Van Mourik Broekmanweg 6
2628 XE Delft
P.O. Box 49
2600 AA Delft
The Netherlands

www.tno.nl

T +31 88 866 30 00
F +31 88 866 30 10

TNO report

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Projected impact of biodiesel on road transport emissions up to 2030 – background report

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Author(s)	G. Kadijk I. Kooter A. Jedynska S. van Zyl R. Verbeek G. Koornneef
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Summary

Future biofuel targets will lead to application of higher blends of biofuels in vehicles. Biofuels may have, compared to fossil fuel, a deviant chemical structure. This is the main reason to carry out the desk study which reports the impact of higher biofuel blends on engine emissions and the toxicity of these emissions.
This report serves as background report to the letter report “Impact of increasing the blend ratio of biodiesel on engine emission associated toxicity” by RIVM and TNO (ref RIVM Letter report 240007 001/2014), commissioned by the Dutch Ministry of Infrastructure and Environment. The goal of the study by RIVM and TNO is to assess the potential impact of biodiesel blends in transport on public health by means of a literature scan.

This report focusses on the impact of biodiesel blends on regulated and non-regulated emissions, with the main focus on road transport. The time horizon of this study is 2015, with an outlook to 2030. For this, in-house knowledge on fuels, engine technology and emissions is combined with results from literature.

Two types of biodiesel need to be distinguished because of their entirely different chemical compositions. These are FAME (Fatty Acid Methyl Ester) and HVO (Hydrogenated Vegetable Oil) or BTL (Biomass to Liquid).

The uncertainty of the future biodiesel blends is large due to the absence of European targets for the period of after 2020. The target for 2020, is to use (generally blending) of 10% biofuel base on energy content. Physical content can be lower due to the possibility of ‘double counting’.

For the period up to 2030, it is expected that:

- FAME type biodiesel is blended with regular diesel up to some 5% to 7%. However higher blend percentages (such as 30%) for certain market segments or niche markets cannot be fully excluded.
- HVO type biodiesel blend will likely be used to further top up the blend percentage above 7%. For 2030, it is expected that the HVO will not exceed a 5% to 10% blending share. For niche markets a higher blend percentage of up to 30% or even pure HVO might be used.
- In general, the absolute level of regulated and non-regulated emissions decrease due to the more stringent emission levels.

Effect of FAME biodiesel blends on <u>regulated</u> emissions:

- The effects are generally proportional with the blend ratio.
- HC, CO and PM emissions go down, see also Figure 1.
- NO_x and NO_2 emissions can go up (max ca 10%) with FAME and go down (max ca 10%) with HVO type biodiesel.
- Particle number emissions go down with high blend percentages, probably for both FAME as well as HVO biodiesel. Particle size distribution is probably not significantly affected.
- Due to new engine technology of the actual fleet in 2030 the emission factors will decrease. This decrease in emissions is more substantial than the emission reductions which are caused by higher biofuel blends.

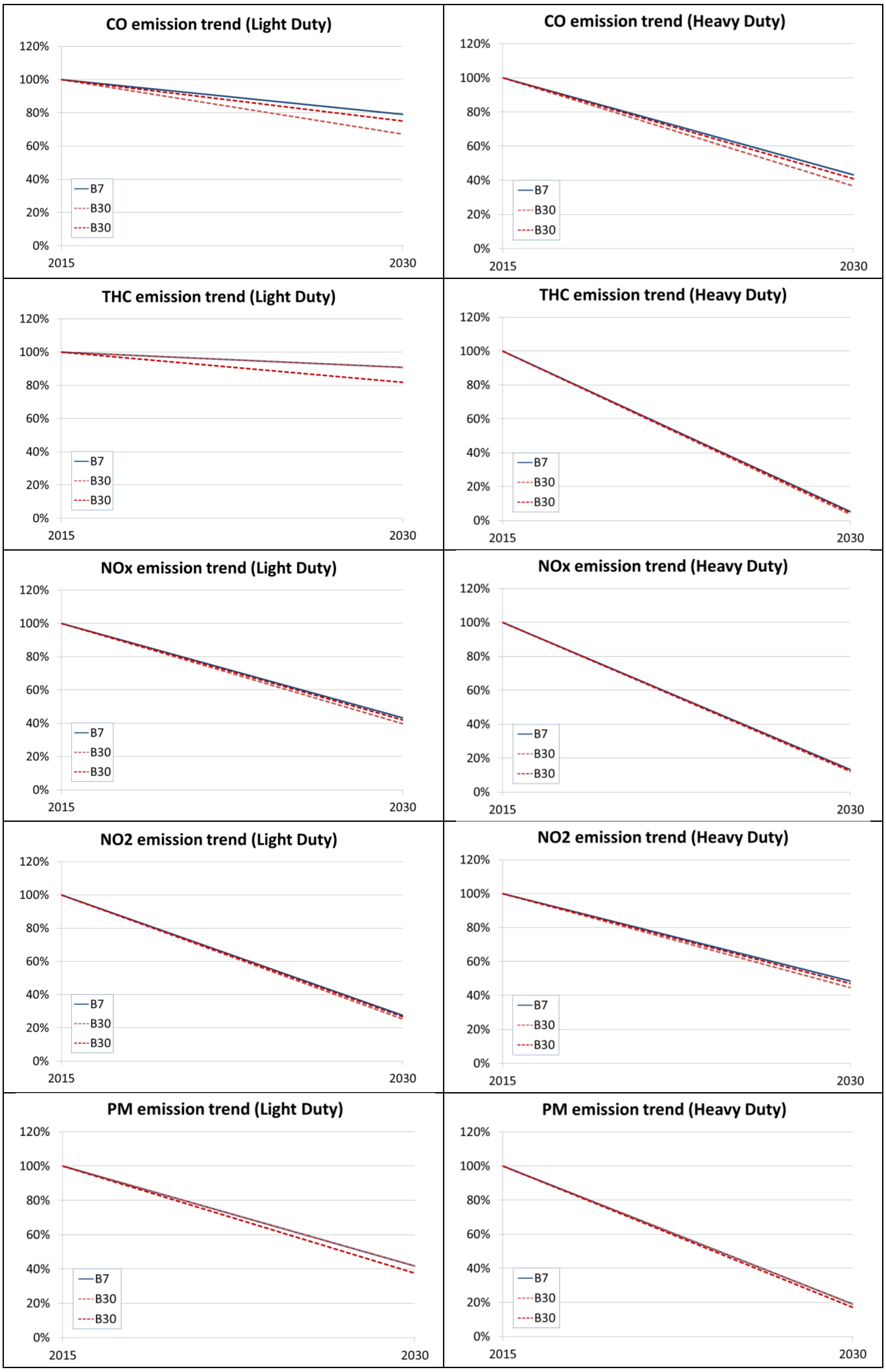

Figure 1: Predicted emissions trends 2015-2030 – Light Duty and Heavy Duty vehicles and the effects of increased biodiesel blends.

Effect of FAME biodiesel blends on non-regulated emissions:

- Polycyclic Aromatic Hydrocarbons (PAH): generally decrease when using B100. Unsaturated biodiesel (e.g. soy bean) shows less decrease compared to saturated biodiesel (e.g. coconut). No consistence response with low blends B7 – B20 are identified.
- Benzenes: some studies show an increase of benzenes and other studies show a decrease when using low biodiesel blend (further investigation is required).
- Nitro- and oxy-PAH's: The very few studies found addressing nitro- and oxy-PAH, showed a decrease of these PAH types with B100. However, nitro- and oxy-PAH's can increase with low blends (this requires further investigation).
- Carbonyl: often appear to increase with biodiesel blend rates.
- Elementary carbon: generally decreases substantial as a function of the biodiesel blend rate for both FAME and HVO type.
- Organic carbon: can vary significantly and does not show a clear pattern with biodiesel blends.

Very few studies addressed the influence of HVO biodiesel. A single study showed a comparable decrease of PAH as for FAME type biodiesel.
In general, there is no particular concern of increasing non-regulated emission with HVO blends due to the plain paraffinic chemical composition of HVO.

For the period up to 2030, the following can be concluded:

- in general, the absolute level of regulated and non-regulated emissions decrease due to the more stringent emission levels and the general application and the higher efficiencies of emission control systems such as (NO_x) catalysts and particulate filters.
- Looking at the influence of FAME type biodiesel blends: some non-regulated components might not show a proportional decrease with the regulated emissions. Further investigation on carbonyl emissions and nitro- and oxy-PAH when using low blend biodiesel is required.

Contents

1 Introduction

This report serves as background report to the letter report “Impact of increasing the blend ratio of biodiesel on engine emission associated toxicity” by RIVM and TNO (ref RIVM Letter report 240007 001/2014), commissioned by the Dutch Ministry of Infrastructure and Environment. The goal of the study by RIVM and TNO is to assess the potential impact of biodiesel blends in transport on public health by means of a literature scan.

Future biofuel emission targets will lead to application of higher blends of biofuels in vehicles. Biofuels may have, compared to fossil fuel, a deviant chemical structure. This is the main reason to carry out this study which reports the impact of higher biofuel blends on engine emissions and the toxicity of these emissions.

This background report focusses on the impact of biodiesel blends on regulated and non-regulated emissions, with the main focus on road transport. For this, in-house knowledge on fuels, engine technology and emissions is combined with results from literature. Measurement of emissions was not part of this study. The time horizon of this study is 2015, with an outlook to 2030.

Chapter 2 of this report discusses the types and status of biodiesel blends on the Dutch and European market, with an outlook to 2030. The development of engine emissions up to 2030 will be described in chapter 3, focusing on regulated emissions. Chapter 4 deals with the impact of biodiesel types and blends on regulated and non-regulated emissions.

2 Biofuel blends on the European and Dutch market

This chapter gives an overview of the current status and the expected situation in 2030 of biofuel blends on the European and Dutch market. The chapter is divided into three sections. Section 2.1 provides an overview of the current European and Dutch legislation that are of influence to the exploitation and blending of biofuel. Since the focus is on biodiesel, the different types FAME and HVO are discussed. Section 0 shows the historical development of biofuel blends up to the current state. Section 2.2 makes a prediction of the share of biofuels in the year up to 2030.

2.1 Evaluation biodiesel blends 2014-2030 in Europe

This evaluation of biodiesel blends is based on the definition of EU goals for biofuel blending, a marketing study performed for DG Energy and some practical knowledge from the sector.

2.1.1 Different types of biodiesel

Biofuels are liquid fuels from a non-fossil biological origin and a renewable energy source, to be distinguished from fossil fuels. Biofuels can be split up into two categories, biogasoline and biodiesel (Eurostat, 2013):

- Biogasoline includes:
  - bioethanol (ethanol produced from biomass and/or the biodegradable fraction of waste);
  - biomethanol (methanol produced from biomass and/or the biodegradable fraction of waste);
  - bioETBE (ethyltertio-butyl-ether produced on the basis of bioethanol: the percentage by volume of bioETBE that is calculated as biofuel is 47 %);
  - bioMTBE (methyl-tertio-butyl-ether produced on the basis of biomethanol: the percentage by volume of bioMTBE that is calculated as biofuel is 36 %).
- Biodiesel includes:
  - biodiesel (a methyl-ester produced from vegetable or animal oil, of diesel quality);
  - biodimethylether (dimethylether produced from biomass);
  - Fischer Tropsch (Fischer Tropsch produced from biomass);
  - cold-pressed bio-oil (oil produced from oil seed through mechanical processing only);
  - all other liquid biofuels which are added to, blended with or used straight as transport diesel.

Product specifications of diesel fuels are documented in European legislation and standards. In norm EN590, the physical and chemical parameters of fuels are defined. The following types of biodiesel are of interest:

- Fatty Acid Methyl Ester (FAME): The most common form of biodiesel uses methanol to produce methyl esters. FAME is chemically different to fossil diesel fuel and can therefore cause potential engine problems. For this reason, blends of FAME are limited to 7 vol% (B7). Biodiesel can also be used in its pure form (B100), but may require certain engine modifications to avoid maintenance and performance problems. B10 or B15, FAME in a blend of 10-15 vol%, is a realistic option for trucks which do not require engine modifications.

- Hydrotreated Vegetable Oil (HVO), also referred to as green diesel, is a synthetic biofuel predominantly existing of paraffin chains. It could be classified as biodiesel; however, based on different processing technology and chemical formula green diesel and biodiesel are different products. Green diesel can be produced which is chemically identical to diesel fuel and does not have the same engine-specific problems as FAME. This means blending ratios up to 30 vol% can be used without additional modifications or checks for the diesel engine.

Diesel fuels with higher FAME blends (> 7 vol%) cause severe engine oil contamination because the fuel partly doesn't evaporate during Diesel Particulate Filter regenerations and will flow as a liquid in the oil sump. This diesel condensation issue limits the use of FAME in vehicles.

