Baltic NECA 2016 and NO_x Abatement

A Study on NO_x abatement and regulation in regards to a Baltic Sea NECA

Kalle Leppäaho

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TABLE OF CONTENTS

1 INTRODUCTION 1
  1.1 Objective 2
  1.2 Research questions 2
  1.3 Delimitations 2
2 BACKGROUND 3
  2.1 Other research studies 3
  2.2 MARPOL 73/78 Annex VI 5
    2.2.1 Regulation 13 5
  2.3 Drivers for NO_x Reduction 8
  2.4 Engine International Air Pollution Prevention Certificate – EIAPP 9
  2.5 Eutrophication of the Baltic Sea 9
  2.6 BALTIC SEA NECA 10
  2.7 Compromise at the MEPC 11
3 STUDY METHODOLOGY 13
  3.1 Literature research 13
  3.2 Qualitative research interview 14
4 ABATEMENT TECHNOLOGIES 15
  4.1 SCR – Selective Catalytic Reduction 15
    4.1.1 Operating principle 16
    4.1.2 The Reduction agent and the catalyst 17
    4.1.3 Operational and technical issues 17
  4.2 EGR – Exhaust Gas Recirculation 17
  4.3 Dual Fuel LNG engines 19
  4.4 Water based technology 19
  4.5 Alternative Fuels 20

4.6 Comparison and review 21
5 INTERVIEWS 23
5.1 The Finnish Shipowners Association – Christina Palmén 23
5.2 HELCOM – Hermanni Backer 24
5.3 Analysis 25
6 DISCUSSION AND CONCLUSIONS 27
6.1 Assessment 29
REFERENCES 30
APPENDIX I: Interview questions 1

BACHELOR'S THESIS
Author: Kalle Leppäaho

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Supervisors: Lapela, Esa

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Summary:

Shipping is a very global industry and therefore shares a global responsibility of the environment. International shipping is a major source of Nitrous oxide emissions globally and especially in the Baltic Sea area. Eutrophication of The Baltic Sea is a major problem and the shipping industry is a considerable contributor to this process through its NO_x emissions.

Environmental regulation has to be taken very seriously in this day and age and both Shipping companies and markets rise and fall in its wake. The next big step in the process of air pollution prevention regulation from ships is Nitrous oxides. The objective of this thesis is to give an overview on currently existing NO_x abatement technology and their feasibility in marine use. The study will also try to clarify the current state of the Baltic Nitrous oxide emission control area (Baltic NECA), its future and practical implications thereof.

This study takes use of qualitative research methods to answer the research questions. The theoretical part of the study is based on previous impact and feasibility research studies and documentation used in the creation of NO_x abatement regulation. A qualitative research interview was conducted to garner expert opinions on NO_x abatement and a Baltic NECA.

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Sammanfattning:

Sjöfart är en global industri och bär därför ett stort ansvar för att värna om miljön. Internationell sjöfart ger upphov till en stor del av de globala kväveoxidutsläppen, speciellt i Östersjöområdet. Eutrofieringen av Östersjön är ett stort problem och sjöfartsindustrin står för en betydande del av den genom sina NO_x utsläpp.

Miljöbestämmelser måste tas på allvar och både rederier och marknader är beroende av dem. Nästa steg i föroreningsförebyggande bestämmelser gäller kväveoxider. Denna avhandlings mål är att ge en överblick över redan befintliga NO_x bekämpningsteknologier och deras ändamålsenlighet i maritima sammanhang. Studien ämnar också klarlägga det aktuella läget samt framtiden och följderna av dessa för Östersjöns kväveoxidutsläppskontrollområde (Baltic NECA).

Denna studie tillämpar kvalitativa forskningsmetoder för att svara på forskningsfrågorna. Den teoretiska delen av studien är baserad på tidigare studier rörande påverkan, genomförbarhet och dokumentation som användes som grund för skapandet av NO_x bekämpningsbestämmelserna. En forskningsintervju genomfördes för att utreda experters åsikter angående NO_x bekämpning och Baltic NECA.

Språk: Engelska Nyckelord: NO_x, abatement, NECA, SCR

Glossary

CMS – Center for Maritime Studies at the University Of Turku

EGR – Exhaust Gas Recirculation

EU – European Union

GHG – Greenhouse gas

HELCOM – Baltic Environment Protection Commission

IMO – International Maritime Organization

LNG – Liquefied Natural Gas

MARPOL – International Convention for the Prevention of Pollution from Ships

MEPC - Marine Environment Protection Committee

NECA – NO_x Emission Control Area

NO_x – Nitrous oxides, NO and NO_2

OSPAR - The Convention for the Protection of the Marine Environment of the North-East Atlantic

PM – Particulate matter

SCR – Selective Catalytic Reduction

SECA - SO_x Emission Control Area

SO_x – Sulfur oxides

1 INTRODUCTION

Shipping is a very global industry and therefore shares a global responsibility of the environment. The realities created by pollution, emissions and greenhouse gases are not arbitrary legislation and regulation but have a very tangible economic effect on both the industry and the environment it operates in. Environmental regulation has to be taken very seriously in this day and age and both shipping companies and markets are affected in a plethora of different ways. This reality can be seen very clearly in action when following the effects of the sulfur emission regulations in the Baltic and North Sea Special areas to be implemented in the beginning of 2015. Significant extra costs to shipping companies causing surcharges to freight rates, layoffs and the out-flagging of vessels with the cited reasoning being heightened fuel costs due to SECA implementation. The next big step in the process of air pollution prevention regulation from ships is Nitrous oxides and this process begins with the International Maritime Organization (IMO) and the International Convention for Prevention of Pollution from Ships (MARPOL).

International shipping is a major source of Nitrous oxide emissions globally and especially in the Baltic Sea area. Eutrophication of The Baltic Sea is a major problem and the shipping industry is a considerable contributor to this process through its NO_x emissions. (Kalli et al. 2010. p. 3) The International Maritime Organization (IMO) and Maritime Environment Protection Committee (MEPC) working under it have been in the process of creating and implementing more stringent air pollution regulation through the International Convention of Pollution Prevention (MARPOL 73/78) for several years.

MARPOL, and more specifically ANNEX VI: Regulations for the Prevention of Air Pollution from Ships, has been under discussion and been amended several times in the last decade. The most notable of these amendments are the Regulations 13 and 14 concerning Nitrous and Sulfur oxides and IMO Special Emission Control Areas (ECA). These regulations are notable because of the major economic effects their implementation will have and has already had on the Shipping industry both globally and in Finland.

This thesis was started with a working hypothesis that the Baltic NECA implementation in 1.1.2016 was assured and that the technology existed for ships to comply with this strict emission regulation. I began with the idea of reviewing the emission limits and the abatement technology and the operational measures taken by shipping companies. As time and more research went by, new resolutions and amendments were made by the MEPC which completely changed the basis of my research by indefinitely postponing the NECA implementation. This led to me slightly changing the objectives of my thesis to further elaborate on the facts why this paradigm change had happened.

1.1 Objective

The objective of this thesis is to create an understanding of what is happening and what has happened with the Baltic Sea NECA process and what are the reasons behind it. This includes understanding the MARPOL Annex VI Tier III regulations and the ramifications of its implementation in terms of feasible technology solutions and the limitations and challenges inherent in the use of such technology.

1.2 Research questions

This thesis will answer the following questions:

What is the background regulation behind NO_x Tier III regulation and NECA’s and the driving force behind it?

