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TNO report

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Impact of biofuels on air pollutant emissions from road vehicles, phase 2.

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Summary

Introduction and objective

The work reported here is the second phase of a programme to provide the Dutch government with knowledge and advice regarding the impact of the use of biofuels for road transportation on the National Emission Ceilings (NEC) for the year 2020. Within NEC the emission levels of NO_x, SO_2, VOC and NH_3 are regulated. The programme is called BOLK [1] and is initiated by the ministry VROM.

BOLK phase 1 was focused on the following aspects:

- What fuel qualities are recommended and can be used in significant quantity up to 2020?
- What engine developments are expected, both for diesel and petrol engines?
- How does engine and after treatment technology interact with the use of biofuels, both on short and longer term, and what are the expected implications for exhaust emissions?

One of the recommendations was to stick to low blends for the bulk fuels (E5 or E10 and B5 or B7) in combination with dedicated fleets for high blends ethanol for passenger cars (FFVs) and high blends of biodiesel for trucks.

The objectives of BOLK phase 2 are the following:

- To update and review the main conclusions of the phase 1 report.
- To calculate the effects of biofuels on emissions on a national level based on three scenarios' for 2020.
- To do recommendations in order to minimize the risks of negative emissions effects.

Fuel mix scenarios for 2020

Important with respect to the scenarios is the distinction between single and double counting biofuel in the context of the EU biofuels directive 2009/28/EC. Double counting means that only half the quantity is needed. This is the case if the biofuels are produced from wastes, residues, non-food cellulosic and ligno-cellulosic material. The biofuels biodiesel (FAME), HVO (Hydrotreatment Vegetable Oil), Biogas and Ethanol can all count single or double depending on the feedstock. BTL will generally count double.

Three fuel mix scenarios that meet the European target of 10% biocomponent content by energy were defined for 2020:

1. *Focus on single counting biodiesel and ethanol.*
   Bulk fuels are B7 and E10 with a substantial share of B30 (scenario 1a) or B100 (scenario 1b) for heavy-duty vehicles.

[1] Beleidsgericht Onderzoeksprogramma Lucht en Klimaat 2008-2009, coordinated by Netherlands Environmental Assessment Agency MNP

2. *Focus on double counting ethanol and biodiesel.*
   2.0% market share (by energy) of E85 for passenger cars and biodiesel only in low blend (<B5).
3. *Focus on air quality.*
   5.6% market share (by energy) of natural gas with 30% biogas for passenger cars and bulk diesel with low blend HVO, BTL and biodiesel.
   Largest share of plug in hybrids and electric (electricity share in road transport 2.2% by energy).

Methodology / emission factors

Since there is not as much emission measuring data for biofuels as there is for fossil fuels, the conventional way of deriving emission factors from the measuring data is not possible. An alternative methodology has been chosen for biofuels. The emission factor for biofuels has been calculated by multiplying the fossil fuel emission factor by a factor for biofuels. The multiplying factor consists of a standard factor, which represents the change in combustion, and a failure factor which represents the effect of potential failures that occur due to the use of biofuel. The failure factor is only implemented with high blends of biodiesel. With ethanol blends additional failure risks are currently not expected.

$$\text{Emission Factor}_{biofuel} = \text{Emission Factor}_{convention} \times \text{Standard Factor}_{biofuel} \times \text{Failure Factor}_{biofuel}$$

For the biofuels minimum, average and maximum emissions factors have been determined, because of the uncertainty with both the fuel characteristics and failure effects with future engines. For high blend biodiesel the three levels are determined with the failure rate: zero, 50% of max and max. With high blends ethanol, the uncertainty is with the fuel characteristics response. The three levels correspond to the same as gasoline (minimum), 50% of increase with Euro 3 and 4 Flexible Fuel Vehicles on high blend ethanol (average) and 100% of that increase (max). For LPG, natural gas and biogas vehicles only one level is used (average) corresponding to the normal emission factors used for the CAR emission prediction.

Emission on a national level

For the calculation of emissions on a national level several inputs were used.
1 fuel mix scenario.
2 emission $\text{factors}_{conventional}$ based on CAR.
3 multiplying $\text{factors}_{biofuel.}$

The multiplying $\text{factors}_{biofuel}$ are defined per engine technology-fuel combination. Combined with the fuel mix of the scenario, this leads to the total emissions per year for a certain vehicle category (heavy duty trucks/vans/passenger cars). The final step is to add the scenario totals for the vehicle categories and the result is the total annual emissions (NOx and PM) for a scenario. Refer to figure 1.

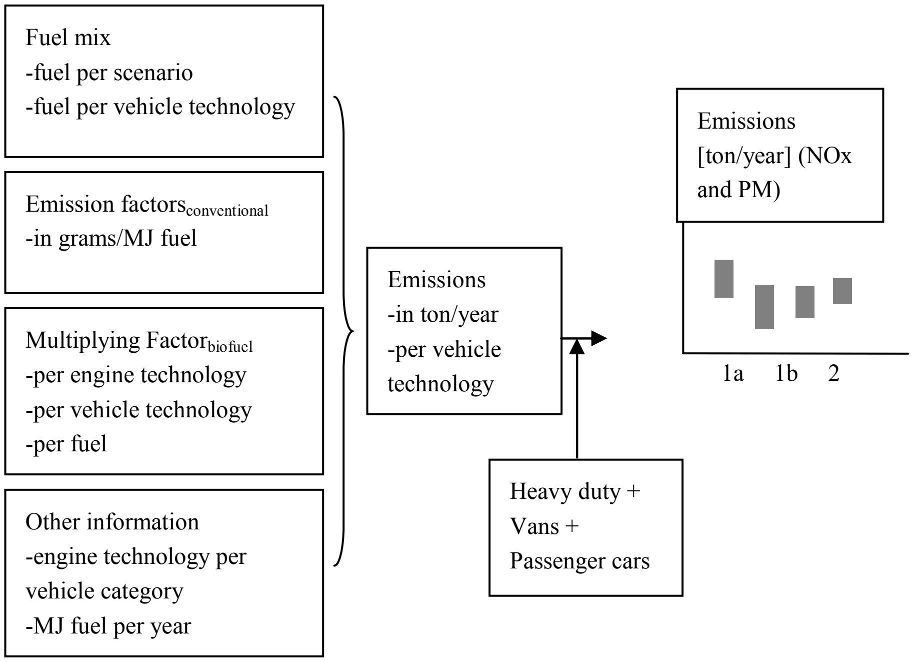

Figure 1. Schematic calculation emissions on a national level including effects of biofuel blends

Results and conclusions

The emissions on a national level for the baseline scenario is presented in table 1.

Table 1: Emissions of the baseline scenario

		vehicle category	
		trucks	passenger car
		emissions (kTon/year)	
Baseline	NOx	31.6	13.8
Total	PM	1.8	3.8

The results for the biofuels scenario 1a, 1b, 2 and 3 are presented in Figure 2**.**

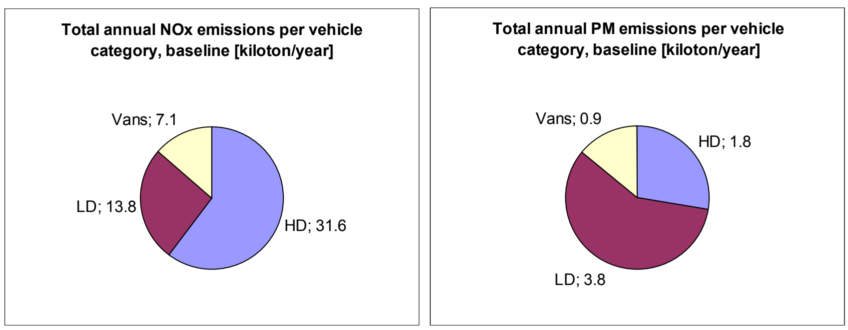

Figure 2. Changes in NOx and PM emissions on a national level for the three biofuel scenarios for 2020

The conclusions with respect to the emissions of NOx and particulates on a national level with the three biofuels scenarios for 2020 are as follows:

- All three scenarios show relative small effects on the NOx and particulates emissions on a national level. In all cases, it is less than respectively about 2% and about 0.5% difference with the baseline emissions (no biofuels) in 2020.
- Compared to the baseline, NOx is generally reduced somewhat in a range from 0 to about 2%. The highest NOx reduction is seen with scenario 3: a reduction of 2.1% (1.12 kton/year).
- The changes in PM emissions are even smaller due to the relative small influence of engine out particulates (tire and brake wear particulates accounts for more than 90%). The variations range from -0.1% to -0.5%. This corresponds to respectively -0.01 and -0.03 kton/year. The largest reduction is seen with scenario 3.

With respect to engine technology and composition of the vehicle fleet, the conclusions are as follows:

- High blends of biodiesel are currently not recommended, because of uncertain durability and performance aspects of the advanced emission control systems of Euro VI trucks when using high blends of biodiesel.
- If high blends of biodiesel are pursued (scenario 1), special incentives and/or regulations are probably needed to cover for additional vehicle, maintenance and fuel costs and to control possible risks of emissions increase.
- Scenario 2 has the lowest impact on the vehicle fleet, because with the 'double count' from second generation feedstock, the amount of biofuel is the lowest[2]. Moreover the additional vehicle and maintenance costs for FFVs (scenario 2) is probably lower than for high blend biodiesel in trucks (scenario 1) or CNG/biogas in passenger cars (scenario 3).
- In general, the conclusions of the phase 1 TNO/CE BOLK report are confirmed by the new findings.
- Compatibility of high blends of biodiesel with advanced emission control systems of diesel engines remains critical. Fuel quality issues are often seen as the source of problems and not all possible issues are fully understood.
- Even though effects on emission are estimated to be small, they can become substantial if failure rates appear to be higher than assumed for this study.

Recommendations

From an air quality perspective, it is recommended to focus on and consequently be prepared for several scenarios in parallel. This means:

- Stimulate double counting biofuels, because it reduces or eliminates the need for high blends of biofuels. Consequently it reduces the risks of higher emissions and maintenance costs.
- Stimulate and monitor fleets with trucks on high blends of biodiesel and with passenger cars on biogas (or a mixture of natural gas and biogas), including emission control system performance, failure rates and durability. Focus should be on Euro V and Euro VI trucks.
- Provide guidelines for truck fleets with high blends of biodiesel for trucks with advanced emission control (EGR, SCR, diesel particulate filters).
- Monitor the quality of fuels with biofuel blend extensively.

[2] Note that this may mean that these biofuels are likely to contribute less to the 6% CO_2 emission reduction target set in the Fuel Quality Directive.

- Carry out costs-benefit calculations for all biofuels, both single and double counting options. Additional fuel costs should be compared with the additional vehicle costs (in case high blends are needed).
- Particulates from tire and brake wear dominate the particulates emissions. It is recommended to further investigate the level, characteristics and associated health risks.

Contents

Appendices

1 Introduction

This TNO-CE Delft report has been written during the second phase of the program BOLK (Beleidsgericht Onderzoeksprogramma Lucht en Klimaat), initiated by the Ministry of VROM. The aim of this program is to investigate what side effects certain climate measures have on air quality. This is important for the Ministry of VROM, since new National Emission Ceilings are being prepared for 2020. One of the measures that have been investigated is the large scale introduction of biofuels in road transport. During the first phase of BOLK, an extensive literature search has been performed on the emissions of vehicles driving on biofuel blends. In this phase, BOLK-2, the aim is to calculate emission factors for biofuels and based on that, the emission effect of large scale biofuel introduction in road transport on a national level. This report focuses on the Tank-to-Wheels part of the biofuel chain, Ecofys investigated the Well-to-Tank part and reports the findings in [Ecofys 2009].

A more detailed explanation of the context is given in section 1.1 and the objectives of BOLK-2 are summarised as well. Section 1.2 explains the structure of the project and the report.

1.1 Context and objectives

Biofuels are an important option for achieving CO^2 emission reductions in the transport sector. In response to the European Biofuels Directive the Dutch government has set targets for the share of biofuels in the total fuel consumption for road transport. The Dutch biofuel target for 2010 has recently been decreased from 5.75% to 4% [Cramer, 2009]. The target for the year 2020 remained at 10%.

For biofuels not only greenhouse gas reductions are claimed, but also benefits with respect to exhaust emissions that affect local air quality. The impacts, however, are generally different for different fuels and available measurement results show a large scatter, with the spread in results often larger than the average of the measured impacts (see e.g. [Smokers & Smit, 2004, TNO/CE 2008]). A complicating factor is that establishing reliable emission factors (average emissions of average vehicles under average driving conditions) for conventional vehicles on conventional fuels already requires advanced statistical analysis of a large amount of measurement results due to the very different emission behaviour of the various vehicle models on the market. Furthermore effects of using pure biofuels in vehicle emissions can not be directly translated into effects of biofuels blended into conventional fuels.

Knowledge of the impacts of the use of biofuels in road vehicles on atmospheric pollutants is important from the point of view of local air quality problems as well as of emissions at the national level. The latter are regulated by means of National Emission Ceilings (NEC). Possible exhaust emission benefits of biofuels can create a win-win situation between air quality and climate policy, but conflicting impacts, i.e. trade-offs between impacts on air quality and greenhouse gas emissions are also possible.

Beginning of 2007 new and more ambitious climate policy targets have been declared at the European as well as national level. Many of the measures foreseen under these climate policies may have side effects on emissions of air pollutants. Some of these side-effects are still uncertain. For the Dutch Ministry of VROM knowledge of these side-effects is important input for the determination of new National Emission Ceilings which are being prepared for the year 2020. This knowledge is also relevant for the local air quality policy that aims at meeting European standards in 2015.

In BOLK phase 1 an extended literature search has resulted in an overview of emission data generated by emission measurements all over the world by various institutions. This is the best overview that could be made, but still the data scattered widely. The aim during BOLK-2 is to generate best emission factors possible with the information that is currently available. The specific objectives of this project are:

- Generating emission factors based on the available data.
  The information that is available about emissions with the use of biofuels is limited compared to that of conventional fuels. Therefore the emission factors generated here are not as reliable as those of fossil fuels.
- Calculating the total emission effect on a national level for three scenarios
- Get a feeling for the differences between three very diverse scenarios.
  Questions that are interesting in this respect are: does stimulating advanced biofuels have a positive effect on emissions at a national level? Will emissions increase or decrease if the current policy will be continued?
- Define policy recommendations on how to prevent NOx or PM increase due to the introduction of biofuels on a large scale. What are the most effective measures to prevent emission increase?

1.2 Structure of the report

The structure of the project is shown in Figure 3. The numbered rectangles are the activities that were needed to come to the final output, which is the emission level of NOx and PM at a national level in three pre-defined scenarios. These scenarios have been defined in consultation with the Ministry of VROM and the BOLK consortium (activity 1 in Figure 3). The scenarios have been defined in such a way, that each of them represents a different policy choice. Since one of the conclusions of the first phase of BOLK was that especially failures of technical origin, cause high emissions, a literature review on the technical risks that can occur with the use of biofuels has been performed (activity 2). The outputs of activity 1 and 2 have been checked with stakeholders in the oil- and automotive industry by means of a small questionnaire (activity 3). Their comments have been incorporated in the report. Based on activity 1,2 and 3 emission factors have been calculated (activity 4) and finally the total emission effect on national level has been calculated for the three scenario’s (activity 5).

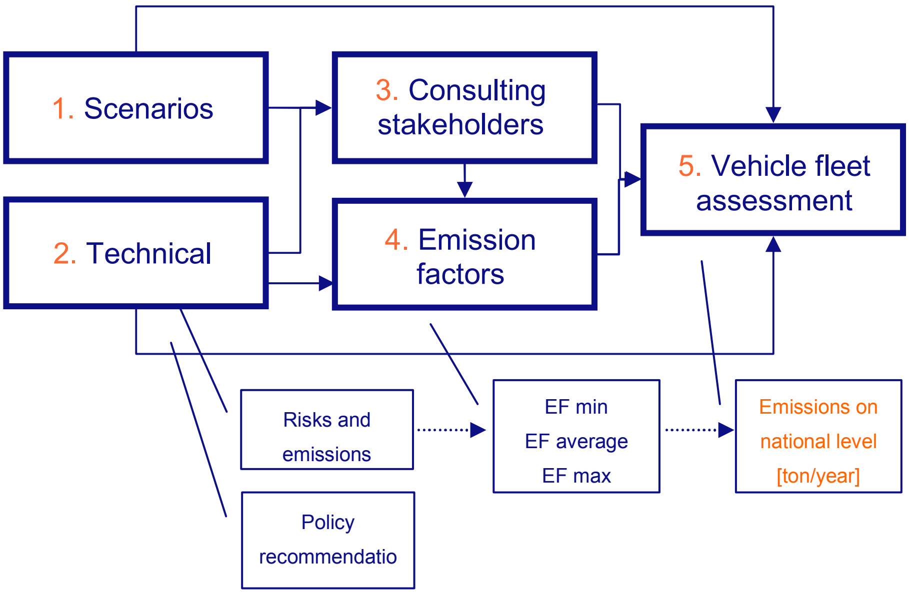

Figure 3: Structure of the BOLK phase 2 project

The structure of the report is in line with the structure of the project. In chapter 2 the choice for and the assumptions made in the three scenarios are explained. Chapter 3 reports of the literature update which has been done in order to update the emission data found during the first phase of BOLK. In chapter 4 a review is done of possible risks that can occur with the fuel blends assumed in the scenarios. This risk analysis is used in chapter 6, in which emission factors are determined for the biofuel blends in different vehicles. In chapter 7 the total effect on the national emission level is calculated. Chapter 5 reports of the stakeholder consultation and how the results of it have been taken into account in this project. Based on all this, policy recommendations to reduce risks are described in chapter 8. Finally, chapter 9 summarises conclusions and recommendations.

2 Biofuel scenarios for 2020/2030

2.1 Introduction

The first step of this study is the development of realistic scenarios for the biofuels that will be used in 2020-2030. These scenarios are then used to assess their effects on the vehicle emissions of pollutants and the resulting impact on air quality, and to determine options with which (potential) emission increases can be reduced or prevented. In addition, Ecofys will use these scenarios as input for their study on the emissions in the rest of the biofuel chains (i.e., from biomass cultivation and production to the vehicle).

In view of the current uncertainties in the development of biofuels in the coming decades, we have determined the most realistic basic assumptions that should be used for the scenarios with a group of experts, of the Ministry of VROM, PBL, TNO, Ecofys and CE Delft. During the meeting on 27 March 2009, the expectations regarding biofuel developments were explored, and a choice was made regarding the main assumptions of three scenarios that will be further developed in the course of the project.

In this chapter, we will first provide an overview of the relevant policy context. Next, we describe the main assumptions of and reasoning behind the three scenarios that were chosen. Finally, we further elaborate on these scenarios, describing what types of biofuels are used, what type of blends, and any other issues relevant for the rest of the project.

The year of focus of the study and therefore of the scenarios is 2020. However, we also provide an indication of the expected developments until 2030 as these may influence the decisions taken in the coming years.

2.2 Policy context

The Dutch biofuel developments in the coming decade are strongly determined by EU biofuel and renewable energy policies. Two EU directives were agreed on in December 2008 that will have a direct impact:

- The Renewable Energy Directive (RED), that sets, among other things, a (mandatory) target of min. 10% renewable energy in transport[3]. The 10% is defined as the total renewable energy share in transport divided by the total energy for transport (sum of fossil- and biofuels and electricity used for transport).
  It also provides a number of sustainability criteria for biofuels that are allowed to count towards this target. The directive also obliges member states to count biofuels from wastes, residues, non-food cellulosic and lignocellulosic (woody) biomass double, which means that 1% of those biofuels will count as 2% for the target. Renewable electricity used in road transport can be multiplied by 2.5. Some of the sustainability issues associated with biofuels, such as emissions due to indirect land use change or the exact definition of degraded land, will be further developed in the coming years. As all other Member States, the Netherlands' national government will have to submit national action plans for this directive by June 2010, and put

[3] In this report all percentage values are expressed in terms of energy%, unless we explicitly state that we mean volume %. This is indicated as vol%.

this directive into law in the coming years (before the end of 2010). The directive will be evaluated in 2014.
- The Fuel Quality Directive, that obliges petroleum companies to reduce the well-to-wheel emissions of their transport fuels by 6% in 2020, compared to 2010. This directive is also concerned with allowing and increasing the availability of blends >5vol% in standard transport fuels. Note that there is no provision for double counting of certain biofuels in this directive.

