

Publishable Final Project Report

Demonstration of 2nd Generation Vegetable Oil
Fuels in Advanced Engines (2ndVegOil) –
TREN/FP7EN/219004/“2ndVegOil“

Agrartechnische Berichte aus Sachsen-Anhalt, Nr. 6

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The term "pure vegetable oil" (PVO) which figures in the title of the project was decided to be abandoned in the course of the project and was replaced by "pure plant oil" (PPO). The latter is the expression which is used among others in the European Standardization Committee (CEN) Workshop Agreement CWA 16379, Fuels and biofuels — Pure plant oil fuel for diesel engine concepts — Requirements and test methods, which is one of the major outcomes of this project. For this reason, the term "pure plant oil" is used thoroughly within this document.

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Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines (2ndVegOil)

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2nd Generation Pure Plant Oil

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1. Executive summary

Pure plant oil (PPO) use as engine fuel offers potentially the most comprehensive ecological, economic and social benefits of all biofuels. The challenges to address when using PPO as transport fuel are engine adaptation, fuel quality control, and emissions control. Further, limitations to the overall production potential have to be taken into account. This was done within the 2ndVegOil project by development and demonstration of tractor engines, 2nd generation pure plant oil (2G-PPO) fuels from different oil plants with a large sustainable production potential, and lubricants.

2G-PPO fuels are characterised by an extremely low content of alkali metals, earth alkaline metals and phosphorous. An oil cleaning method that is applicable for small agricultural enterprises was brought to maturity within the project, and was applied at with two reference presses for the production of all biofuels used for engine development and demonstration. One further, slightly different, further oil cleaning method was developed in parallel and applied on a third reference press, for the production of smaller batches of 2G-PPO.

Engine development was conducted on an engine test stand, and on EU Stage 3A, 3B and 4 compliant engines that were adapted to 2G-PPO operation and successfully tested with different 2G-PPO fuels. A major outcome of these tests is that the type of oil plays a minor role if the oil is almost entirely demineralised and the type of oil is known or identified by means of a fuel detecting sensor. Complementary development and tests on a hybrid engine test stand have proven the potential of hybridization for reducing particulate matter emissions in transient cycles such as the NRTC.

The developed engine concepts, 2G-PPO fuels with selected additives, and two appropriately formulated lubricants were subjected to comprehensive, scientific field tests and a fleet demonstration and monitoring programme in Germany, France, Austria and Poland. 16 tractors were tested in the field, under a broad range of operating conditions, with 8 different 2G-PPO fuels, for a total of 24,000 operating hours. Zero total failures were reported and all minor failures that were attributed to the use of 2G-PPO, instead of diesel as fuel could be traced back to fuel contamination and/ or inappropriate fuel storage. Hence, the proof of concept was provided for the developed combinations of modified diesel engines, 2G-PPO fuels with additives, and lubricants.

A major result of the project with regard to fuel standardisation is a European Standardization Committee (CEN) Workshop Agreement. This CWA defines minimum requirements for two classes of pure plant oil used as fuel in engines with and without exhaust gas aftertreatment system and has been published on 7 December 2011 as CWA 16379, *Fuels and biofuels — Pure plant oil fuel for diesel engine concepts — Requirements and test methods*.

An accompanying project assessment has shown that the main difference between a diesel and a 2G-PPO fuelled tractor lies in the saving of Green House Gas (GHG) emissions. The saving can be more than 60% for a tractor fuelled with 2G-PPO from rape seed, if the 2G-PPO is also used in the cultivation of the seed, and almost 70% for 2G-PPO from false flax (*camelina sativa*) seed if the seed is produced in mixed cultivation with wheat.

2. Project context and objectives

The advantages of pure plant oil compared to other biofuels

The 2ndVegOil project was guided by the theory that pure plant oil, used as engine fuel, has the potential for the most comprehensive ecological, economic and social benefits of all biofuels. In addition to ground-laying engine, fuel and lubricant development and demonstration work, the verification of this theory played a major role within the project.

The outstanding benefits of pure plant oils are due to their physico-chemical properties, and by their way of production, which involves few process steps and can be carried out done economically with small production units. The production process leads to only small energy losses, because no thermal or chemical process steps are involved. It can be implemented in small, decentralised units, without losing cost-effectiveness, thus allowing for short transport distances, and provides potential for additional income generation on farms; this in turn strengthens rural economic structures and social coherence. The non-toxicity and the low flammability are further advantages from a logistics point of view.

All other biofuels have a longer production chain and higher associated energy losses. E.g. ethanol production shows high energy losses because of the required distillation step, and synthetic biofuels, produced by the thermo-chemical process, can hardly be produced with efficiency higher than 50% due to high thermal losses in the gasification stage and the fuel synthesis (Fischer-Tropsch or similar). All biofuels, except pure plant oil, also present a more or less pronounced risk for the environment or for safety, due to the toxicity of some reactants used, and a generally high flammability.

The challenges to be met when using pure plant oil as engine fuel

The challenges to address when using pure plant oil as transport fuel are (1) engine adaptation, (2) fuel quality control, and (3) emissions control. When considering the potential impact of pure plant oil, also (4) limitations to the overall production potential needed to be addressed.

In the first instance, the low ignitability of pure plant oil and the strong temperature dependency of its viscosity make it unsuitable for use in conventional diesel engines. When used in non-modified engines, pure plant oil not only can lead to engine damage, particularly in technologically advanced engines, but also to unacceptably high emissions. Especially, particulate emissions in a cold start condition are tremendously high, while in most other operating ranges, pure plant oil shows advantages compared to conventional diesel.

Different engine adaptation concepts existed at the start of the project to overcome these principle difficulties, including bi-valent operation (start with normal diesel, continuous operation with plant oil), pre-heating of plant oil and a number of mechanical modifications, notably of the injection system. These concepts enabled Euro 3 emission levels, for road vehicles, and EU Stage 2, for non-

road vehicles, to be achieved in diesel engines specifically adapted for rape seed oil confirming to the former German pre-standard DIN V 51605. Development efforts to comply with the Euro 4 norm for road vehicles and EU Stage 3A for non-road vehicles were in progress, but no state-of-the-art solutions were yet in place. However, advanced biofuels should enable emissions to be kept within the limits of the forthcoming Euro 6 norm for road vehicles and EU Stage 4 / US Tier 4 for non-road vehicles. This was the major challenge to be met in this project.

Apart from trans-esterification to biodiesel and cracking/ hydrogenation of pure plant oil to BtL, both considered as different biofuels, no attempts had been made so far to modify pure plant oil in order to better match with engine requirements. The reason for that was that the majority of the advocates of pure plant oil-use as engine fuel considered any modification of the oil as manipulation of its “natural” character. This unpronounced dogma was questioned in this project, and a dual strategy was followed: engines as well as the fuel were adapted, to match each other, so that the combination of both enables high engine performance to be achieved, with minimum fuel consumption, while fulfilling most severe emission limits.

The physico-chemical properties of pure plant oil, which are relevant for engine combustion, are influenced by the seed growing conditions and by the oil pressing process. The consequence is that there are very different oil qualities on the market. Engine operation problems in previous fleet demonstration projects were almost exclusively due to plant oil not fulfilling minimum quality requirements, as they were expressed for instance in the pre-norm DIN V 51605, which applied at the beginning of the project in Germany. Hence, fuel quality definition and control are paramount if plant oil should play a greater role in the biofuels market.

Before the 2ndVegOil project, almost exclusively rape seed and sunflower oil were used as engine fuel in Europe. But, in particular, rape seed cultures are problematic, because rape seeds can hardly be produced in organic agriculture, thus requiring mineral fertilisation, chemical plant protection and related energy input for the production of fertiliser and plant protection chemicals. Furthermore, although ecological considerations make rape seed production desirable in the framework of crop rotation for improving the soil conditions or for increasing the acreage cultivated with flowering plants, rape seed production should also not be widened beyond the present level for ecological reasons. This limits the potential contribution of rape seed oil to the fuel market to a few percent. The situation is only slightly better for sunflower oil. Hence, if used at larger scale, other plant oils must be considered.

New oils for fuels

In this project, false flax (*Camelina sativa*), maize germ (corn), and jatropha oil were comprehensively used for tractor demonstration, in addition to rape seed and sunflower oil. Further, smaller batches of palm oil, coconut oil and soy oil were used for shorter test runs. *Camelina sativa* is a co-crop in mixed-cultivation with cereals and/ or fodder peas. Mixed-cultivation, i.e. growing of two or more plant species at the same time on the same field, allows switching from conventional to organic agriculture without yield losses. The broad leaves of

camelina sativa prevent weeds sprouting. The grains and peas are higher up and less exposed to humidity, therefore less threatened by fungi. This allows chemical plant protection to be avoided almost entirely. The oil from camelina sativa provides an extra yield of 100-300 liters per hectare in addition to the yield of the main crop. The potential of camelina sativa oil from mixed-cultivation could potentially cover a few percent of the total fuel demand in the EU.

Jatropha is produced in the arid zones of tropical countries. It is a hardy plant, which is resistant to drought and pests and can be grown on relatively infertile soils. It grows as a hedge and is used for protecting fields from goats. The oil from the jatropha nut cannot be used as food. There is thus no competition between food and fuel production, as long as jatropha is not grown on fertile soils to increase its yield.

As different oils also have different properties regarding engine combustion and emissions, widening the range of investigated oils increased the challenges of fuel quality and emissions control.

The specific concept and objectives of this project

This project has responded to the above-mentioned challenges, while maintaining the principle advantages of pure plant oil compared to other biofuels. The concept included the following central elements:

- combining the adaptation of the engine with an adaptation of the fuel;
- widening the potential for pure plant oil fuels by considering a broader range of oil seeds. These included, in particular, camelina sativa, which can be grown in combined culture (mixed-cultivation) with cereals or leguminosae, thus increasing the fuel potential tremendously in the EU, and jatropha which increases considerably the fuel potential in hot arid and tropical countries, without harming the environment if grown in extensive farming on infertile soils (also important for EU Mediterranean countries once climate change will have turned these countries into rather arid areas);
- introducing additives to the oil filtering process to achieve ultra-pure plant oil with a reduction of undesired substances to the limit of traceability; this oil was given the name 2nd generation pure plant oil (2G-PPO);
- introducing fuel additives without compromising non-toxicity to increase the ignition properties in a controlled manner (notably to control the oxidation stability);
- introducing lubricant additives to better function with the corresponding plant oil fuel;
- focusing on concepts that enable engines to benefit from the advantages of plant oil under quasi-steady-state conditions, i.e. hybrid engines, thereby exploiting to the maximum the specific advantages of plant oil compared to other biofuels.

The specific objectives were:

- to widen the range of oils considered, in order to increase the available fuel potential;

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- to investigate and demonstrate filtering additives and fuel additives for plant oils in order to better adapt the oil properties to present and future diesel engines, and to ensure a homogeneously high quality;
 - to investigate and demonstrate improved lubricants;
 - to achieve EU Stage 4 (US Tier 4) emission levels in medium-scale demonstration fleets;
 - to transfer the engine and fuel concepts to hybrid engines, preparing the base to achieve Euro 6 emission levels in road vehicles (comparable to EU Stage 4/ US Tier 4);
 - to prepare a proposal for a future European fuel standard.