What are the most promising NO_x abatement technologies for the marine sector and their operational limitations?

What the current state of the Baltic NECA proposal and approval process and what are the reasons behind the compromises inherent in its current state?

1.3 Delimitations

The study will be limited on the main points of the regulatory process of Annex VI and Tier III emission limits and to a general review of the technology available for complying with these limits. Any venture further into capital or operational cost analysis for the different technology goes beyond the scope of this research. The research interviews broach the subject of the overall economic, environmental and health impacts of implementation of this regulation in the future. The analysis will be limited to the Baltic Sea NECA and furthermore to NO_x abatement technologies which the MEPC has seen as Tier III compliant in their current form and can be seen as off the shelf solutions.

2 BACKGROUND

2.1 Other research studies

Several feasibility and impact research studies have been made about NO_x abatement during the MEPC deliberation period before finalizing the amendments for the NO_x regulation in September 2014. These studies include research done more specifically in the North Sea area commissioned by the Danish Ministry of the Environment and the Netherlands Environmental Assessment Agency. The research study commissioned by the Danish Ministry of the Environment was done by Incentive Partners & Litehauze in 2012: *Economic Impact Assessment of a NO_x Emission Control Area in the North Sea.* The Netherlands Environmental Assessment Agency's *Assessment of the environmental impacts and health benefits of a nitrogen emission control area in the North Sea* was done by Hammingh et al.in 2012.

The Danish impact assessment implies benefit-cost ratios of NECA implementation in the range of 1.6-6.8 with some other indirect benefits which cannot be monetized. The economic effect on the total increase of costs for ship operators is argued to be less than 2 % with a very small risk for modal shift or rerouting of shipping patterns due to relatively small increases in freight rates. Since the capital costs are the dominating parameter the more NECA's are implemented the lower the capital expenditure associated with the extra area is (Incentive Partners & Litehauz, 2012).

The Dutch impact assessment also contains cost-benefit analysis which constitutes that even in the least favorable conditions, with high capital cost and low attributed health benefits, NECA implementations is beneficial. Sea based emission control is also cheap when compared to land based emission regulation in the long term and the sooner the limitations are implemented the larger the emission reduction will be in the future. Total years of life lost due to emissions would also be lowered by one per cent in the North Sea coastal areas by 2030 (Hammingh et al., 2012).

Research studies made more directly about the Baltic Sea NECA include a study commissioned by the Finnish Ministry of Transport and Communication: *Limiting NO_x Emission from Ships* done by Karvonen et al. 2010. The goal of this study was to make an economic impact assessment of the effects the MARPOL Annex VI on the Finnish Shipping industry. *Baltic NECA – economic impacts* (Kalli et al. 2010) commissioned by HELCOM is a Finnish study conducted by the Centre for Maritime Studies (CMS) at the University of Turku study which goes into detail about the capital (CAPEX) and operating costs (OPEX) of NO_x Tier III abatement for Baltic Shipping.

The study by Karvonen et al. notes that the only technology feasible for adequate abatement cost analysis at the time of the study was Selective Catalytic Reduction (SCR) due to the lack of knowledge and experience of other currently available technology. Daily costs on vessels equipped with SCR technology would rise by 3.4 per cent on average compared to the cost structure of vessels without abatement in 2010 with a purchase prices of about 50 €/kWh for the abatement equipment itself (Karvonen et al., 2010). Both Finnish studies make the assumption that the fleet operating in the Baltic Sea will become more specialized and that the amount of vessels which only rarely visit the area will be reduced.

The study by CMS sees NO_x abatement in the Baltic Sea area as cost effective as similar emission reduction techniques in waste water treatment and agriculture. The cost effectiveness of a Baltic NECA also increases if the North Sea would also be designated as a Nitrogen Emission Control Area. The effect on freight rates is estimated by Kalli et al. to be in the range of 2 – 4.6 % with the highest increase in operation costs attributed to large and fast container vessels. The study also comments that the use of economic incentives such as reduced fairway fees and emission charges for the vessel operators to compensate for additional costs incurred by the NECA designation are not without problems (Kalli et al., 2010).

An *Economic Comparison of Three NO_x emission abatement systems (2013)* by Häkkinen et al. was made by the University of Applied Sciences in Kymenlaakso in co-operation with BSR Innoship. This study is based on NO_x measurements made on nine vessels with various engine types and abatement technologies, including Selective Catalytic Reduction (SCR, Humidification of Charge Air (HAM) and Direct Water Injection (DWI) in use. The only one of these technologies that can be seen as operationally viable for actual Tier III use, as sole abatement technology, according to the MEPC:s Technological Correspondence group is the Selective Catalytic Reduction (IMO, 2013a. page 4).

2.2 MARPOL 73/78 Annex VI

MARPOL 73/78 Annex VI regulates the prevention of Air pollutions from ships and it applies to all vessels, fixed and floating drilling rigs and other platforms over 400 gross tonnage. The regulation originally entered into force on May 19th 2005 but has thereafter been revised by the MEPC in 2008. The Annex entails the requirements and certification for control of emissions from ships: Regulations 12 through 16 and regulation 18.

Regulation 12	Emissions form Ozone depleting substances from refrigerating plants and firefighting equipment.
Regulation 13	Nitrogen oxide (NO_x) emissions from diesel engines.
Regulation 14	Sulfur Oxide (SO_x) emissions from ships.
Regulation 15	Volatile Organic Compounds (VOC) from cargo oil tanks of oil tankers.
Regulation 16	Emissions from shipboard incinerators.
Regulation 18	Fuel oil quality.

2.2.1 Regulation 13

The regulation and its ramifications more intimately studied in the thesis is Regulation 13 which concerns itself with the Nitrous oxide emissions from diesel engines. Regulation 13 itself is divided into three Tiers of standards of varying emission control which depends on the construction date of the ship and its engines. The regulation applies to all vessels over 400 gross tonnage and each diesel engine with a power output over 130 kW constructed on or after January 1st 2000 (IMO, 2008).

Tier I regulation is a global emission limitation and it was first added to the Annex in 1997. Tier I NO_x regulation came into force on 19.05.2005 after being ratified by sufficient IMO member states (LVM 2010). Both Tier II and III regulation were added as a part of the latest revision to the Annex made by the MEPC in 2008. Tier III regulation was even further amended at the MEPC's 66th meeting in September 2014.

All diesel engines which have undergone major conversions after the implementation dates of any and all Tiers must comply with the highest level of emission control. A major conversion means specific modifications done to an engine:

- Engine replaced by a new engine
- Specific modifications done to the engine which may increase and exceed the emission regulations are described in detail in the NO_x Technical Code 2008.
- The maximum continuous power rating of the engine increased by over 10%

The three different tiers, have different limitations depending on the construction date:

Tier I: Subject to regulation 3 of this Annex, the operation of a marine diesel engine which is installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):

17.0 g/kWh when n is less than 130 rpm;

$45 * n^{(-0.2)}$ g/kWh when n is 130 or more but less than 2,000 rpm;

9.8 g/kWh when n is 2,000 rpm or more.

Tier II: Subject to regulation 3 of this Annex, the operation of a marine diesel engine which is installed on a ship constructed on or after 1 January 2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):

14.4 g/kWh when n is less than 130 rpm;

$44 * n^{(-0.23)}$ g/kWh when n is 130 or more but less than 2,000 rpm;

7.7 g/kWh when n is 2,000 rpm or more.