In addition, the EU sponsors a number of R&D projects aimed at new biofuel production techniques, for example for biofuel production from lignocellulosic biomass or algae, or for biofuels for aviation, and the further development of standards for biofuels is carried out in various CEN (the European Committee for Standardization) working groups.

Despite the strong influence of EU policies, Dutch biofuel related policies can still play a significant role in the developments. These national policies will be determined in the coming years, when the EU directive is being implemented.

In 'Schoon en Zuinig', the government announced to consider a higher biofuel target, of 20% in 2020. In recent months, the feasibility of this target has been studied [Bindraban 2009][SenterNovem, 2008], leading to the conclusion that even though this higher target might be technically feasible, it will be very difficult and perhaps even impossible to achieve this in a sustainable way. In addition, a number of international publications (for example, [SCOPE, 2009][UNEP, 2009][WBGU, 2009]) have appeared recently that are critical about the realistic potential of sustainable biomass for transport, and warn about the potential negative impact of increasing the biofuels demand further. However, at the time of writing of this report, a definite decision on the Dutch target for 2020 has not yet been made.

2.3 The main variables of future biofuel scenarios

We intend to use a limited number of different, realistic scenarios in our project to carry out an indepth assessment of the potential effects of biofuels on air pollutant emissions and air quality in 2020. These scenarios can have different basic assumptions, on the following issues:
1. The total share of biofuel in 2020/2030
2. The types of biofuels used
3. The biofuel blends that will be used, and their share
4. The types of feedstock used for the production of these biofuels.

The last issue is probably not very relevant for the TNO/CE Delft study, but will be relevant for the related Ecofys study. These four issues describe the main variables in the scenarios.

1 Share of biofuels in 2020/2030.
It is generally expected that the total share of biofuels in 2020 will be somewhat below 10%. It is thus assumed that the 10% EU obligation for 2020 will remain in place after the evaluation in 2014, and that cost and sustainability concerns (see, for example, [Bindraban, 2009] for an assessment of sustainability) will lead to a decision of the Dutch government to adhere to the 10% target, and not to aim for a larger share. Note

that the actual biofuels share is likely to be lower than 10%, due to the RED rule that biofuels from waste or lignocellulosic biomass count double[4].

The exact biofuel share also depends on the success of electric transport in the coming decade, as the renewable share of the electricity used for transport will also count towards the 10% target. The share of electricity is, however, not expected to be very significant in most scenarios, for a number of reasons:

a it is expected that a transition to electric vehicles (EVs) and plug in hybrid vehicles (PHEV) will be gradual, and will only affect part of the transport sector in the coming decade, i.e., part of the passenger car market
b not all electricity used in transport counts towards the target, only the renewable energy share. This is currently defined as the average renewable energy share in the power sector. In 2020, this share is expected to be about 20%, in line with the RED obligation for the EU.

2 The types of biofuels used
The current number of biofuel types is relatively limited: large volumes can only be produced of biodiesel and bioethanol/ETBE, and production volumes of HVO[5] are still relatively small but steadily increasing[6]. However, as there are a large number of promising R&D projects being carried out in various parts of the world, we expect that more production routes will become available before 2020.

Many of these options are being discussed in our phase 1 report for BOLK [TNO/CE Delft, 2008], a recent extensive overview of the current initiatives, their status, barriers to their deployment etc. can be found in [IEA Bioenergy, 2008]. Various biochemical and thermochemical routes are being developed, as well as some alternative routes such as HTU[7]. Their deployment in 2020 will depend strongly on the investments in R&D in the coming years, and on whether technological development can successfully reduce their cost and enable large scale production. Other routes that are already technically mature but not yet deployed on a large scale in the Netherlands, namely biogas, might also increase their shares in the coming years, either through government policy or dedicated industry investments, or due to cost improvements.
Clearly, the uncertainty in the types of biofuels in 2020 is relatively large.

3 The biofuel blends that will be used
The various types of biofuel can be blended into the 'normal' gasoline and diesel sold at the petrol stations. In the case of biodiesel and bioethanol this can be done up to a certain percentage, currently 5 vol% but that will increase in the coming years, up to 7 or 10 vol%. Some other biofuels such as HVO or Fischer Tropsch diesel can, however, also be blended at higher percentages without causing problems with engines and fuel systems in the current vehicle park. The maximum blends that are allowed for a specific biofuel are determined by EU regulations, and depend on the characteristic of the biofuel (compared to current fossil transport fuels), and on how the blends interact with current engine materials, injection technology, etc.

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[4] Note that less biofuels means that more renewables need to be used in other energy applications (electricity and heat) in order to meet the EU national target for renewable energy in 2020. This is, how-ever, outside the scope of this project, the impact of this effect on pollutant emissions in these sectors will thus not be assessed.
[5] Hydrotreatment Vegetable Oil
[6] Note that the number of feedstocks used is much larger. This will be addressed in issue 4.
[7] Hydro Thermal Upgrading

The fuels that can only be blended into the 'normal' transport fuels up to a certain percentage may also be sold at higher blends, at dedicated pumps for vehicles that can run on these blends. Typical higher blends for current biofuels are B30 or B100 for biodiesel and E85 for bioethanol, but other percentages may be chosen as well. Biogas may be sold in blends with CNG, or as 100% biogas.

The general expectation is that fuel suppliers will first try to blend as much biofuels into the normal transport fuels as they can. As there is no biofuel tax exemption in the Netherlands, the price of higher blends is relatively high and thus unattractive. However, if the 10% target can not be met that way, any excess biofuels will have to be sold as higher blends, probably to specific niche markets and fleets. There is still quite a large uncertainty regarding whether the most probable higher blend biodiesel is B30 or B100, the preferred high ethanol blend is E85.

4 The types of feedstock used for the production of these biofuels
Biofuels may be produced from a large variety of biomass. Currently, these are mainly agricultural (food and feed) crops such as rapeseed, corn, wheat, sugar beet, sugar cane, oil palms, etc. A relatively small share of biofuels is produced from waste streams such as used frying fat. In the future, when biofuels can be produced from lignocellulosic biomass or organic waste, or if other types of biomass such as algea or seaweed can be cultivated on a large scale, the range of feedstock can be further expanded.

2.4 Basic assumptions of the scenarios

Looking at this list of variables and considering both current expectations and uncertainties, we have chosen three different scenarios to work with in the remainder of this project. These scenarios are set up to allow a full assessment of the range of air quality effects that may be expected from biofuels in the coming decade, given the uncertainties in the future biofuel developments.

Please note that these scenarios are therefore developed with the aim to explore the potential air quality impact of biofuels, rather than to develop the most realistic scenarios for the future. The choices made here may thus seem quite drastic in some cases. This is not because we think that it is likely to happen, but rather to cover the 'playing field', and show the potential impact of drastic choices or developments on pollutant emissions. The actual future developments are expected to be somewhere in this 'playing field'. We have limited the scenarios to the biofuel and biogas options that we currently envisage to have the highest chance of maintaining or achieving a significant market share in the coming decade. A number of biofuels currently under development, for example HTU diesel and butanol. have therefore not been included.

The scenarios are the following:

- **Scenario 1: Current biofuels**

This scenario assumes that we will continue to use the types of biofuel in 2020 that are technically mature today, and that part of the growth in biofuel volume in the coming years will come from 2nd generation biofuels from waste and lignocellulosic biomass (2% in 2020). We further assume a relatively modest growth of electric transport.

This scenario thus assumes that the current biofuels and their feedstock can be developed further and made sufficiently sustainable to meet the future EU RED sustainability standards. There will be some production of biofuels from waste streams and residues, using technologies that are already mature today: biodiesel from used frying fat and HVO diesel from various vegetable and animal fat and oil residues. R&D of 2nd generation bioethanol and Fischer Tropsch diesel has not led to significant market introduction of these processes, due to technological problems, high investments, operational or logistical cost, etc.

- **Scenario 2: Ambitious development of 2nd generation biofuels**

This scenario assumes that the concerns about emissions from direct and indirect land use change and competition with food dominate the biofuels debate in the coming years. This leads to a much stronger growth of 2nd generation biofuels than in the first scenario (4% in 2020), and only a limited amount of the current biofuels. We assume here that 2nd generation bioethanol will be the only advanced 2nd generation production process that is successful in 2020. The ethanol will be blended into the bulk petrol as much as allowed, the remainder will have to be sold to niche markets as E85.
We further assume a relatively modest growth of electric transport.

- **Scenario 3: Local air quality**

This scenario assumes that the biofuel growth between 2010 and 2020 is achieved with routes that result in the least pollutant emissions from vehicles in urban areas. We thus opt for biogas, BTL (Biomass to Liquid, also known as Fischer Tropsch Diesel) and HVO (Hydrogenated Vegetable Oil), and a relatively high share of electric vehicles (thus assuming that their development is successful in the coming years). In addition to these low emission biofuels, the standard gasoline and diesel at the pump will contain 4% bioethanol and biodiesel respectively. As this scenario is quite a strong deviation from the current situation and the developments expected in the short term, we would expect that quite drastic and probably costly policies are necessary to move toward this direction. Both biogas and HVO production technology is technologically mature and proven, but electric and plug in hybrid vehicles, and BTL production are still very costly and it remains to be seen whether these technologies can mature sufficiently in the coming decade. The rationale behind the 4% bioethanol and biodiesel is that this will be the 2010 biofuel level in the Netherlands, so that the current production capacity can remain in operation in the next decade.

2.5 Details of the scenarios

Based on these outlines, the scenarios were developed further. Starting point for all three scenarios were the WLO Global Economy (update 2009, URGE Scenario) prognoses for the transport sector in the Netherlands in 2020[8].

The total number of vehicles and energy consumption in transport was based on WLO data, were a distinction was made between passenger cars, light goods vehicles and heavy duty vehicles. The distribution of the market share of energy consumption over the cars with different properties (such as: petrol, plug in hybrid on diesel and purely electric) was estimated using a vehicle model based on the annual sale of new vehicles[9] and the vehicles sold for each category. The annual mileage for each car of conventional type was determined from WLO data, the mileages of new car types were estimated according to expected performance and function. For instance, plug in

[8] Actualisatie referentieramingen, Energie en emissies 2008-2020, B.W, Daniels (ECN) and C.W.M. van der Maas (ed) (PBL), August 2009
[9] based on an extrapolation of CBS STATLINE data

hybrids on diesel were assumed to travel a greater annual distance than purely electric vehicles.

From these assumptions and calculations, estimates of the market share (in terms of energy use) of the different vehicles and fuels could be derived for the different scenarios. The volume of biofuels needed to obtain the goal of 10% by 2020 were then calculated for each uptake scenario. The actual reduction in CO2 emissions was also determined. The assumptions specific to the scenarios are described in the following.

Scenario 1a: Business as usual (with B100)
The Business as usual scenario was implemented using the following assumptions:

- The bulk transport fuels, i.e. the standard petrol and diesel at the pump, are assumed to contain 7% biofuel.
  - The bulk petrol contains 7 % ethanol (E10), the ethanol is produced from food crops (1st generation).
  - The bulk diesel contains 6.4% biodiesel (B7), partly produced from waste products (these count double towards the RED target), the rest from vegetable oils.

  These blends are expected to be the maximum allowed in the bulk fuels in 2020.
- 2% of the transport fuel energy is provided by biodiesel that is produced from waste products such as frying oil. This amounts to almost 350 million litres. Current production of biodiesel from frying fat is about 125 mln litres in the Netherlands, the growth to 350 mln would have to come from increased use of frying fat for biodiesel production, or from HVO production from other types of vegetable or animal waste streams.
  - It is thus assumed that the further development of 2nd generation bioethanol and of Fischer Tropsch diesel production has not lead to significant shares of these products.
- The remainder of the 6.4% biofuel in diesel is 1st generation biodiesel and HVO from vegetable oils (90/10). We expect that up to 7 vol% biodiesel can be blended into the bulk diesel in 2020 (6,4 energy%), HVO does not have any restrictions regarding maximum blends.
- A medium uptake of electric vehicles results in 16.000 purely electrical vehicles (EVs) and 50.000 plug in hybrids (PHEV) in 2020[10]. The PHEVs on petrol are assumed to drive 80% of their kms electrically, the diesel PHEVs drive 50% electrically. The renewable energy share in the electricity is assumed to be 20%. Taking into account that this renewable energy counts 2.5x towards the 10% target according to the RED rules, these vehicles then contribute by 0.15% to the target.
- The remainder of the 10% target was filled up with 1st generation biodiesel in a B100 niche market in HD vehicles.

Note that even though we assume in this scenario that 1st generation biofuels will still have a significant market share, these will not necessarily be the same as today. Developments in this area will be driven by the EU sustainability criteria described earlier, by technical improvements in agriculture and conversion technologies, and by increased integration of biofuel with fossil fuel refineries (e.g., HVO, or blending of pretreated vegetable oils into existing refineries).

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[10] The slow uptake EV model was based on the slow uptake scenario used in (Cenex, 2008) and adjusted to fit the Dutch situation.

The costs of this scenario are expected to be relatively low, compared to the other scenarios, as current and planned biofuel production facilities can remain in operation, and most of the biofuel can be blended into the bulk fuels. As a niche of B100 is required to meet the 10% target, some investments in B100 pumps, fuel distribution and B100 compatible trucks will be necessary, but these costs are expected to be limited.

Scenario 1b: Business as usual (with B30)
As it is currently still uncertain whether a niche market for high blend FAME will be sold as B100 or as B30, we have added this variant to Scenario 1, in which everything is the same as in Scenario 1a, except that the remainder of the 10% target is not met by B100, but by B30.

This scenario may come into practice if the availability of B30 vehicles remains (much) higher than that of B100 vehicles, and costs remain lower.

Scenario 2: Ambitious development of 2nd generation biofuels
This scenario assumes that the concerns about emissions from direct and indirect land use change and competition with food dominate the biofuels debate in the coming years. The resulting national and global policies, government incentives and industry investments lead to a successful development and market introduction of 2nd generation bioethanol, displacing most of the 1st generation biofuels from the market.

- This scenario assumes a share of 4% 2nd generation biofuels in 2020. As these count double towards the transport target of the RED directive, they contribute to the target as 8%. These consist of:
  - 150 million litres of biodiesel from waste products, which is somewhat higher than the current Dutch biodiesel production from frying fat (about 125 mln litres)
  - The remainder is provided by 2nd generation bioethanol (920 mln liters).
- We assume the same medium uptake of electric vehicles as in Scenario 1, resulting in a 0.15% contribution to the target.
- This leaves 1.7% of the transport energy to be met by 1st generation biofuels. We take this to be 1st generation biodiesel, produced from crops that have high yield (GJ/ha) and high greenhouse gas emission savings, as they will have to meet the EU sustainability criteria.
- A maximum of 7% bioethanol (E10) is added to petrol in the bulk market.
- The rest of the bioethanol will be supplied to a significant niche market for E85 in passenger cars, and to a more limited segment of busses and special HD vehicles that will use ED95.
- The biodiesel will be blended into the bulk diesel, resulting in a 3.3% (energy) blend.

The costs of this scenario depends strongly on the technological development of the 2nd generation production processes, on the feedstock and feedstock transport cost, and on the production volumes of these processes [IEA, 2008]. The E85/ED95 niche markets require separate pumps and fuel distribution, and vehicles. The additional cost of E85/ED95 vehicles are limited, though.
It is expected that the ethanol production can make use of current ethanol production facilities, with additional preprocessing of the feedstock. As the biodiesel demand is reduced significantly compared to current levels, this may lead to closure of relatively new biodiesel production facilities - depending on the biodiesel demand in other countries.

It should be noted that the contribution of biofuels to the CO_2 reduction target set in the Fuel Quality Directive (FQD) is likely to be lower in this scenario than in the first. The double counting of certain biofuels is only valid for the RED, not for the FQD target. This means that other measures might have to be taken to reduce CO_2 emissions of the transport fuel chain, in order to meet the FQD target. Whether this is a significant effect or not will depend on the CO_2 emission reduction of the double counting biofuels, in comparison with that of the single counting biofuels.

Scenario 3: Local air quality
The scenario in which local air quality is given priority in future biofuels development is based on these assumptions:
- 4% 1st generation biodiesel and bioethanol (the 2010 levels)
- Relatively fast uptake of electric cars, resulting in 160.000 EVs and 500.000 PHEV in 2020. Using the same assumptions about the kilometers driven and the renewable energy share as in the previous scenarios, these cars lead to a contribution of 1.1% to the 10% RED target.
- The remainder of the 10%, 4.5%, is covered by BTL, HVO and biogas. These are the fuels with the lowest air polluting emissions, according to the first Bolk study [TNO/CE, 2007]
- Biogas, BTL and HVO have equal shares in this 4.5%. As the biogas and BTL are assumed to be produced from waste streams, they count double, the HVO is assumed to be produced from food crops. The equal shares are taking into account the double counting, therefore the actual volume of HVO (in energy content) sold is double to that of BTL and biogas.
  - Note that biogas does not need to be the actual gas that is burned inside the vehicle. Biogas is assumed to be added to the natural gas network and attributed to transportation by certification.
  - This scenario requires a fast uptake of CNG (gas) cars, and the availability of CNG/biogas at sufficient pumps.
- No B100 or E85 niche markets are necessary in this scenario

The cost of this scenario is expected to be relatively high, for a number of reasons:
- The natural gas / biogas requires different vehicles, dedicated distribution and pumps.
- Production of BTL is expected to be expensive, especially as long as the production volumes are limited.
- The current production facilities of ethanol and biodiesel will become redundant (depending on the demand outside the Netherlands).

More details about the assumptions used for the electric vehicle market introduction and use are described in Appendix A.

2.6 Results

The resulting total volumes of biofuels are shown in Figure 4, for the three scenarios. Clearly, the different scenarios assume very different developments in the biofuel industry. The first two scenarios differ in the shares of 1st generation versus 2nd generation biofuels – we assume here that the 1st generation biofuels are the ones that count single, the 2nd generation biofuels count double in the RED. The second scenario still requires a significant volume of the 1st generation (single counting) biofuels, but use Fisher-Tropsch, HVO and biogas. We have indicated these separately in the graph. The biofuel volumes in scenarios 1a and 1b are the same.

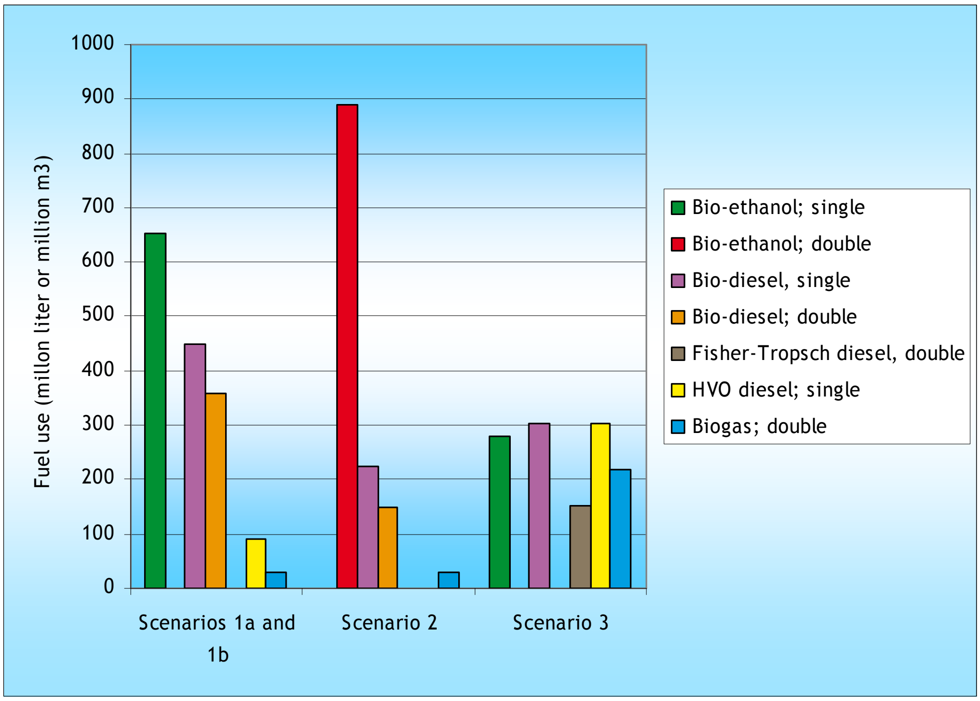

Figure 4 Overview of the total volume of the various biofuels consumed in the three scenarios per fuel type (mln liter for the liquid biofuels, mln m3 for biogas)

Figure 5 show how much each of the biofuels and renewable electricity contribute to the 10% RED target, in the three scenarios.

