Emissions for the ferry routes: 1) Rødby - Puttgarden, 2) Gedser - Rostock and 3) Trelleborg - Rostock

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Introduction

It is the objective of this report to present calculations of the emissions from the ferries on the routes between 1) Roedby - Puttgarden, 2) Gedser - Rostock and 3) Trelleborg - Rostock in 2025. The paper also describes the calculation methodology, i.e. the assumptions about sailing schedule and the associated ferry technology (ferry types and development of engine technology). In connection with such long term predictions it is also important to consider the legislation and regulations on environmental issues which will have a great impact on the development of the engine technology and the quality of the fuel used by the ferries over the next decades (as example content of sulphur).

Rødby - Puttgarden

Today 5 ferries are sailing on the route, 4 identical ferries, built in 1997, with a capacity of 365 cars and an old small ferry *Holger Danske*, with a capacity of approx. 50 cars. This ferry is solely used for carriage of dangerous goods. This ferry is disregarded in the analysis described in this report.

Reference for the scenario in 2025, is the transport work done in 2003 by the four double-ended ferries on the route. As the four big ferries were built in 1997 they should still have more than 30 years expected operation left before scrapping seen from a statistical point of view. Therefore they are considered still active in the 2025 scenario however in a lengthened version. According to the data supplied by COWI for this analysis the scenario with the existing ferries in a lengthened version should be sufficient while keeping the same number of crossings per year as to day, see table 1 and fig. 1 and 2.

According to table 1 the traffic increase is 5162000/3217969 x 100 = 160 % from 2003 to 2025. Keeping the sailing frequency unchanged (number of sailings per ferry per year) the average utilization will slightly decrease from 32 to 30 %.

Table 1 Ferry statistics including data from COWI for 2025
Rødby Puttgarden - Statistics 1997 - 2009 based on ShipPax Information Statistics

	1997	1998	1999	2000	2001	2002	2003	2009	2025
Number of trips	32323	32424	34424	35180	34450	35578	34449	34541	34541
Number of trips (Holger Danske)	0	0	2190	2190	2190	2190	2190	2190	2190
Number of trips (remaining 4 ferries)	32323	32424	32234	32990	32260	33388	32259	32351	32351
Number of trips per remaining ferry	8081	8106	8059	8248	8065	8347	8065	8088	8088
Passenger total	5974575	5850475	5616722	5429932	6027887	6612993	6421490	6304798	6421490
Cars total	932855	968020	1016972	1182544	1382678	1589125	1574369	1667080	2377000
Busses total	35304	33889	31248	30575	32066	34673	33038	27993	48000
Trailers total	254903	264346	259191	280164	274265	275081	278482	314394	509000
Railway wagons	20095	9938	9638	9664	9344	9750	8600	8600	0
Equivalent car units	2584840	2558575	2565547	2832879	3007773	3235395	3217969	3465015	5162000
Mean capacity per ferry	294	294	290	290	290	290	291	365	502
Car equivalents per trip	80	79	75	81	87	91	93	100	149
Utilization in %	**27.2**	**26.8**	**25.7**	**27.8**	**30.1**	**31.4**	**32.1**	**34.4**	**29.8**

