 One participant noted that urea solutions have not historically been considered as engine-room working fluids. However, if their usage becomes commonplace this would require consideration as to whether class rules should be revised to address the ship structure and machinery system requirements relating to the storage and handling of urea solutions, and whether specific requirements would be necessary for urea loaded as dry bulk powder. Another participant noted that class rules have historically considered ammonia as a refrigerant used within dedicated, gas-tight, enclosed spaces outside the machinery spaces. Ammonia used in a different manner, such as in an SCR system, would need to be addressed differently in these rules.

55 www.integer-research.com, *AdBlue & DEF Monitor: AdBlue and DEF Suppliers Look to Maritime Selective Catalytic Reduction Applications*, Issue 13, April/May 2011.

34 One participant took exception to the use of ammonia as the reductant. They stated that both anhydrous and aqueous ammonia have disadvantages in terms of distribution, handling and storage on the ship. They added that an important point for marine ships is the dissipation of ammonia. Here anhydrous ammonia was discussed as a gas that is lighter than air, which will generally dissipate rather than collect in lower areas of the ship. However, it was noted that in the presence of moisture (such as high relative humidity), the liquefied anhydrous ammonia gas forms vapours that are heavier than air. These vapours may spread into low-lying areas where people may be exposed to the ammonia vapour.

Availability of Consumable Product: Urea

35 A number of the commenters pointed out that urea is already a global commodity and is generally considered to be widely available because of its use in land-based vehicles/engines, and stationary sources. The hundreds of ships equipped with SCR today use some kind of urea, and some participants noted that as a result urea for marine use is available across most of the globe including Canada, the United States, Europe, Asia, and the Middle East. As an example, one commenter stated that the present SECA (Sulphur Emission Control Area) in the North Sea and Baltic Sea is expected to be expanded to an ECA. The majority of the ships in these areas are already using SCR technology that have a well-established storage and distribution network for AUS 40 /NO_xCare 40. Another commenter addressed the expansion of urea availability in Canada and the United States by noting that both countries have implemented IMO approved ECAs covering the east and the west coast 200 nm off land. One participant specifically noted that Canadian distribution networks follow the Waterloo-Quebec City corridor with major distribution points in Ontario and Quebec. Another stated that the United States regulations that go into force beginning in 2014 will require urea availability for the United States market two years earlier than the IMO regulation. In addition, the product is already available in United States. Yarwil together with Yara and Wilhelmsen are expected to establish the storage and distribution network to meet the maritime demand.

36 Two participants placed the demand for marine urea in the context of other demand for this product. The first commenter also noted that land-based SCR applications require some 20 million tons of urea solution. The total demand for urea solution in marine applications at present is about 30 thousand tons, or less than one per cent of the total land-based use. When the Tier III NO_x standards become effective in 2016, the maritime demand for urea will still be relatively small because it is only required to be used by ships built, or that undergo a major conversion beginning in 2016, that are equipped with SCR technology, and only while they operate in ECA areas. Marine demand is expected to grow slowly over time as more new ships and major conversions become subject to the requirements. The second participant also noted that marine urea demand is expected to peak at approximately one million tons in 2020, and will always be small compared to land-based industries. Another participant stated that according to the International Fertilizer Industry Association (IFIA), urea supply is projected to expand by 25 per cent over the next five years. Currently, the total supply of urea is 155.6 million metric tonnes (Mt) compared to demand of 153.3 Mt, primarily for agricultural uses. By 2015, IFIA projects that total urea supply will be 190.5 Mt with a potential surplus in excess of 18 Mt in 2015. In comparison, the United States Environmental Protection Agency estimates the urea demand (in solution with water) for SCR-equipped ships operating in the North American ECA to be only about 0.4 Mt in 2020. This suggests that sufficient quantities of urea will be available for marine applications starting in 2016. The commenter concluded that even considering growth in SCR use as new ships are constructed beyond 2020 and the potential for increased urea demand in the event of the establishment of further NO_x ECAs in

Europe and elsewhere, it appears that urea supply will be more than sufficient to meet demand in the marine market.

37 One participant noted that it is advantageous for the AUS40 market that the SCR-based regulations for the automotive industry precede the regulations for the maritime industry, thereby ensuring the ready availability of urea in Europe (AdBlue), America (DEF), Brazil (ARLA32) and in Asia. The commenter concluded that the large investments in production, storage and distribution networks have been done to secure the supply and distribution of urea.

