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

www.tno.nl

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

TNO report

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Assessment of pollutant emissions with Shell GTL fuel as a drop in fuel for medium and heavy-duty vehicles, inland shipping and non-road machines

Date	16 September 2014
Author(s)	Ruud Verbeek
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Summary

Alternative fuels are getting substantial attention during the last few years, especially as a way to reduce the pollutant emissions of vehicles, ships and machines. Especially communities show interest in the use of alternative fuels and electric transport in order to improve the air quality for people working with and around diesel engines.

In this context Shell asked TNO to review available information with respect to the potential advantages of Shell GTL ("Gas-to-Liquids") fuel as a drop in fuel for existing and for new commercial diesel vehicles, inland ships and non-road mobile machinery.

The following technical information was available and reviewed for this study:
- Information of earlier TNO publications
- External technical publications .
- Technical reports with test results with GTL fuel.

Based on these evaluations, the following is concluded with respect to Shell GTL fuel as replacement for regular diesel fuel (EN590):

- GTL shows a reduction in all regulated pollutant emissions NOx, PM, CO and HC. Test results showed variations between test programs, as can be expected due to differences between engines.
- For relative simple systems such as Euro III engines, measurements showed NOx reductions in the range of 5% to 19% and PM reductions in the range of 10 – 34%.
- For engines with more advanced emission control systems, the relative variations in NOx and PM can be larger. For Euro V SCR engines, measurements showed NOx reductions in the range of 5% to 37% and PM reductions up to 33%, depending on engine type and test cycle. The relative large variations are due to the low level and the fact, that emission control systems such as AdBlue dosage can respond differently to GTL depending on the precise system design. No information has been presented for Euro VI engines.
- For the relative conventional ship engines, measurements showed NOx reductions in the range of 8% to 13% and PM reductions in the range of 15% – 60%.
- Very limited information was available for non-road mobile machinery. However, based on the positive experimental results of GTL on a broad range of engines in combination with the characteristics of GTL and the resulting positive effect on combustion, it is very likely that similar emission reductions are applicable as for HD engines.

It can be concluded that pollutant emissions of existing fleets can be reduced significantly by the application of GTL. The reduction is instantaneous and can be seen as an alternative to replacement by newer or cleaner vehicles, ships or machines or it can serve as a complementary measure. In absolute sense, the emission reductions are the largest when GTL is used for relative higher polluting engines such as used in older vehicles or used in ships or mobile machinery.

Contents

1 Introduction

Alternative fuels are getting substantial attention during the last few years, especially as a way to reduce the pollutant emissions of vehicles, ships and machines. Especially communities show interest in the use of alternative fuels and electric transport in order to improve the air quality for people working with and around diesel engines.

TNO participated in several studies in the Netherlands during the past few years in which GTL was included as one of the fuel options:
- Natural gas in transport: evaluation of all transport modalities
- Factsheets ‘brandstoffen voor het wegvervoer’ (fuels for road transport)
- Factsheets ‘rondvaart Amsterdam’ (canal cruise ships)

Shell has the opinion that GTL fuel is a good option to reduce the pollutant emissions of a wide variety of engines of existing and new vehicles, ships and machines. In order to provide independent information to its clients, Shell asked TNO to review existing and new technical information and to summarize the effects of GTL in a report addressing three market areas:
- Commercial transport
- Inland ships
- Non-road mobile machinery

The following technical information was reviewed for this study:
- Information of earlier TNO publications, in particular:
    - Natural gas in transport: an assessment of different routes. [TNO/ECN/CE Delft 2013].
    - Impact of biofuels on air pollutant emissions from road vehicles [TNO/CE 2009], [TNO/CE 2008].
- Technical publications provided by Shell such as SAE publications,
- Technical reports with test results with GTL. These were mostly carried out by independent parties.

In section 2 of this report general information of GTL is provided and an overview is given of the results of earlier studies with GTL. The sections 3, 4 and 5 contain the specific information regarding heavy-duty vehicles, inland ships and non-road mobile machinery. This is followed by some general conclusion in section 6.

The evaluations in this report are focused on the influence of GTL on emissions when GTL is used as a drop in fuel[1].