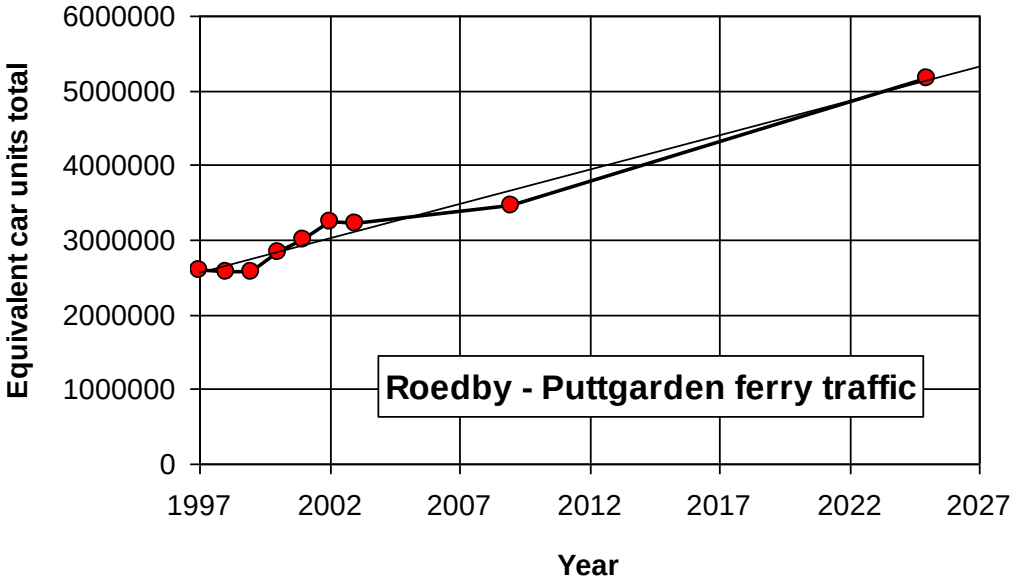

Fig. 1 Development of ferry traffic in car equivalent units for Rødby - Puttgarden including assumptions in 2025

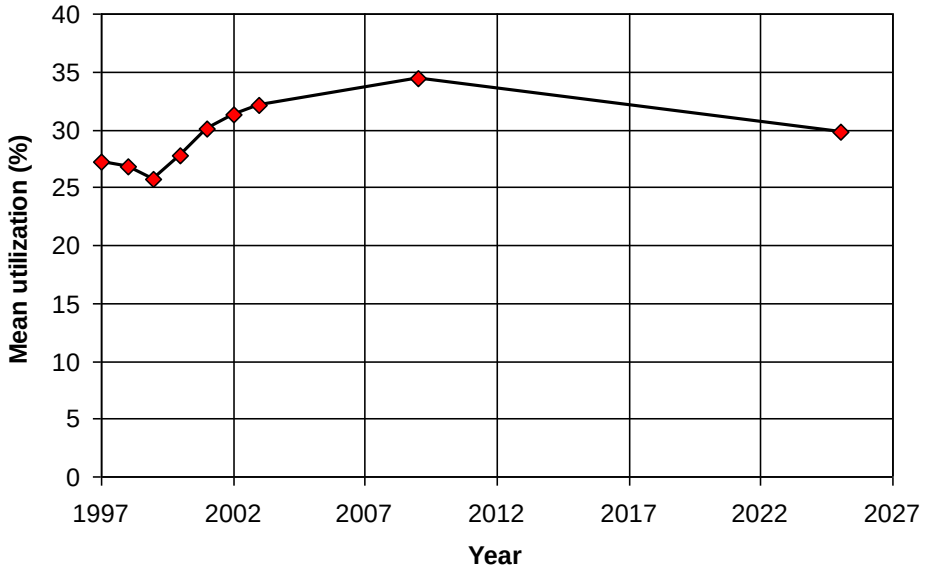

Fig. 2 Development of the mean car capacity utilization of the ferries on the Roedby-Puttgarden route since the introduction of the new ferries in 1997

Development of engine technology

For the existing ferries it is assumed that the propulsion engines (diesel-electric machinery) will remain unchanged with respect to oil consumption over the rest of the operation period extending beyond 2025.

Ferry types

The different ferry types used in the present analysis have been summarized in table 1.

The ferry types are as follows:

Type 0: Existing ferry type on the route without platform deck when the ferry was built in 1997
Type 1: Existing ferry type with an extra platform deck giving extra person car capacity
Type 2: Existing ferry type in lengthened version (+ 40 m)

The ferry alternatives are realistic alternatives for each of which a detailed route analysis has been carried out to calculate the necessary propulsion power in order to calculate the fuel oil consumption

Table 2 Size and capacities for the ferry alternatives used in the analysis for Roedby - Puttgarden

Ferry type	Length	Breadth	Car capacity	Lanes for lorries	Equivalent car capacity *)	Relative fuel oil consumption
	(m)	(m)	(person cars)	(m)	(person car units)	(100 %)
0	134	24	128	580	290	100
1	134	24	265	290	350	102
2	174	24	95	1420	500	130

*) The equivalent car capacity has been calculated by the factors from the TEMA 2000/2010 model

Exhaust gas emissions

There is strong focus on the emissions from shipping especially on NOx and SO_2 emissions. According to the MARPOL Annex IV regulations and as the Baltic Sea is a so-called sulphur emission control area there will be a sulphur limit of 1.0 % in the fuel oil used on the ships sailing in this area from 2010 and this limit will be 0.1 % from 2015. The diesel engines shall also fulfil special requirements with regard to NOx emissions which have been known for some years, such that many engines built since 2000 are already fulfilling these NOx requirements, the so-called Tier I requirements.