38 Another participant stated that it is also advantageous that the market for particular grade of urea used in the maritime segment is transparent and relatively predictable, enabling sufficient time to plan for and implement an increase in that grade's production, as required. As an example, the participant cited a particular company that is today's largest supplier of urea to SCR systems in the maritime market. This company is already delivering their product to ships in the Far East, Middle East, the Americas, Asia and Europe. They also noted that this company is the world's largest producer of this brand of urea and is building up the availability of the product in line with the increasing demand. Another commenter stated that urea manufacturers will figure out the demand and ramp up the supply and logistics supply chain accordingly.

39 With respect to restrictions on urea, one participant explained that some trade restrictions exist, for example prohibitive export taxes from China for part of the year (low agricultural season), or prohibitive import duties in the United States for urea imports from Russia. However, they concluded that these do not affect the widespread availability of urea in any country because urea is produced in about 58 countries. Another participant noted that in Japan, the amount of supply of urea for ships is expected to be sufficient. In that country there are no restrictions on import, export and sales.

40 With respect to port infrastructure, one participant specifically stated that SCR-grade urea-water solutions are already available or are expected to become available in ports in many parts of the world. Land-side equipment including hostlers, trucks, rail, and various other non-road equipment are or will be subject to stringent NO_x emission limits that are expected to be met through high-efficiency, advanced after treatment technology like SCR. Therefore, these ports will already have urea facilities. The comment continued that it is possible to extend these facilities for ships; alternatively, new SCR distribution centres could be provided. Due to recent environmental standards for highway vehicles, there are more than 3,700 urea pumps at retail outlets in Europe and more than 3,600 locations providing urea in North America. The participant concluded that the current urea distribution systems are expected to expand to ports in response to urea demand for use on ships, and that this could occur through construction of urea distribution facilities for ships or through specially equipped barges.

41 One participant commented that the yacht sector is different from other marine vessels in that they neither follow standard routes nor operate from commercial ports. Therefore, this participant raised urea availability as a significant concern for yachts in more remote areas. So, while yachts operating within an ECA might stimulate the development of some urea infrastructure those coming to an ECA from other lands might struggle to source urea.

SCR and Ship Type Constraints

42 The correspondence group was tasked to identify any subsets of marine diesel engines where there will not be technologies available to comply with the Tier III standards. While subsets were identified by some participants as incompatible with Tier III technologies, other participants commented that practical Tier III compliance options will be available for all newly-built ships. The subsets raised by participants to the correspondence group regarding SCR are discussed below.

43 One participant generally noted their expectation that problems will be raised with regard to fitting SCR systems to engines with wet exhaust gas lines, small marine-engines which are derived from industrial engines, and where additional alterations are impossible to carry out as retrofit solution. Another participant commented that these high-speed engines use higher quality fuel which provides better circumstances for SCR. In this case, the SCR systems may be more compact and possibly more similar to those used in heavy duty diesel applications, e.g. trucks. Another participant challenged this conclusion. They noted that smaller high-speed engines cannot use present solutions for on-road or non-road (land based) engines due to the higher sulphur content of the marine fuel, including future Emission Control Area fuel with a 1,000 ppm maximum sulphur requirement. That participant originally stated that the SCR systems for these engines must be capable of using distillate fuels with sulphur levels as high as 15,000 ppm. At those levels SCR substrate volumes would be 30-50 per cent greater. Another participant stated that compliance with the Tier III NO_x limit is only required when a vessel operates in these areas if the keel of such a vessel was laid on or after 1 January 2016, and that the required sulphur level in the NO_x Emission Control Area would be limited to a maximum sulphur content of 1,000 ppm because all such areas are also SO_x Emission Control Areas where the fuel sulphur limit applies. Therefore, the SCR systems on smaller vessels would not need to be sized for 15,000 ppm fuel sulphur.

44 In subsequent comments the participant concerned with sulphur levels as high as 15,000 ppm acknowledged that marine fuels with 1,000 ppm, and in some cases 500 ppm, will be globally available. However, they maintained that other design considerations such as the high power density of these marine engines compared to their on-road counterparts and the possibility of higher exhaust temperatures would still result in substrate volumes being 30 per cent larger. The commenter concluded that the suggested benefit of using smaller SCR systems on ships equipped with high-speed engines remain problematic for that reason. Another participant noted that concerns with the size of SCR systems using conventional catalyst materials can be mitigated by use of vanadium as the catalyst, if vanadium had not been previously considered. Vanadium catalysts are more sulphur tolerant as they are less prone to the formation of ammonium sulphates and less prone to fouling.

45 Another participant noted that SCR does not have to be used outside of an Emission Control Area, so to the extent a bypass is used when operating in these areas, the sulphur content of the fuel becomes a non-issue. However, another participant stated that the space available for a bypass in large yachts made this approach infeasible. One participant pointed out that Annex VI allows for the possibility that a future area may be designated as a NO_x Emission Control Area but not an SO_x control area. If such an area were to be established, than the fuel sulphur could be as high as 35,000 ppm.