2.1.2 *EU legislation in short*

The most important formal European goals for liquid fuels are defined in:

- The Renewable Energy Directive (RED) states that 10% of the energy required by transport must be renewable in 2020 (Directive 2009/30/EC).
- The Fuel Quality Directive (FQD) requires that 6% of the well-to-wheel (WTW) CO_2 emissions must be reduced with reference to 1990 (Directive 2009/28/EC).

In these directives, the European goals and legislations are documented up to the year of 2020. Beyond that point (2020+), there is only one overall goal for renewable liquid fuels of 27%. For the year 2030 there exist no formal directives yet for road transport. The discussions for liquid fuels are currently ongoing in European Parliament. The following developments are expected:

- 10% cap on first generation,
- no target for advanced biofuels,
- no CO_2 penalty for ILUC (Indirect Land Use Change),
- possibly a target of 5% on second generation biofuels for 2030

2.1.3 *NL legislation in short*

The most important legislation which forms the basis for biofuels in the Netherlands is given by 'Besluit Biobrandstoffen wegverkeer 2007'. In 2009, 2011 and 2012 adaptations have been done. Blending of biofuels is a macro-obligation, this means that total amount of sold fuels must contain a certain share of biofuels (on energy basis). Biofuels of different sources are allowed. Hydrogenated biodiesel can be counted double.

Actual status of biodiesel blends in The Netherlands

Figure 2 shows the development of biofuel on the European market between 1990 and 2011 on energy basis. It can be seen that the amount of biofuels in general and biodiesel in specific has experienced a large increase in growth over the last years.

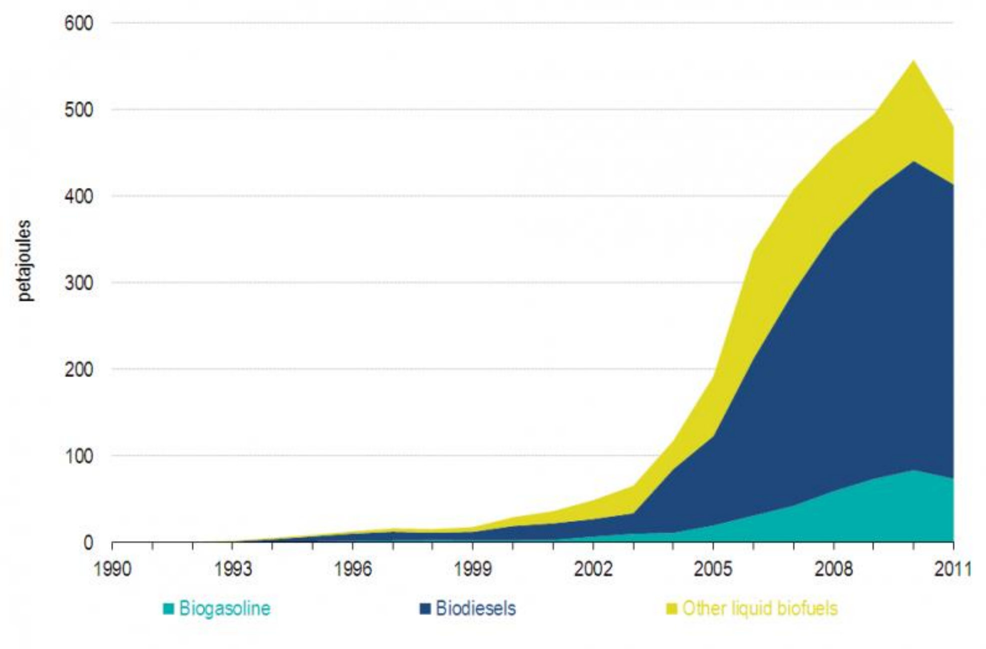

Figure 2: Development of biofuels on the European market (Eurostat, 2013)

2.1.4 *Required and realized biofuel blending percentage*

Table 1 shows data of the annual required and realized biofuel blending percentage as well as the required reduction in GHG emissions. The realized biofuel blending percentage is measured by Netherlands Emission Authority (NEA) since the 2011. Results are documented annually. The latest report dates of 2013.

Table 1: Overview of Dutch required and realized biofuel blending percentages

	Required biofuel blending percentage	Realized biofuel blending percentage	Share of double-counted biofuels	Share single-counted biofuels	Required reduction in GHG emissions
	[e%]	[e%]	[e%]	[e%]	[%]
2005	2,0				35
2006	2,5				35
2007	3,0				35
2008	3,25				35
2009	4,0				35
2010	4,0				35
2011	4,25	4,31	40	48	35
2012	4,50	4,54	51	65	35
2013	5,00				35
2014	5,50				35
2020	10,0				60

2.1.5 *Share of biodiesel and biogasoline, single- and double-counting biofuels*

Figure 3 shows the relative shares of all biofuels sold in the Netherlands in 2012. It can be seen that 65-70% of the sold biofuels was FAME, 65% of the biodiesel were double-counting. It can be seen that HVO only accounts for a small amount to all biofuels, 1,3%. It can be concluded that a large share of biodiesels sold in 2012 are double-counting, i.e. produced from tallow (animal fat), used cooking oil , etc.

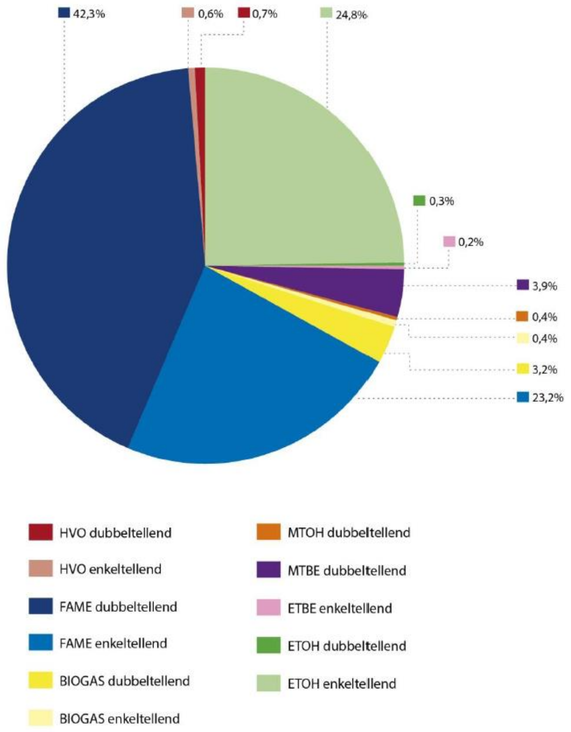

Figure 3: Relative shares of biofuels produced in the Netherlands in 2012

In comparison to 2011, the following development has been observed:

- Single-counting FAME is predominantly produced from oil-containing plants, of which canola/rapeseed is the most important. The share of this raw material has doubled from 2011 to 2012.
- Double-counting FAME is produced two-thirds from animal fats and tallow and one-third from used cooking oil (UCO). In 2012, the relative contributions of these materials were similar to those in 2011.

The biofuel produced from canola/rapeseed and tallow are the most representative. Rapeseed is produced relatively fast in comparison to tallow which requires several years production time from raw material to end product. Furthermore, the production environments differ greatly.

2.2 Prediction of biodiesel blends in The Netherlands up to 2030

In the NEA report of 2012 it can be seen that about 50% of the raw materials of double-counting' biodiesel come from abroad. When the production of biodiesel from waste is well under way in other countries, the availability of this commodity in the Netherlands will decline. In this case, there is a chance that there will be more demand than supply in the Netherlands.

The situation of the biofuels market in the Netherlands is currently different to the European market because there are relatively many double-counting biofuels in the Netherlands. In time it is expected that the situation on the Dutch market will look like the average European situation as more production capacity for double-counting biofuel will become available in other European countries. It is expected that B7 will be permanently applied.

In the biofuels marketing study by CE Delft and TNO conducted for DG Energy in 2012 (see Kampman et al., 2013) the options to realize 2020 RED and FQD targets have been studied extensively. Recommendations were made for two scenarios:

- The 50/50 scenario is based on a study commissioned by DG Energy and states that the biofuels target can be achieved by 50% on the basis of biodiesel and 50% on the basis of bio-ethanol.
- In the NREAP (National Renewable Energy Action Plan) scenario the focus lies on biodiesel. The biofuels target is achieved for example with 66% biodiesel and 34% bioethanol.

Table 2: Recommendation for biofuel blends (diesel and gasoline) to achieve 2020 RED and FQD target (10% biofuels on an energy basis) according NREAP scenario.

	Biodiesel (in Mtoe)	Bioethanol (in Mtoe)
Total demand NREAPs	21.6	7.3
Marketing through B7 and E10 in road	12.8	6.7
Fungible fuels (HVO)	2.4	
Blending limit from B7 to B10	1.5	
20% market share of B30 for trucks in captive fleets	4.9	
Blending limit from E10 to E20, 12% market share of E20		0.6

The NREAP scenario is the most realistic scenario given that it is based on aspects like stock availability, prices and practical blend capabilities. In Table 2 is a summary of the recommendations for biofuel volumes for the NREAP scenario. The following recommendations were made to achieve the required biofuel blending percentage for diesel vehicles:

- Blending as many biofuels as possible to reach the blending limits (B7 and E10),
- Blending of the available HVO,
- Increasing the blending limits blending limit for diesel from 7% to 10% (B7 to B10). B7 must remain available for vehicles which are not able drive on B10 (especially cars).
- Introduction of B30 for trucks (market share of approx. 20% is required).

The question is whether 4% of double-counting biofuels is available in volume. According to the biofuels marketing study only a small 10% of biofuels can be made from residues and waste at European level. The required energy for transport on renewable electricity probably has to be added to this sum. The various options are shown in Table 3. In a previous study it was estimated that HVO could attain approximately 1.3% on a European level. If 40 % of biofuels could actually be produced from residues and waste streams in the Netherlands there would be no or hardly any vehicles required which drive on higher blends such as B10 or B30. If this is not realistic, then B30 (for trucks) is important and probably necessary to achieve the 10% target. B30 (20 % of the fleet) is then used to realize the missing volume of diesel and gasoline vehicles.

Table 3: Options to achieve a biofuels blending percentage of 10% on an energy basis

	Share on energy basis	Incl. ca. 10% double-counting*	Incl. ca. 40% double-counting	Availability of HVO*	Addition with renewable electricity
B7	6.5%	7.1%	9.1%	ca 1.3%	
E10	6.5%	7.1%	9.1%		yes

* Expected to be available on an European level

2.2.1 *B10 and B30*

B10 or B15 for trucks is a realistic option which is not expected to lead to problems. In case 40% double-counting is possible at European level, then B10 and/or HVO are good options for the RED 2020 target of 10% biofuel blending. If only 10% of double-counting is possible, then B10 trucks are not enough to achieve the RED 2020 target.

In a previous European study, B30 for trucks (20% market share) emerged as an important option to achieve the 2020 RED target. For Euro VI trucks the type approval and the complexity of the technology constitutes a barrier, since the manufacturer would have to perform a type approval apart separately for B30. At this moment, that is hardly done because B30 is only used very limitedly and since possible emission benefits for Euro VI are no longer relevant. If B30 actually gets a substantial market share (through stimulation or obligation) then the trucks will become available.

2.2.2 *HVO*

The available volume of HVO in the coming years is relatively small: approximately 1-1.3% of diesel at European level. Higher blends like HVO30 and HVO100 and are suitable to decrease emissions of EURO V and older vehicles (by about 10%). However, in 2020, when Euro VI will be dominant this will most likely not play a significant role anymore. It therefore seems more reasonable to add HVO to diesel in a very low blend (1-2%) or to focus their application to older vehicles and mobile machines. Deployment of GTL is very similar to HVO in terms of composition and properties, yet fossil. GTL is currently placed on the market as pure fuel (100%). A marketing argument is the reduction of harmful emissions.

2.3 Summary and outlook

The overall conclusion is that large scale deployment of B7 is possible in Europe and the Netherlands. Apart from that, the deployment of B10 and B30 is possible on a relatively large scale. HVO30 and HVO100 (+GTL100) cannot be excluded and is possible on a small scale.

Regarding biodiesel blends for the period 2014 – 2017, the following is concluded:
- B7 will generally be the maximum blend.
- B30 and B100 can be deployed on a small scale for EURO V and older vehicles.
- The deployment of HVO is relatively small. HVO and GTL will be used primarily as a 30% or pure (100%) blend for applications where emissions are important (Euro V buses and older, mobile machinery).
- 30% HVO blend can be added to B0 as well as to B7.

With respect to biodiesel blends for the period 2018 – 2020, the following is expected:

- It is still uncertain with which biofuel blends in the Netherlands and in Europe the European blending percentage target of 10% will be achieved by 2020. This mainly depends on the double-counting capabilities and the actual availability of this double-counting fuel.
- B7 is the most likely blend for diesel, because blends higher than 7% could lead to problems in especially passenger cars. For higher blends there are barriers for both, cars and trucks, because of the legal framework surrounding the type approval (and the slowness with which this can be adjusted).
- B10 for trucks is possible and is one of the most cost-effective options to contribute to the 2020 RED target.
- B30 for trucks is also possible and certainly not excluded. It is an important option to realize the 2020 RED target in case 40% or more double-counting of biofuels is not among the possibilities.