The following progress beyond the state-of-the-art was expected:

- new engine concepts for a wider range of pure plant oils used as engine fuel;
- new concepts for plant oils (2G-PPO) better fitting to specific engine requirements, achieved through ultra-pure cleaning, blending, and additives, without giving up the specific advantages of non-toxicity and low flammability (the latter at least for the major part of the logistics chain);
- development/ demonstration of lubricant oils for engines running on 2G-PPO;
- successful demonstration of the operation of 2G-PPO-fuelled advanced tractors complying with EU stage 3A to 4 / US Tier 3 to 4 emission limits;
- successful operation of a 2G-PPO-fuelled hybrid vehicle engine fulfilling EU Stage 4 (comparable with Euro 6) emission limits;
- specific proposals for quality norms at European level, including the preparation of a EU-wide standard for 2G-PPO.

3. The project consortium

The consortium partner organisations

The 2ndVegOil project has been composed of 10 partners from Germany, France, Poland, Austria and The Netherlands who brought in complementary background and competences from the fields of engine development and construction, plant oil pressing and cleaning, lubricant formulation, agriculture, sustainable regional development, and standardisation.

John Deere, the consortium leader, is the worldwide largest producer of agricultural machines. It brought in its specific know-how on the requirements of series production of engines, and its specific know-how on vegetable oil fuelled engines, acquired previously in the course of a co-operation with VWP.

VWP is the worldwide leading company in the field of vegetable oil fuelled engines, holding a number of patents in the field and having a proof record of several 1,000 successfully converted vehicles running without problems and with low emissions on pure vegetable oil.

TUM was represented by the department LVK which is one of the leading university chairs on internal combustion engines. It brought in the know-how on hybrid engines and was in charge of transferring the results obtained on tractors to hybrid engines, thus ensuring the link to the automobile industry as well as to the academic world.

The **Lubrizol** Corporation is an innovative specialty chemical company that produces and supplies technologies that improve the quality and performance of our customers' products in the global transportation, industrial and consumer markets. These technologies include lubricant additives for engine oils, other transportation-related fluids and industrial lubricants, as well as fuel additives for gasoline and diesel fuel. Lubrizol developed and tested in-house advanced engine oils containing its additives, which were provided for the tests and demonstrations in the project.

Waldland, together with VWP, holds the know-how on the production of vegetable oil of a very high quality in decentralised oil presses and has already equipped an oil press with the latest most advanced oil press technology. This oil press will be further modified by Waldland in the project and will supply the oil for the tests and demonstrations activities.

RAEE is an experienced regional energy agency and working on the implementing pure vegetable oil activities in France. They were in charge of organising the demonstration fleet and disseminating results in France.

FRCUMA is a regional non-profit umbrella organization. It gathers eight departmental federations in charge of supporting 900 CUMAs (Cooperatives for the Use of Machinery in Agriculture). Under FRCUMA's supervision, the member farmers of two CUMAs were in charge of implementing the demonstration fleet and establishing a 2nd generation plant oil press in France.

ITP (formerly: IBMER) is a leading institute for agriculture and energy in Poland which has the necessary infrastructure for implementing the demonstration fleet and disseminating results in Poland.

NEN is the national standardization body of the Netherlands. It holds the Secretariat of the European standards' committees working on (bio)fuels and sustainability criteria. It brought in its capacity for defining a European standard for 2nd generation plant oil-based fuels and guided the other project partners at this regard.

IBDI - regineering is primarily specializing in energy conversion methods in sustainable cycles in decentralized energy sources. As a partner of VWP, IBDI works on projects in the fields of development and demonstration of plant oil fueled engines.

B.A.U.M. Consult GmbH is a consultant for sustainable development of communes, regions and enterprises. It was not an official consortium partner, but supported John Deere in the project management as a subcontractor. Further, B.A.U.M. was in charge of the establishment and maintenance of the project website and of the project assessment.

Contact names and addresses

Acronym	Organisation name	Contact name	Email
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Figure 1:

The project consortium at Cuma Plaine de Faverges/ France (from left to right and from back to front):

Prof. Dr.-Ing. Georg Wachtmeister (TUM), Alain Haupais (French engine expert), Tino Wunderlich (IBDI), Dr. Georg Gruber (VWP), Yves Francois (Cuma PdF), Hannes Blauensteiner (Waldland), Dominique Jacques (RAEE), Marjan Wesselingh (NEN), Christian Duft (IBDI), Dr. Michael Stöhr (B.A.U.M.), Stefanie Dieringer (John Deere), Dr. Andreas Hubert (TUM), Christine Schübl (Waldland), Simon Peal (Lubrizol), Stefan Innerhofer (IBDI), Prof. Dr.-Ing. Peter Pickel (John Deere).



Figure 2:

The project consortium in Poznan/ Poland (from left to right, standing persons first):

Prof. Dr.-Ing. Peter Pickel (John Deere), Dr. Andreas Hubert (TUM), Dr. Georg Gruber (VWP), Stefanie Dieringer (John Deere), Dr. Piotr Pasyniuk (ITP), Georg Rütz (John Deere), Christine Schübl (Waldland), Hannes Blauensteiner (Waldland), Jarno Dakhorst (NEN), Dr. Michael Stöhr (B.A.U.M.), Dominique Jacques (RAEE), Charles Guillot (FRCuma), Reinhardt Six (RAEE – until 2009)

4. Key statements of consortium partners

John Deere

Ich selbst fand meinen Einstieg bei John Deere und zum Thema Pflanzenölkraftstoff durch eine eher trockene Masterarbeit zum Thema „Analyse der technisch-wirtschaftlichen Trends und Anwendungspotenziale erneuerbarer Energien bei mobilen landwirtschaftlichen Arbeitsmaschinen“. In dieser Studie, die zeitlich in der Bewilligungsphase von 2nd VegOil lag, wurden marktverfügbare Biokraftstoffe hinsichtlich ihrer Energiebilanz bei der Erzeugung, sowie hinsichtlich der wirtschaftlichen Vor- und Nachteile analysiert. Dabei war ich zu Beginn der Arbeit eher skeptisch gegenüber Biokraftstoffen.



Stefanie Dieringer with Prof. Dr.-Ing. Peter Pickel



Dabei war ich zu Beginn der Arbeit eher skeptisch gegenüber Biokraftstoffen.

Die Ergebnisse der Studie – beste Energieeffizienz bei der dezentralen Erzeugung von Rapsölkraftstoff gegenüber Ethanol, Biodiesel und Biomethan, sowie eine Kosteneinsparung von bis zu 60% gegenüber fossilem Agrardiesel – haben mich jedoch nach und nach von der Idee überzeugt. Wenn man weitere Aspekte wie die parallele Erzeugung von Nahrungsmitteln (Presskuchen als Eiweißfuttermittel) und Kraftstoffen (Pflanzenöl als Nebenprodukt der Futtermittelerzeugung!) berücksichtigt, macht diese Idee eines energieautarken Landwirts mehr und mehr Sinn. Auch die Tatsache, dass das nachhaltige Produktionspotential von Pflanzenölen in Deutschland in etwa dem Kraftstoffverbrauch des Agrarsektors entspricht, sind gute Argumente für Pflanzenölkraftstoffe in der Landwirtschaft. Zu guter Letzt entspricht diese für die Selbstversorgung mit Pflanzenölkraftstoff nötige Anbaufläche etwas 10% der landwirtschaftlichen Nutzfläche und damit etwas weniger als der benötigten Anbaufläche für Futtermittel der Zugtiere („Hafermodell“).

Mein persönliches Fazit ist, dass der Einsatz von Pflanzenölkraftstoffen am besten in der Landwirtschaft plaziert ist, wobei die pflanzlichen Rohstoffe entsprechend der jeweiligen Standorteigenschaften und individuellen Randbedingungen gewählt werden sollten.

2nd VegOil begann auf dem Höhepunkt der Nachfrage nach Pflanzenölkraftstoffen 2008. Kurze Zeit später brach der Markt jedoch, unter anderem durch politische Maßnahmen verursacht, ein. Dieses Projekt ermöglichte es uns als John Deere, dennoch weiter an einer Technologie zu arbeiten, die für unsere Kunden zumindest kurzfristig scheinbar uninteressant war. Zusammen mit Projektpartnern aus verschiedenen Fachbereichen ist es uns gelungen, den Weg hin zum Stufe 4 Pflanzenölmotor zumindest zu ebnen. Was vorher meist als unmöglich eingestuft wurde – die Verwendung von Pflanzenölkraftstoffen in Motoren mit modernen Abgasnachbehandlungssystemen – wurde in 2nd VegOil erfolgreich umgesetzt. Außerdem wurde die Rohstoffbasis für Pflanzenölkraftstoffe erfolgreich erweitert, so dass es Landwirten in verschiedenen Regionen der Welt möglich sein wird, selbst erzeugten Kraftstoff zu nutzen.

I entered John Deere and the plant oil fuel subject during a rather theoretical master thesis („Analysis of Technical and Economical Trends and Application Potentials of Renewable Energies in Mobile Agricultural Machines,,), which I wrote during the period of the project’s final approval. It was a survey analysing the energy efficiency of the production of various commercially available biofuels, as well as their economical benefits.

Being very sceptical towards biofuels at the beginning of the survey, my results (decentrally produced rapeseed oil showed the best energy efficiency compared to biodiesel, ethanol and biomethane) convinced me of a very smart idea: plant oil fuel as a by-product of the protein feed production! This enables our farmers to be more independent from protein and fossil fuel imports, this approach can secure the food supply in the future.

Looking at the production potential of plant oils, it becomes clear that this cannot be a fuel for the whole mobile sector. My personal conclusion is that it only makes sense in local or regional production chains, as a fuel both produced and used by agriculture.

The 2nd VegOil project started at the peak of a booming plant oil fuel market in 2008. Shortly after the project kick-off, the demand for plant oil fuel engines broke down for several reasons, amongst others because of a changed tax legislation regarding biofuels and agricultural diesel subsidies. During these harsh times, the 2nd VegOil project enabled us to continue the work on a technology which wasn’t much requested by our customers for the time being. Together with our project partners coming from different disciplines we were able to clear the way for a stage 4 plant oil powered engine. Furthermore, we were able to widen the fuel feedstock to a variety of plants, potentially making farmers of all regions independent from fossil fuels and enabling them to feed the world.

Stefanie Dieringer

John Deere ETIC
www.deere.com

Vereinigte Werkstätten für Pflanzenöltechnologie (VWP)

Mit Firmengründung in 1994 hat VWP immer einen ganzheitlichen Entwicklungsansatz verfolgt, der sich auf die Komponenten Motor/Emission, Kraftstoffqualität/Normierung und nachhaltige Pflanzenölproduktion mittels neuartiger Ölpflanzen (Leindotter/ Jatropha) u.a. im sogenannten Mischfruchtanbau bezog. Durch die Motorentwicklungspartnerschaft von VWP und John Deere Werke Mannheim konnte dieser Ansatz ab 2001 internationalisiert und auf europäischer Ebene vorangetrieben werden. 2ndVegoil sollte eine Antwort auf sämtliche Problemstellungen der Zukunft geben, um innerhalb der erneuerbaren Energien die Pionierstellung von reinem Pflanzenöl in der Landwirtschaft zu prolongieren und auch in Europa zu positionieren.



The VWP team (from left to right): Thomas Kaiser, Alois Dotzer, Dr. Georg Gruber.

Von allen EU-unterstützten Pflanzenölprojekten war 2ndVegoil für VWP zweifellos das komplexeste Projekt mit der größten Herausforderung und dem höchsten Risiko. Schließlich ging es nicht mehr um Deutschland und Rapsöl allein, sondern um die Demonstration der Alltagstauglichkeit modernster Common-Rail-Traktormotoren in vier Ländern mit fünf unterschiedlichen Pflanzenölen, drei Abgasstufen und auf einem Hybridprüfstand der Technischen Universität München mit Elektro- und Pflanzenölmotor. Es spricht sehr für die Qualität der von unserem technischen Vorstand, Alois Dotzer, verantworteten Pflanzenöltechnologie, dass im Laufe der dreieinhalb Jahre praktisch keine relevanten, pflanzenölbedingten Schäden an den Motoren aufgetreten sind. Aus der Vergangenheit bekannte Düsenverkokungen, Ablagerungen, Schmierölauffüllungen mit notwendigen verkürzten Wechselintervallen etc. spielen keine Rolle mehr.

