# 2nd VegOil

# Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines

## Workpackage WP2

## Engine development

## Deliverable N° 2.9:

# Assortment of representative load cycles

# Publishable Summary

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prepared by:

TUM – LVK and JD

Dipl.-Ing. Andreas Hubert; Prof. Dr.-Ing. Georg Wachtmeister

Lehrstuhl für Verbrennungskraftmaschinen – Technische Universität München
Schragenhofstrasse 31
80992 München - Germany
Partner website : www.lvk.mw.tum.de
Project website: www.2ndVegOil.eu

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# 1 Introduction

Within the EU funded project „**Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines**" the Chair of internal combustion engines (Lehrstuhl für Verbrennungskraftmaschinen, LVK) of the Technische Universität München works on the work package WP2 "engine development". The objective of this work package is to develop engines able to comply with the EU Stage 4 (for non-road vehicles) emission norm if fuelled with the 2nd generation vegetable oil fuel developed in work package WP3. The WP2 consists of development work regarding, in particular, exhaust gas aftertreatment systems (responsible: John Deere) in the first project steps. On the other hand, another project goal is to develop a hybrid engine system allowing keeping below future emission limits.
The development work at the engine laboratory of the LVK is done on a hybrid test stand. This test stand was built up in the project months 1 to 9 (please see Deliverable D2.7 for further information). During this time testing and first measurements were executed, which are briefly described in Deliverable D2.8. For developing a hybrid engine operation strategy for the hybrid engine test stand explicit differentiated operation profiles (e.g. typical for tractor engines) and operation cycles, which are specified by the EU for emission certification of non road diesel engines, have to be selected and captured (Deliverable D2.9). The goal is to decide on the arrangement of a testing matrix which will be a reference hybrid test stand operation procedure for investigating 2nd generation vegetable oil-fuelled engine operation. This matrix considers not only the targeted emission limits as the most important goal, but also a realistic tractor engine load profile which is focussed on the power output and the fuel consumption.

# 2 Reference to project planning: key partners, scope of the key partner, timetable and milestone

The key partner for the selection of representative engine load cycles that are typical for tractor engines is John Deere. This partner has the experience regarding the operation of tractors for example in case of ploughing or transport activities.
The scheduled time for Task 2.9 "Assortment of representative load cycles in conjunction with the consortium" is one month (month 9). It ends with the milestone M2.3H ("Testing matrix is filled in") which could be achieved within the foreseen time. This document summarises the results of Task 2.9.

# 3 Load cycles concerning (future) emission limits

The load cycles concerning the certification of an emission step (like the EU STAGE 3A) are specified by the EU, [1] to [4]. In case of the JD CD6068HL481 tractor engine, these cycles are the stationary cycle (**N**on **R**oad **S**tationary **C**ycle) and the transient cycle (**N**on **R**oad **T**ransient **C**ycle).
Figure 1 shows the directives for mobile work machinery and tractors:

| **Regulations** | |
|---|---|
| ***European Union*** | ***USA*** |
| 97/68/EG<br>2004/26/EG<br>2000/25/EG<br>2005/13/EG | 40 CFR 89<br>40 CFR 1039<br>40 CFR 1068 |
| ⇒ Stage I, II, III A, III B & IV | ⇒ TIER 1, 2, 3, 4 |
| **Test cycles** | |
| ***European Union*** | ***USA*** |
| NRSC for Stage IIIA<br>NRSC for Stage IIIB/IV (aeriform)<br>NRTC necessary for Stage III B/IV<br>(particulate matters only)<br>NRTC possible for Stage IIIB/V<br>(aeriform) | for TIER 4: NRTC |

**NRSC, NRTC**

*Fig.1: Emission regulations*

<u>Non-Road Stationary Cycle</u>

The NRSC consists of 8 steps with the duration of 600s (Fig. 2).

| step | engine speed | engine load | duration | weighting factor |
|---|---|---|---|---|
| [-] | [rpm] | [%] | [sec.] | [%] |
| 1 | Nominal speed | 100 | 600 | 15 |
| 2 | Nominal speed | 75 | 600 | 15 |
| 3 | Nominal speed | 50 | 600 | 15 |
| 4 | Nominal speed | 10 | 600 | 10 |
| 5 | Intermediate speed | 100 | 600 | 10 |
| 6 | Intermediate speed | 75 | 600 | 10 |
| 8 | Idle speed | 0 | 600 | 15 |

