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EMISSIONS IN INLAND NAVIGATION

- **Although inland waterway transport benefits from economies of scale, greenhouse gas emissions and pollutant emissions are raising increasing concern and attention.**
- **Technical, operational and transport management measures exist to limit emissions, but implementation costs limit their market penetration.**
- **Operational measures have the highest cost-benefit ratio, and stricter emission standards will apply for new engines from 2019 onwards.**

DEFINITIONS AND CONTEXT

The transport sector is generating different effects on the environment. Transport infrastructure (roads, railway lines, locks, dams, etc.) represents and intervention on nature and landscape. Based on this infrastructure, and in strong interaction with it, the transport of goods and passengers causes external effects like noise, emissions and accidents. The present report aims to give a short overview of the ecological profile of inland shipping compared to the two land transport modes, road and rail. Based on this comparison, different possibilities for reducing energy consumption and emissions are presented. The report ends with some conclusions.

GREENHOUSE GAS EMISSIONS AND POLLUTANT EMISSIONS

Certain emissions contribute to global warming and are therefore called greenhouse gas emissions (GHG). Other emissions do not – at least not directly – affect the climate, but are harmful to air quality and human health. These emissions are called pollutant emissions. The relevance of emissions in the IWT sector reflects the fact that, until today, almost 100% of the fuel used by inland vessels is gasoil, which is very similar to diesel. Therefore, the most relevant emissions in IWT are:

1. Pollutant emissions - mainly nitrogen oxides (NOx), particulate matter (PM), hydrocarbons (HC) and carbon monoxide (CO)

2. Greenhouse gas emissions (GHG) –mainly CO_2

Most measures for the reduction of emissions in IWT at the same time also reduce fuel consumption, and therefore have both ecological and economic benefits. This does not apply to all measures: important exceptions are exhaust gas reduction techniques that can reduce pollutant emissions (PM and NOx) by up to 80-90%, but do not lead to less fuel consumption.

WELL-TO-WHEEL AND TANK-TO-WHEEL EMISSIONS

The well-to-wheel (or well-to-propeller) approach comprises all emissions caused by a transport mode: emissions during fuel extraction, fuel production, fuel transport, and finally the emissions caused by the combustion of fuel in the engines.

The tank-to-wheel (or tank-to-propeller) approach contains only those emissions that occur from the combustion of fuel in the engines (of a vessel, a truck or a train).

Within this report, the well-to-wheel (or well-to-propeller) approach is followed, as it gives a more comprehensive picture of the ecological profile of a mode of transport. This is especially relevant for electric rail transport. About 80% of European rail traffic uses electric traction today (UIC / CER (2015). Therefore, the emissions of rail traffic, based on a tank-to-wheel approach, would be almost zero.

But for the generation of electricity, significant emissions can be produced. If electricity is produced by a coal fired power plant for example, the well-to-wheel emissions would be quite high. This is taken into account only by the well-to-wheel approach. For electric rail transport, the well-to-wheel emission factors presented in this report are based on the average mix of electricity produced in the Netherlands.

Comparisons of emissions between different transport modes should follow the well-to-wheel approach.

EMISSIONS IN IWT
COMPARED TO OTHER TRANSPORT MODES

Comparisons of emissions between different modes of transport are challenging, due to the large influence of the vehicle or vessel size, the infrastructure and operational factors.

Within this report, this intermodal comparison follows a study by the Dutch research institute CE Delft. This institute has developed long standing expertise in studying the ecological profile of different transport modes, including inland navigation. The study[11] was published in 2016 and represents an actualization of a previous study published in 2011. For the calculation of emissions in IWT, practical data for 100 inland waterway vessels were provided by BLN-Schuttevaer, with data according to these parameters:

- Vessel parameters (length, width, draught, capacity)
- Annual tonnage transported
- Annual distance travelled, loaded and empty
- Description of sailing area
- Annual diesel consumption

These data enabled energy consumption per ton-kilometer and CO_2 emissions for different vessel types to be determined. Pollutant emissions per ton-kilometer are calculated using reported emission factors for engines of different construction years.[12]

In Western Europe, two vessel types are representative of the majority of transports: the Large Rhine vessel (110 m length), and the Rhine-Herne canal vessel (85 m length). The Rhine-Herne canal vessel has a loading capacity of around 1,500 tonnes, which is equal to the current average loading capacity of the Western European dry cargo fleet (based on national administration data). But on smaller inland waterways in Belgium, the Netherlands and France, the type Kempenaar (55 m length) is also relevant. On the Lower Rhine and Danube there are pushed convoys carrying more than 10,000 tonnes of cargo.