Neben den detaillierten Motoranpassungen war dies auch den hochwertigen Kraftstoffen der 2. Generation reiner Pflanzenöle mit drastisch abgesenkten Werten für P, Ca/Mg geschuldet. Das VWP/ Waldland-Verfahren konnte seine Funktionalität für mehrere Pflanzenöle dauerhaft und zuverlässig nachweisen und somit die dezentralen Ölmühlen im Wettbewerb um die Kraftstoffe der Zukunft halten. Die Ergebnisse fanden ihren Weg auch in die erste europäische (unverbindliche) Pflanzenöl-Vornorm. Das von der Europäischen Normungsbehörde (CEN) veröffentlichte CWA 16379 kann in seiner Bedeutung für die weitere internationale Marktentwicklung gar nicht hoch genug eingeschätzt werden. Einmal bezieht es sich auf Pflanzenöle allgemein und zum anderen regelt es über zwei sich unterscheidende Normen sowohl die Kraftstoffqualitätsanforderungen modernster Pflanzenölmotoren, aber auch die Qualitätsanforderungen der überwiegend sich im Markt befindlichen Motoren mit schlechteren Abgasstufen.

Als Vorsitzenden des CWA 16379 und Projektleiter bei VWP war für mich die internationale Zusammenarbeit und die vertrauensvolle, konzentrierte Atmosphäre unter den Projektpartnern immer Ansporn und Inspiration gleichzeitig. Herzlichen Dank dafür!

Für die drängenden Probleme der Welt, nämlich die Veränderung des Klimas, die Preis- und Ressourcenabhängigkeit von fossilen Energien und die Notwendigkeit, bei zunehmender Weltbevölkerung die Menschheit mit nachwachsender Energie und Nahrung gleichzeitig und preisgünstig zu versorgen, liefert 2ndVegoil vor allem für die Landwirtschaft die derzeit schlüssigste Antwort. Nach unserer langjährigen Pionierarbeit ist nun auch auf europäischer Ebene durch 2ndVegoil der Nachweis für einen möglichen Paradigmenwechsel in der Landwirtschaft geliefert worden: der Wechsel und die Abkehr von einem auf Ressourcenausbeutung ausgelegten zentralen und endlichen fossilen Energiekonzept hin zu einem dezentralen und nachhaltigen, erneuerbaren Energiekonzept ist technisch sofort machbar und ökonomisch und ökologisch sinnvoll.

After founding the company in 1994, VWP has always focused on an integrated R&D concept which included the components engine / emissions, fuel quality / norms and standards and sustainable plant oil production, e. g. companion cultivation with *camelina sativa*. This approach has been more internationalized and brought up on European level since 2001 through the R&D partnership between John Deere Mannheim and VWP. It was the goal of 2ndVegoil to bring answers to all future problems in order to prolong and stay pioneers within the renewable energy section using pure plant oil for farming and also to establish oneself in Europe.

Out of all supported plant oil projects through the European Union 2ndVegoil was doubtless the most complex project for VWP with the greatest challenges and the highest risk, as the focus was not only on Germany and canola anymore. Furthermore, 2ndVegoil had to demonstrate the general functionality of modern Common-Rail tractor engines in four European countries with five different plant oils, three emission levels and a hybrid test stand at the Technical University of Munich with an electric generator and a plant oil engine. It was an outstanding result that the plant oil technology that was developed by our technical manager Alois Dotzer has practically not shown any relevant plant oil related engine failure within the last three and a half years. Coke residues on injectors, pistons, piston rings, the rising level of lubrication oil with consequently reduced intervals of lubrication oil change which all were known from the past do not occur anymore.

After all these good results were not only owed to the detailed engine adaptations but also to the high quality fuel of 2nd Generation vegetable oil with drastically reduced parameters for phosphorus, potassium and magnesium. The so called VWP / Waldland purification system could continuously and reliably proof its functionality for several plant oils and therefore keep the decentralized oil mills competitive within the future fuels. The results also found their way into the first European (non-binding) plant oil pre-norm. The CWA 16379 which was published by the European Agency for Norms and Standards (CEN) has a very high meaning for future market developments of the idea of using pure plant oil in diesel engines. For once it refers not only to a single plant oil but to plant oils in general. Additionally, it regulates through two different norm tables the fuel quality requirements of advanced plant oil engines and also the fuel quality requirements of the already in the market existing plant oil engines with reduced emission levels.

As chairman of CWA 16379 and project leader at VWP the international cooperation and the confidential and concentrated work atmosphere amongst the project partners was always motivation and inspiration at the same. Thank you very much!

For the most pestering world problems such as climate change, dependency on rising prices and decreasing resources of fossil energies and the need of providing food, feed and fuel to an increasing world population at the same time to affordable prices, 2ndVegoil especially for the agricultural sector is the most conclusive answer. After our long lasting pioneer work in this sector 2ndVegoil was enabled to proof that a paradigmatic change in fueling agriculture is possible even on European level. 2ndVegoil could demonstrate that a change from a centralized fossil fuel energy concept which is based on limited resources to a decentralized and sustainable renewable energy concept is technically immediately practicable and economically and ecologically feasible.

Dr. Georg Gruber

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Technische Universität München (TUM)

Die Sicherstellung der Energieversorgung und damit auch der Mobilität ist eine der wichtigen Aufgaben unserer Gesellschaft. Um dieses Ziel zu erreichen, müssen alternative Energieträger gefunden werden. Unter den möglichen Alternativen hat kaltgepresstes Pflanzenöl insbesondere für den Betrieb von landwirtschaftlichen Maschinen ein hohes Potential als Kraftstoff für die Zukunft. Wichtige Randbedingungen hierzu



sind eine dezentrale Herstellung mit möglichst wenig Prozessaufwand und eine gute Verträglichkeit für den Verbrennungsmotor. Mit den Forschungsaktivitäten innerhalb des EU-Projektes 2ndVegOil konnte eindeutig nachgewiesen werden, dass beide Randbedingungen erfüllbar sind. Die Qualität des Pflanzenölkraftstoffes der 2. Generation wurde mit Maßnahmen, welche weiterhin ohne Raffineriestritte auskommen, deutlich verbessert. Im Vergleich zu Pflanzenöl der 1. Generation ist nun die Motorverträglichkeit ausgesprochen gut. Wird dazu noch die erforderliche Antriebsleistung durch Hybridisierung unterstützt, dann lassen sich auch zukünftige Abgasgrenzwerte einhalten. Durch das Projekt 2ndVegOil ist Pflanzenöl zu einem attraktiven Kraftstoff für den landwirtschaftliche Einsatz geworden.

To secure the energy supply and consistently the mobility is one of the important objectives our society. In order to achieve this target alternative energy sources have to be found. Among possible alternatives, plant oil shows a rather high potential for a future fuel particularly for agriculture engines. However, important boundary conditions are decentralized production with simple processes and a good compatibility with the needs of combustion engines. The activities within the EU-research project 2ndVegOil have revealed that both boundary conditions can be fulfilled. The quality of the 2nd generation plant oil was significantly improved still without refinery measures. Compared with 1st generation plant oil, the engine-compatibility is greatly good. With an additional support of hybrid propulsion system even future emission limits can be kept. With results of the project 2ndVegOil plant oil becomes an attractive fuel for agricultural engines.

Prof. Dr.-Ing. Georg Wachtmeister

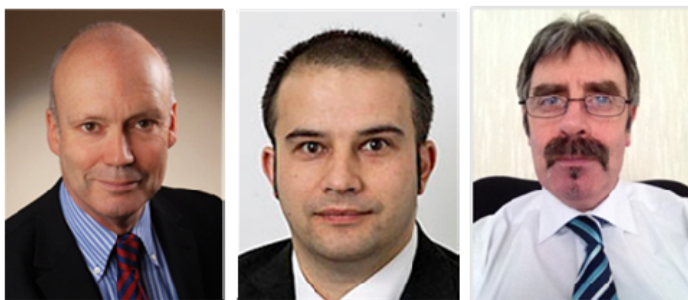
Ordinarius

Lehrstuhl für Verbrennungskraftmaschinen TU München

www.lvk.mw.tum.de

Lubrizol Ltd.

As Lubrizol entered this project, we were well aware of increased challenges that bio-diesel fuels present for diesel engine lubricants, but were not so experienced regarding pure plant oils. This project presented an ideal opportunity to test two different quality levels of engine oil in tractors, fuelled by pure plant oils, with and without exhaust gas after treatment. The performance level of the lubricants ensures that can be made widely available to farmers.

The Lubrizol logo consists of the word "Lubrizol" in a bold, black, sans-serif font. A blue swoosh underline is positioned beneath the letters "i", "z", "i", and "o".

During the field trials, no lubricant related failures were experienced. Extensive field testing and monitoring of aged lubricant quality revealed no lubricant related engine problems. The valuable lesson learned was that the effective filtration of the vegetable oils, and appropriate conversion of the John Deere tractor engines, allowed use of widely available lubricants, with a 250 hour oil drain interval. In other words there should be no commercial barriers to effective lubrication of tractors burning 2nd generation vegetable oils.

Participating in the 2nd VegOil project gave Lubrizol access to a wide range of experts from both the technical and practical application point of view. This was absolutely key in coming to a successful conclusion to the project and provided a rewarding experience for the Lubrizol team members.

Simon Peal

Lubrizol Deutschland GmbH

www.lubrizol.com

Waldland Naturstoffe GmbH

Waldland ist ein KMU in der Region Waldviertel, im nördlichen Niederösterreich, und produziert in Kooperation mit rund 800 LandwirtInnen Agrarrohstoffe, wie Pharmapflanzen, Gewürze oder Backsaaten, die an den Waldland Betriebsstandorten für verschiedenste Abnehmer weiterverarbeitet und veredelt werden. Das Unternehmen ist aber auch Spezialist bei der Ölverarbeitung. Viele verschiedene Pflanzenöle aus Raps, Mariendistel, Sonnenblume, Maiskeimlingen, Leindotter oder Mohn werden hier produziert und verarbeitet. Diese großen Mengen an kaltgepresstem Pflanzenöl werden vorwiegend für die Futtermittelindustrie (45%), technische Zwecke (35%), aber auch für die Lebensmittelindustrie (20%) hergestellt.



The Waldland project team (from left to right): Ing. Gerhard Zinner CEO and Project Manager, Christine Schübl B.A. Project Administration, Ing. Hannes Blauensteiner Project Coordinator

Im Geschäftsfeld der Pflanzenöle ist Waldland Spezialist, von der Ölpflanzenproduktion bis hin zur Ölpresung und Verarbeitung, dies machte das Unternehmen zu einem kompetenten Projektpartner für die Pflanzenöleentwicklung. Technische Öle, wie Pflanzenölkraftstoff nach DIN 51605, etablierten sich als stetig wachsender und zukunftssträchtiger Bereich. Waldland möchte an der Forcierung einer autarken Landwirtschaft von fossilen Kraftstoffen mitwirken. Mit der Teilnahme an dem EU Forschungsprojekt stellte sich das Unternehmen der Herausforderung, einen Pflanzenölkraftstoff für modernste Motoren, in höchster Reinheit und Qualität, produzierbar mit einem innovativen, aber zugleich möglichst einfach zu implementieren Herstellungsverfahren für dezentralen Ölmühlen jeglicher Kapazitätsgröße zu entwickeln.