[1] An engine can also be specially optimized for a GTL type of fuel. In that case certain additional advantages could be achieved such as a lower fuel and/or AdBlue consumption and possibly larger emission benefits. These benefits might not occur simultaneously though.

2 Effect of GTL on combustion and emissions

2.1 Shell GTL specification

GTL is a paraffinic diesel fuel. In 2012 a special Technical Specification for paraffinic diesel fuels was completed. This is TS 15940 which followed the earlier CEN Workshop Agreement CWA 15940 (2009). TS 15940 is recently updated to a prEN 15940 specification which was the last step in the process to come to an ‘EN’ specification. CEN prEN 15940 applies to a range of paraffinic fossil as well as renewable fuels such as GTL, CTL (Coal to Liquid), BTL (Biomass To Liquid) and HVO (Hydrotreated Vegetable Oil).

Table 1: Typical properties of EN590 diesel (0% FAME) and GTL fuel. Source [Kind 2010]

Property	Units	EN 590 Diesel	GTL Fuel
Density (15 ºC)	kg/m3	830	775*
Viscosity (40 ºC)	mm2 /s	2.9	2.45
Cetane Number	CFR	56	> 70
IBP	ºC	170	200
FBP	ºC	360	310
Sulfur	mg/kg	< 10	0
Hydrogen content	%w	13.6	14.7
Carbon content	%w	86.3	85.2
Calorific value	MJ/kg	42.9	44.0
	MJ/l	35.6	34.1
FAME content	%	0	0

* Typical average of current production is 778 kg/m3

2.2 Effect of GTL on combustion

Shell GTL fuel is a Fischer Tropsch diesel and classified as a ‘paraffinic diesel fuel’. Another paraffinic diesel fuel is for example HVO (Hydrotreated Vegetable Oil). Based on quite a number of publications, the paraffinic diesel fuels seem to have a similar effect on the combustion of the diesel engine. They all have a high cetane number which shortens the ‘ignition delay’ of the combustion. As a consequence the combustion starts earlier and more gradual within the period of fuel injection. The more gradual combustion usually leads to better mixing, more homogeneous combustion and consequently lower NOx and PM emissions and a reduction in engine noise [Kitano 2005].

2.3 Results from earlier studies

In 2008 and 2009, a large number of publication regarding GTL and Fischer Tropsch fuels were reviewed for the Dutch ‘BOLK’ projects [TNO/CE 2009], [TNO/CE 2008]. The results of these analysis is presented in the Figures 1 and 2 below for respectively heavy-duty and light-duty (passenger car) engines. These were all relative conventional engines up to Euro V. Figure 1 and 2 show in general that the application of GTL results in reductions of all regulated components: NOx,

Particulates (PM), CO and HC.
For PM and CO, the reduction is generally in the range of 0 to 40%, and for NOx and HC, the reduction is generally in the range of 0 to 20%.

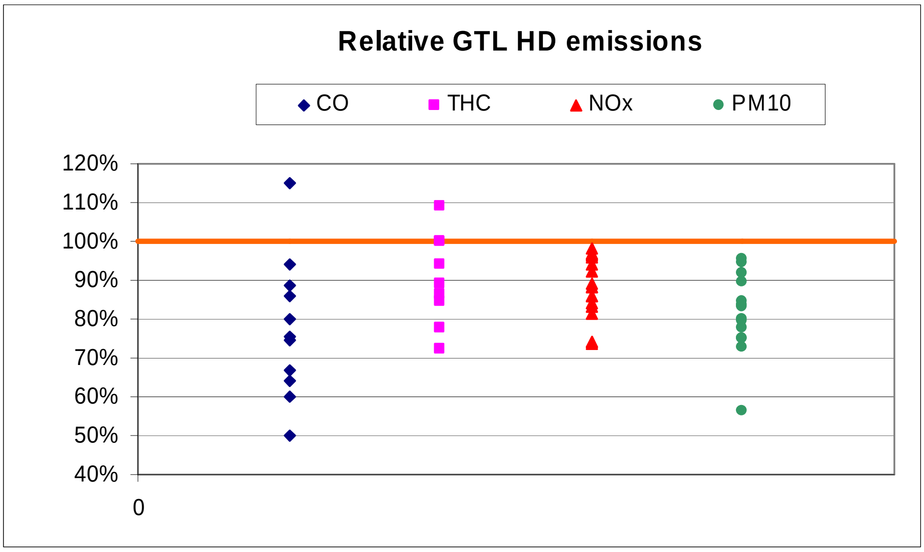

Figure 1: Exhaust emissions from HD engines on GTL [Alleman 2003], [Clark 2005], [Krahl 2005], [Thompson 2004], Source [TNO/CE 2008].

