

**“Binnenvaart voortdurend duurzaam”  
Environmental Performance of Inland Shipping**

27th January 2004

Final Report

9P1060

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## SUMMARY

In order of Stichting Projecten Binnenvaart (SPB), on behalf of Centraal Bureau voor de Rijn- en Binnenvaart (CBRB) and Koninklijke Schuttevaer, Royal Haskoning conducted this study to assess the environmental performance of different inland vessels in comparison with road transport.

### Goal

The goal of this study is to assess the environmental performance of propulsion engines in inland shipping in Europe as a refinement of the RIVM study "To Shift or not to Shift". This refinement constitutes of a stretching of the time horizon from 2010 to 2020 and the calculation of the effects of reductions on the emissions of inland vessels.

The environmental performance of inland shipping is assessed to clarify whether modal shift towards inland shipping does contribute or does not contribute to improvement of the environmental performance of the entire transport chain. The general environmental performance of a transport modality constitutes of a large number of environmental parameters. Most significant parameters in inland shipping are the Nitrogen Oxides (NO<sub>x</sub>), Carbon Dioxide (CO<sub>2</sub>), Particle Matter (PM<sub>10</sub>) and Sulphur Dioxide (SO<sub>2</sub>) emissions from propulsion engines. Chapter two describes other parameters constituting the environmental performance of inland shipping.

### Conservative assumptions

This study assesses these four types of emissions for different types of inland vessels. The assessments are made for the year 2000 (based on data from different studies), 2010 and 2020 (projections based on changes in legislation (Appendix 6) and technical development). The projections are based on rather conservative assumptions. The SCR-catalyst is taken into account as a promising technique, but other new possible revolutionary techniques as improvements in efficiency of propulsion (Z-drive and whale tail), the reduction of friction (air lubrication of ships) and in reduction of emission as the development of the fuel cell and steamjet aerosol collector (sjac) are not taken into account. The performance of inland transport is compared with "best case" calculations from other studies for road transport. (chapter 7).

## Approach

For several transport routes the emissions as a result of inland shipping will be compared to the emissions as a result of road transport. The emissions will be calculated from the direct vehicle / vessel emissions per kilometre, from the transport distance over road (Figure 2: I) and over water (Figure 2: II) for this specific transport route.

Additionally the cases are selected in which the environmental performance of inland shipping is significantly better than the performance of road transport. In practice transport by inland shipping is often followed by short distance road transport from the port of destination to the final destination. For these selected cases the maximum number of kilometres of additional road transport (Figure 2: a) is calculated at which the environmental performance is still better than the performance of road transport. Finally, for container trades, the maximum number of kilometres of additional road transport is also calculated when Ecotrucks are used for this final step in the transport chain instead of regular trucks<sup>1</sup>.

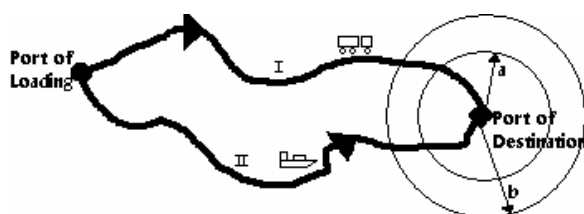


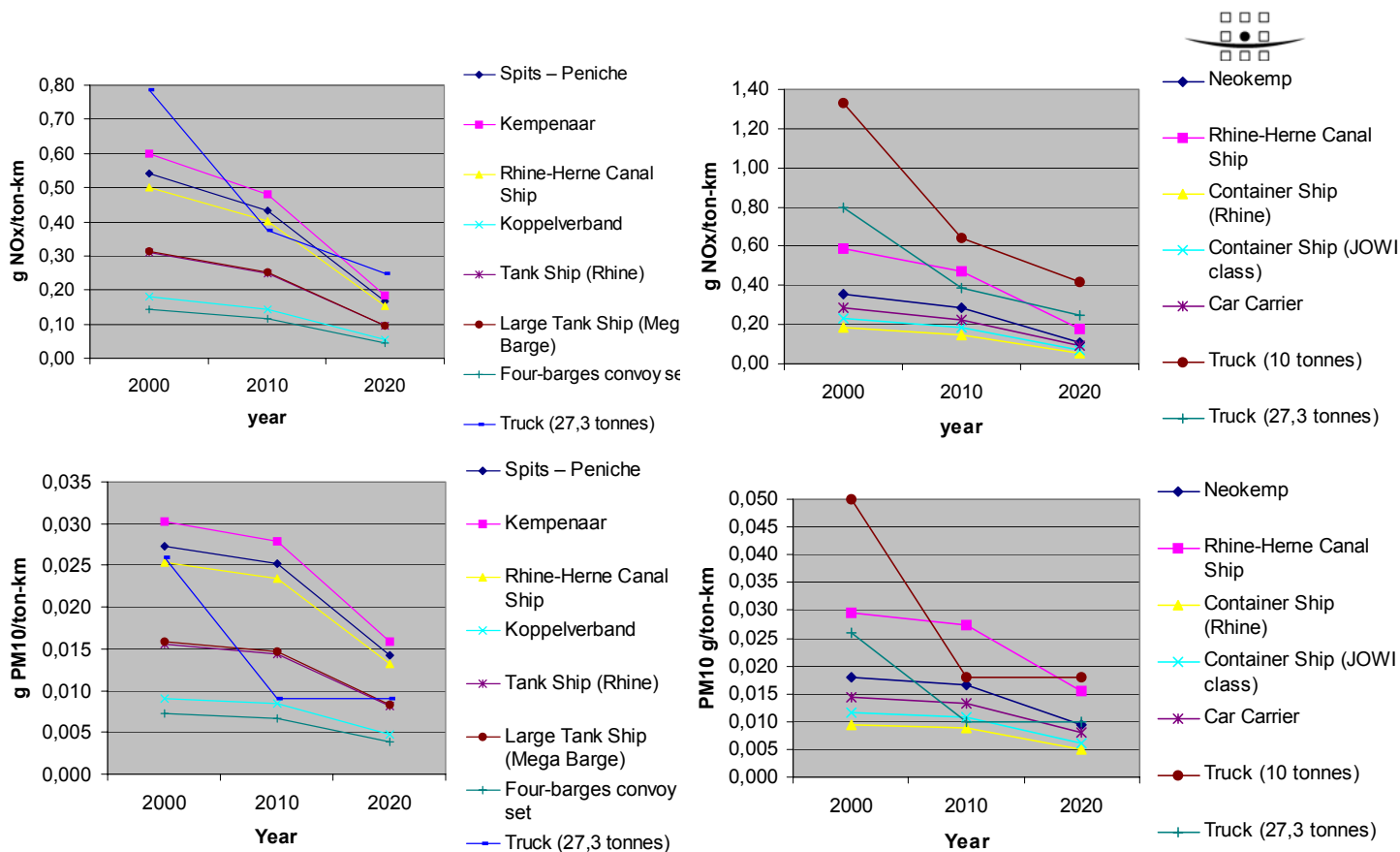
Figure 2: Schematic overview of the study

## Results

Chapter 7 consists of realistic transport cases. The map below shows one of these cases: the transport routes by road by inland ship to transport 11.500 tonnes dry bulk from the Port of Rotterdam to Cologne (Keulen) area. In this case it is compared to transport this load by a large four barges convoy set or by 422 large (27,3 tonnes) trucks. The transport distance for inland shipping is about 60 kilometres more than the distance for road transport. The calculation show that the environmental performance of the convoy set is better than the performance of the trucks. Additionally it is assumed that the load should be transported to a site in the area of Cologne by trucks. The blue circle shows the area within which with respect to the environmental performance it is favourable to use the convoy set for the first step of the transport, followed by a second step of road transport, instead of transporting only by road transport. (See Appendix 5 for details)



<sup>1</sup> Ecotrucks are not considered in the main comparison, because there was no data available in "To Shift or not to Shift" and because in the current Dutch test situation Ecotrucks were only allowed to operate to or from an inter-modal hub.



The graphs above show the reduction of the emissions of Particle Matter and Nitrogen Oxides by different ship types between 2000 and 2020. From the graphs follows that the large reduction for road transport takes place between 2000 and 2010. Due to mentioned factors the large reduction of emissions for inland transport takes place between 2010 and 2020.

### Conclusions

1. It follows from the study that the environmental performance of both road transport and inland transport are dependent from a large amount of parameters. These parameters differ widely between transport cases. Because of this wide variety it is not possible to make a general comparison of the environmental performance of road transport and the environmental performance of inland shipping.
2. The calculations for specific cases in this study clearly show the advantage, with respect to the environment, of inland shipping in relation to transporting only by road transport. Even when inland transport is followed by substantial additional road transport many cases show the advantage with respect to the environment of inland shipping. In most of the cases it can be concluded that modal shift towards inland shipping does contribute to an improvement of the environmental performance of the transport chain.
3. For modal shift towards inland shipping follows from this study it can contribute to an improvement of the environmental performance of the transport chain. This could be a chance in relation to the Kyoto targets for emissions reduction. Further study should quantify these potential benefits (both technical and economic).

4. For cases in which the travelled distance of transport by road transport is equal to the distance for inland shipping and there is no additional (to or from) transport inland shipping has a better environmental performance than road transport.
5. From the case calculations follow great possibilities for relative shorter distance (60 – 150 kilometres) inland shipping with respect to environmental performance. In practice short distance inland shipping is already used for palletized or container transport (Distrivaart concept or Neokemp concept).
6. The innovation towards cleaner and more efficient engines has a large positive effect on both road transport and inland shipping. Because inland ships use engines comparable to road transport the effects of these innovations are comparable. However in general it takes longer until these innovations contribute to a reduction in emissions in inland transport compared to road transport. This is due to two reasons:
  - Manufactures first develop innovations in engines for the large market of road transport. When these innovations are successful the manufactures also make the innovations available to smaller markets as the market of engines for maritime engines vessels.
  - The average lifetime of vessels and engines in inland vessels is higher than the lifetime of engines in road transport. This results in a lower rate of substitution.

The developments in legislation follow on the technical developments. These calculations in this study show clearly the enormous effect of nowadays policy on the environmental performance of inland shipping in the years 2010 and 2020. It can be stated that the environmental performance will make a giant leap in following decades.
7. Draft Directive 2003/476 proposes a limit on the sulphur content of the fuel used for inland vessels of 1.000 parts per million. From interviews during this study follows that a tightening of this limit to 500 parts per million would be technical possible.
8. From the case calculations should be learned that from an environmental point of view inland shipping is an excellent transport mode for the primary step in the transport chain, both long distance and short distance. In many cases the transport by inland ship will be preceded or followed by short distance road transport. In this view inland transport and road transport are ideal complementary transport chain partners for a high performance in efficiency and in environmental aspects.
9. From the calculations for container transport follows that the environmental performance of the transport chain can even be more enhanced when (to and from) road transport takes place with Ecotrucks instead of regular trucks.
10. The two main drivers for the favourable environmental performance of inland shipping are the economies of scale and the low resistance as result of friction.

## **SAMENVATTING**

In opdracht van de Stichting Projecten Binnenvaart (SPB), welke in opdracht van het Centraal Bureau voor de Rijn- en Binnenvaart (CBRB) en de Koninklijke Schuttevaer handelde, heeft Royal Haskoning een onderzoek gedaan naar de milieuprestatie van verschillende typen binnenvaartschepen in vergelijking met transport over de weg.

### **Doel**

Het doel van deze studie is de milieuprestatie te bepalen van het transport per binnenvaartschip in Europa, als verfijning van het RIVM-rapport "To Shift or not to Shift". Deze verfijning spitst zich toe op het verruimen van de tijdshorizon van 2010 tot 2020 en het doorrekenen het effect van reducties van de emissies van binnenvaartschepen. De milieuprestatie wordt bepaald om na te gaan of een verschuiving van vervoer van de weg naar de binnenvaart een bijdrage levert aan de verbetering van de milieuprestatie van de gehele transportketen. De totale milieuprestatie van een transportmodaliteit bestaat uit een aantal milieuparameters. De meest significante parameters voor de binnenvaart zijn de emissies van stikstofdioxide ( $\text{NO}_x$ ), koolstofdioxide ( $\text{CO}_2$ ), fijn stof ( $\text{PM}_{10}$ ) en zwaveldioxide ( $\text{SO}_2$ ) van aandrijvingsmotoren. In hoofdstuk twee worden andere parameters beschreven die de milieuprestatie van de binnenvaart bepalen.

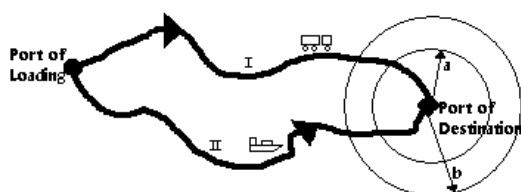
### **Conservatieve aannamen**

De studie bepaalt deze vier emissies voor verschillende binnenvaartschepen. Deze bepaling wordt gedaan voor het jaar 2000 (gebaseerd op werkelijke data), 2010 en 2020 (projecties gebaseerd op veranderingen in EU en CCR wetgeving (Zie Appendix 6)). Deze projecties zijn gebaseerd op conservatieve aannamen. De SCR-katalysator is in de calculaties in deze studie al wel meegenomen, maar andere mogelijk revolutionaire technieken zoals de verbeteringen in de efficiency van de aandrijving (Z-drive en walvisstaart), de vermindering van weerstand (luchtsmering) én de emissiereductie (brandstofcel en sjac) zijn nog niet meegenomen in deze studie. De milieuprestatie van de binnenvaart is vergeleken met "best case" calculaties van andere studies voor het wegtransport.

## Aanpak

Voor verschillende transportroutes wordt emissie als een resultaat van transport per binnenvaartschip, vergeleken met de emissie volgende uit een zelfde transport over de weg. Deze emissies worden bepaald uit de directe voertuig- of vaartuigemissies per afgelegde kilometer. Deze emissies volgen direct uit de afstand over de weg (Figuur 1: I) en over het water (Figuur 1: II) voor deze specifiek transport case.