With respect to biodiesel blends for the period 2020 – 2030, the following is expected:

- Maximal of 10% blending for first generation biofuels (using corn corps etc.).
- Possibly a target of 5% will be introduced for second generation biofuels (using used cooking oil, etc.).

3 Engine emission technologies up to 2030

This chapter shows an overview of expected emission reductions according to European legislation and development of emission control technology, with the time horizon from today until 2030. This will be focused on road transport, with additional remarks on non-road mobile machinery and inland shipping.

3.1 European emission regulations

In Table 4 an overview of the European emission legislation for the different categories is given. In Appendix A an overview of regulation 97/68/EC is reported.

Table 4: Overview of European emission legislation for different categories

Category	EU-Directive	Regulation or test standard	Emission standard	Unit
Mobile application Light Duty (LD)	715/2007/EC	ECE R83/06	Euro 1 – 6	[g/km]
Mobile application Heavy Duty (HD)	715/2009/EC	ECE R49/05	Euro I – VI	[g/kWh]
Non-mobile machinery	97/68/EC	ISO 8178	Stages I, II, IIIa, IIIb, IV	
Inland Vessels	97/68/EC	ISO 8178		
Rail transport	97/68/EC	ISO 8178		

http://www.dieselnet.com/standards/eu/nonroad.php

See shipping and aircraft are not part of this study.

Due to these emission standards manufacturers are forced to apply emission control technologies. For diesel engines oxidation catalysts, diesel particulate filters (DPF), exhaust gas recirculation (EGR), selective catalytic reduction (SCR) and Lean NOx traps (LNT) are options for reduction of engine emissions.

3.2 Possible emissions of combustion engines

The theoretical combustion of hydrocarbons yields thermal energy and two chemical products, these are water (H_2O) and carbon dioxide (CO_2). For a complete combustion of one kilogram fuel 14,6 kilogram air is needed.

However combustion never is ideal and small amounts of pollutants are produced as well as by-products. A description of pollutants (CO, HC, SO_2 and particulates) and by-products (NO and NO_2) are described in the next paragraphs.

In 2030 it is expected that most engines are equipped with emission control technologies such as Diesel Particulate Filters and NOx reduction technologies. These technologies have high conversion rates and consequently the impact of biofuels on the conversion rates of these technologies must be taken into account. If high conversion rates (> 90%) of emission technologies are applicable and not influenced by higher biofuel rates it is expected that the impact of higher biofuel rates on emissions is negligible because the absolute level of emissions is mainly determined by the performance of the emission technologies.

3.2.1 *Hydrocarbon emissions (regulated)*

Hydrocarbon fuels are a mixture of different hydrocarbon molecules. The chain length of the hydrocarbons and the structure of the molecules have a major impact on the properties of the fuel and on the rate of formation of pollutants. Generally a more complex hydrocarbon structure (like polycyclic aromatics) will lead to more PM formation in the combustion chamber.
In modern engines more than 99,5% of the fuel is completely burned. The residual fraction is emitted and mostly this fraction is burned in an aftertreatment system (oxidation catalyst).

However some hydrocarbons leave the tail pipe. They are measured as ‘total hydrocarbons’, no further differentiation of hydrocarbons is made (except the methane fraction). Some biofuel molecules (FAME) contain oxygen and this has a positive effect on hydrocarbon emissions.

Certain concentrations of hydrocarbons are a potential or direct thread for human health. The determination of these pollutants takes place with special sample collection techniques and test equipment which is able to determine different hydrocarbon types. These are:

3.2.1.1 *Polycyclic Aromatic Hydrocarbons(unregulated)*

1. naftaleen
2. acenaftyleen
3. acenafteen
4. fluoreen
5. fenantreen
6. antraceen
7. fluoranteen
8. pyreen
9. benzo[a]antraceen
10. chryseen
11. benzo[b]fluoranteen
12. benzo[k]fluoranteen
13. benzo[a]pyreen
14. indeno[1,2,3-cd]pyreen
15. dibenzo[a,h]antraceen
16. benzo[g,h,i]peryleen

3.2.1.2 *Oxy and nitro PAH’s (unregulated)*

1. 1,4-Naphthoquinone
2. 1-Naphthalenecarboxaldehyde
3. 9-Fluorenone
4. 9,10-Anthraquinone

5. 1,8-Naphthalic Anhydride
6. 9,10-Phenanthrenequinone
7. Benzanthrone
8. 1-Pyrenecarboxaldehyde
9. Benz[a]anthracene-7,12-quinone
10. 1-Nitronaphthalene
11. 2-Nitronaphthalene
12. 4-Nitrobiphenyl
13. 2-Nitrofluorene
14. 3-Nitrofluoranthene
15. 1-Nitropyrene
16. 6-Nitrochrysene

3.2.1.3 Aldehydes (unregulated)

1. formaldehyde
2. aceetaldehyde
3. acroleine
4. aceton
5. propionaldehyde
6. crotonaldehyde
7. n-butyraldehyde
8. benzaldehyde
9. iso-valeraldehyde
10. n-valeraldehyde
11. o-tolualdehyde
12. m-tolualdehyde
13. p-tolualdehyde
14. hexanal
15. 2,5-dimethylbenzaldehyde

3.2.2 Particulate Mass emissions

Due to a lack of oxygen in certain parts of the combustion chamber particulate emissions are produced. The measured carbon mass emission is split into two parts: Elementary Carbon(EC) and Organic Carbon (OC).). Some biofuel molecules (FAME) contain oxygen and this has a positive effect on particulate emissions of applications without diesel particulate filter. Diesel engines without closed particulate filters emit certain amounts of PM10. Engines which are equipped with a closed Diesel Particulate Filter have negligible PM-emissions.

3.2.3 Particulate Number emissions and particle size distribution

Particle number emission is measured according to current emission standards but the particle size distribution is not part of this standard. For scientific reasons the particle size distribution can be measured with an Electrical Low Pressure Impactor. This impactor enables measurement of real-time particle size distribution and concentration in the size range of 6nm - 10µm with 10Hz sampling rate.

3.2.4 Nitrogen Oxide emissions

Due to presence of nitrogen and oxygen in air and the heat of the combustion nitrogen is oxidised to NO and NO_2. NO and NO_2 (NOx) is regularly measured with a chemiluminescent analyser. Special attention is needed for NO_2 emissions because in a former project there were indicators of high impacts on certain test results. Diesel oxidation catalysts tend to convert NO into NO_2.

3.2.5 *CO emissions*

Incomplete combustion of hydrocarbons results in the formation of carbon monoxide. The CO volume fraction is measured with an infrared analyser. Some biofuel molecules (FAME) contain oxygen and this has a positive effect on carbon monoxide emissions of applications without diesel particulate filter. If an oxidation catalyst is mounted most CO is converted into CO_2.

3.2.6 *CO_2 emissions*

In a combustion engine carbon is oxidised to CO_2. CO_2 emission is determined by means of an infrared analyser.

3.2.7 *SO_2 emissions*

The main SO_2 emission is caused by the presence of sulphur in the fuel. Currently European diesel fuels contain less than 10 ppm sulphur and it is not expected that SO_2 formation can be detected.

3.3 Emission control technologies

Description characteristics diesel emission control technologies
Emission control technologies are applied to reduce CO, THC, NOx and PM10 emissions to the required legislative levels.

Currently all diesel Euro 6 and Euro VI vehicles are equipped with a wall-flow DPF (for reduction of PM10 and PN emissions) and different options are available for reduction of NOx emissions. For diesel vehicles the mainstream technologies are divided in engine internal measures and aftertreatment measures.

The next technologies have been implemented in Euro 6 and Euro VI vehicles but are not present in the other sectors. It is expected that the sectors of non-mobile machinery, inland vessels and rail transport will implement these technologies in the next decades.

In this paragraph an overview of the main emission control technologies for diesel engines is given.

Diesel engine internal measures:

- Reduced engine compression ratio: reduces the peak temperature of the combustion which reduces the production of NOx.
- Advanced fuel injection systems: multiple pre, main and altered fuel injections with increased injection pressure enhances mixing of air and fuel to reduce PM emissions.
- Higher injection pressures: allows smaller droplets of fuel during injection which reduces PM emissions.
- Variable turbocharger geometry (VTG): increased volumetric efficiency of the engine over a wide range of engine loads and rpm which reduces CO_2 emissions. VTG comes also in hand to enable high EGR rates.
- Improved EGR: cooled EGR decreases combustion temperatures and the relative lack of oxygen reduce the forming of NOx with increase of PM.

EGR in the form of low pressure EGR after DPF reduces NOx without contaminating the inlet trajectory.

- Inducing charge motion and air-fuel mixing: increases good vaporisation of fuel in the air which reduces the forming of PM.
- Exhaust temperature management (fast warming up): reduces the time that catalysts are ineffective (faster light-off) to reduce NOx, CO and HC.

Diesel after-treatment measures:

- Oxidation catalysts: oxidation catalysts for diesel reduce CO and THC emissions and ensure a more optimal NO_2/NOx ratio for NOx reduction in a SCR.
- Wall-flow DPF for PM control: for diesel vehicles a DPF is assuring capturing PM.
- Selective catalytic reduction (SCR): reduces NOx emissions by spraying a solution of water and urea in the exhaust prior to a catalytic converter. The urea will be converted to ammonia (NH_3). The converter converts the NOx and ammonia into harmless N2 and H_2O.
- Lean NOx catalysis/traps (LNC/LNT): reduces NOx emissions by capture/storage of NOx and applying periodic lean and rich fuel air mixtures which the LNT needs for reduction of NOx. The reduction of NOx is accomplished by the forming of ammonia and assuring a limited SCR function.
- Close-coupled catalysts: are catalyst bricks placed close to the engine and close to each other to ensure a fast warm up and thus ensuring a fast light-off. For diesels this could be a closed coupled combination of DOC, DPF, LNT/SCR as close as possible to the engine.
- Insulating exhaust piping: reduces the energy absorbed by the surroundings of the exhaust pipes which shortens the light-off time of a catalyst.
- Reducing thermal mass exhaust system: has the same effect of insulating exhaust piping (see previous point). Extra benefit of reducing thermal mass is a weight reduction of the vehicle which is beneficial for the CO_2 emissions.

Impact of increased biodiesel rates on the functionality of these technologies:
Application of higher FAME rates yields less PM-emissions and less HC-emissions of engines, however diesel particulate filters are still needed to fulfil current emission requirements. Higher FAME rates (> 7 vol%) may lead to failures of DPF’s because regeneration processes of DPF’s are based on fuels with a maximum FAME-content of 7 vol%. Higher FAME volumes may lead to disturbed regenerations of the DPF because the boiling curve of the biofuel is higher than the boiling curve of fossil diesel fuel. Furthermore higher FAME rates (> 7 vol%) cause severe engine oil contamination which results in shorter maintenance intervals and higher costs. HVO’s do not meet these problems and can be applied with higher blend rates.

Prediction of the applied engine emission reduction technologies up to 2030
Which emission regulations will be applicable in 2030?
In the next decades the development of emission legislation will be continued because air pollution still is an important issue. Most sectors will face reduced emission limit values. However the effective implementation of new technology in the different sectors will differ. I.e. handheld equipment has a life time of 7-10 years

but inland vessels have a lifetime of more than 30 years. For the automotive sector the maximum realistic emission reduction will probably be reached with the next step of this legislation (Euro 6+ and Euro VI+). Other sectors, such as inland vessels, still have a path to develop and they have specific issues (i.e. durability) to be solved. For certain applications, like handheld equipment with a diesel engine, the European emission regulations will be applicable in Stage V. Possibly a Stage VI regulation will be applicable. In Table 5 an overview of expected emission regulations in 2030 is given.

Table 5: Expected emission regulations in 2030

Sector	Expected emission regulation 2030	Expected effective average life time
		[years]
Automotive LD	Euro 6+	15
Automotive HD	Euro VI+	11
Non-mobile machinery	Stage V or VI	15
Inland vessels	Stage V or VI	30
Rail transport	Stage V or VI	10-50

Currently non-mobile machinery with small diesel engines < 19 kW do not need to meet an emission legislation. This category contains handheld machinery which is relatively cheap. Implementation of better technology for reduction of exhaust emissions is relatively expensive and hard to implement because this category has many types and configurations of machinery and production volumes are often small. However in the near future it is expected that the scope of emission regulations will grow and more engine applications must fulfil emission requirements.

Consequently the fleet in 2030 will still contain non-road applications without engine aftertreatment technology. Even some Euro 6 road vehicles, which will be sold around 2020, will be part of the Dutch fleet in 2030.