46 Another participant provided examples on Tier III strategies installed on 20 passenger ships (primarily "car/passenger" ships) including LNG and SCR technologies. Six of these passenger/ferry ships have SCR installed; the remainder including passenger, car/passenger-ferries use LNG. It was noted by one participant that

SCR systems have been installed on a small number of recreational craft less than 24 m to comply with emission limits at a comparable level to Tier III (such as NO_x tax/Scandinavia and Lake Constance and Austria/Germany/Switzerland regulations). However, these systems all operate on clean (low or ultra-low sulphur) fuels with sulphur content between 100 and 10 ppm, which is available locally but not more widely. Recreational ships used outside of these areas must be designed to use a wide range of fuel, and therefore use of SCR on these ships generally may be more problematic.

47 One participant stated that, for the time being, SCR is the only applicable technology for yachts greater than 24 metres in length.[56] However, this participant expressed concerns that there is not space in existing designs to incorporate SCR. The participant raised a number of physical constraints for installing SCR in yachts greater than 24 metres in length including: assembling systems with complete exhaust piping in engine-rooms, engine-room ventilation issues, lack of infrastructure to support the extra equipment weight, reduced access between engines, increased displacement from extra weight that affects ship trim and speed. The participant noted that the industry is working with engine and after treatment manufacturers to better understand the implications of the Tier III standards for yachts and that this information would be available to the correspondence group in 2012.

48 This same participant noted that a range of large yachts, including planning and semi-displacement vessels, will very likely be significantly impacted by the Tier III regulation. A provisional assessment shows that the range of vessels affected will be from 24 m load line to approximately 400 GT. The definitive range of vessels critically affected by Tier III needs to be defined in more detail and these parameters are subject to the conclusions of a design study that is being conducted by the participant and which will be available in early January 2013. It is expected the range of vessels critically affected by Tier III will represent at least 25 per cent of the current large yacht fleet by unit numbers.

49 This participant raised several concerns relating to the issue of space constraints in existing large yacht designs. First, due to large capital investments in the moulds used to manufacture these serially-produced ships, ship designs cannot be modified to incorporate SCR in the 2016 time frame. The participant added that many yacht models built today will still be in production beyond 2016 and noted that one yacht builder identified 50 per cent of their current product portfolio to be in production in 2016. Second, fitting SCR into existing designs would require that the guest cabin accommodation be compromised, which will adversely affect charter operations for these vessels and result in lost sales. Third, the lead time needed for further developing SCR for constrained spaces would require a market sufficiently large to support new investments in SCR technology for this market segment. With current book orders not exceeding 60 units per year, it is unrealistic to expect such targeted investment. Fourth, responding to the 2016 implementation date requires that the development, planning, and design decisions need to start in 2013. The participant provided two examples of companies facing these lead time constraints. The participant also stated that a Tier III implementation study amongst a large number of its member yards was being conducted in order to assess the impact of the regulation, and that the results of that assessment are expected in early 2013.

50 Two participants addressed whether a delay in the effective date of the Tier III NO_x requirement may be useful to address the issues associated with large yachts, as described above. One stated that an extension of the implementation date would be welcome and suggested that any delay should be an absolute minimum of five years,

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56 Regulation 13.5.2.2 of MARPOL Annex VI specifically excludes ships designed and used solely for recreational purposes less than 24 metres from the Tier III NO_x standards.

followed by a technical review clause to assess if the impact on the sector is in proportion to the environmental benefits. In this latter regard, the participant added that the environmental effect of this sector is comparatively small because of low annual engine operating hours and the high percentage of the time spent operating at low engine loads. The other participant stated that the design and building process for new yachts can take up to three to five years. Given the current state of technology, the participant noted that some cases will need new innovative ways to address the space constraints associated with SCR equipment. Therefore, the participant suggested that IMO quickly give clarity to this question.

51 A number of other participants expressed the view that compliant SCR systems either can be fitted into or will be available for all ship types, including yachts. One of these participants stated that the Tier III standard was clearly written several years ago as applying to new-build vessels operating in NO_x Emission Control Areas, and that this was done to address concerns over vessel design. All sectors have had up to eight years to incorporate the IMO requirements and compliance into 2016 designs. Another participant noted that in the case of small yachts with high installed power, for example semi-displacement yachts, some space constraints can be found. Further, in these cases it is not yet fully clear how the equipment can be installed, and that some innovative ways need to be found to accommodate SCR in these ships.

