Appendix 1 – Participants of the Demo Project

Steering committee

Broström - Mr. Olle Noord (SC) & Mr. Peter Stenberg (TCP)	Sweden
Destination Gotland – Mr. Jan-Eric Nilsson & Mr. Jan-Erik Rosengren	Sweden
P & O Lines - Mr. Mike Ridley	UK
SEAaT (Shipping Emissions Abatement and Trading) - Mr. Don Gregory	UK
Stena Line - Mr. Johan Roos	Sweden
Swedish Ship owners Association (SSA) - Mr. Bertil Arvidsson	Sweden

Primary Stakeholders

Broström

Destination Gotland

P & O Lines

SEAaT

Stena Line

Sponsors

VINNOVA (Swedish Agency for Innovation Systems) – Carl Naumburg	Sweden
Swedish Ship owners Association (SSA) Mr. Bertil Arvidsson	Sweden
Swedish Maritime Administration (SMA) - Mr Stefan Lemieszewski	Sweden
Wallenius Lines – Mr. Per Croner & Mrs. Sara Gorton	Sweden
Biofrienly Ltd – Noel Carroll & Michael T. Carroll	UK/USA

Project management

PricewaterhouseCoopers – Mr. Martin Gavelius and Mr. Ola Hansén

Other project participants

IVL (The Swedish Environmental Research Institute) - Mr. David Cooper,	Sweden
CA Clase – Mr. Mikael Nevohnen	Sweden

Appendix 2 – Schemes, Initiatives and Standards of relevance for the Demo Project

Several existing legislations, proposed legislation, emission trading schemes and other initiatives, standards, standard proposals, etc have relevance to the Demo project (IMO Annex VI to MARPOL, IMO NOx Code[1], prEN 14181[2], Ghg Protocol,etc)

IMO Annex VI to MARPOL

An amendment to Annex VI of the International Convention for the Prevention of pollution from ships has been adopted within the Assembly of the International Maritime Organisation (IMO). Annex VI refers to the Regulations for the Prevention of pollution from ships. In the amendment, limits have been set for NO_x emissions on new diesel engines (with a power output of more than 130 kW installed on ships constructed on or after 1st January 2000). The NO_x emission limits given in g/kWhcorr are evaluated form a curve dependent on engine speed. Secondly, worldwide fuel sulphur will be limited to a maximum of 4,5 wt-% and SO_x emission control areas (SECAs) are introduced where the adoption of mandatory measures for reducing SO_2 will be enforced. In the latter case this can be achieved by either fuel capping at 1,5 wt-% or by exhaust cleaning down to < 6,0 g/kWh.

The aim of the IMO Technical NO_x Code is to specify the requirements for testing, survey and certification of marine diesel engines to ensure that they comply with the assigned limit values.

It should be noted that the Annex VI will apply 12 months after the date when 15 or more states representing 50% of the worlds gross tonnage have signed. Current predictions estimate that it could start to apply from the summer of 2004.

Besides providing a mandatory incentive for emission reductions and stimulating abatement technology, the IMO initiative has relevance to a future EU trading scheme in that it provides harmonised measurement procedure and survey routines.

Swedish Maritime Administration – Environmentally differentiated fairway dues

Environmentally differentiated fairways dues (enforced in Sweden from 1 January 1998) reflect the ships' emissions of NO_x and SO_2. The total level of the fairway dues and cost to shipping in general is unchanged, but a distinction is made so that individual ships using abatement technology pay less and those ships with higher emission levels pay more. For NO_x, the differentiation starts stepwise at 12 g/kWhcorr down to 2 g/kWhcorr and for SO_2, for fuel sulphur contents < 1,0% (< 0,5% for passenger ships). Furthermore the scheme has led to 20 Swedish ports introducing port rebates based on this differentiation.

Measurement and verification procedures have been set up largely following the guidelines within IMO Technical NO_x Code. Besides stimulating the use of abatement technology in general, the scheme has relevance to the proposed trading scheme in that it has successfully demonstrated verification procedures anticipated for use with low sulphur fuel. In addition, although continual NO_x emission monitoring is not specified, the required periodic NO_x certification measurements have provided a "new founded awareness" of NO_x emission testing within the maritime sector.

[1] IMO Technical NO_x Code, (1998) Annex VI to MARPOL 73/78 Regulations for the Prevention of Air Pollution from Ships and NO_x Technical Code. International Maritime Organisation, Report IMO – 664E.

[2] prEN 14181, (2001) 'prEN 14181 - Stationary source emissions – Quality assurance of automated measuring systems'. European Committee for Standardisation. Draft

Greenhouse Gas Protocol Initiative[3]

The mission of the Greenhouse Gas Protocol Initiative (GHG Protocol) is to develop and promote internationally accepted greenhouse gas (GHG) accounting and reporting standards through an open and inclusive process.

Jointly convened in 1998 by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI), the GHG Protocol is a multi-stakeholder partnership of businesses, NGOs, and governments that serves as the premier source of knowledge about corporate GHG accounting and reporting.

This corporate accounting and reporting standard draws on the expertise and contributions of numerous individuals and organizations from around the world. The resulting standard and guidance are supplemented by a number of user-friendly GHG calculation tools on the GHG Protocol website (www.ghgprotocol.org).

Unlike for financial accounting and reporting, there are no ‘generally accepted accounting and reporting practices’ for corporate GHG emissions. The GHG Protocol is a significant milestone on the journey toward generally accepted GHG accounting and reporting practices. It builds on extensive dialogue, which has taken place between diverse stakeholder groups over the last three years; on the road testing of an earlier draft by more than 30 companies in 10 countries; and on extensive peer reviews. It is intended that in the future the GHG Protocol will be revised using feedback from its application.

The standard, guidance, and tools will help companies and other organizations:

- develop a credible GHG inventory underpinned by GHG accounting and reporting principles
- account and report information from global operations in a way that presents a clear picture of GHG impacts, and facilitates understanding as well as comparison with similar reports
- provide internal management with valuable information on which to build an effective strategy to manage and reduce GHG emissions
- provide GHG information that complements other climate initiatives and reporting standards, including financial standards

[3] www.ghgprotocol.org

Appendix 3 Continuous emission monitoring for the marine application

Continual pressure over the past 30 years has been directed to land-based combustion sources to demonstrate regulatory emission compliance. Consequently emissions monitoring equipment for this application has been developed and can now be considered well tested, approved and mature. In a recent survey more than 95% of 250 plant owners (covering ca. emission 375 sources) reported that none or only minor problems occur while monitoring continuously for NOx (Swedish Environmental Protection Agency, 2001). A parallel development has however not occurred within the marine industry. Although emission monitoring methodology has been proposed largely in the IMO Technical NOx Code and much of the land-based equipment and experiences are transferable, the level of approval and long-term operating experience of continual emission monitoring at sea is at present minimal.

The ship's environment is a demanding one with high temperatures, movements and vibration, dust, electromagnetic interference, dripping and spraying of fluids etc. Many smaller ships have very little room for extra equipment and any monitoring devices must use the available space without disturbing normal operation. Thus shipboard continuous measurement system needs to be compact, robust and able to withstand all these potential difficulties. Not least, the acidic character of the sample gas (especially for ships using HFO) can be detrimental to long-term system operation. A recent UK Marine Safety Agency survey among emission monitoring equipment manufacturers indicated however, that their equipment is capable of providing accurate measurements for the marine application and fulfilling safety requirements for marine electrical equipment (Brookman, 1996). Similar views have also been obtained from several Swedish emission monitoring equipment suppliers.

A number of review articles and measurement standards are available in the literature dealing with the different measurement principles for emission monitoring including specific discussions for onboard systems (Brookman, 1996; Herman, 2002; IMO Technical NOx Code, 1998: ISO 8178, 1996; Värmeforsk, 2000). A recent workshop focused on reviewing emissions monitoring technology for use on board ships (BP Emissions Monitoring Workshop, 2002). Several options are available for the type of measurement system and principle used for gas analysis (Table 1). For the purposes of this study, only a few are considered as acceptable on the basis of operating experiences, measurement accuracy and not least recommendations from international standard groups (not least the IMO Technical NOx Code, 1998). To this end, the measurement principles pertinent to this study are outlined in bold blue text in the Table.

As regards measurement strategy, it appears unlikely that a periodic or intermittent measurement strategy can be used for the trading scheme in view of land-based monitoring requirements and increased measurement uncertainty. These options may however be permissible in future IMO guidelines (IMO, 2001).

For NO_x measurements, chemiluminescence is the chosen method in IMO Technical NO_x Code. A clause exists however, stating that "other principles may be used if they are proven equivalent". In addition, one must bear in mind that a variety of chemiluminescence analysers are on the market with significant differences in cost, quality and consequently performance. Other principles for example *NDIR* and *NDUV* for monitoring solely NO present an interesting option. The advantages are that they have a better long-term durability, are cheaper and require less service. The disadvantages are however that NO2 is not measured. Even with a so-called NO2 converter (which form a part of chemiluminescence analysers), long-term operation with high S fuels may lead to rapid deactivation of the converter. NDIR and NDUV may also have possible measurement range difficulties and the principle is not as linear as chemiluminescence. Interestingly, one SCR supplier started with chemiluminescence analysers for steering urea injection in their systems but due to operating problems switched to using NDIR analysers with better results.

The lifetime of the gas analysers and measurement system in general is expected to be ca. 8 - 12 years (for land-based systems). Some evidence suggest a longer life span for NDIR and NDUV analysers in comparison to chemiluminescence analysers.

One of the few published studies for long-term (1 year) NOx monitoring on board a ship (on one main engine) was carried out using a Predictive Emission Monitoring System (PEMS) (Cooper and Andreasson, 1999). In this case measured O2 (using a robust, point in-situ electrochemical probe) was used to indirectly measure NOx. Initially an engine-specific, empirical function (based on engine effect, O2 and ambient parameters as input) was determined through measurements using a conventional NOx analyser. Thereafter the NOx analyser was removed and data from the input parameters used to calculate corrected emissions that were transferred to a land-based office every 24 hours through a modem data communication system. As a check on the system's performance, measurements using the conventional NOx analyser were repeated after 6 months and at the end of the year. A follow-up study to further test this measurement approach is currently in progress. Regarding the present application, PEMS could offer a cost-effective measurement solution that could be applied to NOx monitoring on IEM ships. For SCR however, the PEMS system might be applicable but in a more complex form e.g. other data inputs such as urea flow rate would be required. A disadvantage to consider however is the slightly poorer measurement uncertainty with the technique (ca. 7% for NOx concentration), which strictly speaking renders the technique outside IMO's definition for direct NOx monitoring i.e. that "other principles may be used if they are proven equivalent to chemiluminescence". The main advantages of the system proved to be its robustness, easy calibration (little instrument drift) and significantly lower equipment costs. Furthermore, the method can be considered as "indirect NOx monitoring" which could qualify for the "engine parameter check method" according to IMO Technical NOx Code for demonstrating compliance.

Table 1 Basic principles for continuous emission monitoring

Measurement stategy	
Periodic or certification measurements	Short-term measurements (ca. 1 hr) at a specific engine load carried out by external measurement consultant. Measurement frequency ca. every year or longer. Adopted in IMO Technical NOx Code for verifying compliance by so called confirmatory measurements.
Intermittent measurements	Emission monitoring equipment used on board for routine checks of emission levels at steady state engine load levels. Possibly daily or other prescribed time interval.
Continual measurements	**Emission monitoring system used continuously during all times of engine operation.**
Gas sampling principle	
Extractive	**Sample is extracted via a multipoint probe over the channel cross section and then transported via a heated gas line for analysis. Prior to concentration measurement in gas analysers, the gas is dried (cooled) and filtered (gas conditioning system).**
Extractive dilution	As above, but the sample gas is diluted with air at the sample probe and thus eliminating the need for gas conditioning prior to analysis.
Path In-situ	Gas analysis occurs directly over the entire

	cross-section of the exhaust channel.		
Point in-situ	Gas analysis occurs in the exhaust channel at a fixed, "representative" point.		
Remote Sensing	Gas analysis occurs by an optical analysis of the exhaust plume from a remote site.		
Gas analysis principle	NO_x	SO_x	CO_2
Chemiluminescence	**X**		
Electrochemical sensors	X	X	
Non-dispersive ultraviolet (NDUV)	(X)	**X**	
Non dispersive infrared (NDIR)	(X only NO)	**X**	**X**
Pulsed UV Fluorescence		**X**	
Fourier Transform Infrared (FTIR)	X	X	X

The IMO Technical NOx Code prescribes an extractive measurement system using a multi-hole gas probe. Gas analysis shall be accomplished by chemiluminescence (wet or dry gas) for NOx and infrared (dry gas) for CO2. The corresponding recommendation for SO2 has not been covered in either the Technical NOx Code or ISO 8178 fully, since gaseous SO2 is normally indirectly calculated from the fuel sulphur content. In ISO 8178 however; SO2 measurements are necessary for aftertreatment systems (e.g. scrubbers) but "since SO2 measurement is a difficult task and has not been fully demonstrated for exhaust measurements, prior agreement of parties is involved". Generally NDIR systems are cheaper but suffer from interference and require an extremely dry sample gas.

Recently within the IMO, group work has commenced on providing guidelines for on board NOx measurements including continuous monitoring (IMO, 2001). At present four different proposals (Japan, Panama USA, and EUROMOT) have been put forward. The development of this work should be followed and considered in the eventual monitoring equipment used in the future emission trading system. International consensus within IMO on reaching recommendations for continuous NOx monitoring will probably however take time.

It should be noted that, many new sensors types (especially electrochemical and solid state in-situ sensors, but also laser technology) are under development and may in the future enable monitoring at a reduced cost and improved measurement uncertainty (Herman, 2002). The development of emission monitoring sensor technology for diesel engines is also stimulated by upcoming regulations requiring onboard measurements on heavy goods vehicles.

Appendix 4 Marine emission abatement technology

Several reviews have been written on NO_X and SO_2 emission formation from marine diesel engines and the available abatement technology (Trozzi and Vaccaro, 1998; Klokk, 1997; Kågeson, 1999; IMO, 2000; Davies et al., 2000; Farrell, 2002). Long-term operating experience of marine emission abatement and the number of options available are more limited than for land-based emission sources. Development in this field is however progressing. Most reports covering abatement technology performance on board specific ships are, either restricted or represent single certification measurements at a specific engine load. Long-term experience and real-world emission performance data is still lacking for most of the abatement techniques.

An overview of the abatement technology considered as applicable to ships is presented in Table 1. Of the techniques presented, SCR and IEM have probably had the greatest impact so far regarding abating NO_X emissions, while for SO_2 the use of low-sulphur fuels has been very significant in the past decade. With increased incentives through legislation calling for maritime emission reductions at local and regional levels (Swedish Maritime Administration, 1998) and also customer demands, a greater use and development of abatement technologies is foreseen.

Table 1 Basic principles for marine emission abatement

NO_x abatement technology	
Selective Catalytic Reduction (SCR)	40% urea solution is injected into the exhaust gas channel as a fine mist. A reduction catalyst downstream of the injection point enables the ammonia (from decomposed urea) and NO_x to react forming N_2 and H_2O. High reduction efficiency can be achieved and long-term marine experience is available. Some units have an additional oxidation catalyst to remove small quantities of unwanted ammonia slip (back to NO_x) and reduce hydrocarbon emissions.
Internal Engine Modifications (IEM)	Usually involves the re-optimisation of normal engine components during engine development to include low NO_x in the list of demands. Involves optimisation of injection timing, fuel injector geometry and characteristics (e.g. so-called slide valves), compression ratio, combustion chamber shape, air excess ratio, air swirl and charge air cooler. Also additional features like pre-injection and exhaust gas re-circulation (EGR). Delayed injection is a simple measure to quickly achieve NO_x-reduction but usually leads to higher fuel consumption and increased thermal load on exhaust components.
Humid Air Motor (HAM)	Heat losses from the turbocharger cooling system is used to evaporate seawater to provide clean water vapour in the engine charge air. Shown to be cost-effective with 70 – 80 % NO_x reduction. Few long-term installations tested however.
Water injection into combustion chamber	Requires rebuild of engine and injection of freshwater into combustion air at the cylinder inlet. A water/ fuel ratio of 0,3 – 0,4 has reported to give 20 – 40% reduction without “significant” fuel consumption penalties.
Fuel / water emulsion	As in all water additive techniques, the combustion temperature is reduced and thereby NO_x formation is limited. Water premixed with the fuel in an emulsion can achieve this. Corrosion problems are the main concern thus

	switching to 100% fuel is usually required for engine stops and starts.
SO_2 abatement technology	
Low sulphur fuel	Substituting residual oil fuels for lighter distillate grades such as marine diesel oil or gas oil with lower fuel sulphur content. Also possibility of using heavy fuel oils previously desulphurised. Imposes increased fuel cost compared to residual oils. Can require separate fuel tanks and lubricating oil systems for dual fuel engines. Low sulphur fuel usually gives benefits for engine maintenance time and repairs.
Flue gas desulphurisation (FGD)	By using the natural alkalinity of seawater, SO_2 in the exhaust channel can be removed efficiently by using scrubbers. Few long-term installations tested.

In addition to the techniques above, several fuel additives are marketed as a way to reduce the NO_X and/or SO_2 emissions, the additive “Green Plus” marketed by Biofriendly Ltd. The additives have been tested on several ships (however not within the scope of the DEMO Project[1]).

[1] PricewaterhouseCoopers and IVL have not made any evaluation regarding the performance of these additives. Consequently no the opinion on the performance of these additives is expressed in the report.