Which technologies will be applied in 2030?
In order to meet future emission standards for diesel engines emission control technologies are needed.

Table 6: Expected applied emission technologies in 2030

Sector	Expected emission regulation 2030	Expected emission technologies
Automotive LD	Euro 6+	EGR+DPF+SCR or LNT
Automotive HD	Euro VI+	EGR+DPF+SCR
Non-mobile machinery	Stage V or VI	EGR and/or SCR or LNT
Inland vessels	Stage V or VI	DPF+SCR
Rail transport	Stage V or VI	DPF+SCR

3.4 Prediction of the emission reductions up to 2030

3.4.1 PM emissions and biofuels

Currently Euro 5 vehicles are delivered on the market but soon these will be replaced by Euro 6 vehicles. For petrol vehicles these two emission standards are equal and the three-way catalyst technology enables very low emissions.
Modern diesel vehicles are equipped with Diesel Particulate Filters which have a very high filtration efficiency. They must operate with certain fuel specifications because regeneration strategies of DPF's are complex.

Regenerations of Diesel Particulate Filters, PM emissions and biodiesel
Euro 5 and 6 diesel vehicles are equipped with diesel particulate filters and their PM-emissions are extremely low, see Figure 4. From time to time this DPF is regenerated and very often extra fuel must be injected which must be burnt in the oxidation catalyst. The released thermal energy is needed to heat the DPF up to 550 °C. With these regenerations the stored carbon is burnt into CO_2. One primary condition of this regeneration process is a diesel fuel with a maximum FAME-content of 7 vol%. In case of a higher FAME-content DPF regenerations can be disturbed because the evaporation of liquid FAME occurs at relative high temperatures (compared to fossil diesel), see Table 7. Higher FAME blends are not possible in diesel fuel because the regeneration strategies of diesel particulate filters are based on evaporation properties of the fuel. However higher blends of HVO in diesel fuel are possible because the evaporation properties of HVO and fossil diesel fuel are similar.

Table 7: Boiling curves fuel

	Boiling curve
	[°C]
Fossil diesel	160 - 380
FAME	320 - 350
HVO	180 - 300

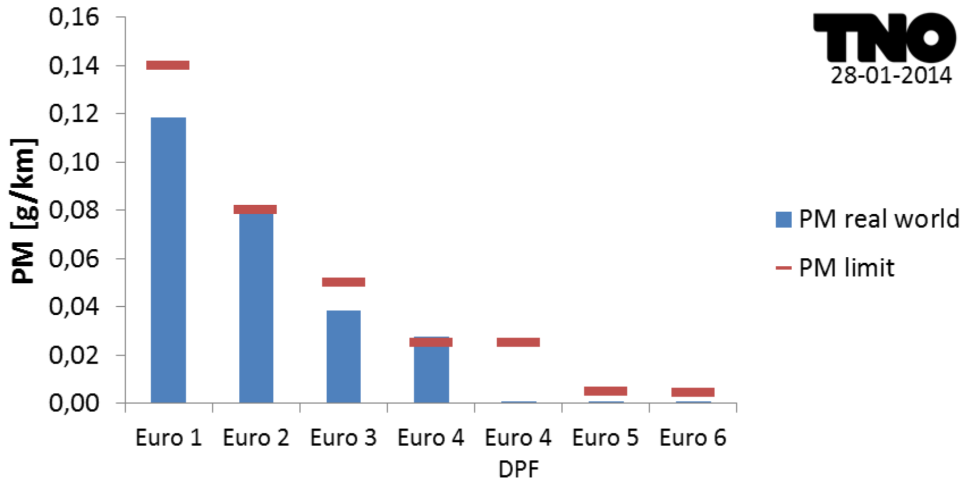

Figure 4: PM emission factors and type approval limit values of diesel passenger cars

3.4.2 NOx emissions and biofuels:

3.4.2.1 Road vehicles

In Figure 5 an overview of NOx Type Approval limit values and real world data (emission factors) of light duty vehicles is given. In case of a higher blend ratio of biodiesel (FAME or HVO) the NOx emission of a Euro 5 or Euro 6 diesel vehicle could differ widely, but with pure HVO the NOx emissions might decrease 0-20% (see Verbeek et. al, 2008 and 2009). With higher biofuel rates the NO/NO2 ratio is not influenced.

Currently NOx emissions of vehicles are controlled with EGR, SCR and LNT technologies. EGR and SCR technologies are not very sensitive for different biofuel rates. On the contrary LNT technology is based on strict fuel properties because the frequent regenerations are based certain engine out CO-emissions. In case of higher FAME rates the engine out CO-emission will decrease and more frequent LNT-regenerations are needed. Application of higher HVO-rates influence engine out CO emissions less.

NOx-PM ratio trends of diesel LD-vehicles:

In Figure 4 an overview of PM Type Approval limit values and real world data (emission factors) is given. The relative low PM emission and the NOx emissions of Euro 4,5 and 6 vehicles result in an increased high NOx/PM-ratio, see Figure 6. In most cases an oxidation catalyst is part of this aftertreatment technology. This catalyst converts NO into NO_2, under low load conditions more than 50% of the total NOx emission can be converted into NO_2.

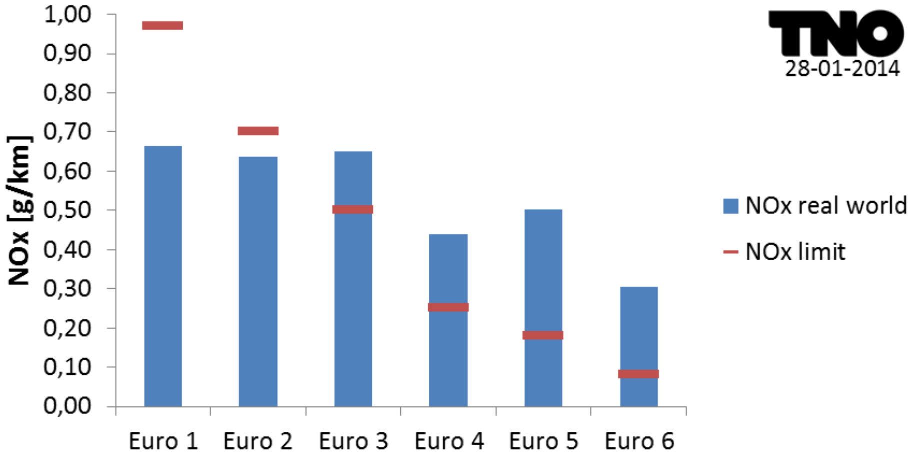

Figure 5: NOx emission factors and type approval limit values of diesel passenger cars.

In Figure 6 the NOx-PM ratios of Euro 1 up to Euro 6 vehicles are reported. Due to the application of Diesel Particulate Filters in Euro 4,5 and 6 vehicles the ratio has risen from about 16 to 320-528. The PM mass emissions of these vehicles are extremely low and due to the application of oxidation catalysts the direct NO_2 emission is higher than vehicles without oxidation catalyst.

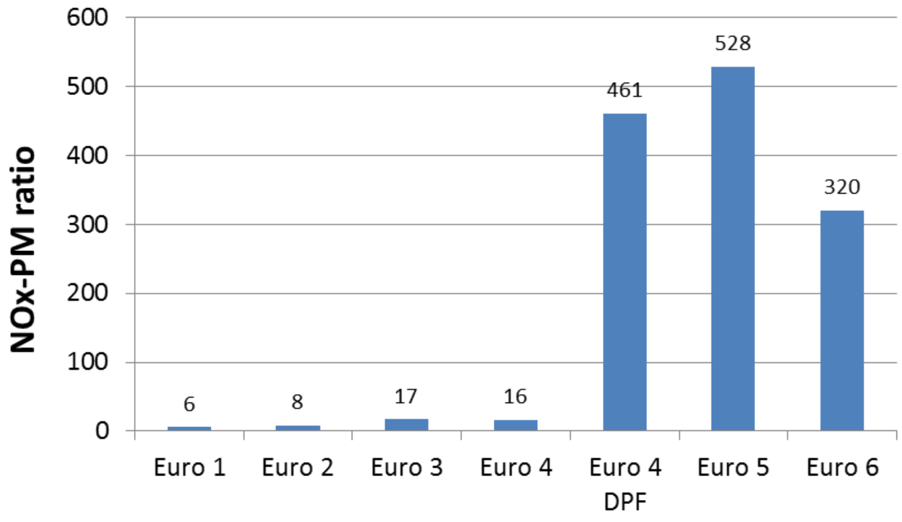

Figure 6: NOx-PM ratios of Light Duty vehicles

Application of higher biodiesel blends will result in lower engine out PM-emissions. However in any case this PM-emission is reduced by the DPF to very low levels. As a result of the application of DPF's the biodiesel rate in diesel fuel doesn't affect the PM emissions of vehicles.

Heavy duty mobile applications

In Figure 7 an overview of NOx Type Approval limit values and real world data of heavy duty vehicles is given. In Figure 8 an overview of PM Type Approval limit values and real world data is given. Due to the low PM emissions of Euro IV, V and VI vehicles NOx/PM-ratios are relatively high, see Figure 9. In most cases an oxidation catalyst is part of this aftertreatment technology. This catalyst converts NO into NO_2.

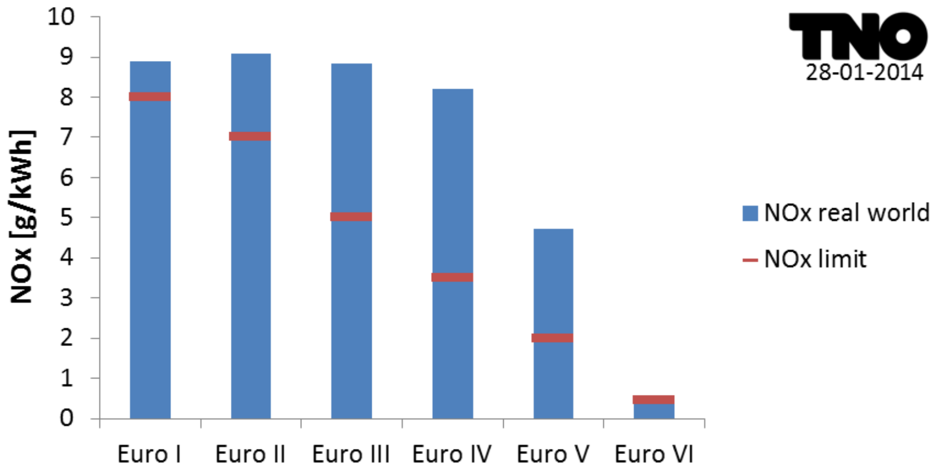

Figure 7: NOx real world emissions and type approval limit values of heavy duty vehicles.

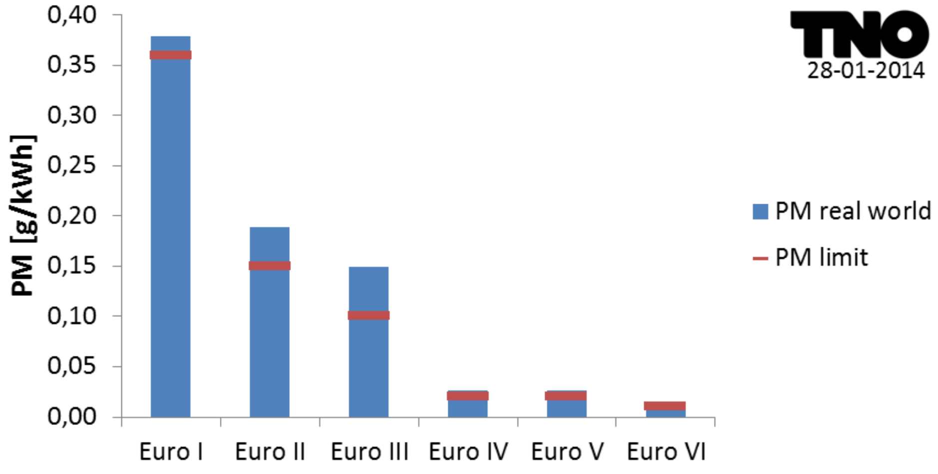

Figure 8: PM real world emissions and type approval limit values of heavy duty vehicles.

In Figure 9 the NOx-PM ratios of Euro I up to Euro VI vehicles are reported. Due to the application of advanced combustion control in Euro IV and Euro V vehicles the ratio has risen from about 24 to 176-311 because the PM mass emissions of these vehicles are relatively low. The NOx aftertreatment system of Euro VI vehicles and the application of DPF's result in a low NOx-PM ratio.