Waldland ist nun reich an Erkenntnissen und besitzt aufgrund der erfolgreichen Ergebnisse des EU Forschungsprojektes 2ndVegOil die Kompetenz, Pflanzenölkraftstoffe aus verschiedenen Ölpflanzen herzustellen, sogar in höherer Qualität als im EU-weiten Standard CWA 16379 festgelegt, aber auch die Fähigkeit das gewonnene Know how weltweit zu verbreiten.

Ein weiterer Benefit ist, dass das erfolgreiche Konzept des 2ndVegOil Projektes, direkt auf die Region Waldviertel umlegbar ist. Aufgrund der innovativen Projektergebnisse ist es auch österreichweit möglich viele kleine regionale Ölerzeuger für die Herstellung eines modernen Pflanzenölkraftstoffes aufzurüsten, wodurch regionale LandwirtInnen mit diesem Biokraftstoff beliefert werden können. Die Region würde dadurch unabhängig vom fossilen Kraftstoff werden, eine sichere Lebensmittelproduktion erreicht, sowie die Diversifizierung der Landwirtschaft in der Region unterstützt.

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Waldland is a medium-sized enterprise in the Waldviertel, a region in the north of lower Austria. In cooperation with about 800 farmers are agricultural commodities produced, as medicinal plants, spices or bakery seeds, which are processed and refined in Waldland's operating locations for various costumers. Furthermore the company is specialised in oil production. Many different vegetable oils from rape seed, milk thistle, sunflower, maize germ, camelina or poppy seeds are produced and processed. These large quantities of cold pressed vegetable oils are mainly manufactured for food industry (45 %), technical purposes (35 %), as also for food industry (20 %).

In business of vegetable oils Waldland is specialist, from the production of oil plants up to oil pressing and processing. That makes the enterprise to a competent project partner for vegetable oil development. Technical oils, as plant oil fuel according to DIN 51605, established as continuous increasing and promising segment. Waldland likes participating to expedite of a self-sufficient, independent agriculture from fossil fuels.

By participating on the EU research project, challenges the company the development of a plant oil fuel in highest purity and quality for advanced engines, which should be producible with an innovative and as simple as possible to implementable manufacturing process for decentralized oil mills each capacity size.

Waldland is now, because of the outstanding results of the research project, richer in knowledge and owns the competence to produce plant oil fuel from various oil fruits. Even in higher quality as determined in the EU-wide standard CWA 16379, as to spread knowledge worldwide. The additional benefit is that the successful project concept is directly apportionable to Austria and the Waldviertel region. So it is possible to upgrade a lot of small oil producers for the manufacture of advanced pure plant oil fuel, and farmers can be served with this bio fuels. The region could become independent of fossil fuels, a secure food production effected, as diversification of regional agriculture supported.

Gerhard Zinner, Christine Schübl, Hannes Blauensteiner

Waldland Naturstoffe GmbH

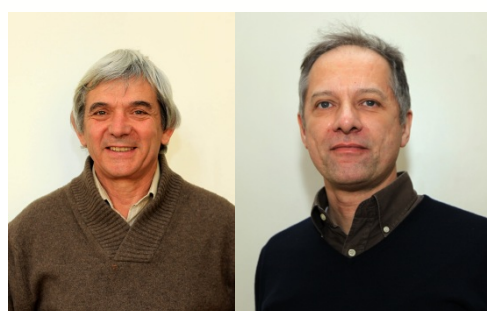
www.waldland.at

Fédération Régionale des CUMA de Rhône-Alpes (FRCUMA)/ Rhônalénergie-Environnement(RAEE)

Deux groupes d'agriculteurs Français organisés en CUMA (Coopératives d'Utilisation de Matériels Agricoles) se sont engagés dans le projet 2ndVegOil, avec la conviction qu'il fallait renforcer **l'autonomie énergétique** des exploitations agricoles, après les constats suivants:



Rhône-Alpes



- **L'ère du pétrole** bon marché est révolue. Pour la sécurité alimentaire, il est urgent de rechercher des alternatives fiables aux carburants fossiles.
- **La biomasse** est une source d'énergie qui n'aggrave pas l'effet de serre. Par leur fluidité et leur densité énergétique les biocarburants peuvent remplacer les produits pétroliers.
- **Les huiles végétales (HVP) pures** sont particulièrement intéressantes : meilleur bilan énergétique en circuit court, produites localement avec des technologies accessibles aux agriculteurs, source de revenu complémentaire... tout en n'étant que des tourteaux si appréciés pour l'alimentation des animaux (moins d'importations).
- Les HVP carburant **ne s'opposent pas à l'alimentation**. Avant la motorisation, 15% des surfaces étaient consacrés aux fourrages pour les animaux de trait. Une sole raisonnable d'oléagineux remplirait demain la même fonction, avec plus d'efficacité.

Toutefois, l'avenir de **cette filière était menacée** par l'incompatibilité croissante des HVP avec les moteurs modernes, optimisés avec des carburants fossiles pour satisfaire aux nouvelles normes d'émission. Fallait-il choisir entre les bénéfices globaux des HVP ou la réduction des seuls polluants réglementés ?

Le voyage d'étude de mars 2005 à Fürstfeldbruk (Allemagne), organisé par Rhônalénergie-Environnement dans le cadre du projet « 100% RENET », nous a permis de rencontrer de futurs partenaires du projet 2ndVegOil. Nous avons rapidement partagé leur expérience et leur conviction en faveur d'une approche combinant :

- Une **amélioration de l'HVP**, qui reste accessible dans les conditions de production à la ferme,

- Une **adaptation de moteurs** de série à un coût compatible avec les moyens financiers des agriculteurs.

En 2006, le gouvernement Français a enfin légalisé la production et l'utilisation d'HVP carburant en agriculture. Mais il restait à convaincre l'entourage politique et professionnel de la nécessité d'**anticiper pour co-construire** une avancée (tel que la prénorme CWA 16379) plutôt que se contenter de l'existant et risquer subir plus tard des décisions inadaptées aux réalités du terrain.

Ce fut tout le mérite des agriculteurs qui se sont lancés dans un partenariat nouveau avec des industriels et des scientifiques à l'échelle européenne. Une merveilleuse occasion de **mieux se connaître**. Merci également à la Région Rhône-Alpes et au Département du Rhône, qui ont bien voulu joindre leur soutien financier à celui de la Commission Européenne.

Aujourd'hui, avec la force de leur expérience, les agriculteurs sont devenus les meilleurs promoteurs des techniques qu'ils ont testées, et qu'ils ont **décidé de continuer** à utiliser après la conclusion du projet ... mais dans l'attente d'une offre commerciale par les constructeurs. Car les HVP ont vraiment leur place dans le bouquet énergétique du futur.

Two groups of French farmers, organized within CUMAs (Cooperatives for the Use of Machinery in Agriculture), took actively part in the *2ndVegOil* project. They were convinced that energy self-sufficiency of the farms must be strengthened, based on the following facts:

- **The era of cheap oil is over.** For food safety, it is urgent that a reliable alternative to fossil fuels be found.
- **Biomass** is a power source that does not increase the greenhouse effect. As fluids with a high energy density, biofuels may replace petroleum-derived products.
- **Pure Plant Oils (PPO)** are especially interesting: best energy ratio in short cycle, can be produced locally with technologies accessible to farmers, extra source of income ... and they are the by-product of oilcake, a very valuable feed for cattle (thus less imports).
- PPOs are **not detrimental to food production.** Before motorization developed, 15% of farm lands were devoted to fodder production for draught animals. A reasonable part of oilseed crops in farm lands could still provide farm energy, with a greater efficiency.



The project team in France with the overall project coordinator (from left to right): Prof. Dr.-Ing. Peter Pickel (John Deere, overall project coordinator), Dominique Jacques (Rhônalpénergie-Environnement), Charles Guillot (FR Cuma), Yves François (chairman of Cuma Pleine de Faverges and test farmer), Lionel Ogier (chairman of Cuma VP), Dominique Ronzon (test farmer), Gilles Lentillon (press operator).

However, the future of **this sector was being threatened** by the growing incompatibility between PPOs and advanced engines which have to be optimized with fossil fuels in order to comply with new emission standards. Were we doomed to choose between either the overall benefits of PPO or reduction of just the regulated pollutants?

In 2005, a **study visit** in Fürstfeldbruk (Germany) was organized by *Rhônealénergie-Environnement* within the « 100% *RENET* » European project. We then got to know some future partners of the *2ndVegOil* project. After hearing of their experience, we soon shared their conviction in favor of a converging approach that could combine:

- an **improvement of PPO**, that should remain accessible under farm conditions,
- an **adaptation of serial engines**, at a cost within the financial means of farmers.

In 2006, at last, the French Government legalized the production and the use of PPO as fuel. But we still had to convince the political and professional environment that it was necessary to **be proactive in starting new initiatives** – such as the CWA 16379 pre-norm – rather than just rely on what existed and take a risk of having to accept later on decisions that may not be well adapted to the conditions in the field.

The farmers had the courage of venturing into a new kind of partnership with industrial operators and scientists at European level. This provided a wonderful opportunity to get to **know each other better**. *Région Rhône-Alpes* and *Département du Rhône* should also be thanked for their financial support in addition to the *European Commission*.

Today, based on their experience, the farmers have become the best proponents of the techniques they could test and that they decided to **keep using** after the conclusion of the project ... while waiting for a commercial offering. Indeed, PPOs have their place in the portfolio of energy solutions needed in the future.

Charles Guillot

FRCuma Rhône-Alpes
www.cuma.fr

Dominique Jacques, Patrick Biard

Rhônealénergie-Environnement
www.raee.org

Instytut Technologiczno-Przyrodniczy (ITP)

Zespół pracowników naukowych i pomocniczych Instytutu Technologiczno-Przyrodniczego, Oddziały w Warszawie i Poznaniu nadzorowali wykorzystanie do codziennych prac w gospodarstwach rolniczych pięć ciągników John Deere zasilanych czystym olejem roślinnym. Łącznie w trakcie trwania projektu ciągniki przepracowały około 8 300 rbh zużywając łącznie ponad 84 000 litrów czystego oleju rzepakowego. Ciągniki pracowały przy pracach polowych i transportowych od lekkiego transportu drogowego, poprzez lekka orkę, prace z agregatem uprawowo-siewnym po rozlewanie gnojowicy wozem asenizacyjnym 24 000 l w ciężkich warunkach polowych.



W trakcie eksploatacji wystąpiło kilka usterek. We wszystkich ciągnikach należało wymienić w wyniku uszkodzenia czujnik ciśnienia oleju oraz zawór magnetyczny. Ponadto zarejestrowano wycieki oleju z przedniego mostu, pęknięcie węża wysokiego ciśnienia, uszkodzenie silnika krokowego. Wszystkie te usterek nie wynikały z rodzaju stosowanego paliwa i były typowymi usterekami występujący również w eksploatacji ciągników z zasilaniem standardowym. W jednym przypadku usterka związana z wymianą kompletu wtryskiwaczy i pompy wysokiego ciśnienia była związana ze stosowanym paliwem. Niewłaściwe warunki przechowywania paliwa i w rezultacie dostanie się do niego wody spowodowało tak poważne uszkodzenie podzespołów ciągnika. Ponadto instalacja elektryczna oryginalnego systemu podgrzewania paliwa okazał się nieodporny na wilgoć i wymaga dopracowania.