Tier III: Subject to regulation 3 of this Annex, the operation of a marine diesel engine which is installed on a ship constructed on or after 1 January 2016:

.1 is prohibited except when the emission of nitrogen oxides (calculated as the total weighted emission of NO2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):

3.4 g/kWh when n is less than 130 rpm;

9 $*n^{(-0.2)}$ g/kWh when n is 130 or more but less than 2,000 rpm; and

2.0 g/kWh when n is 2,000 rpm or more;

.2 is subject to the standards set forth in subparagraph 5.1.1 of this paragraph when the ship is operating in an Emission Control Area designated under paragraph 6 of this regulation; and

.3 is subject to the standards set forth in paragraph 4 of this regulation when the ship is operating outside of an Emission Control Area designated under paragraph 6 of this regulation.

(IMO, 2008)

Table 1 NO_x limits in MARPOL Annex VI

Tier	**Effective Date**	**NO_x Limit (g/kWh)**		
		N<130	130<=N<2000	N>2000
Tier I	2000	17	$45*n^{-0.2}$	9.8
Tire II	2011	14.4	$44*n^{-0.23}$	7.7
Tier III	2016	3.4	$9*n^{-0.2}$	2.00

IMO. 2014. Page 170

Annex VI Regulation 13 Tier III levels of NO_x reductions in operational terms mean an 80% reduction in emissions when compared to Tier I emission levels as can be clearly seen in Figure 1 which is a graphical depiction of the functions seen in Table 1.

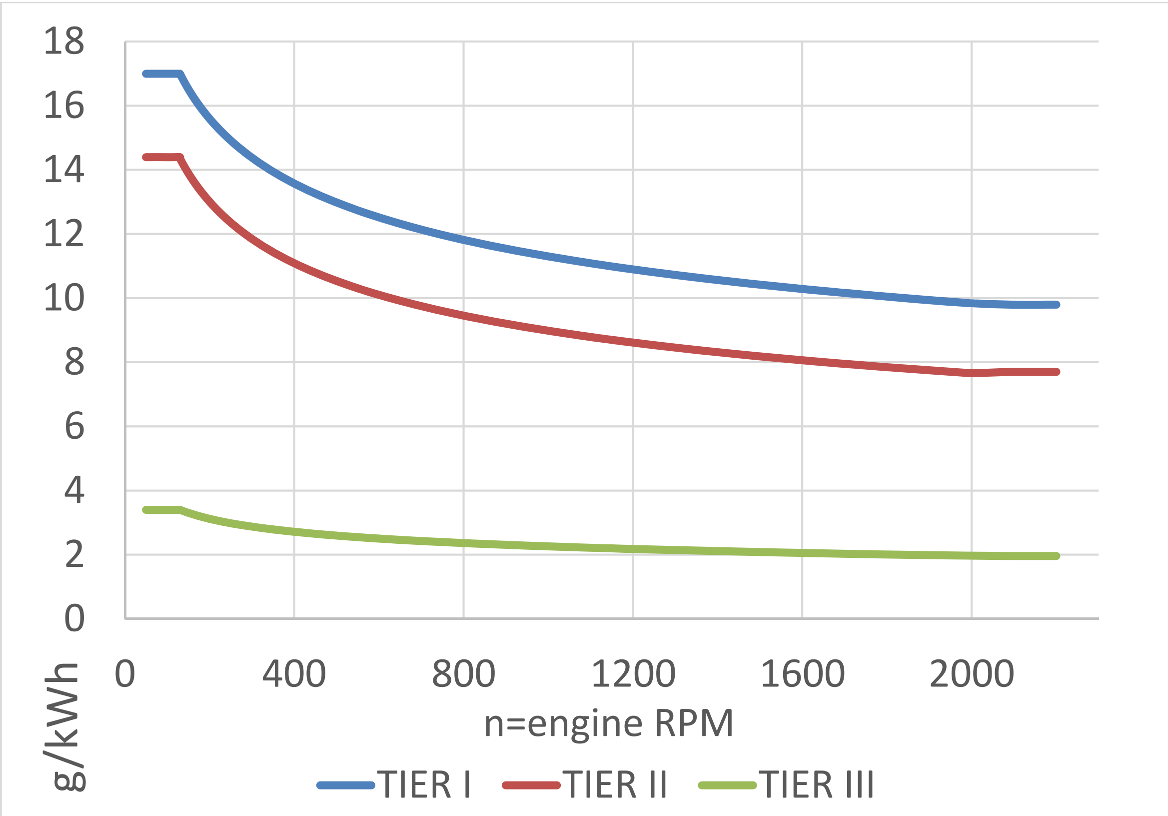

Figure 1 NO_x emission limits for different Tiers as a function of the engine speed (By author)

2.3 Drivers for NO_x Reduction

Nitrous oxides are formed in the heat of the engine and can cause several harmful on both the environment and the health of human populations. Nitrous oxides acidify the environment and a positive correlation between NO_x concentrations and hospital admissions due to respiratory disease has been shown in studies and decreased life expectancy. The significant harmful effects caused by NO_x emissions are eutrophication, ground ozone formation, acid depositions and particulate matter (PM) formation (HELCOM. 2011 Page 18).

NO_x emission reductions are driven several different elements:

- Requirements by National and International Regulation
- Environmental concerns
- Fossil fuel availability, cost and energy security

Because of the importance of NO_x emission reduction some countries are not waiting for international regulation and have taken the matter in their own hands through market based economic instruments. The Norway tax fund, and the Swedish fairway due –system are both good examples. The Norwegian tax fund is an agreement between 15 business organizations and the Ministry of Environment in which the shipping industry gets lower rates on the fiscal NO_x tax. In exchange the shipping companies commit to emission reduction through investments in LNG technology which are then subsidized with the funds of NO_x emission tax. (Johnsen 2013) The Swedish system gives a rebate on the gross tonnage portion of their fairway dues if the vessels emission levels are lower than 10 g/ NO_x/kWh.

2.4 Engine International Air Pollution Prevention Certificate – EIAPP

Regardless of the Tier of NO_x emission abatement the diesel engine falls under according to Regulation 13 it needs an EIAPP certification from the flag state. To get the engines certified it must first demonstrate compliance with the set NO_x emission limits. EIAPP certification is the responsibility of the flag state but it is most often delegated to the classification society. The certification process is done in accordance the standards set by the NO_x Technical Code (2008) issued by IMO (DNV).

2.5 Eutrophication of the Baltic Sea

The Baltic Sea is brackish-water Sea with a very long coast line and a large catchment area. The Baltic is also quite shallow with a mean depth of only 53 meters and the water exchange with the North Sea is interspersed and very slow. The interval between salt pulses from the narrow Danish Straits and the Sound can be several years. All of these properties create an extraordinary environment and makes its ecosystem very unique and sensitive to eutrophication due to pollutant accumulation. Eutrophication is seen as the most serious environmental challenge for The Baltic Sea with already evident damage observed.

Eutrophication causes an enrichment of the ecosystem due to accelerated growth of algae and plant life caused by increased amounts of nutrients like nitrogen which is a byproduct of NO_x emissions. These changes in the ecosystem negatively impact the biodiversity and also alters the natural food-web structures, changes the composition of species and disturbs population dynamics. (HELCOM. 2011).