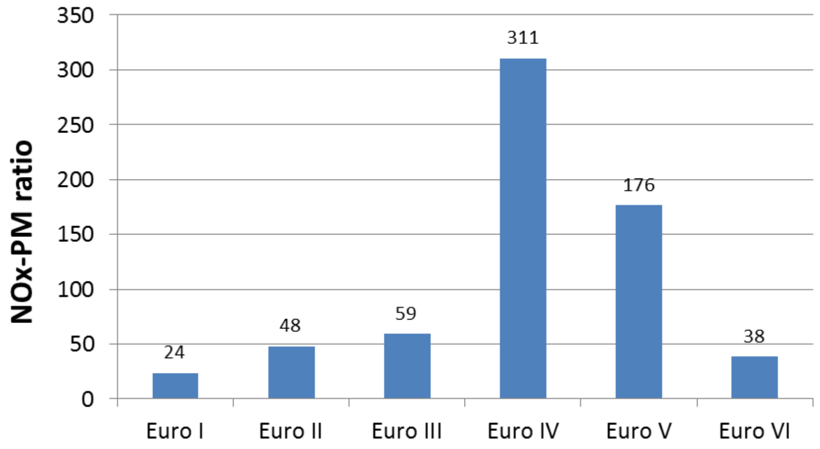

Figure 9: NOx-PM ratios of Heavy Duty vehicles

Application of higher biodiesel blends in vehicles without DPF will result in lower PM-emissions. For DPF equipped vehicles the biodiesel rate in diesel fuel doesn't affect the PM emissions of vehicles because the DPF has a very high filtration efficiency.

Application of higher biodiesel blends may result in slightly higher engine out NOx emissions but this increase of NOx emission is partly neutralised by application of NOx aftertreatment systems (SCR or LNT).

3.4.2.2 *Non Road Mobile Machinery (NRMM)*

Currently the majority of NRMM has been equipped with Stage II and Stage IIIa+b technology. Due to different categories of NRMM (based on power, applications, implementation dates) and practical life times in 2030 it is expected that Stage IV and Stage V technology will applied on the majority of the fleet. However the Stage V emission limits are not yet available. In Table 8 current and estimates of future emission factors of NRMM are reported.

Table 8: Emission factors Non Road Mobile Machinery (construction sector)

Component	Emission factor		Reduction
	2010	2030*	2010-2030
	[g/kg fuel]	[g/kg fuel]	[%]
CO	5.0	3,0	40
THC	1,6	0,5	69
NOx	18	3,0	83
NO	-	-	-
NO2	-	-	-
PM	1,2	0,2	83

*TNO Expert opinion

In 2030

- Application of higher biodiesel blends (HVO or FAME) in NMRR without DPF will result in lower PM-emissions. For DPF equipped vehicles the biodiesel rate in diesel fuel doesn't affect the PM emissions of vehicles because the DPF has a very high filtration efficiency.
- Application of higher biodiesel blends (FAME) in NMRR may result in slightly higher engine out NOx emissions but this increase of NOx emission is partly neutralised by application of NOx aftertreatment systems (SCR). For a HVO blend a small decrease of NOx emissions is expected.
- Application of higher biodiesel blends (FAME) in NMRR may result in lower engine out CO and THC emissions. If an oxidation catalyst is mounted this emission reduction is partly neutralised.

3.4.2.3 *Inland Vessels*

Emission legislation is up to now described by CCR-legislation. The latest step is CCR2 which was implemented in 2008. The emissions limits corresponds roughly with the Euro II heavy duty vehicles legislations.

In the future, the legislation for inland vessels will be implemented as an additional paragraph in the European Non-road mobile machinery legislations. Possible future emission limits are discussed in several working groups with government and industry specialists. An overview of different options is included in an impact assessment study carried out for the Commission (Quispel 2013). Option 1 is presented in the table and figure below. Distinction is made between new and existing engines. For the projection of the emissions to 2030, the following assumptions are made:

- The legislation of new engines is implemented according to the table below: Stage 4B in 2017 and Stage 5 in 2022.

- The legislation for existing engines is not effectively implemented before 2030.
- Engine replacement rate by new engines is 7% per year.
- Real-world emissions are assumed to be a factor of two higher than the Stage 4B and 5 legislation.

The projected emission reductions up to 2030 as well as the influence of biodiesel blends are reported in the following chapter and in Appendix **Error! Reference source not found.**.

Table 9. Proposed emission limits for inland vessels. Source (Quispel 2013). Option 1.

	Emission class	year	NOx	PM
			g/kWh	g/kWh
New engines	Stage 4B	2017	1.2	0.020
	Stage 5	2022	0.4	0.010
Existing engines	Stage 4A	2017-2027	1.8 - 2.1	0.030

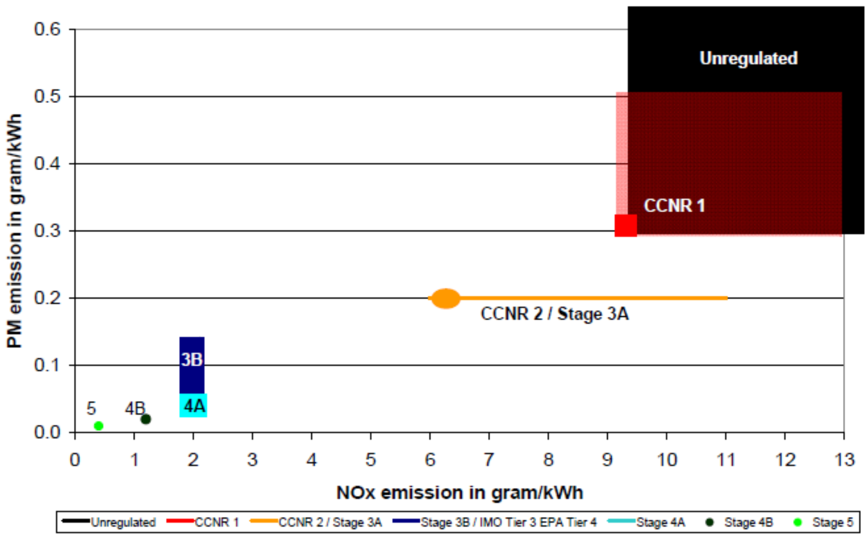

Figure 10. Proposed emission limits for inland vessels. Source (Quispel 2013)

3.4.2.4 *Rail transport*

For rail transport the life time of a vehicle is relatively long and replacement or overhaul of engines is daily practice. The implementation scheme of new emission legislation is based on NRMM legislation (see 3.4.2.2). Due to the life time of these engines in 2030 it is expected that the majority of the locomotives will be equipped with Stage IIIa and Stage IIIb engines. In case of application of biofuel blends the expected emission reductions are equal to inland vessels.

4 Impact of biofuels on regulated and non-regulated emissions

In this chapter, the impact of biofuels on regulated and non-regulated emissions are discussed. The results of this chapter are based on the conclusions of the previous chapters. Once again, the focus lies on the biodiesel types, HVO and FAME. In the next four subsections, the impact of each type is evaluated separately for regulated and non-regulated emissions.

4.1 Impact of hydrogenated biodiesel on regulated emissions

Increase blending of hydrogenated biodiesel reduces regulated emissions. In comparison to the predominant technologies in 2030, the impact of hydrogenated biodiesel on regulated emissions is small.

Table 10 to Table 12 show the impact of hydrogenated biodiesel on regulated emissions for Light Duty, Heavy Duty and Inland vessels. Different references are used, for Light Duty Euro 5, for Heavy Duty Euro V and for Inland vessels CCR II. The expected predominant technology in 2030 is given in the total right of the tables, for Light Duty Euro6+, Heavy Duty Euro VI and Inland vessels Stage IV and V. Due to lack of reliable data, non-road mobile machinery (NRMM) is not shown here. However, it can be said that regulated emissions of NRMM are typically higher than road transport and lower than for inland vessels. Road transport and inland vessels therefore create a bandwidth between two extremes.

In all three sectors it can be seen that increased blending of HVO reduces the regulated emissions NOx, THC, CO and PM. However, the expected predominant technology in 2030 reduces these emissions much more.

Table 10: Impact of hydrogenated biodiesel on regulated emissions (Light Duty)

	Unit	HVO-0 (Euro 5)	HVO-5 (Euro 5)	HVO-10 (Euro 5)	HVO-15 (Euro 5)	HVO-20 (Euro 5)	HVO-25 (Euro 5)	HVO-30 (Euro 5)	HVO-100 (Euro 5)	HVO-0 (Euro 6+)
NOx	[g/km]	0.506	0.506	0.502	0.500	0.498	0.497	0.495	0.468	0.24
THC	[g/km]	0.02	0.02	0.019	0.019	0.018	0.018	0.017	0.01	-
CO	[g/km]	0.25	0.25	0.238	0.231	0.225	0.219	0.213	0.125	-
PM	[g/km]	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Table 11: Impact of hydrogenated biodiesel on regulated emissions (Heavy Duty)

	Unit	HVO-0 (Euro V)	HVO-5 (Euro V)	HVO-10 (Euro V)	HVO-15 (Euro V)	HVO-20 (Euro V)	HVO-25 (Euro V)	HVO-30 (Euro V)	HVO-100 (Euro V)	HVO-0 (Euro VI)
NOx	[g/km]	4.80	4.80	4.704	4.656	4.608	4.560	4.512	3.84	0.878
THC	[g/km]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	-
CO	[g/km]	1.60	1.60	1.57	1.56	1.55	1.54	1.52	1.34	-
PM	[g/km]	0.019	0.019	0.019	0.018	0.018	0.018	0.018	0.015	0.136

Table 12: Impact of hydrogenated biodiesel on regulated emissions (Inland vessels)

	Unit	HVO-0 (CCR II)	HVO-5 (CCR II)	HVO-10 (CCR II)	HVO-15 (CCR II)	HVO-20 (CCR II)	HVO-25 (CCR II)	HVO-30 (CCR II)	HVO-100 (CCR II)	HVO-0 (Stage IV+V)
NOx	[g/km]	43.00	43.00	42.57	42.36	42.14	41.93	41.71	38.70	17.5
THC	[g/km]	2.00	2.00	1.97	1.96	1.95	1.94	1.92	1.74	1.0
CO	[g/km]	10.00	10.00	9.84	9.76	9.68	9.60	9.52	8.40	5.0
PM	[g/km]	1.20	1.20	1.18	1.16	1.15	1.14	1.13	0.96	0.5

4.2 Impact of hydrogenated biodiesel on non-regulated emissions

Not much is published on the non-regulated emissions of HVO. In one of the view studies Pabst et al. compared emissions of PAH from HVO fuel, RME biodiesel and diesel. Without use of catalyst the emissions of all individual PAH were lower for HVO fuel in comparison to RME biodiesel and diesel. After SCR catalyst treatment absolute PAH emissions were much lower for both diesel and HVO fuel. Compared to the use of diesel HVO still shows an overall reduction in the sum of PAH, although there is significant increase in the heavier PAHs (benzo[a]pyrene, benzo[ghi]perylene, indeno[1,2,3-cd]yrene) for HVO compared to diesel (Pabst et al. 2014).

4.3 Impact of FAME on regulated emissions

Increase blending of FAME reduces regulated emissions. In comparison to the predominant technologies in 2030, the impact of FAME on regulated emissions is small.

Table 13 to Table 15 show the impact of FAME on regulated emissions for Light Duty, Heavy Duty and Inland vessels. Again, different references are used, for Light Duty Euro 5, for Heavy Duty Euro V and for Inland vessels CCR II. The same expected predominant technology in 2030 is given in the total right of the tables. Due to lack of reliable data, non-road mobile machinery (NRMM) is not shown here.

In all three sectors it can be seen that increased blending of FAME reduces the regulated emissions NOx, THC, CO and PM. However, the expected predominant technology in 2030 reduces these emissions much more.