Dzięki udziałowi w projekcie 2ndVegOil i w Oddziale ITP w Poznaniu podjęto próby nad wytwarzaniem paliwa roślinnego spełniającego warunki normy i możliwe do stosowania w zaawansowanych silnikach wysokoprężnych ciągników John Deere. Opracowano i wdrożono oryginalną technologię tłoczenia i oczyszczania oleju rzepakowego na cele paliwowe. Przeprowadzone badania laboratoryjne potwierdziły osiągnięcie wyznaczonego celu. Technologia ta stała się przedmiotem zgłoszenia patentowego wzoru użytkowego. Ponadto kierownictwo instytutu zdecydowało o kontynuowaniu badań nad doskonaleniem produkcji oleju z innych niż rzepak roślin oleistych. John Deere 6830 Premium będący własnością Gospodarstwa Doświadczalnego ITP w Poznaniu pozostawiono w wersji zasilanej czystym olejem roślinnym.

Doświadczenia zgromadzone w trakcie realizacji projektu w pełni potwierdziły możliwość stosowania czystego oleju roślinnego jako samodzielnego paliwa do wysokoprężnych silników ciągników rolniczych John Deere przystosowanych fabrycznie do zasilania takim olejem. Możliwe jest to w dowolnej temperaturze otoczenia. Produkcja takiego paliwa, ze względu na prostą i taną technologię może być prowadzona w gospodarstwie rolnym lub zespole gospodarstw na własne potrzeby. Uniezależnia to rolnika od podaży i zmiennych cen paliw ropopochodnych i umożliwia alternatywne zagospodarowanie własnych plonów roślin oleistych. Polscy rolnicy wykazali istotne zainteresowanie użytkowaniem ciągników zasilanych czystym olejem roślinnym.

The team of researchers and support staff of the Institute of Technology and Life Sciences, Branches in Warsaw and Poznan supervised day to day the farm works of five tractors of John Deere powered by pure vegetable oil. In total during the project time, all tractors consumed more than 84 000 liters of pure rapeseed oil and the total operating time was around 8 300 hours. The tractors were engaged in all farm works ranging from mild road transport by any field work ending with the fertilization tanker trailer of 24 000 liters manure capacity in really heavy field conditions.

During the operation there were several defects which result from normal use. In all tractors, the oil pressure sensor and solenoid had to be replaced due to damage. In addition, we recorded an oil leakage from the front axle, a high pressure hose rupture, a damage of the stepper motor. All these defects were not due to the type of fuel used and were typical faults occurring also in the tractors equipped with standard diesel motor. In one case, the high pressure pump and all injectors have been completely damaged, and the case was related to the kind and quality of the fuel used. It should be assumed that the major reason of those damages was improper fuel storage. Consequently, water penetrated into the fuel and the system that detects water in the fuel did not work properly. In addition, the electric harness of the fuel heating system proved to be resistant to moisture and needs to be further developed.

Trough participation in the 2ndVEGOIL project, the ITP Branch in Poznan developed its own technology for plant oil production complying with the conditions and standards available for use in advanced engines John Deere tractors. A novel technology of extraction and purification of rapeseed oil for own purposed has been implemented. Laboratory tests confirmed the achievement of the objective. This technology has become the subject of utility model patent application. Furthermore, the institute management decided to continue work on improving the oil production technology from other oil seeds than rapeseed. After the project completion, one John Deere 6830 Premium tractor continues to belong to the ITP experimental farm in Poznan and has not been re-converted to the diesel powered version. It will continue be used as pure plant oil powered tractor.

The experience gained during project fully confirmed the possibility of using pure vegetable oil as fuel in advanced engines John Deere tractors at any ambient temperature. The production of such fuel due to the simple and cheap technology can be carried out on a farm by a farm team for their own needs. In effect farmers become more independent from fossil fuel, and they can better manage their own oilseed crops. Polish farmers have shown significant interest in the use of tractors powered by pure vegetable oil.

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Nederlands Normalisatie-Instituut (NEN)

Since its establishment by the Dutch engineers association and the industry organization union almost hundred years ago, NEN has been open to the need of the stakeholders. Standards, even without a formal governmental mandate have been our course. Since I joined NEN in 2000, this concept of swift action on drafting norms, close market relationship and dissemination of research to the market has been a lead in my work (although it was quite new for NEN).

The logo for NEN (Nederlands Normalisatie-Instituut) consists of the letters 'NEN' in a bold, blue, sans-serif font, set against a light blue rectangular background.

In 2002, I took over the secretariat of the CEN Technical Committee 19 on petroleum products. Just before, we published our first biofuel specification. Since then, developing standards for biofuels has been of major importance to the oil and car industry. However, it has always been difficult to get consensus between those groups and the new-coming biofuel producers, especially when so-called niche products or applications were concerned.



Recently in NEN, we led several European projects linked to sustainable biofuels. Short term standardization work, leading to so-called CEN Workshop Agreements (CWA) by a small set of stakeholders and larger research dissemination work has also led to input in CEN standards. It was logical that NEN stepped into the 2ndVegOil project when contacted by John Deere. I did not know much about tractors, but was aware of the pitfalls of bringing limited field data into an understandable and workable standard.

Assisted by two colleagues at various points in the process, we worked on drafting a proposal for CEN and a business plan clarifying our needs. We engaged double the amount of partners involved of various countries. It was good to see that many young people were involved and that also other researchers participated. They are usually not largely involved in these type of pre-standardization developments. On the other hand, several participants promoted the work via magazines at the end and always stood for not excluding use in African and Asian countries and for small farmers. All this resulted in a text that was not only "bio", but also "sustainable".

It is a great satisfaction to me that we could produce CWA 16379 with a broader scope than meant by 2ndVegOil, with a wider application and within the given timeframe. It again proves to me that standardization can be direct and market-oriented. We took some hurdles within the group, but we also developed a new manner of describing driveability for a plant oil fuel. A nice side-effect is that our standardization drafting became the lead for a PhD-work on decision-making processes that a student linked to one of the workshop participants is undertaking. The cooperation with all project partners has been enjoyable and inspiring to me. I thank the partners for their patience with the consensus-forming process.

Ortwin Costenoble
NEN, Delft, www.nen.nl

regineering Duft & Innerhofer(IBDI)

Das EU Projekt „2ndVegOil“ verfolgte unter anderem das Ziel, Pflanzenöle zweiter Generation (2G-PPO) im Feldtest zu erproben und deren Alltagstauglichkeit nachzuweisen. Dies geschah unter dem Fokus der Einhaltung aktueller und zukünftiger Abgasnormen. Außerdem konnten neben Rapsölen auch Leindotter-, Sonnenblumen-, Jatropha- und Maiskeimöle zweiter Generation erfolgreich getestet werden.



Für regineering erwies sich das Vorhaben als äußerst erfolgreich. Oder, um es in Zahlen auszudrücken: 16–4–24.000–0 (16 Traktoren wurden in 4 Nationen über 24.000 Stunden im Feldtest mit 0 Motorschäden betrieben!). Die Traktoren zeigten auch im Alltag stabile Leistungen mit 2G-PPOs. Die Betreuung und Auswertung des Feldtests sowie die technische Begutachtung speziell der Einspritzdüsen eröffneten regineering weiteres Wissen für eigene Entwicklungstätigkeiten im Bereich Dieselmotorentchnik und Pflanzenölnutzung.



Als Schlussfolgerung steht für regineering fest, Pflanzenölkraftstoffe sind zukunftsweisend. Sie bieten in der Landwirtschaft eine umweltverträgliche und nachhaltige Alternative zu fossilen Kraftstoffen, nicht nur in Deutschland. Dafür sind fortlaufende professionelle Forschung und Entwicklung ebenso notwendig wie auch nachhaltige politische Rahmenbedingungen, die alle Anstrengungen unterstützen und nicht blockieren. Die Frage ist nicht, ob dezentrale Lösungen wie Pflanzenölkraftstoffe gebraucht werden, sondern wann.

The main task of the EC project „2ndVegOil“ was to trial 2nd generation pure plant oils (2G-PPO) in modern engines, and to proof their suitability for a daily use. The project focused also on complying with exhaust emission limits of the future. Additionally, not only 2G-PPO based on rapeseed, but also camelina sativa, sunflower, jatropha and maize germ could be tested successfully.

The project turned out a fully success for regineering. You can also use numbers to underline the outstanding results as 16–4–24,000–0 (16 tractors were tested in 4 Nations, were driven more than 24,000 hours and 0 total engine failures occurred). The tractors showed stable power outputs with 2G-PPO during a custom use. The support of the field trials as well as technical reviews, especially of the injectors, gave regineering the opportunity to widen its technical knowledge and research and development activities (R&D) in the field of diesel engine technologies using 2G-PPO.

As the main conclusion, regineering determines that 2G-PPO will have a future. 2G-PPO can give agriculture the opportunity to fully replace fossil fuels in a sustainable and environmental friendly manner not only in Germany. Although a professional and continuous R&D work has to be done. As well political frame work has to be adjusted to push 2G-PPO forward instead of blocking it. The question is not if decentralized solutions as 2G-PPO will be needed generally, but when.

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Die Nutzung von reinem Pflanzenöl als Kraftstoff und von Ölkuchen als Tierfutter in geschlossenen, nachhaltigen, regionalen Wirtschaftskreisläufen ist eine Vision, die B.A.U.M. seit vielen Jahren auf seine Fahnen geschrieben hat. Reines Pflanzenöl war stets ein Element nachhaltiger regionaler Entwicklungskonzepte, die B.A.U.M. erarbeitet hat, und die in zahlreichen Regionen umgesetzt worden sind. Eine von diesen ist die Solidargemeinschaft BRUCKER LAND e.V., ein Verein zur Vermarktung nachhaltig erzeugter Güter aus der Region für die Region im Landkreis Fürstfeldbruck bei München, eine andere der aus diesem hervorgegangene Verein ZIEL 21 – Zentrum Innovative Energien e.V. zur regionalen Förderung erneuerbarer Energien.



Im Jahre 2001 erarbeitete ich einen Fördermittelantrag im 5. EU-Forschungsrahmenprogramm für ein Projekt zur nachhaltigen Energieversorgung von Regionen, 100% RENET. Eine der sieben beteiligten Regionen war der Landkreis Fürstfeldbruck. Frau Elsbeth Seiltz, damals Mitglied des Vorstands der genannten Vereine, machte den Vorschlag, zwei umfangreichere Arbeitspakete zur Entwicklung und Felderprobung von Pflanzenölfahrzeugen und Blockheizkraftwerken (BHKW) in dem Projekt vorzusehen und von den Vereinigten Werkstätten für Pflanzenöl (VWP) bearbeiten zu lassen. Damals kam nur die Nutzung von Rapsöl in Frage, aber es stand bereits die visionäre Vorstellung im Raum, zu einem späteren Zeitpunkt durch die Nutzung von Leindotteröl aus Mischfruchtanbau die vielfältigen wirtschaftlichen, ökologischen und sozialen Vorteile von Pflanzenölkraftstoff aus regionaler Produktion in vollem Umfang auszuschöpfen. Es war auch allen Beteiligten bewusst, dass Pflanzenöl bevorzugt als Kraftstoff in landwirtschaftlichen Maschinen eingesetzt werden sollte, doch leider war damals noch kein Landmaschinenhersteller zu einer Entwicklungskooperation bereit.

Das 100% RENET Projekt brachte einen entscheidenden Sprung der Pflanzenölmotorenteknik nach vorne. VWP gelang es in diesem Projekt, einen Motor mit Direkteinspritzung der Emissionsklasse EU Stufe 3 erstmalig mit Pflanzenöl zu betreiben. Dabei wurde auch erstmalig erkannt, welche eminente Bedeutung die nahezu vollständige Entfernung von Kalzium, Magnesium und Phosphor aus dem Öl hat. Damit war der Weg für die folgende Kooperation von VWP mit John Deere gebnet, welche die Grundlagen für das 2ndVegOil Projekt legte.