In de praktijk wordt transport per binnenvaartschip vaak gevolgd of voorafgegaan door een natransport op de weg over een korte afstand. Dit transport vindt dan plaats vanaf de haven van aankomst naar de uiteindelijke bestemming. Voor een aantal geselecteerde cases wordt de afstand natransport (Figuur 1: a) berekend bij welke de milieuprestatie van de combinatie binnenvaart en natransport op de weg een betere prestatie heeft dan die van uitsluitend wegvervoer. Uiteindelijk wordt voor containertransport ook dit maximale aantal kilometers natransport berekend indien er van Ecotrucks gebruik wordt gemaakt<sup>2</sup>.



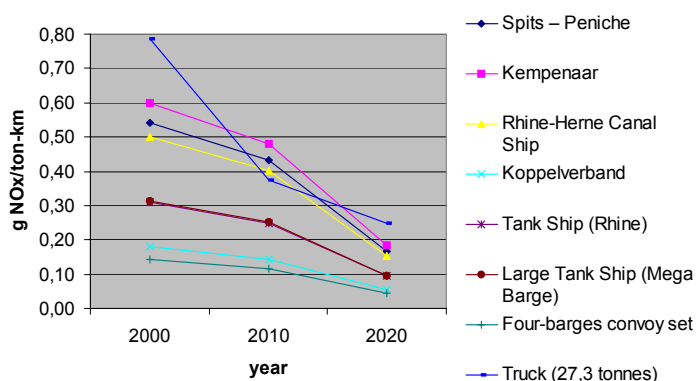
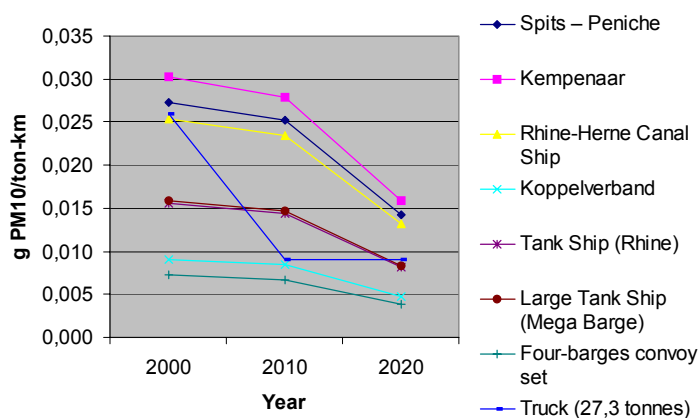
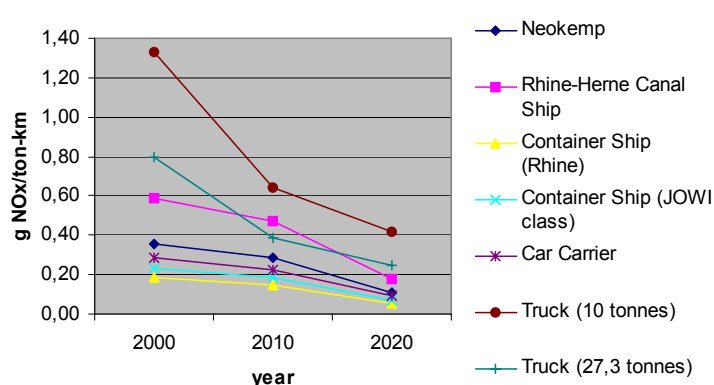
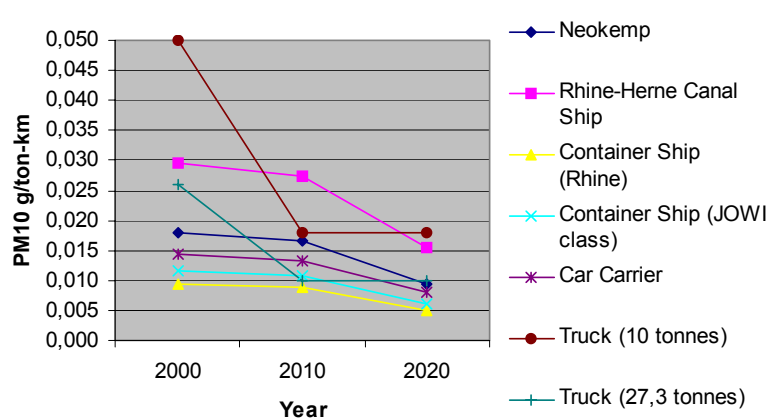
Figuur 1: Schematische weergave van de studie

## Resultaten

In hoofdstuk 7 worden een aantal realistische transportcases doorgerekend. De onderstaande kaart geeft één van deze cases weer: het vervoer over de weg of over het water van 11.500 ton droge bulk vanuit de haven van Rotterdam naar Keulen en omgeving. In deze case wordt de vergelijking gemaakt dit transport uit te voeren met één vierbaks duwcombinatie of met 422 grote vrachtauto's (27,3 ton). De transportafstand per binnenvaartschip is ongeveer 60 kilometer meer dan de afstand over de weg. De berekening geeft duidelijk aan dat de milieuprestatie van de duwbakcombinatie beter is dan die van de trucks. Vervolgens is berekend tot welk aantal kilometers natransport (over de weg) het transport per binnenvaartschip met het oog op de milieuprestatie de voorkeur verdient. (details in Appendix 5)



<sup>2</sup> In deze studie worden Ecotrucks alleen bekeken voor het natransport, dit omdat er binnen "To Shift or not to Shift" hierover geen data beschikbaar was en omdat Ecotrucks binnen de Nederlandse situatie alleen werden toegestaan voor transport van of naar een intermodaal knooppunt.


**Stikstofoxide emissies BULK transport**

**Fijn stof emissies BULK transport**

**Stikstofoxide emissies NON-BULK transport**

**Fijn stof emissies NON-BULK transport**

De bovenstaande grafieken laten de afname van de emissies van fijn stof en stikstofoxiden zien voor verschillende typen binnenvaartschepen tussen 2000 en 2020. Uit de grafieken volgt dat de grootste stap in de afname voor het wegvervoer wordt gezet tussen 2000 en 2010. Om in dit rapport genoemde redenen vindt de grote stap in de afname van de emissies voor de binnenvaart plaats tussen 2010 en 2020.

### Conclusies

1. Uit de studie volgt dat de milieu performance van zowel wegtransport als transport per binnenvaartschip afhankelijk zijn van een groot aantal wijd uiteenlopende parameters. Omdat deze parameters zeer veel verschillen binnen verschillende transport cases is het niet mogelijk de milieu performance van de binnenvaart in *algemene* termen te vergelijken met de milieu performance van het wegtransport.
2. De berekeningen voor een aantal specifieke cases tonen duidelijk het milieuvoordeel van de binnenvaart ten opzichte van het wegverkeer aan. Dit blijkt ook voor cases waarin het transport per binnenvaartschip wordt gevolgd door een substantiële afstand wegvervoer. Voor de meeste cases kan er worden geconcludeerd dat een modal shift naar de binnenvaart een bijdrage levert aan de verbetering van de milieu performance van de gehele transportketen.
3. Uit deze studie volgt dat een modal shift naar de binnenvaart de milieu performance van de transportketen kan verbeteren. Mogelijk biedt dit een kans in het kader van de (Kyoto-)verplichtingen tot emissiereductie. Nadere studie dient te worden verricht om deze bijdrage te kwantificeren (zowel technisch als financieel).

4. Indien de afgelegde transportafstand gelijk is en er geen voor- of natransport nodig is (locaties zijn met het binnenvaartschip bereikbaar) heeft de binnenvaart een betere milieupformance dan het wegtransport.
5. Uit de case berekeningen volgen belangrijke mogelijkheden voor het toepassen van de binnenvaart op trajecten met een relatief kortere afstand (60 – 150 kilometer) met het oog op de milieu performance. In de praktijk blijkt de binnenvaart al succesvol actief te zijn in vervoer van pallets en containers over korte afstand. (Distrivaart- en NeoKemp-concept)
6. De innovatie naar steeds schonere en efficiëntere motoren heeft een groot positief effect op zowel het wegtransport als het transport over de binnenwateren. Omdat de motoren die in binnenvaartschepen worden gebruikt vergelijkbaar, zijn met de motoren die in het wegvervoer worden gebruikt zijn de effecten die de innovaties hebben ook vergelijkbaar. Alhoewel het over algemeen langer duurt totdat deze innovaties ook een bijdrage leveren aan de reductie van de emissies in de binnenvaart. Dit wordt ingegeven door de volgende twee redenen:
  - Producenten voeren innovaties eerst door in de grotere markt van het wegverkeer. Wanneer deze innovaties succesvol zijn, komen ze ook voor de kleinere markt van de binnenvaart beschikbaar;
  - De gemiddelde levensduur van schip en motor in de binnenvaart is hoger dan die in het wegtransport. Dit heeft een lagere vervangingsnelheid van bedrijfsmiddelen zoals de motor tot gevolg.De ontwikkelingen in de wet- en regelgeving volgen de technologische ontwikkelingen op dit vlak. De berekeningen in deze studie tonen duidelijk het grote effect aan dat het huidige beleid heeft op de milieuprestatie van de binnenvaart in de periode van 2010 tot 2020.
7. De ontwerp Richtlijn 2003/4476 stelt een aanscherping van de limiet op het zwavelgehalte van brandstof gebruikt in de binnenvaart voor naar 1.000 parts per million. Uit interviews gehouden gedurende dit onderzoek blijkt dat een verdere aanscherping van deze limiet naar 500 parts per million technisch al mogelijk is.
8. Uit de case berekeningen kan worden afgeleid dat de binnenvaart vanuit een milieuoogpunt een excellente transportmodaliteit is voor de primaire stap in de transportketen, voor zowel de lange als korte afstand. In veel gevallen wordt het transport per binnenvaartschip gevolgd of voorafgegaan door een voor- of natransport over de weg over een beperkte afstand. Vanuit dit gezichtspunt zijn wegtransport en de binnenvaart ideale complementaire partners voor een optimale prestatie met het oog op efficiëntie en milieuaspecten.
9. Uit de berekeningen voor het containertransport door de binnenvaart volgt dat de milieuprestatie voor het containertransport in de keten nog verder kan worden verbeterd door in het voor- of natransport gebruik te maken van Ecotrucks in plaats van reguliere trucks.
10. De twee factoren die leidend zijn voor de gunstige milieu performance van de binnenvaart zijn de schaalvoordelen en de lage wrijvingsweerstand.

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- Appendix 6. Emission limits: CCR and EU

# 1 INTRODUCTION

## 1.1 Goal

The goal of this study is to assess the environmental performance of propulsion engines in inland shipping in Europe as a refinement of the RIVM study “To Shift or not to Shift”. This refinement constitutes of a stretching of the time horizon from 2010 to 2020 and the calculation of the effects of reductions on the emissions of inland vessels.

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## 1.2 Conservative assumptions

This study assesses these four types of emissions for different types of inland vessels. The assessments are made for the year 2000 (based on data from different studies), 2010 and 2020 (projections based on changes in legislation (Appendix 6) and technical development). The projections are based on rather conservative assumptions. The SCR-catalyst is taken into account as a promising technique, but other new possible revolutionary techniques as improvements in efficiency of propulsion (Z-drive and whale tail), the reduction of friction (air lubrication of ships) and in reduction of emission as the development of the fuel cell and steamjet aerosol collector (sjac) are not taken into account. The performance of inland transport is compared with “best case” calculations from other studies for road transport. (chapter 7).

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For several transport routes the emissions as a result of inland shipping will be compared to the emissions as a result of road transport. The emissions will be calculated from the direct vehicle / vessel emissions per kilometre, from the transport distance over road (Figure 2: I) and over water (Figure 2: II) for this specific transport route.

Additionally the cases are selected in which the environmental performance of inland shipping is significantly better than the performance of road transport. In practice transport by inland shipping is often followed by short distance road transport from the port of destination to the final destination. For these selected cases the maximum number of kilometres of additional road transport (Figure 2: a) is calculated at which the environmental performance is still better than the performance of road transport. Finally, for container trades, the maximum number of kilometres of additional road transport is also calculated when Ecotrucks are used for this final step in the transport chain instead of regular trucks<sup>3</sup>.

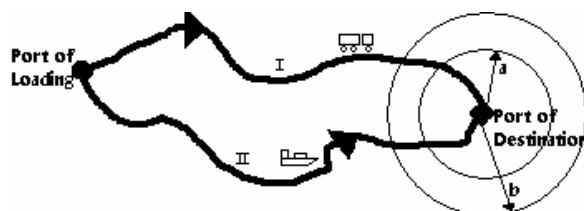


Figure 2: Schematic overview of the study

<sup>3</sup> Ecotrucks are not considered in the main comparison, because there was no data available in “To Shift or not to Shift” and because in the current Dutch test situation Ecotrucks were only allowed to operate to or from an inter-modal hub.

## 2 EMISSIONS AS INDICATORS OF ENVIRONMENTAL PERFORMANCE

In general it can be stated that all economic activities involve the consumption and manipulation of energy and materials, which results in the production of products, services and residuals. All these outcomes will have their impact on the environment. Residuals (treated or untreated) have to be disposed of and are mostly released as emissions to water, soil or air. Therefore, residuals are a main issue when the impact on the environment is concerned.

Measuring the environmental performance of a vehicle or a vessel is a way to make impacts on the environment more visible and provides a comparative method supportive to development strategies and future planning.

To determine the overall environmental performance of a vehicle or a vessel thoroughly, all stages of the lifecycle should be considered. This study only focuses on the environmental performance of the vessel during the stage of operational use.

During this stage of operational use, the vessel has various environmental impacts. These impacts include: emissions to air and water and the production of waste. For inland shipping the emissions to air are considered most critical at this moment. At the moment the emission reduction of Nitrogen Oxides and Particle Matter is a priority for the Dutch government. The emissions of Carbon Dioxide and Sulphur Dioxide are considered a potential priority for the (near) future.

This study is not an exhaustive assessment of the overall environmental performance of inland shipping, but this study focuses on the critical aspects of the environmental performance of inland shipping. Therefore, these four emissions to the atmosphere from inland shipping ( $\text{NO}_x$ ,  $\text{CO}_2$ ,  $\text{PM}_{10}$  and  $\text{SO}_2$ ) will be used to determine the environmental performance of this transportation modality. These emissions are directly related to energy consumption and the type of fuel used. Subsequently, there is a direct relation with the applied techniques and the technologies. The indicators mentioned are relatively easy to measure or calculate and can be effectively used to indicate the environmental performance of the shipping as transportation modality.