Table 13: Impact of FAME on regulated emissions (Light Duty)

	Unit	B-0 (Euro 5)	B-5 (Euro 5)	B-10 (Euro 5)	B-15 (Euro 5)	B-20 (Euro 5)	B-25 (Euro 5)	B-30 (Euro 5)	B-100 (Euro 5)	B-0 (Euro 6+)
NOx	[g/km]	0.506	0.506	0.516	0.521	0.526	0.531	0.536	0.607	0.24
THC	[g/km]	0.02	0.02	0.021	0.022	0.022	0.023	0.023	0.03	-
CO	[g/km]	0.25	0.25	0.263	0.269	0.275	0.281	0.288	0.375	-
PM	[g/km]	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Table 14: Impact of FAME on regulated emissions (Heavy Duty)

	Unit	B-0 (Euro V)	B-5 (Euro V)	B-10 (Euro V)	B-15 (Euro V)	B-20 (Euro V)	B-25 (Euro V)	B-30 (Euro V)	B-100 (Euro V)	B-0 (Euro VI)
NOx	[g/km]	4.80	4.80	4.896	4.944	4.992	5.040	5.38	5.76	0.878
THC	[g/km]	0.04	0.04	0.039	0.039	0.038	0.038	0.038	0.032	-
CO	[g/km]	1.60	1.60	1.568	1.552	1.536	1.520	1.504	1.28	-
PM	[g/km]	0.019	0.019	0.018	0.018	0.017	0.017	0.017	0.010	0.136

Table 15: Impact of FAME on regulated emissions (Inland vessels)

	Unit	B-0 (CCR II)	B-5 (CCR II)	B-10 (CCR II)	B-15 (CCR II)	B-20 (CCR II)	B-25	B-30	B-100	B-0 (Stage IV+V)
NOx	[g/km]	43.0	43.0	43.5	43.8	44.0	44.3	44.3	48.2	17.5
THC	[g/km]	2.00	2.00	1.90	1.85	1.80	1.75	1.70	1.00	1.0
CO	[g/km]	10.0	10.0	9.70	9.55	9.40	9.25	9.10	7.00	5.0
PM	[g/km]	1.20	1.20	1.14	1.11	1.08	1.05	1.07	0.61	0.5

4.4 Impact of FAME on non-regulated emissions

PAH

Aromatic compounds and derivatives are toxic, mutagenic and carcinogenic. The intensity of these effects depends on their structure and on how they mix with each other, which makes it very difficult to predict the carcinogenic or mutagenic effects of the mixtures (Lapuerta, Armas & Rodríguez-Fernández 2008).

In general a decrease in the aromatic and polyaromatic emissions are found when using biodiesel (Schröder et al. 2012, Westphal et al. 2013, Chang et al. 2014) although a noticeable dependency on engine operation conditions (load, driving cycle, oxidizing catalysts etc.) is usually acknowledged (Macor, Avella & Faedo 2011, Borrás et al. 2009, Kado et al. 1996, Karavalakis et al. 2011, Karavalakis et al. 2010) Decreases are found between 12-43% with use of 20% biodiesel blends, and up to 70-90% when pure biodiesel was used (Turrio-Baldassarri et al. 2004, Kooter et al. 2011b, Lin et al. 2006). From a literature review, Krahl et al. (Krahl et

al. 1996) concluded that PAH emissions decreased when rapeseed-oil biodiesel was used for all engine types and operation conditions.
Although less reported it is shown that not all PAHs reduce equally. The experimental results of Karavalakis et al. showed that the use of biodiesel (B30 SEM) in a Euro4 engine resulted in increases (+20-40%) in light PAH emissions as compared to diesel fuel, which were the dominant PAH compounds in the test matrix. However, larger PAHs (-25-50%) and those compounds which are known for their carcinogenic properties were found to decrease with biodiesel. The biodiesel fuels produced from mainly unsaturated feedstocks resulted in higher PAH emissions than the saturated palm-based biodiesel (Karavalakis et al. 2011). This saturation dependency among the biodiesel is also observed by Schroder et al which find an increase in total PAH for CME<PME<RME<LME<SME (Schröder et al. 2012).
In the study by Karavalakis et al. no adverse effect was observed for the nitro-PAH and oxy-PAH emissions with the use of biodiesel independent its origin. PAH emissions were found to be affected by the average speed and load of the driving cycle, as well as by the cold-start conditions. Some increases in PAH emissions were observed over the cold-start NEDC and Artemis Urban, while most PAH compounds were significantly lower during Road and Motorway operation (Karavalakis et al. 2011).
The results of another study by Karavalakis using a Euro2 engine indicate that biodiesel may affect PAH emissions as well in a non-uniform way, showing decreases in light PAH emissions. The application of pure biodiesel and of high concentration biodiesel blends may affect the toxicological characteristics of diesel particulate matter due to potential increases of certain toxic compounds in its composition. On the positive side, the lower PAH emissions during the real-world Artemis driving cycles should be considered as more representative of actual conditions in comparison with the legislated cycles which underestimate the vehicle’s load. It should be pointed out that PAH emissions presented are from a single diesel vehicle not equipped with diesel particle filter (DPF), but still representative of the existing vehicles in the European fleet (Karavalakis et al. 2010).
Using a EuroIV engine Pabst et al showed decreased PAH values(-20%) when using 20% biodiesel and pure biodiesel (RME) without SCR application. Using SCR application decreased all absolute PAH values compared to the non SCR situation, although an increase in larger PAH (benzo[a]pyrene, benzo[ghi]perylene, indeno[1,2,3-cd]yrene) is found compared to the use of biodiesel compared to diesel (Pabst et al. 2014).
Rojas et al showed that application of 15% PME results in an decrease (20-75%) light PAH and and increast of 10-0%of heavy PAH (Rojas, Milquez & Sarmiento 2011).
Not necessarily does the B100 reflects the trend by lower biodiesel blends. Kooter et al have shown decrease in PAH with B100 (RME), whereB10 and B20 show an increase in the light PAH (Kooter et al. 2011). Guarieiro 2014 show an increase in measured PAH for B100 (WCO) where a decrease is found for B25 and B50 (Guarieiro et al. 2014).

Carbonyls(Aldehydes and ketones)
Aldehydes and ketones are oxygenated compounds, which appear in intermediate phases of the combustion process. These compounds are precursors of ozone formation (and other oxidative species) in the troposphere (photochemical smog).

It is widely believed that biodiesel could increase emissions of these oxygenated compounds as a consequence of the increased oxygen content. Some papers report increases when using pure or blended biodiesel as fuel (Chai et al. 2013, Ballesteros et al. 2008, Cheung, Zhu & Huang 2009, Machado Corrêa, Arbilla 2008, Fontaras et al. 2009). However, also decreases or insignificant differences are found (Fontaras et al. 2009, Di, Cheung & Huang 2009, Guarieiro et al. 2008, Karavalakis et al. 2009)
Chai et al. (Chai et al. 2013) found increase of the total carbonyl compounds emission of B100 between 4 and 66% in comparison with B50, depending on motor load. Emission rates of B100 were between 1.5 and 44% higher than emissions of diesel.

Fontaras et al. reported increase and decrease of carbonyl compounds depending on sort of biodiesel (Fontaras et al. 2010). The use of palm oil, rapeseed oil and sunflower oil methyl esters led to higher emission levels by 81%, 116% and 29% respectively, while used frying oil and soybean oil methyl esters led to a decrease of the emission levels on the order of 61% and 57% respectively, compared to the reference diesel fuel.
A 20% increase in formaldehyde and acetaldehyde was found when using pure biodiesel (Pinto et al. 2005).
Machado Correa et al. reported increase of emissions for most carbonyls except for benzaldehyde (Machado Corrêa, Arbilla 2008). Benzaldehyde showed a reduction on the emission (between 3.4 for B2 and 6.9% for B20) and other carbonyls showed a significant increase: 2.6-35.5% for formaldehyde; 1.4-16% for acetaldehyde; 2.1-22% for acrolein+acetone; 0.8-10.0% for propionaldehyde; 3.3-26.0% for butyraldehyde.

Slight decreases of around 10% in formaldehyde and acetaldehyde emissions when using pure biodiesel were reported (EPA 2002).
Di et al. reported also formaldehyde decreases after the addition of biodiesel (Di, Cheung & Huang 2009). For pure biodiesel, the formaldehyde emissions varied between 23 and 96% depending on motor loads in comparison to ultra-low sulfur diesel.
Kooter et al reported carbonyl decreases of 55% for both B20 and B100 RME using a EuroIII engine (Kooter et al. 2011).

The effect of catalyst on aldehydes emissions was investigated in the number of studies. Zhu et al. reported 40% of formaldehyde emission reduction of Euro V diesel and biodiesel emissions after use of diesel oxidation catalyst (DOC) (Zhu et al. 2013). But the formaldehyde emission of biodiesel in comparison to reference diesel was in both cases only about 15% lower.

Reduction of total carbonyl emissions by DOC was studied by Ballesteros et al. (Ballesteros, Guillén-Flores & Martínez 2014). Reduction of carbonyl emission by DOC for biodiesel (originated from animal fat) was the lowest – 45% in comparison to 85% emission reduction for reference diesel. Total carbonyl increased by 20% by use of B50, and up to 100% by use of pure biodiesel (B100) of animal fat source. Individual components like formaldehyde and acetaldehyde increased 50-100% with B50 (Ballesteros, Guillén-Flores & Martínez 2014).

BTX
Benzene, toluene and xylene (BTX) are of concern because they have been identified as carcinogenic, mutagenic, and teratogenic (Krahl et al. 2002, Krahl et al. 2002). The main sources of benzene, toluene and xylene are unburned molecules from fuel, prosynthesis and structural modifications during combustion (Correa, Arbilla 2006).
In general benzene emissions decrease with the increase of engine load (Cheung, Zhu & Huang 2009, Di, Cheung & Huang 2009) . Toluene and xylene emissions also decrease with engine load. However, their emissions have different trends compared with benzene. For toluene the lowest emissions are obtained with biodiesel, while the blended fuels (biodiesel with methanol) and the diesel fuels have similar levels of toluene emissions. For xylene, the levels of emissions from different fuels are almost the same (Cheung, Zhu & Huang 2009). In addition to engine load also exhaust gas temperature is an important factor on BTX emission. No clear trend in BTX concentrations in emissions is found when biodiesel is used. Some report increases of benzene when using biodiesel (Turrio-Baldassarri et al. 2004, Di, Cheung & Huang 2009).Turrio-Baldassarri et al. reported increase of benzene emission by 60% for 20% rapeseed oil biodiesel blend (Turrio-Baldassarri et al. 2004). Di et al found increase of benzene emission between 26 and 50%, depending on engine loads (Di, Cheung & Huang 2009).
Other studies indicated decrease of benzene between 43-100% (Cheung, Zhu & Huang 2009, Bermúdez et al. 2011, Ferreira et al. 2008).
Bermudez et al did not detected benzene in exhaust of different biodiesels (palm oil, rapeseed an soybean) while emission of benzene for diesel was 0.05 g/kg (Bermúdez et al. 2011). (Ferreira et al. 2008)Ferreira et al. reported benzene emissions decrease by 20% for 10% biodiesel use (soybean oil) (Ferreira et al. 2008).
Di et al. found decrease of toluene en xylene between 60 and 80% depending on engine loads (Di, Cheung & Huang 2009). Similar results were shown by Turrio-Baldassarri. Toluene and xylene emissions were reduced by 77% and 63% respectively for 20% biodiesel (Turrio-Baldassarri et al. 2004).

Metals
The major elements emitted from diesel engines are Ca, Mg, Zn, Pb, Cr, and Ni. Depending on the origin of fuel, mineral oil metal content in the fuel varies. However, it is also noticeable that the metal contents in lubricating oil also plays an important role in the emission of metal contents in engine exhaust particularly for Ca and Zn (Agarwal, Gupta & Kothari 2011).
There is decrease of metal concentrations in exhaust with increase of engine load (Ca, Cr, Cu, Fe, Mg, Na, Ni, Pb, Zn). With exception of Ni which shows an increase with higher engine load (Agarwal, Gupta & Kothari 2011). Concentrations of Cu, Na, Ni, Pb decrease with use of biodiesel, whereas concentrations of Mg, Zn, Fe were slightly higher for biodiesel (Agarwal, Gupta & Kothari 2011).
In another study an increase is found for: Fe, Al, Zn, Cr, Mg. Pb Cd, Na and Ni when 20% biodiesel is used (Dwivedi, Agarwal & Sharma 2006). Betha et al. found an increase of Zn, Cr, and Ni when 50% and pure biodiesel is used (Betha, Balasubramanian 2013).

EC/OC
Few studies investigated the OC and EC.

Kooter et al observed a 90% decrease in the EC fraction and no change in OC fraction when pure biodiesel is used compared to diesel (Kooter et al. 2011).
The biodiesel application increased the OC emissions by 12–190% and decreased the EC emissions by 53–80%, depending on the fuel and engine operation parameters (Zhang 2011). Therefore OC/EC was increased by three to eight times with biodiesel application.
In contrast, use of 20% biodiesel of waste-edible-oil source showed a decrease of OC by 49%, but the particulate EC concentration increased as the percentage of waste-edible-oil-biodiesel increased (Tsai et al. 2014). Another study showed decrease of OC and EC with the increase of biodiesel fraction (Lopes et al. 2014).

1,3-butadiene
1,3-butadiene is an air toxic which is recognized as a genotoxic carcinogen by the Expert Panel on Air Quality Standards and classified as a group B2 carcinogen by US EPA. It is commonly found in the exhaust gas of diesel and petrol vehicles and the quantity of 1,3-butadiene in the atmosphere could be dominated by road vehicle exhaust emission.1,3-butadiene emissions is dependent on the engine load with lower emissions by high engine load (Di, Cheung & Huang 2009). Use of waste cooking oil biodiesel decreased the 1,3-butadiene emission by 17–40% depending on the engine load (Di, Cheung & Huang 2009).
Cheung et al. found substantial decrease of 60% of 1,3-butadiene emissions for biodiesel made of waste cooking oil (Cheung, Zhu & Huang 2009).

