2nd VegOil

Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines

Workpackage WP2

Engine development

Deliverable N° 2.7:

Hybrid engine test stand

Publishable Summary

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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 workpackage WP2 “engine development”. The objective of this workpackage 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 workpackage WP3. The WP2 consists of the development work regarding especially after treatment systems (responsible: John Deere) in the first project steps. A further project goal is to develop a hybrid engine system, allowing to keep below future emission limits.
The development work at the engine laboratory of the LVK is done on a hybrid test stand. How this system works, how it is built up and which measurement is applied is documented in this deliverable. Furthermore, it is described here the necessity of the single measurement.

2 Reference to project planning: key partners, their scope, timetable and milestones

The key partner in the WP2 “engine development” is John Deere, which delivers the combustion engine for the hybrid test stand. The combustion engine is a central element for the whole hybrid system.
The second important partner is VWP, which is responsible for the combustion engine adaption regarding the use of the 2nd generation vegetable oil fuel (in case of the Hybrid test stand this is rape seed oil, delivered by the project partner Waldland).
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.
For building up the test stand, the scheduled time is nine months. The task 2.7 “Hybrid engine assembly at the TUM test bed” ends with the milestone M2.1H “Hybrid engine test stand is operational”. The milestone could be achieved within the foreseen time.

3 Hybrid engine test stand

For the 2nd VegOil project a certain range of tractor models was selected for the fleet demonstration. These models are the 6830 Premium, 6930 Premium, 7430 Premium and 7530 Premium tractors of John Deere. Those models are powered by the 6068 Powertech Plus engine at different power levels. The 6830 Premium and 6930 Premium tractors have got the CD6068HL481 engine and the 7430 Premium and 7530 Premium the CD6068HL482. Those two engine models differ for example in the stability of the crankshaft, but not in major technological properties like air or fuel system. The different power levels are implemented by different ECU software versions. The 6068 Powertech Plus engines are four-valve engines with a high pressure common rail system for fuel injection. They are turbocharged and have an external exhaust gas recirculation (EGR) system including cooler to control NO_x emissions.
Those tractor models were selected as they are the largest and most powerful tractors produced at the John Deere Werke Mannheim (JDWM). After evaluation of the market demand it is clear that mostly owners of large tractors with numerous operating hours demand a plant oil powered tractor. In that case the highest saving potential is achieved and the investment in the engine technology is profitable.
For the test stands the CD6068HL481 was selected.

The operation of internal combustion engines with vegetable oil at part load is very difficult because of the low temperature. The – compared to mineral diesel – higher inflammation point of vegetable oil retards the ignition and leads to a less favourable combustion. Quick load changes are equally difficult to handle in vegetable oil fuelled engines. The combustion is disturbed, presumably due to pressure waves in the injection system.

In tractors as well as in hybrid engines, these problematic operation conditions are rare. In fact, hybrid engines offer some scope for suppressing them almost entirely. Hybrid engines can use the electric motor for part load operation and as an additional driver when the load rises quickly.

The LVK test stand simulates a hybrid system, thus allowing studying experimentally different hybrid engine configurations. This simulation will be done with a four-quadrant-machine, which is able to drive, respectively to consume, the power of the combustion engine. In case of a towed operation mode of the combustion engine, the power consumption of the four-quadrant-machine is representative (with consideration of the efficiency) for the recuperation power of the simulated hybrid module. In the operation mode “electric driving”, the combustion engine is off, whereas in case of a fast load rise the operation mode “boost function” assures the hybrid module adoption as an additional driver. The combustion engine is supported by the four-quadrant-machine which will simulate a real hybrid system.

With this test stand, the development of an engine operation strategy on the basis of hybrid operation will be developed whereby the disadvantageous combustion engine operation points regarding vegetable fuels can be avoided. Furthermore, an improvement of efficiency can be expected. General hints will be elaborated how the operation strategy can be adapted to different load profiles.