DEMO Project - Phase 2 Emission Reporting Test

The test started March 26, 2004 and was terminated at June 24, 2004.
NOx reductions monitored during test were **144366** kg.
This application has been made available by Öhrlings PriceWaterhouseCoopers, Stena Line, CA Clase and HiQ.
Note: GMT currently corresponds to CET -2 hours e.g. 9:30 GMT = 11:30 current time in Sweden.

Show: the latest 24 h **Display details:** ☑ Main Engine 1 (ME1) ☐ ME2 ☐ ME3 ☐ ME4

	Date	GMT Time	Ship	Total Accumulated Reduction (kg NOx)	Latitude	Longitude	ME1 avg load	ME1 energy(kWh)	ME1 actual emissions(kg NOx)	ME1 baseline emissions(kg NOx)	ME1 created reduction(kg NOx)	ME1 accumulated reduction(kg NOx)	ME2 avg load	ME3 avg load	ME4 avg load
1	2004-06-24	12:51:29	Stena Jutlandica	144366	5742 N	1155 E	74%	4795	9.6	61.1	51.5	47809	74%	1%	0%
2	2004-06-24	11:51:25	Stena Jutlandica	144262	5735 N	1130 E	64%	4147	8.3	52.8	44.5	47757	88%	1%	74%
3	2004-06-24	10:51:24	Stena Jutlandica	144104	5728 N	1057 E	55%	3564	7.1	45.4	38.3	47713	75%	1%	67%
4	2004-06-24	09:51:22	Stena Jutlandica	143967	5726 N	1032 E	14%	907	1.8	11.6	9.7	47674	14%	1%	10%
5	2004-06-24	08:51:19	Stena Jutlandica	143940	5725 N	1035 E	90%	5832	11.7	74.3	62.6	47665	90%	1%	84%
6	2004-06-24	07:51:15	Stena Jutlandica	143755	5731 N	1110 E	93%	6026	12.1	76.8	64.7	47602	92%	1%	18%
7	2004-06-24	06:51:11	Stena Jutlandica	143613	5737 N	1140 E	56%	3629	7.3	46.2	39.0	47537	56%	1%	0%
8	2004-06-24	05:51:11	Stena Jutlandica	143534	5742 N	1156 E	21%	1361	2.7	17.3	14.6	47498	22%	1%	0%
9	2004-06-24	04:51:08	Stena Jutlandica	143504	5741 N	1152 E	72%	4666	9.3	59.4	50.1	47484	74%	1%	0%
10	2004-06-24	03:51:06	Stena Jutlandica	143402	5734 N	1127 E	93%	6026	12.1	76.8	64.7	47434	92%	1%	56%
11	2004-06-24	02:51:03	Stena Jutlandica	143233	5728 N	1053 E	67%	4342	8.7	55.3	46.6	47369	66%	1%	59%
12	2004-06-24	01:51:01	Stena Jutlandica	143099	5726 N	1032 E	22%	1426	2.9	18.2	15.3	47322	23%	19%	18%
13	2004-06-24	00:51:00	Stena Jutlandica	143042	5725 N	1040 E	93%	6026	12.1	76.8	64.7	47307	92%	82%	87%
14	2004-06-23	23:50:56	Stena Jutlandica	142795	5732 N	1116 E	90%	5832	11.7	74.3	62.6	47242	87%	35%	61%
15	2004-06-23	22:50:53	Stena Jutlandica	142605	5740 N	1147 E	35%	2268	4.5	28.9	24.4	47180	33%	1%	-1%
16	2004-06-23	21:50:51	Stena Jutlandica	142558	5742 N	1156 E	24%	1555	3.1	19.8	16.7	47155	21%	1%	-1%
17	2004-06-23	20:50:50	Stena Jutlandica	142527	5741 N	1152 E	86%	5573	11.1	71.0	59.9	47139	83%	69%	69%
18	2004-06-23	19:50:47	Stena Jutlandica	142313	5732 N	1121 E	93%	6026	12.1	76.8	64.7	47079	91%	82%	86%
19	2004-06-23	18:50:44	Stena Jutlandica	142068	5726 N	1045 E	50%	3240	6.5	41.3	34.8	47014	49%	43%	43%
20	2004-06-23	17:50:44	Stena Jutlandica	141939	5726 N	1032 E	16%	1037	2.1	13.2	11.1	46979	18%	14%	13%
21	2004-06-23	16:50:43	Stena Jutlandica	141897	5725 N	1037 E	94%	6091	12.2	77.6	65.4	46968	92%	10%	87%
22	2004-06-23	15:50:42	Stena Jutlandica	141700	5732 N	1112 E	94%	6091	12.2	77.6	65.4	46903	92%	1%	69%
23	2004-06-23	14:50:38	Stena Jutlandica	141522	5739 N	1144 E	46%	2981	6.0	38.0	32.0	46837	46%	1%	0%
24	2004-06-23	13:50:37	Stena Jutlandica	141457	5742 N	1156 E	15%	972	1.9	12.4	10.4	46805	15%	1%	0%

Appendix 6 - Costs associated with emission monitoring at sea

The incentive to implement emission abatement and undertake continual emission monitoring will be a reflection of the value of the emission reduction credits or allowances that may be marketed. One must also bear in mind the background "costs" of not implementing any form of abatement voluntarily. To make emission trading an attractive proposal, the cost of abatement and monitoring should be substantially smaller than the gains through the market value of the verified emission reductions. Consequently a critical aspect of this project will be a cost assessment of all influencing factors over a given life-time. With this in mind, the costs associated only with emission monitoring for a case study are outlined in Table X. The costs are very approximate especially for installation, external calibrations and external confirmatory measurements which can vary significantly. These costs are however based on interviews with monitoring equipment suppliers, engine manufacturers and on actual operating experiences gained with the systems. For example, the annual cost for operation, maintenance, data collection and data handling of automatic NO_x measuring systems among Swedish land-based systems has been estimated to 100 kSEK per system but with considerable variation (Swedish Environmental Protection Agency, 2001). Note that costs dealing with the purchase of and maintenance of the abatement technology, are excluded and also the external verification audit. The minimum column (8 engine ship) for external effect/fuel calibration assumes a 12-month interval (80 kSEK per calibration) and for external confirmatory measurement a 24-month interval costing 100 kSEK per measurement. For the maximum column (8 engine ship) the corresponding values are 3 months at 150 kSEK and 12 months at 200 kSEK.

Table 1 Estimate of costs (SEK) associated with emission monitoring over a 10 year period (expected life time of monitoring system)

	Ship with SCR, 8 engines		Ship with IEA on 1 Main engine	
	Min	Max	min	Max
Investment cost of 1 complete measurement system (with switching), 15m between sampling point and gas analysers.	680	850	450	600
Installation cost	100	400	50	100
Internal maintenance, calibration tubes, data handling, reporting etc.	700	1700	500	1500
External effect and fuel cons. Calibration	800	6000	600	5000
External confirmatory emission test	500	2000	400	1600
TOTAL for 10 yr period	2780	10950	2000	8800
Ca. COST per yr	300	1100	200	900

IVL report

IVL Swedish Environmental Research Institute

APPENDIX 7
FINAL DEMO Project report

FOR PRICEWATERHOUSECOOPERS

U 826

Continual NO_x emission monitoring on board *Manon* and *Stena Jutlandica*

David Cooper and Eje Flodström 2003-08-21

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RAPPORTSAMMANFATTNING
Report Summary

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Rapportförfattare/author

David Cooper and Eje Flodström

Rapportens titel och undertitel/Title and subtitle of the report

Continual NO_x emission monitoring on board *Manon* and *Stena Jutlandica*

Sammanfattning/Summary

IVL Swedish Environmental Research Institute Ltd. has carried out continual NO_x emission monitoring on board two ships equipped with NO_x reduction abatement technologies. The study was aimed to provide a practical demonstration of the feasibility of using continual emission monitoring to determine marketable NO_x emission reductions at sea.

Firstly, measurements were undertaken on the Pure Car/Truck Carrier, *Manon*, on a 17-hr voyage from Malmö (Sweden) to Drammen (Norway) during 18th-19th July, 2003. The low-NO_x slide fuel valves installed on the main engine of *Manon* were shown to achieve a marketable NO_x reduction of 660 ±106 kg NO_x for the test voyage within EU waters (based on a general baseline methodology set at the IMO NO_x emission limit curve, i.e. 17 g/kWh_{corr}).

The second demonstration was performed on the passenger ferry, *Stena Jutlandica*, for six 3 hr 15-min crossings each between Gothenburg (Sweden) and Fredrikshavn (Denmark) during 13th-14th August, 2003. The ship is equipped with Selective Catalytic Reduction (SCR) on all diesel engines for reducing NO_x emissions. In this exercise, a multi-engine measurement system was used to follow the NO_x emissions from main engines 2 and 4. For the two engines studied, a marketable, “real” NO_x reduction of 1737 ± 347 kg NO_x for the six voyages was determined (based on a ship specific baseline methodology i.e. separate measurements on the engines without SCR in operation).

In general, the measurement equipment and calculation routines outlined in the Phase 1 draft report of this project (the DEMO Project) were shown to be suitable on board the two measurement ships.

Nyckelord samt ev. Anknytning till geografiskt område eller näringsgren/Keywords
Ship emissions, NO_x, continual emission monitoring, marketable reduction

Bibliografiska uppgifter/Bibliographic data

Arkivnr U-826

Contents

1 Introduction

1.1 Background

PriceWaterhouseCoopers AB have initiated a multi-phase project financed by several stakeholders in the shipping industry aimed at demonstrating that monitoring and verification of nitrogen oxides (NO_x) emission reductions and sulphur dioxide (SO_2) emission reductions from ships are feasible. In turn, the Swedish Environmental Research Institute has been contracted to outline suitable shipboard emission measurement techniques and calculation routines (Phase 1), and secondly to provide a practical demonstration at sea (Phase 2). Thus this work (Phase 2a) focuses on the first emission monitoring exercises in the project, on board two ships using two different kinds of NO_x abatement methodology.

1.2 Objective

The objective of these measurements was to demonstrate the functionality of the measurement equipment and methodology suggested in the draft Phase 1 report (Hansén *et al.*, 2003) for two ships using two different types of NO_x abatement technology. Specifically, the work focuses on determining the marketable[1] NO_x emission reductions for the ships during typical voyages.

2 Methodology

2.1 Technical ship data

Technical data for the measurement ships are presented in Table I.

Table I Technical data for the measurement ships

Ship name	***Manon***	***Stena Jutlandica***
NO_x abatement technology	low-NO_x fuel slide valves on ME	SCRs on all 8 diesel engines
Length and width, m	199,1 x 32,3	184 x 28
Dead-weight, tonnes	22 526	6 300
Int. GRT, reg. t	57 018	29 691
Pass./ car capacity	5 850 cars	1500 / 550
Engines	1 ME and 2 AEs	4 MEs and 4 AEs
Service speed, knot	19	21,5
Year of delivery	1999	1996
Main engines (ME)	Hanjung MAN B&W 8S60MC, 14710 kW (2 stroke slow speed diesel)	MAN B&W 9L 40/54, 6480 kW (4 stroke medium speed diesel)
Auxiliary engines (AEs)	Wärtsilä 4R32LNE, 1 620 kW (4 stroke medium speed diesel)	MAN B&W 8L 28/32H, 1740 kW (4 stroke medium speed diesel)
Fuel type	ME use Heavy Fuel Oil (HFO/IF380) AEs use Marine Diesel Oil (MDO/DMB)	MEs and AEs use Low Sulphur Heavy Fuel Oil (HFO/IF180)

2.2 Measurement site

Measurements on board *Manon* were carried out on the ME using a sampling hole (2½” size) at deck level 6. Gas analysers were located in the engine room, ca. 4 m below the sample hole at deck level 5 (see Figure 1). ME measurements were made during the 17-hr voyage from Malmö to Drammen (departure 22:00 18th July, arrival 14:40 19th July). The weather conditions during the voyage were favourable; little swell, light winds, and air temperature of ca. 20 – 25 ^{o}C.

[1] In this report the word “marketable emission reduction” is used in the sense that in a potential future emission trading system (or other market based instrument) the achieved emission reduction (achieved emission level below an assigned baseline), will after third party verification have an economic value to the ship owner.

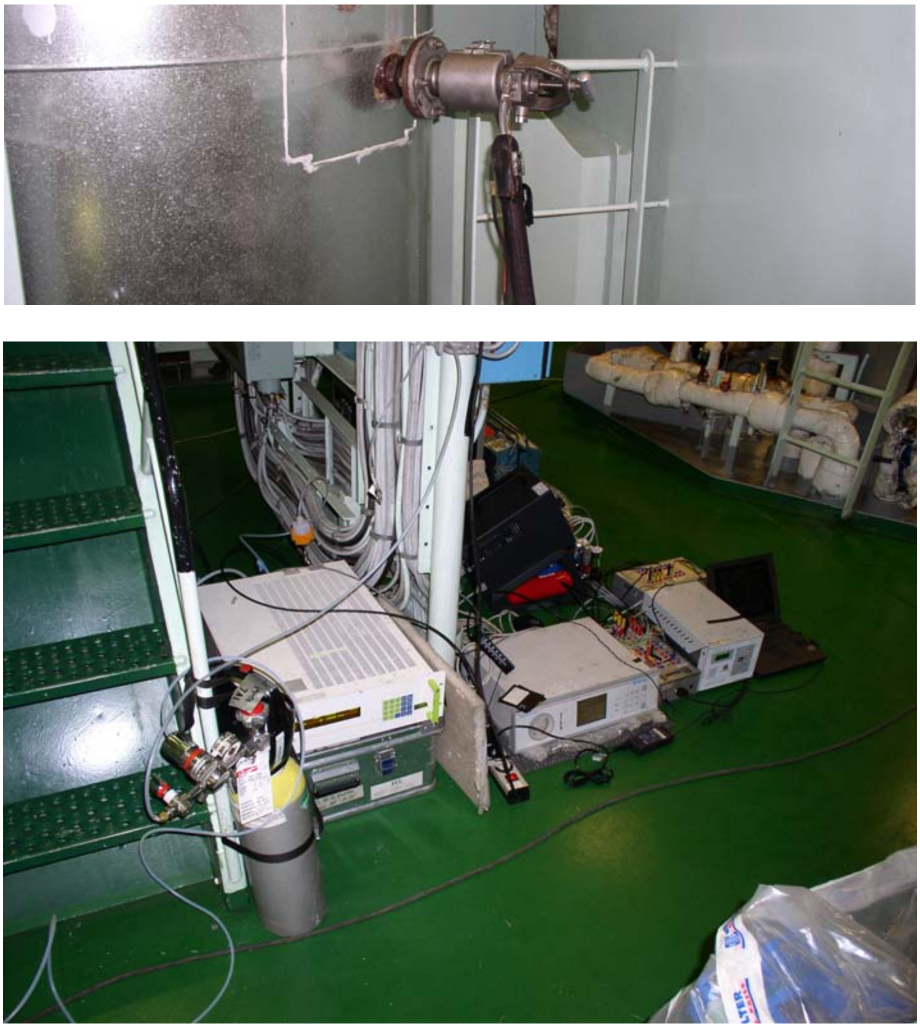


Figure 1. Measurement equipment set-up on board *Manon*.

Measurements on board *Stena Jutlandica* were carried out on ME2 and ME4 using sampling holes (2½ " size) at deck level 8 and in the starboard engine casing. By using two gas probes and heated lines and a valve switching system at the gas conditioning system, exhaust gas was sampled every 6 minutes in turn from each engine. Gas analysers were also located in the engine casing, ca. 10 m below the sample holes at deck level 7 (see Figure 2). Due to a malfunction of a cooling fan on the starboard side and the relatively high ambient temperatures in the casing (35 – 46 ^oC), the gas conditioning system was periodically lifted out on deck to avoid over heating. The measurements were made during six 3 hr 15-min voyages between Gothenburg (Sweden) and Fredrikshavn (Denmark). The total measurement period was ca. 24 hours; from the Fredrikshavn departure at 11:50 13th August, to the arrival in Fredrikshavn at 11:15 14th August. The weather conditions during the voyage could be characterised by little swell, light winds, but air temperatures of up to 28 ^oC and occasional rain showers.