### 3 VESSEL TYPES

The most straightforward way of assessing the environmental performance of inland shipping is to calculate the emissions based on a general or average inland vessel type. However due to the large variety in vessel types operating in inland transport, each with different shipping patterns influencing the emissions, it is not possible to define a general inland vessel type.

To express this large variety of vessel types twelve different vessel types, which are commonly used in the European Union, have been selected. The emissions will be calculated for each of these vessel types. The selected types vary in size, the rivers they sail, the type of cargo (bulk or non-bulk), etc.

Relatively important characteristics for this study are the Load Factor and the percentage of empty hauls. The Load Factor expresses the average percentage (in weight) of the Load Capacity used when the vessel is loaded. The percentage of empty hauls expresses the percentage of kilometres the vessels sail without carrying load. A Car Carrier for example practically always sails half of the voyages without carrying cars. In contrary container vessels practically never sail voyages without carrying (empty or loaded) containers.

Table 1 consists of relevant characteristics of the selected vessel types. More detailed characteristics of these vessel types are presented in a table in Appendix 2.

**Table 1: Relevant characteristics of selected vessel types**

	Length	Width	Draught		Load Capacity	Load Factor	Empty Hauls
			Loaded	Empty			
	(m)	(m)	(m)	(m)	(tons)	(%)	(%)
<b>Bulk</b>							
Spits – Peniche	38,5	5	2,20	1,00	350	0,95	0,25
Kempenaar	63	6,6	2,50	1,25	550	0,95	0,25
Rhine-Herne Canal Ship	80	9,5	2,60	1,30	1.350	0,95	0,25
Koppelverband <sup>4</sup>	196	11,4	3,50	1,65	5500	0,88	0,20
Tank Ship (Rhine)	110	11,4	3,30	1,65	3.500	0,91	0,25
Large Tank Ship (Mega Barge)	135	17	3,60	1,70	6.000	0,87	0,25
Four-barges convoy set	193	22,8	3,90	0,60	11.340	0,98	0,25
<b>Non-bulk</b>					(teu <sup>5</sup> )		
Neokemp	63	7	2,50	1,25	48	0,95	0
Rhine-Herne Canal Ship	80	9,5	2,60	1,30	96	0,95	0
Container Ship (Rhine)	110	11,4	3,20	1,50	200	0,92	0
Container Ship (JOWI class)	135	16,85	3,40	1,60	470	0,90	0
					(cars)		
Car Carrier	110	11,4	1,90	1,50	600	0,98	0,5

<sup>4</sup> Self-propelled cargo ship equipped for pushing one barge in line

<sup>5</sup> Twenty-foot Equivalent Unit (size of a container used in sea transport)

## 4 METHOD OF CALCULATION

### 4.1 Introduction

The transport sector of inland shipping consists of a large variety of vessel types. Each of these vessel types has different sizes, weights, loading capacities and shipping patterns. To cope with this variety twelve different vessel types have been identified in chapter 3 that are commonly used in the European Union. In this report we will calculate the emissions for each vessel type separately.

### 4.2 Direct vessel emissions per ton-kilometre

The direct vessel emissions for inland shipping can be calculated from the energy consumption of the vessel and the emission parameters by formula I:

<b>I</b>	$EM_{vessel} = em_{MJ-fuel} * E_{vessel}$		
$EM_{vessel}$	Direct vessel emission	[g/ton-km]	
$em_{MJ-fuel}$	Emission parameter	[g/MJ]	
$E_{vessel}$	Energy consumption of the vessel	[MJ/ton-km]	

Chapter 5 contains a description of which emission parameters are used and the way that they are determined.

The calculation of the energy consumption of the vessel in tonne-kilometres is based on the energy use of the loaded vessel per kilometre (formula II). Certain vessel types sail a percentage of the voyages without any load. The energy use for these empty voyages has to be added to the energy use of the loaded vessel. To convert this term to tonne-kilometres it has to be divided by the average load of the vessel. The average load is calculated by multiplying the load capacity of the vessel by the percentage of this capacity, which is on the average used on loaded trips (load factor) and by the percentage of empty trips.

<b>II</b>	$E_{vessel} = \frac{(1 - Voy_{empty}) * e_{loadedvessel} + e_{emptyvessel} * Voy_{empty}}{Loadfactor * LoadCapacity * (1 - Voy_{empty})}$		
$Voy_{empty}$	Percentage of empty voyages	[%]	
$e_{loadedvessel}$	Energy consumed by loaded vessel	[MJ/km]	
$e_{emptyvessel}$	Energy consumed by empty vessel	[MJ/km]	
Loadfactor	Average percentage of load capacity used when loaded	[%]	
LoadCapacity	Maximum capacity of the vessel	[tonnes]	

The first step is to determine the average load carried by a vessel. The starting point of the calculation is the loading capacity of the vessel types. These capacities are common knowledge in the sector and are obtained from the CBRB. In addition the average load carried by a vessel (average load factor) and the percentage of empty voyages are obtained by telephone interviews with operational managers and other officials from different Dutch shipping organisations.

The energy consumed per kilometre for the different vessel types when loaded and when empty is calculated by formula III from the fuel demand and the enthalpy. The

formula is explained in Appendix 4. Relevant parameters in this formula are: efficiency of the screw, efficiency of transmission, dimensions of the vessel, speed of the vessel and average dimensions of the waterway. This formula is in accordance with the methodology used in the system of emission registration<sup>6</sup> by the Dutch Ministry of Transport, Public Works and Water Management.

<b>XIII</b>	$EM_{vessel,scen} = Dist_{vessel,scen} * EM_{vessel} * Load$	
$EM_{vessel,scen}$	Vessel emissions for case	[g]
$Dist_{vessel,scen}$	Transport distance for vessel relative to water	[km]
$EM_{vessel}$	Calculated direct vessel emission (Formula I)	[g/ton-km]
Load	Load to be transported	[tonnes]

### 4.3 Modal Shift in practice

Chapter 7 contains a comparison of the emissions of transport cargo by road transport and by inland shipping between two places. These are calculated for a series of realistic transport cases.

The emissions for transport by inland shipping are calculated from the port to port distance by inland transport<sup>7</sup>, the calculated direct vessel emission and the load transported in formula XIII.

The distance in this formula is the distance travelled relative to the water. This distance is equal to the distance travelled over land, when the average water flow equals zero. To compensate for travelling with the water flow or against the water flow the distance travelled relative to water is calculated from the distance travelled relative to land, the speed of the vessel and the water flow (formula XIV)

<b>XIV</b>	$Dist_{relat,water} = \frac{Dist_{relat,land}}{1 + \frac{Speed_{vessel}}{Speed_{water}}}$	
$Dist_{relat,water}$	Travelled distance relative to the water	[km]
$Speed_{vessel}$	Speed of the vessel	[m/s]
$Speed_{water}$	Speed of the waterflow	[m/s]

For road transport the emission calculations (formula XV) are based on the distance of transport by road, the emissions per transported ton-kilometre, the loading capacity of the truck and the number of trucks necessary to transport the volume.

<b>XV</b>	$EM_{truck,scen} = Dist_{truck,scen} * EM_{truck} * LoadCap_{truck} * Nr_{truck}$	
$EM_{truck,scen}$	Truck emissions for case	[g]
$Dist_{truck,scen}$	Transport distance for road transport	[km]
$EM_{truck}$	Truck emissions per ton-kilometre	[g-ton-km]
$LoadCap_{truck}$	Maximum capacity of the truck	[tonnes]
$Nr_{truck}$	Number of trucks necessary to carry the load	[ ]

<sup>6</sup> Source: "Schatting energieverbruik binnenvaartschepen" – Adviesdienst Verkeer en Vervoer - 22 oktober 2003

<sup>7</sup> Source: "Wegwijzer voor de binnenscheepvaart" - CBRB

The transport distance for transport<sup>8</sup> by inland shipping is obtained from a logistics department of a Dutch inland shipping company. For road transport the transport distances are obtained from a route planner<sup>9,10</sup>. The emissions per (road) transported ton-kilometre and the loading capacities of the trucks are obtained from the RIVM study “To Shift or not to Shift” and represented in Appendix 1.

As described the emissions of nitrogen oxide, carbon dioxide and particle matter are calculated for both road transport and transport by inland shipping. Additionally the cases are selected in which the environmental performance of inland shipping is significantly<sup>11</sup> better than the performance of road transport. In practice transport by inland shipping is often followed by short distance road transport from the port of destination to the final destination. For these selected cases the maximum number of kilometres of additional road transport is calculated at which the environmental performance equals the performance of road transport. This number of kilometres is calculated by formula XVI:

<b>XVI</b>	$AddDist_{truck,scen} = \frac{EM_{vessel,scen} - EM_{truck,scen}}{EM_{truck} * LoadCap_{truck} * Nr_{truck}}$
AddDist <sub>truckscen</sub>	Additional Distance for road transport in case [km]

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<sup>8</sup> For the port of Rotterdam kilometre point 1015 in “De Nieuwe Waterweg” is used for measurement of transport distance for inland shipping.

<sup>9</sup> For the port of Rotterdam the Professor Gerbrandyweg in Rotterdam Botlek (close to kilometre point 1015) is used for measurement of transport distance for road transport.

<sup>10</sup> Route Planner: [www.routenet.nl](http://www.routenet.nl)

<sup>11</sup> At least two of the three calculated types of emissions for inland shipping are lower than these calculated for road transport. In practice: both nitrogen oxides and carbon dioxide emissions are lower.

## 5 EMISSION PARAMETERS

### 5.1 Introduction

The four types of emission reviewed in this study are all related to the energy consumption of the vessels. This chapter describes how the amount of emission is determined in relation to the consumed energy (emission parameters) for each of these four types of emission.

The emission parameters for 2000 are based on different studies mentioned in the following paragraphs of this chapter. The emission parameter for the years 2010 en 2020 are derived from the parameters for 2000 based on developments in legislation, technical development and the rate of substitution in the market.

Both the development of European Union (EU) legislation and the development of legislation in the CCR<sup>12</sup> are relevant. Considering CCR regulation phase 1 and phase 2 are taken into account. With regard to EU legislation following directives are taken into account:

- Directive 1997/68/EC: legislation to regulate emissions from nonroad mobile equipment;
- Draft Directive 2002/765 as amended by the European Parliament in October 2003: stage III/IV emissions standards following on Directive 97/68/EC;
- Directive 2003/17/EC: Environmental specifications for market fuels;
- Draft Directive 2003/476: legislation to regulate the sulphur content of marine fuels.

Appendix 6 contains a brief summary of emission limit from both CCR and EU.

In this study it is assumed that both regulatory bodies of CCR and EU will mutually acknowledges the regulations of each other.

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<sup>12</sup> Central Commission for Navigation on the Rhine

## 5.2 Substitution rate of engines

An important factor in determining the future emissions for inland shipping is the rate of substitution (~ average lifetime) of the engines within the ships.

The ships register for the Rhine<sup>13</sup> holds relevant data for the ships sailing the Rhine. Within this register also relevant data of the engines within these ships is stored. The data however on the lifetime of these engines is not accurate.

The average lifetime of an engine within an inland vessel is mainly dependent on the type engine. The engines can be divided into three classes based on the amount of rotations per minute: slow-speed, medium-speed and high-speed engines. The VIV<sup>14</sup> trade association supplied the average lifetime of engines within these classes. The percentage of engines within the market of each class followed from a query in the IVR database.

Table 2 shows the combination of the mentioned input to calculate an average lifetime for the engines. In practice slow-speed engines are almost always replaced by medium-speed or high-speed engines. This trend is not taken into account in the calculation of the average lifetime.

**Table 2: Average lifetime engines**

Engine Class	Rotations per minute	% of population	Average lifetime (years)
Slow-speed	<400	18%	30
Medium-speed	400-1000	19%	20
High-speed	>1000	62%	10
Average		100%	15,6

## 5.3 Nitrogen Oxides

Nitrogen oxides (NO<sub>x</sub>), a mixture of nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>), are formed from industrial processes, motor vehicles and other fuel combustion processes. Nitrogen oxides are the main contributors to acidification and eutrophication. They also have a negative influence on the air quality: NO<sub>2</sub> is a poisonous gas (the yellowish-brown colour of the smog) and causes the formation of ozone (photochemical smog or summer smog).

Germanischer Lloyd assessed<sup>15</sup> the emissions of nitrogen oxides from engines of inland vessels in 2001. In this study existing measurements of 55 engines were combined in a multi-discriminant analysis with technical parameters<sup>16</sup> of engines in the Dutch fleet. This combination results in an emission parameter for the Dutch fleet in 2000. (Appendix 1)

<sup>13</sup> IVR - the international Association for the representation of the mutual interest of the inland shipping and the insurance and for keeping the register of inland vessels in Europe

<sup>14</sup> Vereniging van Importeurs van Verbrandingsmotoren

<sup>15</sup> Erarbeitung von Verfahren zur Ermittlung der Luftschadstoffemissionen von in Betrieb befindlichen Binnenschiffmotoren – Germanischer Lloyd - 2001

<sup>16</sup> number of revolutions, capacity, and utilisable medium pressure

The nitrogen oxides emission parameters for 2010 and 2020 (Appendix 1) are derived from the parameter for 2000 based on the following assumptions:

- the emission related characteristics of the population in 2001 are equal to the characteristics of the engine population in 2000;
- the years of manufacture of the engines within the classes are equally distributed;
- from 2002 newly manufactured engines have a NO<sub>x</sub> emission parameter of 9,3 g/kWh (equal to the maximum allowable emission<sup>17</sup> in the CCR-I regulation);
- from 2008 newly manufactured engines have a NO<sub>x</sub> emission parameter of 6 g/kWh (CCR-II regulation and Stage III of COM(2002)/765<sup>18</sup>);
- as a result from the Dutch “VERS” arrangement from 2004 until 2010 every year 60 (new-built or retrofit) ships will be equipped with an SCR-catalyst<sup>19</sup> (emission parameter of 2 g/kWh<sup>20</sup>) due to subsidising. When other EU-countries introduce comparable arrangements this effect will be largely extended;
- after 2010 all new-built ships will be equipped with an SCR-catalyst (in accordance with Stage IV of COM(2002)/765).

#### **5.4 Carbon Dioxide**

The emission of carbon dioxide from the combustion of fuel is one of the largest contributions to the human emission of carbon dioxide. The emission of carbon dioxides contributes to the greenhouse effect.