The experimental measurements will be complemented by numeric simulations for estimating the most advantageous configurations. Experiments and numeric simulations are repeated for approaching iteratively the optimum configuration and operation mode. The engine test stand allows assessing torque, angular velocity, consumption, exhaust gas temperature, etc. In addition, exhaust gas composition and particulate are measured.

Figure 1 shows the scheme of the LVK Hybrid engine test stand:

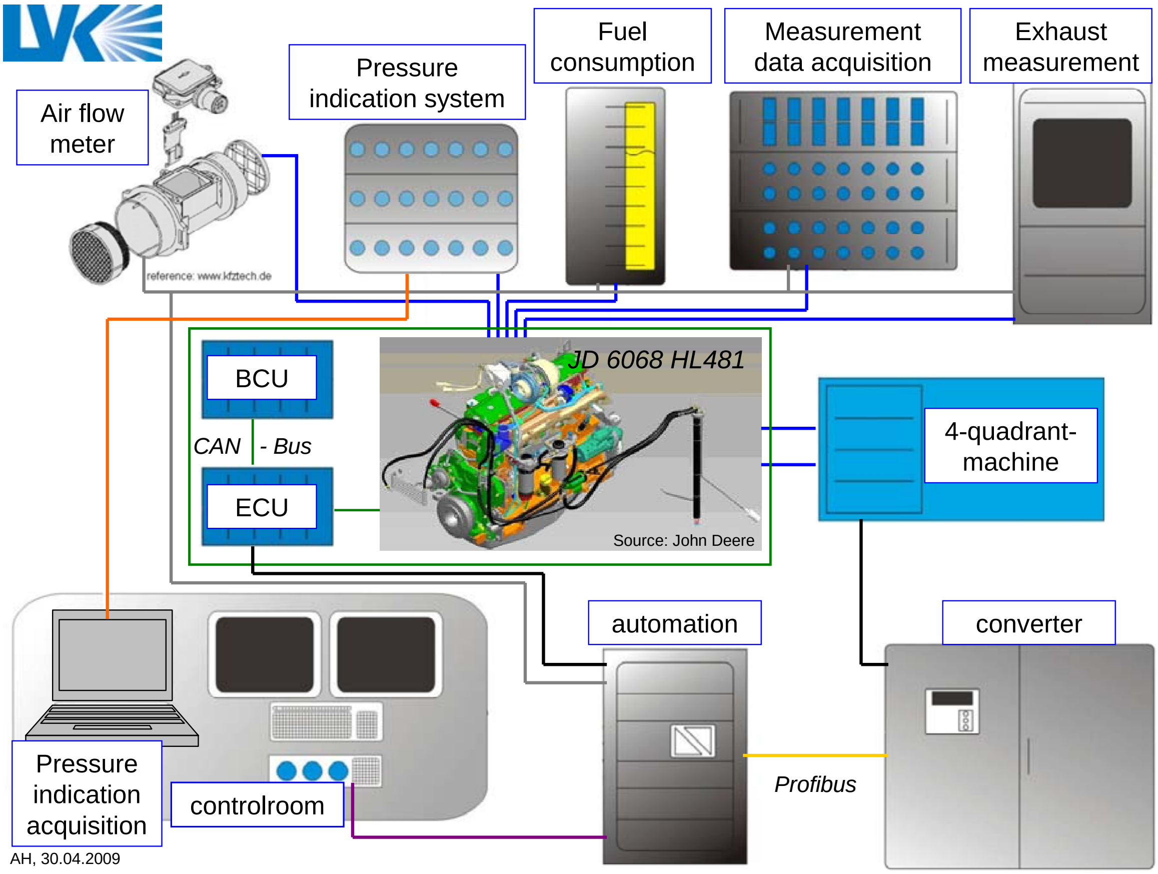

Fig.1: Hybrid test stand schema

The central element (green box) is the internal combustion engine, a John Deere 6068 HL481 diesel engine. This six cylinder engine with a state-of-the-art common rail injection system, a cooled exhaust recirculation system and a turbocharger with variable turbine geometry has a swept volume of 6,8l, a maximum power output of 142kW and a maximum torque of 726Nm. The communication between the ECU (**E**lectronic **C**ontrol **U**nit), the BCU (**B**ody **C**ontrol **U**nit; simulates the tractor) and the engine bases upon the common CAN system (**C**ontroller **A**rea **N**etwork; an asynchronous, sequential fieldbus system developed by BOSCH for automobile control unit communication).