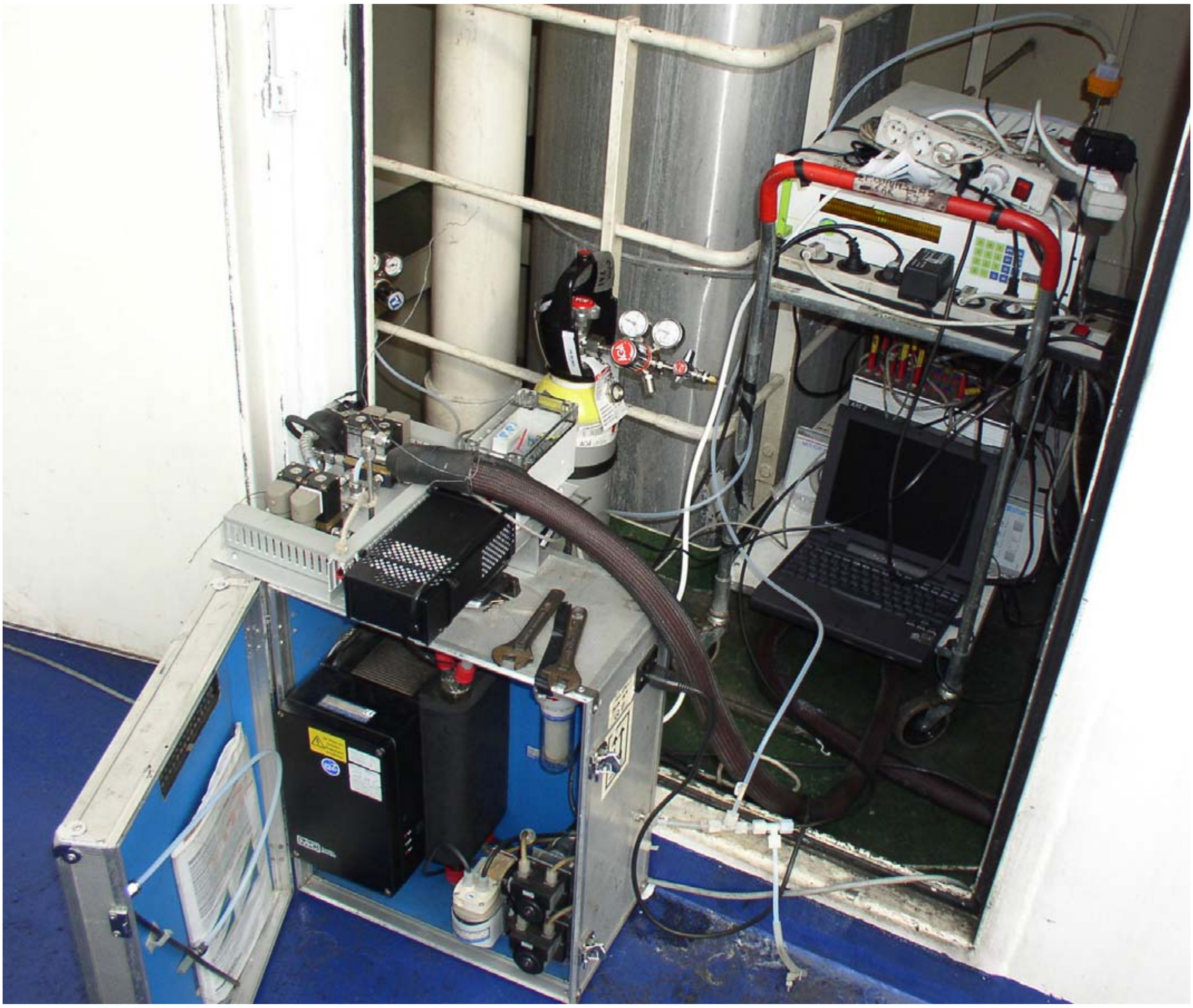


Figure 2. Measurement equipment set-up on board *Stena Jutlandica*

Normal engine operation occurred for all voyages except on board *Manon* where a 75% engine load set-point was required for ca. 2 hours (from 00:30 to 02:30 on 19th July). Since this represented no significant deviation from normal operation it has very little effect on the total marketable NO_x emission reduction measured.

2.3 Measurement parameters and techniques

A summary of the six primary measurement parameters (in red) and constants used (in blue) in the emission calculations are presented in Table II.

Table II Measurement parameters and constants, techniques and instrumentation

Parameter	Technique
NO_x ($NO + NO_2$), *NO_x in dry ppm*	Ecophysis CLD 700EL, chemiluminescence (continual) [1)]
CO_2, *CO2D in dry vol-%*	Maihak Multor 610, infra-red (continual) [1)]
Barometric pressure, *pB in kPa*	Vaisala PTB 101B barometer (periodic)
Air temperature at engine intake, *Ta in deg K*	Testo 600 thermometer (periodic)
Rel. Humidity at engine intake, *Ra in %*	Testo 600 hygrometer (periodic)
Engine load, *P in kW*	From ship's instrumentation (fuel pump index) (continual if possible)
Fuel carbon content, *BET in wt-%*	Default value of 86,7 %
Fuel heating value, *LHV in MJ/kg*	Ship fuel analysis certificate; 40,44 (*Manon*) and 41,7 (*Stena Jutlandica*)
Charge air temperature, *TSC in deg K*	Ship instrumentation (periodical); 313 (*Manon*), 321 (ME2 *Stena Jutlandica*), 323 (ME4 *Stena Jutlandica*)
Ref. charge air temperature, *TSCref in deg K*	From engine manufacturers;); 308 (*Manon*) and 314 (*Stena Jutlandica*)

[1)] Uses an extractive measurement system (stainless steel multi-hole probe, 10 m heated line, gas conditioning system) where concentrations were analysed in the dry sample gas.

Unfortunately, on *MV Manon* a continual measurement of the engine load could not be arranged in time for the measurements. An installation of the IVL 0-20 mA logger in series with the display panel showing the fuel pump indicator was judged as a safety risk as this may have interfered with the adjacent digital governor unit using the same signal. Since time was not available to check this installation with the appropriate personnel from NORControl A/S, IVL in discussion with the electrical engineer on board (Lars Johanisson) decided to opt for a manual approach. Thus, the engine load was read off at the panel display as often as possible (every minute during load changes). Although this proved time-consuming the overall results were very satisfactory. By comparing values of other engine parameters (turbocharger speed, engine speed, charge air pressure etc.) to the fuel pump values and discussing these with the chief engineer and MAN B&W (Jensen and Pedersen, 2003), the fuel pump values were adjusted as best as possible to correspond to the engine load.

Engine load measurements from the fuel pump index in the engine room on *Stena Jutlandica* were however logged simultaneously and synchronised with the exhaust measurements without difficulties.

As indicated in the Phase 1 draft report (Hansén *et al.*, 2003), the measurements were carried out following the standard procedures set out in ISO 8178, 1996 and IMO Technical NO_x Code, 1997 (6.3 "Simplified Measurement Method"). Measurement equipment performance fulfilled the requirements of IMO Technical NO_x Code, 1997 and forms part of IVL's accreditation status routinely assessed by SWEDAC (Swedish Board for Accreditation and Conformity assessment)[2]. The equipment and calibration standards used are presented in Table III. The fuel analysis certificates (used for obtaining LHV) were obtained from the chief engineers on board each ship and the reference charge air temperatures from the engine manufacturers (Glensvig, 2000; Gallersdörfer, 2003).

[2] Enquiries concerning accreditation procedure, certification documents, inspection routines etc. can be directed to SWEDAC, Box 878, 501 15 Borås (Tel. 033-177700). IVL Swedish Environmental Research Institute has been given accreditation number 1213.

Table III. Measurement equipment (as required in IMO Technical NO_x Code, 1997).

Instrument	Manufacturer/model	Range used	Calibration standard
NO_x gas analyser	Ecophysics CLD700EL	0 – 1000 ppm	894 ppm ± 2 rel-% tolerance AGA Gas OTM-5 20600 00633
CO_2 gas analyser	Maihak Multor 610	0 – 20 vol-%	14,7 vol-% ± 2 rel-% tolerance AGA Gas OTM-5 38400 21086
Intake air temp. instrument	Nordtec Testo 600	-20 – 80 °C	SP/SWEDAC traceable calib. Certificate F1 06477
Intake air humidity instrument	Nordtec Testo 600	0 – 100 Rel. %	SP/SWEDAC traceable calib. Certificate F1 06477
Atmos. pressure barometer	Vaisala PTB 101B	60 – 106 kPa	SP/SWEDAC traceable calib. Certificate MTmF 113308

Gas concentration and ME effect measurement signals were recorded every 15 seconds and 1 minute averages stored using PC driven Intab AAC-2 and Tiny Tag loggers. The time was synchronised to Central European Time. As indicated in the draft Phase 1 report, a record of ship position, in addition to the measured emission reductions, will be required for the future trading system. The possibilities available for logging ship position will however be dealt with later in Phase 2b of the project. During this work, the ships position was manually noted on *Manon* (voyage left EU waters) where time allowed. *Stena Jutlandica* operated entirely within EU waters.

Emission calculations were based on the so-called "universal" mass balance in IMO Technical NO_x Code, 1997 and as described in detail in the Phase 1 draft report (Hansén *et al.*, 2003).

The gas analysers were calibrated at four (*Manon*) and seven (*Stena Jutlandica*) separate intervals during the voyages and the measurement signals compensated for signal drift. It is conceivable that for a future, permanent measurement system installed in a temperature-controlled housing, the number of necessary calibrations required would most probably be less than that in these measurement campaigns.

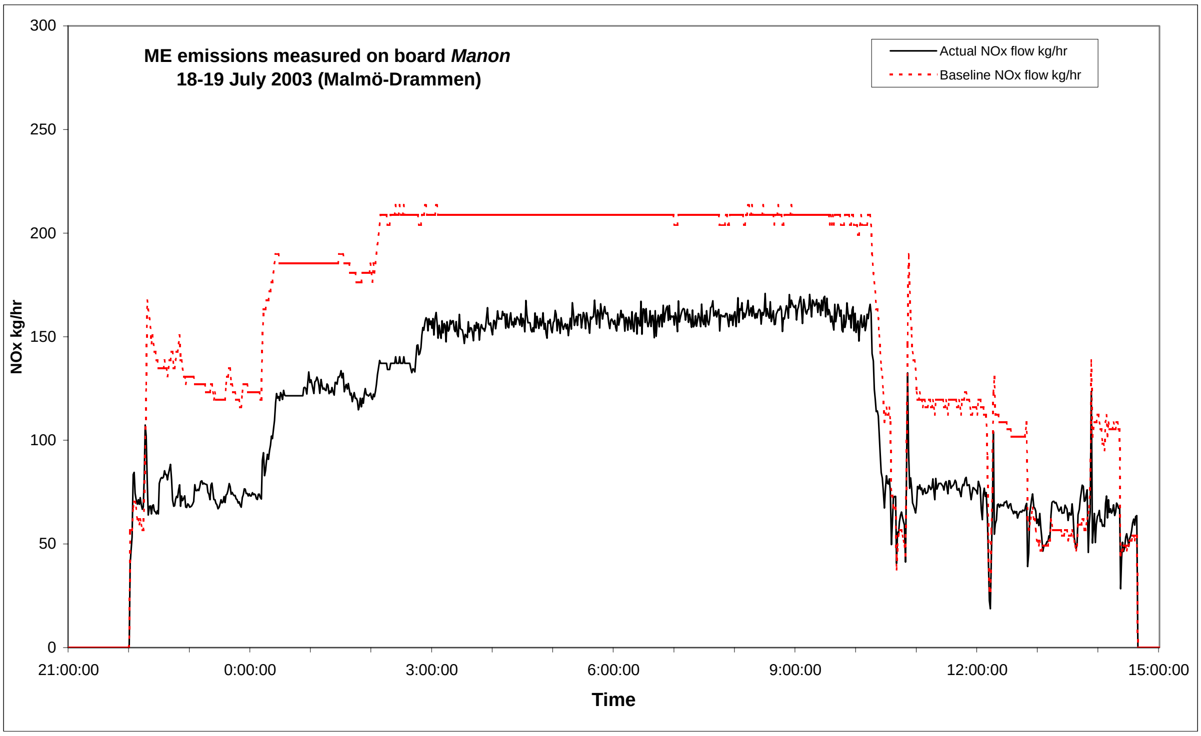
3 Results

The evaluated NO_x emissions (baseline and actual) and marketable reductions measured during the voyages are presented in Figures 3, 4 and 5. The corresponding emission reports showing the hourly reductions are shown in Tables IV and V. Other raw data including concentration, engine load and exhaust flow profiles and ship position are included in Appendix 1 (*Manon*) and Appendix *2 (Stena Jutlandica*). Note that *Manon* left EU waters at precisely 10:35 and entered Norwegian sea territory, i.e. the emissions after 10:35 have not been included in the emission reduction report[3].

[3] In the Phase 1 Draft report it assumed that a future market based system for reducing emissions from sea going ships will have a boundary at a certain distance from shore. In order to demonstrate that it is possible to monitor the emission reductions within (and outside) the system boundary, the future boundary was assumed to be the EU territory waters in this case.

It is important to bear in mind that for *Manon* the general baseline methodology following the IMO NO_x emission limit curve (i.e. NO_x baseline set at 17,0 g/kWh_{corr}) was adopted[4]. A ship specific baseline was not available. Thus the *Manon* emission reduction credits are based on this theoretical and "politically assigned" baseline, with an uncertainty from this rigid baseline of ± 16% (95% confidence level). For *Stena Jutlandica* however, baseline emissions were measured separately (at 75% engine load) just prior to the test voyages by switching off the urea flow to the SCRs. Thus for *Stena Jutlandica* a ship specific baseline methodology was used in calculating a "real" marketable reduction (i.e. NO_x baseline set at 15,4 g/kWh_{corr} for ME2 and 15,0 g/kWh_{corr} for ME4). The uncertainty in this case has been estimated to ± 20% (95% confidence level).

During the measurements no abnormalities were reported and the engines and abatements systems were considered to be running as normal.



[4] Several baseline methodologies are possible for a future trading system. Different methodologies are presented and discussed in the Phase 1 Draft report.

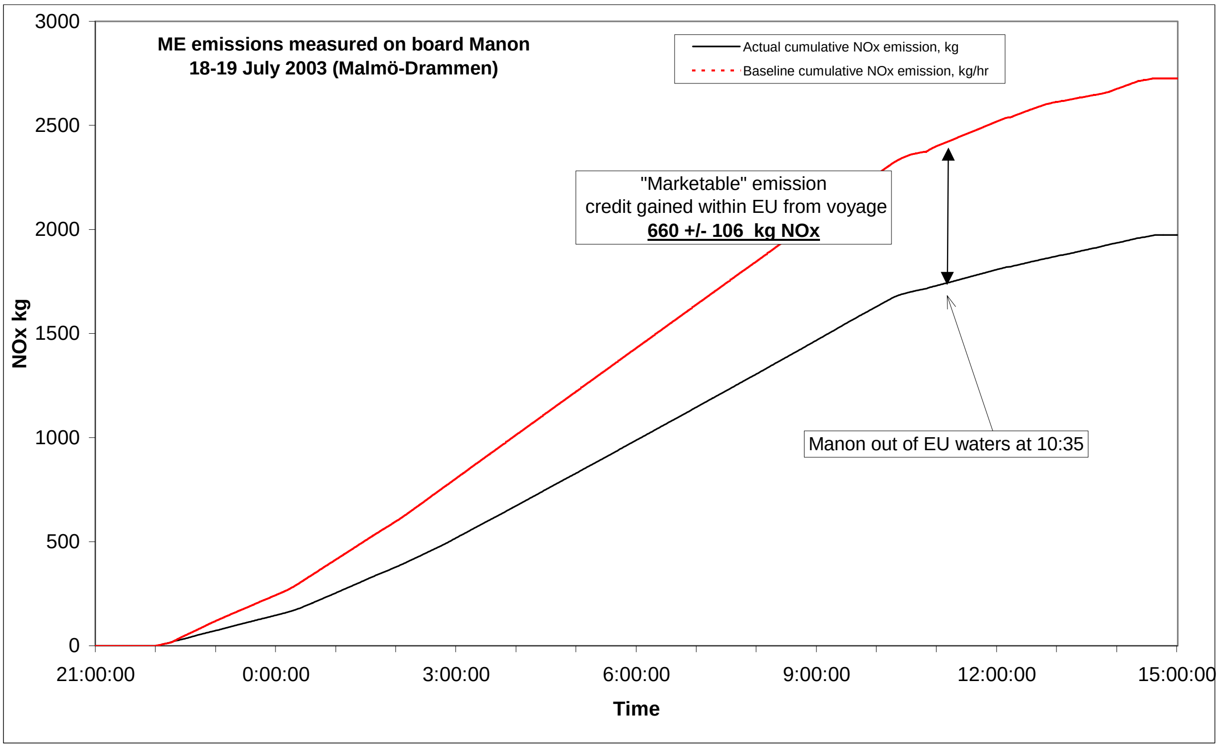
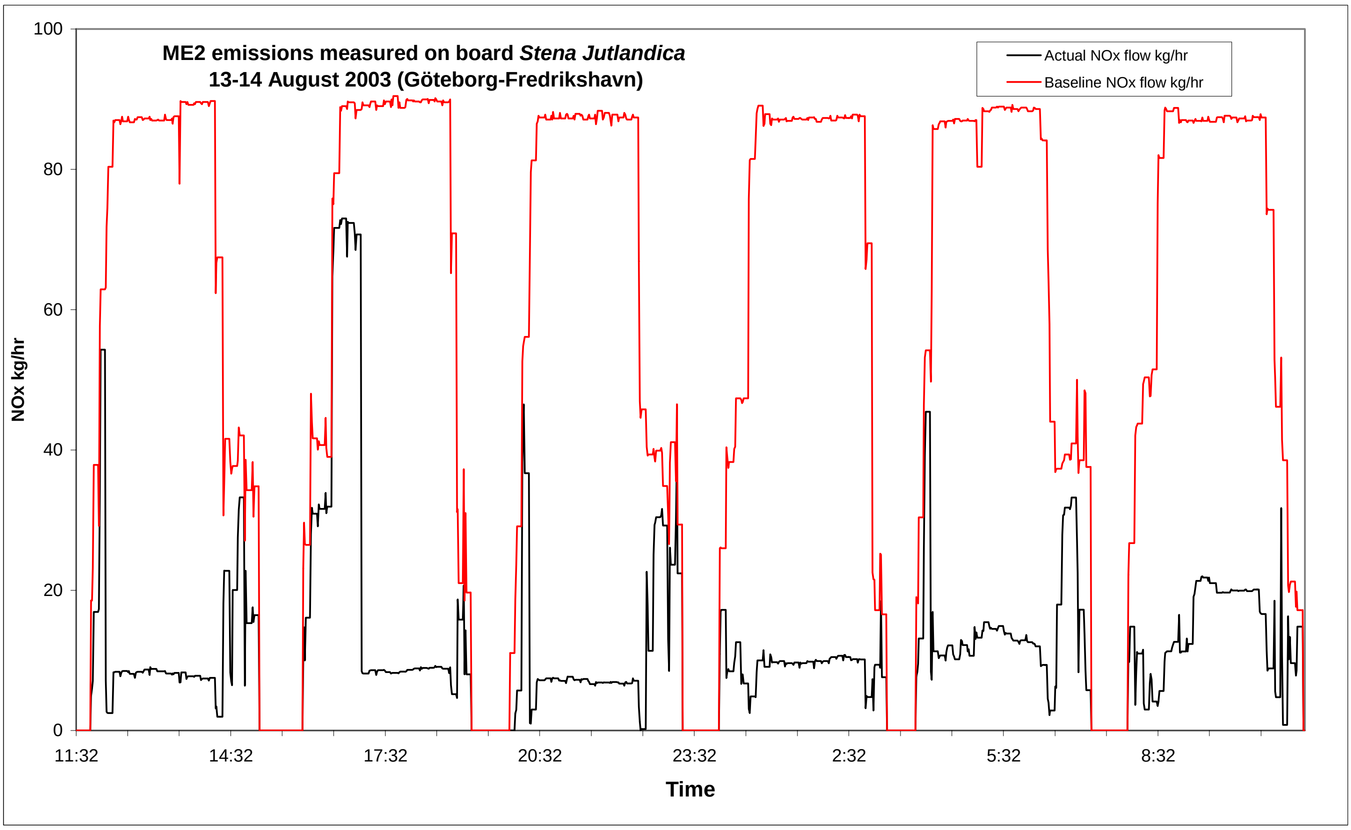


Figure 3. Measured NO_x emissions on board *Manon*.