The emission parameter of carbon dioxide depends on the type of fuel and the completeness of combustion. The calculations are based on the use of diesel as fuel and complete combustion, resulting in the emission of 73,3 g/MJ diesel<sup>21</sup> for all the years. (Appendix 1)

#### **5.5 Particle Matter**

The emission of particle matter is closely related to the composition of the fuel used and the quality of the process of combustion in the engine. The technical state of the engine is primarily decisive for the amount of emitted particle matter. During the lifetime of an engine the rate of emitted particle matter generally increases.

At this moment there is not enough data to make a statistically sound calculation of the average emission of particle matter by these engines. In a study by Germanischer Lloyd, the population of engines is divided into two classes with different contributions to the emissions of particle matter. The average emissions of particle matter are estimated for each of these two classes. These estimated values are used in our calculation as emission parameter for the year 2000 (Appendix 1)

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<sup>17</sup> The maximum allowable emission varies between 9,2 and 13 g/kWh, dependent of the capacity and the number of revolutions of the engine. According to the database of IVR 86% of the engines in the population have a capacity and number of revolutions resulting in a maximum allowable emission of nitrogen oxides between 9,2 and 9,5 g/kWh.

<sup>18</sup> As the emissions limits for Nitrogen Oxides in COM(2002)/765 are expressed as the sum of both hydrocarbons and Nitrogen Oxides these limits cannot be exactly converted into limits for Nitrogen Oxides solely.

<sup>19</sup> Comparable to Euro5 regulation for road transport

<sup>20</sup> Selectieve Katalytische Reductie – Koninklijk Instituut voor de Marine – May 2003

<sup>21</sup> Vergelijkingskader Modaliteiten vs 1.2 – NEA – November 2002

The particle matter emission parameters for 2010 and 2020 (Appendix 1) are derived from the parameters for 2000 based on the following assumptions:

- the emission related characteristics of the population in 2001 are equal to the characteristics of the engine population in 2000;
- the years of manufacture of the engines within the two classes are equally distributed;
- new manufactured engines from 2002 have a PM<sub>10</sub> emission parameter of 0,54 g/kWh (equal to the maximum allowable emission in the CCR-I regulation);
- new manufactured engines from 2008 have a PM<sub>10</sub> emission parameter of 0,2 g/kWh (CCR-II regulation and most tight category in Stage III of COM(2002)/765);
- stage IV of COM(2002)/765 consists of a further tightening of the emission limits for inland waterway vessels with the regard to particle matter by the 2011 and 2012. Since this study is based on conservative assumptions and this stage is due to a technical review in 2007 it is not included in this study.

## 5.6 Sulphur Dioxide

Sulphur dioxide is the result of a chemical reaction between sulphur components in fuel and oxygen from combustion air. Therefore, the emission of sulphur dioxide depends on the sulphur content of the fuel. In particular, emission of sulphur dioxide by inland shipping mainly depends on the sulphur content of the fuel and the amount of fuel used. By applying lighter fuels and more energy efficient engines, the emission of sulphur dioxide can be reduced effectively.

The sulphur dioxide emission parameters for 2000 are based on a sulphur content of 1.700 parts per million<sup>22</sup> of the fuel. The current limit for the sulphur content of fuel is 2.000 part per million and follows from the EU Directive 1999/32/EU.

Draft Directive 2003/476/EU will tighten this limit for inland vessels to 1.000 parts per million. Directive 2003/17/EC forces states to make sulphur-free (10 parts per million) fuel available within the EU from 2009 for road transport use. It is assumed that this development will also have an impact on the decrease of the sulphur content of fuel for inland ships. The emission parameters for 2010 are based on an average sulphur content of 500 parts per million.

As engine related technical developments in inland shipping follow the developments in road transport it is assumed that for 2020 sulphur-free (10 parts per million) fuel will be available for inland shipping.

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<sup>22</sup> Compare to a sulphur content of 27,000 parts per million for marine heavy fuel used in sea-going ships.

## 6 DIRECT VESSEL EMISSIONS

The calculated values for the direct vessel emissions for the twelve selected vessel types are represented in Appendix 3. Chapter 6 consists of graphical representations of the calculated emissions for population averages. These calculations are based on the average lifetime of engines, technical developments and developments in legislation mentioned in chapter 5.

### 6.1 Nitrogen Oxide

The Nitrogen Oxide emissions per ton-kilometre for vessel types in bulk trades for the years 2000, 2010 and 2020 are represented in figure 2. The values for vessel operating in non-bulk trades are represented in figure 3. As comparison the emissions<sup>23</sup> of road transport are added in the figures.

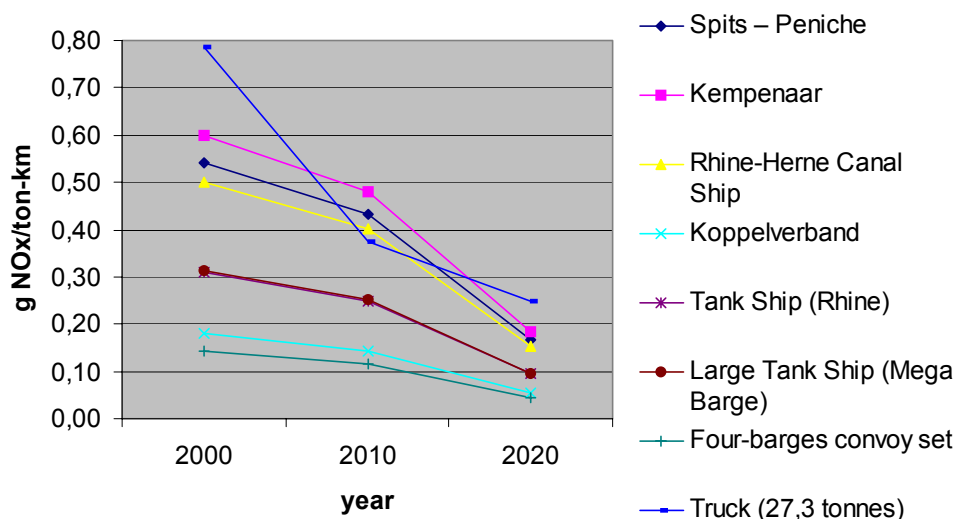


Figure 2: Nitrogen Oxide emissions for 2000, 2010 and 2020 for BULK SHIPPING

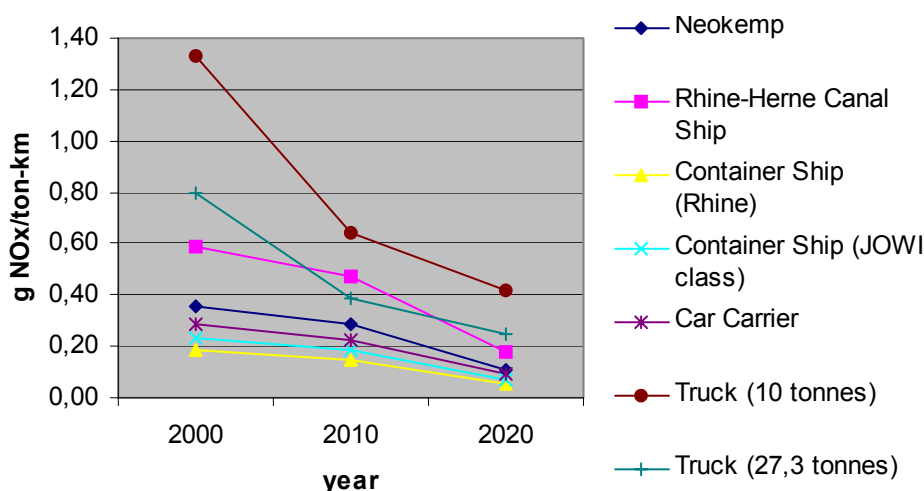


Figure 3: Nitrogen Oxide emissions for 2000, 2010 and 2020 for NON-BULK SHIPPING

<sup>23</sup> Emissions of road transport as calculated in the RIVM study “To Shift or not to Shift” (See Appendix 1 for more details)

## 6.2 Carbon Dioxide

Figure 4 and 5 show the amount of emitted CO<sub>2</sub> for each vessel type per ton-kilometre. This amount is stable for the years 2000, 2010 and 2020.

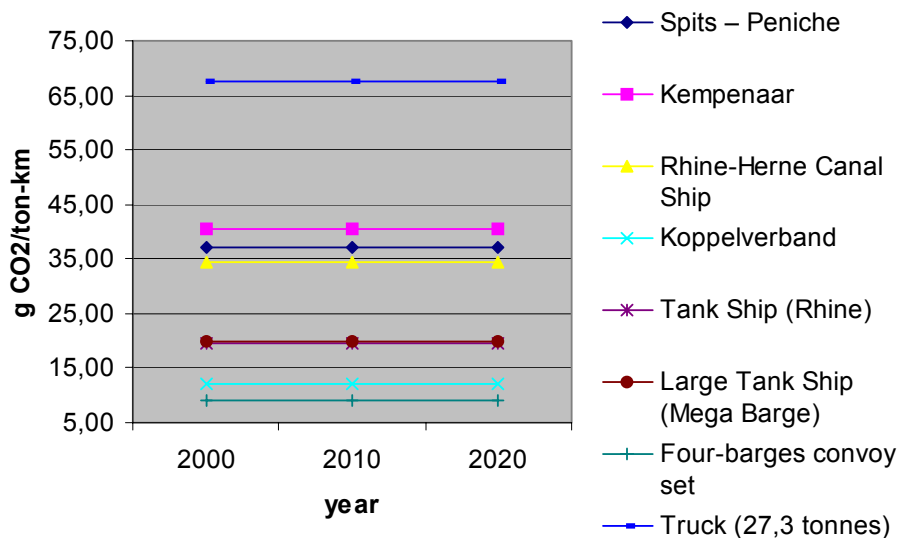


Figure 4: Carbon Dioxide emissions for 2000, 2010 and 2020 for BULK SHIPPING

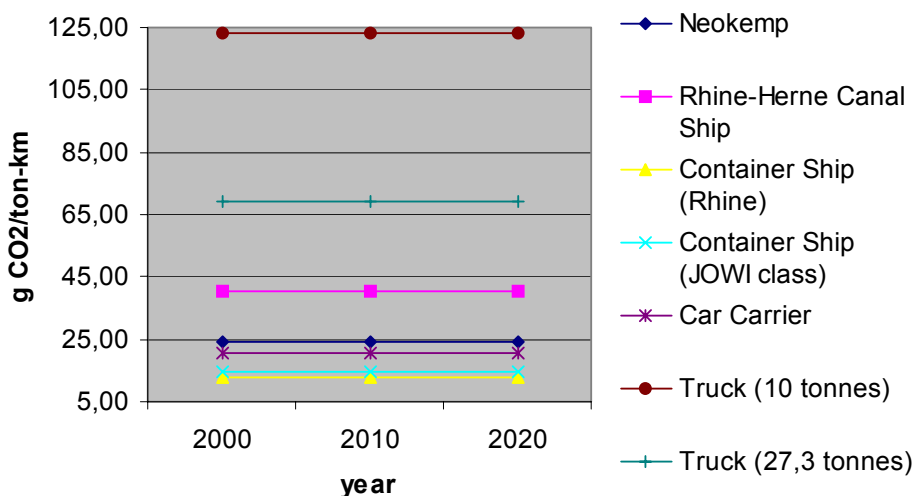


Figure 5: Carbon Dioxide emissions for 2000, 2010 and 2020 for NON-BULK SHIPPING

Within the inland shipping sector research is done to reduce the fuel consumption of the ships. The reduction of the amount of fuel used has a positive effect on the reduction of all assessed emissions. Considering Carbon Dioxide, reduction of the amount of fuel consumption is practically the only way to reduce this emission. Table 3 comprises of four promising techniques in this field.

**Table 3: Fuel reduction potentials of promising techniques (other than combustion engines)**

<b>Technique</b>	<b>Potential fuel reduction (%)</b>	<b>Research / Testing by:</b>
Z-drive	15 – 30%	Veth Engines
Whale Tail	30 – 40 %	MARIN
Fuel Cell	100%	Several institutes
Air Lubrication	10 - 20 %	MARIN
A-Tempomaat	10 – 20%	Bureau Innovatie Binnenvaart
Jet Nozzle	30 %	Bureau Innovatie Binnenvaart
Weight Reduction	Unknown	On-going development
Improvement of Hydrodynamics	Unknown	On-going development

### 6.3 Particle Matter

The Particle Matter emissions per ton-kilometre for vessel types in bulk trades for the years 2000, 2010 and 2020 are represented in figure 6. The values for vessel operating in non-bulk trades are represented in figure 7.