For the engine operation there are different systems and components necessary:

a) The air Flow meter measures the aspirated air mass of the combustion engine.
b) The pressure indication system captures the cylinder pressure, the intake pressure and the exhaust pressure of cylinder 1 of the engine. In conjunction with the pressure indication acquisition it is possible, to do thermodynamic analysis in the later project steps. This analysis will help develop an engine operation strategy for the hybrid operation.
c) The fuel consumption is also an important engine parameter. A description of the fuel system follows in this document.

d) The measurement data acquisition is responsible for recording all measured parameters (like power output, torque, different temperatures, pressures, ...).
e) The exhaust measurement consists of a system for aeriform emission measurement (NO_x, CO, HC, O_2, CO_2) and for particulate matters. These systems are described in the following.
f) The 4-quadrant-machine consumes the power of the combustion engine - driving the engine is also possible.

The 4-quadrant-machine (Fig. 2) as well as the combustion engine is controlled with the test stand automation system. The engine load (respectively the engine torque) is forced with the 4-quadrant-machine (the 4-quadrant-machine "retards" the engine - the engine holds against this load with (more) fuel injection), whereas the engine is speed-regulated. That means the ECU gets a voltage from 0 to 4.4 V for engine speeds from 850 rpm to 2300 rpm from the automation system.