*Fig.2: NRSC steps [1]*

This cycle is used for the emission step EU STAGE 3A and is also permissible for the steps EU STAGE 3B / 4 in case of the limited aeriform emissions for $NO_x$, HC and CO. The several engine speeds indicated in Fig.2 still need to be translated in absolute values for different engines [1]: in case of the JD 6068HL481 these speeds are:

- nominal speed: 2100 rpm
- intermediate speed: 1575 rpm
- idle speed: 850 rpm

The engine load is given in percentage: e.g. “engine load 100%” means maximum engine torque at the according engine speed.

<u>Non-Road Transient Cycle</u>

The NRTC is necessary for particulate matter emission certifications regarding the steps EU STAGE 3B / 4. It is also possible to use it for measuring the aeriform emission (usually in case of engine operation at the LVK test stand all measurement equipment is operational: aeriform emissions as well as particulate matter are always logged with the measurement acquisition).

Fig. 3 shows the engine speed and torque profile over the duration of the NRTC (more then 1200s).

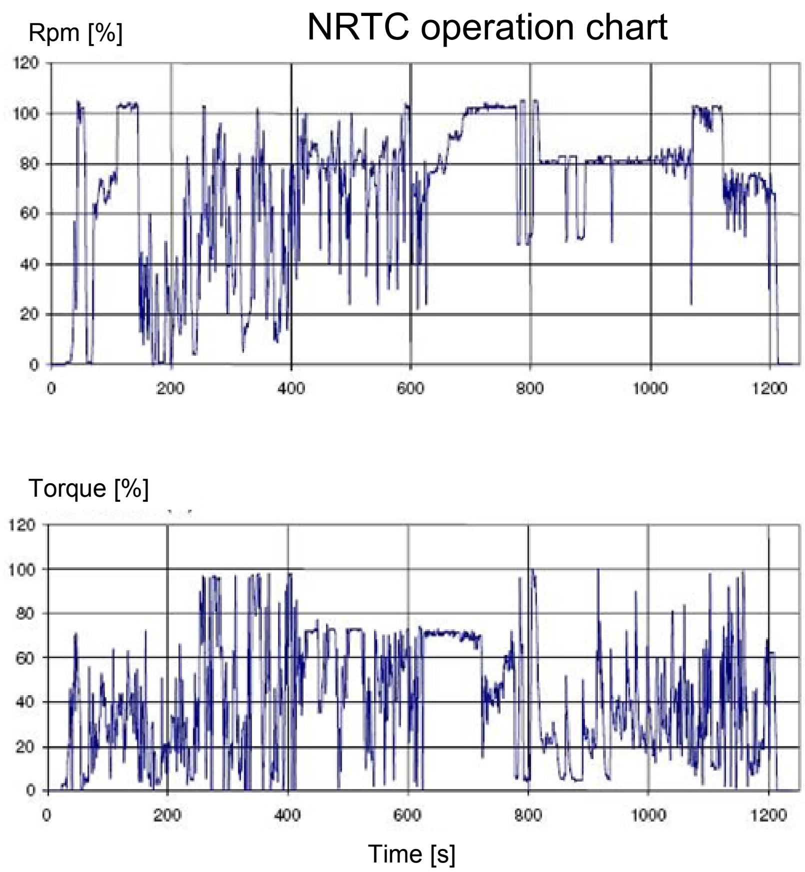



*Fig.3: NRTC operation chart [1]*

The engine speed and torque are denoted in percentage values: for the JD 6068HL481 diesel engine the profiles have to be translated into absolute values. This conversion is specified in [1]:

“engine speed = 100%” is the reference engine speed (=$n_{ref}$): $n_{ref} = n_{low} + 0.95\,(n_{high} - n_{low})$
where:

$n_{low}$: lowest speed at 50% nominal power output = 900rpm
$n_{high}$: highest speed at 70% nominal power output = 2200rpm
$n_{ref}$ = 2135 rpm
The role of TUM is to assemble a hybrid engine at a test bed (task 2.7), to do reference measurements and tests with mineral diesel fuel (task 2.8), and to assort representative load cycles in close dialogue with the other consortium partners (task 2.9). After these preparatory activities, tasks 2.10 to 2.13 cover the proper measurements with 2nd generation vegetable oil fuel, simulation, validation of data and conclusions. This deliverable covers the work done under task 2.7.