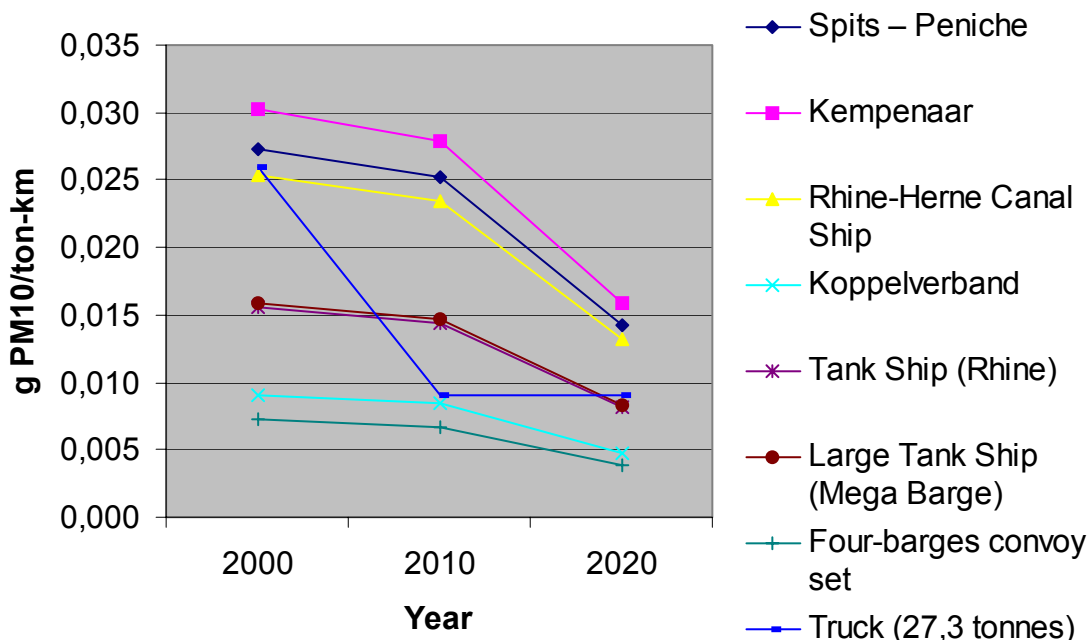


Figure 6: Particle Matter emissions for 2000, 2010 and 2020 for BULK SHIPPING

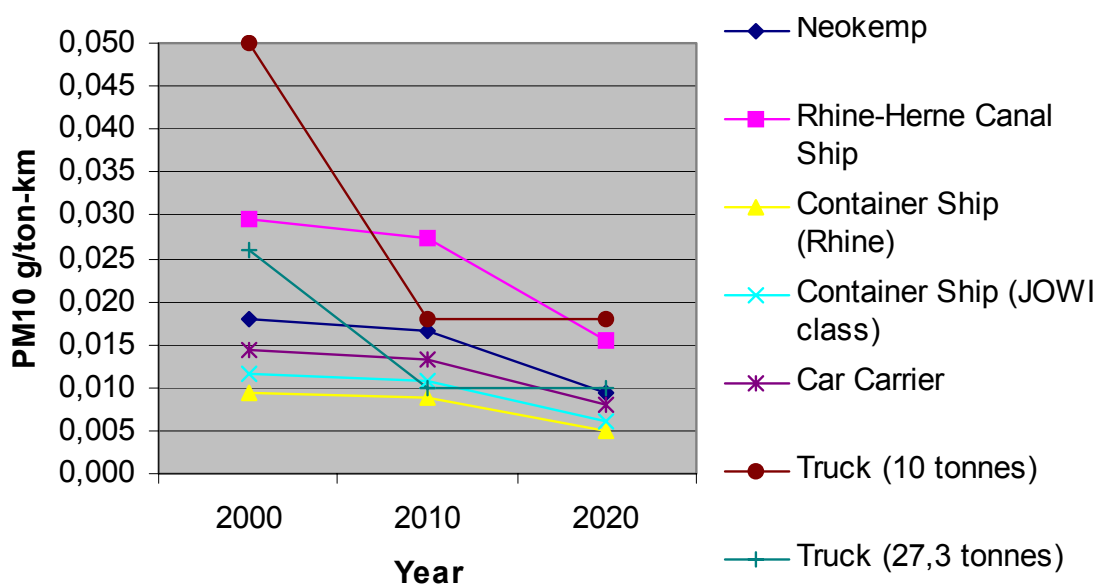


Figure 7: Nitrogen Oxide emissions for 2000, 2010 and 2020 for NON-BULK SHIPPING

## 6.4 Sulphur Dioxide

The Sulphur Dioxide emissions per ton-kilometre for vessel types in bulk trades for the years 2000, 2010 and 2020 are represented in figure 8. The values for vessel operating in non-bulk trades are represented in figure 9. The RIVM study “To Shift or not to Shift” did not contain data calculated values for the emissions of road transport for these years. For this reason there is no comparison with road transport available in the graphs.

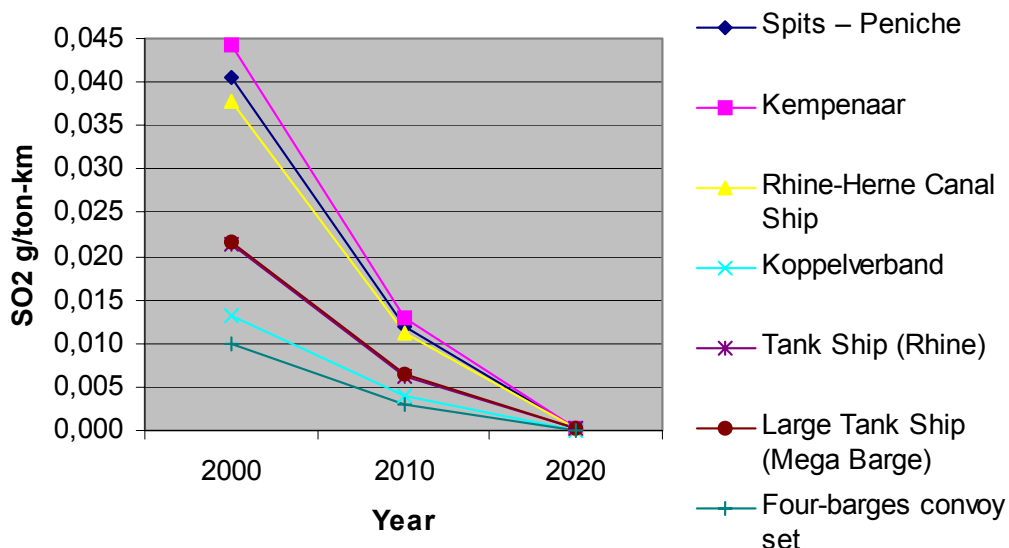


Figure 8: Sulphur Dioxide emissions for 2000, 2010 and 2020 for BULK SHIPPING

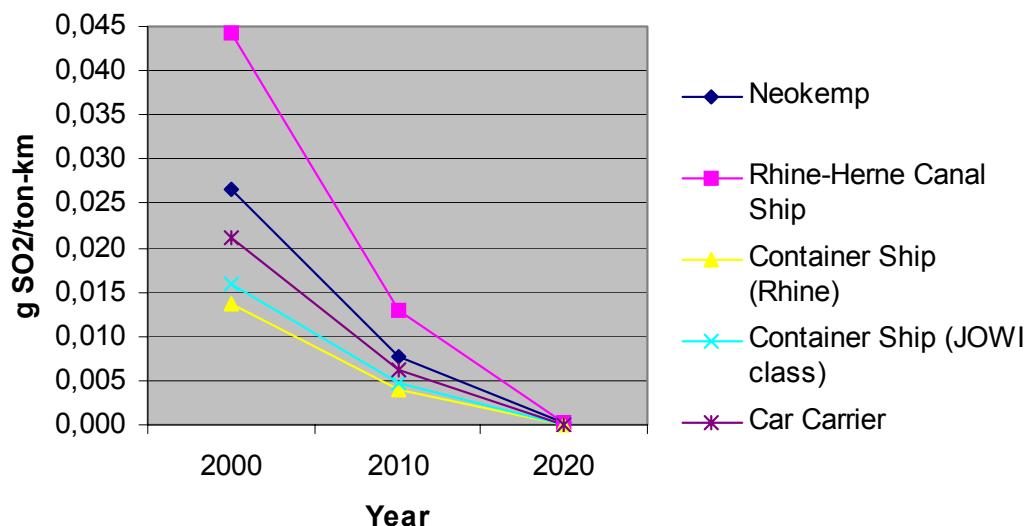


Figure 9: Sulphur Dioxide emissions for 2000, 2010 and 2020 for NON-BULK SHIPPING

## 7 MODAL SHIFT IN PRACTICE

### 7.1 Introduction

Chapter 7 contains different realistic transport cases for 2020. The calculation are based on ship characteristics in Chapter 3 and the calculated emissions in chapter 5. For each case (table 4) the emissions are calculated to transport a specific amount of cargo, by road transport (I) and by inland ship (II), from a Port of Loading to a Port of Destination.

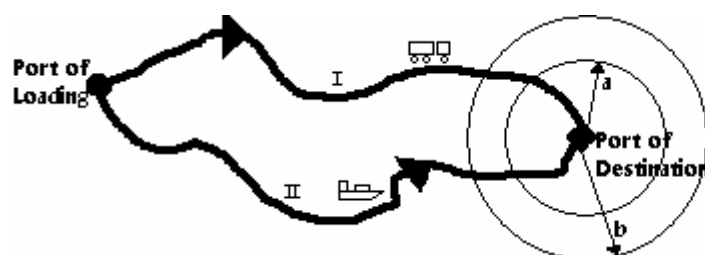


Figure 10: Schematic overview of the study

An additional calculation is made for the cases in which the emissions<sup>24</sup> of inland shipping are significantly<sup>25</sup> lower than the emissions by road transport. Transport by inland ship is often followed by short distance road transport (a) from the Port of Destination to the final destination. The number of kilometres additional short distance road transport is calculated at which the environmental performance of road transport (I) equals the performance of inland shipping and additional road transport (II + a). In this way the size of the circle around the Port of Destination is calculated within which transport by inland shipping has a better environmental performance than road transport. For container trades this circle (b) is also calculated when the additional road transport takes place by an Ecotruck.

<sup>24</sup> Following the RIVM report "To Shift or not to Shift" the comparison of transport modes takes place with regard to the emissions of Carbon Dioxide, Nitrogen Oxides and Particle Matter. The emissions of Sulphur Dioxide are not taken into account.

<sup>25</sup> Significantly lower: at least two of the three assessed emissions are lower

**Table 4: Overview Modal Shift in practice cases**

Type of Trades	Port of Departure	Area of Destination	Cargo	Distance a <sup>26</sup>
<b>Container trades</b>	Rotterdam	Nijmegen	48 TEU	25 km
	Rotterdam	Groningen	90 TEU	146 km
	Rotterdam	Antwerp	200 TEU	90 km
	Praque	Regensburg	470 TEU	n/a
<b>Dry bulk</b>	Rotterdam	Amiens	350 tonnes	160 km
	Mannheim	Rouen	550 tonnes	11 km
	Rotterdam	Cologne	11.500 tonnes	181 km
<b>Liquid bulk</b>	Rotterdam	Thionville	3.500 tonnes	n/a
	Rotterdam	Mainz	6.000 tonnes	129 km
	Antwerp	Vienna	1.350 tonnes	128 km
	Groningen	Antwerp	3.500 tonnes	169 km
<b>Cars</b>	Dunkirk	Born	600 cars	9 km
<b>Seine-Nord Connection</b>	Rotterdam	Paris	3.500 tonnes	169 km

<sup>26</sup> Additional road transport possible (See figure 10)

## 7.2 Container Trades

### 7.2.1 Port of Rotterdam to Nijmegen area – 48 TEU



The map above shows the route of transport of 48 TEU by road (in red) and by inland shipping (green) from the port of Rotterdam to the port of Nijmegen. The emissions related to this transport are calculated in Appendix 5. The (inner) blue circle around Nijmegen shows the amount of additional road transport (25 kilometres) possible within the environmental performance of the combination of inland shipping and road transport is better than the environmental performance of transporting just by road transport.

The (outer) black circle (36 kilometres) shows the amount of additional road transport possible when using an Ecotruck<sup>27</sup> for the second step in the transport chain. (See Appendix 5 for details) In 2003 a first test period ended in the Netherlands. In this period certain Ecotrucks were permitted on the road under restrictions. One of these restrictions was the use Ecotrucks was only allowed for transport to or from an inter modal hub

### 7.2.2 Port of Rotterdam to Groningen area – 90 TEU



In this case the transport of 90 TEU by a moderate inland ship (Rhine – Herne Canal Ship) is compared by transporting the same load with 45 large trucks. The transport distance for inland shipping is 73 kilometres shorter than the distance for road transport. The environmental performance of inland shipping combined with road transport prevails within a circle of 146 kilometres around Groningen. This circle is extended with 73 kilometres when using an Ecotruck. (See Appendix 5 for details)

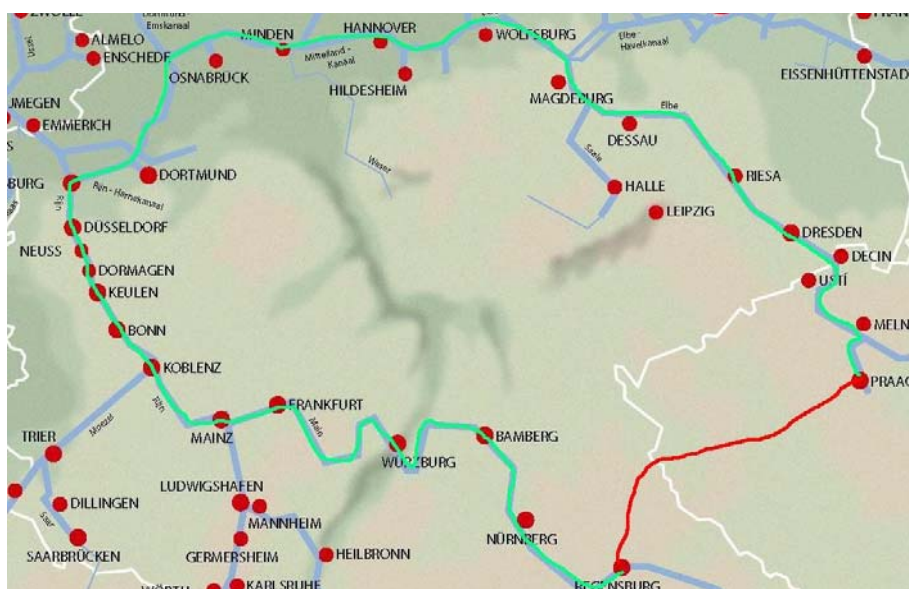
<sup>27</sup> Truck able to carry 3 TEU. This truck is about 30% more energy efficient than a standard truck. (Reference: Praktijkproef LZV – Adviesdienst Verkeer en Vervoer – 11. December 2002)

### 7.2.3 Port of Rotterdam to Antwerp area - 200 TEU



For the transport of 200 TEU from the port of Rotterdam to the Antwerp area it is possible to use one container ship (Rhine) or 100 trucks (27,3 tonnes). The environmental performance of inland shipping combined with road transport prevails within a circle of 90 kilometres around Antwerp (128 kilometres for an Ecotruck). In this study the emissions resulting from transshipment are not taken into account. In this specific case (short distance and large quantity of containers) taking transshipment into account would tone down the difference. (See Appendix 5 for details)

### 7.2.4 Port of Prague to Regensburg area - 470 TEU



In this case transporting 470 TEU takes 1.825 kilometres (green line) by inland transport (Containership JOWI class) or just 261 kilometres by road transport (red line). It is assumed that road transport takes place with large trucks (27,3 tonnes) carrying 2 TEU each. The economies of scale as a result of the use of inland ships cannot outweigh the enormous difference in transport distance. All three assessed emissions are lower for road transport than for inland transport. (See Appendix 5 for details)