Es ist mir nach dieser Vorgeschichte eine große Freude, dass im 2ndVegOil Projekt die Nutzung von Leindotteröl aus Mischfruchtanbau als Kraftstoff in Feldversuchen mit Traktoren erfolgreich demonstriert wurde. Damit ist die vor über zehn Jahren gehegte Vision der Realisierung einen entscheidenden Schritt näher gekommen. Neben der Fördermittelantragstellung und der Unterstützung von John Deere bei der Koordination des Projektes gehörte zu meinen Aufgaben auch die Durchführung einer Technologiefolgenabschätzung. Dabei gelang der Nachweis, dass Rapsölkraftstoff sehr wohl den Mindestwert von 60% Treibhausgasminderung einhalten und Leindotteröl ihn sogar deutlich übertreffen kann. Dass dieses Ergebnis nun mit solcher Klarheit vorliegt, bereitet mir eine besondere Genugtuung. Nicht zuletzt möchte ich unterstreichen, dass die Zusammenarbeit mit John Deere und den anderen Projektpartnern stets äußerst angenehm und inspirierend war.

The use of pure plant oil as a fuel and of oil-cake as animal fodder in sustainable closed substance cycles at regional level is a vision that B.A.U.M. has made a mission for many years. Pure plant oil fuel has always been an element of sustainable regional development concepts that B.A.U.M. has elaborated and that were put into practise by many regional development organisations. One of them is the Solidargemeinschaft BRUCKER LAND e.V., an association for the marketing of sustainable products “from the region, for the region” in the District of Fürstenfeldbruck nearby Munich, another one is its spring-off association ZIEL 21 – Zentrum Innovative Energien e.V. for the regional promotion of renewable energies.

In 2001, I have set up a proposal for funding within the EU’s 5th Framework Programme (FP5) for a project on sustainable energy supply of regions, 100% RENET. One of the seven participating regions was the District of Fürstenfeldbruck. Mrs. Elsbeth Seiltz, member of the board of the two mentioned associations at the time, had the idea to include two comprehensive work packages on the development and demonstration of pure plant oil-fuelled cars and combined heat and power stations (CHP) in the work programme, and to involve the Vereinigte Werkstätten für Pflanzenöltechnologie (VWP) as a project partner. At that time, only the use of rape seed oil could reasonably be considered, but we already had the vision of using false flax (*Camelina sativa*) oil from mixed cultivation to fully exploit the multiple economical, ecological and social benefits of pure plant oil from regional production at a later occasion. All involved were also conscious that pure plant oil should first of all be used as fuel in agricultural machines, but unfortunately, no manufacturer of agricultural machines was ready for development cooperation at that time.

The 100% RENET project resulted in a considerable forward leap of pure plant oil engine technology. VWP succeeded to run a direct injection engine of emission class EU Stage 3 for the first time with pure plant oil. In this process, the importance of the almost complete removal of calcium, magnesium and phosphorous from oil also became clear for the first time. This paved the way for the subsequent cooperation of VWP with John Deere which laid the basis for the 2ndVegOil project.

Following these preliminaries, I am pleased that the use of false flax oil from mixed cultivation as tractor fuel has successfully been demonstrated in the 2ndVegOil project. Thus, the more than ten years old vision has made a considerable forward leap towards its implementation. Besides writing the project proposal and supporting John Deere in the coordination of the project, the project assessment was one of my tasks. In the course of the latter, it could be proven that pure rape seed oil can indeed comply with the minimum climate gas saving of 60% and false flax oil can even significantly outperform this value. It is a great satisfaction to me that there is now so clear evidence for this fact. Last but not least, I would like to emphasise that the cooperation with John Deere and the other project partners has always been very enjoyable and inspiring.

Dr. Michael Stöhr

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5. Scientific and technological results

Combustion engine development

The work on the engine development consisted of two distinct parts: (1) development work on tractor engines preparing the field demonstration of tractors fuelled with 2nd generation pure plant oil (2G-PPO), and (2) development work on a hybrid engine test stand (see next section). The combustion engine development started with a survey on the state-of-the-art exhaust aftertreatment technologies and the impact of plant oil fuels on their use. This survey provided an overview of state-of-the-art technologies for exhaust aftertreatment systems for diesel engines, with a particular focus on off-road vehicles. The impact of the use of pure plant oil as fuel on such systems was presented. Biofuel exhaust gases tend to plug diesel particulate filters (DPF) because of ash forming elements in the fuel. Furthermore, some of these elements are toxic for diesel oxidation catalysts (DOC). Hence, it is of utmost importance to reduce these elements in the fuel through appropriate cleaning and to establish fuel standards that limit the ash-forming and DOC-toxic elements.

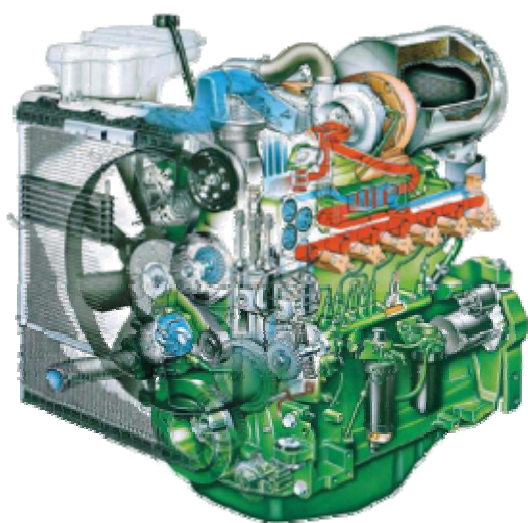


Figure 3: EU Stage 3A compliant JD 6068 PowerTech Plus engine

It turned out at the beginning of the project that a redesign of the existing Stage 3A serial adaptation technology for tractor engines was necessary. This became clear when unexpected bad cold-start behaviour and an early damage of the fuel pump were discovered in a John Deere (JD) manufacturing year (MY) 2008 engine that was adapted to pure plant oil in a way that had been proven suitable for MY2007 engines. As no changes of the engine from MY2007 to MY2008 were known to JD, nor were visible at first glance, a thorough investigation of the components from sub-suppliers was done. Undocumented changes were detected in the fuel pump and the injection system. A change of the cold start software map and the installation of an internal pre-heating system enabled a return to the performance achieved previously with adapted MY2007 engines. The work led to an improvement to the adaptation kit for pure plant oil tractors that was used for the subsequent engine development and tractor demonstration work.

For the further development work, JD configured a test stand for engines to perform tests of engines with diesel and, after conversion, with pure plant oil at the Technical University of Kaiserslautern. The teststand allowed engine and emission parameters to be measured. Engine performance and emission tests were first conducted with 2nd generation rapeseed (2G-PPO-RS), sunflower (2G-PPO-SF), camelina sativa (2G-PPO-CS), and jatropha oil (2G-PPO-JA) on a JD 6068 PowerTech Plus Stage 3A engine that was adapted for pure plant oil operation. All plant oils used for the tests fulfilled the then valid German pre-norm DIN V 51605 and, in addition, had extremely low values for phosphorous (P), calcium (Ca) and magnesium (Mg) after purification of the oils.

They were denoted as 2nd Generation Pure Plant Oil (2G-PPO) fuels, if the sum of P, Ca and Mg content was below 3.5 mg/kg. However, almost all the oil used in the project, except smaller batches in the beginning, contained even less P, Ca and Mg. The 2G-PPO-RS used for the engine development had < 0.8 mg/kg P and < 1.2 mg/kg Ca+Mg, while P, Ca and Mg were below the detection limit of 0.5 mg/kg for P and Ca+Mg for all other oils. Reference measurements were made with Shell V-Power Diesel that complied with the norm DIN EN 590.

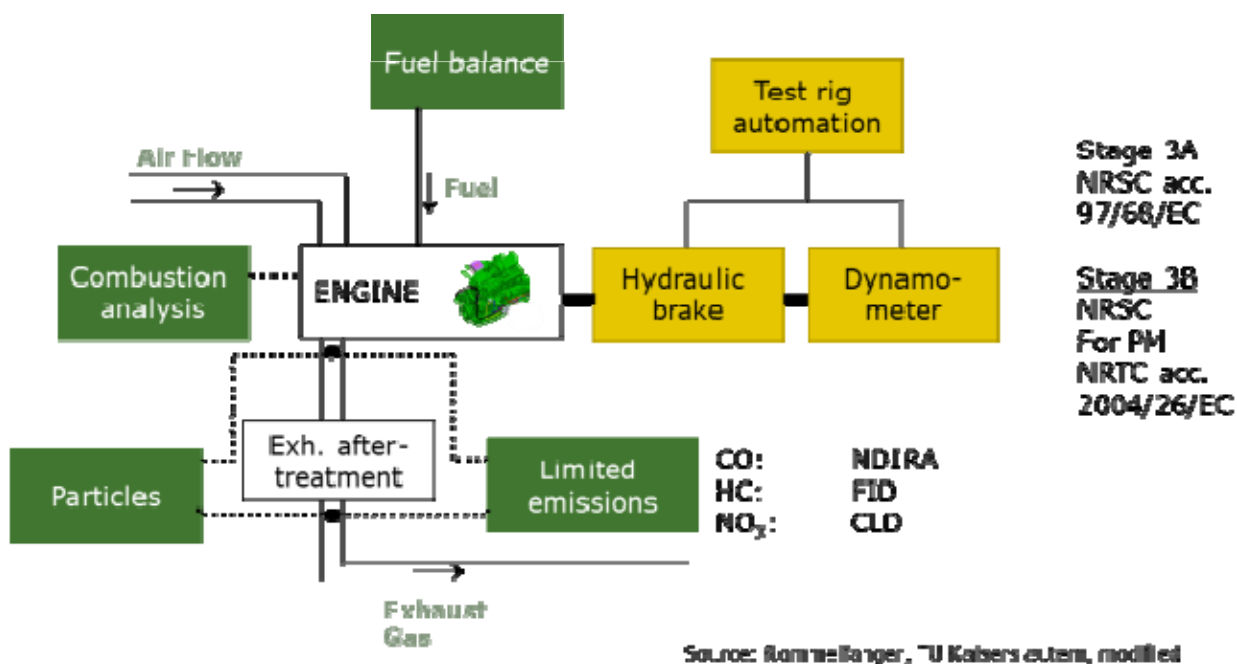


Figure 4: Test stand at the Technical University of Kaiserslautern

The engine performance, after adaptation and during operation with 2G-PPO, was very close to the performance achieved with the original unmodified engine when it was fuelled with diesel. Emissions measured in the Non-Road Stationary Cycle (NRSC) remained, for all tested 2G-PPO, within the EU Stage 3A limits that apply for engines in the power range of 130-560 kW. The emission components which were the closest to the limit were nitrogen oxides (NO_x). In addition, emissions in the Non-Road Transient Cycle (NRTC) were measured for diesel and 2G-PPO-RS. For a part of the NRTC measurements, a diesel particulate filter (DPF) was retrofitted. The NRTC is only obligatory for PM emissions from EU Stage 3B on onwards, but was measured to gain a first impression of the engine performance in this cycle. NO_x emissions were above the limits for EU Stage 3A in NRTC, while particulate matter (PM) were below the EU Stage 3A limit without DPF and kept even below the limits of the EU Stage 3B regulation with DPF.