52 One participant raised concerns with the application of SCR to Mobile Offshore Drilling Units (MODU). Specifically, the commenter stated that in nearly all routine operating conditions, the prime movers are not sufficiently loaded to achieve exhaust temperatures necessary for optimal performance of the catalyst. The low operating temperature combined with rapid engine load variations would lead to clogging of the catalyst bed and extensive ammonia slip. Another participant responded that there are already the provisions under regulation 3.3.4 of MARPOL Annex VI, which exempt engines solely dedicated to seabed mineral extraction. This participant also stated that the Tier III standard was set very much with SCR in mind. The participant specifically noted that if it should be found that the engine load applied, not only to MODUs but to any ship, is below the 25 per cent mode point and that reactor outlet temperature is such that the SCR does not operate properly, then it would be acceptable if the SCR unit did not function, taking into consideration the auxiliary control device provisions of paragraph 9 in regulation 13 of MARPOL Annex VI, in conjunction with the provisions of chapter 3, paragraph 3.1.4 of the NO_x Technical Code 2008. Other participants, while not specifically addressing the regulatory applicability of the requirements to MODUs, disagreed and noted that such ship types need to comply with the Tier III NO_x standards.

SCR Certification Issues

53 A few participants noted that SCR technology may raise certification issues that are not addressed in the NO_x Technical Code.

54 One participant noted that some SCR installations suffer from inadequately designed urea injection and mixing stages. Because of this, and the concern that an SCR system may be mis-installed, at least one participant suggested that confirmatory tests be performed across all of the certification speed and load points during the ship's sea trial to ensure that the combined engine and SCR system comply with the regulation 13 NO_x requirements (see BLG 14/12/3 and MEPC 62/4/13). This confirmatory test would detect any issues regarding the combined engine and SCR system performance with respect to compliance with regulation 13 of Annex VI, requiring corrective action before the ship is issued its IAPP. The requirements for confirmatory testing were reduced in the SCR certification guidelines that were finalized at MEPC 62; currently, only the parent engine

in an engine group has to undergo the confirmatory test, thus allowing hundreds of installations to go unchecked. The commenter concluded by noting that EUROMOT, among others, was among those who argued against confirmatory testing of every installation.

55 Another participant suggested that SCR deterioration over time be addressed within the initial certification of such systems. No other comments were received that specifically addressed this certification-related issue.

Exhaust Gas Recirculation (EGR)

Description of EGR Technology

56 Exhaust gas recirculation (EGR) is an emission reduction technology that reduces peak combustion temperature in order to reduce NO_x emissions. This emission reduction method is designed such that a non-combustible gas is added to the combustion process. In this strategy, some exhaust gas is typically routed from the exhaust system and mixed with the incoming combustion air, lowering the overall oxygen content of the incoming air, as well as helping to absorb some of the heat energy created during the combustion process. Both of these features reduce the engine's peak temperature and subsequently lower the engine's NO_x emissions.[57] Additionally, a suggested alternative to adding the exhaust gases with the incoming combustion air is to use an "internal" EGR, which uses an early closing of the exhaust valve to trap and retain a portion of the exhaust gasses from the previous combustion event within the engine's cylinder.[58]

EGR Emission Reduction Potential

57 Some participants noted that EGR has a high NO_x reduction potential, though it is likely to be part of a package of combined technologies to meet Tier III levels – such as water strategies or SCR.[59] However, in a supporting document submitted by another participant, MAN B&W stated that in a test programme, it was able to meet the Tier III NO_x emission standard with EGR alone when applied to a 4T50ME-X 7MW test engine.[60]

Current Use of EGR Technology

58 Some participants noted that EGR technology will not be available to meet the Tier III NO_x limits in 2016 for the majority of engine sizes. The use of EGR technology to meet the Tier III NO_x limits has been demonstrated on some 2-stroke slow speed engines.[61] More work is required to expand the technology to the broader range of marine engines operating today, including higher-speed engines.

59 Currently, there is at least one manufacturer that is taking orders for an EGR-equipped engine which meets the Tier III standards while operating on high sulphur residual fuels.[62] One participant added that one manufacturer is actually taking orders for a complete line of high-sulphur, EGR-equipped, low-speed engines in the 3-84 MW power range, and that EGR is the sole NO_x reducing technology on these engines. Some participants noted that several companies have been investigating EGR technologies, and these studies suggest that Tier III NO_x standards can be achieved through the application of

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57 MAN Diesel & Turbo, *Tier III Compliance, Low Speed Engines*.

58 Wärtsilä, "Emissions Control Technology Development for Wärtsilä 2/4Stroke Engines," Leo Schnellmann, January 14, 2011, www.aqmd.gov/aqmp/2012aqmp/symposium/Panel3-Schnellmann.pdf.