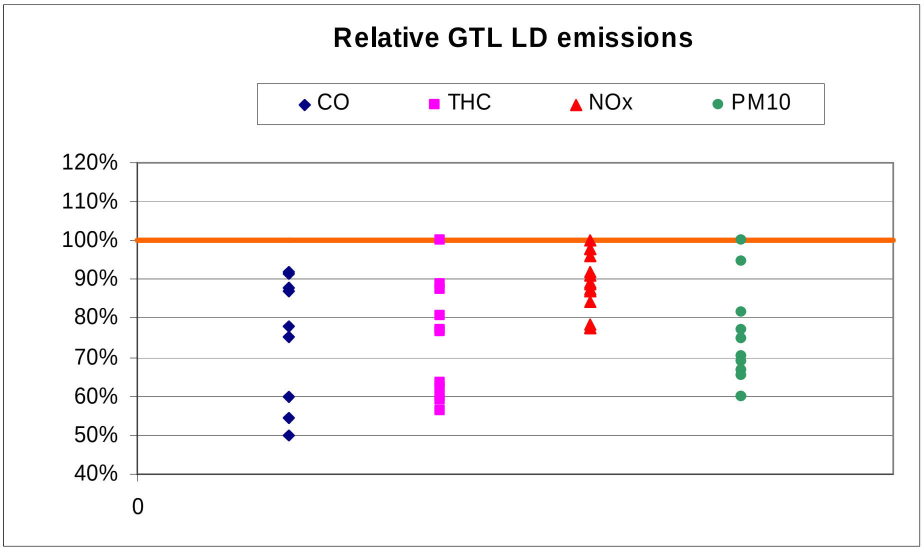

Figure 2: Exhaust emissions from LD vehicles on GTL [Alleman 2003], [Kitano 2007], [Schaberg 2005]. Source [TNO/CE 2008].

Later, partly using the same publications, a number of references were evaluated in order to get insight in emissions response to GTL with different advanced emission control technologies such as EGR and SCR (with AdBlue injection). The results are presented in table 2 below. Refer to Alleman 2003, Krahl 2005, Thompson 2004, Clark 2005a, Clark 2005b, Clark 2001. Refer to Table 2.
From a theoretical point of view, differences between EGR (internal engine / combustion measure) and SCR (aftertreatment measure) can be expected. With SCR you would expect a certain amplification of the engine out NOx change due to

the aftertreatment, if the SCR engines have relatively simple control of the AdBlue injection (generally the case for Euro IV and V). Table 2 shows indeed a relatively large NOx reduction of 19% on average with SCR engines.
With EURO IV EGR engines, a similar response on NOx is seen as with Euro III and earlier engines. With the engines, the PM reduction is quite large, namely 29% on average for the evaluated engines (2 engines).

Table 2: Average emission reductions with GTL compared to diesel with different engine technologies; Euro III and earlier, Euro IV with EGR and Euro V with SCR.

Average emissions*	CO	HC	NOx	PM10
Euro III and older	14%	23%	11%	21%
Euro IV EGR	19%	15%	12%	29%
Euro V SCR	25%	n/a	17%	23%

* Refer to table 5, section 3.3, for ranges in emission reduction.

2.4 GTL effect with ship engines

Measurement results with Shell GTL fuel on two ships were made available [SGS 2013, 2014], equipped with the same engine type. These measurements were partially done with two NOx calibrations, typically for respectively CCRI and CCRII engines.
These measurements showed the following emission reductions of GTL in comparison to EN590:
- NOx : in the range of 8% to 13%
- PM: in the range of 15% to 60%

For a full description, refer to section 4.3.