In the next step, engine performance and emission tests with 2G-PPO-RS were successfully passed with a new and subsequently adapted JD PowerTech PVX engine with integrated DOC/DPF that has been designed to fulfill EU Stage 3B emission limits with diesel fuel. Basic tests were carried out with diesel and, after adaptation of the engine, 2G-PPO-RS. The engine showed a similar behaviour to the preceding EU Stage 3A PowerTech Plus engine. After hardware and software modifications,

the engine's full load curve deviated less than 1% from the original diesel operation full load curve when fuelled with 2G-PPO. Emissions measured in the NRSC remained within the EU Stage 3B limits for engines in the net power range between 130 and 560 kW, when run with 2G-PPO. Again NO_x proved to be the most critical exhaust gas component, while post-DOC/DPF emissions of carbon monoxide (CO), unburned hydrocarbons (HC) and PM remained well within the EU Stage 3B limits.

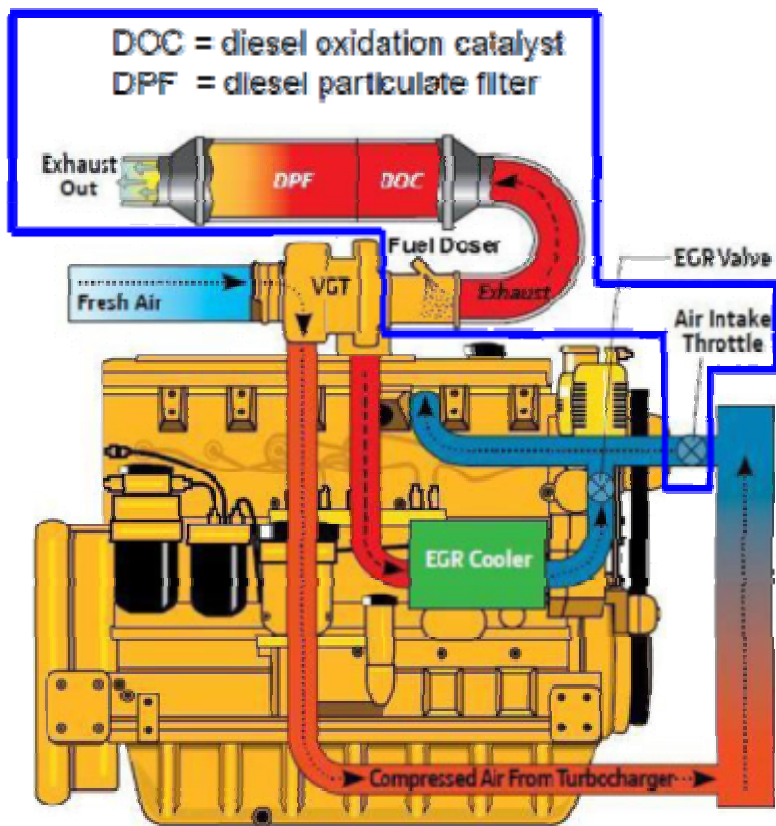


Figure 5: EU Stage 3B compliant PowerTech PVX prototype engine

In order that the JD PowerTech PVX engine with integrated DOC/DPF meets the EU Stage 3B emission limits also for NO_x when being operated with 2G-PPO, the engine software settings were further fine-tuned. A suitable set of parameter values was sought by varying several engine parameters, for three points of the NRSC, while fuelling the engine with 2G-PPO-RS. The thus identified optimum parameter set was used for tests with 2G-PPO-RS, 2G-PPO-CS and 2G-PPO-JA. The emissions complied with the EU Stage 3B limits in the NRSC for all three oil fuels. In the same way, tests in the NRTC were successfully passed. The emissions of PM from both the warm and cold engine stayed significantly below the EU Stage 3B threshold (identical with EU Stage 4 for PM) when it was fuelled with 2G-PPO-RS, 2G-PPO-CS and 2G-PPO-JA.

For achieving the EU Stage 4 emission levels with 2G-PPO fuels, a JD PowerTech PSX engine with integrated after-treatment device (ATD) was used. The ATD consists of a DOC, a DPF, and an integrated selective catalytic reduction catalyst (SCR). The DOC and DPF are the same as those on the JD PowerTech PVX engine. Measurements were again done with diesel reference fuel and 2G-PPO-RS, 2G-PPO-CS, and 2G-PPO-JA fuels. The engine software was set differently for diesel and 2G-PPO fuels, so that the same full load power was obtained for all fuels. After some further fine-tuning of the software settings that optimised the NO_x emissions, the EU Stage 4 emission limits could be met for all 2G-PPO fuels in the NRSC and NRTC. Figure gives an overview of the engines of different emission classes on which development work was carried out with different 2G-PPO.

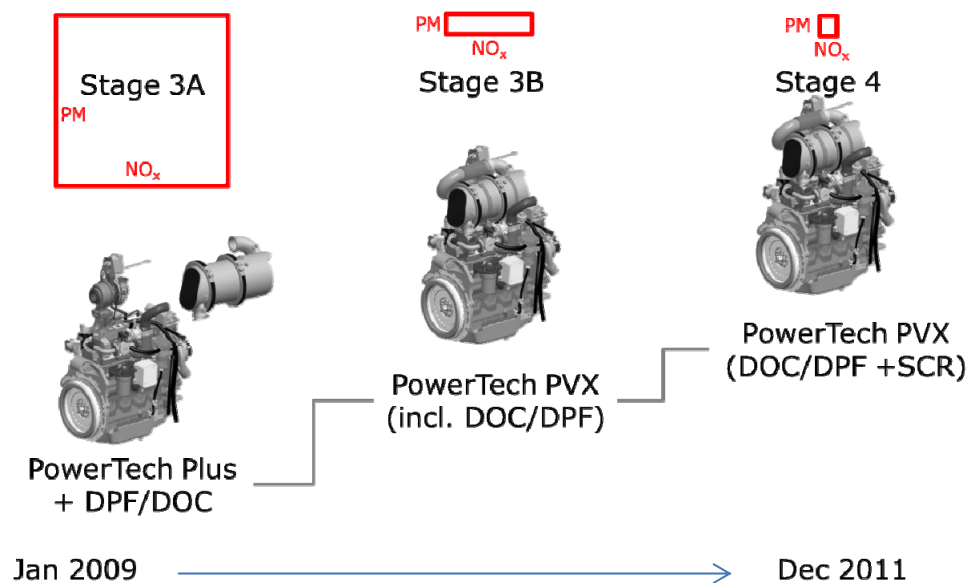


Figure 6: Prototype engines used for engine development on test stand

Hybrid engine development

A hybrid test stand was set up at the Technical University of Munich. It consisted of a John Deere 6068 PowerTech Plus four-valve tractor engine with common rail system for fuel injection, turbocharger and external exhaust gas recirculation (EGR) system. A 4-quadrant-machine simulated the hybrid system and acted either as a brake or an electric motor. The engine test stand allowed the assessment of torque, engine speed, fuel consumption, and exhaust gas temperature, composition and particulate matter (PM) content.



Figure 7: Hybrid test stand

The hybrid test stand was validated and reference tests and measurements with diesel fuel (EN 590) were executed. The collected comprehensive measurement data were used (1) for later comparison with the 2nd Generation Pure Plant Oil (2G-PPO) measurement data, and (2) as input data for the simulation and (3) for validating the simulation results.

The hybrid engine development focused on emissions and fuel consumption. Representative load cycles were selected for the final testing matrix. The latter consisted of the Non-Road Transient Cycle (NRTC) for certification of the emission steps EU Stage 3B and 4 and a reduced Deutsche Landwirtschafts-Gesellschaft (DLG) Powermix cycle. First, basic measurements (NRSC) with 2G-PPO-RS on the hybrid engine test stand were done. Only a few operation points were unfavourable for 2G-PPO-RS use as fuel. One is the starting phase. Using the pre-heating system from the project partner VWP fully solved all problems in this phase. Furthermore, carbon monoxide (CO) emissions were higher than in diesel operation for low engine speeds and loads. This was solved by adapting the injection strategy. PM emissions were low in all operation modes. It needed to be checked whether this remained the case for NRTC measurements. Further development work was needed to lower nitrogen oxides (NO_x) emissions to achieve the emission limits EU Stage 3B and 4.

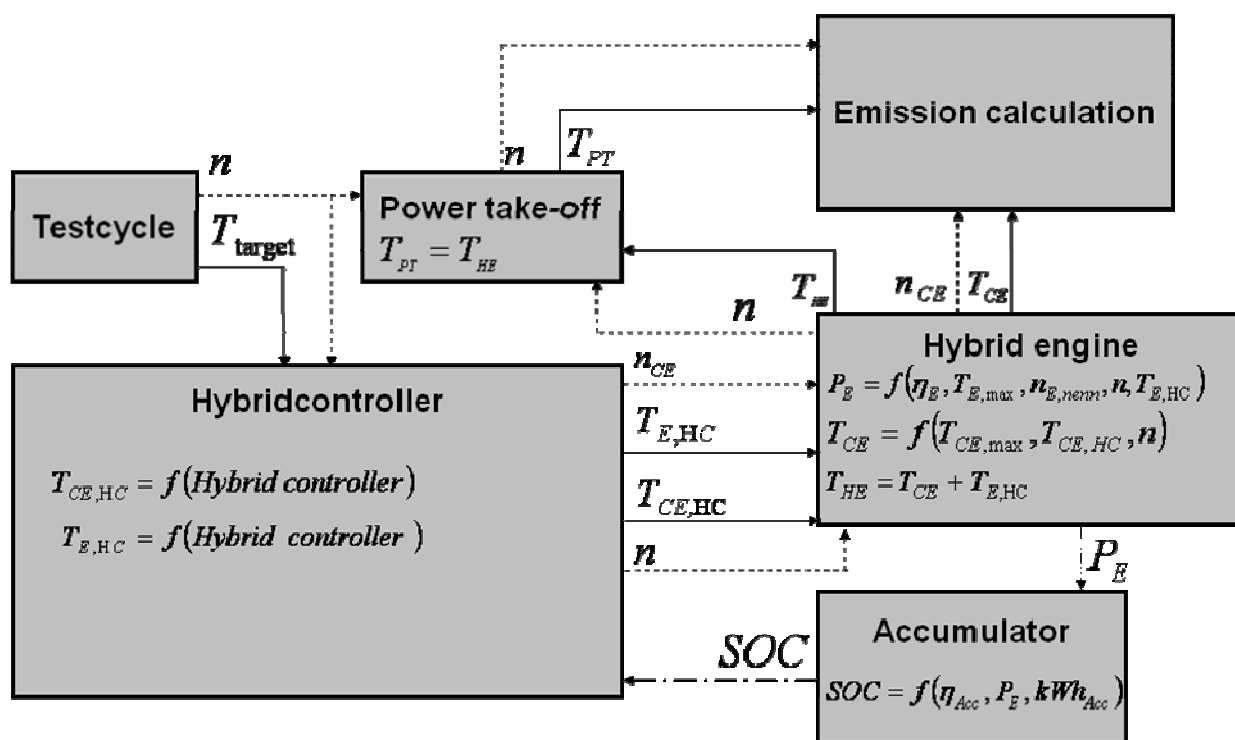


Figure 8: Hybrid model calculation scheme

A model for the hybrid system was developed and programmed with the Dymola software using the Modelica language. The main aim of the hybrid development work was to reduce emissions, notably PM. A parallel hybrid system was modelled, i.e. the speed of the combustion engine and the electric motor was the same in the model. The distribution of the required torque on both components was the adjustable parameter. A synchronous electric motor was selected because of its good efficiency values over a broad torque range. Apart from optimising the torque of the combustion engine in stationary operation, the reduction of transients optimises the emissions. An optimum controller for near-stationary operation and a dynamic border torque controlling strategy that reduces torque gradients in transient operation were developed. They were combined by a constant speed detection module and complemented by a start-stop controller. In the NRSC the

simulation showed no advantages of hybridization. In the NRTC up to 27% soot reduction was achieved, depending on hybrid system configuration and operation strategy.