59 Caterpillar, Caterpillar Presence at SMM Hamburg 2010.

60 MAN Diesel & Turbo, *Tier III Compliance, Low Speed Engines.*

61 MAN Diesel & Turbo, *Tier III Compliance, Low Speed Engines.*

62 Bunkerworld News, *Maersk Orders Second Generation Exhaust Gas System,* 14 Nov 2011.

EGR. This was confirmed in one engine manufacturer's literature that was submitted to the CG.[63]

EGR Technological Concerns and Potential Solutions

60 Some participants raised concerns over higher-speed engines operating with EGR technology and future fuel sulphur content. Sulphur in the fuel can result in the production of sulphuric acid and ash in the exhaust that may corrode and foul the EGR system. However, these untoward effects can generally be addressed by fitting an exhaust scrubber to the engine's exhaust stack. Additionally, some participants also noted that under certain load operations, any formation of particulate matter (PM) should be monitored when using EGR for NO_x reduction. To mitigate any potential issues from the PM, EGR should be used as part of a package of combined emission reduction technologies. Fuel sulphur levels may hinder the operation of EGR systems as the exhaust gasses could have higher sulphur levels, therefore a scrubber may be needed to remove impurities from the recirculated gas. Other participants noted that there are some aspects that need further consideration; manufacturers are continuing to work on improving these technology systems. One participant submitted a document from MAN that described the results of testing on a MAN B&W low-speed engine that was equipped with an EGR system and was Tier III NO_x compliant. The engine manufacturer concluded that the use of a Tier III EGR system will decrease particulate emissions, as well as hydrocarbon and sulphate emissions.[64]

61 A concern was expressed by one participant that heat rejected to the coolant system is higher than normal on engines with cooled EGR. They specifically noted that when modifying an engine to incorporate EGR NO_x control technology, the coolant circuit and the capacity of the coolant pump would need to be reviewed. The turbocharging system may also have to be rematched to suit the altered intake and exhaust flow rates, and in some cases this may mean moving to two-stage turbocharging. Packaging two-stage turbochargers is likely to required additional space around the exhaust side of the engine, and attention to potentially hot surfaces.

EGR Consumable Product: Washwater Treatment

62 Many participants thought that EGR coupled with an installed scrubber (to remove sulphur and other impurities from the recirculated exhaust gas) may be preferred over an SCR system for NO_x reduction because the EGR system would not incur the additional costs related with urea consumption. If this approach is used, additional consumables would be required to treat the washwater used in the scrubbing process, as well as disposal of the system's washwater residues. For example, depending on the scrubber design, one participant suggested the use of magnesium hydroxide (MgOH2) with EGR technologies to reduce the acidity of the washwater from the installed gas scrubber before disposing of the liquid overboard, as MgOH2 is relatively easy to procure at low prices and would be consumed at a rate of less than one tenth of the fuel.

Liquefied Natural Gas

63 A third technology raised by the participants to achieve the Tier III NO_x limits is the use of liquefied natural gas (LNG).

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63 MAN Diesel & Turbo, *Tier III Compliance, Low Speed Engines.*

64 MAN Diesel & Turbo, *Exhaust Gas Recirculation on MAN B&W Tier III Low Speed Engine-Focus on Particulate Matter.*

64 One commenter stated that LNG is expected to be a highly practical strategy for many ship applications (see list of LNG-fuelled ships in document MEPC 65/INF.10), including ferries, fishing ships, and containerships, as well as LNG tankers. There are already more than 20 ships powered by LNG engines in the worldwide cargo fleet, with many more on order.[65] In addition to the potential to reduce NO_x emissions well below Tier III NO_x limits, LNG engine technology would provide significant savings in fuel costs, especially relative to the use of distillate fuel. At the same time, however, LNG is less energy dense than diesel fuel oil and, therefore, LNG ships generally require additional fuel storage to maintain the same operating range.

Dual Fuel LNG

65 Due to its low self-ignition characteristics, the use of liquefied natural gas (LNG) as a fuel in marine engines requires some form of in-cylinder charge ignition source. In a dual-fuel LNG configuration, the primary combustion charge is natural gas, but the ignition source is a pilot injection of diesel fuel or heavy fuel oil.

66 The reference material submitted by participants to the correspondence group shows that a variety of dual-fuelled propulsion engines are either currently available or in development. Wärtsilä reports that its medium-speed four-stroke 20DF, 34DF, 50DF dual-fuel engines are available from 0.8-17.5 MW with a speed range of 500-1200 rpm and are Tier III compliant today in gas mode.[66] They have accumulated more than 1.5 million engine running hours with a total power installed of over 4,000 MW as of the end of 2010. Also, MAN B&W reports that its 51/60DF meets Tier III (in gaseous fuel mode). These engines are medium-speed four-stroke, and range in power from 6,000 kW-18,000 kW.[67] MAN is currently testing the 4T50ME-GI and expects to have it available in 2012. The 4T50 ME-GI is a low-speed two-stroke dual-fuelled engine that would also meet Tier III.[68] Finally, MaK reports that it is planning a dual-fuel product launch in 2014.[69] One commenter suggested that only dual-fuelled engines using pre-mixed fuel injection technology currently have the ability to achieve the Tier III NO_x standards, while dual-fuelled engines using direct injection technology can achieve only some reduction from the Tier II NO_x standards.