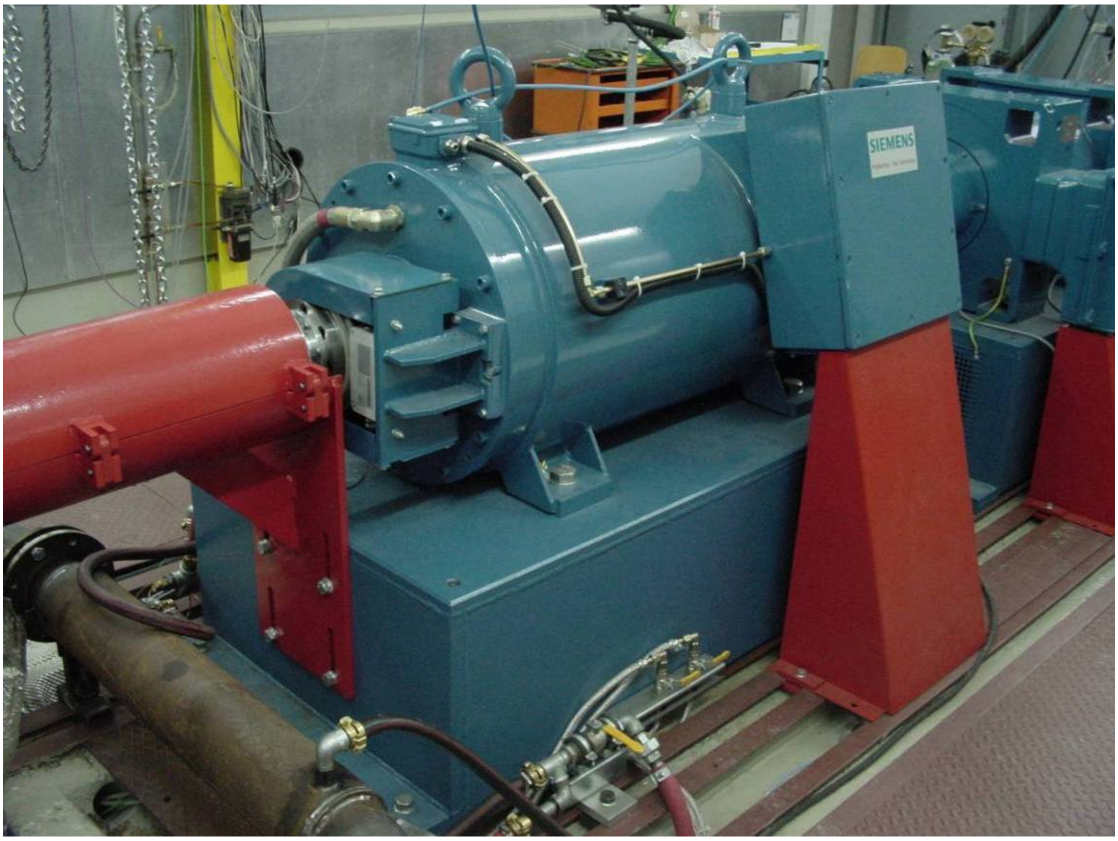

Fig. 2: 4-quadrant machine simulates hybrid functionalities

4 Engine condition determination

At the beginning after reception in Month 2, the JD engine was disassembled to determine and to document the new condition. This was necessary for later engine condition comparisons, especially in case of vegetable oil operation. Out of literature researches, the experience of the LVK and the experience of the project partners John Deere and VWP it is known, that in case of vegetable oil (rape seed oil) operation there can be problems with coking, e.g. on the valves, in the injectors or on the piston crown of the combustion engine. Therefore an accompanying engine condition determination will be executed, to eliminate an engine failure because of e.g. tightened piston rings (which could result out of coking).
The following figures give an impression of the condition of the new engine.

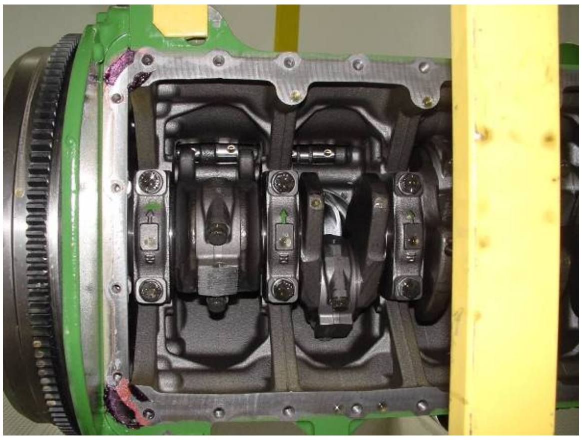

Fig. 3: Snapshot from the bottom after disassembling of the cylinder 1 oil pan (cylinder 6 next to the flywheel)

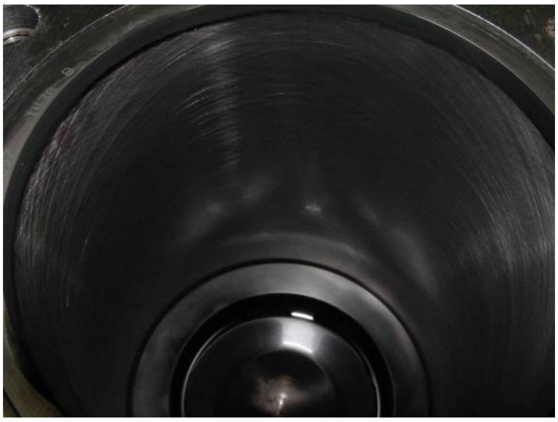

Fig. 4: cylinder liner and piston of

Fig. 5: part of the cylinder head (from the bottom)

Fig. 6: piston with piston rings

5 Adaption and purpose of measurement

After disassembling the combustion engine, the next step was the adaption of measurement. In terms of the fact that pure vegetable oil combustion engine operation is sensitive for temperature (the kinematic viscosity of rape seed oil is approximately ten times higher then diesel fuel at a temperature of 40 °C), thermal elements were adopted in several parts of the combustion engine.

These parts are:

- fuel temperature (several measuring points over the fuel flow system from tank to injector)
- air intake temperature
- cylinder head (6 thermal elements, one per cylinder)
- cylinder liner top dead center / bottom dead center of cylinder 1, which is the coolest because of the cooling fluid flow in the combustion engine
- exhaust temperature
- cooling fluid temperature
- lubricant temperature
- exhaust gas recirculation temperature

Furthermore different pressures are measured, like the above described pressure indication system for thermodynamic analysis, but also “static” pressures (that means pressures, which vary very slowly compared to the cylinder pressure) like the intake or the exhaust pressure before and after the cylinder head, respectively.