2.5 GTL with advanced emission control systems

In [Liebig 2009], the influence of GTL and BTL on the regeneration performance of a passenger car diesel engine was extensively investigated. This included the loading of the DPF, the intervals between regeneration and the achieved temperature levels. It was concluded that for the Volkswagen particulate filter system, the interval period between regenerations could be extended by 70%, probably due to the lower soot load over time. The temperature during regeneration were very similar for standard diesel and for GTL. Increasing the interval between regenerations has a positive influence on fuel consumption and potentially (or likely) a positive influence on engine maintenance costs. The latter since regenerations pose a relatively high thermal load to the engine and can lead to engine oil deterioration. The positive influence on diesel particulate filter regeneration could especially be important for mobile machinery with engines complying with Stage IIIB emissions legislation (refer to section 5). For Stage IIIB engines diesel particulate filters are generally applied. Mobile machinery operation is characterized by large variations in average load with also extended periods of low load operation. Under these circumstances more frequent DPF regenerations are necessary which can probably be reduced by the application of GTL. Specific test data to further support this, is desired.

Several heavy-duty vehicle manufacturers are formally supporting the use of GTL in their engines. One of the large worldwide fuel injection system suppliers extensively tested Fischer Tropsch (GTL) in their fuel injection system and concluded that: the results obtained indicate that the performance of F-T fuel is at least comparable to conventional hydrocarbon fuels and superior in a number of areas [Delphi 2010].

3 Emissions of Medium and Heavy-Duty vehicles

3.1 Emissions legislation

An overview of the European medium and heavy-duty vehicles emissions legislation is presented in Table 3 below. Heavy-duty engines are used in trucks and buses with a Gross Vehicular Mass above 3.5 tonnes. Euro VI is currently applicable for all new vehicles entering into the market.

Table 3: Overview European emission limits for heavy-duty CI truck and bus engines (GVM > 3,500 kg)

Date	Test cycle	Unit	CO	NMHC	NO_x	PM	PN (#/kWh)
Euro-IV-2005	ESC	g/kWh	1.5	0.46	3.5	0.02	
	ETC	g/kWh	4.0	0.55	3.5	0.03	
Euro-V-2008	ESC	g/kWh	1.5	0.46	2.0	0.02	
	ETC	g/kWh	4.0	0.55	2.0	0.03	
Euro-VI–2013[1)]	WHSC	mg/kWh	1500	-	400	10	$8x10^{11}$
	WHTC	mg/kWh	4000	160	460	10	$6x10^{11}$

1) Formal date is 31-12-2012 for new type approvals. 1 year later for all entries.

3.2 Emission control technologies

In Table 4 an overview is given of the emission control technologies used on heavy-duty vehicles. For each of the three Euro classes shown, two main technology options are used.

Selective Catalytic Reduction of NOx with AdBlue injection upstream of the catalyst, is used quite dominantly for the emissions classes Euro IV, Euro V and Euro VI. Exhaust Gas Recirculation (EGR) is used for a smaller proportion of the Euro IV and Euro V vehicles as is shown in the table. For most of the Euro VI solutions, these technologies are used together for NOx reduction, while also a wall flow particulates filter is installed.

Table 4: Emission Control technologies used for heavy-duty vehicles

Emission class	Emission control technology options	Estimated market share
Euro IV	SCR	75%
	EGR + oxy catalyst or diesel particulates filter	25%
Euro V	SCR	95%
	EGR + oxy catalyst or diesel particulates filter	5%
Euro VI	EGR + SCR + DPF	90%
	SCR + DPF	10%

SCR = Selective Catalytic Reduction of NOx. EFR = Exhaust Gas Recirculation. DPF is Diesel Particulate Filter.

3.3 Effects of GTL on emissions

An overview of the influence of Shell GTL fuel on pollutant emissions is shown in table 5 below. This is done for the Euro classes Euro III, IV and V. The percentage reduction compared to standard diesel is shown. For both NOx and PM emissions two columns are given. The first column shows the direct engine test bed results, while the second column gives a calculated projection for modelled (real) driving in the Netherlands. Consequently this does not reflect all driving conditions. The calculation is based on the average engine out emissions reduction in combination with the estimated NOx reduction of the SCR catalyst. The engine test results are generally measured during the type approval tests. These tests are characterised by the rather high load pattern (higher than during average driving). Never the less, the projected real driving results are quite similar to the engine test bed results.