67 Participants expressed a variety of opinions regarding the ability of duel-fuelled LNG engines to meet the Tier III NO_x standard on diesel fuel, as required by the NO_x Technical Code, generally stating that the potential is there but is different depending on engine size, duty cycle or the amount of diesel fuel used as a pilot. Two participants suggested that slow speed dual-fuelled LNG engines cannot meet the Tier III NO_x standard, and one stated that while some engine types can meet the Tier III NO_x standard in dual-fuelled operation, smaller high-speed, automotive-based dual-fuelled engines could not meet the standard without additional measures such as SCR/EGR. One commentator suggested that this paragraph applies to direct fuel injection.

68 One participant noted the current or expected product offerings discussed above, which show that a variety of medium-speed, four-stroke dual-fuelled LNG engine models from Wärtsilä and MAN are currently available which meet the Tier III NO_x standard. Further, a compliant low-speed, two-stroke model offering from MAN is expected in 2012.

[65] DNV, A review of the world fleet of LNG fuelled ships, February 2011.
[66] Wärtsilä. Shipping in the Gas Age. 2010.
[67] http://www.mandiesel.com.cn/files/news/filesof16061/Brochure_4-Stroke_L+V5160DF.pdf.
[68] http://www.marinelog.com/index.php?option=com_content&view=article&id=859%3A2011may00201&Itemid=107.
[69] www.cat.com/cda/files/2408082/7/SMM+Press+Kit+FINAL.pdf.

69 One participant stated that there is a need for clear testing procedures for dual-fuel engines.

Single Fuel LNG

70 Due to its low self-ignition characteristics, the use of liquefied natural gas (LNG) as a fuel in marine engines requires some form of in-cylinder charge ignition source such as a spark plug. In a single-fuelled LNG configuration, the combustion charge is entirely natural gas, and the ignition source is a spark plug, effectively making the engine's operation similar to an otto-cycle gasoline engine.

71 Some participants correctly noted that single-fuelled LNG engines are not currently covered by regulation 13. Specifically, one participant noted that the definition of fuel oil in regulation 2.9 of MARPOL Annex VI is very broad and encompasses LNG in general. However, regulation 13 explicitly restricts the NO_x requirements to marine diesel engines and regulation 2.14 of MARPOL Annex VI defines marine diesel engines as engines operating on liquid or dual fuel. This definition effectively excludes the applicability of regulation 13 for engines running on pure LNG, as the LNG will be gasified by the time it enters the engine's combustion chamber. Nevertheless, several participants stated that single-fuelled LNG engines are capable of meeting the Tier III NO_x standard, at least for some engine types. One participant noted that Rolls Royce has reported that its Bergen Gas Engine: S.I. "Lean Burn" C23:33 & B32:35:40 can currently meet the IMO Tier III NO_x standard. The engines range from over 1,500 kW to nearly 9,000 kW. With more than 500 sold and over 20 million running hours; these engines have been in operation for over 20 years. The majority of the group that specifically commented on applying the regulation 13 NO_x standards to single-fuelled LNG engines also recommended that MEPC consider amending MARPOL Annex VI to accomplish this. These participants also supported the inclusion of single-fuelled compressed natural gas (CNG) and liquefied propane gas (LPG) in any such amendment. One participant specifically raised the issue of extending the Tier II NO_x limits to these engines, and noted that careful consideration would need to be given to the differences in how the Tier II and III standards are applied relative to engine replacements and new builds, respectively.

LNG Fuel Availability

72 One participant stated that the LNG distribution system for ports is still in the early stages of development but that LNG fuelling stations are expected to become more common with increased demand. In the near term, the limited refuelling infrastructure means that LNG technology is most practical for ships operating on set routes with established refuelling facilities. However, the technology will become more attractive for long-haul shipping as the LNG refuelling infrastructure grows and expands to more ports.

73 Another participant generally agreed with the above characterization, noting that dual-fuel LNG was a valuable option for short sea shipping in 2016. More time is needed for the development of LNG technology for deep sea shipping. A first precondition is LNG bunkering facilities. To better address the needs of marine customers, a system of small-scale and medium-scale terminals with feeder ships bringing LNG from the import terminal to these terminals and bunker ships, etc., must be established. A number of small-scale terminals are expected to be established in Denmark, Norway, Sweden and Finland by 2020 as well as in Germany, Belgium and the Netherlands.[70]

[70] Danish Maritime Authority, "North European LNG Infrastructure Project – A feasibility study for an LNG filling station infrastructure and test of recommendations," Copenhagen, May 2012.