An oxygen sensor is adapted after the turbine of the turbocharger to measure the oxygen concentration of the exhaust gas, whereby it is possible to suggest the air-fuel ratio (A/F-Ratio). The A/F Ratio describes the air/fuel mixture. Based on this ratio it is possible to draw conclusions regarding the combustion temperatures, the emission formation or the efficiency.

Figure 7 shows the combustion engine on a designed and constructed frame, which also carries the engine external cooling system connection. Not only the engine itself needs cooling fluid, but also the intercooler, the fuel cooler (for fuel temperature conditioning) and the pressure indication system to avoid thermal drifts.

Fig. 7: Engine on framework, cooling system assembly

As described before, it is very important to know the fuel temperature, especially in the fuel tank. The fuel tank system scheme is shown in the following figure:

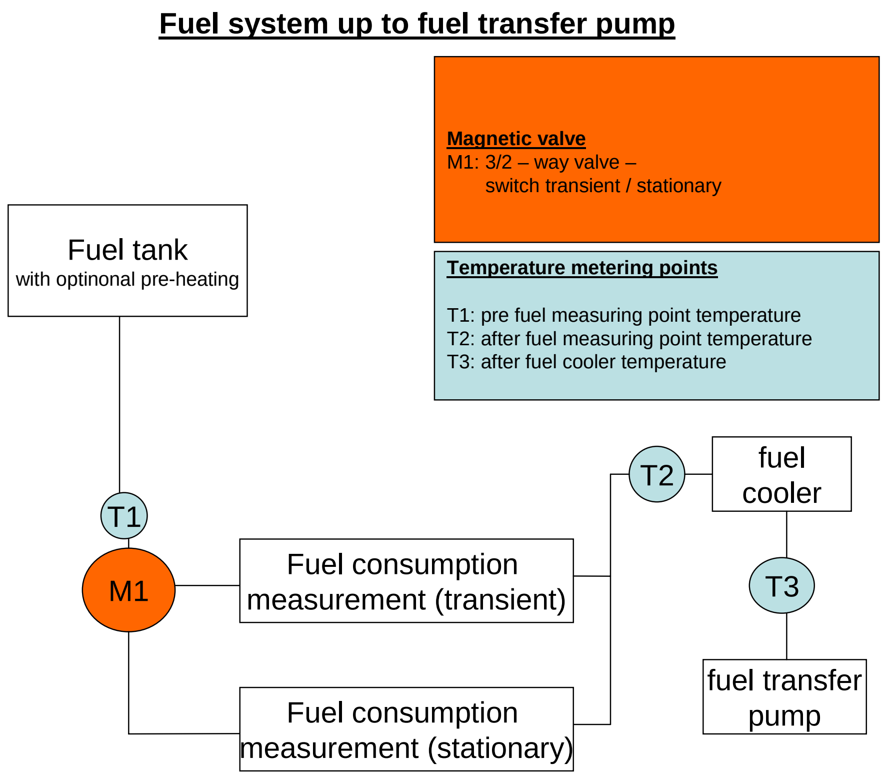

Fig. 8: Fuel tank system with measuring points

The fuel tank has the possibility of pre-heating the vegetable oil fuel getting similar viscositiy to diesel fuel, which is necessary for using the transient fuel consumption measurement, which is based on a centrifugal measurement methode (and requires a defined viscosity of the medium that flows through).
It is possible to switch between the fuel consumption measurement for stationary or for transient measurements.
Before the fuel reaches the transfer pump of the combustion engine, a fuel cooler makes sure that the vegetable oil fuel has the same temperature again as diesel fuel would have without pre-heating.