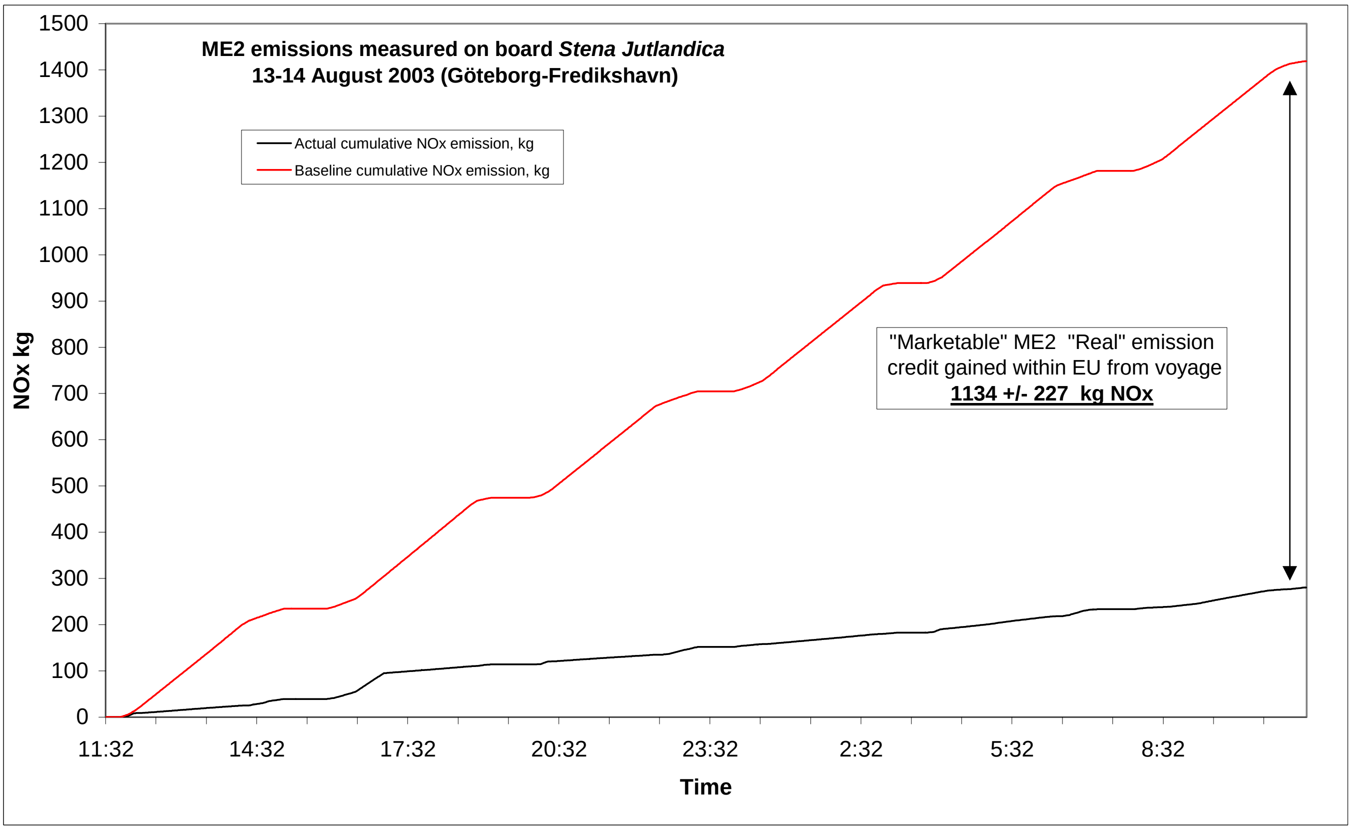
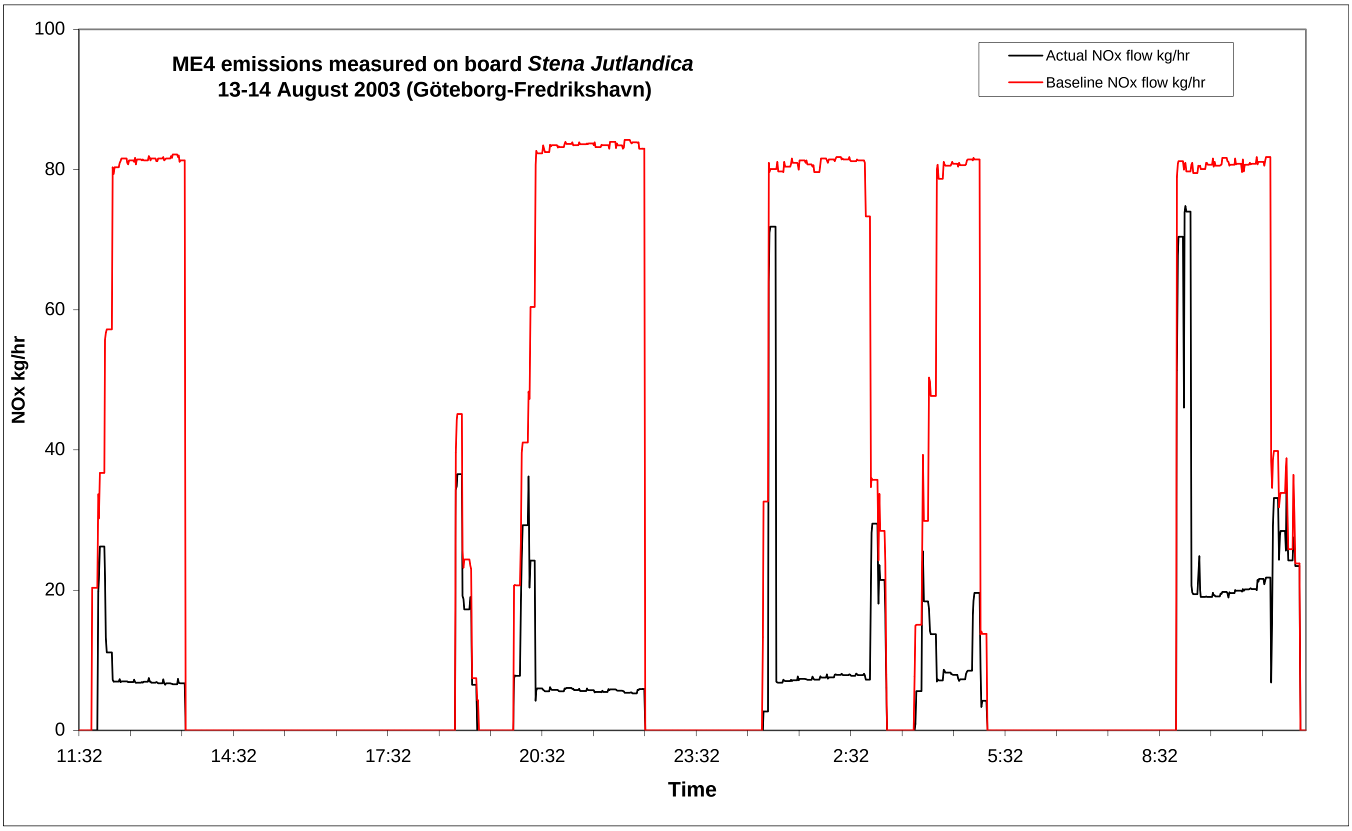


Figure 4. Measured NO_x emissions from ME2 on board *Stena Jutlandica*.



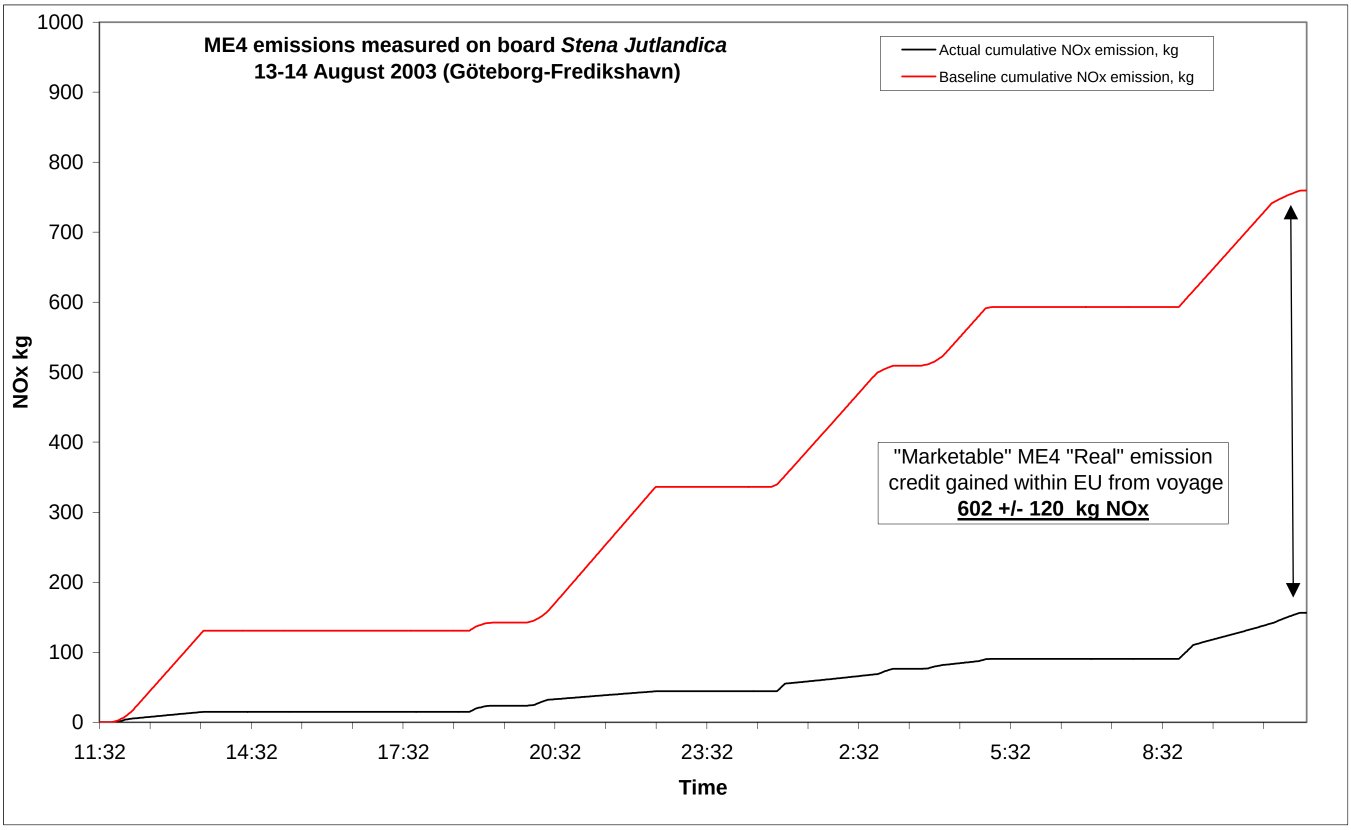


Figure 5. Measured NO_x emissions from ME4 on board *Stena Jutlandica*.

Table IV. **An example of the emission reduction report for *Manon*.**

ME Emission Reduction report for Manon 18-19 July (Malmö-Drammen)	
time	EU NOx emission reduction (kg)
2003-07-18 18:00	0
2003-07-18 19:00	0
2003-07-18 20:00	0
2003-07-18 21:00	0
2003-07-18 22:00	45
2003-07-18 23:00	51
2003-07-19 00:00	63
2003-07-19 01:00	59
2003-07-19 02:00	67
2003-07-19 03:00	55
2003-07-19 04:00	52
2003-07-19 05:00	50
2003-07-19 06:00	50
2003-07-19 07:00	48
2003-07-19 08:00	47
2003-07-19 09:00	46
2003-07-19 10:00	27
2003-07-19 11:00	0
2003-07-19 12:00	0
2003-07-19 13:00	0
2003-07-19 14:00	0
SUM--->	**660**
(emissions at 18:00 refer to emissions from 18:00 up to 18:59 etc.)	

Table IV. **An example of the emission reduction report for *Stena Jutlandica*.**

ME2 and ME4 Emission Reduction report for Stena Jutlandica 13-14 August (Göteborg-Fredrikshavn)			
time	ME2 NOx emission reduction (kg)	ME4 NOx emission reduction (kg)	SUM
2003-08-13 11:00	4	4	8
2003-08-13 12:00	71	69	140
2003-08-13 13:00	80	40	120
2003-08-13 14:00	38	0	38
2003-08-13 15:00	3	0	3
2003-08-13 16:00	13	0	13
2003-08-13 17:00	77	0	77
2003-08-13 18:00	71	4	75
2003-08-13 19:00	3	2	5
2003-08-13 20:00	61	55	116
2003-08-13 21:00	81	78	158
2003-08-13 22:00	48	36	84
2003-08-13 23:00	4	0	4
2003-08-14 00:00	51	7	58
2003-08-14 01:00	77	68	145
2003-08-14 02:00	71	66	137
2003-08-14 03:00	6	4	11
2003-08-14 04:00	67	65	131
2003-08-14 05:00	74	3	77
2003-08-14 06:00	42	0	42
2003-08-14 07:00	7	0	7
2003-08-14 08:00	57	3	60
2003-08-14 09:00	68	53	122
2003-08-14 10:00	57	44	102
2003-08-14 11:00	4	1	4
SUM--->	**1134**	**602**	**1737**
(emissions at 18:00 refer to emissions from 18:00 up to 18:59 etc.)			

4 Discussion

In conclusion, the marketable emission reductions were determined as ca. 753 ± 120 kg NO_x for the ME during a Malmö-Drammen 17-hr voyage on board *Manon* and ca. 1736 ± 347 kg NO_x for ME2 and ME4 during six Göteborg-Fredrikshavn crossings over 24 hrs on board *Stena Jutlandica.* The emission reduction for *Manon* was based on a theoretical baseline whereas for *Stena Jutlandica* the emission reduction was a "real" reduction (measured baseline).

The measurement methodology as outlined in the Phase 1 draft report (Hansén *et al.*, 2003) has been demonstrated as suitable thus far. Procedure for recording engine effect (lacking on *Manon*) can however be improved given a greater time period for planning prior to the measurements. Regarding recording ship position this will be addressed together with emission measurements on other ships in the following Phase 2b study.

To our knowledge continual NO_x emission monitoring studies covering complete voyages using similar methodology as to that described here has now been demonstrated on 10 different ships (Cooper, 1996; Cooper and Andreasson, 1998; Cooper 2001; Cooper and Ekström, 2003; Ahlbom and Duus, 2003).

In general the portable exhaust monitoring equipment has been proven satisfactory despite excessive ambient temperatures in some cases (e.g. on board *Stena Jutlandica* in this study). The studies have however not been performed on voyages with significant tilting and jolting (i.e. small ships during heavy seas) nor for extended periods (i.e. most cases < 5 days). Measurement uncertainty and eventual erroneous data (e.g. in exhaust flow) can arise for periods with rapid engine load changes where calculated fuel consumption (from engine effect) and measured CO_2 values are not fully concerted. By introducing conditional calculation steps these can however most likely be minimised.

An interesting follow-up project to this work would be to conduct a more, long-term demonstration (6 – 12 months) of a measurement system that is operated and calibrated entirely by the ship's crew.

5 References

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Jensen, Jan and Pedersen, Sören (2003) MAN B&W, Copenhagen, Denmark, Tel 00-45-33-851100, personal communication, 22nd July 2003.