Overview of non-regulated pollutants
For an overview of the response of PAH to biodiesel blends for different engine technologies, refer to the table below. There is increasing interest on the non-regulated emissions which are air toxics, such as polyaromatic hydrocarbons (PAHs) and aldehydes, when biodiesel is fueled instead of diesel. However, these non-regulated emissions are not always routinely measured in studies. In addition the measured compounds not always show a consistent pattern across different studies. It is well acknowledged that differences in non-regulated emissions occur depending on engine operating conditions, such as load, cycle mode, catalyst application etc.
Due to the known toxicity of many of the non-regulated emissions, not only the absolute change in emission is important in going from diesel to biodiesel application but also the relative change compared to PM mass emissions.
Changes in PAH emission show in general a decrease of 70-90% when pure biodiesel is used compared to diesel, which is depended on engine operating conditions (load, cycle mode, etc.) (Xue, Grift & Hansen 2011). However it is observed that the use of pure biodiesel (B100) does not necessarily reflects the same trend in change compared to that of biodiesel blends. Kooter et al have shown decrease in PAH with B100 (RME), whereB10 and B20 show an increase in the light PAH (Kooter et al. 2011). Guarieiro 2014 show an increase in measured PAH for B100 (WCO) where a decrease is found for B25 and B50 (Guarieiro et al. 2014).
Application of catalyst systems in absolute way show a decrease in PAH emissions. However it might affect particular PAH components more than other, especially the larger PAH components seem to increase compared to the diesel (B0) situation.
Another clear effect is that the saturation grade of the biodiesel source influences the PAH formed, where unsaturated biodiesels result in higher PAH emissions.

Carbonyl compounds emissions have discordant results for biodiesel showing both increase and decrease in formaldehyde, methyl ester components etc. However it is widely accepted that, biodiesel increases these carbonyl emissions because of the substantial oxygen content of biodiesel. In addition, engine operating conditions (load and cycle mode), engine types also have an effect on these emissions, and methanol tends to increase acetaldehyde emissions (Xue, Grift & Hansen 2011). Benzene emissions are equivocal and both increases up to 60% and decreases up to 100% have been reported in the use of biodiesel (blends).

Further studies on non-regulated emissions of biodiesel should be carried out to obtain conclusive trend, especially for the carbonyl compounds and BTX emissions. The use of catalyst reduces substantially PAH emissions. On the other hand catalyst reduces carbonyl emissions in biodiesel exhaust less effective than for diesel exhaust which means that carbonyl compounds emissions will be a concern even with common use of known catalytic technologies.

Table 16: Influence of biodiesel (FAME) on PAH emissions, compared to B0

study	**biodiesel**	**type**	**engine**	**PAH**
Macor 2011	B30	RME	Euro3	10%
Karavalakis 2011	B30	SME	Euro4	Light: +20-40% Heavy:- 25-50%
Karavalakis 2010	B50	SME	Euro 2	All -40%
Schroder 2012	B100	CME<PME<RM E<LME<SME	EuroIII	Increase in PAH along biodiesel
Pabst 2014	B20	RME	EuroIV	All -20%
	B20		EuroIV + SCR	Light: -20-70% Heavy: +100-400%
Chang 2014	B20	WCO		-50% (total only)
Kooter 2011	B20	RME	EuroIII	Light: +20-35%
	B100	RME	EuroIII	All: -80%
Turrio-Baldassarri 2004	B20	RME	Euro II	All: -20%
Rojas 2011	B15	PME	?	Light: -20-75% Heavy: +10-60%
Guarieiro 2014	B25	WCO	?	-15.85

Light PAH = ... Heavy PAH = ...

Table 17: Influence of biodiesel (FAME) on carbonyl emissions, compared to B0

study	biodiesel	source	engine	carbonyl	formaldehyde	acetaldehyde
Ballasteros 2014	B50	Animal fat	Euro5	16%	100%	50%
			+catalyst	140%	40%	100%
	B100		Euro5	86%	145%	80%
			+catalyst	975%	130%	350%
Di 2009	B40	WCO	light		-50%	60%
	B100				-85%	45%
Lin 2009	B20	PME	Heavy duty	Light; shows up to 35% increase; heavy shows up to 40% decrease		
Turrio-Baldassarri 2004	B20	RME	EuroII	20%		
Kooter 2011	B20	RME	EuroIII	-55%		

4.5 Projected impact of biodiesel blends on emissions up to 2030

In the subsections below, the projected impact op biodiesel blends on emissions up to 2030 are discussed separately for regulated and non-regulated emissions.

4.5.1 Regulated emissions

In comparison to the impact of these vehicle technologies, the projected impact of biodiesel blending on regulated emissions in 2030 is small.

The tables below, Table 18 to Table 21, show projected emission trends for all four sectors (Light Duty, Heavy Duty, Inland vessels and Non-road mobile machinery) for 2015 up to 2030. The emission data are Dutch emission factors of 2013. Two tables are used per sector, one showing the absolute values in g/km, the second shows relative values in %. Four columns are shown for each emission. The first column gives the emission factors as they are in 2015 (taken from VERSIT+), the second shows them as they are expected in 2030 if 7% blending is applied. The third and fourth column show emission factors if taking into account 30% blending. Since these values are still highly indicative, an error margin is given by min and max values.

Table 18: Light Duty emission trends 2015-2030 (absolute values in g/km and relative values in %)

	2015 (B7)	2030 (B7)	2030 (B30 min)	2030 (B30 max)
CO	4,822	3,813	3,241	3,622
THC	0,522	0,474	0,332	0,427
Nox	0,301	0,130	0,120	0,126
NO2	0,08	0,02	0,020	0,021
PM	0,012	0,005	0,005	0,005

	2015 (B7)	2030 (B7)	2030 (B30 min)	2030 (B30 max)
CO	100%	79%	67%	75%
THC	100%	91%	64%	82%
Nox	100%	43%	40%	42%
NO2	100%	28%	25%	27%
PM	100%	42%	42%	38%

Table 19: Heavy Duty emission trends 2015-2030 (absolute values in g/km and relative values in %)

	2015 (B7)	2030 (B7)	2030 (B30 min)	2030 (B30 max)
CO	3,075	1,326	1,127	1,260
THC	0,477	0,025	0,018	0,023
Nox	6,646	0,878	0,808	0,852
NO2	0,39	0,19	0,17	0,18
PM	0,074	0,014	0,014	0,013

	2015 (B7)	2030 (B7)	2030 (B30 min)	2030 (B30 max)
CO	100%	43%	37%	41%
THC	100%	5%	4%	5%
Nox	100%	13%	12%	13%
NO2	100%	48%	45%	47%
PM	100%	19%	19%	17%

Table 20: Inland vessel emission trends 2015-2030 (absolute values in g/km and relative values in %)

	2015 (B7)	2030 (B7)	2030 (B30 min)	2030 (B30 max)
CO	10,0	5,0	3,5	4,5
THC	2,0	1,0	0,9	0,7
Nox	43,0	17,5	17,5	18,7
NO2	3,0	3,0	3,0	3,3
PM	1,2	0,5	0,30	0,45

	2015 (B7)	2030 (B7)	2030 (B30 min)	2030 (B30 max)
CO	100%	50%	35%	45%
THC	100%	50%	43%	35%
Nox	100%	41%	41%	43%
NO2	100%	100%	100%	110%
PM	100%	42%	25%	38%

Table 21: Non-road mobile machinery emission trends 2015-2030 (absolute values in g/km and relative values in %)

	2015 (B7)	2030 (B7)	2030 (B30 min)	2030 (B30 max)
CO	5,00	3,00	1,80	2,40
THC	1,60	0,50	0,35	0,45
Nox	18,0	3,0	3,0	3,3
NO2	1,40	0,45	0,50	0,55
PM	1,20	0,20	0,12	0,18

	2015 (B7)	2030 (B7)	2030 (B30 min)	2030 (B30 max)
CO	100%	60%	36%	48%
THC	100%	31%	22%	28%
Nox	100%	17%	17%	18%
NO2	100%	32%	36%	39%
PM	100%	17%	10%	15%

For Light Duty and Heavy Duty, the emission trends are also graphically displayed in Figure 11. Graphs for inland vessels and non-road mobile machinery are given in Appendix **Error! Reference source not found.**. It can be seen, that independent of biodiesel blending, the emissions of road transport are expected to reduce (significantly) up to 2030. This is mainly related to the increased uptake of 'clean' vehicle technologies in the fleet.

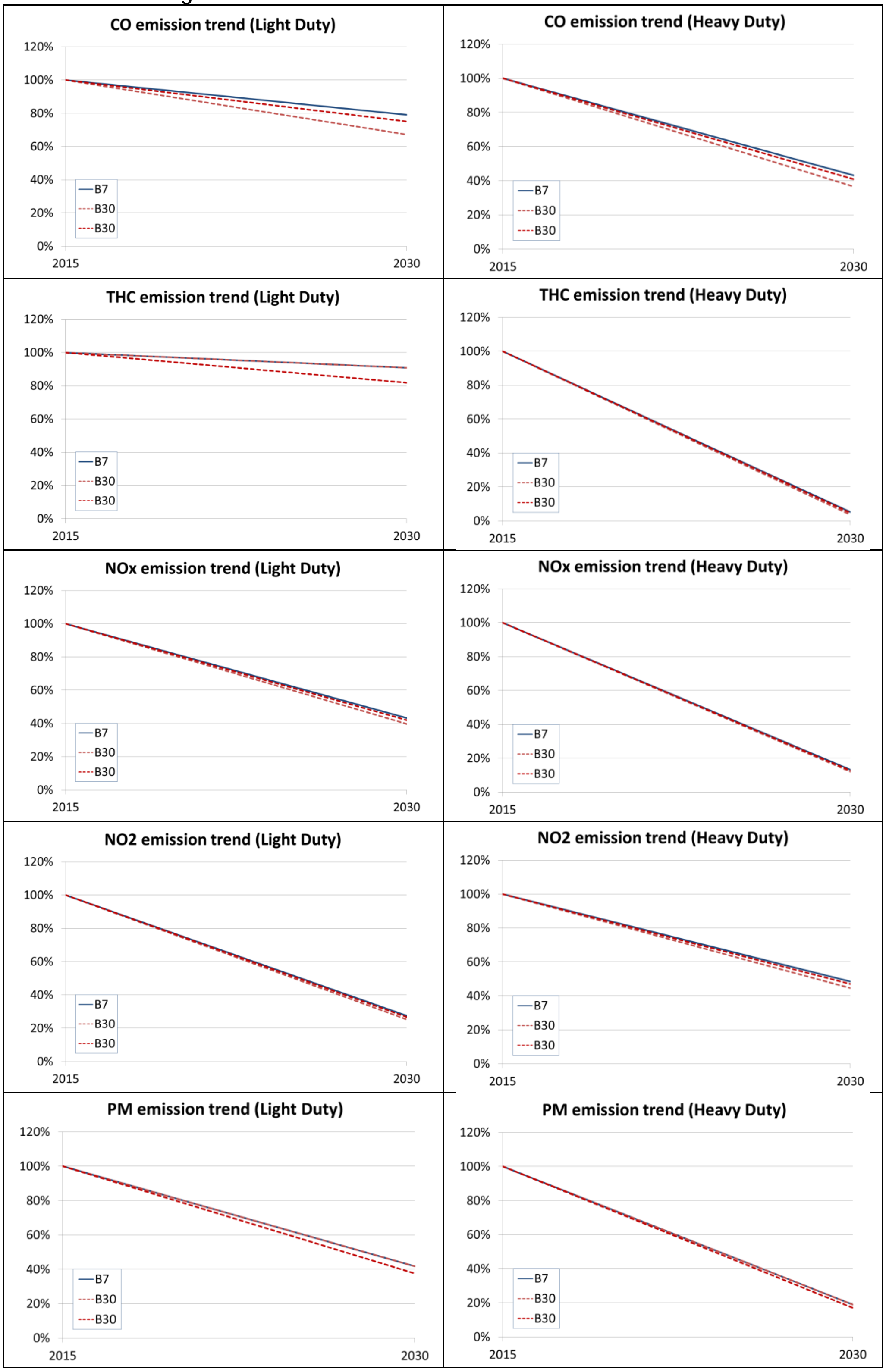

Figure 11: Predicted emissions trends 2015-2030 – Light Duty and Heavy Duty vehicles and the effects of increased biodiesel blends.

5 Conclusions

In this study, the impact of biodiesel blends on regulated and non-regulated emissions are studied for the following market segments: cars, heavy-duty vehicles, mobile machinery and inland ships. This lead to the conclusions as described below.

Expectation of biodiesel blends up to 2030
Two types of biodiesel need to be distinguished because of their entirely different chemical compositions:
- FAME, which is a methyl ester and consequently has oxygen groups within its molecules.
- Paraffinic based biodiesel such as HVO (Hydrogenated Vegetable Oil) and BTL (Biomass to Liquid). These are plain hydrocarbons without oxygen groups or aromatics.