The EU directive 2004/26/EG specifies the emission measurement. For measuring the aeriform emission components nitrogen oxids, hydrocarbons and carbon monoxide, a “Horiba Mexa emission analyser” is used. It works with the chemiluminescence (NO_x), the infrared (CO) and the flame ionisation (HC) measurement procedure.
Particulate Matter (PM) is deposited gravimetricly using the “Nova Microtrol” system which extracts a part of the exhaust mass flow out of the engine exhaust system (part exhaust flow measurement with mass flow regulation).
Fig. 9 shows both:

Fig, 9: Exhaust measurement (left: Horiba Mexa, right: Nova Microtrol)

The tapping points for both systems are shown in Fig. 10. The points are on a location in the exhaust system after the muffler, which guarantees that exhaust from all six cylinders is measured.

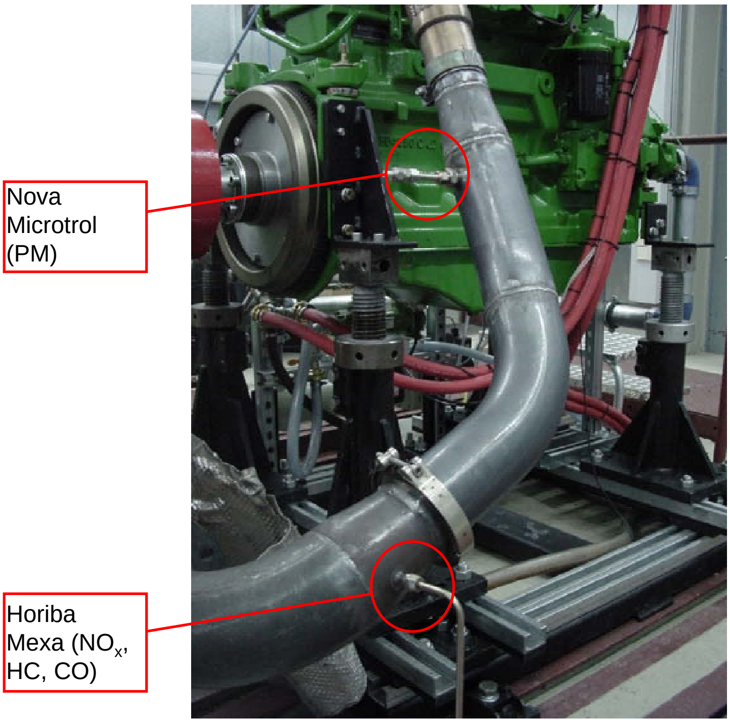

Fig. 10: Extraction points at the exhaust pipe

The extracted mass flow is piped over a paper filter, on which the PM is deposited (Fig. 11). After weighing the filter element, which was loaded e.g. for 600s with particulate matter out of the part exhaust flow, the conversion of the emissions in [g/kWh] is performed after the measurements.