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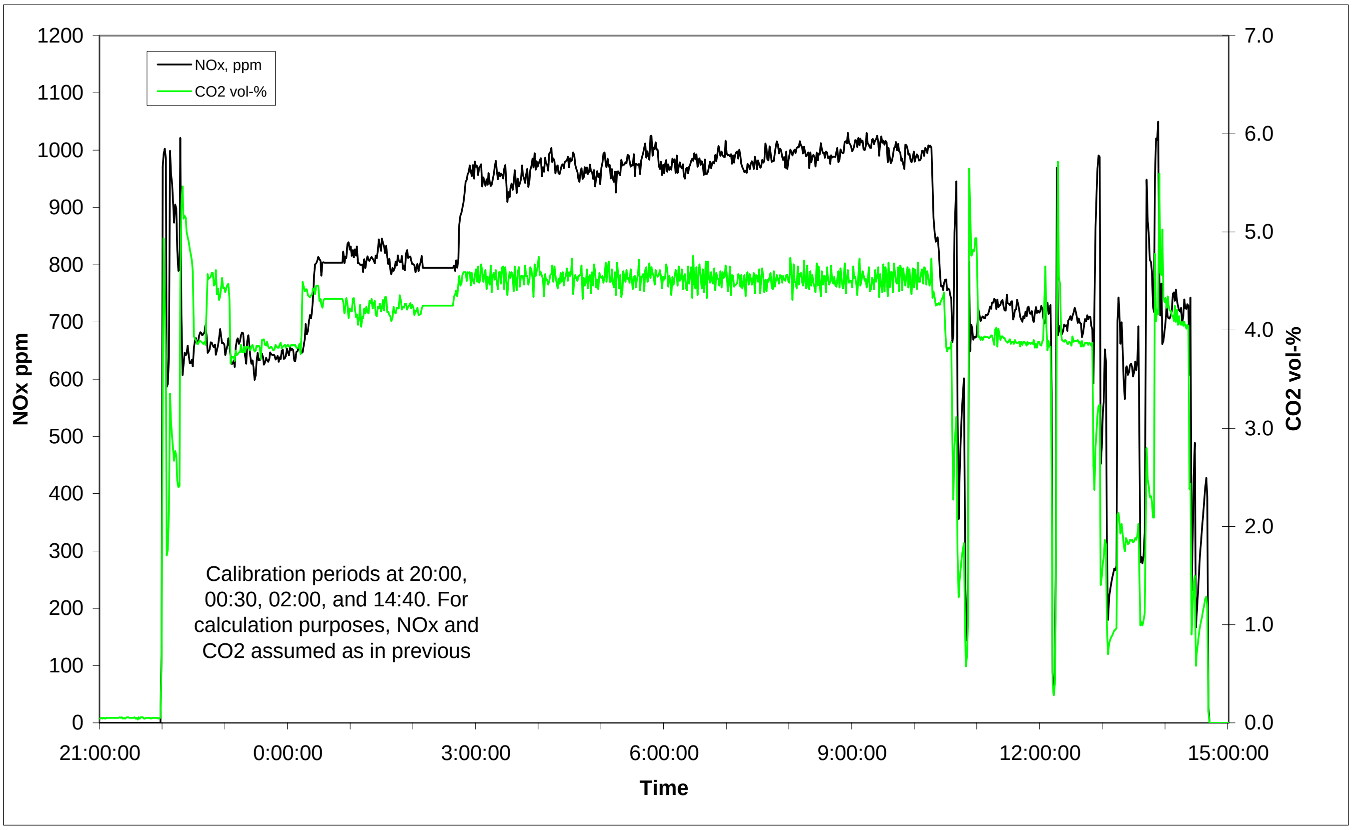
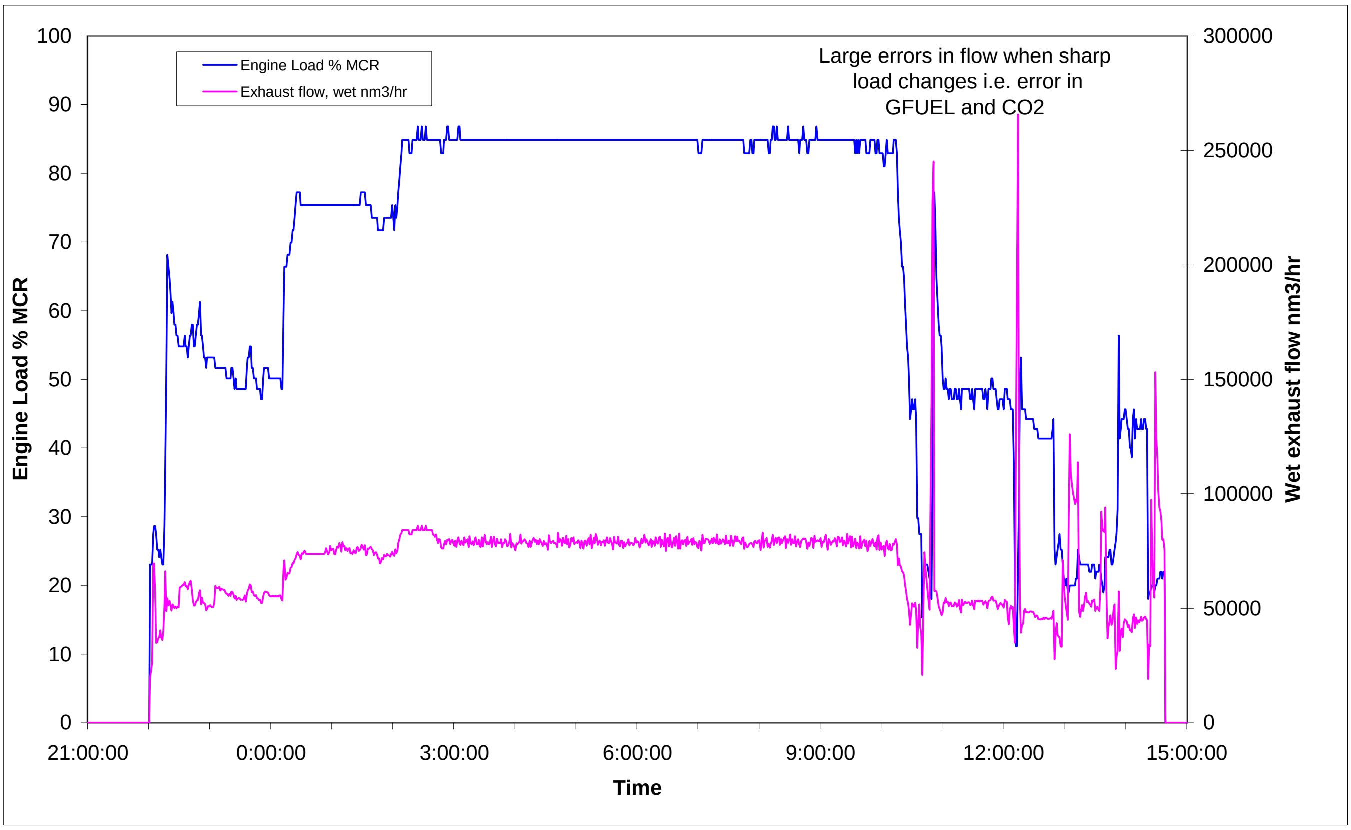
Appendix 1

Raw data from measurements onboard *Manon* 18-19 July 2003



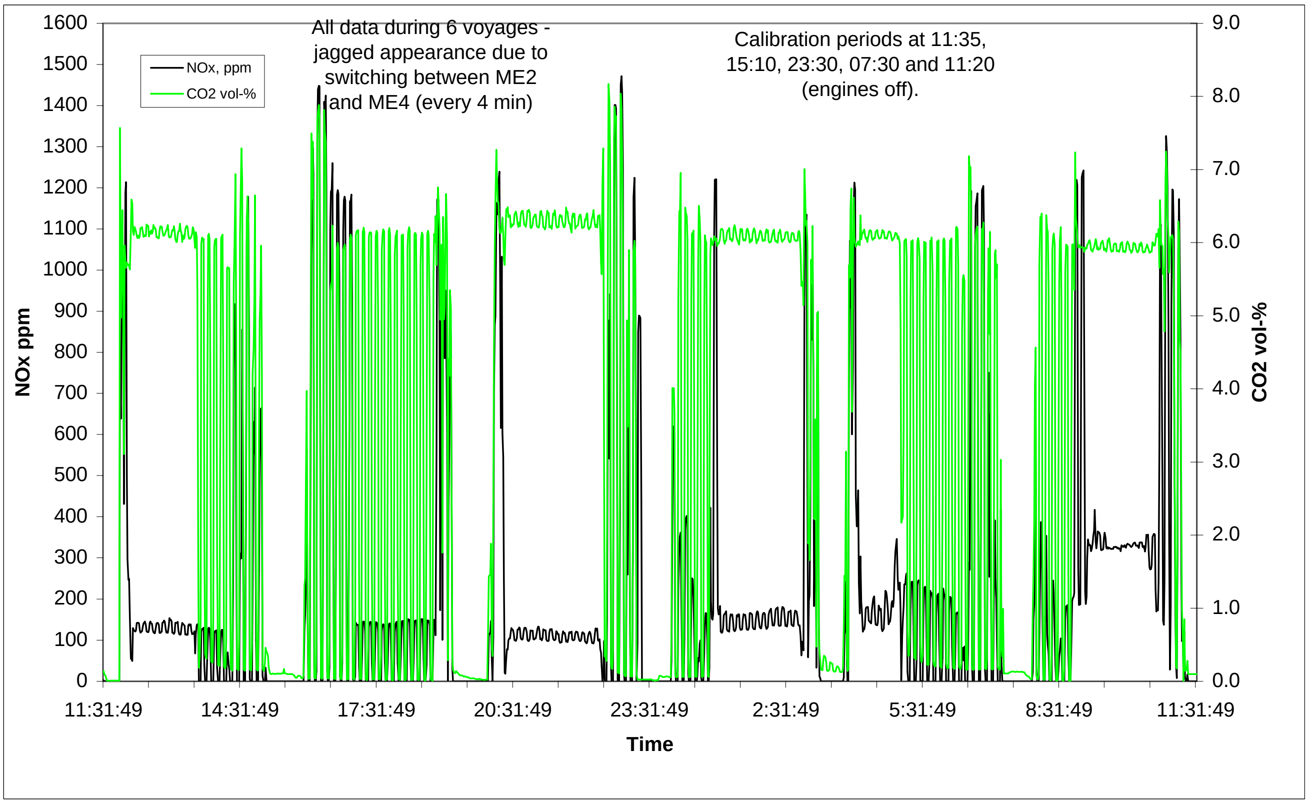


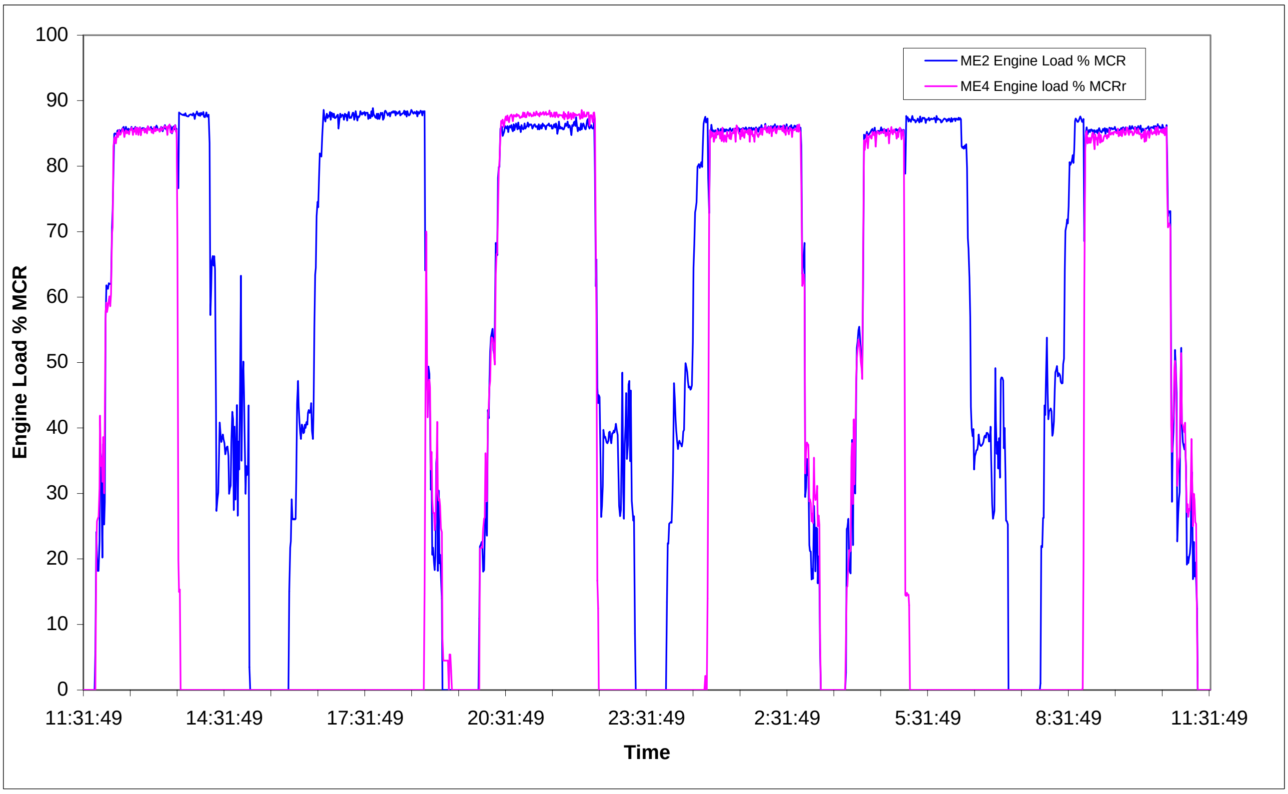
Noted ship positions during voyage on board *Manon* 18-19th July 2003.
(Manon left EU waters at 10:35)

time	latitude position	longitude position
22:15	55 38.132 N	012 58.229 E
23:30	55 53.735 N	012 44.786 E
23:57	55 59.739 N	012 41.296 E
01:07	56 14.216 N	012 41.296 E
08:15	58 18.951 N	010 58.404 E
09:56	58 51.149 N	010 40.762 E
11:16	59 09.628 N	010 39.548 E
13:10	59 32.996 N	010 24.469 E

Appendix 2
August 2003

Raw data from measurements onboard *Stena Jutlandica* 13-14



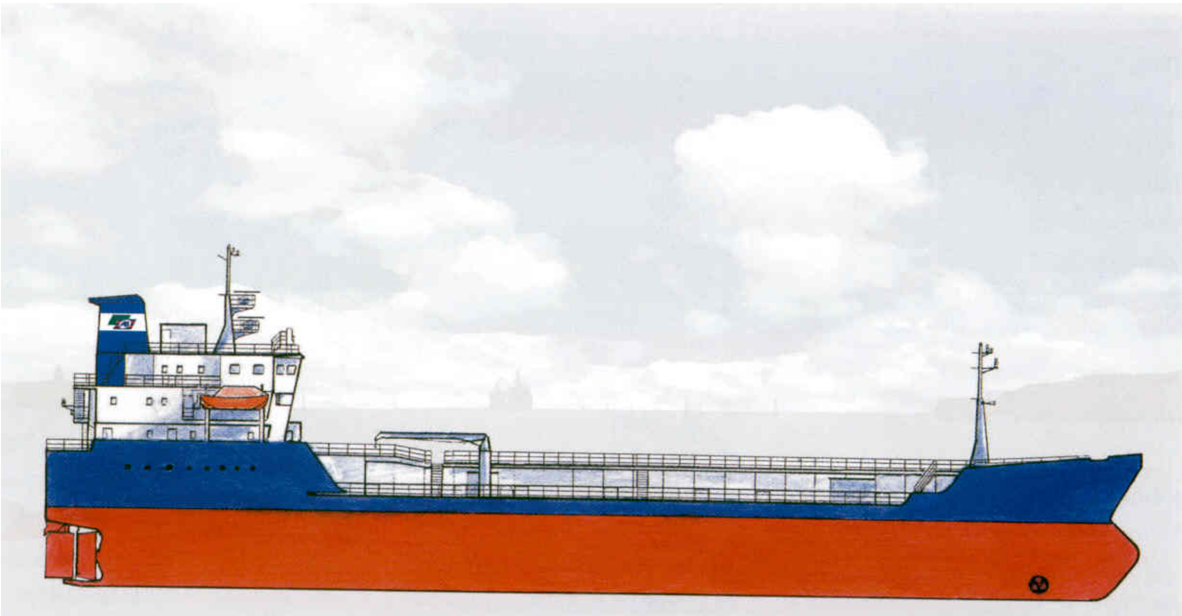


IVL report
IVL Swedish Environmental Research Institute

APPENDIX 8
FINAL DEMO Project Report

FOR PRICEWATERHOUSECOOPERS
U-905B

Sulphur emission monitoring on board *Bro Atland*



Eje Flodström 2004-02-20

IVL

Organisation/Organization IVL Svenska Miljöinstitutet AB IVL Swedish Environmental Research Institute Ltd.	**RAPPORTSAMMANFATTNING** **Report Summary**
Adress/address Box 47086 402 58 Göteborg	**Projekttitel/Project title** Demonstration of Emission trading: Phase 2b
Telefonnr/Telephone 031-725 62 00	**Uppdragsgivare/Client** PriceWaterhouseCoopers AB

Rapportförfattare/author

Eje Flodström

Rapportens titel och undertitel/Title and subtitle of the report

Sulphur emission monitoring on board *Bro Atland*

Sammanfattning/Summary

IVL Swedish Environmental Research Institute Ltd. has demonstrated continuous engine load measurement via turbocharger speed and fuel logging on board a ship sailing in European waters. The study was aimed to provide a practical demonstration of the feasibility of using continuous power registration to verify fuel consumption as a basis for sulphur trading purposes.