Other Technologies

74 Several participants identified additional emission control technologies that could be used separately or in combination with other technologies to meet the Tier III NO_x standard. These technologies include water-based technologies (direct injection, fuel-water emulsions, humid air motor (HAM)), Miller cycle timing combined with two-stage turbocharging, extreme low NO_x tuning, and advanced multi-pollutant scrubbers ($CSNO_x$).

75 There are three main water-based technologies. All of these water-based approaches to reducing engine-out NO_x are based on limiting the formation of NO_x by limiting the peak combustion temperature. It is the heat capacity of water, its ability to absorb combustion energy, which limits the peak combustion temperature, and hence NO_x formation.

76 The first of the water-based technologies is direct water injection, where water is either injected into the intake manifold or directly into the combustion cylinder. The NO_x control efficiency increases as the water/fuel ratio increases, and Wärtsilä reports NO_x reductions of over 50 per cent using direct water injection with an 80/100 per cent water/fuel ratio.[71] One participant noted that this technology is successfully being used on several ships, with a 50 per cent reduction in NO_x demonstrated.

77 The second water-based technology is fuel-water emulsion. Fuel-water emulsions for marine engines can be either diesel fuel-water mixtures, with emulsifying and/or stabilizing agents added, or heavy fuel oil-water mixtures. When a fuel-water mixture is injected into the combustion chamber, vaporization of water within the mixture increases fuel dispersion (making the combustion of fuel more efficient) and absorbs combustion heat, which limits the formation of NO_x. MAN notes that, in the case of heavy fuel oil, up to 30 per cent water can be emulsified into the fuel, resulting in a 30 per cent reduction in NO_x.[72]

78 The third water-based technology is intake air humidification. One specific method using this water-based technology is MAN's Humid Air Motor (HAM) approach, where the combustion air is saturated with water vapour produced aboard the ship from raw seawater using engine heat sources. This approach can result in NO_x reductions of 65 per cent. One participant stated that HAM needs to be combined with EGR to achieve the Tier III NO_x standard. Another participant noted technical issues associated with the HAM system, mainly corrosion in scavenging air receivers and coolers. However, another participant noted that one engine equipped with the HAM system has been in operation for the last 10 years without problems on Viking Lines n/s **Mariella**. Wärtsilä also offers an intake air humidification system, known as the WET-PAC system. Another commenter suggested that water could be directly injected into the intake manifold to obtain the same results.

79 While each of these water-based technologies have been demonstrated in use, one participant stated that past experience has shown operational problems under long-term service and that there are still major in-service problems to overcome. Also, these technologies require onboard water storage, which means that they may be best suited for ships operating on shorter routes where water can be bunkered more frequently. Two participants noted that water-based technologies are not capable of meeting the Tier III NO_x standard alone and would need additional measures to comply with the standard.

[71] Wärtsilä, "Emissions Control Technology Development for Wärtsilä 2/4Stroke Engines," Leo Schnellmann, January 14, 2011.
[72] MAN Diesel and Turbo. Technology for Ecology: Medium Speed Engines for Cleaner Air.

80 Miller cycle timing in conjunction with two-stage turbocharging as developed by ABB, is another promising NO_x reducing technology.[73] With Miller cycle timing in a four-stroke engine, the inlet valve is closed sooner than in typical operation, resulting in the combustion air being expanded on the intake stroke, and thus cooled prior to combustion. Such intake air cooling can be achieved on 2-stroke engines by varying the timing of the exhaust valve closure. While the cooling of the intake air is desirable for NO_x control, the effect of these strategies alone is that a smaller air mass is inducted into the combustion chamber with each stroke, decreasing engine power and compromising response to load changes. In order to counteract the effect of smaller intake air mass, this Miller cycle valve timing is coupled with advanced turbocharging, such as two-stage turbocharging in ABB's case, or VTA Variable Turbine Area turbocharger and the MAN Diesel STC Sequential Turbocharging systems as being developed by MAN-diesel.[74]

81 A few other NO_x reducing technologies were also presented in the comments. One participant noted publically available data from Wärtsilä on Extreme Low NO_x tuning by means of high-pressure turbocharging.[75] Another participant mentioned the potential NO_x reduction associated with non-thermal plasma desorption. Two participants mentioned work going on regarding methanol and conversion to Di Methyl Ether (DME). Finally, one participant noted Ecospec's $CSNO_x$ system.[76] The $CSNO_x$ system is a 3-in-1 control system which makes use of treated water which is used to react with exhaust gas to remove NO_x, SO_2 and CO_2. According to the $CSNO_x$ brochure available on the Ecospec website, the $CSNO_x$ system is capable of NO_x removal rates as high as 66 per cent. One commenter suggested that the consumables associated with $CSNO_x$ be considered, however, no information was submitted regarding the identity or nature of these consumables.