VESSEL TYPES CHOSEN FOR THE INTERMODAL EMISSION COMPARISON

Vessel type	Transported goods	Loading capacity (tonnes)
Kempenaar	Heavy bulk	616 t
Rhine-Herne canal vessel	Heavy bulk	1,537 t
Large Rhine vessel	Heavy bulk	3,013 t
Coupled convoy	Heavy bulk	5,046 t
4-barge pushed convoy	Heavy bulk	11,181 t

Source: CE Delft (2016)

[11] *CE Delft (2016), STREAM Freight Transport 2016 – Emissions of Freight Transport modes*
[12] *For the detailed methodology, see CE Delft (2016), page 51*

For rail freight traffic, the most common type of vehicle is the medium-length electric train, as around 80% of rail freight traffic in Europe is achieved with electric trains today.

Decarbonisation of fuels is already much in progress in the rail sector: 80% of European goods traffic by rail is carried out by electric traction today.

TRAIN TYPES CHOSEN FOR THE INTERMODAL EMISSION COMPARISON

Train types	Transported goods	Loading capacity (tonnes)
Diesel, medium length train	Heavy bulk	1,914 t
Electric, medium length train	Heavy bulk	1,914 t

Source: CE Delft (2016)

Within road transport, the average type of freight carried is medium weight cargo. Heavy tractor-semitrailers combinations account for over 75% of ton-kilometers. In transport with lighter trucks (load capacity < 20 t), medium weight trucks play an important, and in terms of emissions, representative role.

TRUCK TYPES CHOSEN FOR THE INTERMODAL EMISSION COMPARISON

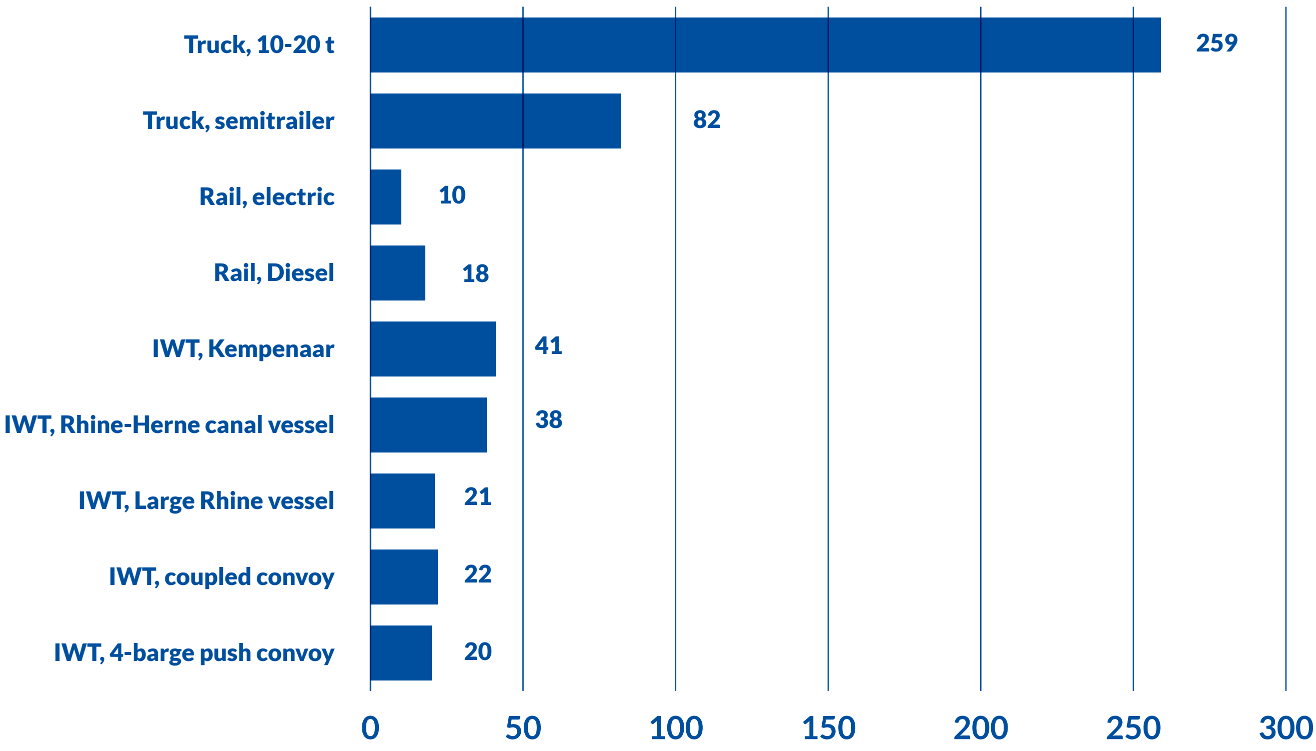
Truck types	Transported goods	Loading capacity (tonnes)
Truck, 10-20 tonnes	Medium-weight-bulk	7.5 t
Truck, semitrailer heavy	Medium-weight-bulk	29.2 t