Table 5: NOx and PM emission reduction with GTL compared to standard diesel. Range with test cell measurements is shown and projection for Dutch driving conditions

% Reduction with GTL	NOx		Particulates	
	Range engine test cell	Projection for modelled driving conditions	Range engine test cell	Projection for modelled driving conditions
Euro III	5 – 19	12	10 – 34	21
Euro IV	5 – 22	14 – 19	20 – 38	20
EURO V	5 – 37	15 – 23	22 – 33	18

More information for the Euro V engines is presented in figure 3. This shows an overview of the pollutant emissions with GTL relative to standard diesel, EN590 (with 10 ppm sulphur in most cases). Refer to [Shell 2013], [Thompson 2004], [Clark 2005a] and [Clark 2005b].

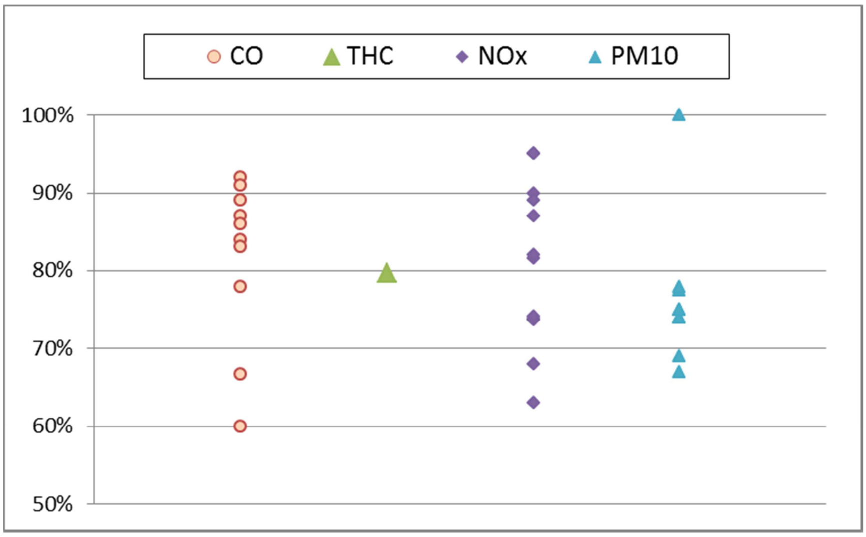

Figure 3: Emissions with GTL compared to standard diesel for Euro V engines (EN590=100%). PM point 100% (0% reduction) refers to one exceptional cycle (garbage truck cycle).

In Table 5 and Figure 3, it can be seen that the relative variations in emissions, especially for NOx, are larger for Euro V engines than for Euro III and Euro IV engines. This is due to the fact that the absolute levels are lower and probably also due to differences between engines in control strategy of the SCR catalyst (especially the precise response of AdBlue dosage to GTL).

For Euro VI engines, no results with GTL were presented. The NOx requirements for Euro VI are almost a factor 5 more stringent than for Euro V. Euro VI will most likely have a closed loop control on NOx, which may rule out possible advantages of NOx. A closed loop control is however not expected to rule out all possible differences[2],
in which case GTL is expected to still give a small NOx reduction. A this stage, without any proof from the engine test cell, it is concluded that there is probably a small NOx reduction with GTL although the level is uncertain. It is however noted that NOx levels with Euro VI are really low such that this kind of NOx reduction is of lower significance than reductions with older engines.

[2] Some projections were done, which indicated that a closed loop control would likely compensate 75% to 90% of the engine out NOx variations. The remaining 10-25% does lead to a tailpipe NOx reduction of around 10%.

4 Emissions of Inland ships

4.1 Emissions legislation

An overview of the generally applicable legislation for Rhine vessels is presented in Table 6 below. For NOx for engines with more than 560 kW engine power, a range is shown. The NOx level is dependent on max engine speed (n_{max}) using the following equations:

- CCNR1: NOx limit is $45\ n_{max}^{-0.2}$ (g/kWh)
- CCNR2: NOx limit is $45\ n_{max}^{-0.2} - 3$ (g/kWh)

The highest number in the table corresponds to an engine with a max speed of 600 rpm. The NOx limit goes down when max engine speed goes up.