Annotation:

The calculation of the reference engine speed has to be executed on the basis of the engine power output that has been reached on the test stand. Engine power can diversify from engine to engine due to e.g. manufacturing tolerances. Also, calculations have to be executed for different fuels (diesel / vegetable oil). The stated engine speeds are examples for demonstration this coherence (nominal power output specification for the example calculation (Diesel fuelled): 131kW@2100rpm)

"engine torque = 100%" means maximum engine torque at the according engine speed

Emission limits of the different EU STAGES and rate of achievement

Please see the following figures for the emission limits for a 142kW non road diesel engine [7]:

### Stage III A Standards for Nonroad Engines

| Cat. | Net Power | Date* | CO | $NO_x$ + HC | PM |
|---|---|---|---|---|---|
| | kW | | g/kWh | | |
| H | 130 ≤ P ≤ 560 | 2006.01 | 3.5 | 4.0 | 0.2 |
| I | 75 ≤ P < 130 | 2007.01 | 5.0 | 4.0 | 0.3 |
| J | 37 ≤ P < 75 | 2008.01 | 5.0 | 4.7 | 0.4 |
| K | 19 ≤ P < 37 | 2007.01 | 5.5 | 7.5 | 0.6 |

* dates for constant speed engines are: 2011.01 for categories H, I and K; 2012.01 for category J

### Stage III B Standards for Nonroad Engines

| Cat. | Net Power | Date | CO | $NO_x$ | HC | PM |
|---|---|---|---|---|---|---|
| | kW | | g/kWh | | | |
| L | 130 ≤ P ≤ 560 | 2011.01 | 3.5 | 2.0 | 0.19 | 0.025 |
| M | 75 ≤ P < 130 | 2012.01 | 5.0 | 3.3 | 0.19 | 0.025 |
| N | 37 ≤ P < 75 | 2012.01 | 5.0 | 3.3 | 0.19 | 0.025 |
| P | 19 ≤ P < 37 | 2013.01 | 5.0 | - | 4,7* | 0.025 |

* NOx + HC

### Stage IV Standards for Nonroad Engines

| Cat. | Net Power | Date | CO | $NO_x$ | HC | PM |
|---|---|---|---|---|---|---|
| | kW | | g/kWh | | | |
| Q | 130 ≤ P ≤ 560 | 2014.01 | 3.5 | 0.4 | 0.19 | 0.025 |
| R | 56 ≤ P < 130 | 2014.10 | 5 | 0.4 | 0.19 | 0.025 |

*Fig.4: Emission limits for the EU STAGES 3A, 3B, 4*

For all emission targets within the project 2nd Veg Oil, the accomplishment can only be granted if no deterioration of the engine is observed and if the fuel consumption in the case of a vegetable fuelled engine keeps below the reference diesel consumption plus 10%.
The rate of achievement in the interval within EU Stage 3B and EU Stage 4 is defined as follows:

$$R_a = (\log NOx_{3B} - \log NOx_m)/(\log NOx_{3B} - \log NOx_4)$$

$$\text{as long as } p_m \leq p_{3B} = p_4$$

$R_a$ is the overall ratio of achievement (a percentage number between 0 and 100%), $NOx_m$ and $p_m$ are the measured values of $NO_x$ and particulates, $NOx_{3B}$ /$p_{3B}$ and $NOx_4$ /$p_4$ are the respective limit values for EU Stage 3B and EU Stage 4 and log is the decimal logarithm. Note that $p_{3B} = p_4$.
*Example: in the case of a measured $NO_x$ emission of 1.2 g/kWh and a $p_m$ emission of 0.025 g/kWh, the rate of achievement $R_a$ would be 32%.*

The most important goal for the LVK in this project is to develop a hybrid engine operation strategy for the NRTC. This is the cycle which is allowed to be used for the EU STAGE 4 emission certification.