## 7.3 Dry Bulk Trades

### 7.3.1 Port of Rotterdam to Amiens area - 350 tonnes

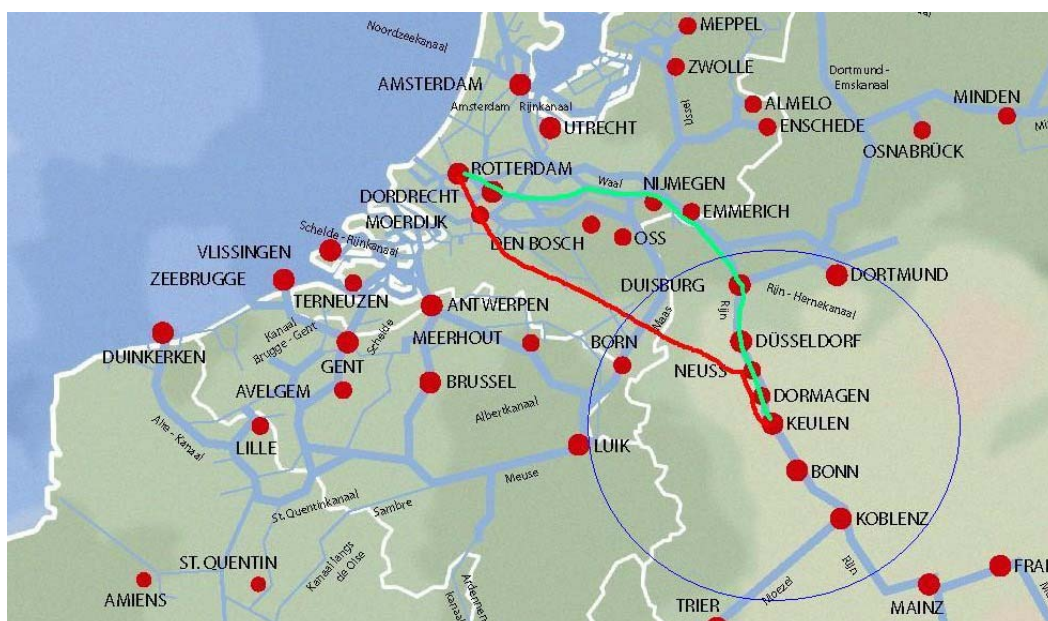


The emissions related to the transport of 350 tonnes dry bulk from Rotterdam to Amiens by a small inland ship (Spits-Peniche) is compared to transporting the same load by small trucks (10 tonnes). The transport distance is almost equal. In this case the emission of Particle Matter is slightly lower for the road transport. The emissions of both CO<sub>2</sub> and NO<sub>x</sub> are lower when the transport by inland ship is followed by up to 160 kilometres additional road transport. (Appendix 5 for details).

### 7.3.2 Mannheim to Rouen area - 700 tonnes

In this case the transport of 700 tonnes of dry bulk by two small inland ships (Spits - Peniche) is compared by transporting the same load with 70 trucks. The transport distance for inland shipping is almost twice the distance of the distance for road transport. The environmental performance of inland shipping combined with road transport prevails within a circle of 11 kilometres around Rouen. For this transport case there is not map available. (See Appendix 5 for details)

### 7.3.3 Rotterdam to Cologne area - 11.500 tonnes



In this case the transport of 11.500 tonnes of dry bulk, by a large four barges convoy set, is compared by transporting the same load with 422 large trucks. The transport distance for inland shipping is about 60 kilometres more than the distance for road transport. The blue circle around Cologne (Keulen) shows the amount of additional road transport (181 kilometres) possible (See Appendix 5 for details)

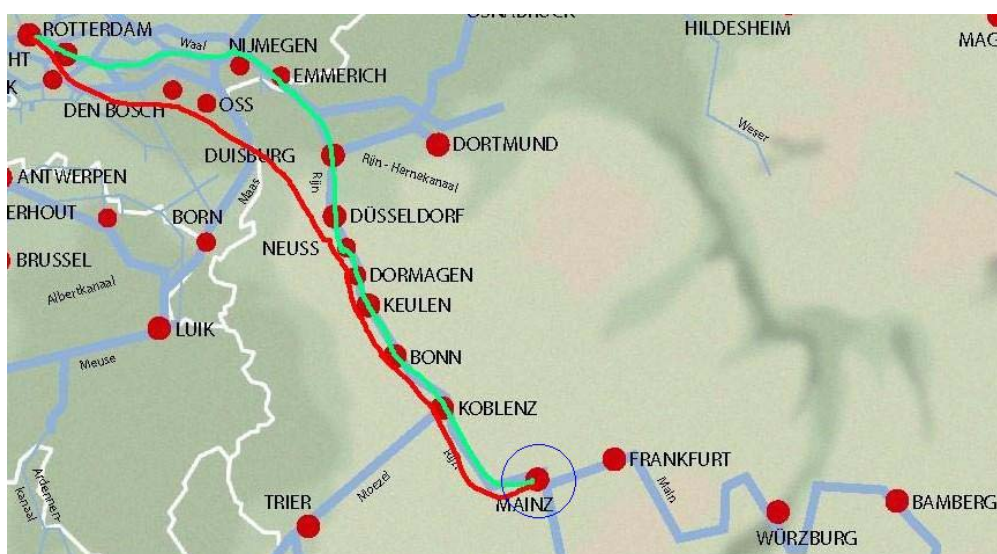
## 7.4 Liquid Bulk Trades

### 7.4.1 Port of Rotterdam to Thionville area - 3.500 tonnes



In this case the transport of 3.500 tonnes of liquid bulk, by a large Tank Ship (Rhine), is compared by transporting the same load with large trucks. The transport distance for inland shipping exceeds the distance for road transport by almost 300 kilometres. In this case the emissions of both Nitrogen Oxides and Particle Matter are higher for inland transport than for road transport. (See Appendix 5 for details)

#### 7.4.2 Port of Rotterdam to Mainz area - 6.000 tonnes



For the transport of 6.000 tonnes liquid bulk from the port of Rotterdam to the Mainz area it is possible to use one large tank ship (Mega Barge) or 220 large trucks. The environmental performance of inland shipping combined with road transport prevails within a circle of 129 kilometres around Mainz. (See for details Appendix 5)

#### 7.4.3 Port of Antwerp to Vienna area - 1.350 tonnes



For the transport of 1.350 tonnes liquid bulk from the port of Vienna (Wenen) to the Antwerp area it is possible to use one large tank ship (Rhine) or 50 large trucks. The transport distance is fifty kilometres less for inland transport. The environmental performance of inland shipping combined with road transport prevails within a circle of 128 kilometres around Vienna. (See for details Appendix 5)

#### 7.4.4 Groningen to Antwerp area - 3.500 tonnes



For the transport of 3.500 tonnes liquid bulk from the Port of Groningen to the Antwerp area it is possible to use one large tank ship (Rhine) or 129 large trucks (27,3 tonnes). The environmental performance of inland shipping combined with road transport prevails within a circle of 169 kilometres around Antwerp. (See for details Appendix 5)

#### 7.5 Dunkirk to Born area – 600 cars



For the transport of 600 cars from the port of Dunkirk (Duinkerken) to the Born area it is possible to use one large car carrier or 75 trucks. The environmental performance of inland shipping is slightly better than the environmental performance of road transport. (See for details Appendix 5)

## 7.6 Seine-Nord connection

The improvement on the infrastructure within the European Union focuses on the development of Trans European Networks (TEN). The realisation of the so-called Seine-Nord connection is prioritised<sup>28</sup> to strengthen the TEN for inland navigation. The Seine-Nord connection connects the Seine estuary with the Schelde estuary and will make it possible for inland vessel up to 4.400 tonnes to sail from Rotterdam to Paris<sup>29</sup>.



In this policy scenario a calculation is made for the hypothetical situation of the Seine-Nord connection being in operation in the year 2020. A load of 3.500 tonnes liquid bulk should be transported from Rotterdam Botlek to the Paris area. The environmental performance of inland shipping prevails in this situation within a circle of 169 kilometres around Paris.

<sup>28</sup> According to the findings of the Van Miert High-Level Group on Trans-European transport networks

<sup>29</sup> The French government claimed on 18<sup>th</sup> December 2004 that the Seine-Nord connection will be available from 2015.

## 8 CONCLUSIONS

1. It follows from the study that the environmental performance of both road transport and inland transport are dependent from a large amount of parameters. These parameters differ widely between transport cases. Because of this wide variety it is not possible to make a general comparison of the environmental performance of road transport and the environmental performance of inland shipping.
2. The calculations for specific cases in this study clearly show the advantage, with respect to the environment, of inland shipping in relation to transporting only by road transport. Even when inland transport is followed by substantial additional road transport many cases show the advantage with respect to the environment of inland shipping. In most of the cases it can be concluded that modal shift towards inland shipping does contribute to an improvement of the environmental performance of the transport chain.
3. For modal shift towards inland shipping follows from this study it can contribute to an improvement of the environmental performance of the transport chain. This could be a chance in relation to the Kyoto targets for emissions reduction. Further study should quantify these potential benefits (both technical and economic).
4. For cases in which the travelled distance of transport by road transport is equal to the distance for inland shipping and there is no additional (to or from) transport inland shipping has a better environmental performance than road transport.
5. From the case calculations follow great possibilities for relative shorter distance (60 – 150 kilometres) inland shipping with respect to environmental performance. In practice short distance inland shipping is already used for palletized or container transport (Distrivaart concept or Neokemp concept).
6. The innovation towards cleaner and more efficient engines has a large positive effect on both road transport and inland shipping. Because inland ships use engines comparable to road transport the effects of these innovations are comparable. However in general it takes longer until these innovations contribute to a reduction in emissions in inland transport compared to road transport. This is due to two reasons:
  - Manufactures first develop innovations in engines for the large market of road transport. When these innovations are successful the manufactures also make the innovations available to smaller markets as the market of engines for maritime engines vessels.
  - The average lifetime of vessels and engines in inland vessels is higher than the lifetime of engines in road transport. This results in a lower rate of substitution.

The developments in legislation follow on the technical developments. These calculations in this study show clearly the enormous effect of nowadays policy on the environmental performance of inland shipping in the years 2010 and 2020. It can be stated that the environmental performance will make a giant leap in following decades.

7. Draft Directive 2003/476 proposes a limit on the sulphur content of the fuel used for inland vessels of 1.000 parts per million. From interviews during this study follows that a tightening of this limit to 500 parts per million would be technical possible.
8. From the case calculations should be learned that from an environmental point of view inland shipping is an excellent transport mode for the primary step in the transport chain, both long distance and short distance. In many cases the transport by inland ship will be preceded or followed by short distance road transport. In this view inland transport and road transport are ideal complementary transport chain partners for a high performance in efficiency and in environmental aspects.
9. From the calculations for container transport follows that the environmental performance of the transport chain can even be more enhanced when (to and from) road transport takes place with Ecotrucks instead of regular trucks.
10. The two main drivers for the favourable environmental performance of inland shipping are the economies of scale and the low resistance as result of friction.

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## **Appendix 1. Emission parameters**

### Emission parameters of Inland Shipping for the year 2000

	Engine	Emission Factors			
	Efficiency	NO <sub>x</sub>	CO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>
		g/MJ	g/MJ	g/MJ	g/MJ <sup>30</sup>
<b>Bulk</b>					
Spits – Peniche	0,36	1,06	73,3	0,054	0,08
Kempenaar	0,37	1,08	73,3	0,054	0,08
Rhine-Herne Canal Ship	0,36	1,06	73,3	0,054	0,08
Koppverband	0,37	1,08	73,3	0,055	0,08
Tank Ship (Rhine)	0,39	1,15	73,3	0,058	0,08
Large Tank Ship (Mega Barge)	0,39	1,15	73,3	0,058	0,08
Four-barges convoy set	0,39	1,15	73,3	0,058	0,08
<b>Non-bulk</b>					
Neokemp	0,37	1,08	73,3	0,054	0,08
Rhine-Herne Canal Ship	0,36	1,06	73,3	0,054	0,08
Container Ship (Rhine)	0,37	1,08	73,3	0,055	0,08
Container Ship (JOWI class)	0,39	1,15	73,3	0,058	0,08
Car Carrier	0,37	1,08	73,3	0,055	0,08

- Calculated according to the method of calculation in Chapter 4

### Emission parameters for Inland Shipping for the year 2010

	Engine	Emission Factors			
	Efficiency	NO <sub>x</sub>	CO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>
		g/MJ	g/MJ	g/MJ	g/MJ
<b>Bulk</b>					
Spits – Peniche	0,36	0,85	73,3	0,050	0,02
Kempenaar	0,37	0,86	73,3	0,050	0,02
Rhine-Herne Canal Ship	0,36	0,85	73,3	0,050	0,02
Koppverband	0,37	0,87	73,3	0,051	0,02
Tank Ship (Rhine)	0,39	0,92	73,3	0,054	0,02
Large Tank Ship (Mega Barge)	0,39	0,92	73,3	0,054	0,02
Four-barges convoy set	0,39	0,92	73,3	0,054	0,02
<b>Non-bulk</b>					
Neokemp	0,37	0,86	73,3	0,050	0,02
Rhine-Herne Canal Ship	0,36	0,85	73,3	0,050	0,02
Container Ship (Rhine)	0,37	0,87	73,3	0,051	0,02
Container Ship (JOWI class)	0,39	0,92	73,3	0,054	0,02
Car Carrier	0,37	0,87	73,3	0,051	0,02