The uncertainty of the future biodiesel blends is large due to the absence of European targets for the period of after 2020. The target for 2020, is to use (generally blending) of 10% biofuel base on energy content. Physical content can be lower due to the possibility of ‘double counting’.

For the period up to 2030, it is expected that:
- FAME type biodiesel is blended with regular diesel up to some 5% to 7%. However higher blend percentages (such as 30%) for certain market segments or niche markets cannot be fully excluded.
- HVO type biodiesel blend will likely be used to further top up the blend percentage above 7%. For 2030, it is expected that the HVO will not exceed a 5% to 10% blending share. For niche markets a higher blend percentage of up to 30% or even pure HVO might be used.

Market segments and engine technology
There are currently differences in emission control technologies between the different market segments (cars, heavy-duty vehicles, mobile machinery and inland ships), primarily due to the differences in the emission requirements. Especially requirements for inland ships are lagging behind by some 10 years. By 2030, it is expected that NOx reduction catalysts and diesel particulate filters will generally be applied, only inland ships may not need the diesel particulate filter.

Effect of biodiesel blends on emissions

Effect of FAME biodiesel blends on <u>regulated</u> emissions:
- The effects are generally proportional with the blend ratio
- HC, CO and PM emissions go down.
- NOx and NO2 emissions can go up (max ca 10%) with FAME and go down (max ca 10%) with HVO type biodiesel.
- Particle number emissions go down with high blend percentages, probably for both FAME as well as HVO biodiesel. Particle size distribution is probably not significantly affected.

- Due to new engine technology of the actual fleet in 2030 the emission factors will decrease. This decrease in emissions is more substantial than the emission reductions which are caused by higher biofuel blends.

Effect of FAME biodiesel blends on non-regulated emissions:
- PAH: generally decreases when using B100. Unsaturated biodiesel (e.g. soy bean) shows less decrease compared to saturated biodiesel (e.g. coconut). No consistence response with low blends B7 – B20 are identified. Occasionally light and heavy PAH can have an opposite response (Some studies show a decrease of light PAH with increasing blend rate and an increase of heavy PAH's with increasing blend rate).
- Benzenes: some studies show an increase of benzenes and other studies show a decrease when using low biodiesel blend (further investigation is required)
- Nitro and oxy-PAH's: The very few studies found addressing nitro and oxy PAH, showed a decrease of these PAH types with B100. However, nitro and oxy-PAH's can increase with low blends (this requires further investigation).
- Carbonyl: often appear to increase with biodiesel blend rates, although one study showed a decrease of heavy carbonyl as a function of biodiesel blend rate.
- Elementary carbon: generally decreases substantial as a function of the biodiesel blend rate for both FAME and HVO type biodiesel (percentage with low blends t.b.d).
- Organic carbon: can vary significantly and does not show a clear pattern with biodiesel blends.

Very few studies addressed the influence of HVO biodiesel. A single study showed a comparable decrease of PAH as for FAME type biodiesel.
In general, there is no particular concern of increasing non-regulated emission with HVO blends due to the plain paraffinic chemical composition of HVO.

For the period up to 2030, the following can be concluded:
- in general, the absolute level of regulated and non-regulated emissions decrease due to the more stringent emission levels and the general application and the higher efficiencies of emission control systems such as (NO_x) catalysts and particulate filters. This applies to all modalities such cars, heavy-duty vehicles, mobile machinery and inland ships.
- Looking at the influence of FAME type biodiesel blends: some non-regulated components might not show a proportional decrease with the regulated emissions. Further investigation on carbonyl emissions and nitro- and oxy-PAH when using low blend biodiesel is required.

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7 Signature

Delft,15 May 2014

TNO

Gertjan Koornneef
Project leader

Gerrit Kadijk
Author

A Overview emission legislation Non Mobile Machinery

Directives on emissions from non-road mobile machinery
The legislative file of Non-Road Mobile Machinery (NRMM) contains today seven directives: the "mother" Directive 97/68/EC, the amendments Directive 2002/88/EC, Directive 2004/26/EC, Directive 2006/105/EC, Directive 2010/26/EU, Directive 2011/88/EU , and the last amendment Directive 2012/46/EU:

- Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery (OJ L 59, 27.2.98).
  Directive 97/68/EC (first publication in the Official Journal) ... bg cs da de et el es fr ga hr it lv lt hu mt nl pl pt ro sk sl fi sv
  Directive 97/68/EC - consolidated text ... bg cs da de et el es fr ga hr it lv lt hu mt nl pl pt ro sk sl fi sv
- Directive 2002/88/EC of the European Parliament and of the Council ... bg cs da de et el es fr ga hr it lv lt hu mt nl pl pt ro sk sl fi sv of 9 December 2002 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery
- Directive 2004/26/EC of the European Parliament and of the Council ... bg cs da de et el es fr ga hr it lv lt hu mt nl pl pt ro sk sl fi sv of 21 April 2004 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery
  Corrigendum to Directive 2004/26/EC ... bg cs da de et el es fr ga hr it lv lt hu mt nl pl pt ro sk sl fi sv
- Council Directive 2006/105/EC ... bg cs da de et el es fr ga hr it lv lt hu mt nl pl pt ro sk sl fi sv of 20 November 2006 adapting Directives 73/239/EEC, 74/557/EEC and 2002/83/EC in the field of environment, by reason of the accession of Bulgaria and Romania
- Commission Directive 2010/26/EU ... bg cs da de et el es fr ga hr it lv lt hu mt nl pl pt ro sk sl fi sv of 31 March 2010 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery
- Directive 2011/88/EU of the European Parliament and of the Council ... bg cs da de et el es fr ga hr it lv lt hu mt nl pl pt ro sk sl fi sv of 16 November 2011 amending Directive 97/68/EC as regards the provisions for engines placed on the market under the flexibility scheme
- Commission Directive 2012/46/EU ... bg cs da de et el es fr ga hr it lv lt hu mt nl pl pt ro sk sl fi sv of 6 December 2012 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery

The NRMM Directive regulates exhaust emissions from and test procedure for the different types of engines.
The "mother" directive, 97/68/EC, covers diesel fuelled engines for common NRMM. It became effective from 1 January 1999 for certain types of engines. The first stages presented in 97/68/EC, stage I (1 January 1999) and stage II (1 January 2001), covers diesel fuelled engines between 37 and 560 kW.

The second directive, 2002/88/EC, extends the scope of 97/68/EC to cover spark ignited engines (petrol engines) up to 18 kW for engines installed in handheld and non-handheld equipment. Stage I (and stage II) became effective in August 2004 with some exemptions for certain applications. The work with transposition is going on in the Member States.

The third directive, 2004/26/EC, extends the scope of 97/68/EC, which covers diesel fuelled engines from 19 kW to 560kW for common NRMM and regulates the emission in 3 further stages. The directive includes also to constant speed engines as well to railway and inland maritime engines (inland waterway transport sector). For the 2 latter categories there are no upper limits concerning engine power. The different stages in the 2004/26/EC directive are as follows:

- Stage III A covers engines from 19 to 560 kW including constant speed engines, railcars, locomotives and inland waterway vessels.
- Stage III B covers engines from 37 to 560 kW including, railcars and locomotives.
- Stage IV covers engines between 56 and 560 kW.
  The stage III A will be effective (place on the market) from 1 January 2006 for certain types of engines, stage III B from 1 January 2011 and stage IV from 1 January 2014. In the directive there is a flexibility scheme that allows manufacturers to place engines on the market that only fulfil the previous stage when a new stage is in force.
  The directive 2004/26/EC is aligned with the US proposal TIER IV of further stages of emission limit values. A working group within the GRPE - Working Party on Pollution and Energy (UNECE) is working with a world wide harmonised test procedure.

The fourth directive, 2006/105/EC, introduced some modifications to the Directive 97/68/EC, amending Annex VIII, point 1, section 1. This concerns the approval certificate numbering system, with the code for each MS.

The fifth directive, 2010/26/EU, modifies type approval requirements for stages IIIB and IV.

The sixth directive 2011/88/EU revises the flexibility percentage for Stage IIIB engines.

The seventh directive 2012/46/EU is related to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in NRMM. Directive 2012/46/EU updated Directive 97/68/EC so as to reflect technical progress in areas such as:

- Symbols and abbreviations, specifications and tests, specification of conformity of production assessment and parameters defining the conformity of production (ANNEX I).

- Type-approval process with reference to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery (ANNEX II).
- Test procedures for combustion ignition engines (ANNEX III).
- Analytical and sampling procedures for gaseous emissions tests (ANNEX IV).
- Type approval certificate modifications (ANNEX VII)
- Data sheet for type approved engines (ANNEX XI)
- Recognition of alternative type approvals (ANNEX XII)

B Inland vessels and non-road mobile machinery emission trends 2015-2030

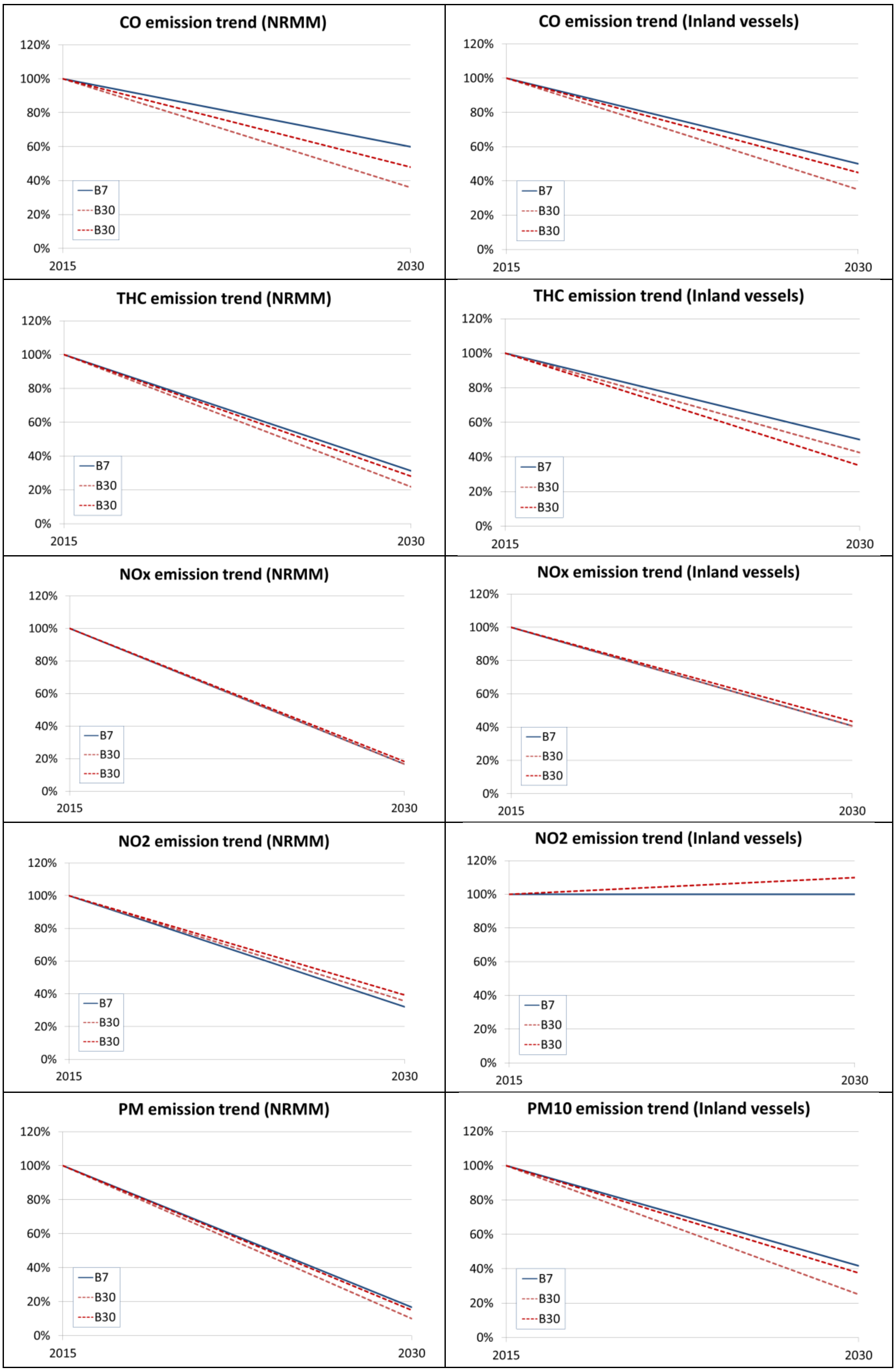

Figure 12: Emissions trends 2015-2030 –Inland vessels and Non-road mobile machinery (NRMM)