2.6 BALTIC SEA NECA

The Baltic Sea has already been designated as a Special Emission Controlled Area by the IMO in regards to MARPOL Annex VI Regulation 14 which regulates the amount of sulfur oxides in ships emissions. This regulation and the Sulfur oxide emission control are in the Baltic Sea will come into effect on January 1st of 2015. The geographic limits of the established Baltic Sea ECA can be seen in Figure 2.

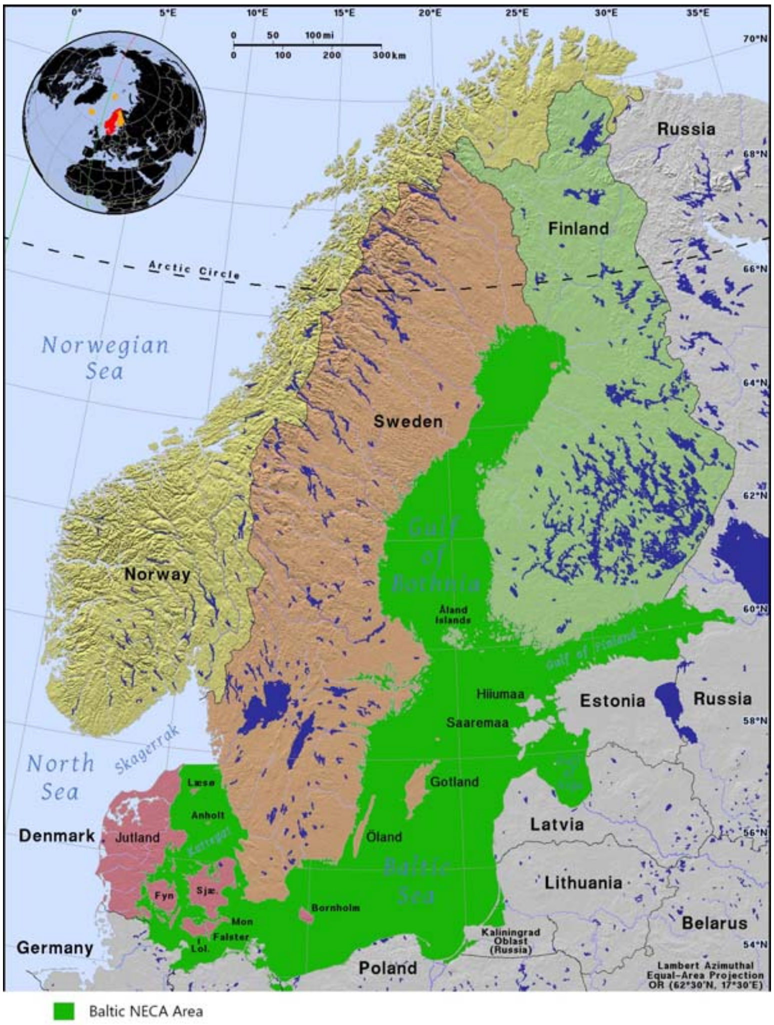

Figure 2 Geographical limits of the Baltic NECA (Public Domain)

Denmark and other Scandinavian countries have been seeking to establish a new NECA in the Baltic Sea and all the ground work has already been done including several drafts of the application. The HELCOM application for Baltic NECA status to the IMO has been technically ready since the commissions meeting 33/2012 in Helsinki in March 2012. A future Baltic NECA would also affect the same area (Figure 2) as has been stated in the draft versions of the HELCOM NECA applications. At the Commissions Ministerial Meeting in Moscow 2010 a decision was made to work towards submitting a joint proposal for a Baltic NECA, preferably by 2011, by the Baltic Sea countries to the IMO. (HELCOM, 2013).

Both the HELCOM application for a Baltic Sea NECA and the Tier III NO_x regulation itself by the IMO has so far been opposed by The Russian Federation, which in the fall of 2013 managed to block the joint application during the HELCOM Ministerial Meeting in Copenhagen (HELCOM. 2013). The Russian Federation has in both instances cited a need for further technical consultation in regards to the availability of technology and infrastructure for Tier III compliance (IMO 2013b). All that remains of the intention to submit the application to the IMO is this note in the final Ministerial declaration by the Commission:

> "WE TAKE NOTE of the fact that due to the need for further technical consultations amongst some of the Contracting Parties as regards to the availability of technology to implement the Tier III NO_x emission standards under MARPOL Annex VI, the application on the Baltic Sea NECA has not yet been submitted to IMO. WE NOTE that in that context, in order to move forward, HELCOM Stakeholder Conference "Baltic Sea – NO_x Emission control area" was organized in March 2013 which discussed the availability of technology to implement the Tier III NO_x emission standards under MARPOL Annex VI, including further enhancement of existing and development of new relevant technology. A review of the status of technological developments to implement the Tier III NO_x emissions standards has been prepared by IMO and considered in May 2013" (HELCOM 2013).

2.7 Compromise at the MEPC

At the 65th meeting of the Marine Environment Protection Committee the Russian Federation submitted a document "*Comments on the report of the Correspondence Group on Assessment of Technological Developments to Implement the Tier III NO_x Emission Standards under MARPOL Annex VI*" (MEPC 65/4/27). In this document the Russian Federation comments on and declares the lack of technological readiness and infrastructure for NO_x Tier III implementation and explicitly calls for an extension for the implementation of Regulation 13 (IMO 2013b). The MEPC took the comments under advisement and subsequently made a decision on the matter at the 66th meeting of the Committee in September of 2014.

The Russian Federation had several points of concern directed towards the quality and scope of the Tier III abatement technology review conducted by the correspondence group in the MEPC document 65/4/7. The main grievances stated in the document submitted by the Russian Federation are that the review focused too exclusively on solely SCR technology and stated many argument showing the drawbacks of SCR usage in marine application. The problems with SCR technology according to research by the Russian Federation are the following:

- Leads to side products and greenhouse emissions (ammonia, CO2) which are already regulated by IMO instruments and are as toxic and harmful to the environment as NO_x emissions.
- Is only reliable in a narrow temperature range and engine load.
- Use of high sulfur fuel lead to bad catalyst deterioration and therefore also a SO_x scrubber may be needed in conjunction with SCR to combat the adverse effects. This leads to even further problems with space requirements and leads to a complicated system.
- Notable concern is that these issues have not been solved even in the considerable time SCR systems have been in both marine and land application.
- The other alternatives for NO_x abatement are very briefly described and based solely on the review cannot be considered as viable for implementation by the set date. (IMO 2013b)

The Russian Federations seemingly failed to extend the implementation date from the intended 1.1.2016 but in reality their goals were clearly met. MEPC made a compromise of retaining the effective date for Regulation 13 Tier III implementation, but the wording of the Regulation was significantly changed. The Regulation now specifically targets and affects ships operating in the already implemented ECA's:

> .2 that ship is constructed on or after 1 January 2016 and is operating in the North American Emission Control Area or the United States Caribbean Sea Emission Control Area;
>
> when:
>
> .3 that ship is operating in an emission control area designated for Tier III NOX control under paragraph 6 of this regulation, other than an emission control area described in paragraph 5.1.2 of this regulation, and is constructed on or after the date of adoption of such an emission control area, or a later date as may be specified in the amendment designating the NOX Tier III emission control area, whichever is later.
>
> (IMO. 2014. Page 170-171)

This amendment to the Annex VI Tier III regulation in effect shifts the responsibility of future NO_x abatement through NECA implementations, from the MEPC and IMO to the flag states and in the Baltic Sea more directly to HELCOM. Since the HELCOM Ministerial meeting in Copenhagen in 2013 the issue of a Baltic NECA application has not been discussed and according to Backer its status is very much open and the main focus now is on alternate fuels instead of NECA. (Personal communication 08.10.2014)

3 STUDY METHODOLOGY

This study takes use of qualitative research methods to answer the stated research questions. I base the theoretical part of the study on literature and research done in the technical and regulatory aspect of NO_x abatement and impact and feasibility studies previously made in the field.