In the coming years the engine technology becomes more and more refined such that the engines will be governed more and more electronically (as example the so-called “common rail” technology), such that the combustion process can be controlled to minimise the exhaust emissions, especially the NOx emissions. Another measure to reduce the emissions (also the other products than NOx) is the use of exhaust gas catalysts. One of the leading companies in this market is the Danish company Haldor Topsøe A/S, which has developed catalysts not only for NOx reduction but also for reduction of unburned hydrocarbons (HC) and particles (PM).

Using catalysts and other technical measures for reduction of exhaust emissions has a negative economical influence on the ships´ building price and on the operation costs. When these measures become more and more common the price will decrease. There will probably also be a clear political and environmental pressure which means that it will probably be normal to use engines with low NOx exhaust gas emissions. Therefore the NOx emissions have been assumed reduced by 80 % in 2025 compared with the present standard, i.e. the present NOx level at Tier I has been reduced to a Tier III level in 2025, although this is not a requirement for existing ferries (except if their engines are modified extensively).

The HC and CO level are assumed unchanged while the PM level is reduced as a consequence of the lower sulphur content. The PM reduction is calculated according to TEMA 2000/2010

Based on the emission factors from TEMA 2000/2010, table 2 and the above mentioned probable reductions in emission factors revised emission factors have been calculated as shown in table 3. These factors have

been used for calculations of the exhaust emissions shown in table 4, where the transport capacity, energy demand and exhaust emission are listed for the selected alternatives.

Table 3 Emission factors for 2025 for Roedby - Puttgarden

Ferry type		**Type 0**	**Type 1**	**Type 2**
Year of operation		2003	2025	2025
Number of car units per ferry	(-)	290	365	500
Reduction in specific fuel oil consumption	(%)	0	0	0
Specific fuel consumption	(g/kWh)	190	190	190
Energy consumption per trip	(%)	100	102	130
CO_2 emission factor	(g/kg oil)	3206	3206	3206
CO_2 emission factor	(g/kWh)	609	609	609
NOx emission factor	(g/kWh)	12	2.4	2.4
NOx emission factor	(g/kg oil)	63	12.6	12.6
Sulphur content	(%)	0.75	0.1	0.1
SO_2 emission factor	(g/kWh)	2.99	0.40	0.40
SO_2 emission factor	(g/kg oil)	15.8	2.1	2.1
HC emission factor	(g/kWh)	0.50	0.50	0.50
Catalytic HC emission factor	(g/kg oil)	2.63	2.63	2.63
CO emission factor	(g/kWh)	1.6	1.6	1.6
CO emission factor	(g/kg oil)	8.4	8.4	8.4
Particulate emission factor (PM)	(g/kg oil)	1.37	1.13	1.13
Particulate emission factor (PM)	(g/kWh)	0.26	0.21	0.21

Ferry types

Type 0	Existing ferry type on Roedby-Puttgarden
Type 1	Existing ferry type on Roedby-Puttgarden with ex
Type 2	Existing ferry in lengthened version (+ 40 m)

Table 4 Calculated emissions for Roedby-Puttgarden in 2025

Ferry emission scenarios for 2025 for Roedby - Puttgarden

Year		**2003**	**2025**	**2025**	**2025**	
Assumed number of ferries	(-)	4	4	4	4	**Interpolation sheet**
Assumed ferry types on the route		4 x Type 0	4 x Type 1	2 x Type 1 + 2 x Type 2	4 x Type 2	**2025**
Transport capacity for all ferries per crossing	(cars)	1160	1460	1730	2000	1861
Transport capacity in percentage	(%)	100	126	149	172	**160**
Total oil consumption	(tons/year)	35485	36195	41162	46130	43569
Total energy consumption	(TJ/year)	1519	1549	1762	1974	1865
Total CO_2 emissions	(tons/year)	113552	115823	131720	147617	139420
Total NOx emissions	(tons/year)	2241	457	520	583	550
Total SO_2 emissions	(tons/year)	559	76	86	97	91
Total HC emissions	(tons/year)	93	95	108	121	115
Total CO emissions	(tons/year)	299	305	347	388	367
Total PM emissions	(tons/year)	49	41	46	52	49

Gedser - Rostock

On Gedser - Rostock two new large ferries are under construction which will be in operation in 2012. These ferries will be powered by diesel engines, but they have been prepared for conversion to LNG driven operation in the future, if LNG becomes more avaiable, especially in the Baltic region, where there are already serious discussions for a possible change from diesel operation to LNG operation as is already seen in the Norwegian infrastructure at several domestic ferry routes.