The demonstration was undertaken on the product tanker *Bro Atland*, on a 21-hr voyage from Antwerpen (Neherlands) to Le Havre (France) during 18th-19th December, 2003.

In general, the measurement equipment and calculation routines outlined in the Phase 1 draft report of this project were shown to be suitable.

Nyckelord samt ev. Anknytning till geografiskt område eller näringsgren/Keywords

Ship emissions, Sulphur, SO_2, continual emission monitoring, marketable reduction

Bibliografiska uppgifter/Bibliographic data

Arkivnr U-905B

CONTENTS

1 INTRODUCTION

1.1 Background

PriceWaterhouseCoopers AB have initiated a multi-phase project financed by several stakeholders in the shipping industry aimed at demonstrating that monitoring and verification of emission reductions from ships are feasible and may serve as a basis for emissions trading. In turn, the Swedish Environmental Research Institute has been contracted to outline suitable shipboard monitoring techniques and calculation routines (Phase 1), and secondly to provide practical demonstrations at sea (Phase 2).

This study (Phase 2b) focuses on demonstrating techniques for monitoring fuel consumption and fuel analyses to enable quantification of sulphur emissions from ships. An earlier study (Phase 2a), reported in IVL report U-826, has shown the feasibility of monitoring NO_x-emissions on board two ships using two different kinds of NO_x abatement methodology.

1.2 Objective

The objective of these measurements was to demonstrate the simultaneous monitoring of fuel consumption by two independent methods to obtain verifiable data on total sulphur emissions from a ship. Fuel samples were taken and analysed in an independent laboratory. This refers back to the methodology suggested in the draft Phase 1 report (Hansén *et al.*, 2003).

2 METHODOLOGY

2.1 Technical ship data

Technical data for the ship in question are presented in Table I.

Table I Technical data for the measurement ship

Ship name	***Bro Atland***
Signal	SJTA
Length and width, m	144,1 x 23
Dead-weight, tonnes	16 326
GT	11 377
Capacity	19 550 m^3
Engines	1 ME and 4 AEs
Service speed, knot	19
Year of delivery	1999
Classification	DNV +1A1 Tanker for Oil Products and Chemicals ESP E0 ETC HL(1.54) W1-OC ICE-1A
Main engines (ME)	MAN B&W 9L 40/54, 6 480 kW @ 550 r/min (2 stroke slow speed diesel)
Auxiliary engines (AEs)	Volvo MD162, 390 kW (4 stroke medium speed diesel)
Fuel type	ME use Heavy Fuel Oil (HFO/IF380) AEs use Marine Gasoil (GO)

Bro Atland operates in Western Europe shipping oil products between refineries and depots.

2.2 Conditions

The measurements were undertaken during 21-hr voyage from Antwerpen (Netherlands) to Le Havre (France). Logging started upon main engine startup when leaving the outer lock in Antwerpen and ended after main engine shutdown in Le Havre. (20:00 18th December to 17:00 19th December). Weather conditions were extremely good with no swell and air temperature of ca. 0 – 15 ^{o}C.

At sea the auxiliaries are usually turned off and a shaft generator on the main engine produces the electricity. The original intention was to register the power signal from one of the auxiliary generators, which is available, to monitor the auxiliary engines. However due to a malfunction in the equipment, unnoticed due to very short preparation time for the test, only one channel was available on the data logger and this was used for the main engine. This makes little difference as the auxiliary engines were shut down 10 minutes after the start of the test period and were restarted on low load only about 2 hours before the end of the measurement.

The voyage was an empty one, meaning that no logging could be undertaken during unloading operation. (Unloading operation is dimensioning for the auxiliary engine power). A reading during the unloading indicates a total power need of about 600 kW.

Most of the voyage was done at 85 % ME load except for power reductions for the transfer of pilots and for avoiding traffic conflicts in the English Channel.

Due to short planning term and the difficulty of obtaining the desired fuel along the ship's route, no low-sulphur fuel was used in this demonstration. This is not of any major importance, as the main objective was the demonstration of fuel consumption monitoring techniques. The case with low sulphur fuel was thus only evaluated theoretically, see below.

2.3 Equipment

Fuel consumption of the main engine was monitored in two different ways: Taking periodical readings on the permanently installed fuel flow meter and the more approximate method of calculating the fuel consumption from a signal that varies with engine load.

The ship has no facilities for the direct monitoring of main engine load. The main engine is run as a constant speed unit meaning that load variation are taken up as changes in shaft torque which is very hard to monitor. Fuel rack position, which governs the injected fuel quantity, is only indicated on a mechanical scale on the main engine.

The chosen signal for monitoring engine load is the turbocharger speed. Power and fuel consumption are derived from the results of the engine's original bench test at the manufacturer. Turbocharger speed is not ideal as it varies with other factors beside engine load, such as the maintenance status of the turbocharger (friction and backpressure) and exhaust temperature.

Each month, the ship's main engine is run through a test of the cylinder pressure where the power is calculated from the pressure curve and the turbine speed is registered. This test may be used to periodically monitor the changes in turbine characteristics over time.

A signal for the turbocharger speed is available on the main engine control panel (4-20mA). This was connected to a data logger over a signal insulator. Measurements were done in 5-second intervals and averaged over 10-minute periods.

No direct calibration was possible of the turbocharger speed in order not to interrupt the ship's normal operation. The speed is registered by a magnetic pickup as a frequency and then converted into a current signal.

Fuel consumption was monitored by manual reading every hour from a mechanical flow counter on the main engine fuel line. (This is usually used only for daily reading of the fuel consumption.)

2.4 Fuel system and sampling

The ship has one main engine and two boilers running on HFO. Four auxiliary engines are fuelled with gasoil.

HFO is bunkered in three tanks. The fuel is pumped from these to two settling tanks and then via separators to two service tanks. Normally one pair of settling/service tanks is used for the main engine and one pair for the boilers. This allows the use of the boiler pair for small oil remainders, as the boilers are not sensitive to blended fuel qualities.

For the gasoil there are two bunker tanks and one service tank only. The service tank content is continuously circulated through a separator.

Bunkering is usually (98%) done to an empty tank to avoid unnecessary mixing of the fuels.
The tank level is measured with an air bubble device. The volume is then calculated with sounding tables. These are not based on actual measurements but are derived from drawings. Also the level readout is dependent on trim, movements etc. This leads to a fairly large error in the volume measurement.

No flow meter exists for the boilers. Instead the consumption is estimated from the running hours of the burners which is registered. The burners only have one power level and use a simple on/off regulation.

The usual routine for the transfer of HFO to the main engine is that the settling tank is filled from to 40 m3 once every day. Automatic transfer from the settling tank continuously holds the service tank at 27,9 m3 (according to the Norcontrol computerised management system screen).
Presently there are no openings suitable for sampling directly in the HFO tanks. If necessary, this could easily be incorporated according to the Chief Engineer. There is a sounding pipe, which is continuous from the top to the bottom of the tank, and a drain outlet pipe in the bottom.

The gasoil can be easily sampled through a centrally located pipe and tap used to extract GO for cleaning purposes (GO is used as a solvent for cleaning of components in the HFO-system).
Fuel samples were taken from two different positions in the HFO fuel system, both after the service tank, in the part of the fuel system leading up to the main engines, see Appendix 4. A gasoil sample was taken directly from the gasoil tank. For the laboratory results, see Appendices 1 a-c.

During the test, the fuel was continuously drawn from one single service tank, which could be monitored from tank level readings. Bunker tank levels were entered daily in the engine room logbook.

2.5 Evaluation

The relationship between turbine speed, engine power output and fuel consumption is derived from the engine test bench diagrams as seen in Appendix 2. The relationship between turbine speed (curve 10) and specific fuel consumption (SFC, curve 9) are thus obtained for the test conditions.

The latest cylinder pressure measurement, see Appendix 3 was used to obtain one recent calibration point for the turbocharger speed vs. engine load. This led to a correction factor of 0,94 to be applied to the actual turbine speed. This factor includes corrections for different fuel heat calorific values.

The diagram below describes the obtained relationship between turbine speed and fuel consumption. This curve is combined with the logged turbine speeds to arrive at the fuel consumption every 10th minute of the journey.

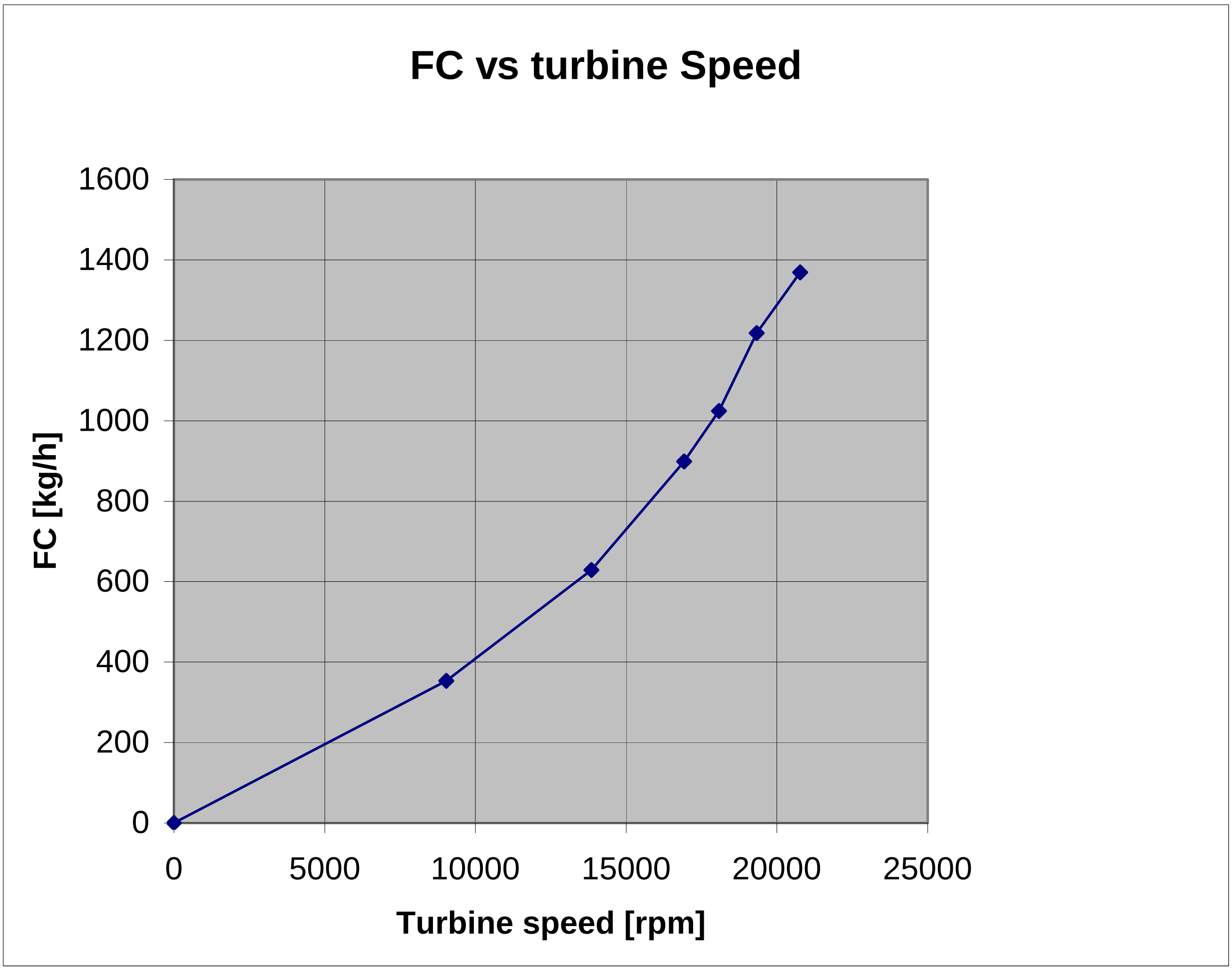


Figure 1. Relationship between turbine speed and fuel consumption, Bro Atland, main engine.

The fuel flow meter fuel gives readings in cubic meters that are converted to kg from the analysed density compensated for fuel temperature.

3 RESULTS

The turbine speed and main engine load over time is shown in Figures 2 & 3 below. Visible are periods of shallow water transit, effects of traffic and power reductions for the transfer of pilots.

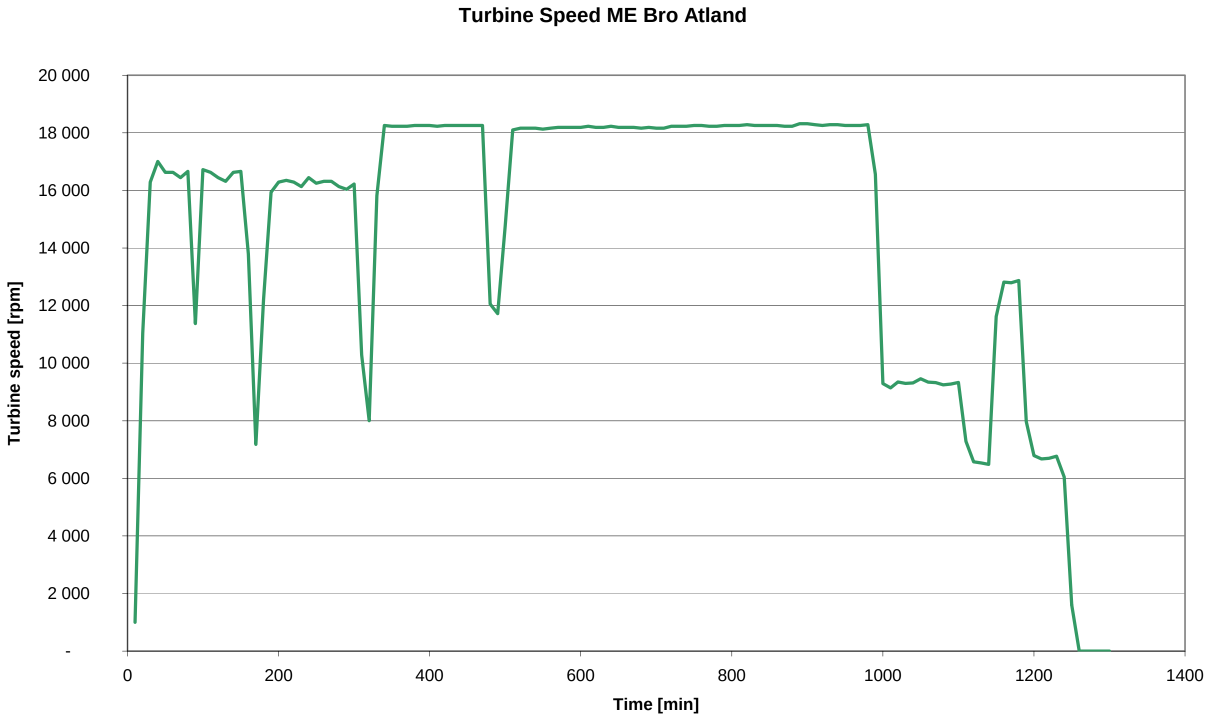


Figure 2. Main Engine, turbine speed over time, Bro Atland voyage Antwerpen-LeHavre, 18th-19th september 2003.

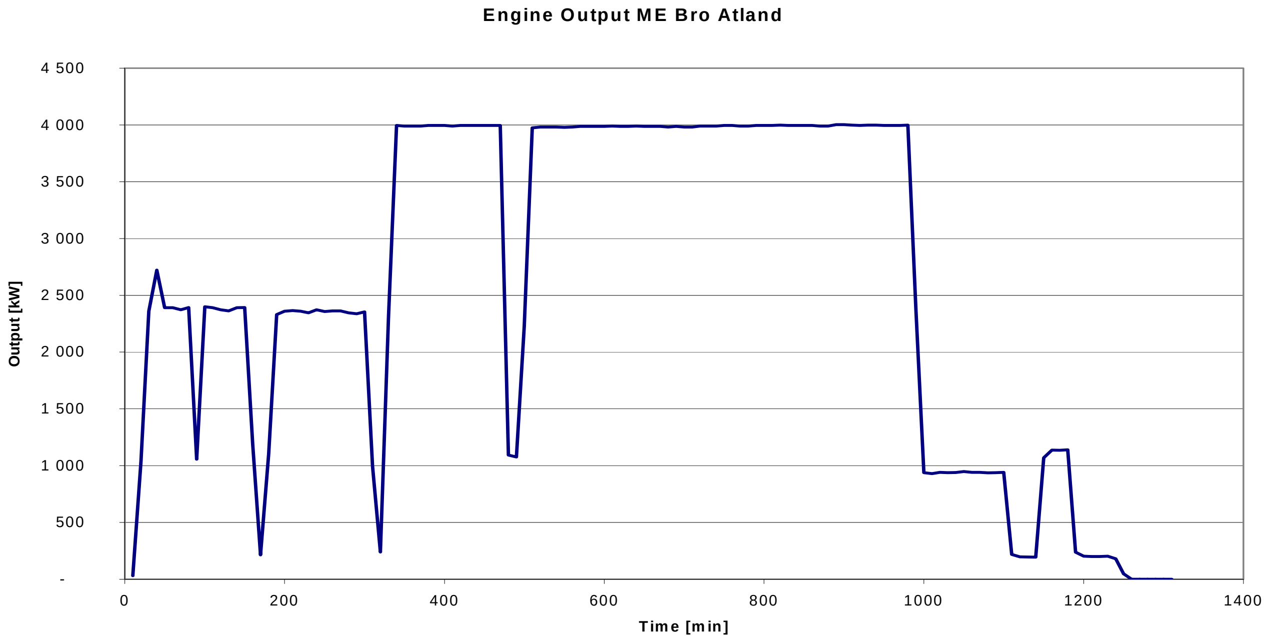


Figure 3. Main Engine, power output over time, Bro Atland voyage Antwerpen-LeHavre, 18th-19th September 2003.