3.1 Literature research

I did extensive literature research into earlier impact and feasibility studies made into NO_x abatement technology and read the documentation regarding Regulation 13 of MARPOL Annex VI. The documentation regarding the MEPC's process of creating and amending

Annex VI is very extensive in regards to both feasibility and availability of the abatement technology and comments from countries both for and against the more stringent NO_x regulation.

3.2 Qualitative research interview

I will conduct a qualitative research interview several participants. The purpose of these interviews is to get a holistic understanding of the current situation and answer the stated research questions.

1. What is the background history and motivation for NO_x regulation?
2. What the current state and operational readiness is for NO_x abatement technology
3. What the current state of the Baltic Sea NECA application.

The answers garnered from the qualitative research interview of experts in the field shall be analyzed and reflected upon. The subjective views of the interviewee's can be compared with the conclusions of the research studies already made in this field that are used as the background theory for this thesis.

The study is conducted as a qualitative interview because quantitative data concerning any large scale NOx abatement implementation is to be considered confidential information by the engine manufacturers and therefore unavailable and also most unsuitable for answering the stated research questions.

The semi-structured interviews with the chosen key people were conducted via e-mail by me in September 2014. The interviews were conducted through e-mail because of cost and time restrictions. The interviews can be considered as online, asynchronous, in-depth, qualitative research interviews. I have mitigated the known issues of e-mail interviews through extensive research into the subject matter and properly planned questions and by following up on points left vague by the first round of inquiry.

4 ABATEMENT TECHNOLOGIES

Nitrogen Oxide abatement methods used in marine applications are technologies which have already been proven in use in several instances in power plants and other land based industries. The ones most viable for marine applications with Tier III reduction capabilities are Selective Catalytic Reduction (SCR), Exhaust Gas Recirculation and Liquefied Natural Gas (LNG) engines. These were also the main technologies reviewed by the MEPC and with most solutions already available by engine manufacturers. There are several other promising technologies for NO_x abatement but these have not been as viable for Tier III compliance either because their reduction potential as a standalone system is not sufficient or because the technology is still in pilot phase. These technologies include alternative fuels other than LNG and different abatement solutions for traditional marine diesel engines. The most notable of these include water based technology, direct water injection, humid air motors, fuel water emulsions, Miller cycle timing and advanced multi pollutant scrubbers (IMO 2013a).

4.1 SCR – Selective Catalytic Reduction

Selective Catalytic Reduction with ammonia used as the reduction agent was first patented in the United States in 1957 by the Engelhard Corporation and has been used in thousands of systems since. SCR is the most prominent NO_x abatement technology with the largest NO_x reduction capabilities. It is widely used in land based applications, power plants, trucks, trains, cars and also been in marine use for years. “SCR is considered a proven, commercially available technology capable of removing 95% or more of NO_x in an exhaust gas.” (IACCSEA, 2013. p. 1). SCR is a proven technology with a long track record in marine usage even with most of the applications being retrofits and not new buildings which are the ones that will actually fall under Tier III regulation in the future.

4.1.1 Operating principle

SCR uses a chemical reaction between a reduction agent and nitrogen oxides accelerated by a catalyst. The reduction agent used in marine reactors is ammonium used as a solution of urea and water. The main chemical reactions with SCR are the following:

CH_4N_2O	$\rightarrow$	$4NH_3 + HNCO$	(1)
$HNCO + H_2O$	$\rightarrow$	$NH_3 + CO_2$	(2)
$4NO + 4NH_3 + O_2$	$\rightarrow$	$4N_2 + 6H_2O$	(3)
$6NO_2 + 8NH_3$	$\rightarrow$	$7N_2 + 12H_2O$	(4)

1. Urea ($CO(NH_2)_2$) is evaporated and decomposed in the exhaust to isocyanic acid (HNCO) and ammonia, which further hydrolyzes with the water (H_2O) in the solution to create carbon dioxide (CO_2) and more ammonia (NH_3). Reactions (1) and (2)
2. Nitrogen oxide and Nitrogen Dioxides in the exhaust gas are reduced to Nitrogen gas (N_2) and water (H_2O) by the ammonia and the catalyst (3) (4)

The main components deeded for SCR

1) A reducing agent storage (urea tank)
2) A reducing agent feeding and dosing unit
3) A reducing agent injection and mixing unit
4) reactor with catalyst elements

The pump transfers the reduction agent to the dosing unit which regulates the flow rate to the injection unit based on the engine load. The injector then sprays the urea into the exhaust gas duct and from there it flow to the reactor itself where the catalytic reduction takes place (Wärtsilä, 2014).

4.1.2 The Reduction agent and the catalyst

The industry standard is the AUS-40 marine urea solution, which contains 40 % urea by mass and is best suited for SCR usage of marine diesel engines and is very safe to handle. It is very similar to AdBlue which is the standard aqueous urea solution used for road vehicles to comply with Euro V NO_x emission regulations in the EU. The catalyst used in marine SCR applications is a typical titanium-vanadium catalyst.

4.1.3 Operational and technical issues

Some notable issues with SCR technology have been found, but most of them are easily addressed through proper planning, operation and maintenance. These issues include ammonium slip, CO_2 emission increase, catalyst deterioration and narrow operational temperature range. These are the same concerns indicated by the Russian Federation in their comment to the MEPC with the explicit goal of postponing the entire NO_x regulation until 2021. All these claims were actually shown to be untrue or irrelevant by the MEPC document 66/6/6 submitted by Canada, Denmark, Germany, Japan and the United States (IMO. 2013c)

4.2 EGR – Exhaust Gas Recirculation

The second technology with great potential for Tier III NO_x abatement is called Exhaust Gas Recirculation. In this system 30 - 40% the exhaust gases are cooled, cleaned and recirculated into the scavenge air receiver. The temperature peak and the O_2 levels in the combustion chamber thus lowered and also the NO_x emission formation. (MAN B&W)