Source: CE Delft (2016)

For PM, the emissions due to wear-and-tear were also taken into account. These emissions are caused by abrasion from tyres, brake linings and road surface. They are relevant for trucks, where they can be in the same magnitude as the PM emissions from engines.

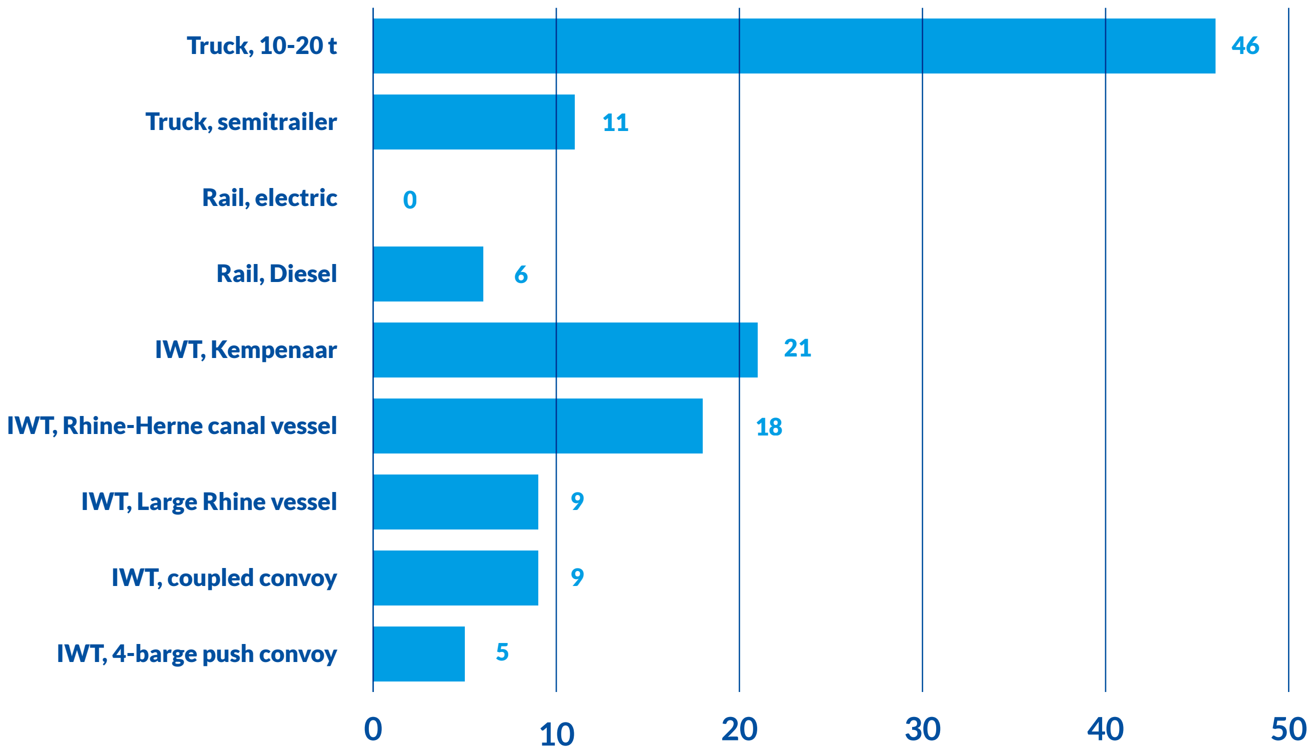
The following figures show the emission factors according to CE Delft for the different vessel, train and truck types. Within IWT, it is straightforward to see the influence of the vessel size: larger vessels have lower fuel consumption values per ton-kilometer and therefore lower emissions per ton-kilometer than smaller ones. Four-barge pushed convoys have the lowest values of the vessel types presented here.