Conclusion of Technology Review by Terms of Reference (ToR)

82 **ToR .1: range of technologies (engine fitting, material, appliance, apparatus, other procedures, alternative fuels or compliance methods) that may be used to comply with the Tier III NO_X standards.**

83 The following technologies were found to have the potential to achieve the 2016 and later Tier III NOx limits, either alone or in some combination:

.1 Selective Catalytic Reduction (SCR);

.2 Exhaust Gas Recirculation (EGR);

.3 Liquefied Natural Gas (LNG), either in a dual-fuel (diesel pilot injection with gaseous LNG as the main fuel) or alternative fuel arrangement; and

.4 Other Technologies: direct water injection, humid air motor (HAM), scrubbers, treated water scrubber, variable valve timing and lift, Dimethyl Ether as an alternative fuel.

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[73] "ABB Turbocharging: The Power2 miracle – NO_x down, power up, fuel down". www.ecospec.com.

[74] MAN Diesel and Turbo. Technology for Ecology: Medium Speed Engines for Cleaner Air.

[75] Wärtsilä, "Emissions Control Technology Development for Wärtsilä 2/4Stroke Engines," Leo Schnellmann, January 14, 2011.

[76] www.ecospec.com.

84 **ToR .2: the current use of these technologies on marine diesel vessels with a view towards characterizing the introduction and demonstration of these technologies in real world applications.**

85 Document MEPC 65/INF.10, which accompanies this final report, contains lists of vessels equipped with SCR (annex 2) and vessels fuelled with LNG (annex 3).

86 **ToR .3: progress of engine and after-treatment manufacturers towards developing such technology and expectations for bringing Tier III NO_x technologies fully to market by 2016.**

87 Engine manufacturers are already making great strides toward bringing Tier III-compliant engines to market by 2016. Some engine manufacturers are already marketing Tier III engines using SCR technology. Other manufacturers continue to investigate EGR technology and the application of LNG technology to the marine sector.

89 **ToR .4: identification of any subsets of marine diesel engines where there will not be technologies available to comply with the Tier III standards.**

90 One participant expressed concern regarding the application of NO_x reduction technology, specifically SCR systems, to at least some models of recreational yachts greater than 24 metres in length by the 2016 compliance date. This participant recommended that the Tier III NO_x implementation date be delayed a minimum of five years for yachts with length greater than 24 metres, and that a technology review be conducted for these vessels before that date to evaluate the progress being made by the industry. The remaining participants either expressed no opinion of this issue, except to request that IMO clarify its position on the NO_x compliance date for recreational yachts, or to note that SCR is a viable technology for all applications, including recreational yachts.

91 **ToR .5: where relevant, the global availability of consumable products used by a certain technology to reduce emissions to the required standard in Tier III, including supply chain issues, e.g. restrictions on import, export and sale.**

92 No significant concerns were associated with the availability of consumables in general or for the reductant (urea) and catalyst materials used by SCR systems in particular.

93 **ToR 6: recommend whether the effective date in regulation 13.5.1.1 of MARPOL Annex VI should be retained or, if adjustment is needed, reasoning behind that adjustment.**

94 The information assessed by the CG did not suggest a need to delay the 2016 implementation date of the Tier III NO_x standards contained in regulation 13 of MARPOL Annex VI.

95 **ToR 7: provide an interim report to MEPC 64 and submit a final report to MEPC 65 in 2013.**

96 An interim report was submitted to MEPC on 8 February 2012. This document is the final report to MEPC 65.

97 Although outside of the scope of the ToR for the CG, the group discussed the application of regulation 13 to pure, gaseous-fuelled engines and specifically whether single-fuelled gaseous engines should be regulated under regulation 13 of MARPOL Annex VI. The broad conclusion of the group was that these engines should be required to meet the same air pollution requirements as other engine types with regard to NO_x emissions.

Recommendations

98 The effective date of the Tier III NO_x standards in regulation 13.5.1.1 of MARPOL Annex VI should be retained.

99 Member States and observer organizations are invited to submit papers to MEPC 65 regarding the application and timing of the Tier III NO_x limits to recreational yachts greater than 24 metres in length.

100 The Committee also may wish to consider applying the standards contained in regulation 13 of MARPOL Annex VI to marine engines fuelled solely by gaseous fuels by a future date, i.e. pure LNG, CNG, and LPG.

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