Emission factors as they are expected in 2025 assuming LNG operation are given in table 5. The average fuel consumption is based on values from Scandlines presented at a ferry conference on the 22 November 2010 in Skibsteknisk Selskab.

Table 5 Expected emission factors for LNG operation of new ferries on the Gedser - Rostock route

Ferry type		**Type 0**	**Type 0**	**Type 0**
Year of operation		2025	2025	2025
Number of equivalent car units per ferry	(-)	570		
		DO	**LNG**	**94% LNG + 6 % DO**
Specific fuel consumption	(g/kWh)	190	165	167
CO_2 emission factor	(g/kg fuel)	3206	2750	2777
CO_2 emission factor	(g/kWh)	609	454	
CO_2 emission factor	(g/MJ)	74.9	55.0	
NOx emission factor	(g/kWh)	9.6	3	3.4
NOx emission factor	(g/kg oil)	51	18	20.1
Sulphur content	(%)	0.1	0	
SO_2 emission factor	(g/kWh)	0.40	0	
SO_2 emission factor	(g/kg oil)	2.1	0	0.1
HC emission factor	(g/kWh)	0.50	0.50	
HC emission factor	(g/kg oil)	2.63	2.63	2.6
CO emission factor	(g/kWh)	1.6	1.60	
CO emission factor	(g/kg oil)	8.4	8.42	8.4
Particulate emission factor (PM)	(g/kg oil)	1.13	0.23	0.3
Particulate emission factor (PM)	(g/kWh)	0.21	0.04	
Mean fuel consumption per trip	**kg/trip**	**3600**		**3155**

In table 6 and fig. 3 is given the ferry statistics for the route including an assumption for 2025.

Table 6

Gedser - Rostock - Statistics 2004 - 2009 based on ShipPax Inforn

	2004	**2008**	**2009**	**2025**
Number of trips	5577	7285	6549	**6550**
Number of trips per ferry	2789	3643	3275	**3275**
Passenger total	1264041	1642781	1516980	
Cars total	212490	301625	279842	
Busses total	15282	15169	13911	
Trailers total	70952	106185	80040	
Railway wagons	0	0	0	
Equivalent car units	643660	908395	749597	**1370000**
Mean capacity per ferry	200	200	200	**480**
Car equivalents per trip	115	125	114	**209**
Utilization in %	**57.7**	**62.3**	**57.2**	**43.6**