REPRESENTATIVE EMISSION FACTORS FOR CO2, BULK TRANSPORT (G/TKM)



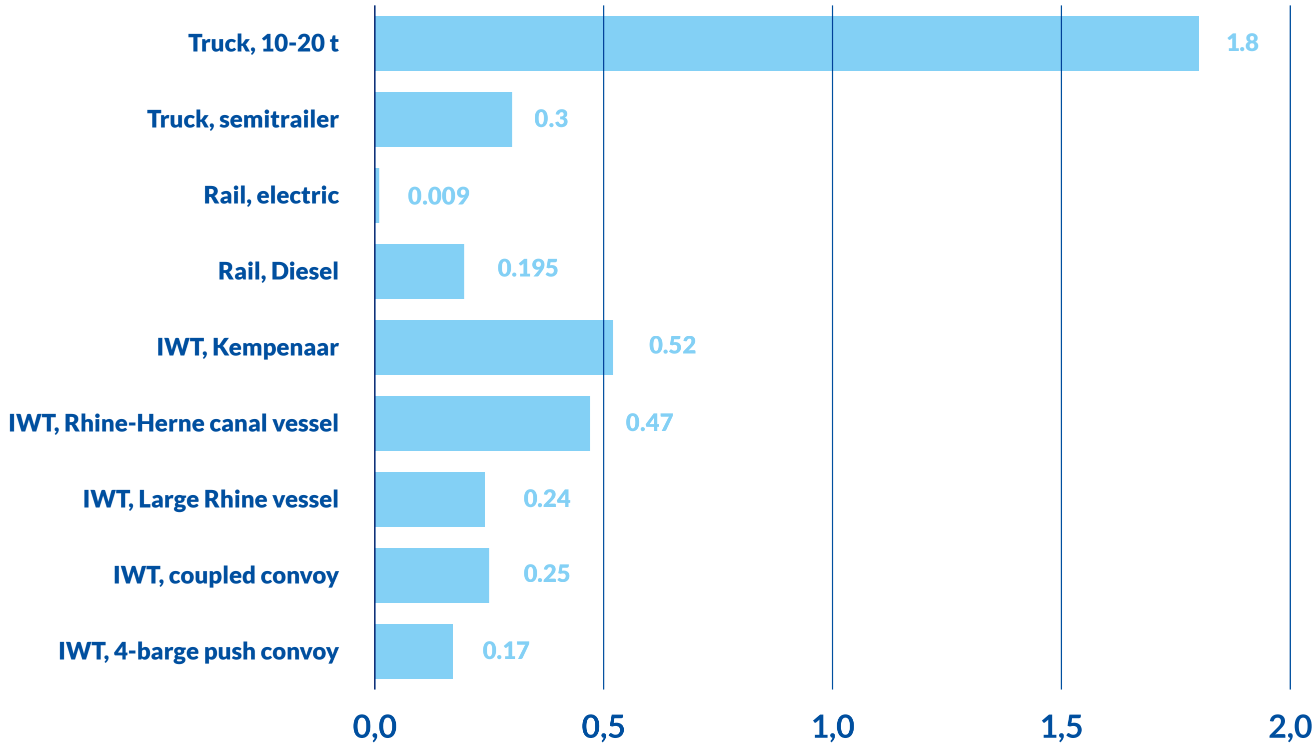
Source: CE Delft (2016), STREAM Freight transport 2016. Well-to-wheel emissions approach