<sup>30</sup> Conversion factor: 3,6 g/kWh = 1 g/MJ

## Emission parameters for Inland Shipping for the year 2020

	Engine	Emission Factors			
	Efficiency	NO <sub>x</sub>	CO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>
		g/MJ	g/MJ	g/MJ	g/MJ
<b>Bulk</b>					
Spits – Peniche	0,36	0,33	73,3	0,028	0,000
Kempenaar	0,37	0,33	73,3	0,028	0,000
Rhine-Herne Canal Ship	0,36	0,33	73,3	0,028	0,000
Koppolverband	0,37	0,33	73,3	0,029	0,000
Tank Ship (Rhine)	0,39	0,35	73,3	0,030	0,000
Large Tank Ship (Mega Barge)	0,39	0,35	73,3	0,030	0,000
Four-barges convoy set	0,39	0,35	73,3	0,030	0,000
<b>Non-bulk</b>					
Neokemp	0,37	0,33	73,3	0,028	0,000
Rhine-Herne Canal Ship	0,36	0,33	73,3	0,028	0,000
Container Ship (Rhine)	0,37	0,33	73,3	0,029	0,000
Container Ship (JOWI class)	0,39	0,35	73,3	0,030	0,000
Car Carrier	0,39	0,35	73,3	0,030	0,000

## Nitrogen Oxide

The emissions parameters for Nitrogen Oxide are calculated by multiplying the engine efficiency with year average in the following table:

Class*	Average emission (g/kWh output)	Part of Engine Population		
		2000 (%)	2010 (%)	2020 (%)
I	9	48,9	20,7	
II	11	36,8	15,6	
III	13	5,0	2,1	
IV	15,5	9,3	3,9	
CCR I	9,3		34,5	12,7
CCR II	6		7,6	7,6
SCR-catalyst**	2		15,6	79,7
Weighted average (g/kWh output)		10,54	8,43	3,23
(g/MJ output)		2,93	2,34	0,90

\*Classes based on figure 1-28, page 28 (Germanischer Lloyd – 2001)

\*\*Based on size of Dutch inland shipping fleet of 6.000 ships

## Carbon Dioxide

A constant emission parameter of 73,3 g/MJ is used for the emission of Carbon Dioxide. [Vergelijkingskader Modaliteiten vs 1.2 – NEA – November 2002]

### Particle Matter

The emissions parameters for Particle Matter are calculated by multiplying the engine efficiency with year average in the following table:

Class***	Average emission (g/kWh output)	Part of Engine Population		
		2000 (%)	2010 (%)	2020 (%)
I	0,2	17	8	0
II	0,6	83	40	0
CCR I	0,54		38	23
CCR II	0,2		13	77
Weighted average				
Average (g/kWh)		0,53	0,49	0,28
Average (g/MJ)		0,15	0,14	0,08

\*\*\*Classes based on table 1-6, page 33 (Germanischer Lloyd – 2001)

### Sulphur Dioxide

The emissions parameters for Sulphur Dioxide are represented in the following table:

Year	Parts per Million in fuel	Emission (g/MJ)
2000	1700	0,080
2010	500	0,024
2020	150	0,007

- According tot paragraph 5.6

## Road Transport

Chapter 6 consists of graphs representing the direct vessel emissions of inland ships. In these graphs direct vehicle emissions of road transport are added as a comparison. These emissions of road transport are based on the results from the RIVM study “To Shift or not to Shift”. The following table consists of the used values. These values are calculated from the average of the best case and worst case in the RIVM study (page 94) following the EC-scenario. “To Shift or not to Shift” presents results for the years 2000 and 2010. Appendix A of this RIVM-report presents the development of the EC-scenario between 2010 and 2020 with respect to the emission parameters: a reduction of Nitrogen Oxides emission with 34% and a stand still in the reduction of particle matter and carbon dioxide emissions.

<b>Emission Parameters Road Transport g/ton-kilometre</b>				
<b>Bulk Transport</b>				
Truck (10 tonnes)	<b>NO<sub>x</sub></b>	<b>CO<sub>2</sub></b>	<b>PM<sub>10</sub></b>	<b>SO<sub>2</sub></b>
2000	<i>not available</i>	<i>not available</i>	<i>not available</i>	<i>not available</i>
2010	<i>not available</i>	<i>not available</i>	<i>not available</i>	<i>not available</i>
2020	<i>not available</i>	<i>not available</i>	<i>not available</i>	<i>not available</i>
<b>Truck (27,3 tonnes)</b>				
2000	0,79	67,7	0,026	<i>not available</i>
2010	0,38	67,7	0,009	<i>not available</i>
2020	0,25	67,7	0,009	<i>not available</i>
<b>Non-bulk Transport</b>				
<b>Truck (10 tonnes)</b>				
2000	1,33	123,0	0,050	<i>not available</i>
2010	0,64	123,0	0,018	<i>not available</i>
2020	0,42	123,0	0,018	<i>not available</i>
<b>Truck (27,3 tonnes)</b>				
2000	0,80	69,2	0,026	<i>not available</i>
2010	0,39	69,2	0,010	<i>not available</i>
2020	0,25	69,2	0,010	<i>not available</i>

- Source: RIVM Report “To Shift or not to Shift”

The emission parameters (g/km) for road transport used in the transport case calculation in chapter 7 are represented in the following table. The values are calculated from the RIVM-report “To Shift or not to Shift” based on the “best case” results for 2010 and the development of the emissions parameters between 2010 and 2020 as the average between the EC and EC-plus scenario as stated in Appendix A of the RIVM-report

Additionally the calculations for road transport in Chapter 7, are based on the assumption that transports above 1.000 tonnes takes place with 27,3 tonnes trucks and other transports with 10 tonnes trucks. Since there were no values available for bulk 10 tonnes trucks, values for non-bulk 10 tonnes trucks were used for all trades.

<b>Emission parameters Road Transport 2020 Chapter 7</b>	<b>NO<sub>x</sub> (g/km)</b>	<b>CO<sub>2</sub> (g/km)</b>	<b>PM<sub>10</sub> (g/km)</b>
Truck (27,3 tonnes) (bulk)	4,59	1570	0,22
Truck (27,3 tonnes) (non-bulk)	4,73	1605	0,22
Truck (10 tonnes) (all)	2,84	1045	0,15

- Source: RIVM Report “To Shift or not to Shift”



## **Appendix 2. Energy Consumption Vessel**

	Class	Length	Width	Draught		Load Capacity		Engine	Load	Waterway average		Empty	Speed		Energy Consumption		
				Loaded	Empty			Efficiency	factor	Depth	Width	hauls	Loaded	Empty	Loaded	Empty	Average
<b>Bulk</b>		(m)	(m)	(m)	(m)	(ton)	(teu)	%	%	m	m	%	(km/h)	(km/h)	(MJ/km)	(MJ/km)	(MJ/ton-km)
Spits – Peniche	2	38,5	5	2,20	1,00	350		0,36	0,95	5	50	0,25	13,6	17,3	132	112	0,51
Kempenaar	3	63	6,6	2,50	1,25	550		0,37	0,95	5	50	0,25	13,9	16,9	226	191	0,55
Rhine-Herne Canal Ship	5	80	9,5	2,60	1,30	1.350		0,36	0,95	5	50	0,25	15,8	19,1	472	395	0,47
Koppelverband	7	196	11,4	3,50	1,65	5500		0,37	0,88	5	50	0,20	13,5	18	635	682	0,17
Tank Ship (Rhine)	8	110	11,4	3,30	1,65	3.500		0,39	0,91	7,5	100	0,25	16,5	18,5	680	512	0,27
Large Tank Ship (Mega Barge)	8	135	17	3,60	1,70	6.000		0,39	0,87	7,5	100	0,25	16,5	18,5	1142	826	0,27
Four-barges convoy set	8	193	22,8	3,90	0,60	11.340		0,39	0,98	7,5	100	0,25	13	17	1146	727	0,12
<b>Non-bulk</b>																	
Neokemp	4	63	7	2,50	1,25	850	48	0,37	0,95	5	50	0	14,7	17,2	268	209	0,33
Rhine-Herne Canal Ship	5	80	9,5	2,60	1,30	1150	96	0,36	0,95	5	50	0	15,8	19,1	472	395	0,43
Container Ship (Rhine)	7	110	11,4	3,20	1,50	3000	200	0,37	0,92	7,5	100	0	13,5	18	475	486	0,17
Container Ship (JOWI class)	8	135	16,85	3,40	1,60	6000	470	0,39	0,90	7,5	100	0	16,5	18,5	1076	789	0,20
Car Carrier	7	110	11,4	1,90	1,50	2900		0,37	0,98	5	100	0,5	13	17	363	434	0,28

- Vessel characteristics: length, width, draught and load capacity are obtained from the Dutch shipping organisation CBRB
- Engine efficiency follows from a survey<sup>31</sup> in the Dutch fleet. From the survey average values for engine efficiency for each class are available.
- Loadfactor follows from a survey in this study. The values are checked by the Dutch shipping Organisation CBRB
- Percentage of empty hauls follows from survey in this study. The values were compared with the values used in the RIVM report “To Shift or not to Shift”. The values for bulk transport are in the same range. The values for non-bulk are not. This results from the fact that also empty containers are counted as load. This reduces the number of empty hauls.
- The speed of the vessels follows partly from the referred survey by TNO-MEP / AVV and partly from consulting practice parties
- Load capacity for non-bulks Neokemp&Rhine-Herne Canal Ship is based on tech. load capacity. In certain cases this capacity differs significantly from the permitted load capacity.

<sup>31</sup> Protocol voor berekening emissies door verbrandingsmotororen - TNO-MEP / AVV – October 2003



## **Appendix 3. Direct Vessel Emissions**

**Direct vessel emissions 2000**

	Emissions			
	NO <sub>x</sub>	CO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>
	g/ton-km	g/ton-km	g/ton-km	g/ton-km
<b>Bulk</b>				
Spits – Peniche	0,54	37,23	0,027	0,041
Kempenaar	0,60	40,66	0,030	0,044
Rhine-Herne Canal Ship	0,50	34,52	0,025	0,038
Koppelverband	0,18	12,18	0,009	0,013
Tank Ship (Rhine)	0,31	19,65	0,016	0,021
Large Tank Ship (Mega Barge)	0,31	19,93	0,016	0,022
Four-barges convoy set	0,14	9,16	0,007	0,010
<b>Non-bulk</b>				
Neokemp	0,36	24,28	0,018	0,027
Rhine-Herne Canal Ship	0,59	40,48	0,030	0,044
Container Ship (Rhine)	0,19	12,63	0,009	0,014
Container Ship (JOWI class)	0,23	14,69	0,012	0,016
Car Carrier	0,30	20,56	0,015	0,022

**Direct vessel emissions 2010**

	Emissions			
	NO <sub>x</sub>	CO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>
	g/ton-km	g/ton-km	g/ton-km	g/ton-km
<b>Bulk</b>				
Spits – Peniche	0,43	37,23	0,025	0,012
Kempenaar	0,48	40,66	0,028	0,013
Rhine-Herne Canal Ship	0,40	34,52	0,023	0,011
Koppelverband	0,14	12,18	0,008	0,004
Tank Ship (Rhine)	0,25	19,65	0,014	0,006
Large Tank Ship (Mega Barge)	0,25	19,93	0,015	0,006
Four-barges convoy set	0,12	9,16	0,007	0,003
<b>Non-bulk</b>				
Neokemp	0,29	24,28	0,017	0,008
Rhine-Herne Canal Ship	0,47	40,48	0,027	0,013
Container Ship (Rhine)	0,15	12,63	0,009	0,004
Container Ship (JOWI class)	0,18	14,69	0,011	0,005
Car Carrier	0,24	20,56	0,014	0,007

**Direct vessel emissions 2020**

	Emissions			
	NO <sub>x</sub>	CO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>
	g/ton-km	g/ton-km	g/ton-km	g/ton-km
<b>Bulk</b>				
Spits – Peniche	0,17	37,23	0,014	0,000
Kempenaar	0,18	40,66	0,016	0,000
Rhine-Herne Canal Ship	0,15	34,52	0,013	0,000
Koppelverband	0,06	12,18	0,005	0,000
Tank Ship (Rhine)	0,09	19,65	0,008	0,000
Large Tank Ship (Mega Barge)	0,10	19,93	0,008	0,000
Four-barges convoy set	0,04	9,16	0,004	0,000
<b>Non-bulk</b>				
Neokemp	0,11	24,28	0,009	0,000
Rhine-Herne Canal Ship	0,18	40,48	0,016	0,000
Container Ship (Rhine)	0,06	12,63	0,005	0,000
Container Ship (JOWI class)	0,07	14,69	0,006	0,000
Car Carrier	0,10	20,56	0,009	0,000

**Appendix 4.**  
**Formula: Energy Consumed per Vessel-kilometre**

## Energy Consumed

<b>III</b>	$e_{consumed} = f_{demand} * enthalpy$	
$E_{consumed}$	Energy consumed by the vessel	[MJ/km]
$f_{demand}$	Fuel demand by the vessel	[kg/km]
Enthalpy	Amount of energy in one kilogram fuel	[MJ/kg]

## Fuel Demand

The fuel demand follows from the energy demand by the engine and the efficiency of the engine.

<b>IV</b>	$f_{demand} = m_{demand} * Eff_{engine}$	
$m_{demand}$	Energy demand by the engine	[kWh/km]
$Eff_{engine}$	Efficiency of the engine	[kg/kWh]

## Energy Demand

The energy demand per kilometre for all different vessel types both loaded and empty is calculated from the sum of resistances around the vessel, the travelled distance, the efficiency of the screw and the efficiency of transmission by formula V.

<b>V</b>	$m_{demand} = \frac{R_{tot} * Dist}{eff_{screw} * eff_{transmission}}$	
$m_{demand}$	Energy demand by the engine	[J/km]=[kg*m <sup>2</sup> /km*s <sup>2</sup> )
$R_{tot}$	Total resistance for the moving vessel	[N]=[kg*m/s <sup>2</sup> ]
Dist	Travelled distance = 1	[km]
$Eff_{screw}$	Efficiency of the screw = 0,55	[%]
$Eff_{transmission}$	Efficiency of transmission = 0,91	[%]

## Total Resistance

The total resistance is calculated from the size of the vessel (width, length, draught, speed), waterway characteristics (width and depth of the waterway) and several physical parameters (pressure co-efficient, blockage resistant co-efficient, kinematic viscosity, gravity acceleration, density of water).