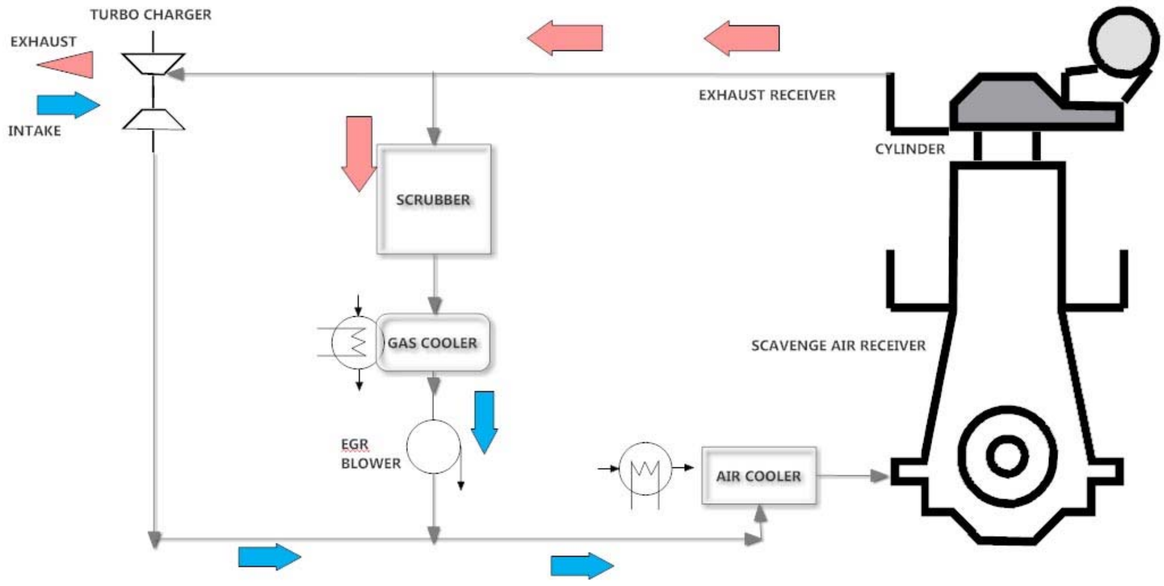

Figure 3 EGR process diagram (by author)

Exhaust gas recirculation has a high potential for emission reduction and Tier III solutions for 2-stroke engines based purely on EGR technology are available off the shelf. The EGR system might be the preferred choice because of the lack of additional costs related to urea consumption and supply (IMO 2013a). The basic EGR process diagram can be seen in figure 3, the exhausts from the engine enter the receiver and circulate through scrubbers and coolers and then are circulated back into the combustion chamber through the scavenge air receiver.

EGR technology is not as promising for all marine diesel engine types as SCR and in most cases needs additional reduction technology in the form of water based or exhaust gas after treatment. More development is needed for a broader range of engine types with EGR based Tier III compliance. Other noted problems associated with EGR technology when used with high sulfur fuels is higher levels of SOx emissions and the formation of sulfuric acids in the EGR system which leads to corrosion (IMO 2013a). These problems can be addressed through additional exhaust gas after treatment through scrubbers within the EGR system as can be seen in figure 4. The need for scrubbers is one of the drawbacks with EGR technology because they require water treatment facilities and chemicals which creates need for additional space and consumable chemical products for wash water treatment onboard (IMO 2013a).

4.3 Dual Fuel LNG engines

Dual Fuel engines are engines which use liquefied natural gas as the main combustion charge, but require an ignition source in the form of injected diesel of heavy fuel oil due to the low self-ignition characteristics of natural gas. Dual Fuel engines are highly practical because they comply with both the low sulfur requirement of Regulation 14 and Tier III NO_x emission requirements of Regulation 13 stated in Annex VI of the MARPOL (IMO 2013a).

Dual fuel LNG engines have great potential for emission reduction in gas mode and several dual fuelled engines are currently available and in development. Especially medium speed four-stroke engines using pre-mixed fuel injection technology are ideal for Tier III compliance. Slow speed, large dual fuel engines on the other hand cannot at this moment reach these levels of emission reduction (IMO 2013a). Dual Fuel LNG technology is on the rise especially in the Norwegian offshore shipping industry due to the Norwegian NO_x tax fund which subsidizes both new buildings and retrofits of LNG technology.

Problems with all LNG based marine propulsion at the moment is the lack of Global infrastructure and bunkering facilities. This creates a dilemma within the industry which leads to the situation where no operators are ready to commit to the technology before the bunkering infrastructure is created and vice versa. Also the lack of bunkering facilities leads to LNG onboard storage problems, because it is not as energy dense as traditional fuels used in shipping. Therefore LNG engine technology is only a viable option for ships on short and set routes with established refueling facilities (IMO 2013a).

4.4 Water based technology

Water based technologies are similar to EGR in their chosen method of limiting NO_x emissions simply through lowering the peak combustion temperature. These technologies include humid air motors, direct water injection and fuel water emulsion. All of these technologies rely on the large heat capacity of water to absorb energy from the fuel combustion to limit the temperature and also the formation of NO_x emissions (IMO 2013a).

In direct water injection the water is directly inserted into the intake manifold or the combustion cylinder. The NO_x emission reduction capabilities are limited to about 50 percent and its efficiency increases with ratio of water to fuel in the combustion chamber. This method is quoted in the technology review as successfully being used on several ships (IMO 2013a).

The second type of water based abatement technology is fuel water emulsion. The fuel water emulsion is either a HFO-water emulsion or a water diesel emulsion created with stabilizing agents and an emulsifier. The use of an emulsion of water and fuel injected into the combustion chamber not only lowers the NO_x emission created by 30 per cent but also makes the combustion itself more efficient through increased fuel dispersion (IMO 2013a).

The final water based technology is based on the humidification of the engine intake air. This means that the introduction of water into the combustion process is done through the engine intake air supply and not through the fuel injection process. Air needed for the combustion process is saturated by water vapor which in turn lower the peak combustion temperatures. This process is known to produce NO_x emission reduction of 65 per cent (IMO 2013a).

All the water based reduction technologies have some inherent problems associated with them. The most obvious one is that in the fact none of them reach the reduction potential required for Tier III compliance as a stand-alone system. In addition to this fact there are also several in-operational problems to overcome when it comes to long term service which include need for large water storage onboard or short routes with the possibility of bunkering water and also corrosion problems within the combustion cylinder (IMO 2013a). These problems combined make the water based reduction technology a poor choice when striving for anything higher than Tier II compliance unless when used in conjunction with other abatement processes e.g. EGR.

4.5 Alternative Fuels

The alternative fuels capable of Tier III NO_x reduction capabilities include LNG as a single fuel through lean burn mono fuel spark ignition and Dimethyl Ether (DME) and similar clean burn alcohol and ether based bio fuels. There are several potential biofuels with emission reduction capabilities which are globally available and can be produced from many abundant types of biomass. The most notable ones applicable for marine use are Biodiesel, DME, and straight Vegetable Oil, bio-methane, bio-ethanol and pyrolysis bio-oil (Florentinus et al. 2012). It is possible to replace marine fossil fuels with biofuels without the need for large modifications or retrofits but most of them do not seem to be an actual alternative at the moment due to limited availability and high cost.

The exception to this rule is On Board Alcohol to Ether (OBATE) which is essentially enriched methanol. OBATE is a mixture of dimethyl ether, methanol and water and works as an alternative fuel in traditional diesel engines. OBATE also has zero sulfur emissions reduces both NO_x and PM emission below Tier III limits. The advantage of this technology is that easily handled and pumped readily available, but poor fuel, methanol is upgraded into a better fuel for diesel engines on board the vessel. This happens through a dehydration process in a catalytic converter that is situated onboard the vessel. This process upgrades low grade alcohols into useable fuels for standard marine diesel engines.

OBATE, methanol and DME were tested as fuel alternatives for marine use in a project by the Nordisk Energiforskning in their Alcohols and Ethers as Marine Fuel (SPIRETH) –program. The findings were indicative that it is possible to convert ship's main engines to operate on methanol and DME –based alternatives and to reduce all IMO regulated emissions through this technology. The project has led to full scale conversion projects by the shipping company Stena which was intimately a part of the SPIRETH –project (Ellis et al 2014).