REPRESENTATIVE EMISSIONS FACTORS FOR PARTICULATE MATTER (PM), BULK TRANSPORT (1000 G/TKM)



Source: CE Delft (2016), STREAM Freight transport 2016. Well-to-wheel emissions approach

REPRESENTATIVE EMISSIONS FACTORS FOR NITROGEN OXIDES (NOX), BULK TRANSPORT
(G/TKM)



Source: CE Delft (2016), STREAM Freight transport 2016. Well-to-wheel emissions approach

The following conclusions can be drawn:

- For CO2 emissions, all IWT vessel types have lower emissions than the most common truck type (semitrailer), but higher emissions than the most common railway type (electric railway).
- For pollutant emissions PM and NOx, IWT vessels have higher emissions than electric railways, the most common railway type.
- If we compare pollutant emissions between IWT and road traffic, we see that one of the most common vessel types (the Large Rhine vessel) as well as the larger vessel types have lower emissions than truck semitrailers. The second very common vessel type, Rhine-Herne-Canal, has higher emissions than the truck semitrailers.

From the figures, the overall conclusion seems to be that IWT vessels emit relatively few greenhouse gases, but can have rather high values for pollutant emissions, when compared to railways and trucks. Therefore, it is worth thinking about emission reduction measures specifically for the IWT sector. The next chapter will analyse these measures.

MEASURES
FOR REDUCING FUEL CONSUMPTION AND EMISSIONS IN IWT

Emission reduction measures in inland shipping can be categorized into three main groups:

- Technical measures: measures related to the propulsion system, vessel design and vessel equipment, exhaust after treatment, engine internal measures, use of alternative fuel/energy (LNG, electricity, hydrogen, biofuel)
- Operational measures: measures related to speed reduction, smart steaming, journey planning, on board information systems, optimal maintenance
- Traffic and transport management: measures related to the organisation of the logistical chain, to the interface between inland waterway vessels and other transport modes, to the interface of inland waterway vessels and infrastructure (locks, terminals in inland and seaports, etc.)

Based on a literature review, for most of the above-mentioned options, the reduction potential (in terms of reduced energy consumption compared to a conventional diesel engine without any greening measures), the applicability (new construction/ retrofit), the approximate costs, and the approximate payback time were investigated.

A synoptic overview of the investigation results can be found in the following table. It has to be said that the indicated costs and payback times are only a broad indication, and can differ, depending on particular technical and economic circumstances. The payback times are of course influenced by fuel price evolutions.

TECHNICAL, OPERATIONAL AND TRAFFIC MANAGEMENT MEASURES FOR REDUCING ENERGY CONSUMPTION IN IWT

Area	Measures	Applicability	Decrease of energy consumption	Additional costs (€)	Payback time (years)
Technical	Father-and-son engine[13]	New and retrofit	10%	150,000	7-8
	Diesel-electric propulsion	Only new vessels	10%	200,000	10
	Electric propulsion	Only new vessels	10%	300,000	15
	Liquefied natural gas (LNG)	New and retrofit	No	new: 1,000,000 retro: 1,400,000	16-20
	Particulate matter filter (PMF)	New and retrofit	No	500,000	-
	Selective catalytic reduction (SCR)	New and retrofit	No	500,000	-
	Flexible tunnel	New and retrofit	10%	60,000	1.5-3
	Optimized hull form	New and retrofit	10%	150,000	3-4
	Weight reduction by composite materials	Only new vessels	5-15%	Increase in hull costs by 30%	10-15
Operational	Speed reduction/ Smart steaming	All vessels	10-30%	250€ for a training course	0.1-0.2
	On-board information systems/Journey planning		10%	Low costs	< 1
	Optimal maintenance		5%	Low costs	< 1
Traffic and transport management	Reduction of empty trips		high	No general quantification possible	
	Improving interface in seaports		high		
	AIS/RIS/Inland ECDIS		high		