Table 6: Overview of Rhine vessel 'RheinSchUO' emission limits

Date	Stage	Max Power (kW)	CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	PT (g/kWh)
2003	CCNR 1	130 - 560 >560	5.0 5.0	1.3 1.3	9.2 9.2 -12.5	0.54 0.54
2007	CCNR 2	130 - 560 >560	3.5 3.5	1.0 1.0	6.0 6 - 9.5	0.2 0.2

For the future, the emission legislation for inland ships in Europe will be brought under the Directive 97/68/EC for non-road mobile machinery, within a separate paragraph. Future emission limits are under discussion for quite some time. In (Quispel 2013) among other Stage 4B and Stage 5 emission limits were proposed for respectively 2017 and 2022. The NOx limits are respectively 1.2 and 0.4 g/kWh and the PM limits are respectively 0.02 and 0.01 g/kWh. If this will indeed enter into force, the emissions limits of inland ships will become very comparable to those of heavy-duty vehicles and non-road machines by 2022.

4.2 Emission control technologies

Up to 2003, the engines were basically optimized for fuel consumption, which resulted in a relatively high NOx figure of some 9 to 12 g NOx/kWh. For CCNR2 a NOx reduction of 25% to 30% was necessary. This was to a large extend accomplished by optimizing the fuel injection parameters to accomplish combustion with the lower required NOx. No specific NOx control technologies such EGR (Exhaust Gas Recirculation) or deNOx catalysts were necessary.

This wil change with the proposed Stage 4 and Stage 5 legislation.
The following emission control technologies are then expected, in line with those of Heavy-duty vehicles Euro V and Euro VI:

- For Stage 4B: SCR deNOx catalyst
- For Stage 5: SCR deNOx with diesel particulate filter

4.3 Effects on emissions

Detailed measurement reports with Shell GTL fuel were available of the main engines of 2 inland ships and of two auxiliary engines. The two ships are the MS INVADO and the NOVAMENTE. These are representative Dutch inland ships of respectively 110 m and 135 m long. The measurements were carried out by an independent service provider, SGS Environmental Services, commissioned by Shell Global Solutions and VIDOL Marine [SGS 2013], [SGS 2014]. Both ships were tested with GTL and EN590. The INVADO's original engine is classified as CCNR0, but does meet CCNR1. The NOVAMENTE is classified as CCNR1. The emission reductions with GTL compared to standard diesel fuel EN590 of all measurements are presented in Table 7 below.

Table 7: Emission reduction with GTL compared to diesel with marine engines. Source [SGS 2013]], [SGS 2014], [Pon 2008]

		Engine class	Measure-ment	year	CO	HC	NOx	PM	Smoke
Inland ship: MS Invado, Caterpillar 3512B, 1119 kW at 1600 rpm	high NOx	CCR0	SGS	2013	0%	10%	8%	37%	
	low NOx	CCR2*	SGS	2013	0%	10%	13%	16%	
Inland ship NOVAMENTE, Caterpillar 3512B, 1014 kW at 1600 rpm		CCR1	SGS	2013	11%	≈ 50%	10%	≈ 60%	
Caterpillar D3408 marine auxiliary engine, 250kW at 1500 rpm		-	PON	2008	17%	-	≈ 4%	-	32%
Caterpillar 3408 marine auxiliary engine, 320kW at 1500 rpm		-	PON	2006	15.3 %	-	8.9%	20.7 %	

* Actually classified as CCNR0 but with special software to meet CCNR2.

Table 7 shows a substantial variation in reduction percentages with GTL for all components. This is however in average level and variation quite similar to the response of HD engines as is presented in Figure 1. Based on the ship measurements, the PM reduction might be slightly higher than with the HD engines, although the reasons for this are not yet understood. It should be noted, that the number of measurements on ships is still low and limited to different types of Caterpillar engines

Based on these results (Table 7), it is concluded that the following emissions reduction ranges with GTL have been found for ship engines (CCNR0 - CCNR1):

NOx: ~ 8% - 13%
PM: ~ 15% - 60%
CO: ~ 0 - 20%
HC: ~ 10% - 50%

5 Emissions of Mobile machinery

5.1 Emissions legislation

The regulations for non-road are specified by Directive 97/68/EC and following Directives. It has a substantial number of engine categories, including separate paragraphs for Locomotive and Inland ships.
Stage I/II (Directive 97/68/EC), is the first European legislation to regulate emissions for non-road mobile machinery (NRMM). Stage III/IV (Directive 2004/26/EC) included Stage IIIA/B for rail industry. The Directive 2010/22/EU amends the earlier legislation applicable to agricultural and forestry tractors.