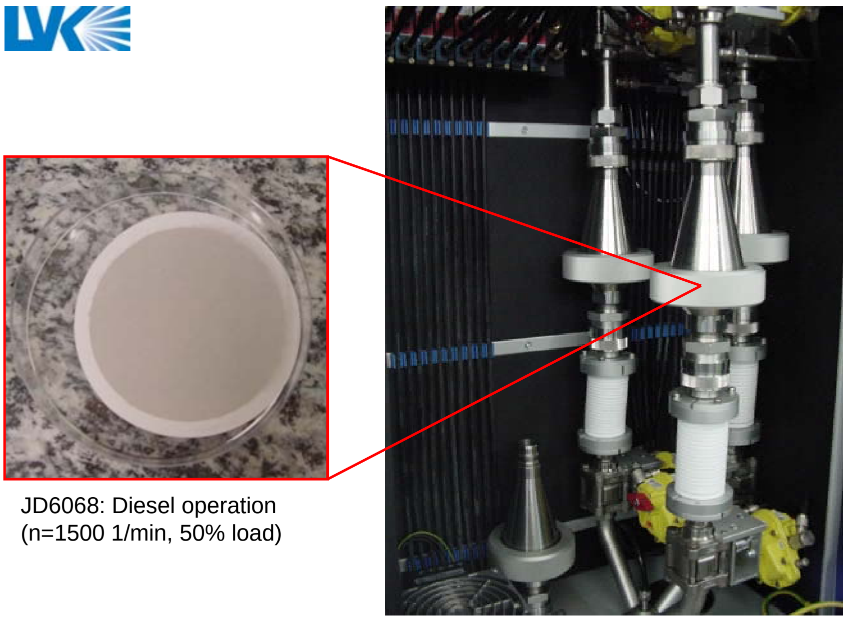

Fig. 11: Filter bodies (right) and filter element after Diesel operation

Following explanations (chapter 6) by Dipl.-Ing. Stefan Innerhofer (VWP)

6 Engine adaption regarding the use of plant oil (VWP)

For the use of vegetable in advanced diesel engines it is necessary to convert the engines. All parts which are in contact with the fuel have to be adapted to vegetable oil.
These are:

- Vegetable oil fuel cycle
- Fuel filters
- Fuel regulating valve
- Fuel pump with pre-resistor
- Fuel preheating equipment
- Electronic control unit (ECU)

7 Conclusion and summary

In Task 2.7 the hybrid test stand was built up. After extensive testing with diesel as fuel (please see Deliverable D2.8), the engine adaption regarding the use of vegetable oil was executed by VWP. The hybrid test stand is in operation (Fig. 12): it simulates a hybrid system, thus allowing experimental studying of different hybrid engine configurations in the next project steps.

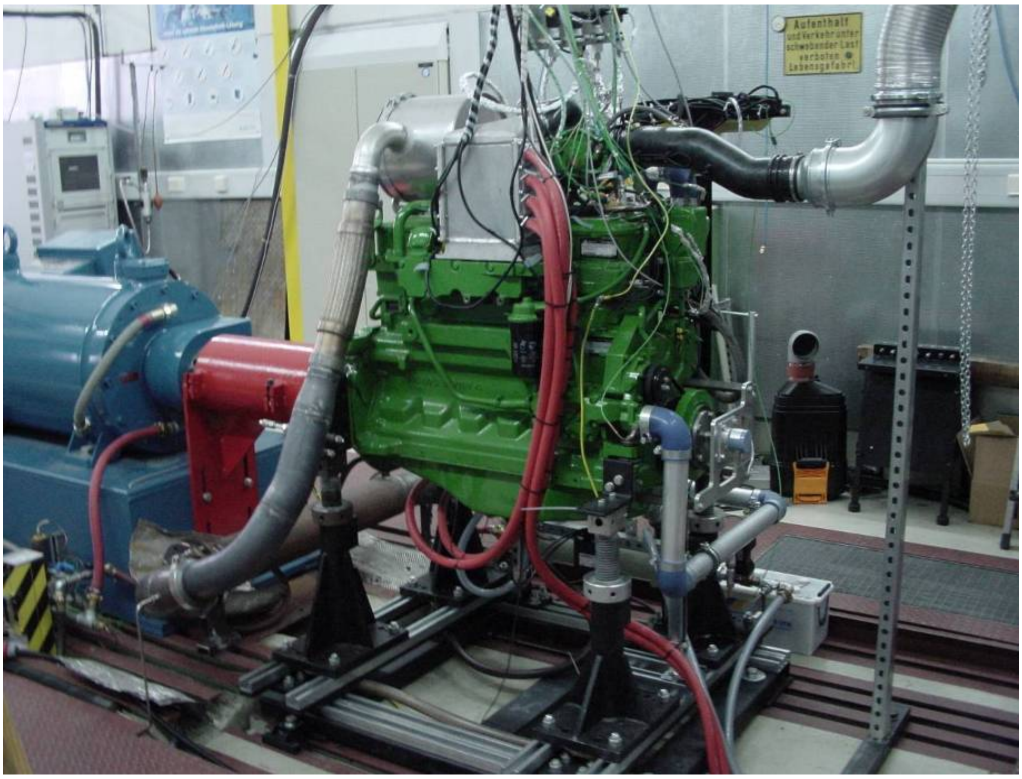

Fig. 12: Hybrid test stand