In Figure 4, the two different methods of fuel consumption monitoring are compared. The results are highly proportional but a systematic difference of about 7,5 % remains. This can probably be improved upon with a single or periodical calibration between the methods and of the engine load measurement, something that wasn't possible within the frames of this project.

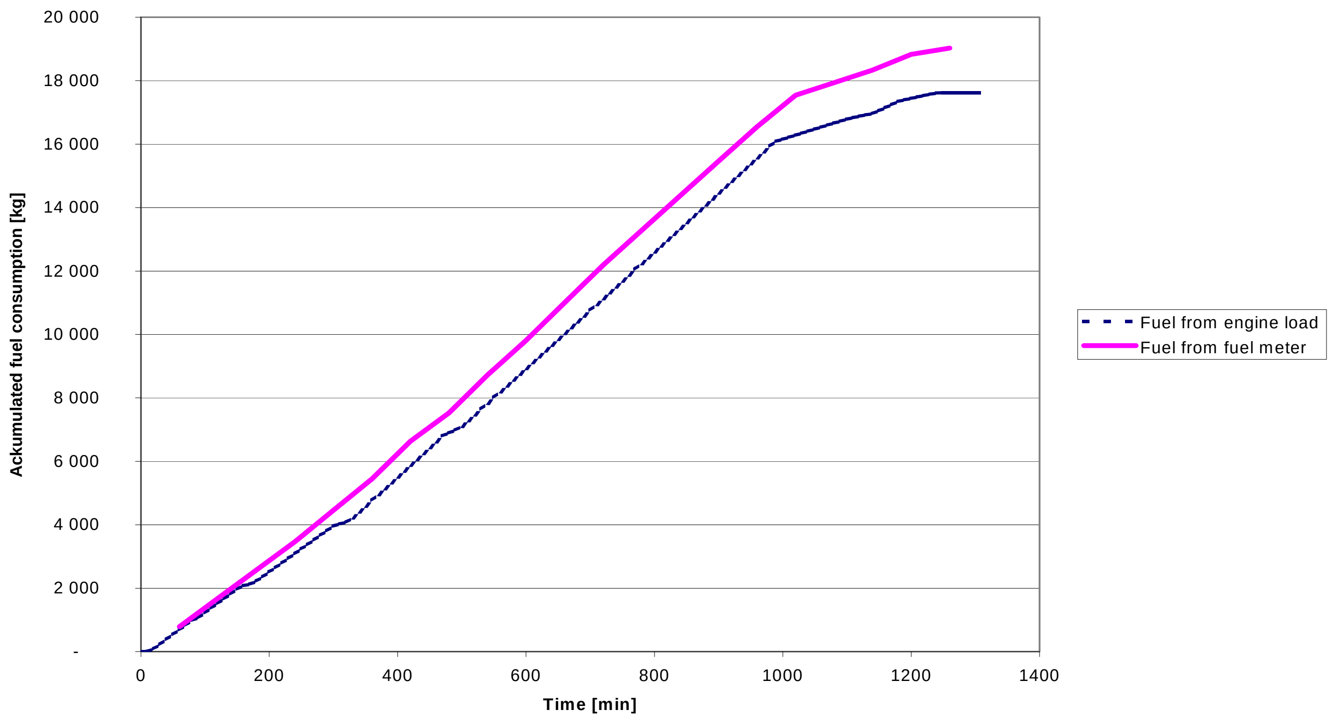


Figure 4. Accumulated fuel consumption, Bro Atland voyage Antwerpen-LeHavre, 18th-19th September 2003.

Using the analysed fuel sulphur content of 2,9 % and the fuel consumption from the fuel meter, the total emissions during the voyage may be calculated to 552 kg sulphur or 1 104 kg if counted as SO_2. The estimate based on engine load results in a figure of 511 kg sulphur corresponding to 1 022 kg SO_2.

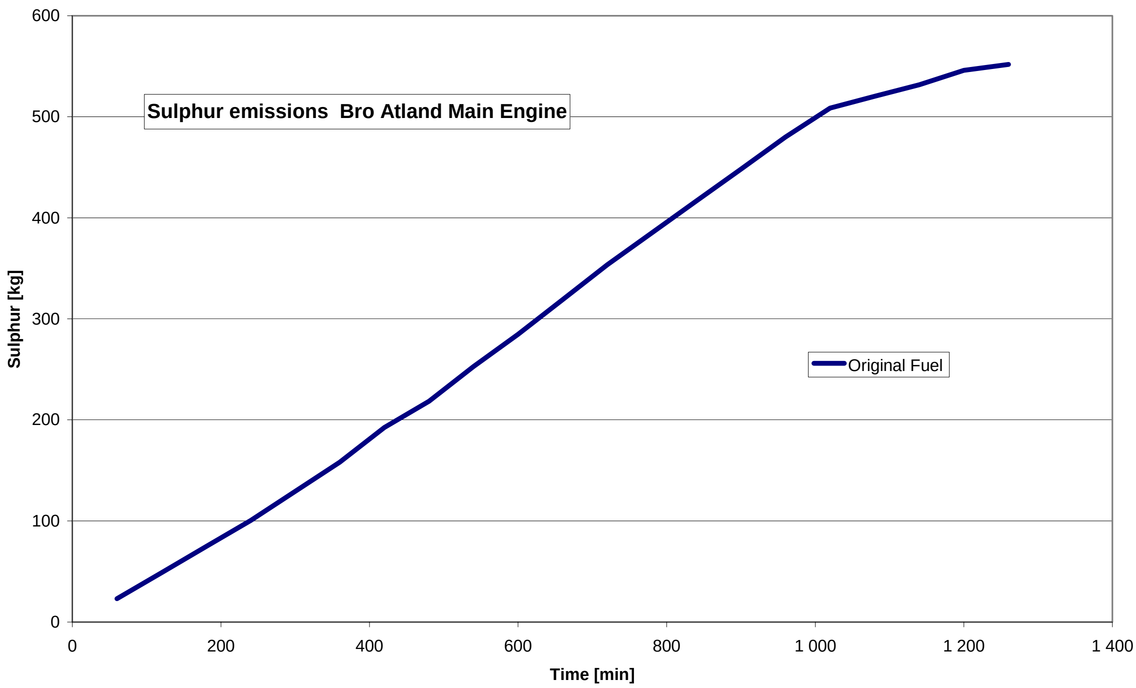


Figure 5. Accumulated sulphur emissions, Bro Atland voyage Antwerpen-LeHavre, 18th-19th September 2003.

The following diagram describes a hypothetical case where the ship is simulated to use fuel with 0,5 % sulphur. A fictive baseline of 1,5 % sulphur has also been assumed. In this case the reduction from baseline is about 190 kg of sulphur over 21 hours.

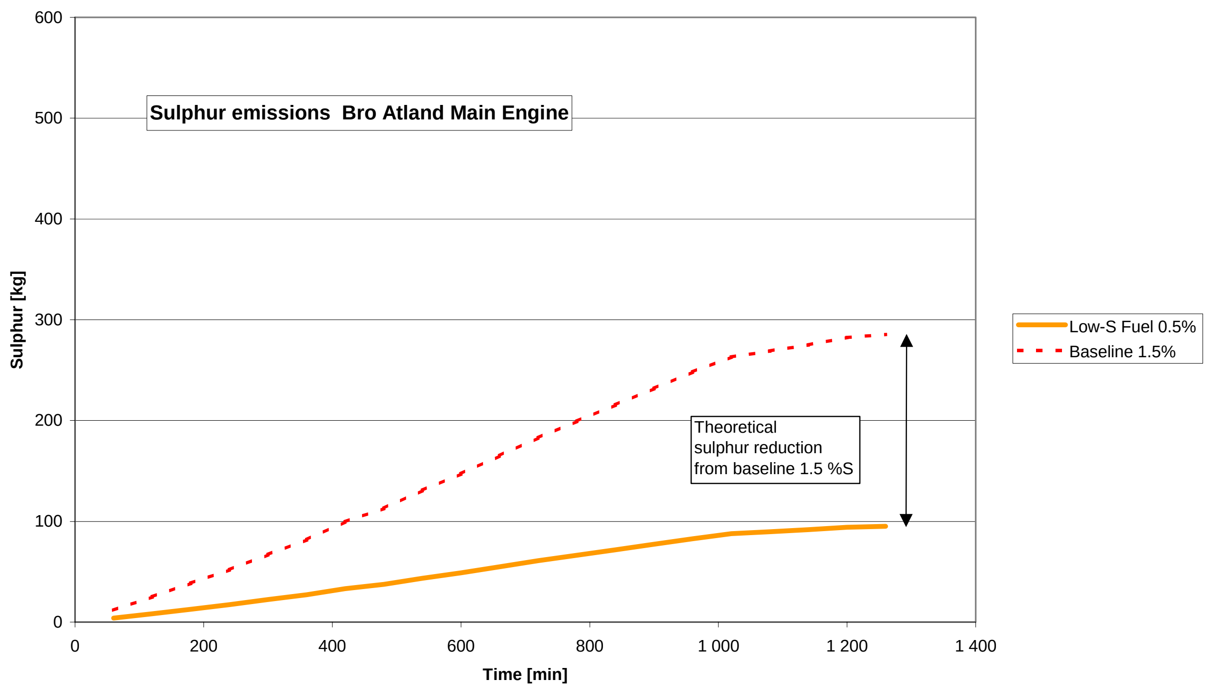


Figure 6. Accumulated sulphur emissions with assumed 0.5 % fuel sulphur compared to a fictive baseline of 1,5 % S, Bro Atland voyage Antwerpen-LeHavre, 18th-19th September 2003.

4 DISCUSSION

The feasibility has been shown to simultaneously monitor fuel consumption in more than one way, which enables independent verification of fuel use. The methodology as outlined in the Phase 1 draft report (Hansén *et al.*, 2003) has been demonstrated as suitable thus far. The level of accuracy and practicality may be increased considerably by use of calibration routines and simple registration devices.

The observed difference between the two methods of fuel consumption monitoring lies within the expected uncertainty range for the measurements as estimated in the Phase 1 report (5-15% for fuel consumption) despite the lack of calibration for some parameters.

Tank level measurements are generally not accurate enough for short-term fuel consumption measurement. Registration of tank level should however be sufficient to monitor which tank is in use when running on different fuels. This might be used to verify entries in, for example, a manual fuel log.

An interesting follow-up project to this work would be to conduct a more, long-term demonstration (6 –12 months) of a measurement system that is operated and calibrated entirely by the ship’s crew and with true changes of fuel used.

5 REFERENCES

Ahlbom J. and Duus U. (2003) ‘*Rent skepp kommer lastat’*, (In Swedish) report of Project Grön Kemi. Exhaust measurements on *MV Aida* included in the report were carried out by IVL in April 2002.

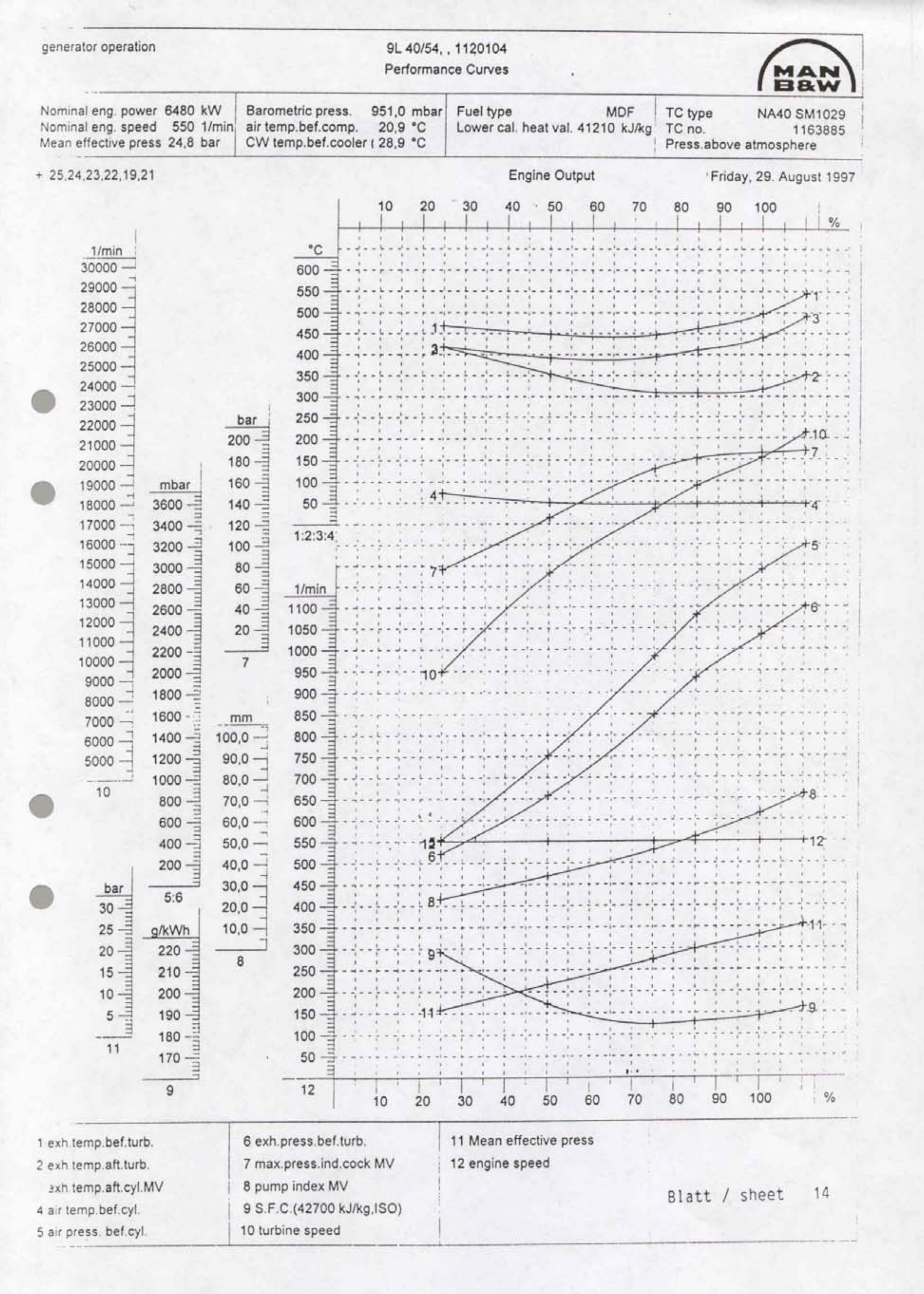
Hansén, O., Gavelius, M., Jacobsson, J., Cooper, D. and Flodström , E. (2003) *‘Feasilibity of emission trading at sea – Phase 1 draft document 2003-05-16*’

Cooper, D & Flodstrom E, (2003) ‘*Continual NOx emission monitoring on board Manon and Stena Jutlandica*, IVL Rapport U-826

ISO 8178 (1996), *'ISO 8178 - Reciprocating internal emission combustion engines - Exhaust emission measurements, Parts 1 and 2*'.