Source: own compilation based on DNV GL (2015), Pauli (2016), Development Centre for Ship Technology and Transport Systems (DST), Hazeldine, Pridmore et al. (2009)

[13] *This system consists of a combination of a smaller and a larger engine, which are deployed depending on the navigation situation and according to their optimal power range. For the energy demanding upstream transport, only the larger engine can be active, while the smaller one can be inactive. For downstream transport, when less power is needed, only the smaller engine could be deployed. Overall, this system leads to savings in fuel consumption.*

Operational measures have a very positive cost-benefit ratio, as they are cheap, easy to implement and have very short payback times. Speed reduction and journey planning are important examples.

Selective catalytic reduction (SCR) and particulate matter filters (PMF) are exhaust after treatment systems. SCR reduces nitrogen oxides NOx by 85-90%, and PMF reduces particulate matter by 90-95%. Therefore, these systems are very efficient at reducing pollutant emissions. But for a single engine of some 1,000 kW, which is a common engine size for a self-propelled vessel in Europe, the price for exhaust after treatment systems is almost as high as the price for a new engine (Pauli 2016). Besides, PMF can lead to slightly higher fuel consumption levels by 2-3% (European Commission 2013).

LNG's main advantages are a significant reduction of pollutant emissions (80% for NOx, 75% for PM). The effects on greenhouse gas emissions are not as positive, as methane slip occurs when the combustion process is not perfect. Methane slip is very harmful for global warming - its global warming potential is about 28 to 34 times higher than that of CO2 (Pauli 2016). Further technological evolution is needed in order to reduce methane slip.

LNG has high investment costs. Therefore, LNG as a fuel should be much cheaper than gasoil in order to come to acceptable payback times. However, actual low oil prices limit the profitability of LNG.