4.6 Comparison and review

Most of the feasibility and economic studies have been made with only SCR in mind. This is mostly because it is the most widely used NO_x abatement technology both in shipping and in land applications. SCR technology has existed for decades and as such was the main technology even in the MEPC's technology review and quoted as: "SCR can meet the Tier III limits as a sole emission reduction strategy for most, if not all, marine engines and vessel applications." (IMO 2013a).

One of the main problems with SCR is the additional space requirements in the engine room created by the need to have storage for the reduction agent and the catalytic exhaust after treatment installed in the exhaust stack. In addition to the space requirements the SCR system also adds a lot of complexity into the engine supporting systems and therefore more operating and maintenance costs.

Exhaust gas recirculation works well on slow speed 2-stroke engines and when packaged with water based reduction technology has great potential as an abatement solution. It has not been as extensively studied or seen as much marine operation as SCR and more work is required for it to work on a broad enough spectrum of marine engines. The more simple construction and lack of a reducing agent compared to SCR makes it a compelling technology for many operators even though in some engines there is a minor fuel consumption penalty.

LNG is the supreme solution in the long term in terms of cost and emission reduction potential in all notable aspects: NO_x, SO_x, PM and GHG (greenhouse gas). LNG is the ideal packaged solution for emission reduction in short sea shipping in the Baltic and The North Sea, because it complies with all upcoming emission regulations. LNG engine technology is also widely available from several suppliers with choices between several different types in either Dual Fuel arrangement for fuel flexibility or mono fuel solutions for simplicity. The problems compared to other technologies include the lack of possible drop in fuels, initial capital investment and onboard storage on longer voyages compromises cargo carrying capacity when using cylindrical storage.

As noted previously the water based reduction technologies do function quite well and have seen years of marine operation. The main problems with this type of reduction method is that it is incapable of reaching the levels of NO_x reduction needed for Tier III compliance. It is therefore a subsidiary method which can be used in conjunction with the other technologies to reach amiable emission reduction.

Alternative fuels such as biofuels, methanol and DME certainly have a large part to play in the emission reduction solutions of the future. Some functioning pilot programs and retrofits are already in operation. There is still a definitive need for further development of the technology and infrastructure associated with these fuels and engines before they can be regarded as operational off the shelf technology for marine NO_x Tier III abatement. They are the biggest clean fuel alternative with reserves that can be created from biomass without reliance on fossil fuels.

5 INTERVIEWS

For this thesis I conducted a qualitative research interview with experts in the field of NO_x abatement. Requests for interviews were sent to several experts including: Juha Kalli (formerly CMS), Dr. Tapani Stipa (The Baltic Institute of Finland), and Sari Repka (CMS), all of which have published or co-written research studies on NO_x abatement technology and NECA impact studies. Interview requests were also sent to Hermanni Backer, a professional Secretary of The Baltic Marine Environment Protection Commission (HELCOM) and the Advisor Responsible for Environmental issues at The Finnish Shipowner's Association (FSA), Christina Palmén. The only positive responses to the interview requests were received from Hermanni Backer and Christina Palmén from HELCOM and FSA respectively.

These experts were chosen to participate in the study because of their experience, insight, privileged access and special knowledge in the field of NO_x abatement and regulation especially in the Baltic region. The Finnish Shipowner's Association was also elected to participate to get more insight into their views on the possible effects of the regulation on Finnish shipping. The lack of responses to the qualitative research interview made answering some of my research questions challenging. It can be concluded that the research failed to yield any responses that could be regarded as actual expert opinions in the field of study due to the lack of participants. The respondents are nevertheless part of organizations which have an effect upon the Baltic NECA issue in the future and as such have inherent value as insight into the inner workings and goals of their respective employers.

5.1 The Finnish Shipowners Association – Christina Palmén

Christina Palmén is the Advisor Responsible for Environmental issues at Finnish Shipowner's Association and has a Bachelor's Degree in Marine Technology from the Åland University of Applied Sciences. She was chosen for this research study to get a perspective from someone representing the ship owners of Finland and because of her expertise on environmental issues.

The view of Christina Palmén is that that the shipping industry only generates a very small part of the NO_x emissions in the Baltic Sea and the infrastructure and technology for NO_x abatement still needs more time for research and development. The FSA supports actions for eutrophication prevention and NO_x abatement in the Baltic Sea but wants to also emphasize the participation of all sectors, not just shipping. The main focus should be on minimizing large nutrient loads and to keep in mind that shipping only creates ~1.5 % of the whole nitrous load in the Baltic Sea.

The Shipping industry sees it as paramount, both for minimizing the nutritional load in the Baltic Sea and for the competitiveness of shipping in the Baltic, that the North Sea is also designated as a NECA simultaneously. Regulations regarding IMO special areas should be based on Economic impact and benefit assessments.

Any possible NECA application should be done in co-operation with all the countries surrounding the Baltic Sea and it is also good to keep in mind that The Russian Federation is the party which made the application for postponing the Tier III regulations, with implications that satisfactory technology is still not available.

Not enough experience with NO_x abatement on board ships is available. The shipping companies with SCR installations on board their ships have run into major problems. The biggest questions arise from the fact that the main engines always have to be run on full loads and “slow steaming” is not possible. Urea must be used as a reduction agent, the side-effect of which is “ammonium slip”. There is also lack of proof about using scrubbers and catalytic reduction in the same exhaust line.

The decision made in IMO’s MEPC-66 meeting in the spring regarding Amendments to regulation 13 are in line with The Finnish Ship Owners associations views and can be seen as a good compromise concludes Palmén (Personal communication: September 30th 2014).

5.2 HELCOM – Hermanni Backer

Mr. Hermanni Backer is a Professional Secretary at HELCOM and has an MSc in Marine Ecology from The University of Helsinki. He has notable experience in Baltic research as both a Project Manager and a researcher at HELCOM before he got his position as a Professional Secretary. He was chosen for this research interview for his intimate knowledge of the NECA application proceedings and involvement in environmental research studies within HELCOM, regarding the Baltic Sea.

According to Backer the application for a Baltic NECA has been technically ready since HELCOM Helsinki Commission Meeting 33/2012 which was held in Helsinki on 6.-7.3.2012.Mr. Backer thinks the Baltic NECA application would have stronger arguments if there was a parallel application from the OSPAR members in the North Sea. That being said he also points out that the nutrient pollution problem arising from NO_x emissions is not the same as in the Baltic and there is an argument to be made for a Baltic NECA application even without the participation of The North Sea states.

When asked about feasible NO_x abatement technologies and possible problems with their implementation Mr. Backer denotes that off the shelf technology exist and this has been shown in several studies. Backer is of the opinion that SECA regulation which is going to be implemented in 2015 can be positively linked to NECA regulation by promoting LNG and other alternative fuels which also reduce NO_x emissions.

Regarding the Baltic eutrophication issue Backer thinks it should be noted that shipping in the Baltic is the source of over 13000 tons of airborne nitrogen deposited to the sea annually, close to the total contribution of all land based airborne emissions in countries like Russia or Sweden. This means that NO_x emissions from shipping are not a negligible source of nutrient pollution. If the Baltic Sea would be established as a NO_x ECAs it is expected to reduce Nitrogen pollution of the Baltic Sea by around 7000 tons annually (i.e. half the airborne load of Sweden).