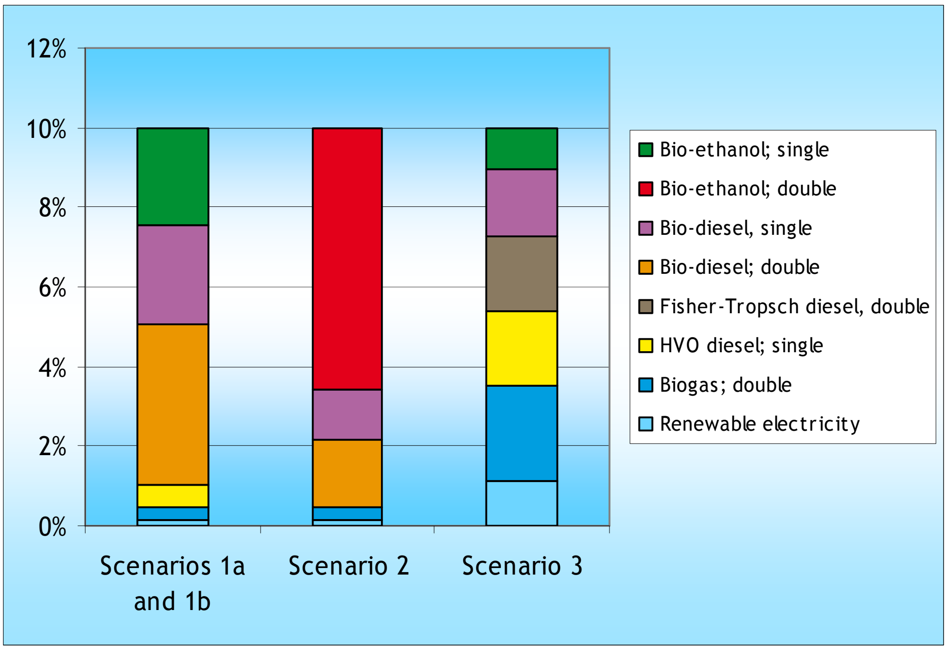

Figure 5 Contribution of the various biofuels to the 10% target set in the RED

Note that these scenarios can also be expected to lead to very different costs and (global) environmental impact, and would probably require quite different policy measures to realise them. We will discuss costs later in this report, policy measures are part of the scope of this project.

In addition, the contribution of the biofuels in these scenarios to the 6% CO_2 reduction target set in the Fuel Quality Directive (FQD) varies as well, as the double counting of certain biofuels is not applied in the FQD (as explained in the previous paragraph). These contributions depend on the CO_2 emission reduction of the various biofuels. For example, if we assume that the single counting biofuels achieve a 60% CO_2 reduction, and the double counting biofuels achieve 70%, the contributions of the three scenarios to the FQD target are 4.8%, 3.8% and 4.9%, respectively.

To determine the impact of these biofuel scenarios on air pollutant emissions of the vehicles, we need more detailed data on the blends, and on the types of vehicles that they will be sold to. The following tables provide an overview of these data, for the three scenarios. The tables show results for passenger cars (Table 2), light good vehicles
(

Table 3) and heavy duty vehicles Table 4) separately.

Table 2 The bulk blends and niche markets in the various scenarios, for passenger cars

		Scenarios 1a and 1b		Scenario 2		Scenario 3	
	Fuel	Blend percentage (energy %)	Market share (% energy)	Blend percentage (energy %)	Market share (% energy)	Blend percentage (energy %)	Market share (% energy)
Bulk	Petrol + biofuel	7.0%	58.7%	7.0%	56.7%	2.3%	54.6%
	Diesel + biofuel	7.1%	38.0%	3.3%	38.0%	7.5%	34.2%
	LPG	0.0%	2.7%	0.0%	2.7%	0.0%	1.4%
	CNG + biofuel	30.0%	0.2%	30.0%	0.2%	30.0%	5.6%
	Plug-in hybird, petrol[a]	80.0%	0.28%	80.0%	0.3%	80.0%	2.7%
	Plug-in hybrid, diesel[a]	50.0%	0.1%	50.0%	0.1%	50.0%	1.2%
	Electric	100%	0.03%	100%	0.03%	100%	0.3%
Niche	B30	28.1%	-	27.9%	-	29.2%	-
	B100	100%	-	100%	-	100%	-
	E85	79.2%	-	79.2%	2.0%	79.2%	-
	Electric	100%	-	100%	-	100%	-

[a] Blend percentage of plug in hybrids indicates the share of electricity used for these vehicles.

Table 3 The bulk blends and niche markets in the various scenarios, for light goods vehicles

		Scenarios 1a and 1b		Scenario 2		Scenario 3	
	Fuel	Blend percentage (energy %)	Market share (% energy)	Blend percentage (energy %)	Market share (% energy)	Blend percentage (energy %)	Market share (% energy)
Bulk	Petrol + biofuel	7.0%	0.5%	7.0%	0.5%	2.3%	0.4%
	Diesel + biofuel	7.1%	97.8%	3.3%	97.7%	7.5%	91.0%
	LPG	0.0%	0.3%	0.0%	0.3%	0.0%	0.3%
	CNG + biofuel	7.0%	1.1%	7.0%	1.1%	7.0%	3.5%
	Plug-in hybird, petrol[a]	80.0%	-	80.0%	-	80.0%	-
	Plug-in hybrid, diesel[a]	50.0%	0.3%	50.0%	0.3%	50.0%	4.5%
	Electric	100%	0.02%	100%	0.02%	100%	0.2%
Niche	B30	28.1%	-	27.9%	-	29.2%	-
	B100	100%	-	100%	-	100%	-
	E85	79.2%	-	79.2%	-	79.2%	-
	Electric	100%	-	100%	-	100%	-

[a] Blend percentage of plug in hybrids indicates the share of electricity used for these vehicles.

Table 4 The bulk blends and niche markets in the various scenarios, for heavy duty vehicles

		Scenario 1a		Scenario 1b		Scenario 2		Scenario 3	
	Fuel	Blend percentage (energy %)	Market share (% energy)	Blend percentage (energy %)	Market share (% energy)	Blend percentage (energy %)	Market share (% energy)	Blend percentage (energy %)	Market share (% energy)
Bulk	Petrol + biofuel	-	-	-	-	-	-	-	-
	Diesel + biofuel	7.1%	96.6%	7.1%	88.8%	3.3%	98.5%	7.5%	97.7%
	LPG	-	-	-	-	-	-	-	-
-	CNG + biofuel	100%	1.0%	100%	1.0%	100%	1.0%	100%	1.0%
	Plug-in hybird, petrol[a]	10.0%	-	10.0%	-	10.0%	-	10.0%	-
	Plug-in hybrid, diesel[a]	10.0%	-	10.0%	-	10.0%	-	10.0%	-
	Electric	-	-	-	-	-	-	-	-
Niche	B30	28.1%	-	28.1%	10.0%	27.9%	-	29.2%	-
	B100	100%	2.3%	100%	-	100%	-	100%	-
	ED95	100%	0.2%	100%	0.2%	100%	0.5%	100%	1.3%
	Electric	100%	-	100%	-	100%	-	100%	-

[a] Blend percentage of plug in hybrids indicates the share of electricity used for these vehicles.

2.7 Cost of the biofuels

Costs of current biofuels have been quite variable over the past few years due to changing feedstock prices, government subsidies, market forces (in times of shortages or overproduction) and changes in the oil price. Cost estimates for the future biofuels in these scenarios (Fisher-Tropsch and bioethanol from ligno-cellulosic biomass) are even more difficult to make, as these are still in an R&D stage, and not yet being produced on any significant scale. This makes a cost prediction for these biofuels in the coming decade very difficult and highly uncertain, as cost reductions may be significant once technology development is successful and production volumes increase, but costs may remain high if these conditions are not met.

To some extent, the scenarios we developed here imply a certain cost development: scenario 2 requires a significant production volume increase in the coming decade, which is only feasible if technology development is progressing well. Costs or biofuel production will then reduce, as production volume increases. However, the level of cost reductions will depend on whether the overall demand for these biofuels increases in the Netherlands only, in the whole EU or even globally – cost reductions roughly scale with production volumes.
Along the same lines, scenario 3 would only come true if costs of electric vehicles and plug in hybrid vehicles reduce sufficiently for them to gain a significant market share. In scenarios 1 and 2, costs of EVs and PHEVs reduced compared to today, but will remain relatively high, resulting in a relatively limited market share.

Data can be found in the literature that can provide an insight into both the past (actual) cost developments, and into the cost estimates for the future – where the latter are often based on estimates of biomass and production cost, which are both quite uncertain. Furthermore, the costs of the biofuels to consumers will strongly depend on the market demand versus production, on government incentives for these biofuels and on other issues such as import duties for specific feedstocks or biofuels, or prices of co-products.

The volatility and variation of biofuel prices in the past years is illustrated in Figure 6, where price developments are shown for fuel ethanol from the USA, Europe and Brazil, from 2002 to 2007. Clearly, prices have increased significantly in these years, partly due to increases in feedstock prices (to a certain extend driven by increasing global ethanol demand), and partly in conjunction with increasing oil prices. The graph also shows that quite significant differences exist in price between EU-produced and imported ethanol. Import duties, e.g., as currently in place for ethanol from Brazil, may then increase the price of these biofuels to the Dutch consumers.

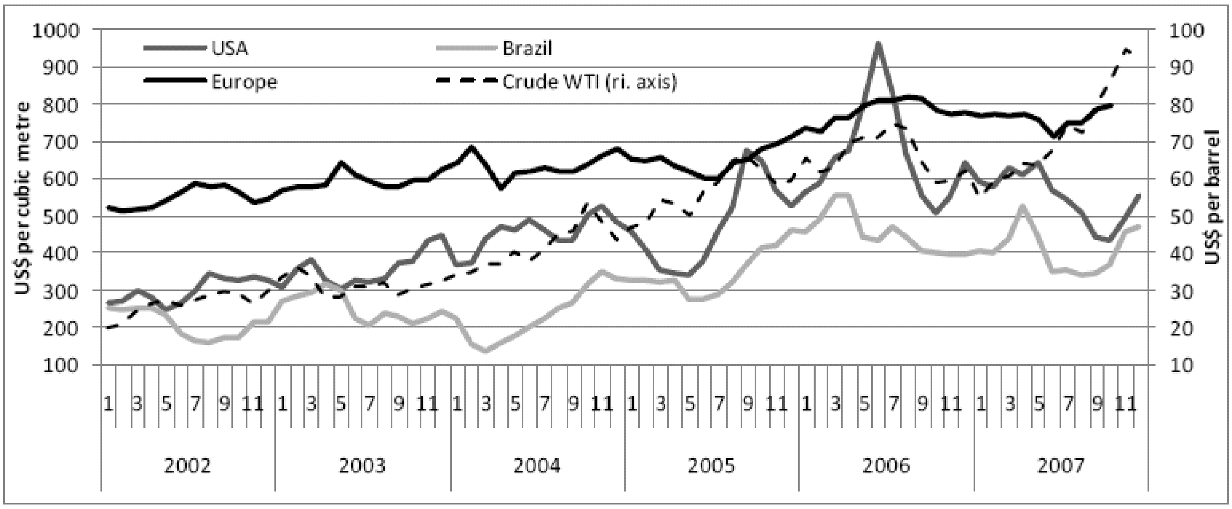

Figure 6 Fuel ethanol prices in the US, Europe and Brazil between 2002 and 2007 (Source: OECD, 2008, data based on F.O. Licht's)

An overview of the expected cost developments of various conventional and future biofuels, as derived by ECN, is shown in Figure 7. According to this study, cost of the biofuels are expected to decrease in the coming decades, where cost of conventional fuels will remain constant until 2020, and increase slowly after 2020. Costs of bioethanol 2nd generation and Fisher-Tropsch diesel are expected to reduce significantly in the coming decades, becoming cheaper than bioethanol 1st generation and biodiesel around 2020. However, despite these expected cost reductions, all biofuels are expected to remain more expensive than the conventional fossil fuels.
If these developments come true, the costs of the 2nd scenario in this study would be similar to those of the 1st scenario. Costs of HVO and biogas are not provided in the ECN study, so that no conclusions can be drawn on the cost of the 3rd scenario.

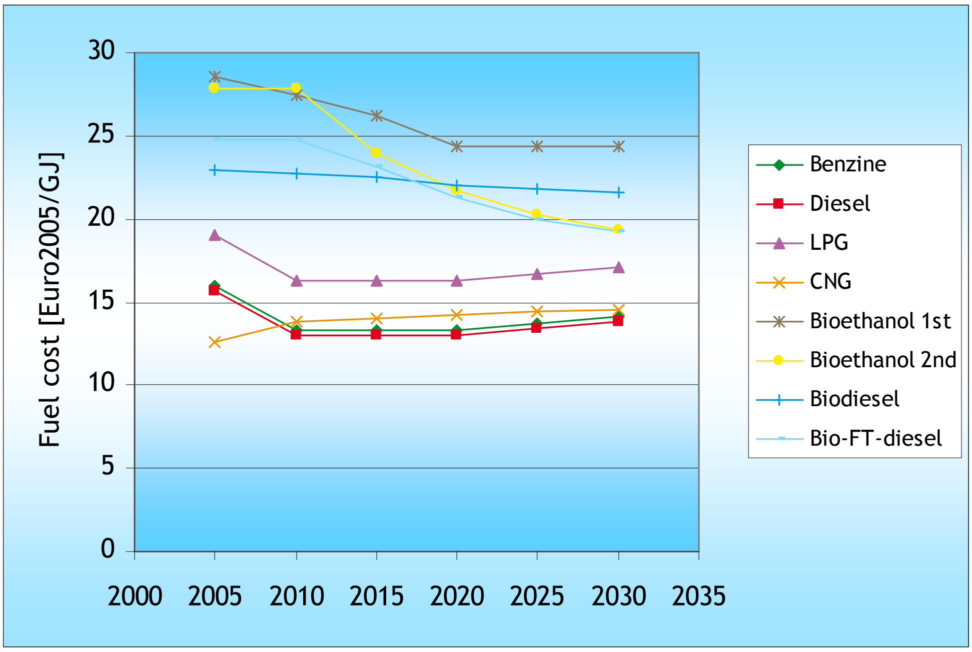

Figure 7: Cost estimates for different types of fuels and biofuels, excl. taxes, in €2005/GJ (Source: ECN2008)

[IEA, 2008] derive cost estimates for 2nd generation biofuels as shown in Figure 8. Clearly, they also expect costs to reduce significantly in the coming 2 decades, if technological development is successful.

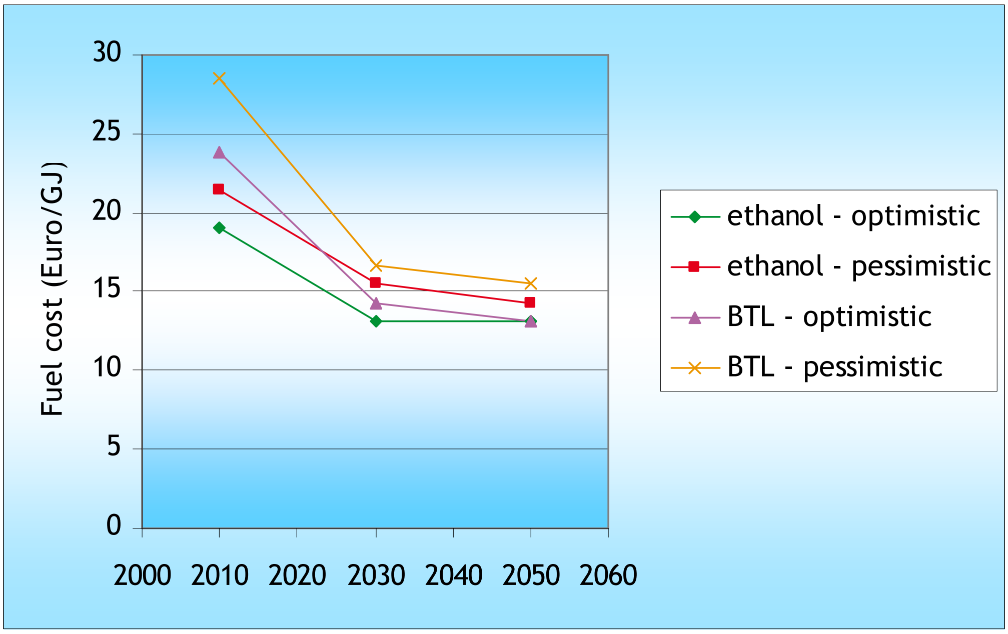

Figure 8: Cost estimates for different types of fuels and biofuels, excl. taxes, in €2005/GJ (Source: IEA, 2008. Assumption used to convert IEA results to Euros: 1 USD = 0.75 Euro.)

However, the cost development of the 2nd generation biofuels given here are still highly uncertain, as the production technology has not yet been scaled up to commercial scale.

The future cost reduction shown here assumes that these technologies will become mature in the coming decade, and production volumes increase.

An assessment of the cost structure of these biofuels also reveals differences between current and future biofuels. Current biofuels cost are determined to a large extent by feedstock costs – and the feedstock of these processes are food crops where production also needs to meet the growing demand from the food sector. [IEA, 2008], for example concludes that feedstock costs account for 55-70% of total production costs, and there are unlikely to fall sufficiently to make 1st generation biofuels more competitive. Feedstock costs of 2nd generation biofuels are expected to be lower than in case of 1st generation biofuels, as these are waste or residue streams. However, investment costs required for a commercially viable Fischer Tropsch production plant are much higher than in case of current biofuels, providing a barrier to their deployment. Also, 2nd generation biofuels require large volumes of biomass feedstock, which poses significant logistics, and supply chain challenges, and potentially increase cost significantly [IEA, 2008]. [IEA, 2008] also provides various cost estimates of 2nd generation biofuels, based on recent US and EU literature. Costs estimates are based on assumptions regarding cost of the biomass feedstock, transport logistics and conversion processes (including expectations regarding economies of scale).

Costs of biogas have been estimated using current cost data, and data from literature. In [JEC, 2007], costs of two biogas production routes were assessed: biogas from liquid manure, and from organic waste. The resulting cost range is 16.8 – 23.1 Euro/GJ. This seems to be quite high, compared to the current cost of biogas at the only public pump in the Netherlands, and other literature sources. Market data are still only very limited, as there is currently only one biogas pump operational in the Netherlands. There, biogas currently costs about 15.3 Euro/GJ (www.fuelswitch.nl, status 20 October 2009). [Mu/CE, 2008] derives cost estimates of 12.0-13.5 Euro/GJ, [CE, 2008] uses 23.0 Euro/GJ. In view of these large ranges and uncertainties of (future) biogas cost, we decided to use an average estimated cost of 19 Euro/GJ in the following calculations.

With the estimates provided above, rough cost estimates could be derived for the various biofuels that are used in the four scenarios analyzed in this report. These are shown in Table 5. As discussed above, it is assumed in scenarios 2 and 3 that costs of the 2nd generation biofuels used in these scenarios reduce, as this seems to be a prerequisite to the actual realization of these scenarios.
Combining these with the total biofuel volumes required in the various scenarios will give an estimate of the total cost of the biofuels in the scenarios, see Table 6. Note that these are the actual costs of the biofuels, i.e. not the additional costs compared to petrol and diesel

Table 5 Cost estimates of the various biofuels used in the four scenarios analysed in this report (Euro/GJ), for 2020

	Scenarios 1a and 1b	Scenario 2	Scenario 3
Bio-ethanol; single	24.4	24.4	24.4
Bio-ethanol; double	27.8	21.7	-
Bio-diesel, single	22	22	22
Bio-diesel; double	22	22	-
Fisher-Tropsch diesel	-	-	21.3
HVO diesel	22	-	22
Biogas; double	19	19	19

Table 6 Cost estimates of the scenarios analysed in this report (million Euro/year), for 2020

	Scenarios 1a and 1b	Scenario 2	Scenario 3
Bio-ethanol; single	338	0	145
Bio-ethanol; double	0	409	-
Bio-diesel, single	317	159	215
Bio-diesel; double	254	106	-
Fisher-Tropsch diesel	-	-	115
HVO diesel	70	-	238
Biogas; double	17	17	131
Total	**996**	**691**	**845**

In Table 7 an overview of addition purchase price of special vehicles used for the scenarios (compatible with biofuels or hybrid/electric). The price can go down over time if the series become larger. It should be noted that apart from this, there are often additional maintenance costs.