The different stages in the 2004/26/EC directive are as follows:

- Stage III A covers engines from 19 to 560 kW including constant speed engines, railcars, locomotives and inland waterway vessels.
- Stage III B covers engines from 37 to 560 kW including, railcars and locomotives.
- Stage IV covers engines between 56 and 560 kW.

There are no limit values concerning engine power above 560 kW so far. For a full overview of engine categories and limit values, refer to http://www.dieselnet.com/standards/eu/nonroad.php.

With non-road there is a lot of variation in limit values and entry into force dates. This is dependent on the engine category and also the engine categories vary per emission stage. The entry into force dates for the different stages and power categories are graphically presented in Figure 4 below.

Stage III A | Stage III B | Stage IV

<table>
<tr><th>Engine categories Net Power (kW)</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th></tr>
<tr><td>19 ≤ P < 37</td><td colspan="6">7.5 (NOx+HC) / 5.5 (CO) / 0.6 (PM) [g/kWh]</td><td colspan="3">under development</td></tr>
<tr><td>37 ≤ P < 75</td><td colspan="3">4.7 (NOx+HC) / 5.0 (CO) / 0.4 (PM) [g/kWh]</td><td colspan="6">4.7 (NOx+HC) / 5.0 (CO) / 0.025 (PM) [g/kWh]</td></tr>
<tr><td>75 ≤ P < 130</td><td colspan="2">4.0 (NOx+HC) / 5.0 (CO) / 0.3 (PM) [g/kWh]</td><td colspan="3">3.3 (NOx) / 0.19 (HC) / 5.0 (CO) / 0.025 (PM) [g/kwh]</td><td colspan="4">0.4 (NOx) / 0.19 (HC) / 5.0 (CO) / 0.025 (PM) [g/kwh]</td></tr>
<tr><td>130 ≤ P < 560</td><td>4.0 (NOx+HC) / 3.5 (CO) / 0.2 (PM)</td><td colspan="3">2.0 (NOx) / 0.19 (HC) / 3.5 (CO) / 0.025 (PM) [g/kwh]</td><td colspan="5">0.4 (NOx) / 0.19 (HC) / 3.5 (CO) / 0.025 (PM) [g/kwh]</td></tr>
<tr><td>P > 560 *</td><td colspan="2">6.0-7.4 (NOx) / 0.4-0.5 (HC) / 3.5 (CO) / 0.2 (PM) [g/kWh]</td><td colspan="4">aligned with US limts (Tier 3) 4.0 (NOx+HC) / 3.5 (CO) / 0.025 (PM) [g/kwh]*</td><td colspan="3">under development - to be aligned with US emission limts (Tier 4)</td></tr>
</table>

Figure 4: Emission limits and entry into force date of five engine categories for non-road engines [source Shell].
* for railcars, main locomotives and shunting locomotives only

5.2 Emission control technologies

An overview of the applied emission control technologies is provided in Table 8 below. In the last column a comparison is made with the heavy-duty vehicle legislation. Shown are approximate corresponding Euro class. The emission control technologies for non-road are generally corresponding to those of the HD vehicles. One difference is that for non-road, EGR is more often used as the main NOx control technology as opposed to SCR deNOx catalytic aftertreatment for HD vehicles. For example, some locomotive engine OEM's use EGR & SCR and optional DPF systems, other use only EGR and two-stage turbo charging (without SCR & DPF) to reach Stage IIIB. In general particulate filters are more often applied than with road transport (up to Euro V).