<b>VI</b>	$R_{tot} = R_f + R_p + R_z$	
$R_f$	Resistance as result of friction. Follows from formula VII	[N] =[kg*m/s <sup>2</sup> ]
$R_p$	Resistance Follows form formula VIII	[N]
$R_z$	Resistance as result of blockage. Follows from formula IX	[N]

<b>VII</b>	$R_f = 0,5 * D_w * v_{eff}^2 * \frac{0,075}{(\log R_n - 2)^2} * T_r$	
$D_w$	Density of water = 1000	[kg/m <sup>3</sup> ]
$V_{eff}$	Effective speed. Follows from formula X	[m/s]
$R_n$	Reynolds number. Follows from formula XI	[ ]
$T_r$	Roughness Co-efficient = 1,4	[ ]

<b>VIII</b>	$R_p = cp * 0,5 * D_w * V^2 * B * T_{max}$	
$cp$	Pressure co-efficient = 0,20	[ ]
$D_w$	Density of water = 1000	[kg/m <sup>3</sup> ]
$V$	Speed of the vessel	[m/s]
$B$	Width of the vessel	[m]
$T_{max}$	Maximum draught for the vessel in this trip	[m]

<b>IX</b>	$R_z = cz * 0,5 * D_w * g * z * B * T_{max}$	
$cz$	Blockage resistant co-efficient = 0,20	[ ]
$D_w$	Density of water = 1000	[kg/m <sup>3</sup> ]
$g$	Gravity acceleration = 9,81	[m/s <sup>2</sup> ]
$z$	Follows from formula XII	[m]
$B$	Width of the vessel	[m]
$T_{max}$	Maximum draught for the vessel in this trip	[m]

<b>X</b>	$V_{eff} = \frac{V}{1 - e^{-\frac{4 * (1-h)}{T_{max}}}}$	
$V$	Speed of the vessel	[m/s]
$h$	Average depth of the waterway	[m]
$T_{max}$	Maximum draught for the vessel in this trip	[m]

<b>XI</b>	$R_n = \frac{V_{eff} * L}{kv}$	
$V_{eff}$	Effective speed. Follows from formula X	[m/s]
$L$	Length of the vessel	[m]
$Kv$	Kinematic viscosity = $1,0 \times 10^{-6}$	[m <sup>2</sup> /s]

<b>XII</b>	$z = \frac{h * \frac{B * T_{max}}{h * w} * (\frac{V}{g * h})^2}{1 - (\frac{B * T_{max}}{h * w}) - (\frac{V}{g * h})^2}$	
$h$	Average depth of the waterway	[m]
$B$	Width of the vessel	[m]
$T_{max}$	Maximum draught for the vessel in this trip	[m]
$V$	Speed of the vessel	[m/s]
$g$	gravity acceleration	[m/s <sup>2</sup> ]
$w$	Width of the waterway	[m]

## **Appendix 5. Calculations Modal Shift in Practice**

## Container Trades (Paragraph 7.2)

<b>Port of Rotterdam to Nijmegen area – 48 TEU</b>			
		<b>Inland Shipping</b>	<b>Road Transport</b>
Distance		135 km	127 km
Water flow		-5 km/u	n/a
Commodity		1 x Neokemp	48 x truck (10 tonnes)
Emissions to port of destination:			
	NOx	13,9 kg	17,3 kg (decisive)
	CO2	3,1 ton	6,4 ton
	PM10	1,2 kg	0,9 kg
Additional road transport for equal environmental performance		25 km by 1 TEU truck or 36 km by Ecotruck	
<b>Port of Rotterdam - Antwerp area - 200 TEU</b>			
		<b>Inland Shipping</b>	<b>Road Transport</b>
Distance		65 km	114 km
Water flow		0 km/u	n/a
Commodity		1 x Container Ship (Rhine)	100 x truck (27,3 tonnes)
Emissions to port of destination:			
	NOx	11,2 kg	52,3 kg (decisive)
	CO2	2,5 ton	17,9 ton
	PM10	1,0 kg	2,5 kg
Additional road transport for equal environmental performance		90 km by 2 TEU truck or 128 km by Ecotruck	
<b>Port of Prague to Regensburg area - 470 TEU</b>			
		<b>Inland Shipping</b>	<b>Road Transport</b>
Distance		1.825 km	261 km
Water flow		0 km/u	n/a
Commodity		1 x Container Ship (JOWI class)	235 x truck (27,3 tonnes)
Emissions to port of destination:			
	NOx	775,7 kg	281,3 kg
	CO2	160,9 ton	96,3 ton
	PM10	66,9 kg	13,4 kg
Additional road transport for equal environmental performance		n/a km by 2 TEU truck	
<b>Rotterdam to Groningen area - 90 TEU</b>			
		<b>Inland Shipping</b>	<b>Road Transport</b>
Distance		190 km	263 km
Water flow		0 km/u	n/a
Commodity		1 x Rhine-Herne Canal Ship	45 x truck (27,3 tonnes)
Emissions to port of destination:			
	NOx	24,1 kg	54,3 kg (decisive)
	CO2	5,4 ton	18,6 ton
	PM10	2,1 kg	2,6 kg
Additional road transport for equal environmental performance		146 km by 2 TEU truck or	209 km by Ecotruck

### Dry Bulk Trades (Paragraph 7.3)

<b>Rotterdam to Amiens area - 350 tonnes dry bulk</b>			
		<b>Inland Shipping</b>	<b>Road Transport</b>
Distance		385 km	385 km
Water flow		0 km/u	n/a
Commodity		1 x Spits - Peniche	35 x truck (10 tonnes)
Emissions to port of destination:	NOx	22,3 kg	38,2 kg (decisive)
	CO2	5,0 ton	14,1 ton
	PM10	1,9 kg	2,0 kg
Additional road transport for equal environmental performance		160 km	
<b>Port of Mannheim to Rouen area - 700 tonnes dry bulk</b>			
		<b>Inland Shipping</b>	<b>Road Transport</b>
Distance		1.215 km	655 km
Water flow		5 km/u	n/a
Commodity		2 x Spits - Peniche	70 x truck (10 tonnes)
Emissions to port of destination:	NOx	127,8 kg	130,0 kg
	CO2	28,7 ton	47,9 ton
	PM10	11,0 kg	6,9 kg
Additional road transport for equal environmental performance		11 km	
<b>Port of Rotterdam to Cologne area - 11.500 tonnes dry bulk</b>			
		<b>Inland Shipping</b>	<b>Road Transport</b>
Distance		330 km	278 km
Water flow		-5 km/u	n/a
Commodity		1 x Four-barges Convoy set	422 x truck (27,3 tonnes)
Emissions to port of destination:	NOx	187,6 kg	538,1 kg (decisive)
	CO2	38,9 ton	184,2 ton
	PM10	16,2 kg	26,6 kg
Additional road transport for equal environmental performance		181 km	
<b>Rotterdam to Vienna area - 5.500 tonnes dry bulk</b>			
		<b>Inland Shipping</b>	<b>Road Transport</b>
Distance		1.535 km	1.184 km
Water flow		-5 km/u	n/a
Commodity		1 x Koppelverband	202 x truck (27,3 tonnes)
Emissions to port of destination:	NOx	518,8 kg	1096,9 kg (decisive)
	CO2	114,6 ton	376,4 ton
	PM10	44,74 kg	62,2 kg
Additional road transport for equal environmental performance		624 km	

## Liquid Bulk Trades (Paragraph 7.4)

<b>Rotterdam to Thionville area - 3.500 tonnes liquid bulk</b>				
		<b>Inland Shipping</b>	<b>Road Transport</b>	
Distance		690 km	405 km	
Water flow		0 km <sup>3</sup> /u	n/a	
Commodity		1 x Tank Ship (Rhine)	129 x truck (27,3 tonnes)	
Emissions to port of destination:	NO <sub>x</sub>	228,8 kg	239,6 kg	
	CO <sub>2</sub>	47,4 ton	82,0 ton	
	PM <sub>10</sub>	19,7 kg	11,4 kg	
Additional road transport for equal environmental performance		n/a km		
<b>Port of Rotterdam to Mainz area - 6.000 tonnes liquid bulk</b>				
		<b>Inland Shipping</b>	<b>Road Transport</b>	
Distance		620 km	453 km	
Water flow		-5 km <sup>3</sup> /u	n/a	
Commodity		1 x Large Tank Ship (Mega Barge)	220 x truck (27,3 tonnes)	
Emissions to port of destination:	NO <sub>x</sub>	327,4 kg	457,1 kg	(decisive)
	CO <sub>2</sub>	67,9 ton	156,4 ton	
	PM <sub>10</sub>	28,2 kg	21,8 kg	
Additional road transport for equal environmental performance		129 km		
<b>Antwerp to Vienna area - 1.350 tonnes liquid bulk</b>				
		<b>Inland Shipping</b>	<b>Road Transport</b>	
Distance		1.600 km	1.102 km	
Water flow		-5 km <sup>3</sup> /u	n/a	
Commodity		1 x Tank Ship (Rhine)	50 x truck (27,3 tonnes)	
Emissions to port of destination:	NO <sub>x</sub>	223,4 kg	252,7 kg	(decisive)
	CO <sub>2</sub>	46,3 ton	86,5 ton	
	PM <sub>10</sub>	19,3 kg	12,0 kg	
Additional road transport for equal environmental performance		128 km		
<b>Port of Groningen to Antwerp area - 3.500 tonnes liquid bulk</b>				
		<b>Inland Shipping</b>	<b>Road Transport</b>	
Distance		245 km	306 km	
Water flow		0 km <sup>3</sup> /u	n/a	
Commodity		1 x Tank Ship (Rhine)	129 x truck (27,3 tonnes)	
Emissions to port of destination:	NO <sub>x</sub>	81,2 kg	181,0 kg	(decisive)
	CO <sub>2</sub>	16,8 ton	62,0 ton	
	PM <sub>10</sub>	7,0 kg	8,6 kg	
Additional road transport for equal environmental performance		169 km		

## Car Trades (Paragraph 7.5)

<b>Dunkirk to Born area - 600 cars</b>				
		<b>Inland Shipping</b>	<b>Road Transport</b>	
Distance		245 km	319 km	
Water flow		0 km <sup>3</sup> /u	n/a	
Commodity		1 x Car Carrier	75 x truck (10 tonnes)	
Emissions to port of destination:	NO <sub>x</sub>	65,9 kg	67,8 kg	(decisive)
	CO <sub>2</sub>	13,7 ton	25,0 ton	
	PM <sub>10</sub>	5,7 kg	3,6 kg	
Additional road transport for equal environmental performance		9 km		

## Seine Nord Connection (Paragraph 7.6)

<b>Rotterdam to Paris area - 3.500 tonnes liquid bulk</b>				
		<b>Inland Shipping</b>	<b>Road Transport</b>	
Distance		245 km	306 km	
Water flow		0 km <sup>3</sup> /u	n/a	
Commodity		1 x Tank Ship (Rhine)	129 x truck (27,3 tonnes)	
Emissions to port of destination:	NO <sub>x</sub>	81,2 kg	181,0 kg	(decisive)
	CO <sub>2</sub>	16,8 ton	62,0 ton	
	PM <sub>10</sub>	7,0 kg	8,6 kg	
Additional road transport for equal environmental performance		169 km		

## **Appendix 6. Emission limits: CCR and EU**

## Central Commission for Navigation on the Rhine

### Phase 1 (from 1.1.2002)

CO [g/kWh ]	P <sub>N</sub> [kW]	HC [g/kWh ]	NO <sub>x</sub> [g/kWh]	PT [g/kWh h]
6,5	37 ≤ P <sub>N</sub> < 75	1,3	9,2	0,85
5,0	75 ≤ P <sub>N</sub> < 130	1,3	9,2	0,70
5,0	P <sub>N</sub> ≥ 130	1,3	$n \geq 2800 \text{ min}^{-1} = 9,2$ $500 \leq n < 2800 \text{ min}^{-1} = 45 \cdot n^{(-0,2)}$	0,54

### Phase 2 (from 1. 1.2008)

CO [g/kWh ]	P <sub>N</sub> [kW]	HC [g/kWh h]	NO <sub>x</sub> [g/kWh]	PT [g/kWh ]
5,5	18 ≤ P <sub>N</sub> < 37	1,5	8,0	0,8
5,0	37 ≤ P <sub>N</sub> < 75	1,3	7,0	0,4
5,0	75 ≤ P <sub>N</sub> < 130	1,0	6,0	0,3
3,5	130 ≤ P <sub>N</sub> < 560	1,0	6,0	0,2
3,5		1,0	$n \geq 3150 \text{ min}^{-1} = 6,0$ $343 \leq n < 3150 \text{ min}^{-1} = 45 \cdot n^{(-0,2)} - 3$ $n < 343 \text{ min}^{-1} = 11,0$	0,2

## Draft Directive 2002/765 as amended in October 2003

### Stage III Limits

Category	Displacement (D)	CO	NO <sub>x</sub> +HC	PM	Date
	dm <sup>3</sup> per cylinder	g/kWh			
V1:1	D ≤ 0.9 and P > 37 kW	5.0	7.5	0.40	31.12.2006
V1:2	0.9 < D ≤ 1.2	5.0	7.2	0.30	
V1:3	1.2 < D ≤ 2.5	5.0	7.2	0.20	
V1:4	2.5 < D ≤ 5	5.0	7.2	0.20	31.12.2008
V2:1	5 < D ≤ 15	5.0	7.8	0.27	
V2:2	15 < D ≤ 20 and P ≤ 3300 kW	5.0	8.7	0.50	
V2:3	15 < D ≤ 20 and P > 3300 kW	5.0	9.8	0.50	
V2:4	20 < D ≤ 25	5.0	9.8	0.50	
V2:5	25 < D ≤ 30	5.0	11.0	0.50	

### Stage IV Limits

Category	Displacement (D)	CO	NO <sub>x</sub> +HC	PM	Date
	dm <sup>3</sup> per cylinder	g/kWh			
V1:1	D ≤ 0.9 and P > 37 kW	5.0	1.5	0.02	31.12.2010
V1:2	0.9 < D ≤ 1.2	5.0	1.5	0.02	
V1:3	1.2 < D ≤ 2.5	5.0	1.5	0.02	
V1:4	2.5 < D ≤ 5	5.0	1.5	0.02	31.12.2011
V2:1	5 < D ≤ 15	5.0	1.5	0.02	
V2:2	15 < D ≤ 20 and P ≤ 3300 kW	5.0	1.7	0.02	
V2:3	15 < D ≤ 20 and P > 3300 kW	5.0	2.0	0.02	
V2:4	20 < D ≤ 25	5.0	2.0	0.02	
V2:5	25 < D ≤ 30	5.0	2.2	0.02	