Table 7. Additional purchase price for special vehicles

Vehicle type	2009	Projection 2020
Passenger cars / vans		
Flexible Fuel Vehicle (E85)	300 - 2000	0 - 1000
Natural gas / biogas	2000 - 7500	2000*
Plug in hybrid	-	5000 – 6800*
Electric vehicle	15000	5000 – 6000*
Trucks		
High blend biodiesel	100 - 2000	100 - 1000

* Refer to [Hanschke 2009]

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2009

3 Emissions of vehicles with biofuels – update phase 1

In the BOLK phase 1 report [TNO/CE 2008] an extensive overview was given of the possible emissions effects of low and high blends of biofuels for both current and future engines. This lead among others to three tables for passenger car otto and diesel engines and truck diesel engines with projected emissions effects for Euro 3, 4, 5 and 6 engines. These tables are included in the industry questionnaire which is presented in Appendix A.
In summary the emissions effects were reported as follows:

- Ethanol in otto engines:
  In general a positive picture due to the good implementation of ethanol within the emissions legislation, especially for Euro 5 phase b and later (>2012). Variations are then possible but within the limits. Some concerns with the application of E10-E20 in standard (non-EEV) vehicles.
- Biodiesel in passenger car diesel engines:
  Relative strong variations in emission results. NOx and PM could both increase or decrease with a biodiesel blend, although NOx would increase more frequently and PM would decrease more frequently. Blends higher than B7 in non-adapted vehicles were not recommended anyhow due to serious engine durability concerns. HVO and BTL (XTL) are recommended and would always lead to some PM and NOx reduction.
- Biodiesel in heavy-duty diesel engines.
  Consistent NOx increase and PM decrease with conventional (Euro III) diesel engines. Risk of large NOx increase with engines with deNOx exhaust aftertreatement if no closed loop NOx control is applied. HVO and BTL (XTL) are recommended and would always lead to some PM and NOx reduction.

In this chapter and also in the chapters 4 and 5, additional literature is reviewed with the focus on emissions effects with the newest (Euro 5 and later). Both emission effects due to fuel properties as well as due to possible durability effects are addressed. For biodiesel the focus is on heavy duty engines, because the high blends will be applied to these engines (refer to fuel scenarios in chapter 2).

3.1 Biodiesel: additional literature

With a biodiesel blend durability aspects are often related to fuel quality issues. This is because a number of the impurities within the production process can result in acids or sludge formation. This can lead to fuel filter fouling, deposits formation on injector tips, sticking piston rings, etc.. An extensive description is for example given by the World Fuel Charter Committee: “biodiesel guidelines”, a common document published by manufacturers organisations world-wide [WFCC-D 2009].

The most common biodiesels are FAME: Fatty Acid Methyl Esters. They are basically produced by adding methanol and a catalyst (KOH, NAOH) to the pure plant oil. The plant oil is converted to FAME and Glycerine. The Glycerine, methanol and the catalyst then need to be removed in order to get the FAME in sufficient purity. The reactions can however also lead to certain esters or other (unstable) by products which cause engine problems if the quantities are too high. These are for example Linolenic acid methyl ester or polyunsaturated acid methyl ester.

3.1.1 USA programs on biodiesel blends

A number of projects were sponsored by the US DOE (department of energy) under the Freedom CAR and Vehicle Technologies Program (Fuels Technologies Subprogram). There was a lot of focus on B20 although also measurements were done with B5 and B100. Examples of projects are:

- effects of biodiesel blends on advanced aftertreatment systems for both passenger car and truck engines. Aftertreatment systems included diesel particulate filter (DPF), Selective Catalytic Reduction of NOx (SCR) and Lean NOx Catalyst (LNT).
- fundamental tests in a single cylinder engine
- 100,000 mile durability test with a number of transit buses.

Effect on PM emission
Biodiesel blend generally results in a shift from Elementary Carbon to Organic Carbon (HC part). For example with a Cummins ISB 2003 HD engine the engine out PM would drop by approximately 25% with B20, but after a DPF (Johnson Matthey Coated Continuously Regenerating Trap, CCRT) the PM level drops by 67%. These are average reductions during the EPA heavy-duty-FTP test. [Howell 2009]. Even more important is the positive effect on the so called "balance point temperature (BPT)". This is the temperature where the soot oxidation is in equilibrium with the soot emission of the engine. Above this temperature the DPF would regenerate the stored soot. Depending on the blend the BPT were as follows:

- ULSD: 360°C
- B20: 320°C
- B100: 250°C

This means that the soot of biodiesel regenerates at a lower temperature. Even with B5 a positive effect was already seen [Howell 2009]. Also tests with transient cycles with low and high average temperatures showed the improved regeneration characteristics of B20 compared to ULSD [Williams 2008].

Effect on NOx
Both engine out NOx as well as NOx reduction of the SCR catalyst were analysed.
In [McCormick 2007] the point is made that there is no average NOx increase with B20. In the EPA420-P-02-001, Draft Report (2002), it was concluded that B20 would lead to an average NOx increase of 2%. In this study however one particular engine was over weighted. Without this there was no average increase of NOx with B20. This is reasonably supported by the BOLK I report, which shows on the average no NOx increase with B20 for HD vehicles. For LD vehicles it showed a NOx improvement of 5-10% with B10. The phenomenon has been attributed to the lower volatility of B20 compared to regular diesel [Nagaraju 2008].
The evaluation of the SCR system performance focused on the effects of the biofuel on the NO2 to NOx ratio dependency to the biodiesel blend and the quantity of soot within the DPF. The impact of the biofuel and the DPF loading remained however uncertain [Williams 2008].

Maintenance costs
[Kenneth 2006] reports about a group of 5 transit buses on B20 which were compared to 4 buses on ULSD during a 100,000 km period. The maintenance costs on the B20 group was 40% higher (0.07 versus 0.05 $ct/mile), but this was mainly due to

replacement of injectors and cylinder head on one bus. Some inconvenience with B20 fleet was caused by fuel filter plugging leading to road calls.

3.1.2 European programs

[Bach 2009] summarised the effects of biodiesel aftertreatment operation. In a program at the Otto-van-Guericke University it was determined that with RME the loading time was 3 to 4.5 times longer than with normal diesel fuel. This was with a 1.9 l passenger car engine and a SiC DPF. It was also determined that the regeneration efficiency improved, which was demonstrated by an about 18°C lower balance point temperature. In another study [Pissavin 2008] it was determined that with a B30 fuel the loading speed of the DPF was 35% lower than with regular diesel. The regeneration efficiency was similar between the two fuels during a step-load test. The regeneration however was about 30% lower under urban driving conditions. This is about compensated by the lower soot loading speed.

[Czerwinski 2009] reports about the influence of GTL[11], RME and ROR (pure rapeseed oil) on nano particle emissions. It was concluded that these fuels have advantages with respect to CO, HC, PM and energy consumption but with a disadvantage for NOx. However these tendencies can reverse at low load conditions. With respect to PM it was concluded that RME and ROR have a higher proportion of OC (organic carbon) than regular diesel. The reduction in PM for RME and ROR at higher load is primarily due to a reduction in EC (elementary carbon). RME and ROR would move the particle size distribution spectra to smaller sizes and increase the nuclei mode due to spontaneous condensates (with ROR this was particularly high during low load and idling.

[Mayer 2005] reports about the emission effects with different blends are evaluated (B10, B15, B20, B30 and B100) with 2 engines in total and with and without a CRT DPF. It was concluded that the overall effects on emissions were small even though with RME the OC/EC changed a lot (higher relative OC with RME) and the number of larger particles as well as the black smoke is reduced. It was concluded that the DPF is still necessary. The CRT type of filter operates fine, even though the oxidation catalyst part is much more important (to oxidize the OC).

[Röj 2009] reports a NOx increase of 80% with B100 in a 412 kW Euro V engine with SCR deNOx system. This confirms the amplification risk of engine out NOx emissions as described in the phase 1 report.

[Verbeek 2009] reports a study in which standard low sulphur diesel (EN590) is compared to pure vegetable-derived fuel (PPO) and biodiesel (FAME). The latter in a series of blends: B5, B10, B20 and B100. Regulated and non-regulated emissions were measured and also biological tests were included. The pure biofuels PPO and B100 showed a fairly strong effect on NOx and PM. Both fuels showed a NOx rise of about 30% and a PM reduction in the range of 60% tot 80%. The EC/OC (Elementary Carbon / Organic Carbon) analysis showed that the particulate mass reduction was entirely due to the reduction of EC. The OC remained more or less constants. The aldehydes, which are primarily present in the gas phase, were not much affected by the biofuels. The biodiesel blends gave some reduction, up to about 25%. The volatile organic carbons

[11] Refer to list of abbreviations, Appendix A

C6-C12 showed a tendency to decrease with biodiesel (up to a factor 2 with B100). With PPO there was also some reduction. Looking at the composition, it can be concluded that the benzene part is the largest and relatively independent of the fuel. The total PAH, 16 EPA PAH and oxy-PAH showed a strong reduction with B100 and PPO. More or less proportional to the reduction of particulate mass. There was however no reduction with B10 and B20, which even showed some increase for oxy-PAH. Nitro-PAH levels showed some reduction with biofuels, but it was much lower than the particulate mass reduction. The biological tests of the extracts of the PM samples showed a mixed picture. The oxidative potential using the DTT assay showed a reduction in reagent consumption (and toxicity) of about 95% for B100 and PPO. The Ames test however, displayed a significant increase in mutagenic potential for both PPO and B100. In addition B100 caused significantly elevated levels of cytotoxicity. Looking at the change in particulate composition with biofuels: reduction of elemantary carbon (EC) and a more or less constant level of organic carbon (OC), it is not entirely clear what would happen to the particulate emission reduction when a diesel particulate filter is applied such as with HD Euro VI. The reduction could be stronger, if all or a large part of the OC is oxidised in the oxidation catalyst. On the other side, depending on the test cycle, OC could just be adsorbed in the DPF and released when there is a high temperature event (longer period of high load). It is concluded that when the PMP measuring protocol is applied, the particulate emission reduction of the DPF with biofuels is probably larger than without biofuels. For the emission factors in chapter 6, it is assumed that the particulate emission downstream of the DPF is proportional to the engine out level. This means a lower particulates emission level due to the biodiesel, also when a DPF is applied.

3.2 conclusions

In general, the conclusions of the phase 1 report [TNO/CE 2008] with respect to emissions effects are still valid.
Additional information with respect to the functioning of (advanced) aftertreatment devices leads to the following conclusions:
- One source confirms the possibility of a steep NOx rise with deNOx aftertreatment if high biodiesel blends are applied.
- The regeneration characteristics of typical continuously regenerating diesel particulate filters can improve with the use of biodiesel.
- In the phase 1 report the effect of biodiesel on particulate emissions with engines with diesel particulate filter were considered to be negligible. This is now adapted to a proportional change (reduction) with engine out particulates emission.

New information with respect to emissions with biofuels is included in the figures of section 6.2.

4 Technical Risks

Biofuels can lead to differences in exhaust emissions because of two reasons: firstly differences in fuel characteristics can lead to different combustion parameters which can change the emissions and secondly differences in fuel characteristics can lead to additional engine wear and failures which can lead to a change in emissions as well. The first point was already shown in BOLK phase 1 [TNO/CE 2008]. This is now further updated and used in the chapters 3 and 6. The second point, risks of wear and failures are discussed in this chapter.

4.1 Risks with biodiesel

In Figure 9 an overview is given of the possible emission effects of biodiesel in diesel passenger car and truck engines. This summarizes both the standard effect due to the fuel characteristics as well as the effects if a failure would occur.

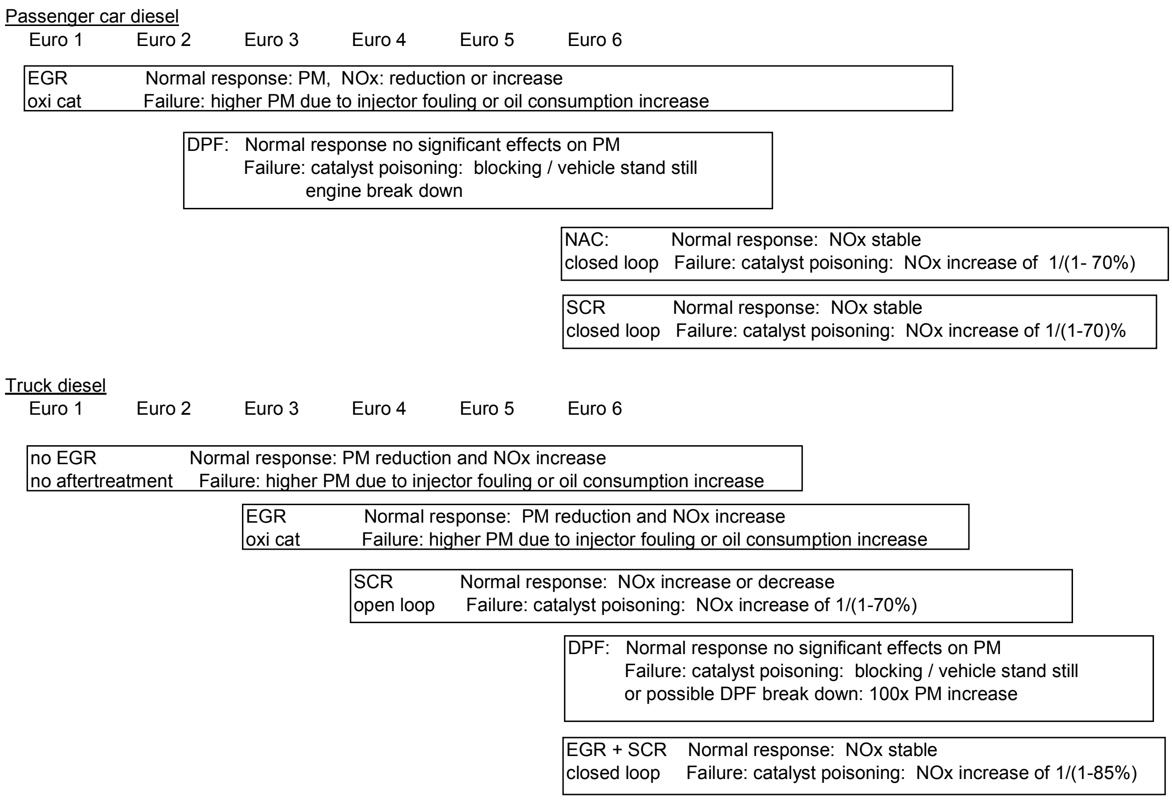

Figure 9: For different engine technologies: standard response of diesel engines to biodiesel and possible effects of failures.

In Table 8 an overview is given of the entry into force dates of the Euro classes within the emissions legislation. There is generally a time span of a year in which the new step is introduced. The begin date is for new vehicle types, while at the end of that year all vehicle types need to comply.

Table 8: Overview entry into force dates dependent on the Euro class

Euro class	Year of entry into force	
	Passenger cars	trucks
1	1993	1993
2	1997 / 1998	1997 / 1998
3	2000 / 2001	2000 / 2001
4	2005 / 2006	2005 / 2006
5	2008 / 2009	2008 / 2009
6	2014	2014

According to the vehicle manufacturers, low blends biodiesel (up to B7) can be used without any restrictions in passenger car en truck diesel engines (WWFC-D 2009). Truck manufacturers do support the use of high blends in trucks, but with some modifications and with an adapted maintenance schedule. This is also the way it is implemented in fuel scenario's (chapter 2): high blends will only be applied for trucks if needed. For that reason the evaluation of the technological risks are here focussed on high blends and truck engines.

A good overview of the issues with high blends is given by the government sponsored R&D programs in USA. A cooperation structure has been set up between government, industry and other stakeholders. Total budget is about 17 million US$, from which more than 50% ($ 9.5 million) is supported by DOE. Partners in this investigation are: National Biodiesel Board (NBB) and member companies, Cummins, Caterpillar, Manufacturers of Emission Controls Association (MECA), Engine Manufacturers Association, etc..
The focus is on the following subjects:

- B20 and B100 blends
- biodiesel ash (Na, K, Ca, Mg and P) effects on DPF, SCR and LNT durability
- effects on emissions of vehicles equipped with DPFs, SCR and LNT catalysts
- lube oil performance impacts
- long term fleet evaluation
- biodiesel fuel quality (fuel composition, cold flow properties)
- evaluation of biofuels from new sustainable sources.

Some preliminary results are presented below:

- The 2007 B100 fuel quality survey indicated that 90% of the biofuel volume meets the critical fuel quality specs (much better than earlier survey's). In 2006 30% failed to meet glycerine specification and 20% failed to meet Na + K spec.
- Accelerated aging test with B20 in a passenger car with LNT/DPF showed 20% deterioration in NOx conversion after 120.000 km. Same test with SCR system showed 30% degradation in NOx conversion efficiency, but his was allegedly caused by a thermal runaway (overheating of SCR catalyst).

Based on the USA programs and other publications, it can be concluded that the risks are associated with the fuel quality, in particular with
a) potential impurities which can lead to problems over time and
b) fuel characteristics such as oxidation stability and cold flow properties which are inferior to fossil or synthetic diesel fuel and vary strongly.

a) risks associated with impurities
The potential impurities are impurities which originate from the production process or are already present in the feedstock. Biodiesel is produced by adding methanol and a catalyst (KOH, NAOH) to the pure plant oil. Magnesium and Calcium are added as adsorbents. The plant oil is converted to FAME and Glycerine. The Glycerine, methanol and the catalyst and adsorbents then need to be removed in order to get the FAME in sufficient purity.

The consequences of the following impurities are [McCormick 2007], [WFCC-D 2009], [Bach 2009] :
- Methanol: degradation of some plastics and elastomers and corrosion of metals
- Glycerin: injector deposits, clogged fuel filters, deposits at bottom of fuel tank
- Unconverted and partly converted fat: poor cold flow properties, injector and in-cylinder deposits and risks of engine failures
- Catalyst (KOH, NAOH): Excessive injector, fuel pump, piston and piston ring wear, filter plugging and problems with lubricants.
- KOH, NaOH, Mg, Ca and Phosphorous can lead to chemical deactivation (poisoning) of oxidation catalyst, SCR catalyst and DPF. In particular it is noted that the 10 ppm phosphorous limit of B100 is much too high (<1 ppm recommended).

b)Risks associated with fuel characteristics
The molecular stucture of FAME differs from that of conventional diesel, while other biofuels like HVO and BTL have stuctures that are very similar to diesel. Therefore no failures due to fuel characteristic differences are to be expected with the use of HVO or BTL. The risk for failures associated with fuel characteristics only exists for FAME.

FAME is produced by the transesterification of a Pure Plant Oil (PPO) and is an ester, while HVO and BTL are linear alkanes like diesel. Diesel is a mixture of carbon chains of between 8 and 21 carbon atoms long. Figure 10 shows the difference between alkanes (diesel, HVO, BTL), ethers (DME), esthers (PPO, FAME), fatty acids (FAME) and alcohols (ethanol).

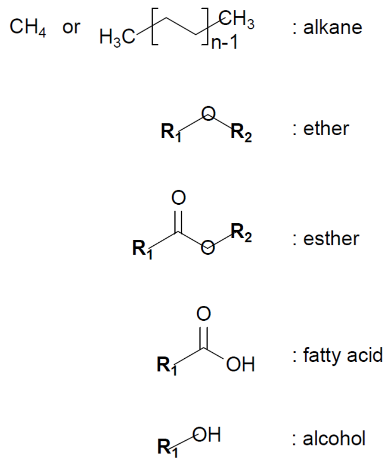

Figure 10: General overview of important biodiesel constituents (or contaminants). Ri denotes a substituent; typically an alkyl group.