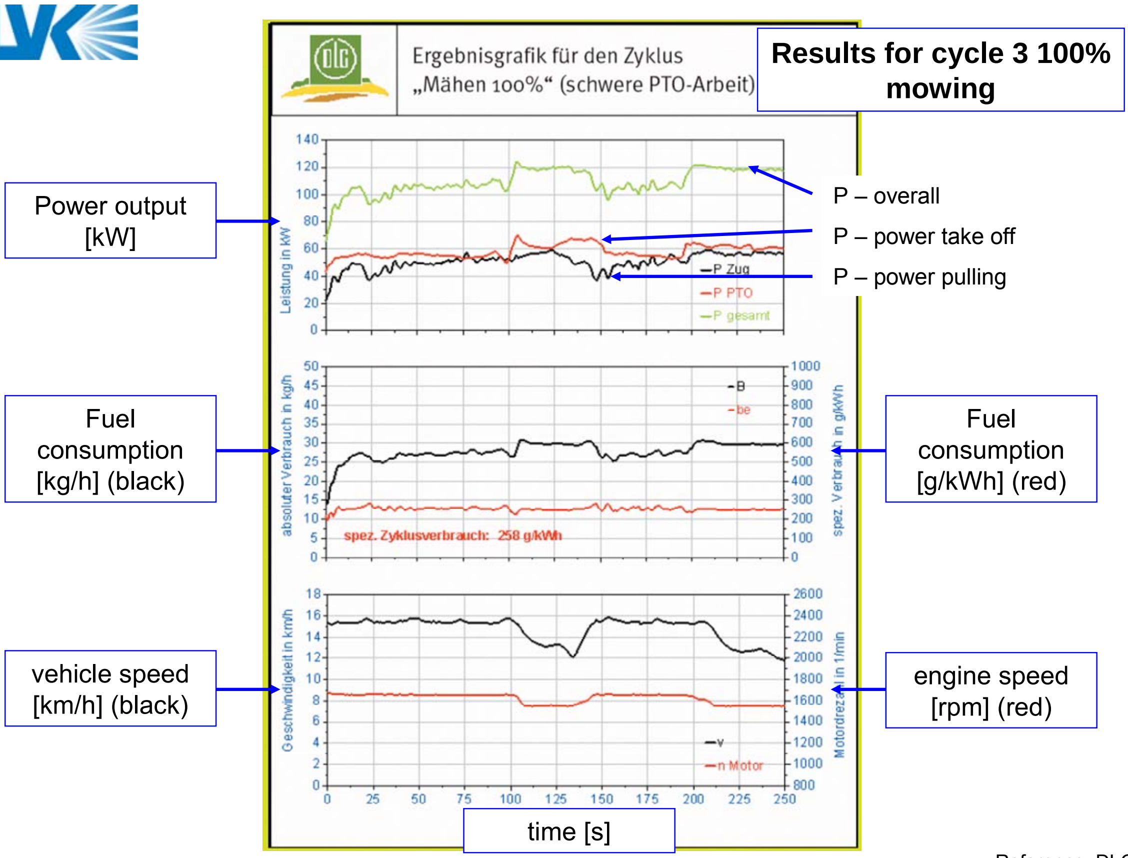
# 4 Load cycles concerning a realistic tractor engine operation

This future hybrid engine operation strategy shall not only be used for the EU specified NRTC cycle, but also for a realistic operation cycle which focuses mainly on the fuel consumption.
For comparisons between different tractors` fuel consumption in the case of realistic operation, the "**D**eutsche **L**andwirtschafts**g**esellschaft" (DLG – German farmers association) developed the "DLG Powermix" together with John Deere`s support: the tested tractor pulls a brake wagon which modifies the tractive output dynamically with either the power take-off shaft or the hydraulic system demand. Meanwhile, the fuel consumption is measured which is an important parameter for comparisons [5]. Figure 5 shows the single Powermix cycles:

| Nr. | working process | classification | vehicle speed (max.) | power take-off shaft speed | cycle duration |
|---|---|---|---|---|---|
| [-] | [-] | [%-] | [km/h] | [rpm] | [s] |
| cycle 1 | 100% plowing<br>100% grubbing | heavy pulling | 9<br>12 | -<br>- | 250<br>250 |
| cycle 2 | 60% plowing<br>60% grubbing | medium heavy pulling | 9<br>12 | -<br>- | 250<br>250 |
| cycle 3 | 100% power harrow<br>100% mowing | heavy take-off shaft work | 6<br>16 | 900<br>900 | 250<br>250 |
| cycle 4 | 70% power harrow<br>70% mowing | medium heavy take-off shaft work | 6<br>16 | 900<br>900 | 250<br>250 |
| cycle 5 | 40% power harrow<br>40% mowing | light take-off shaft work | 6<br>16 | 900<br>900 | 250<br>250 |
| cycle 6 | dung strewing | pulling, power take-off, hydraulics | 7 | 1000 | 500 |
| cycle 7 | pressing | pulling, power take-off, hydraulics | 10 | 1000 | 500 |
| cycle 8 | transporting | pulling | varies | - | - |

*Fig.5: DLG Powermix cycles [6]*

Each cycle is transient. An example of such a cycle shows cycle 3 “100% mowing” in Figure 6.




Reference: DLG

*Fig.6: DLG Powermix – example results for cycle 3 [6]*

For the transport cycle there are no reference values available. Thus it will not be applied on the test stand. The other cycles are partly split into two cycles which can be generally declared as “slow” and “fast” cycle (see Fig. 5), for example 3K would be the slow cycle and 3M the fast one. This makes 12 cycles which together require approximately 62 minutes. To avoid any misunderstanding the nomenclature of the cycles is listed in the following table.

| | |
|---|---|
| 1P | 1 |
| 1G | 2 |
| 2P | 3 |
| 2G | 4 |
| 3K | 5 |
| 3M | 6 |
| 4K | 7 |
| 4M | 8 |
| 5K | 9 |
| 5M | 10 |
| 6MS | 11 |
| 7PR | 12 |

*Fig.7: table – nomenclature of the cycles*

For an increased time and cost efficiency the whole Powermix will be reduced for the hybrid engine test stand. To select a reduced number of cycles the location of all cycles in the engine's part load map was evaluated. On this basis the following six cycles were selected: 2-3-5-8-10-12 for a reduced Powermix. This reduced Powermix cycle is representative for the complete Powermix as there is at least one single cycle for every region in the part load map where the Powermix has a centre.

The speed and torque set point values for all cycles were derived from original measurements at the DLG facilities in Großumstadt. The new, reduced Powermix cycle will be 1781 seconds (approx. 30 minutes) (see Fig.8) The torque values shown in Fig. 8 were scaled especially for the engine at the LVK test stand (Serial number: CD6068L066864) and are based on its full load rated speed torque measured at the test stand with rapeseed oil fuel.


*Fig. 8 Engine speed and torque over time for the CD6068L066864 at the LVK-TUM test stand*

# 5 Conclusion and summary

The reference hybrid engine operation procedure focuses on emission and fuel consumption and is the arrangement for the final testing matrix. It consists of the Non-Road Transient Cycle given by the EU for certification of the emission steps EU STAGE 3B/4 and of a compilation leaned on the DLG Powermix cycles. Decisive for the rate of achievement regarding the emission limits is the NRTC. But also the cycle concerning the realistic agricultural tractor engine load profiles gives the opportunity to obtain results, which can be the basis for strategic decisions regarding the hybrid engine application in future tractors.

# 6 References

[1] European Union - European Parliament and European Council: Directive 2004/26/EC of the European Parliament and European Council, Strasbourg, France, 21.04.2004

[2] European Union - European Commission: Directive 2005/13/EC of the European Commission, Brussels, Belgium, 21.02.2005

[3] European Union - European Parliament and European Council: Directive 97/68/EC of the European Parliament and European Council, Brussels, Belgium, 16.12.1997

[4] European Union - European Parliament and European Council: Directive 2000/25/EC of the European Parliament and European Council, Brussels, Belgium, 22.05.2000

[5] Neunaber M.: Zugleistung, Zapfwelle und Hydraulik: Power Mix [Tractive output, power take-off shaft, hydraulic system: power mix], profi 12/2003, Germany

[6] Feuerstein T., Degrell O.: Praxis aus der Konserve: Der DLG-Powermix [Practice out of the can: the DLG-Powermix], dlg-test.de 02/2005, Germany

[7] Internet: http://www.dieselnet.com/standards/eu/nonroad.php#s3, 20.07.2009