APPENDIX 1

APPENDIX 2


generator operation
9L 40/54, , 1120104
Performance Curves
MAN B&W
Nominal eng. power 6480 kW
Nominal eng. speed 550 1/min
Mean effective press 24,8 bar
Barometric press. 951,0 mbar
air temp.bef.comp. 20,9 °C
CW temp.bef.cooler (28,9 °C
Fuel type MDF
Lower cal. heat val. 41210 kJ/kg
TC type NA40 SM1029
TC no. 1163885
Press.above atmosphere
+ 25,24,23,22,19,21
Engine Output
Friday, 29. August 1997
1 exh.temp.bef.turb.
2 exh.temp.aft.turb.
exh.temp.aft.cyl.MV
4 air temp.bef.cyl.
5 air press. bef.cyl.
6 exh.press.bef.turb.
7 max.press.ind.cock MV
8 pump index MV
9 S.F.C.(42700 kJ/kg,ISO)
10 turbine speed
11 Mean effective press
12 engine speed
Blatt / sheet 14

APPENDIX 3

Imes Cylinder Pressure Measuring EPM-XS/XL

2003-12-18 09:38:51

Ship/PowerStation	Engine Type	Data read
		2003-11-11 16:17:53

Engine Power [kW]	Power A Side [kW]	Power B Side [kW]
5656		

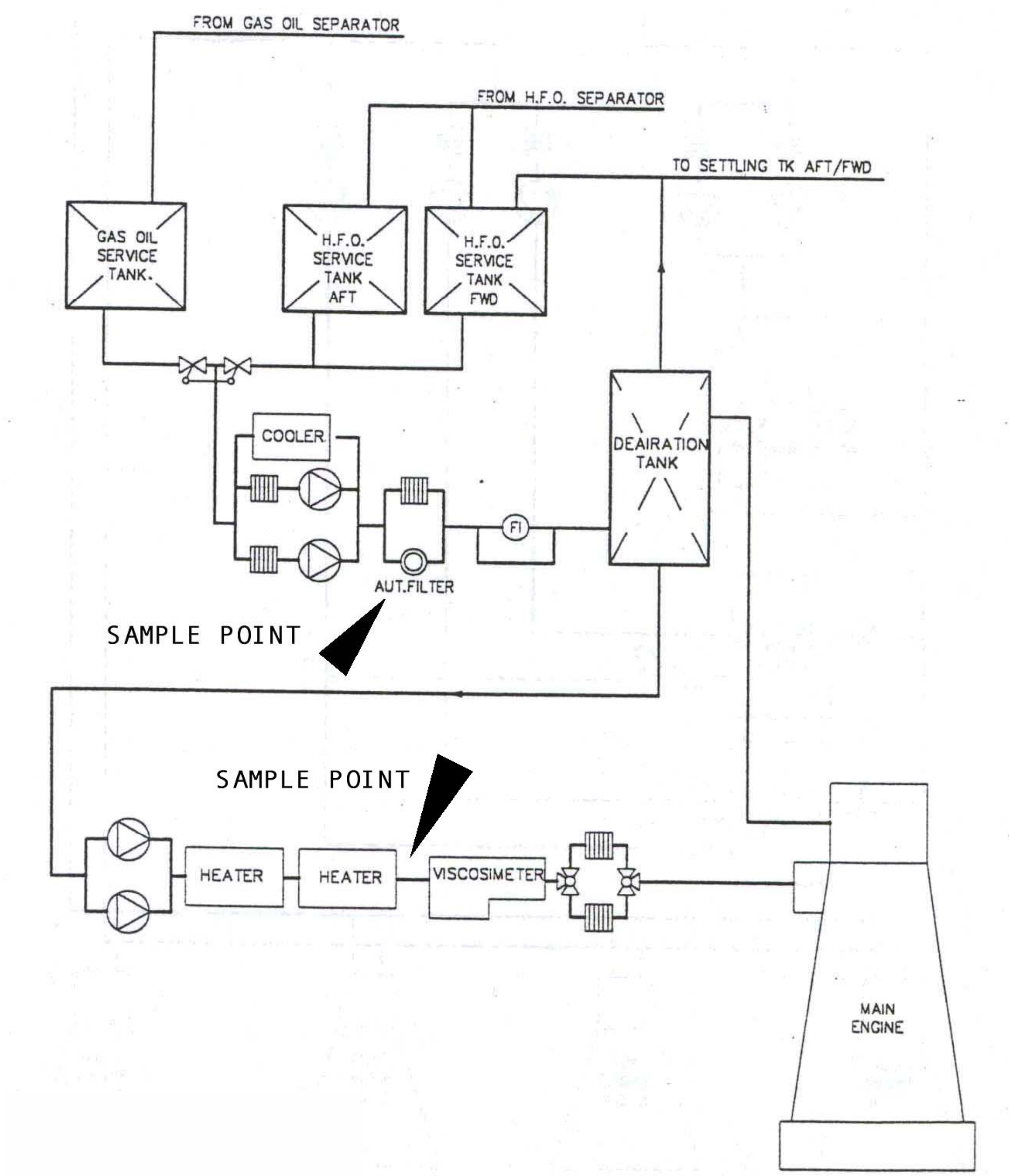
Load	Scav.Air Temp	Scav.Air Press.	TC Speed I	TC Speed II	TC Press. I	TC Press. II
6,2	44,4	2,3	17900			

Angle at PComp	Angle at Injection Start	Angle at Inlet Valve Open	Angle at Exhaust Valve Open
0	0	0	50
	Angle at Exhaust Valve Close	Regulator Index	Sea Water Temp.
	40		11

Cylinders	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Pmaxmean	172	168	168	171	175	166	165	163	163											
Pmaxmax	173	170	169	173	176	168	166	165	164											
Pmaxmin	170	167	166	169	173	164	162	161	162											
T Exhaust	419	387	429	414	405	400	445	428	404											
Pump Index	52	52	52	52	52	52	52	52	52											
MIP	20.49	20.00	19.80	20.59	20.96	19.88	20.71	20.46	20.32											
Power [kW]	632	617	611	637	647	614	641	630	627											
RPM	546	546	546	547	546	547	548	545	546											
Cycles	10	10	10	10	10	10	10	10	10											
Alpha Pmax	13	12	11	12	11	12	12	13	13											
Pcomp	150	148	150	147	150	148	144	148	147											
Pinj	150	148	150	147	150	148	144	148	147											
PInl_open	150	148	150	147	150	148	144	148	147											
PExh_open	54	51	51	52	52	51	51	52	51											
PExh_close	75	71	70	72	72	71	70	72	71											
Max change	4.4	4.4	4.5	4.3	4.4	4.4	4.3	4.4	4.4											

APPENDIX 4

HFO Fuel System Sampling Points



Appendix 9 - Quality Assessment

Two main sources of uncertainty in any emissions inventory (as pointed out: in the GhG Protocol and Eurochem, 2000)

Systemic uncertainty is a consistent difference between a measurement and its true value that is not due to random chance. Systemic uncertainty depends on the internal system adopted to calculate and report emissions data to corporate level. Usually a company has direct control over the choice and management of calculation protocols and internal reporting system. Therefore, companies can ensure low systemic uncertainty by adopting appropriate quality assurance practices.

Systemic uncertainty in this application can for example result from choices such as follows:

- use of emission factors that are poorly researched and uncertain eg in baseline methodology
- use of 'average case' factors not perfectly matched to specific and varying circumstances (e.g. average g NOx/kWh) eg in choosing logged time scale
- deliberate estimation to compensate for missing data (e.g. non-reporting facilities, or missing fuel bills) eg BET
- assumptions that simplify calculation of emissions from highly complex processes eg assumption of complete combustion in calculation

Inherent uncertainty is a difference due to random error, or due to fluctuations between a measurement and its true value. Inherent uncertainty depends on the calculation methodology used, and the measurement of activity/emissions data. In all methods for inventory development, some sources of inherent uncertainty will always be present.

Inherent uncertainty results from random errors such as:

- imprecise measurement of emissions-producing activity (e.g. hours per year specific equipment is used)
- insufficient frequency of measurement to account for natural variability
- instrument noise
- poor calibration of measuring instruments
- human errors of calculation and omission (human errors can be systematic as well i.e. due to misunderstanding or insufficient training).

Inventory quality procedures

In order to minimize uncertainties, the GhG Protocol suggests the companies developing inventories should employ consistent inventory quality procedures. [1]

We find these steps important and useful as a quality standard for the Demo Project as well.

1. Adopt and apply relevant accounting and reporting principles

The accounting and reporting principles explained in the following chapter is the first step toward increased credibility, if these are followed in all phases of the inventory development process.

2. Use a standardized system for calculation and internal reporting

Minimizes the risk of inaccurate reporting.

[1] Chapter 8, "Managing Inventory Quality" in The Greenhouse Gas Protocol, www.ghgprotocol.org.

3. Select an appropriate calculation methodology

The desired level of inventory quality relates to need of the market, i.e. a marketable emission reduction. As the Demo Project goal is to enable emissions trading the emission factors need to be derived from ship fuel and equipment data.

4. Set up a robust data collection system

The importance of a robust data collecting system is crucial to avoid errors.

5. Establish appropriate information technology controls

To ensure authorized use of relevant computer applications, such as calculation protocols, databases, internal and external reporting files, and back-up information.

6. Undertake regular accuracy checks for technical errors

Technical errors can result from various sources such as:

- incomplete identification of emissions sources
- use of incorrect methods or assumptions
- errors in converting measurement units
- use of incorrect data
- mistakes in data entry
- incorrect use of spreadsheets or calculation tools
- mathematical miscalculations

The inventory development process should include numerous quality checks on a regular basis to spot any of the technical errors listed above. The quality checks can take various forms, e.g.:

- track and verify data input
- check spreadsheet formulae
- compare derived emissions factors with published factors
- compare fuel purchase with total fuel use from all identified combustion emissions sources

7. Conduct periodic internal audits and technical reviews

Internal experts who are not directly involved in the inventory development process should carry out periodic technical reviews and audits. These audits shall also include organisational and routine functionality.

8. Ensure management review of the information

It is important that the management are involved in the feedback process in order to gain knowledge of the system functionality.

9. Organize regular training sessions for inventory development team members

In order to ensure the Crews knowledge and to minimise human errors.

10. Perform uncertainty analysis

Qualifying and/or calculating the error range of an emissions estimate should be carried out to evaluate the quality of emissions estimates. Uncertainty, its sources, and methods for its quantification are discussed in following sections.

11. Obtain independent external verification

This is further described in the Verification Section

Appendix 10 - The Level of Sustainability Assurance

Verification engagements performed by PricewaterhouseCoopers include audits, reviews and engagements to perform agreed upon procedures. The characteristics of each type of engagement, including the levels of assurance provided, are summarised in the following table, and described more fully below.

Table 1

	Audit	**Review**	**Agreed upon procedures**
Scope determined by	Auditor	Auditor	Agreed by parties
Tailored to users' needs	No	No	Yes
Cost	Higher	Medium	Depends on work executed
Flexibility	Low	Low	High
Suitability	Limited to past events	Limited to past events	Relevant to past and future events
Publication of report	Yes	Yes	Limited to addressee only; no publication
Level of assurance	Higher	Lower	None
Time to execute	Long	Shorter	Depends on tasks performed
Usefulness	High	Limited	Depends on parties needs

Until emissions measurement and reporting standards are finalised and recognised, the majority of verification work will be by the completion of agreed upon procedures.

The audit, review and agreed upon procedures principles, concepts, working practices (planning, execution and completion) and other policy matters applicable to financial engagements are equally applicable to, and should be followed in, emission reductions verification engagements.

Audit

In much the same way that a financial audit is performed, an audit of emission reductions data draws on financial auditing standards to provide a high, but not absolute, level of assurance that the information subject to audit is free of material misstatement. The auditor plans and executes the required work under these professional auditing standards.

In an emission reduction audit, the auditor will be required to provide assurance that the data subject to the audit has been measured/reported in accordance with a predetermined emissions measurement and reporting standards and is free of material misstatement. Until recognised emissions measurement and reporting standards are developed, the preparer of emissions data will need to define the measurement/-reporting framework that has been used to prepare the emissions data.

The auditor's report on the emissions data will be based on this disclosed measurement and reporting framework. The auditor will therefore need to determine and indicate in the report whether this is a generally accepted framework, both nationally and internationally, and whether the auditor is satisfied that it is appropriate in the circumstances.

The output of a high level assurance is an Audit Opinion. A high level may be suitable for commenting on information including performance data, governance and completeness of coverage in terms of issues. A high level assurance requires significant testing at both Group and business unit level with materiality/risk-based sampling carried out at, for example, site level. As an indication, a high level assurance is in compliance with ISA 100.

Review

The objective of a review engagement is to enable the auditor to state whether, on the basis of procedures performed (which do not provide all the evidence that would be required in an audit), nothing has come to the auditor's attention that causes the auditor to believe that the data being reviewed is not free of material misstatement. The auditor performs the review and reports in accordance with established professional auditing standards applicable to review engagements.

Again, until recognised emissions measurement and reporting standards are developed, the preparer of emissions data will need to define the measurement/reporting framework that has been used to prepare the data. The auditor's report on the data will be based on this disclosed measurement and reporting framework. The auditor will therefore need to determine and indicate in the report whether this is a generally accepted framework, both nationally and internationally, and whether the auditor is satisfied that it is appropriate in the circumstances.

The scope of the work performed in a review remains the responsibility of the auditor, but, as the nature, timing and extent of the procedures are less extensive than those performed in an audit engagement, the auditor is less likely to become aware of all significant matters.

The review is what PricewaterhouseCoopers call a medium level of assurance and the assurance is therefore expressed, by way of a positive or negative assurance.

The output of a positive assurance is constituted of Review Findings. This level is suitable for moderately large assignments where Group and/or business unit aggregation is tested and some sites are visited but the sample of sites is not sufficiently large to allow high assurance. It is suitable for commenting on Group level governance arrangements, data gathering and reporting systems, completeness of coverage in terms of issues and moderate level assurance of performance data. As an indication, a medium level (positive) assurance is in compliance with ISA 100 (with less scope than the high level)

The output of a negative assurance is also constituted of Review Findings. This level is suitable for assignments with medium to large clients but small scope of work, for example, testing Group level aggregation of site level data, reviewing policies and governance arrangements. As an indication, a medium level (negative) assurance is in compliance with ISA 910.

Agreed upon Procedures

In an agreed upon procedures engagement, the auditor is engaged to carry out specific procedures and report the results of these procedures to parties who have agreed the procedures performed. As the auditor does not determine the nature, timing or extent of these procedures, no assurance is expressed. The auditing standards provide guidance as to how the agreed procedures are to be undertaken but not what is to be completed.

The auditor reports information about the work performed together with the factual findings, to allow the parties to draw their own conclusions on the adequacy of the data. No assurance is provided. This report is restricted to those parties who have requested and agreed the procedures to be performed since other parties, unaware of the reasons for the procedures, may misinterpret the results.

The output of a low level assurance forms the Agreed-Upon-Procedures. Either a simple public statement setting out simple findings with respect to agreed upon procedures will be given or no public statement, only a management report will be made. This level is able to cover the majority of subject matter in the sustainability field. As an indication, a low level assurance is in compliance with ISA 920.

Appendix 11 - Assessment of the Control Environment

Assessment of the control environment is required during the planning phase of the engagement prior to the determining the audit strategy. The client's control environment reflects management's philosophy, attitude and demonstrated commitment to establishing a positive atmosphere for the implementation and execution of well-controlled activities.

It influences strongly the effectiveness of the client's systems of control and, accordingly, PricewaterhouseCoopers ability to rely on those controls.

Elements of the control environment	Control factors
Corporate policy	Policy includes commitment to emissions reduction issues ✓ is signed by top management ✓ is adequately communicated to all levels within the entity
Identification and management of high level emissions reduction activities	Procedures to ensure business activities with significant impacts are identified/managed are in place and address: ✓ responsibilities ✓ training ✓ planning ✓ operational process controls ✓ monitoring and measurement
Action plans to achieve objectives and targets	Documented plans are prepared (as part of the business planning process) at relevant operational and functional levels, and include: ✓ actions, including expected outcomes ✓ resources ✓ milestones ✓ responsibilities ✓ reporting ✓ monitoring At the individual Ship level: ✓ ship records and procedures demonstrate that operational changes reported as undertaken have in fact been implemented ✓ such actions are documented and accurate ✓ ship records demonstrate that abatement actions have been effectively implemented (e.g. approval for capital expenditure, invoices for services and/or equipment) ✓ ship records are accurately transmitted to head office for aggregation purposes
Emission forecasts (perhaps not necessary)	✓ are documented at relevant operational and functional levels ✓ level of uncertainty associated with attainment of forecasts has been realistically considered
Emissions Reduction responsibility and resources	✓ sign off of reports, etc by CEO/senior management ✓ responsibility for actions is allocated to line managers with appropriate allocation of specific technical resources

Elements of the control environment	Control factors
	✓ other members of the entity recognise individuals with specific responsibility
Staff training and awareness	✓ employees with responsibilities are competent in the relevant field
Internal and external communication	✓ emissions reduction issues are part of general entity communication ✓ included in internal and external corporate reporting
Internal data management process documentation	✓ system of documented processes is in place ✓ at ships, evidence that managerial processes are consistent with corporate level policy and procedures
Management of operational documents	✓ documents required to measure, monitor, calculate and report emission inventories, to implement abatement actions, and to maintain operational processes are controlled for status, completeness and availability
Controls for significant operations	✓ documented operational controls are in place to manage processes that can affect Nox or So2 emissions ✓ controls/criteria are understood by process operators ✓ process operators are aware of impacts of deviation from established process control parameters ✓ process equipment is maintained in accordance with specified requirements and to meet emission control requirements (in future system) ✓ plans are in place to control and mitigate emergencies that can generate unexpected or increased material emissions, and to ensure that such emissions are reported
Monitoring and measurement of emissions	A complete documented process for the collection and update of emissions information is in place, including: identification of data requirements to allow all emissions to be either measured (i.e. – factual), estimated (i.e. – with assumptions specified and explained) or calculated (i.e. – on a scientific basis from actual or assumed data) calibration and control of required measuring devices traceability, identification and tracking of data from source to processing, aggregation and reporting clear identification of sources of data (e.g. energy, fuel consumption, etc) for aggregate baseline adjustments in respect of acquisitions, divestments, retirements, commissioning, out-sourcing and transfer of assets, etc provision of accurate data related to activity levels where these form the basis of comparability of the emissions inventory consistent use of scientifically verifiable calculation and assessment procedures, including use of appropriate emission factors and units of measurement At the individual ship level, internal checking procedures are in place to ensure consistency of data, for example: invoices and monitoring data for fuel are consistent with head office aggregated data ship figures are consistent with aggregated data

Elements of the control environment	Control factors
	ship data and derived information is clearly identified as factual, estimated or calculated
Access to systems	✓ System and application security should be adequate to prevent unauthorized access to sensitive functions. ✓ -Only appropriate users can enter data and duties are adequately segregated ✓ - There are controls in place to prevent and / or detect duplicate transactions. ✓
Standing data maintenance	✓ - Only appropriate users can enter updates to sensitive data on the master files (e.g. vendors, items, prices). The updates are subject to independent review and approval. ✓
Segregation of duties	✓ - Procedures should be in place to ensure that duties are adequate segregated throughout the process. ✓ - User access to the computer operating system and programs should be appropriately restricted.