Due to the differences in molecular structure, the fuel characteristics differ too. FAMEs have for instance lower stability, worse cold flow properties, a higher boiling point, a lower heating value than diesel, besides the fuel contains oxygen and is more sensitive to microbiological growth. The consequences of these biodiesel characteristics are [Röj 2009], [Verbeek 2009], [Bach 2009]:

- Lower stability: certain esters or other (unstable) by products (i,e, linolenic acid methyl ester or polyunsaturated acid methyl ester) can lead to filter plugging (no jointly agreed test method)
- Cold flow properties: some esters have inferior cold flow properties which increases the risks of filter plugging
- Higher boiling point: can lead to rising biodiesel content in engine lubricant, especially with post-injection used for DPF regeneration. This leads to lubricant and engine cleanliness degradation and possible polymer formation.
- Lower heating value: biodiesel has per kg and per litre an about 10% lower heating value. Because of this combustion characteristics change. Higher quantities of fuel for the same torque leads to a longer injection duration. Also with open loop SCR system, urea (AdBlue) for the same power output will increase. This may compensate for the often increased engine out NOx level but it may also lead to NH3 slip. [Röj 2009] however reports a NOx increase of 80% with B100 in a 412 kW Euro V engine.
- Oxygen in fuel: biodiesel has some 7 to 11 % oxygen while fossil diesel has none. Soot composition is completely different: primarily organic carbon and very little elementary carbon. This leads to completely different regenerations characteristic. Several sources report an improved regeneration with a lower regeneration temperature. This can however also lead to too high exotherm of soot oxidation with active or passive regenerations leading to failures of the DPF. Possible more sticky hydrocarbons may also lead to catalyst face plugging.
- Micro biological growth: biodiesel is much more sensitive to micro biological growth, especially with somewhat higher water content. This can lead to filter and fuel line plugging.

In order to prevent problems the maximum levels of impurities and components, and also other characteristics are extensively specified in the fuel specification (EN14214 in Europe and D6751 in USA). Nevertheless vehicle manufacturers organisation world wide recommend to maximise the biodiesel content within diesel to maximum 5% (B5).

It should be noted that most issues described above do have consequences for exhaust emissions. This is only not the case for issues like filter plugging. A number of the issues cause excessive engine wear such as fuel injection system and piston or piston rings. This does in general lead to an increase in exhaust emissions, especially for particulates.
Based on the information found, in Table 9 an overview is given of possible failures due to the use of high blends biodiesel in truck engines. The consequences of these failures are calculated in chapter 5. Together with an estimated failure rate, this is also included in the emissions calculation on a national level in chapter 6.

Table 9: Possible failures due to the use of high blend biodiesel for different heavy duty engine technologies

Euro class	Emission control technology	Possible failure
Euro III		Injector deposits
Euro IV	SCR	Injector deposits
Euro V	SCR	SCR catalyst poisoning
Euro III	EGR	Injector deposits
Euro IV	EGR	EGR valve sticking or EGR cooler fouling
Euro V	EGR	
Euro VI	EGR + SCR + DPF	Injector deposits
		DPF failure
		EGR valve sticking or EGR cooler fouling
		SCR catalyst poisoning
Euro VI	SCR + DPF	Injector deposits
		DPF failure
Euro VI	DPF only failure	SCR catalyst poisoning

4.2 Risks with BTL, HVO

Biomass to Liquid (BTL) and Hydro-treatment Vegetable Oil (HVO) consists mainly of paraffins and iso- paraffins, with no oxygen and very similar to diesel fuel. Especially BTL is very pure due to the production process. The molecules are synthesised after the biomass is partially oxidised to synthesis gas (mixture of H_2, CO, CO_2). Due to its composition, there are no additional risks compared to diesel fuel. The vehicle manufacturers generally support the use of BTL, HVO as premium biocomponent blend, which can be used to high blend percentages.

4.3 Risks with ethanol

In Figure 11 an overview is given of the possible emission effects of ethanol in gasoline engines. This summarizes both the standard effect to the fuel characteristics as well as the effects if a failure would occur.

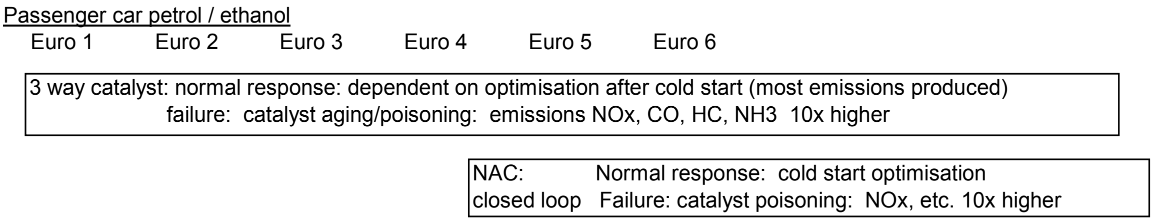

Figure 11: For different engine technologies: standard response of petrol engines to ethanol blends and possible effects of failures.

A distinction should be made between the use of low blends (< E20) in regular petrol cars and high blends (E40-E85) in flexible fuel vehicles.

The manufacturers recommend limiting the low blends to maximal E10 [WFCC-E 2009]. Above that level, there are risks with materials compatibility such as elastomer degradation and corrosion. Primary consequence would be leakage of fuel, which has an environmental and safety impact. Substantial change in exhaust emissions is not expected.

[WFCC-E 2009] consists of guidelines for the 100% anhydrous ethanol to be used as blend up to 10% for regular petrol vehicles and blend up to 85% for flexible fuel vehicles (FFV). The following risks with respect to the fuel composition are described:

- Water in the ethanol can promote corrosion and microbial growth
- Inorganic chloride is extremely corrosive and corrodes metals in vehicle fuel lines, even at low levels of contamination.
- Methanol and sulphate are corrosive as well. Metals such as copper promote oxidation of fuel and because of that cause injector deposits.
- Phosphorous and heavy metals will cause catalyst poisoning.

Because of the risks, the maximum levels of these components are specified. Several of these items can have consequences for exhaust emission, especially in case of injector deposits and catalyst poisoning.

Even though there are some risks which could influence the emissions, they are considered to be at a much lower level than for biodiesel. For that reason and also in the context of this study, influences on emissions due to failures are not taken into account in the emission factors in chapter 6.

4.4 Conclusions

Technical risks with respect to good functioning of emission control devices are primarily present with the use of high blends of biodiesel in diesel engines. No substantial technical risks are currently foreseen with blends of ethanol, HVO, BTL and also not for engines with factory installed natural gas/ biogas fuel systems.

5 Consultation of stakeholders

The consultation consisted of the following items:
- evaluation of formal documents of manufacturers organisations
- bilateral discussions with stakeholders
- obtainment of information via a questionnaire.

Publications of manufacturers' organisations
The vehicle manufacturers are organised via several manufacturers organisations: ACEA (Europe), Alliance and EMA (USA) and JAMA (Japan). In 1998 they created the Worldwide Fuel Charter (WWFC) Committee to provide a better understanding of the impact of fuel quality and to promote harmonisation. Via the WWFC, they provided fuel quality guidelines for both biodiesel and ethanol. They also emphasise that these are first editions. The guidelines will be updated as knowledge and experience with these fuels increase.

According to these guidelines the positions with respect to biodiesel and ethanol are the following:
- Biodiesel (FAME) is only recommended in blend percentages up to 5% (B5)
- For ethanol for spark ignition engines, low and high blends are distinguished. Low blends up to 10% (E10) can be used in regular vehicles while high blends for special flexible fuel vehicles (FFV) can be use op to 85% (E85).
  WWFC is positive with respect to other blendstocks for gasoline such as bio-ethers (i,e, ETBE or ethanol tertiary butyl ether and TAEE or tertiary amyl ethyl ether) and bio-alcohols (i.e. biobutanol)

Bilateral discussions with stakeholders
Some discussions took place with representatives of Dutch vehicle manufacturers. The following information is provided with respect to biodiesel in trucks:
- All biodiesel levels higher than B10 are considered a high blend. Then vehicle adaptations and shorter maintenance intervals are necessary. The adaptation varies per vehicle and include measures like increased fuel filter size and oil sump size.
- Special software is installed for deNOx aftertreatment systems.
- Additional vehicle purchase costs range from EUR 100 to EUR 2000. In addition technical support can be provided (up to about EUR 2000 per vehicle).
- Additional maintenance costs due to the use of high blends are in the range of EUR 400 – 700 per year or 0.01 EUR per km. Costs are for increased number of oil changes and fuel filter replacements.
- Low blends (< B10) are judged to have no influence.

Other stakeholders (i.e. oil companies):
- Rules/legislation should be technology neutral, chain effects should be included
- Emission requirements should be met with all biofuel blends
- Scenario 1 could include E85 in addition to or instead of B30/B100
- Scenario 3: more liquid biofuels such as BTL and HVO and less electric and biogas.

5.1 Questionnaire

A summary of the filled in questionnaires by vehicle manufacturers is given below. The questionnaire is included in Appendix A.

Ethanol (E10 – E85) in current and future Otto engines
The proposal is to use low blends E10 – E20 in standard vehicles and high blends, E40 - E85 in FFVs.

Can E10 be used in the majority of the gasoline vehicles (Euro 5 and 6) in 2020?
Yes (2x), since 1998 all types (1x)

Percentage of vehicles that will be available in a FFV version in the time frame 2015 – 2020:
- depending on the market demand (1x) and fiscal stimulation (1x)
- will remain niche (1x)
- vehicles from before 2007 can suffer engine damage in case of fuelling with higher blend than E5 (1x)

Remarks with respect to FFV (all once):
- unlikely that competitive E85 will be available in all of Europe and current tax exemption for E85 will end sooner or later
- compliance with Euro 5 of FVV is very challenging (HC limit)
- costs increase of FFV technology (probably due to changing engine technology)

Biodiesel in current and future passenger car diesel engines
It is currently planned to limit the biodiesel quantity for passenger cars to 7% FAME (B7). Mostly because of engine durability concerns due to engine lubricant degradation. Nevertheless we would like to review high blends as well.

Possibility of using the following blends:
- B7: ok: if fuel fulfils standards
  in some cases concerns with lubricant dilution and fuel filter clogging
- B30: not possible or technical problems expected (3x)
- B100: not possible or technical problems expected (3x)

Possible blends with BTL and HVO (3 manufacturers):
- BTL and HVO should fulfil EN590 or CEN workshop agreement TC WI WSO038.3:2008 (1x)
- Engine calibration must be adapted for high blends due to lower density
- Seen as advanced biofuel (1x)
- No limitation, although feedstock issue must be observed closely (1x)

Rating of concern about emissions related engine wear issues with B30 and B100 (2 manufacturer):

Engine wear issue	Please indicate concern L (low), M (medium) and H (high)	
	B30	B100
Fuel injection system wear / injector fouling	H, H	H, H
EGR system fouling, EGR valve sticking	H, H	H, H
Catalyst face plugging	M, H	M, H
(SCR) catalyst deactivation	L, H	L, H
DPF failures	H, H	H, H
Other emissions related issues ……………..		
Other failures …………………	engine oil dilution fuel filter plugging	

Biodiesel (B20-B100) in current and future HD diesel engines
Scenario 1 calls for a substantial part of vehicles on B30 or B100 (30% - 100% FAME) for HD vehicles in addition to B7 for main stream.

The following statements were made with respect to the use of high blends, B30 or B100 (all once):

- A larger share on B20-B30 vehicles is preferred over a smaller share B100 vehicles (1x). Small share of B100 vehicles is preferred (1x).
- International standardisation on high blend
- If unavoidable use fixed blend concentration in captive fleet
- From today’s view: B20 and B100 not possible for Euro VI engines (lubricant degradation and injector wear/fouling)
- One fuel specification B10 preferred for all diesel engines
- The joint fuel injection equipment manufacturers do not allow higher blends than B7
- Neither of them ! we are concerned about emission targets and implication on exhaust aftertreatment
- No experience yet with Euro VI. NOx, PM or fuel consumption penalties are possible also with closed loop control.
- Adaptations to run on B100 include gaskets, fuel heater, etc..

Rating of concern about emissions related engine wear issues with B30 and B100 (5 manufacturers):

Engine wear issue (biodiesel fulfilling EN14214)	Indicate concern L (low), M (medium) and H (high)	
	B30	B100
Fuel injection system wear / injector fouling	L, H, H, H, H	M,M, H, H, H
EGR system fouling, EGR valve sticking	L, H, H, H, H	M, M, H, H, H
Catalyst face plugging	L, M, M, H, H	M, M, H, H, H
(SCR) catalyst deactivation	L, M, M, H, H	M, H, H, H, H
DPF failures	L, M, M, H, H	M, M, H, H, H
Other emissions related issues: - OBD impact and high NOx - damage body work of truck near exhaust pipe	 M, H H	 H, H H
Other failures - Corrosion, Sticking, Lacquering - Lubricant dilution - Fuel system clogging in winter	 H H H	 H H H

Possible blend percentages with BTL and HVO (3 manufacturers):
- for BTL: 20%, 20%, 100%, 100%
- for HVO: 20%, 20%, 100%, 100%

Remarks on BTL, HVO:
- BTL and HVO should fulfil EN590 or CEN workshop agreement TC WI WSO038.3:2008
- Engine calibration must be adapted for high blends due to lower density (can be for power output or NOx control)
- Low blends of BTL/HVO preferred in the context of a relatively low production volume.
- Not more than 20% because of lack of practical experience

5.2 conclusions

The following is concluded from the manufacturers’ consultation (the number of manufacturers’ responses per vehicle type is between parenthesis).

Gasoline engines (2):
- E10 as suitable low blend for all vehicles is confirmed
- FFV availability will be dependent on market demands. There are no indications for a big leap in growth of FFVs

Diesel passenger cars (2):
- B7 is accepted, although some concerns with some engines may remain.
- Higher blends than B7 are not acceptable

BTL/ HVO:
- high blends or as neat fuel may be possible provided the specific fuel standards are met.

Diesel trucks (4):
- B7 is accepted (B10 may be generally accepted as well)

High blends in diesel trucks:
- Truck manufacturers emphasized their concerns about the application of high blends of biodiesel (B20-B100). Emissions may be higher. Technical problems may arise especially with Euro VI.
- There are many concerns with wear issues of components important for exhaust emissions (fuel injection system, catalysts, DPF, EGR system).
- NOx may go up. OBD system may be triggered.
- B20-B30 preferred over B100
- If needed than in captive fleets with fixed blend concentration.
- High concern regarding the suitability for Euro VI trucks (starting 2014)

BTL/ HVO:
- These are seen as good quality fuels superior to conventional (FAME) biodiesel
- Blends up to 20% or possibly 100% are possible provided the specific fuel standards are met (EN590 or CEN workshop agreement).
- An adaptation of the engine calibration may be necessary.

6 Emission factors for Biofuels

In this chapter the emission factors are determined for the biofuel blends used in different vehicle types according to the scenario's of chapter 2.
This is done by determining multiplying factors for biofuels for the standard emissions factors used for the CAR emissions prediction on a national level.

In the chapters 3 and 4 two types of emissions effects due to the differences in fuel characteristics of biofuels were discussed:

1. different combustion parameters (direct effect),
2. failures of emission control devices (possible effect after time)

The first item was extensively reported in chapter 5 of the phase 1 report [TNO/CE 2008]. In section 6.2 this is updated with newer data and response functions are determined.
The second item, the possible influence of failures, is only done for high blends of biodiesel in heavy-duty engines. Refer to section 6.3. For an overview of failures with consequences for emission refer to Table 9 in paragraph 4.1.
Ethanol blends in Otto engines are currently not considered to have additional failure risks. This is based in the literature evaluated and the composition of the fuel.

6.1 Calculation methodology

The emission factor for biofuels is calculated by multiplying the emission factor for conventional fuels with a multiplying factor for biofuels:

Emission $\text{Factor}_{\text{biofuel}}$	=	Emission $\text{Factor}_{\text{conventional}}$	*	Multiplying $\text{Factor}_{\text{biofuel}}$

The multiplying factor comprises of two factors that influence emissions. (1)The primary change in emissions is the standard engine response due to different fuel characteristics compared to the conventional fuel. Fuel characteristics that differ are for instance combustion value, oxygen content, viscosity, density and heat of evaporation. The is called Standard $\text{Factor}_{\text{biofuel}}$. (2)For some high blends like biodiesel in trucks, additional emissions could occur due to failure of emission control devices. The emission factor due to failures is called Failure $\text{Factor}_{\text{biofuel}}$.

Multiplying these two factors gives the Multiplying $\text{Factor}_{\text{biofuel}}$.

Multiplying $\text{Factor}_{\text{biofuel}}$	=	Standard $\text{Factor}_{\text{biofuel}}$	*	Failure $\text{Factor}_{\text{biofuel}}$

The Failure Factor depends on (1)the emission increase in case of failure and (2)the failure rate; the chance a failure occurs:

Failure $Factor_{biofuel}$	=	Emission increase in case of failure	*	Failure rate

The definitions that are employed are:
- Emission $Factor_{conventional}$: average emission rate of a given pollutant for a given source, in this case for a certain vehicle on a certain fossil fuel. The unit used for emission factors in this case is g/km.
- Multiplying $Factor_{Biofuel}$: a factor between 0 and 2 by which a conventional emission factor can be multiplied to get the biofuel emission;
- Failure rate: The chance that the failure occurs in a specific vehicle class

With respect to the scenarios, the following assumptions have been made:

- For **bulk fuels** no emission effects are to be expected due to the biofuel
  - For diesel+biodiesel and for petrol+ethanol holds that since the maximum biofuel content within the scenarios is limited to maximum respectively 7% and 10% by volume. This is relatively close to the reference fuels (max. 5 vol% biofuel content) and no significant effects are to be expected.
  - For CNG+biogas it is assumed that the biogas is upgraded to natural gas quality and that the fuel systems are factory installed. CNG and biogas are both methane (CH_4), so there is no difference between the fossil fuel and the biofuel. Upgrading to natural gas quality means a) no large share of CO and CO2, which could lead to reaching limitations within the closed loop lambda control and b) no impurities which could pollute the fuel system or poison the catalyst over time. With factory installed systems the failure rates are expected to be equal to gasoline vehicles. This would not be the case with retrofit systems.

- For **niche fuels** both a standard biofuel emission effect ánd failures can be expected.
  - For E85 no failure effect is to be expected, since it will be used in Flexible Fuel Vehicles (FFV and these are specially developed for it. There is a standard emissions effect, because the vehicles are more optimised for gasoline. This effect is expected to become less after the entering into force of the Euro 5 phase b emission legislation (2012), because then the requirements for E85 are equal to those for gasoline.
  - The use of B30 and B100 in heavy duty vehicles passenger cars, can lead to failures in combination with emission control systems. Table 9 in paragraph 4.1.
  - The fuel characteristics lead to a engine response which results in a standard $factor_{biofuel}$.
    → *Both engine response (and thus a standard $factor_{biofuel}$) and failures are to be expected with B30 and B100 in heavy duty vehicles in case 1.*
- For all applications holds that HVO and BTL blends are limited to maximum 6% blends. Moreover, HVO and BTL fuels are very similar to fossil diesel, so no significant effect is expected on emissions and no failures are expected.

Table 10 summarises which factors are needed for which fuel blends in order to calculate the emission factors.

Table 10: Overview of assumed factors that play a role for several fuel blends. The factors with a 'X' are included in the calculations.

		Emission $factor_{conventional}$	Standard $factor_{biofuel}$	Failure factor
Bulk	Petrol+ethanol (LD)	X		
	Diesel+biofuel (HD+LD)	X		
	Diesel+HVO/BTL (HD+LD)	X		
Niche	B30 (HD)	X	X	X
	B100 (HD)	X	X	X
	ED95 (HD)	X	X	
	E85 (LD)	X	X	

Section 6.2 deals with the engine response to different fuel characteristics (standard $factor_{biofuel}$). In section 6.2.1 this effect is calculated for biodiesel in HD engines and it covers both B30 and B100, section 6.2.2 focuses on ethanol. Section 6.3 deals with the failure factor for B30 and B100.

6.2 Engine response due to fuel characteristics

In BOLK phase 1 [Verbeek *et.al*. 2008] an extensive literature search has been performed. All emission data on biofuels that were found by testing that fulfilled international standards, were collected in a database. In chapter 5 of the report the data were reported in figures per pollutant emission per vehicle category. In this project a smaller literature search was performed in order to update these figures. The updated data will be shown in this chapter and have been used for the calculation of the emission factors.