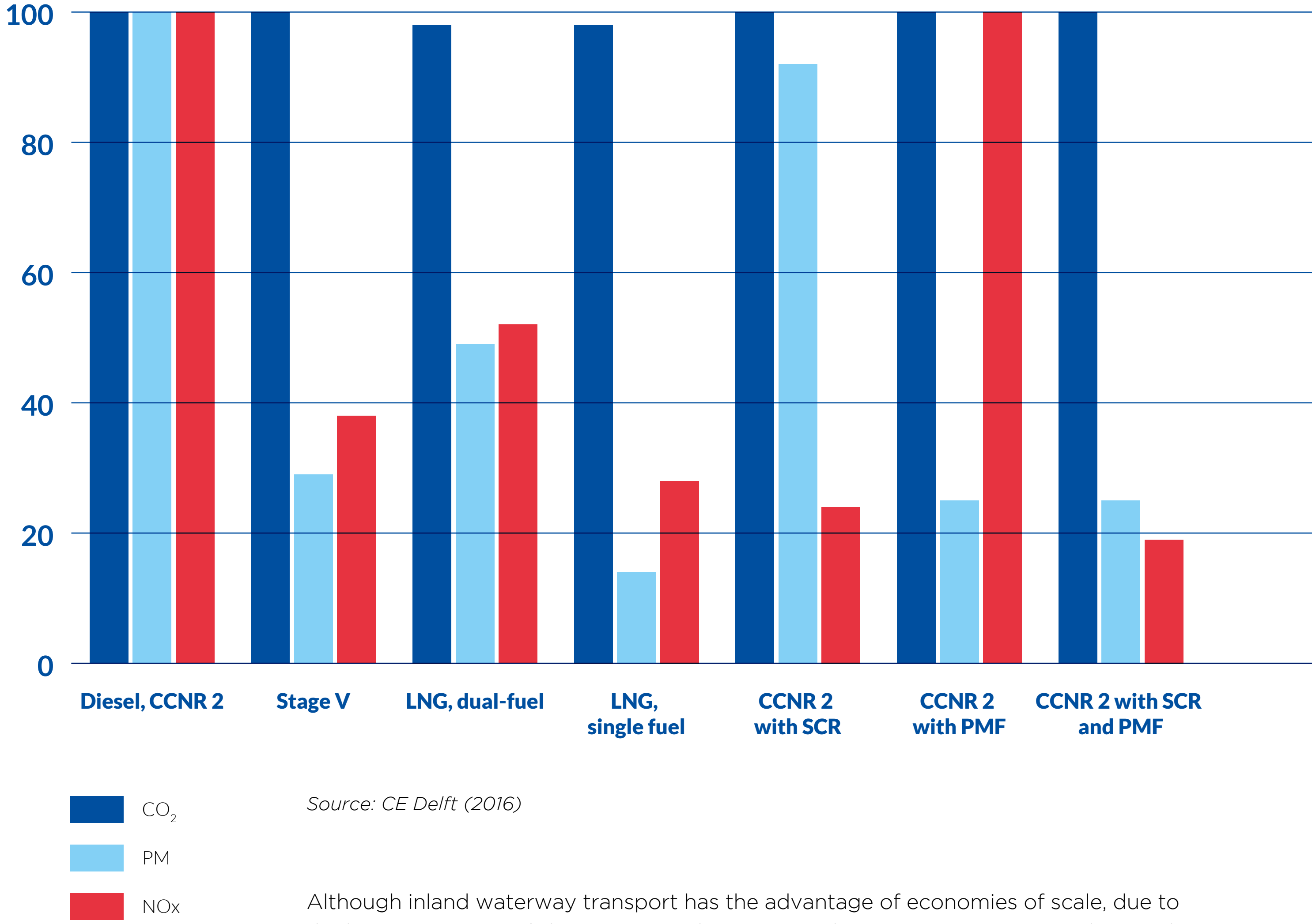
Currently, most projects for LNG vessels are partly publicly funded, for example by the LNG Masterplan Rhine-Main-Danube, a large research project that has received 40 million Euros of EU funding. Its vision is that LNG will be transported by IWT from LNG terminals in seaports to LNG hubs (serving as bunkering stations) in the hinterland. Economically, it can be expected that investment costs for LNG will go down with more vessels using LNG, and the provision of LNG will develop as more bunkering stations become available.

New stringent emission standards (NRMM) will be in place for new inland vessels from 2019 onwards.

The new emission limits (Stage V) that will apply for new engines from 2019 onwards[14] can only be met with single LNG fuel propulsion or with the installation of both exhaust after treatment systems. This is shown in the following figure, where the reference emission level is the CCNR Stage II level, which was applied for new engines in 2007.

[14] *Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery*

COMPARISON OF EMISSION LIMITS ACCORDING TO STAGE V AND CCNR 2 WITH DIFFERENT GREENING OPTIONS (DIESEL CCNR 2 = 100)



Source: CE Delft (2016)

Although inland waterway transport has the advantage of economies of scale, due to the large capacities of ships compared to trains and even more so compared to trucks, the emissions of inland vessels are attracting more and more concern and attention. This is less the case for greenhouse gas emissions, but much more the case for pollutant emissions. These emissions are harmful to nature and human beings, which is relevant both for the personnel working in IWT as well as for populations in densely populated areas, living alongside inland waterways (in port areas or cities).

In theory, many emission reduction measures for IWT exist, but their application is often very costly, and therefore difficult to implement in a market structure with a high share of family businesses. Perhaps the measure with the highest and quickest return on investment (both in economic and in ecological meaning) are operational measures, such as the reduction and optimization of speed, on board information systems, journey planning and automatic cruise control systems.

In addition to these measures, from 2019 onwards, new and much stricter emission standards will apply for new engines. Pollutant emissions should decrease with the gradual integration of new engines into the fleet. A fact that supports this process is the shorter life time of new engines, which applies in general to engines built after 1990. The introduction of LNG vessels contributes further to the reduction of pollutant emissions.