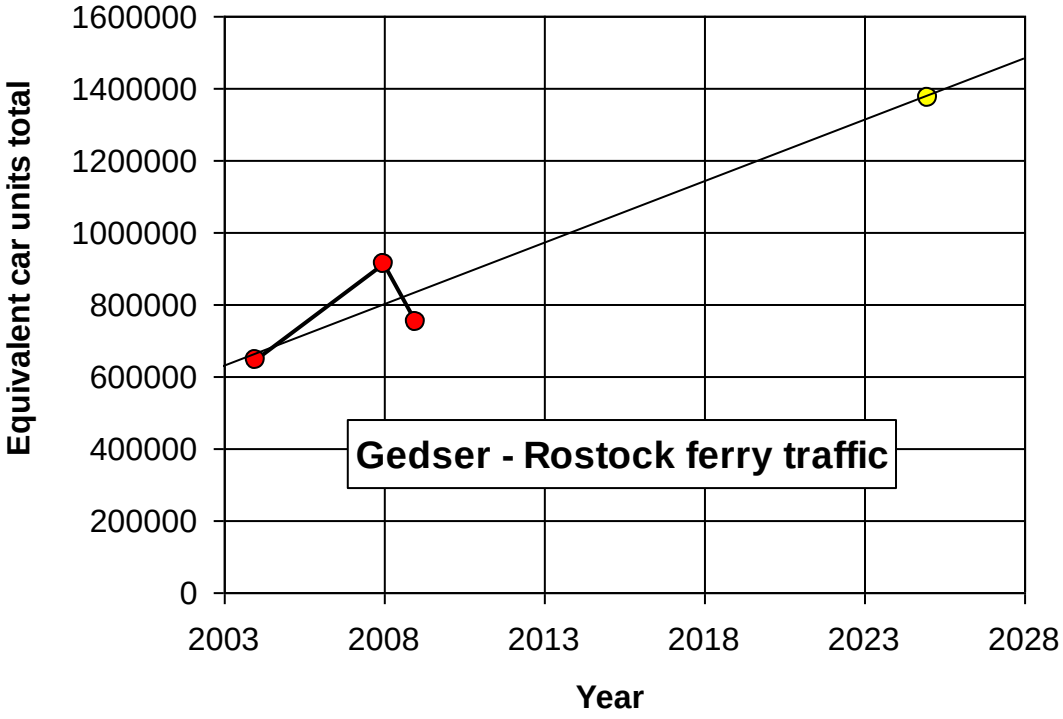

Fig. 3 Traffic on Gedser - Rostock

Based on the above mentioned assumption for traffic in 2025 (6550 trips/year) the emissions have been calculated by using the basic consumption and emission figures in table 5 and the results are shown in table 7.

Table 7 Emission figures for 2025 for Gedser - Rostock

Year		**2025**
Number of crossings per year		6550
Transport capacity per ferry per crossing	(cars)	480
Total fuel consumption	(tons/year)	20664
Total CO_2 emissions	(tons/year)	57390
Total NOx emissions	(tons/year)	416
Total SO_2 emissions	(tons/year)	3
Total HC emissions	(tons/year)	54
Total CO emissions	(tons/year)	174
Total PM emissions	(tons/year)	6

Trelleborg - Rostock

This route is served by two large ferries *Skåne* and *Mecklenburg Vorpommern* built in 1998 and 1996 respectively. Assuming at least 30 years operation they are assumed to be sailing on the route in 2025. As for Rødby-Puttgarden these two ferries are assumed to use oil with a sulphur content of 0.1 % and the machinery is assumed to have been upgraded to Tier III NOx level which means 80 % NOx reduction compared to the present standard (Tier I).

Emission factors as they are expected in 2025 are given in table 8

Table 8 Expected emission factors for ferries on the Trelleborg - Rostock route in 2025

Year of operation		2025
Number of equivalent car units per ferry	(-)	970
Specific fuel consumption	(g/kWh)	190
CO_2 emission factor	(g/kg fuel)	3206
CO_2 emission factor	(g/kWh)	609
CO_2 emission factor	(g/MJ)	74.9
NOx emission factor	(g/kWh)	2.4
NOx emission factor	(g/kg oil)	13
NOx emission factor	(g/MJ)	0.30
Sulphur content	(%)	0.1
SO_2 emission factor	(g/kWh)	0.40
SO_2 emission factor	(g/kg oil)	2.1
Normal HC emission factor	(g/kWh)	0.50
Normal HC emission factor	(g/kg oil)	2.63
CO emission factor	(g/kWh)	1.6
CO emission factor	(g/kg oil)	8.4
Particulate emission factor (PM)	(g/kg oil)	1.13
Particulate emission factor (PM)	(g/kWh)	0.21
Mean fuel consumption per trip	**kg/trip**	**17500**

In table 9 and fig. 4 is given the ferry statistics for the route including an assumption for 2025.

Table 9
Trelleborg - Rostock - Statistics 2004 - 2009 based on ShipPax Inf

	2004	**2008**	**2009**	**2025**
Number of trips	2036	2034	1828	**2000**
Number of trips per ferry	1018	1017	914	
Passenger total	312730	303369	262817	
Cars total	50897	41627	41293	
Busses total	1356	853	624	
Trailers total	117655	148278	126391	
Railway wagons	26815	17724	8493	
Equivalent car units	914102	964522	761298	**800000**
Mean capacity per ferry	970	970	970	**970**
Car equivalents per trip	449	474	416	**400**
Utilization in %	**46.3**	**48.9**	**42.9**	**41.2**