6.2.1 Biodiesel with HD engines

Figure 12 shows the relative change in NOx emissions of HD engines to different biodiesel blends. Figure 6 shows the PM emission response. Both figures show a linear, zero anchored regression line. The regression lines lead to a normalized influence; this is the emission percentage if B100 is used relative to B0, with B0 normalized to 100%. The normalized influence of NOx is 112%, which means a NOx increase of 12% with the use of B100 compared to B0. R^2 measure of how well the formula predicts future outcomes. R^2=1 would result in a perfect match of all data on the regression line, which is never the case. The coefficient of determination of both NOx and PM are high enough for this purpose. For biodiesel use in heavy duty, HC and CO are less interesting than NOx and PM because they are already very low for diesel. For that reason no emission factors are calculated for CO is the coefficient of determination and provides a and HC, but for completeness, the updated figures with emission data are shown in Figure 14 and Figure 15 and the normalized influence is shown in Table 11.

Table 11: Normailzed influence and R^2, calculated by means of a regression line through the data in Figure 12-Figure 15 of Nox, PM, CO and HC for biodiesel use in heavy duty vehicles.

Biodiesel Heavy Duty		
Component	**Normalized influence**	**R^2**
NOx	112%	0,21
PM	43%	0,32
HC	46%	0,41
CO	81%	0,0009

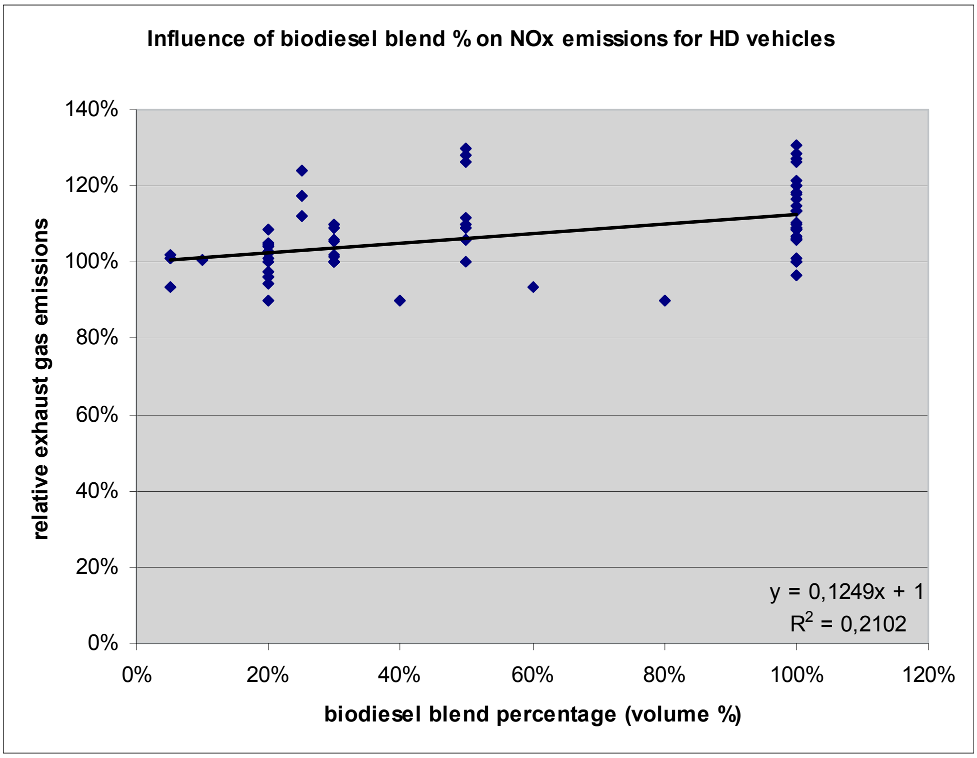

Figure 12: The influence of biodiesel blend% on NOx emissions for HD vehicles (B0=conventional diesel =100%)

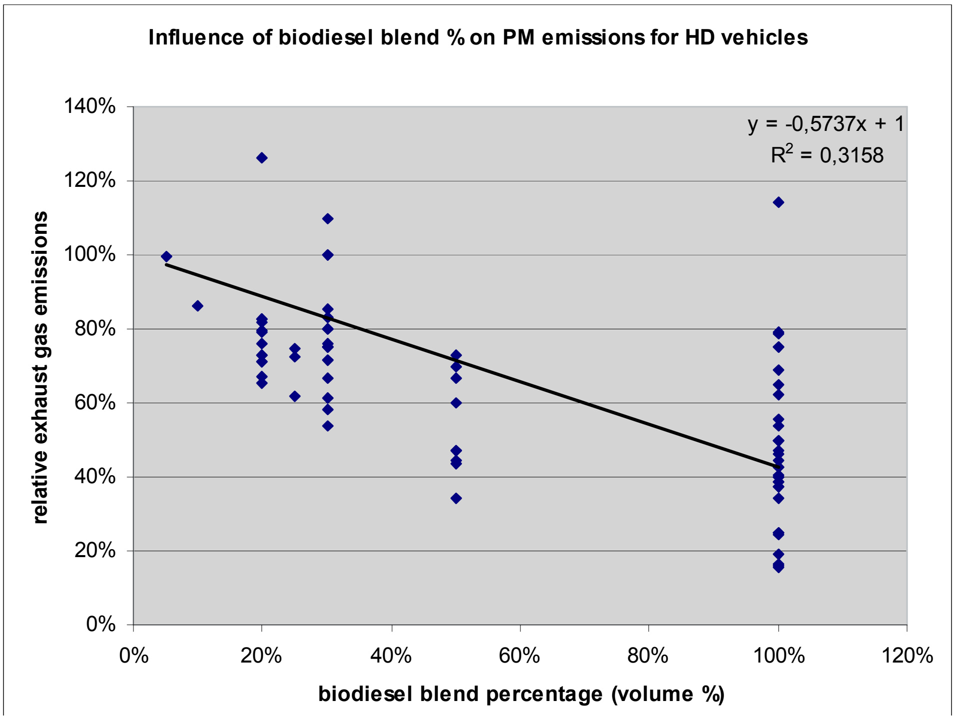

Figure 13: The influence of biodiesel blend% on PM emissions for HD vehicles (B0=conventional diesel =100%)

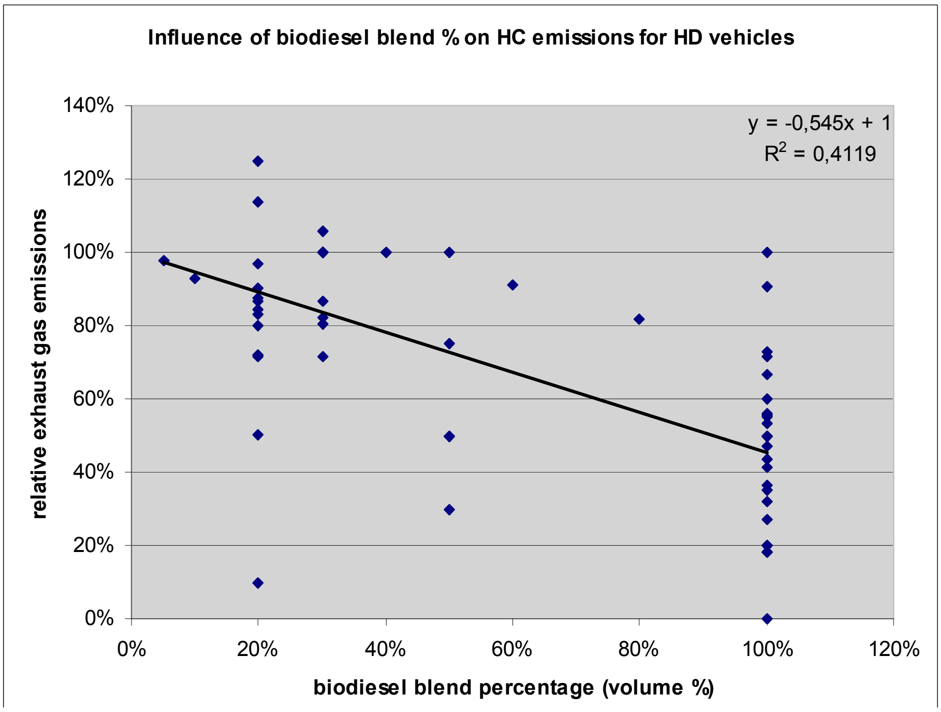

Figure 14: The influence of biodiesel blend% on HC emissions for HD vehicles (B0=conventional diesel =100%)

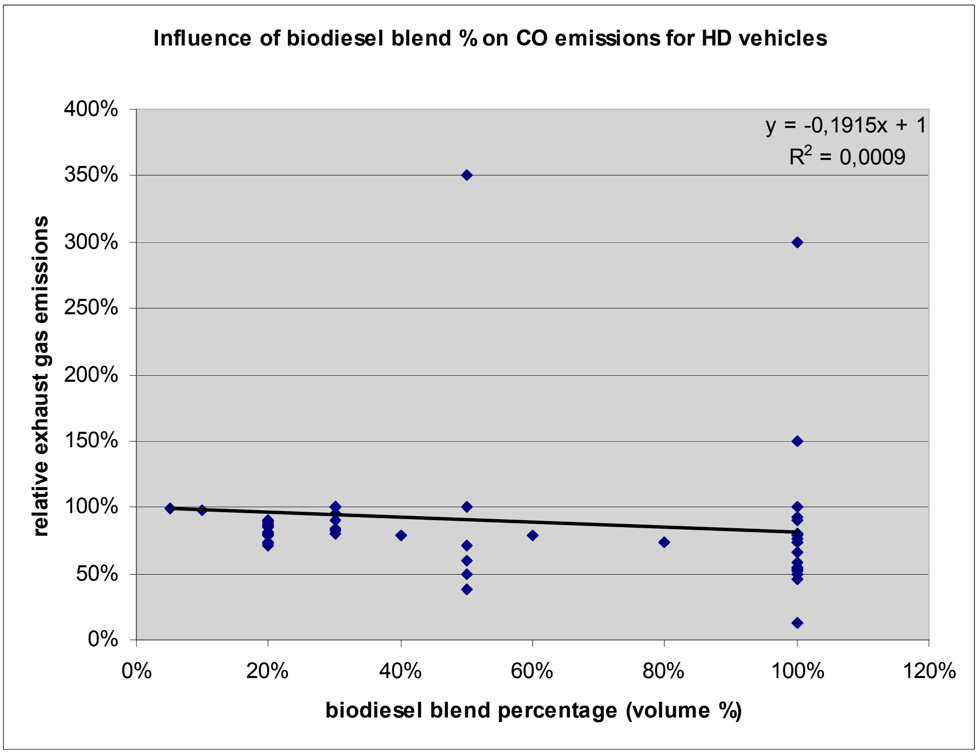

Figure 15: The influence of biodiesel blend% on CO emissions for HD vehicles (B0=conventional diesel =100%)

The experimental data is primarily based on Euro 3 engines. For Euro IV, V and VI engine technology changes a lot (refer to chapter 3). SCR catalysts, oxidation catalysts, EGR systems and diesel particulate filters are added. For particulates emissions and for NOx emissions with EGR engines, it is assumed that the newer engines have the same response as the Euro 3 engines. For engines with SCR however, there can be an relative amplification of the tailpipe NOx in relation to the engine out NOx emissions. This is when open-loop reagent (ADBlue) dosage systems are used, which dose a fixed quantity of reagent. In reality there can be a compensation of this effect due to the lower combustion value of the biofuel blend. Due to absence of thorough data this last effect is not taken into account.

In Table 12 an overview is given of technological options for different engine technologies and conversion efficiencies of emission control systems such as EGR[12], SCR and DPF systems (if applicable). The efficiencies of emission control systems can for example be derived from [Cloudt 2008], [Willems 2007], [Helden 2004], [Helden 2002], [Verbeek 2001]. Table 13 shows the response of B100 to different technology engines for NOx and PM. It is based on the regression lines of the figures above. The ‘amplification’ of the standard Factor for NOx with SCR engines is calculated with the equation: 1/(1- SCR_efficiency) and the SCR efficiencies from Table 12. The standard factors are linear proportional with the blend percentage.

[12] For an explanation on the technical abbreviations, refer to Appendix A

Table 12: Different heavy duty engine technologies with NOx conversion efficiencies for EGR and SCR systems. Abbreviations refer to Appendix A.

	Euro class	After treatment technology	Tailpipe NOx [g/kWh]	Conversion efficiency EGR	Conversion efficiency SCR
open loop	Euro III		5		
	Euro IV	SCR	3,5		0,56
	Euro V	SCR	2		0,75
	Euro III	EGR	5	0,20	
	Euro IV	EGR	3,5	0,40	
	Euro V	EGR	2	0,60	
closed loop	Euro VI	EGR + SCR + DPF	0,4	0,60	0,85
		EGR only failure	0,4	0,60	0,80
		SCR only failure	0,4	0,60	0,85
	Euro VI	SCR + DPF	0,4	0,95	
	Euro VI	DPF only failure	0,4	0,95	

Table 13: Standard Response of HD engines on biodiesel B100 for different engine technologies

	Technology	NOx limit (g/kWh)	PM limit (g/kWh)	Standard Factor$_{biofuel}$ for B100	
				NOx	PM
Euro III		5.0	0.10 / -	1.12	0.43
Euro IV	SCR	3.5	0.02 / 0.03	1.27	0.43
Euro V	SCR	2.0	0.02 / 0.03	1.48	0.43
Euro III	EGR	5.0	0.10 / -	1.12	0.43
Euro IV	EGR	3.5	0.02 / 0.03	1.12	0.43
Euro V	EGR	2.0	0.02 / 0.03	1.12	0.43
Euro VI	EGR + SCR + DPF	0.4	0.01 / 0.02	1.00	0.43
Euro VI	SCR + DPF	0.4	0.01 / 0.01	1.00	0.43

6.2.2 Ethanol

The regressing lines for the standard multiplying factors for NOx and PM for high blends of ethanol in flexible fuel vehicles (FFV).are presented in Figure 16 and Figure 17. The normalised influence and regression factor R2 are presented in Table 14.

Table 14. Normalised influence and R2 for NOx and PM for ethanol in passenger car engines, calculated by means of a regression line through the data in Figure 9 and 10 of

Ethanol		
Component	**Normalized influence**	**R^2**
NOx	128%	0,0071
PM	135%	0,0674

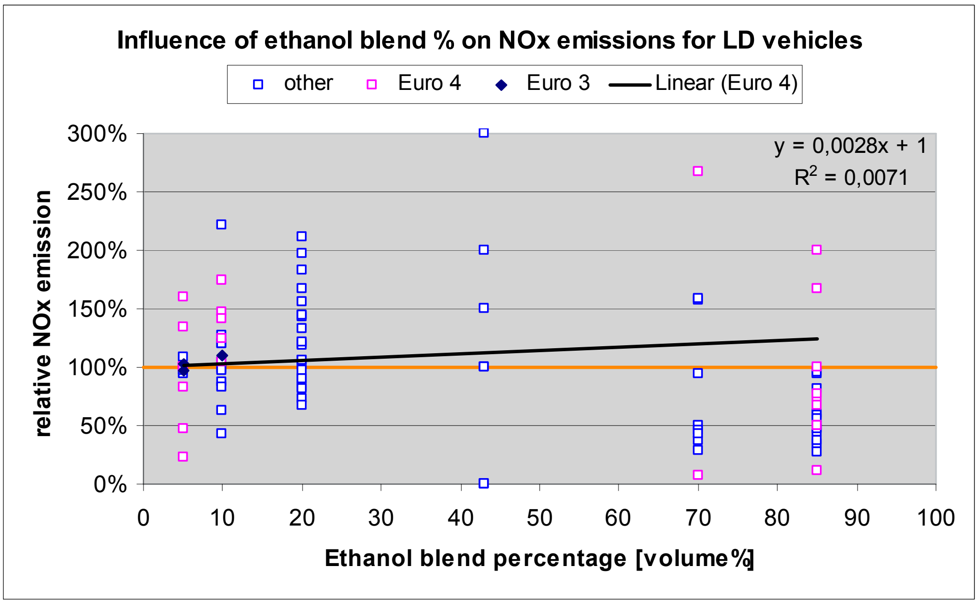

Figure 16: The influence of ethanol blend% on NOx emissions for LD vehicles (E0=conventional gasoline =100%)

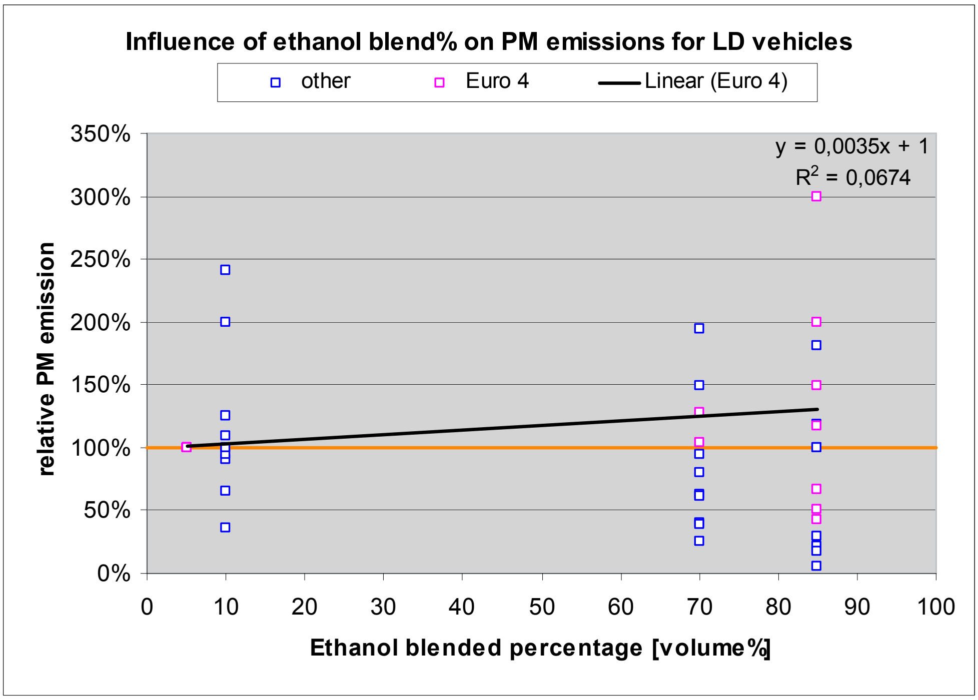

Figure 17: The influence of ethanol blend% on NOx emissions for LD vehicles (B0=conventional gasoline =100%)

The data and R^2 show that the variance is large and that the effects are not well described by the lines. A big part of the reason is that the NOx and PM levels of petrol and ethanol engines are very low (often far below the limit values). Consequently a change then immediately shows up as a large percentage variation. Basically the dataset is skewed; i.e. the distance compared to 100% at the positive side can be much bigger than at the negative side. A more advanced data analysis can be considered. These has not been done, because of the relative small influence of ethanol vehicles on the total

emissions and because of expected improvement with the type approval procedure with Euro 5 phase B entering into force (2012). Then FFVs need to fulfil the same requirements on the high ethanol blend (E85) as on petrol. The emissions are then expected to become closer to gasoline vehicles.
Consequently the regressing lines presented in Figure 16 and Figure 17 are seen as the worst case scenario. The minimum level is assumed to be equal to gasoline and the average level is taken as 50% increase of the regression line. The change according to the regression line is only used for passenger cars with high blends of ethanol (FFVs). Refer to the overview in Table 18.

6.3 Emission factors due to failures

The application of high blends of biodiesel (FAME) can lead to additional emission control system failures. A limited Failure Mode and Effect Analysis (FMEA) have been carried out to determine the quantitative influence on emissions.