Table 8: Emission limits and emission control technologies for two categories non-road engines

Year	Stage	Power kW	NOx g/kWh	PM g/kWh	Technology	≈ HD truck
2006	III A	> 130	4*	0.2	EGR or SCR (optional) Combustion opt.	Euro III
2007		< 130	4*	0.3		
2011	III B	> 130	2	0.025	SCR, EGR, EGR+SCR, EGR + DPF	Euro V
2012		< 130	3.3	0.025	EGR, EGR + DPF	Euro IV
2014	IV		0.4	0.025	EGR + SCR DPF optional	Euro VI

* NOx + HC

5.3 Effects on emissions

Several reports about the application of Shell GTL fuel for non-road machines were available, although they are focused on the practical application of GTL including cold weather operation, noise and smoke measurement. The smoke measurements gives a good indication for the black smoke part of the total particulates emission, but is not an official particulates measurement.

The following reports on non-road machines were available:
- Shell report on Hitachi excavators: focused on cold weather operability
- DB Schenker report of smoke measurements on several (shunting) rail locomotives.

The work with the Hitachi excavators was carried out in close cooperation with Hitachi. The main conclusion was that the start-ability with extreme low temperature (-20°) was fine and that no adverse effects on engine life time is expected.

The smoke measurements at DB Schenker were done with locomotives.
One shunting locomotive was equipped with diesel particulate filter. In a one-off measurement, the use of GTL in comparison to standard diesel, showed substantial smoke reductions. This was generally in the range of some 60% to 85%. In one case, with the diesel particulate filter, an increase in smoke was measured.

This is not considered as very remarkable due to the very low smoke levels with a particulate filter and the fact that particulate filters can store fair amount of sulphates and hydrocarbons.

A smoke measurement differs considerably with a formal particulate emission measurement. The latter is based on the mass of particulates, while a smoke measurement generally uses a light adsorption or a filter paper blackening method. Consequently, the smoke measurement focusses more on the black smoke part of the particulates. This does not include all particulates. As a consequence only the effect of GTL on black smoke is measured. The actual percentage reduction of GTL on the total particulates emission can be smaller or larger.

Even though emission measurement results of non-road engines are hardly available, a positive effect of GTL on the pollutant emissions is expected due to the particular composition and characteristics of GTL and the resulting positive effect on combustion. This is supported by the positive experimental results with a large variation of different engines (refer to sections 2, 3 and 4). Similar positive effects are expected as the effects with heavy-duty engines using similar engine and emission control technologies.

6 Conclusions

TNO evaluated a large number of publications and reports with emission measurement data of GTL in comparison with standard diesel (EN590). The publications with complete emission measurements (NOx, PM, CO and HC) concerned primarily heavy-duty engines and ship engines. Additionally some information was available on smoke measurements with locomotive engines.

Based on these evaluations, the following is concluded with respect to Shell GTL fuel as replacement for regular diesel fuel (EN590):

- GTL shows a reduction in all regulated pollutant emissions NOx, PM, CO and HC. Test results showed variations between test programs, as can be expected due to differences between engines.
- For relative simple systems such as Euro III engines, measurements showed NOx reductions in the range of 5% to 19% and PM reductions in the range of 10 – 34%.
- For engines with more advanced emission control systems, the relative variations in NOx and PM can be larger. For Euro V SCR engines, measurements showed NOx reductions in the range of 5% to 37% and PM reductions up to 33%, depending on engine type and test cycle. The relative large variations are due to the low level and the fact, that emission control systems such as AdBlue dosage can respond differently to GTL depending on the precise system design. No information has been presented for Euro VI engines.
- For the relative conventional ship engines, measurements showed NOx reductions in the range of 8% to 13% and PM reductions in the range of 15% – 60%.
- Very limited information was available for non-road mobile machinery. However, based on the positive experimental results of GTL on a broad range of engines in combination with the characteristics of GTL and the resulting positive effect on combustion, it is very likely that similar emission reductions are applicable as for HD engines.

It can be concluded that pollutant emissions of existing fleets can be reduced significantly by the application of GTL. The reduction is instantaneous and can be seen as an alternative to replacement by newer or cleaner vehicles, ships or machines or it can serve as a complementary measure. In absolute sense, the emission reductions are the largest when GTL is used for relative higher polluting engines such as used in older vehicles or used in ships or mobile machinery.

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8 Signature

Delft, 9 September 2014

Nico Zornig Manager STL	Ruud Verbeek Author