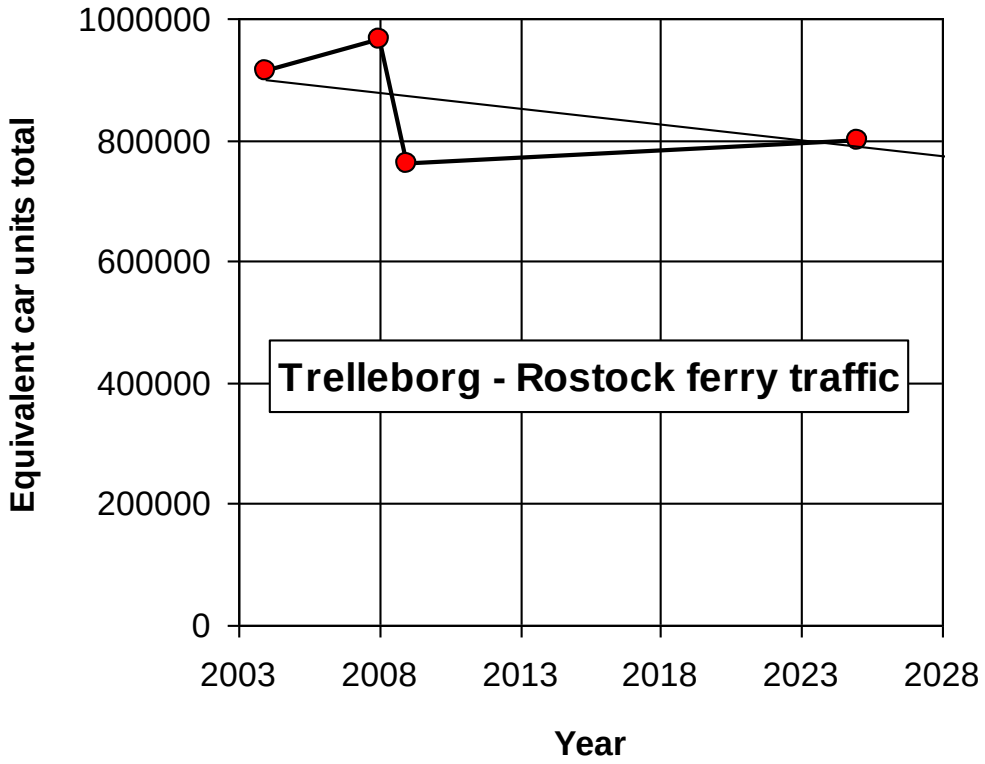

Fig. 4 Traffic on Trelleborg - Rostock

Based on the above mentioned assumption for traffic in 2025 (2000 trips/year) the emissions have been calculated by using the basic consumption and emission figures in table 5 and the results are shown in table 10.

Table 10 Emission figures for 2025 for Trelleborg - Rostock

Year		**2025**
Number of crossing per year		2000
Assumed ferry types on the route		2
Average capacity per ferry per crossing	(cars)	970
Total fuel consumption	(tons/year)	35000
Total CO_2 emissions	(tons/year)	112210
Total NOx emissions	(tons/year)	442
Total SO_2 emissions	(tons/year)	74
Total HC emissions	(tons/year)	92
Total CO emissions	(tons/year)	295
Total PM emissions	(tons/year)	40

Uncertainties of the calculations

Prediction of the exhaust gas emissions in the described scenarios are of course associated with some uncertainties. The basic uncertainties are 1) the number of crossings, 2) the emission factors and 3) the oil consumption per trip.

The uncertainties regarding the number of crossings will not be dealt with in this report, as this issue is solved by COWI. The uncertainties about emission factors is small with respect to sulphur and associated PM emissions as the coming low sulphur requirements are very probable (The Baltic Sea will most probably be an Emission Control Area in the future, at least in 2025. The NOx levels are more unclear. In the present calculations as they are not based on mandatory requirements but more on realistic assumptions which are impossible to quantify.

The oil consumptions per trip for Roedby- Puttgarden and Gedser - Rostock are within plus/minus 10 per cent, while the oil consumption for Trelleborg - Rostock is larger because it is not known with much accuracy which crossing time which will be selected for future operation of the route. To day to sailing times on the route is 6 hours and 7.5 hours. The accuracy of the oil consumption is therefore roughly plus minus 20 per cent.

12th December 2010

Hans Otto Kristensen