Possible failures are often related to impurities within the biofuel composition and/or a not fully understanding of how biofuel can interact with the engine technology.
The most important failure types leading to exhaust emission problems are (refer to chapter 3):

- Fuel injector fouling or fuel injection system wear problems
- SCR catalyst poisoning
- EGR system fouling and EGR valve sticking
- DPF break down due to:
  - differences in thermal load with regenerations caused by differences in physical and/or chemical particulates composition
  - and/or possibly oxidation catalyst poisoning
  - and/or increased particulates emissions due to injector failure or piston-liner wear problem

Table 15 and Table 16 show the engine emission response for respectively NOx and PM with failures, for different technologies for HD engines. The response is a multiplying factor for complete failures of SCR or EGR systems. The factor is consequently directly proportional to the NOx reduction rates of these systems (refer to Table 12). For particulates, the increased PM emission due to injector deposits is assumed to be a factor of 4, but a DPF break down leads to an increase of a factor 100.

Table 15: Multiplying factors for NOx with emission control system failure for different engine technologies

	Technology / failure type	NOx limit (g/kWh)	factor with failure
Euro III	no additional emission contol	5.0	1.00
Euro IV	SCR system failure	3.5	2.27
Euro V	SCR system failure	2.0	4.00
Euro III	EGR system failure	5.0	1.25
Euro IV	EGR system failure	3.5	1.67
Euro V	EGR system failure	2.0	2.50
Euro VI	EGR + SCR + DPF		
	EGR only failure	0.4	3.40
	SCR only failure	0.4	6.67
Euro VI	SCR + DPF: SCR failure	0.4	20.0

Table 16: multiplying factors for particulates with emission control system failure for different engine technologies

	Technology / failure type	PM (g/kWh)	factor with failure
Euro III	fuel injector deposits	0.10	4.00
Euro IV	EGR / fuel injector deposits	0.02 / 0.03	4.00
Euro V	EGR / fuel injector deposits	0.02 / 0.03	4.00
Euro III	EGR / fuel injector deposits	0.10	4.00
Euro IV	SCR / fuel injector deposits	0.02 / 0.03	4.00
Euro V	SCR / fuel injector deposits	0.02 / 0.03	4.00
Euro VI	(EGR +) SCR + DPF: DPF failure	0.01	100.00

Table 17 shows the assumed failure rates for two biodiesel blends, B30 and B100 and dependent on the technology. The failure rate should be seen as the percentage of vehicles driving on that blend with a failure. The numbers are merely based on an expert view, since there is no statistical data. The numbers are seen as the upper limit. For B100 the failure rate is expected to be more than proportionally higher than for B30. For Euro VI a lower rate is assumed for failures of SCR or EGR systems. This is because it is expected that a least a portion of the failures will be detected by the On Board diagnostics system (OBD) and repaired.

Table 17: Assumed failures rates for different technologies

	Technology / failure type	Assumed failure rate	
		B30	B100
Euro III	No additional emission control	0.01	0.05
Euro IV	SCR	0.01	0.05
Euro V	SCR	0.01	0.05
Euro III	EGR	0.01	0.05
Euro IV	EGR	0.01	0.05
Euro V	EGR	0.01	0.05
Euro VI	EGR + SCR + DPF		
	EGR failure (NOx)	0.005	0.025
	SCR failure (NOx)	0.005	0.025
	DPF failure (PM)	0.01	0.05

This is the maximum failure rate that we expect. In reality, not all failures will occur to this extend. Therefore, in consultation with PBL and VROM, we decided to calculate minimum, average and maximum emission factors. Since the emission factors are very indefinite, it is good to show some of the uncertainty this way. Table 10 shows the assumptions made for the minimum, mean and maximum emission factor.

Finally, in Table 19, the multiplying factors are shown for high blends of biodiesel in HD vehicles. It shows a NOx increase and PM in- or decreases for all technology combinations with the use of B30 and B100.

Table 18: Assumptions for minimum, average and maximum emission factors

	Emission $Factor_{biofuel}$	Assumption
Ethanol	Minimum	same as gasoline
	Average	50% of response of current engines
	Maximum	response of current engines
B30+B100	Minimum	failure rate is 0
	Average	50% of assumed failure rates
	Maximum	100% of assumed failure rates

Table 19: Results TNO-BOLK-FMEA analysis: proportional change in emissions (standard and failure together)

			Minimum	Average	Maximum	Minimum	Average	Maximum
Euro-class	Technology	Blend		NOx			PM	
Euro III		30	1.03	1.03	1.03	0.87	0.89	0.90
Euro IV	SCR	30	1.06	1.07	1.07	0.87	0.89	0.90
Euro V	SCR	30	1.11	1.12	1.14	0.87	0.89	0.90
Euro III	EGR	30	1.03	1.03	1.03	0.87	0.89	0.90
Euro IV	EGR	30	1.03	1.03	1.03	0.87	0.89	0.90
Euro V	EGR	30	1.03	1.03	1.04	0.87	0.89	0.90
Euro VI	EGR + SCR + DPF	30	1.00	1.12	1.23	0.87	1.25	1.75
Euro VI	SCR + DPF	30	1.00	1.14	1.29	0.87	1.31	1.81
Euro III		100	1.12	1.12	1.12	0.43	0.51	0.58
Euro IV	SCR	100	1.27	1.30	1.34	0.43	0.51	0.58
Euro V	SCR	100	1.48	1.56	1.63	0.43	0.51	0.58
Euro III	EGR	100	1.12	1.13	1.13	0.43	0.51	0.58
Euro IV	EGR	100	1.12	1.14	1.15	0.43	0.51	0.58
Euro V	EGR	100	1.12	1.16	1.20	0.43	0.51	0.58
Euro VI	EGR + SCR + DPF	100	1.00	1.10	1.20	0.43	2.37	4.89
Euro VI	SCR + DPF	100	1.00	1.24	1.48	0.43	2.66	5.17

6.4 Emission factors other vehicles

The remaining vehicle categories used in the scenarios are the following:
- LPG passenger cars
- CNG + CBG passenger cars
- ED95 in HD diesel vehicles

According to the scenario's (chapter 1), the CNG will contain a certain percentage compressed biogas (CBG). It is assumed that the biogas is upgraded to CNG quality. Consequently the emission factor of CNG plus the CBG blend is identical to the standard emission factor for CNG. Currently, there are no formal emission factors for CNG for the CAR emissions prediction. For that reason the same factors are used as those for LPG vehicles.

ED95 is ethanol diesel which is expected to be used in a very small niche market of HD vehicles. The fuel contains about 93% ethanol with the remaining being ignition improver and water. The fuel is used in specially developed engines which generally comply with the EEV emissions level (Euro V with somewhat reduced PM level). For this exercise the emission factors are assumed to be the same as for standard diesel vehicles.

7 Calculation emission effects on a national level

In this chapter, the previously calculated emission factors (see chapter 6) are used to calculate the emission effects on a national level caused by the introduction of biofuels in a number of pre-defined fuel mix scenarios. A worst case (max), best case (min) and average outcome is calculated for every scenario. First, the methodology used will be described. After this, the end results of the calculations for national emissions of air pollutants are presented.

7.1 Calculation methodology

7.1.1 Calculation methodology: methodology overview

In the preceding chapter, the emission factors of the relevant engine technology / fuel combinations and vehicle categories were calculated. These emission factors were calculated in gram per mega joule consumed fuel. To get from these factors to the total emissions in kTon/year on a national level, a number of calculation steps were made. For every engine technology / fuel combination, the applicable emission factor was multiplied by the energy consumption for the relevant vehicle category in the scenario under consideration. The outcome of this multiplication is the total emission in grams (represented in kTon) for that particular engine technology /fuel combination in the scenario under consideration. The following picture shows this methodology.

Emission factor g/MJ	X	Energy consumption MJ/year	=	Total emissions g/year (kTon/year)

Figure 18 method for calculating total emissions per engine technology / scenario combination

When these calculations are made for all engine technology / fuel combinations in one scenario, the total emissions are summed to give the vehicle category total annual emissions in kTon/year.

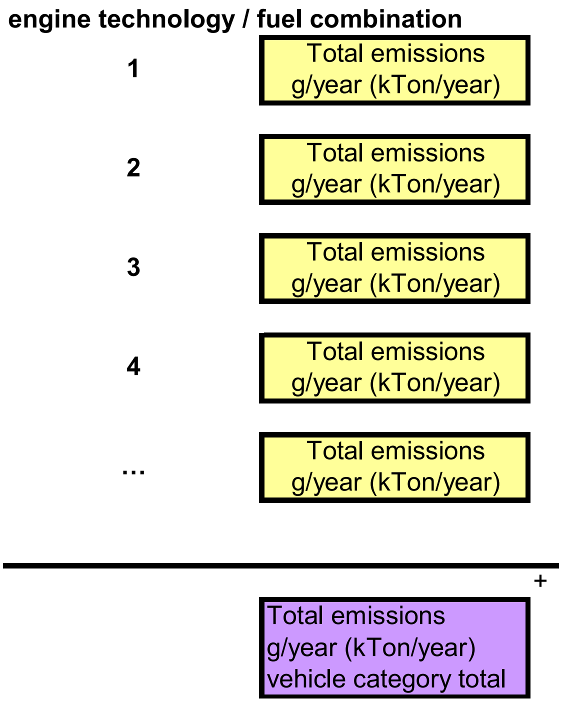

Figure 19: Method for calculating scenario total emissions per year

The preceding calculations were made for three different vehicle classes:

1) HD vehicles
2) Vans
3) Passenger cars

These vehicle classes were separated since the fuel mix for these classes are different in the proposed scenarios. Vans and HD vehicles, for instance, are mostly run on diesel whereas passenger cars are for a much larger percentage powered by petrol.

The final step in the calculation was to add the scenario totals for the different vehicle classes together to get the scenario total annual emissions.

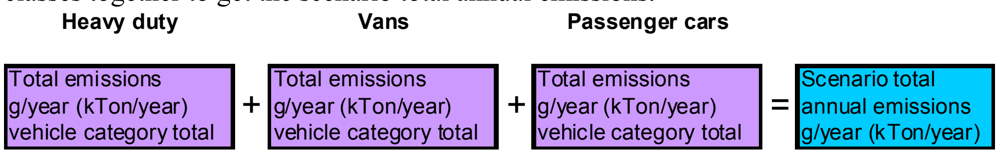

Figure 20: Summation of the vehicle category totals to the scenario totals

The final results of the calculations are included in paragraph 6.2

7.1.2 Calculation methodology: fuel mix scenarios and energy consumption correction

Three fuel mix scenarios were defined for 2020, refer to chapter 2:

1. *Business as usual: focus on single counting biodiesel and ethanol.*
   Bulk fuels are B7 and E10 with a substantial share of B30 (scenario 1a) or B100 (scenario 1b) for heavy-duty vehicles.

2. *Ambitious 2nd generation: focus on double counting ethanol and biodiesel.* 3.6% market share of E85 for passenger cars and biodiesel only in low blend (<B5)
3. *Focus on air quality.* Primarily biogas for passenger cars and bulk diesel with low blend HVO, BTL and biodiesel. Largest share of plug in hybrids and electric (4.2% by energy)

The three different scenario's have a varying composition in types of vehicles such as diesel vehicles, petrol vehicles and electric vehicles. Between these types of vehicles the powertrain efficiencies vary. For example a diesel car has lower fuel energy consumption than a petrol car and an electric vehicle has higher fuel (electric) energy consumption than petrol and diesel engines. The emission factors for this study are in gram per MJ fuel energy. In order to determine the energy consumption per vehicle category, the powertrain efficiencies presented in Table 20 have been used.

Table 20 relative energy consumption per fuel group

Fuel group	Relative energy consumption
Diesel (including biodiesel blends and straight biodiesel)	100%
Petrol (including ethanol blends, LPG, CNG and biogas)	115%
Electricity	50%

For the plug-in Hybrid vehicles, the relative energy consumption was calculated using the energy consumption of electric vehicles and the energy consumption of the "backup" fuel as a base. As an example, a plug in petrol hybrid that travels 75% of its kilometres on electricity has a relative energy consumption of:

0,75*50+0,25*115=66,25%.

As a consequence of the different fuel energy consumption of the different powertrain technologies with passenger cars and vans, the total fuel energy consumption will vary depending on the scenario. The total energy consumption for passenger cars (excluding vans) is presented in Table 21.

Table 21 energy consumption for passenger cars depending on scenario

scenario	Relative passenger cars energy consumption (%)	Additional energy consumption (PJ/year)
Baseline	100%	0
1a, 1b	99.6%	- 1.30
2	100.2%	0.62
3	102.0%	6.47

As a reference, the baseline fuel mix is included in the next table.

Table 22 baseline fuel consumption, all vehicle categories

Baseline fuel consumption in 2020		
Vehicle category	*Fuel consumed (PJ/year)*	*Vehicle description*
HD	137	Heavy duty vehicles
MAB[13]	9	Medium weight bus
LBAD	82	Light diesel van
LPAD	124	Diesel passenger car
LPAB	192	Petrol passenger car
LPAL	9	LPG passenger car
LBAB	0.5	Light petrol van
total	**553.5**	

This data was used to calculate the baseline total emissions on a national level. The assumption made is that 100% of the fuel is consumed by conventional vehicles (not plug-in hybrids or electric vehicles, for instance) and that 100% of this fuel is of fossil origin.

7.2 National level results and discussion

The emissions of the three scenarios are compared to a baseline scenario according to the in 2009 updated UR-GE reference projection of Daniels and Van der Maas[Daniels 2009]. The baseline scenario is a scenario without any emission effects of biofuel blends and also with no natural gas/biogas vehicles, no plug-in hybrids and no electric vehicles. It is very close to scenario 1 but without any high blends. The baseline emissions in kiloton per year are presented in Table 23 and Figure 21. It should be noted that the baseline PM level does include particulates emissions from wear of brakes and tires. This does account for 90% to 100% of the PM emissions depending on the vehicle type (100% for electric vehicles).

Table 23: Emissions of the baseline scenario

		vehicle category		
		trucks	passenger car	trucks
		emissions (kTon/year)		
Baseline	NOx	31.6	13.8	31.6
Total	PM	1.8	3.8	1.8

[13] Although busses are quoted separately in the baseline fuel consumption table, they are added to the HD fleet for all other calculations. The total HD baseline fuel consumption is thus 136PJ/year.

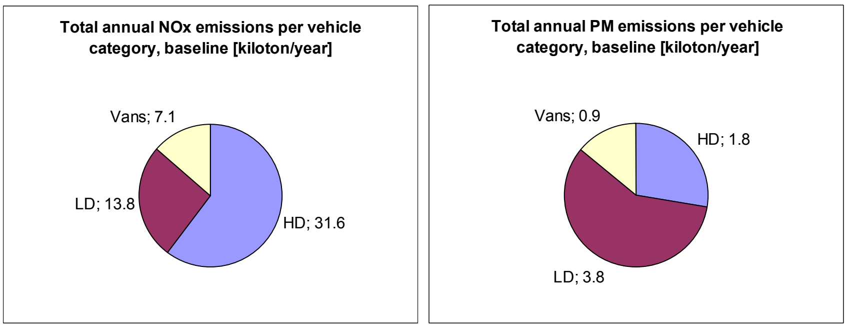

Figure 21 NOx and PM contributions to the baseline scenario per vehicle category for 2020

The results of the calculations of the emissions effect on a national level are presented in Table 24.

Table 24 Resulting emissions on a national level from the three scenarios compared to the baseline. Average projection.

		vehicle category				
		HD	LD	Vans	Scenario difference	
		additional emissions (kTon/year)			kTon/year	%
scenario 1a	NOx	0.24	- 0.25	- 0.08	-0.08	- 0.1%
	PM	0.00	- 0.01	0.00	-0.01	- 0.2%
scenario 1b	NOx	0.32	- 0.25	- 0.08	0.00	0.0%
	PM	0.00	- 0.01	0.00	-0.01	- 0.2%
scenario 2	NOx	0.00	- 0.19	- 0.11	-0.31	- 0.6%
	PM	0.00	- 0.01	0.00	-0.01	- 0.1%
scenario 3	NOx	0.00	- 0.88	- 0.24	-1.12	- 2.1%
	PM	0.00	- 0.03	0.00	-0.03	- 0.5%

The table shows (in the columns underneath “additional emissions (kTon/year)”) the additional emissions of NOx and PM emitted on a national level per year. The two rightmost columns can be used to compare the scenarios totals (HD + LD + Vans) to the baseline (Table 23) and show the absolute and relative emission differences. This is for the average emission factors. For the specification of minimum (best), average and maximum (worst case), refer to Table 18)

According to the table, the differences with the baseline are very small and if there is a difference, it is an improvement. All differences are smaller than 1%, except for a NOx reduction of 2.1% with scenario 3. Scenario 1 and 2 show very little impact on NOx and PM emissions. Scenario 3 shows apart from the NOx reduction a PM reduction of 0.5%. This reduction is caused by the passenger cars (LD) and van categories. In scenario 3, the amount of natural gas and plug-in technology used for these vehicle groups is increased, and the amount of diesel used is roughly 5% lower to correct for this. This shift away from diesel-cycle engines to Otto-cycle engines and electric propulsion is the main reason for the emission reductions. Thus, if scenario 3 had included an increased petrol and plug-in share instead of an increased natural gas and plug-in share, there would also have been a significant reduction in the total NOx emissions.

The NOx decrease in scenario 3 comes at the price of higher energy consumption though. The additional energy consumed by the LD vehicles in scenario 3 is about 7 PJ or some 1,3% of the total energy consumption of the combined vehicle classes.

A graphical response of the changes in NOx and PM emission is shown in

Figure 22 and

Figure 23. These graphs include the minimum, maximum and average levels (refer to Table 18) of the scenarios. Tables containing all data for the minimum and maximum impact can be found Appendix C.
The figure shows a small decrease of NOx for most situations.
Scenario 1 has a significant share of trucks with high blends of biodiesel. This should reduce PM substantial and increase NOx somewhat. The variation is caused by the variation in additional failure risks of emission control systems with the use of high biofuel blends in trucks. The PM is indeed reduced; however also NOx is reduces somewhat in most cases. This is probably caused by slight differences in the vehicle fleet composition between the baseline and biofuel scenarios. Together with the calculation method, fuel energy based emissions factors, this can cause small differences.

The variation in scenario 2 is caused by the possible variation in emissions with FFVs. This scenario has a 3.6% market share of E85 and no biodiesel in high blend. Even though the emissions of FFVs are at best the same as with petrol vehicles, the figures show a small reduction in NOx and PM. This is caused by a small shift from diesel to otto passenger cars and vans. In scenario 3, the shift from diesel to otto is a lot larger, because 5.6% of the energy for passenger cars is delivered by natural gas at the expense of the diesel share (3.5% for vans). Together with the (plug-in) electric vehicles this results in a reduction for both NOx and PM with respectively 2.1% and 0.5%.

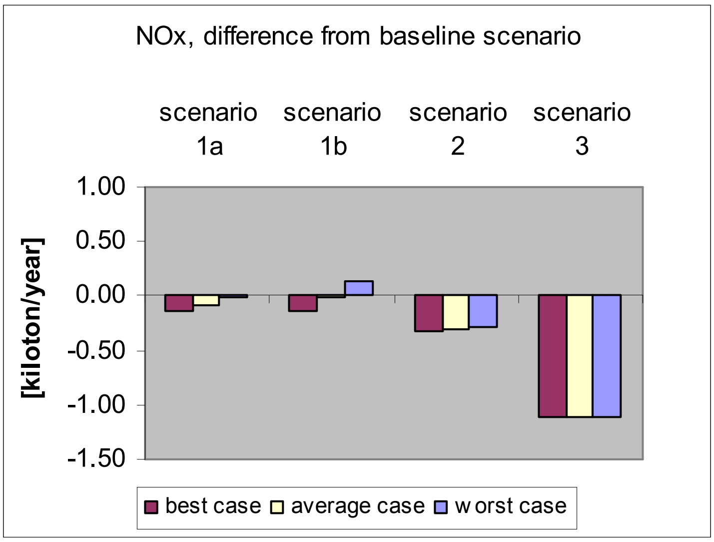

Figure 22. Differences in NOx emissions from the baseline.