According to Backer, in terms of equal treatment under law it is a reasonable claim that also shipping should contribute to the reduction of this significant source of nutrient pollution to the Baltic Sea. Municipalities (e.g. large investments in St. Petersburg) and even private persons (e.g. holiday home and leisure boat owners in Finland) have already invested large sums in technologies to reduce nitrogen and phosphorous loads (Personal communication: October 9th 2014).

5.3 Analysis

The opinions voiced by Palmén have a very distinct resemblance to the statements made by the Russian Federation in the MEPC document 65/4/27. At a glance they seem very much identical. She uses the same arguments and reasoning as the Russian Federation did while trying to postpone the implementation date of the entire MARPOL Annex VI Tier III regulation. The very same arguments of ammonium slip and ‘major problems’ which were debunked in by the MEPC document 66/6/6 (IMO 2013c) and also by the engine manufacturers who are a part of the International Association for Catalytic Control of Ship Emissions to Air (IACCSEA) (Briggs et al. 2014). All the problems with SCR stated by Palmén can and have been addressed by proper planning, operation and maintenance.

The statements made about the readiness of the Baltic NECA application by Mr. Backer can be easily verified through the very detailed and informative HELCOM documentation of the entire background of the Baltic Sea NECA process (HELCOM 2013).

The interviewees seem to disagree on the points regarding abatement technology readiness but seem to be in agreement on the fact that any Baltic NECA application should be done in unison with the North Sea states. This can be concluded to be accurate because of the capital and operational savings derived from a larger geographical area with the same emission regulation. This also minimizes the skewing of competition in the shipping market in Northern Europe.

6 DISCUSSION AND CONCLUSIONS

The Nitrous oxide emission regulation seems to be a dividing issue within Northern Europe. The future of a Baltic NECA is nothing if not uncertain, even though the regulation now exists and technological readiness has been established by several studies. When going through both economic and environmental impact studies the net benefits of regulation and more stringent emission reductions seem to clearly outweigh any operational or capital costs.

The regulation has been postponed and it's very unclear when and how it will be applied to The Baltic Sea are. All this depends on the HELCOM member states and very tangibly on Global politics of The Russian Federation. The ultimate responsibility now rests with flag states, regulations exist but the Baltic NECA application and implementation needs a continued effort on behalf of the countries surrounding the Baltic Sea. International bodies like HELCOM in the Baltic Sea and OSPAR in the North Sea Area are vital in the process of protecting the marine environment.

A clear difference can be seen between the views of the respondent in the research interviews conducted for this study. It could be said that the opposite ends of the argument can be found in their answers. Christina Palmén of the Ship-owners association points out that the shipping industry is not a major source of pollution and thinks the issue should be resolved with a bigger focus on other sectors. The views on the feasibility and availability of NO_x abatement technology also differ very clearly: Backer expresses a view that "off the shelf technology" exists and this has been shown in several studies and Palmén on the other hand cites only problems associated with the technology. Both the FSA and the Russian Federation seem to disagree with this point categorically regardless of data to the contrary.

Like The Russian Federation stated the whole technological review process of the NO_x regulation by the correspondence group at the MEPC and its member states is wholeheartedly based on SCR as a cornerstone for abatement. This, although true, cannot be seen as a good argument against the implementation of the regulations since none of the problems with said technology actually create problems big enough for postponement. LNG as fuel is in most engine types Tier III compliant and when this method is used for abatement all the economic cost estimates made are for SCR and can be seen as pessimistic in comparison.

Compared to land based transportation even the Tier III NO_x abatement regulation is in no way strict. The Economic impact is also gradual because it only affects new tonnage built after the NECA is implemented so the same arguments which were used against SECA implementation cannot be seen as relevant.

There has not really been any big commitments made in the building of a LNG terminal or pipeline infrastructure in the Baltic compared to the effect of the NO_x tax fund has had in Norway. The operators with significant investments into NO_x compliant vessel technology in Finland is Viking Line and Containerships. Containerships has made orders of 4 new Dual Fuel LNG vessels with a future target of 8-10 vessels in operation.

Based on the research done I’ve come to the conclusion that even though the regulation itself is de facto postponed in the Baltic Sea and the North Sea for now it is the undeniable future. Shipping companies intent on surviving the next decades of shipping better invest in technology and know-how now before it’s too late. The smartest and most ecological way to be both SECA and NECA compliant is to invest in LNG based main engine technology, either Dual fuel or single fuel engines.

The sulfur directive has hit the sector hard and the economic impact of Tier III regulation is negligible in comparison and also gradual because it only affects new tonnage built after the implementation date of a NECA. The view of the FSA is that the shipping companies are not willing to make large capital investments in the near future because of the financial burden created by the sulfur regulation implementation in 2015.

National measures and economic instruments have to be used for NO_x emission control until the point in the future when the Baltic NECA implementation is feasable. Different shipping companies are taking different routes to air pollution prevention. Norway and its NO_x fund are choosing alternative fuels in the form of LNG and Stena RoRo in Sweden is taking the methanol approach. Stena is full scale converting its SECA fleet into methanol-diesel operation in increments and the same technology easily makes the vessels Tier III compliant when the need arises.

6.1 Assessment

I had begun my research with the working hypothesis and presumption that the Baltic NECA implementation in 1.1. 2016 was assured and the only matter at hand was to choose the best compliant technology for new buildings. This is what got me interested in the abatement technology and made me wonder how the shipping companies were actually preparing for this future in the Baltic Sea after all the economic challenges and big changes caused by the similar SOx regulation. All this changed of course when in the course of my research the amendments to the Annex VI were accepted at MEPC 66 which effectively postponed the Baltic NECA into the unforeseeable future. This led me to slightly change the objectives of my research to what is now contained within this thesis.

I feel that the thesis was a success in the fact that throughout the process my understanding on the issue of NO_x emission regulation grew immensely. My understanding of the technology involved in the abatement of Nitrous oxides and all the possibilities of alternative fuels are on a completely different level than before. I also now have a greater view on how the IMO processes new amendments and the amount of politics involved in everything. All in all the process of creating this document has been very rewarding and taught me a great many things.

The qualitative research interview conducted for this thesis cannot be seen as a successful endeavor since it failed in many aspects. My choice of conducting the interviews by e-mail did clearly not pique enough interest or credibility in the respondents to make them willing to participate in the interview. I think my choice of experts for these interviews were reasonable but the biggest shortcoming was that none of them actually answered my requests for participation. I think a lot more insight would have been gained if they had.

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APPENDIX I: Interview questions

1. What is your current understanding of the MARPOL 73/78 Annex VI regulation 13 amendments and its implementation in regards to Tier 3 NO_x regulations and a possible Baltic NECA?

2. Are shipping companies actively preparing strategies and operational methods in preparation for more strict NO_x regulation in the Baltic?

3. Is the effect on freight rates going to be significant enough to affect the Finnish Shipping industry in a detrimental way?

4. What kind of action should the Finnish National Government take in NO_x regulation?

5. What kind of economic or technological problems could be encountered with the implementation of a Baltic NECA as of 1.1.2016?

6. What is your view of the economic, environmental and health impacts of NO_x Tier 3 regulation?

7. Describe the current state and next step in the process of application for a Baltic NECA with IMO?

8. What kind of a connection is there between the Baltic NECA application process and a possible future North Sea NECA?

9. Does the 2015 SECA implementation in the Baltic and the North Sea have any effect on NOx regulation and NECA implementations in the Baltic Sea?