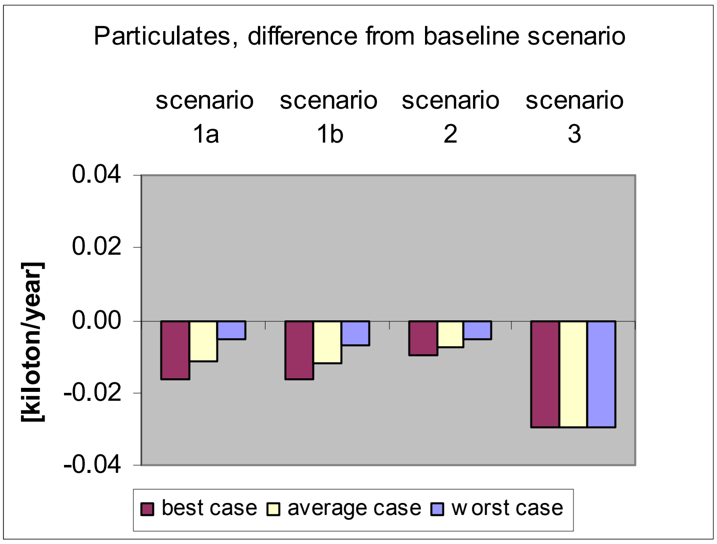

Figure 23. Differences in PM emissions from the baseline.

7.3 Conclusions

The following is concluded with respect to the emissions of NOx and particulates on a national level with the three biofuels scenarios for 2020:

- The changes are very small, within a few percents, with all scenarios.
- Compared to the baseline, NOx is generally reduced somewhat in a range from 0 to about 2%.
- The changes in PM emissions are very small due to the relative small influence of engine out particulates within the total PM emissions (tire and brake wear particulates accounts for more than 90%).
- Scenario 1 shows some improvement in PM emissions (-0.2%), primarily due to the use of biodiesel in high blends for trucks. This can easily be lost though when failure levels of emissions control systems due to the use of biodiesel are higher than expected.
- Scenario 3 shows the lowest emissions as expected (- 2.1% for NOx and - 0.5% for PM) due to the substantial share of natural gas vehicles and (plug-in) electric vehicles.

It should be noted that this is under assumptions of certain maximum failures rates of emission control systems due to high blends of biodiesel in HD engines. Changes in failure rates will have a substantial impact. So it is recommended to monitor these failure rates and take appropriate measures if necessary.

8 Recommendations to reduce risks of biofuels

Based on the information collected and also on the BOLK phase 1 report, it can be concluded that risks of emission increase are present with all types vehicles running on low or high blends of biofuel. Low blends can also contain impurities which lead to problems with emission control systems over time.
The risks are expected to be the largest with the application of high blends of biodiesel for truck engines (high blends are not recommended at all for passenger car diesel engines).
With respect to the diesel engines the risks are twofold: 1) the emission control system for Euro V and VI engines can respond inadequate to high blends of biodiesel and 2) possible impurities in biofuels (which is than generally outside the specification) can lead to problems like injector fouling and catalyst poisoning. This leads to emissions increase over time, especially if injector fouling would lead to a diesel particulate filter failure.
For Euro VI the legal requirements are much higher than earlier types of engines. This applies to both the limit values as well as the test procedures. The test procedures will for the first time include a cold start, considerable OBD requirements and in-service emission requirements. This puts already for a standard B7 fuel a high burden on the vehicle manufacturers. Taking into account the short development time for Euro VI from now, it is probably not realistic that the compatibility with high blends of biodiesel can be developed to the same standards as with standard diesel fuel. Because of this, Scenario 1 with its high share of high blends of biodiesel, is not recommended. It is recommended though to increase the biocomponent share above B7 or B10 with high quality biocomponents such as BTL and HVO.

For engines running on biogas and/or a mixture of natural gas and biogas, the risks are also twofold: 1) if retrofit systems are used, the quality of the systems is not guaranteed under the current type approval systematic and b) biogas can contain a large quantity of inert or low calorific gas or impurities which can lead to a not proper function of the emission control system (if biogas is directly used in the engines without sufficient upgrading and purification).

In order to reduce the risks with high blends of biodiesel the following measures can be taken:
- Provide guidelines for truck fleets with high blends of biodiesel for trucks with advanced emission control (EGR, SCR, diesel particulate filters). The guidelines would for example include the selection of trucks which are properly prepared for high blends of biodiesel. This means some vehicle modification such as increased fuel and/or oil filter size and dedicated software for the emission control devices.
- Stimulate and monitor fleets with trucks on high blends of biodiesel, including emission control system performance, failure rates and durability.
- Monitor the quality of biodiesel (blends) extensively.

For vehicles running on natural gas and/or biogas the risks can be reduced by:
- Purchasing vehicles with factory installed fuel systems. For vehicles with retrofit systems, it is advised to improve the type approval system. This applies also to vehicles with LPG systems.
- Stimulation and monitoring of fleets with cars on biogas (or a mixture of natural gas and biogas), including emission control system performance, failure rates and

durability. This can also include heavy-duty vehicles running on biogas such as LNG/LBG (liquefied natural gas or biogas), even though this is currently not included in the fuels scenarios.
- Only using biogas which is upgraded to natural gas quality.
- Monitoring of the biogas quality.

For vehicles running on ethanol blends, the risks are generally lower because high blend ethanol has been implementing in the type approval procedure quite well. For the low blends, E5 has been implemented and the manufacturers have committed themselves already to levels up to E10. It is recommended to monitor the ethanol blend quality (both low and high blends) and to monitor long term engine durability aspects.

The risks can also be reduced via stimulation of the optimal fuel mix (which in all cases should contain the 10% biocomponents by energy). Especially stimulation of double counting biofuels, because this reduces or eliminates the need for high blends of biofuels. Double counting (in the context of the EU biofuels directive 2009/28/EC) means that only half the quantity is needed. This is the case if the feedstock does not compete with food or is a waste product. The biofuels: biodiesel (FAME), HVO (Hydrotreatment Vegetable Oil) and ethanol can all count single or double depending on the feedstock. BTL will generally count double.

It is recommended to be prepared for several scenarios in parallel, since the costs of being prepared and issuing the right guidelines are low compared to the costs of having to repair or replace a large number of vehicles with emissions control system problems. The guidelines could for example include the selection of the proper vehicles and/or demanding the right quality fuel.

Finally some other recommendations are:
- Carry out costs-benefit calculations for all biofuels, both single and double counting options. Additional fuel costs should be compared with the additional vehicle costs (to extend that high blends are needed).
- Particulates from tire and brake wear dominate the particulates emissions. It is recommended to investigate the possible differences between the vehicle types, such influence of weight and driveline type (hybrid / electric).

9 Conclusions and recommendations

Three fuel mix scenarios were defined in order to meet the European target of 10% biocomponent content by energy for the year 2020. Consequently the effects on emissions were studied for different types and technology vehicles (Euro 3 thru Euro 6) that will be present in the future Dutch car and truck park. This included the effects due to the fuel and combustion characteristics of biofuels and for trucks running on high biodiesel blends also the effects of possible failures. finally, the effects of biofuels on a national emissions of air pollutants were calculated.

9.1 Conclusions

With respect to predictions on a national level the conclusions are as follows:
- Only in scenario 1 a large market share of high blend biodiesel (8% to 33%) is needed for trucks in order to meet the 10% bio-energy target in 2020. Special incentives and/or regulations are probably needed to cover for additional vehicle, maintenance and fuel costs and to control possible risks of emissions increase.
- Scenario 2 has the lowest impact on the vehicle fleet, because with the ‘double count’ from second generation feedstock, the amount of biofuel is the lowest. Moreover the additional vehicle and maintenance costs for FFVs (scenario 2) are probably lower than for high blend biodiesel in trucks (scenario 1) or CNG/biogas in passenger cars (scenario 3).
- All three scenarios show relative small effects on the NOx and particulates emissions on a national level. In all cases, it is less than respectively about 2% and about 0.5% difference with the baseline emissions (no biofuels) in 2020.
- With respect to particulates, with the introduction of the DPF the relative influence of biofuels is small due to the dominating effect of wear particles from tires and brakes.
- Scenario 1 shows some improvement in PM emissions (-0.2%), primarily due to the use of biodiesel in high blends for trucks. This can easily be lost though when failure levels of emissions control systems due to the use of biodiesel are higher than expected.
- Scenario 3 shows the lowest emissions as expected (- 2.1% for NOx and - 0.5% for PM) due to the substantial share of natural gas vehicles and (plug-in) electric vehicles.

With respect to engine technology, the conclusions are:
- In general, the conclusions of the phase 1 TNO/CE BOLK report are confirmed by the new findings.
- High blends of biodiesel are not recommended, because of uncertain durability and performance aspects of the advanced emission control systems of Euro VI trucks when using high blends of biodiesel.
- Fuel quality issues are often seen as the source of problems and not all possible issues are fully understood.
- Even though effects on emission are estimated to be small. They can become substantial if failure rates appear to be higher than assumed for this study.

9.2 Recommendations

It is recommended to focus on and consequently be prepared for several scenarios in parallel. This means:

- Stimulate double counting biofuels, because it reduces or eliminates the need for high blends of biofuels in adapted vehicles[14].
- Stimulate and monitor fleets with trucks on high blends of biodiesel and with passenger cars on biogas (or a mixture of natural gas and biogas), including emission control system performance, failure rates and durability. Focus on Euro V and Euro VI trucks.
- Provide guidelines for truck fleets with high blends of biodiesel for trucks with advanced emission control (EGR, SCR, diesel particulate filters).
- Monitor the quality of fuels with biofuel blend extensively. This includes all fuels (biodiesel, ethanol and biogas) and both low and high blends.
- Carry out costs-benefit calculations for all biofuels, both single and double counting options. Additional fuel costs should be compared with the additional vehicle costs (to extend that high blends are needed).
- Particulates from tire and brake wear dominate the particulates emissions after the introduction of the DPF. It is recommended to investigate:
    - the possible differences between the vehicle types (such influence of weight and driveline type hybrid / electric),
    - reduction measures (more durable tyres, closed brake systems, etc),
    - health aspects of this type of particulate matter.

[14] Note that this may mean that these biofuels are likely to contribute less to the 6% CO_2 emission reduction target set in the Fuel Quality Direcitve.

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Signature

Delft, 28 december 2009

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A Abbreviations

B# mixture of #% biodiesel (FAME) in (1-#)% diesel
B100 100% biodiesel (FAME)
BTL biomass-to-liquid
CBG compressed biogas
CI compression ignition
CNG compressed natural gas
CO carbon monoxide
CO_2 carbon dioxide
CRT continuously regenerating trap
DPF diesel particulate filter
E# mixture of #% ethanol in (1-#)% petrol
E85 mixture of 85% ethanol and 15% petrol
EC European Commission
EGR exhaust gas recirculation
FAME fatty acid methyl ester
FFV flexible fuel(led) vehicle
FT Fischer-Tropsch
GRPE UN-ECE working party on pollution and energy
GTL gas-to-liquid, FT diesel from natural gas
HC hydocarbons
HD heavy duty
HVO hydro-treatment vegetable oil
IEA International Energy Agency
ISO International Organisation for Standardisation
LD light duty
LHV lower heating value
LNC lean NOx catalyst
LPG liquefied petroleum gas
MON motor octane number
MVEG Motor Vehicles Emissions Group
NGV natural gas vehicles
NMHC non-methane hydrocarbons
NOx nitrogen oxides (NO, NO_2)
OBD on-board diagnostics
PM particulate matter
PPO pure plant oil (also VPO)
RME rapeseed methyl ester
RON research octane number
RVP Reid vapour pressure
SAE Society of Automotive Engineers
SCR selective catalytic reduction
SI spark ignition
SME soybean methyl ester
THC total hydrocarbons
UVOME used vegetable oil methyl ester
VPO virgin plant oil (also PPO)
X-TL diesel made from natural gas (GTL), coal (CTL) or biomass (BTL)

B Electric vehicles in the scenarios

In all three scenarios, we assume that both electric cars (EV) and plug in hybrid vehicles (PHEV) will be developed and obtain a share of the transport market in the next decade. However, in view of the current uncertainties about the number of EVs and PHEVs that will enter the market between now and 2020/2030, it is difficult to provide realistic estimates for the future market shares of these vehicle technologies. We have therefore used two rather crude uptake scenarios in this study, based on own estimates of what might potentially be slow and fast uptake scenarios.

In the first two scenarios we assume a slow to moderate introduction of EVs and PHEVs, roughly based on the “business as usual” and high-range scenarios developed in (Cenex, 2008) for the UK, and are also used in (CE, 2009). The resulting number of EVs and PHEVs in the Netherlands can be found in Table B.1.

Table B.1 Number of electric and hybrid vehicles in three electrification scenarios

	2010		**2015**		**2020**	
	EV	PHEV	EV	PHEV	EV	PHEV
Slow uptake scenario	0	0	5.000	20.000	16.000	50.000
Fast uptake scenario	0	0	10.000	40.000	160.000	500.000

All three scenarios use the following assumptions:

- Both electric cars (EV) and plug in hybrid vehicles (PHEV) will be developed and obtain a share of the transport market, in the passenger car and light duty segments.
- The availability of electric vehicles does not influence the total distance (vehicle kilometres) travelled
- In both the slow and fast uptake scenarios, the average kilometres driven per year by EVs is 0.8x that of gasoline cars.
- The average kilometres driven by PHEVs on gasoline is assumed to be equal to that of conventional gasoline cars, and PHEVs on diesel have equal annual mileage to that of conventional diesel cars.
- Electric cars are assumed to consume 0.72 MJ/km (based on data in [CE, 2008]), the PHEVs are assumed to be 20% more efficient than their conventional counter parts.
- Both PHEVs using petrol and diesel will be developed. PHEVs on petrol will run on electricity for 80% of their total mileage while PHEVs on diesel will be mainly used for long distance travel and will only use electricity for 50% of their mileage.

C Questionnaire automotive industry

Use of biofuels in current and future vehicles

October, 2009

TNO and CE are currently evaluating the possible impacts of biofuels on the exhaust emissions in the year 2020. This is part of a larger project carried out for the Dutch ministry of the Environment and Spatial planning to determine the effects of climate policies on emissions of air pollutants in the Netherlands:
http://www.pbl.nl/en/publications/2008/Effects-of-Climate-Policies-on-Emissions-of-Air-Pollutants-in-the-Netherlands.html.
In 2008 TNO and CE prepared a first phase report titled: “Impact of biofuels in air pollutant emissions from road vehicles”. This is attached and can also be downloaded from:
http://www.tno.nl/content.cfm?context=markten&content=publicatie&laag1=196&laag2=1&item_id=372

The objectives of the (current) phase 2 study are the following:
- To review the main conclusions and recommendations of the phase 1 report with the industry and stakeholders.
- To estimate the emissions effects on a national level based on three scenarios.
- To do recommendations in order to minimize the risks of negative emissions effects

The three scenarios contain variations like 1) primarily first generation biofuels, 2) increased share of second generation, 3) focus on air quality with an increased share of vehicles on gaseous fuels and electric vehicles.

This questionnaire refers to the first objective: review with industry and stakeholders.

The questions are split in several parts related to:
1. passenger cars using E10 to E85 blends
2. biofuel for passenger car diesel engines
3. biofuel for heavy-duty diesel engines

You are requested to answer the questions below as much as possible.

Ethanol (E10 – E85) in current and future Otto engines
The proposal is to use low blends E10 – E20 in standard vehicles and high blends, E40 - E85 in FFVs.

Do you expect that E10 can be used in the majority of your vehicles (Euro 5 and 6) in 2020?
…………

Can you indicate the percentage of vehicles that will be available in a FFV version in the time frame 2015 – 2020?
…………

Remarks
………………………………………………………………………………………………
………………..……………………………………………………………………………

Biodiesel in current and future passenger car diesel engines
It is currently planned to limit the biodiesel quantity for passenger cars to 7% FAME (B7). Mostly because of engine durability concerns due to engine lubricant degradation. Nevertheless we would like to review high blends as well.

Do you expect technical problems with the following blends in your vehicles?
B7 …………
B30 …………
B100 …………

The car industry has put forward BTL and HVO (hydro treatment vegetable oil, such as NexBTL) as the superior biofuel, very suitable to meet the total biofuel % target above B5 or B7. Are there any recommendations on the max blend% and can it also be used as a neat fuel:
- for BTL: ………….
- for HVO: ………….

A number of potential engine wear or maintenance issues have been reported by various sources. The issues are generally related to impurities of the biodiesel or to its characteristics. How would you rate your concern about emissions related engine wear issues with B30 and B100?

Engine wear issue	Please indicate concern L (low), M (medium) and H (high)	
	B30	B100
Fuel injection system wear / injector fouling		
EGR system fouling, EGR valve sticking		
Catalyst face plugging		
(SCR) catalyst deactivation		
DPF failures		
Other emissions related issues ……………..		
Other failures …………………		

Remarks
…………………………………………………………………………………………………
……………………………………………………………………………………..……

Biodiesel (B20-B100) in current and future HD diesel engines
Scenario 1 calls for a substantial part of vehicles on B30 or B100 (30% - 100% FAME) for HD vehicle, in addition to B for main stream.

If higher blends (B20 to B100) are unavoidable in order to meet 10% biofuels criteria in 2020. Would you prefer a smaller share of vehicles on B100 or a larger share on B20-B30?

A number of potential engine wear or maintenance issues have been reported by various sources. The issues are generally related to impurities of the biodiesel or to its characteristics. How would you rate your concern about emissions related engine wear issues with B30 and B100?

Engine wear issue	Please indicate concern L (low), M (medium) and H (high)	
	B30	B100
Fuel injection system wear / injector fouling		
EGR system fouling, EGR valve sticking		
Catalyst face plugging		
(SCR) catalyst deactivation		
DPF failures		
Other emissions related issues ……………..		
Other failures …………………		

The car industry has put forward BTL and HVO (hydro treatment vegetable oil, such as NexBTL) as the superior biocomponent, very suitable to meet the total biofuel % target above B5 or B7. Are there any recommendations on the max blend% and can it also be used as a neat fuel (100% HVO or BTL):

- for BTL: ……………
- for HVO: ……………

Remarks
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

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D Emissions on a national level

maximum or best		vehicle category			Scenario difference	
		HD	LD	Vans		
		additional emissions (kTon/year)			kTon/year	%
scenario 1a	NOx	0,30	-0,25	-0,08	-0,02	0,0%
	PM	0,01	-0,01	0,00	-0,01	-0,1%
scenario 1b	NOx	0,46	-0,25	-0,08	0,13	0,3%
	PM	0,00	-0,01	0,00	-0,01	-0,1%
scenario 2	NOx	0,00	-0,18	-0,11	-0,29	-0,6%
	PM	0,00	-0,01	0,00	-0,01	-0,1%
scenario 3	NOx	0,00	-0,88	-0,24	-1,12	-2,1%
	PM	0,00	-0,03	0,00	-0,03	-0,5%
Baseline	NOx	31,62	13,8	7,1		
Total	PM	1,80	3,8	0,9		

average		vehicle category			Scenario difference	
		HD	LD	Vans		
		additional emissions (kTon/year)			kTon/year	%
scenario 1a	NOx	0,24	-0,25	-0,08	-0,08	-0,1%
	PM	0,00	-0,01	0,00	-0,01	-0,2%
scenario 1b	NOx	0,32	-0,25	-0,08	0,00	0,0%
	PM	0,00	-0,01	0,00	-0,01	-0,2%
scenario 2	NOx	0,00	-0,19	-0,11	-0,31	-0,6%
	PM	0,00	-0,01	0,00	-0,01	-0,1%
scenario 3	NOx	0,00	-0,88	-0,24	-1,12	-2,1%
	PM	0,00	-0,03	0,00	-0,03	-0,5%
Baseline	NOx	31,62	13,8	7,1		
Total	PM	1,80	3,8	0,9		

minimum or worst case		vehicle category			Scenario difference	
		HD	LD	Vans		
		additional emissions (kTon/year)			kTon/year	%
scenario 1a	NOx	0,19	-0,25	-0,08	-0,13	-0,3%
	PM	-0,01	-0,01	0,00	-0,02	-0,3%
scenario 1b	NOx	0,18	-0,25	-0,08	-0,14	-0,3%
	PM	0,00	-0,01	0,00	-0,02	-0,3%
scenario 2	NOx	0,00	-0,20	-0,11	-0,32	-0,6%
	PM	0,00	-0,01	0,00	-0,01	-0,1%
scenario 3	NOx	0,00	-0,88	-0,24	-1,12	-2,1%
	PM	0,00	-0,03	0,00	-0,03	-0,5%
Baseline	NOx	31,62	13,8	7,1		
Total	PM	1,80	3,8	0,9		