The optimum hybrid configuration that was identified through modelling was then transferred to the hybrid test stand. The combustion engine was fuelled with 2G-PPO-RS, 2G-PPO-JA, 2G-PPO-SF, and 2nd generation soy oil (2G-PPO-SY) fuel. For comparison, diesel fuel was used. The measurements confirmed the results of the modeling. It became apparent that using oxygenated fuel such as 2G-PPO brings significant advantages for operation with transient cycles. On average, PM emissions were reduced by 20% and NO_x by 30%. Thus the hybrid engine did not achieve the EU Stage 4 emission levels without aftertreatment systems, but enable a significant reduction in emissions in the NRTC cycle.

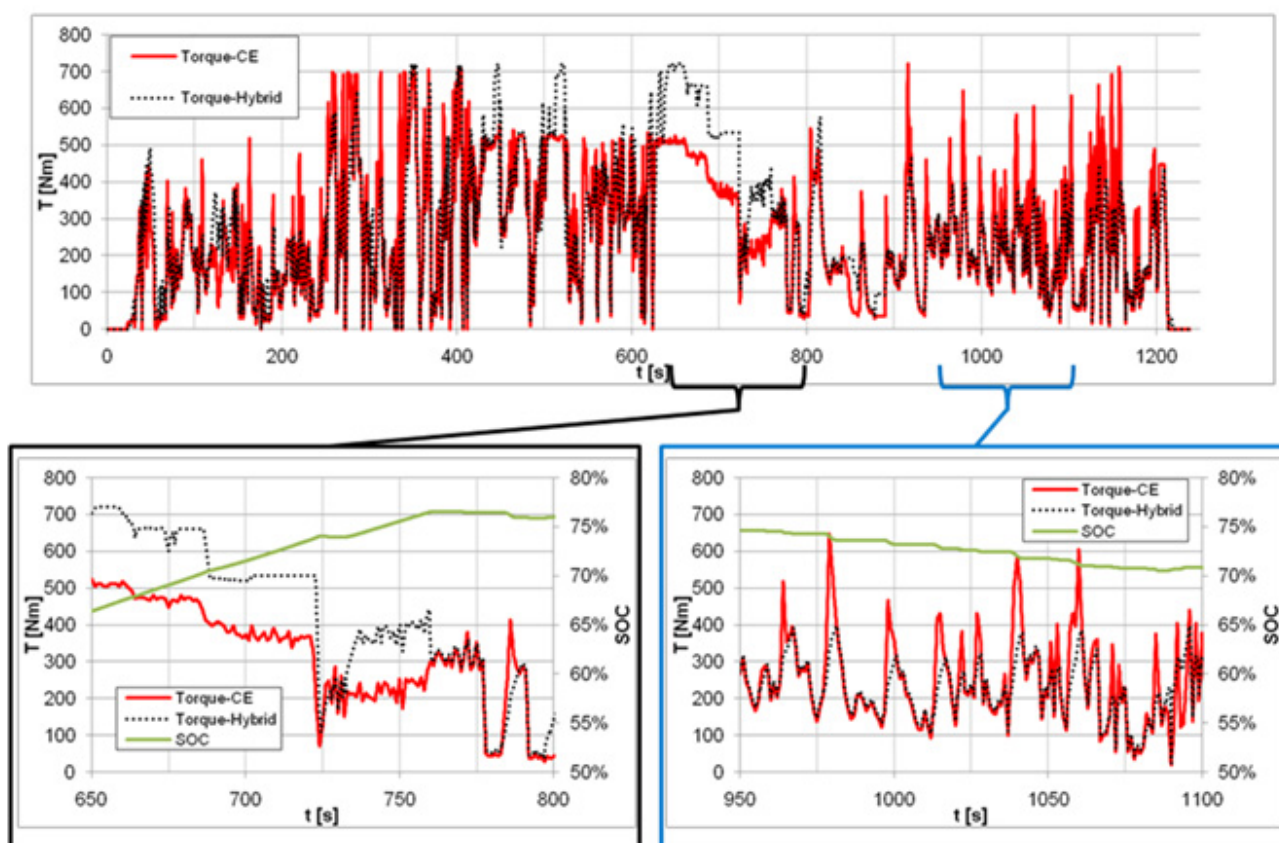


Figure 9: Combustion engine vs hybrid driveline: In the charging phase (bottom left) the accumulator is charged during moderately transient operation. In the discharging phase (bottom right), the dynamic demand for the combustion engine is reduced.

In conclusion, the investigations of hybrid powertrains, fuelled with 2G-PPO, have shown that the potential for reducing PM emissions in transient cycles, such as the NRTC, is about 20%. The use of 2G-PPO fuels has the potential to significantly reduce PM emissions due to the oxygen in the fuel. The hybrid concept leads to an even higher relative improvement of emissions for standard diesel fuel, where this effect of chemically bound oxygen in the fuel does not exist. Here, the hybrid drive enables PM emissions to be reduced by 30%. The hybrid drive does not allow the limits of EU Stage

4 to be met without an aftertreatment system, but the costs for operating the latter are strongly reduced by the hybrid drive. For example, the longer regeneration cycles of the particulate filter enable the fuel consumption to be reduced.

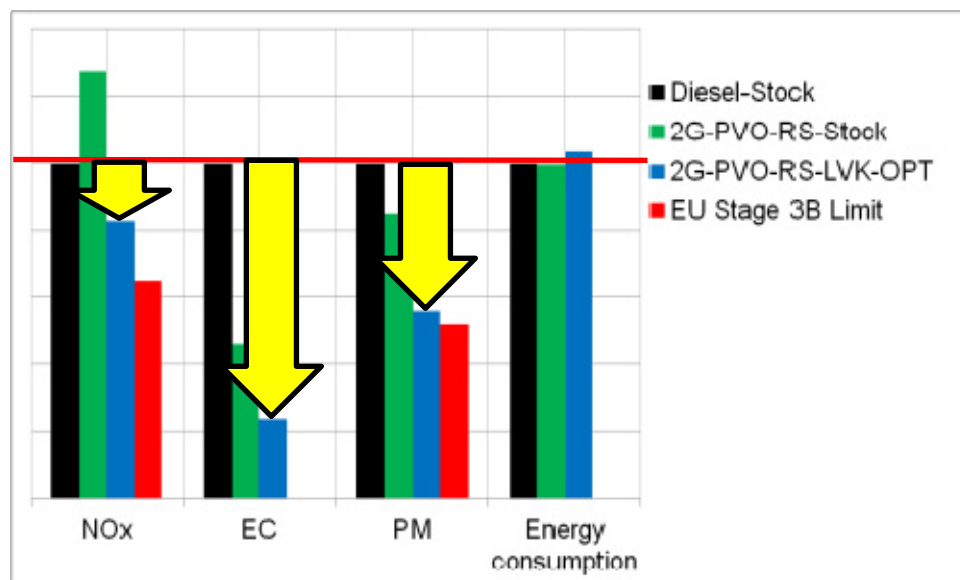


Figure 10: Achieved emission reduction with hybrid operation without exhaust after treatment (EC = elemental carbon)

Fuel development

The work on fuel development was motivated by prior experience that had shown that the content of phosphorous (P), calcium (Ca) and magnesium (Mg) in pure plant oil played a major role in the trouble-free operation of advanced engines. For this reason, the development goal was fixed before project start to considerably lower the content of these elements by oil press optimisation and subsequent cleaning, down to the detection threshold of 0.5 mg/kg for each of the three elements. This objective, which went beyond the then relevant German pre-norm DIN V 51605 (at the end of the project the pre-norm had become a norm with more restrictive thresholds), was planned to be achieved step-wise for successively larger oil samples, putting an intermediate target at 3.5 mg/kg for the sum content of P, Ca and Mg in pure plant oil. The aim was to finally operate three different reference presses that produced first partly, and then fully demineralised oil from different oil seeds to supply the engine development test stands and the tractor demonstration fleet. Additivation of the cleaned oil was explicitly considered as an option in case that the demineralisation would deteriorate the oil with regard to other quality parameters that were regulated by DIN V 51605.

The fuel development work started with reviews of the existing know-how on requirements for oil quality for pure plant oil fuel and the possibilities to comply with these requirements in decentralised oil presses. After the results of these reviews, the first standard for pure plant oil which included variable properties that depend on growth, pressing, storage, etc., was developed in

1982 by E.H. Pryde. He suggested limiting the P content to 20 mg/kg to prevent problems in fuel tanks, lines and filters. When it turned out that the content of P, Ca and Mg in pure plant oil correlated with catalyst poisoning and damage to soot filters, pistons, piston rings, injectors and valves, the first limitation of their content in pure plant oil, used as engine fuel, was formulated in the German pre-norm DIN V 51605 (20 mg/kg for Ca + Mg; 12 mg/kg for P). The knowledge that these limits were still too high, and almost complete removal of these elements should be emphasized was subsequently gained within the Austrian 35 tractor programme (EU Stage 1 and Stage 2 engines, 2003-2008), a research project of John Deere (EU Stage 2 and Stage 3 engines, 2005-2008), a study prepared by Deutz (2008), and notably, by work, conducted by the 2ndVegOil project partner VWP within the EU FP5 100% RENET project (2002-2005).¹

It was known that the content of P, Ca and Mg could be reduced by avoiding corn break, ensuring good maturity of the seeds before harvest, avoiding moisture and related outgrowth as well as soiling, and by a low pressing temperature. Furthermore, the origin of rape seeds was known to have an influence. E.g. summer rape seed oil contains more P, Ca and Mg than winter rape seed oil. According to the reviews, state-of-the-art oil pressing technology allowed the production of rape seed oil that complied with DIN V 51605 in small decentralised oil mills. Hence, for achieving a sum content of P, Ca and Mg below 1.5 mg/kg, additional purification was necessary. In a literature search, it was found that bleaching clay, synthetic silica, kieselguhr, cellulose and perlite reduce the content of P, Ca and Mg when being added to the pressed fuel oil during the purification.

The reviews also revealed that the content of sodium (Na) and potassium (K) required attention. All this was found to be valid for other oils, too, except that preliminary pressing experience suggested that different temperatures and other oil press parameter settings were required for other oil seeds. At first, it was also assumed that the fatty acid composition of the oil played an important role, but this turned out to be wrong – a major finding of 2ndVegOil, as it shows that, in principle, a wide range of oils can be considered for use as fuel in diesel engines!

Before this very important result could be found, development work was carried out on a decentralised oil press in Lower Austria, belonging to Öl- und Bioenergie GmbH. The aim was to optimise the production of large batches of pure plant oil, notably with regard to the content of P, Ca and Mg, while keeping within the limits set by DIN (V) 51605 for all other parameters. Other elements, such as Na, K and Si were also monitored. In a first step, a sum content of < 3.5 mg/kg P+Ca+Mg was achieved for rape seed oil by simple optimisation of the press parameter. Then, nine different filter additives were tested. The additive OBEFIL was found to achieve the highest performance. An advantage is also that the filter cake can still be used as animal fodder even if it contains traces of OBEFIL.

Subsequent work focused on OBEFIL and the optimisation of its use for different plant oils. Finally, the target of reducing the sum content of P, Ca and Mg below 1.5 mg/kg could be achieved for rape seed, sunflower, camelina sativa, jatropha and maize germ oil. The achieved results exceed the initial objectives. The subsequent development concentrated on other previously not considered ash building elements such as Na and K and on the optimisation of the oxidation stability.

¹ www.100re.net

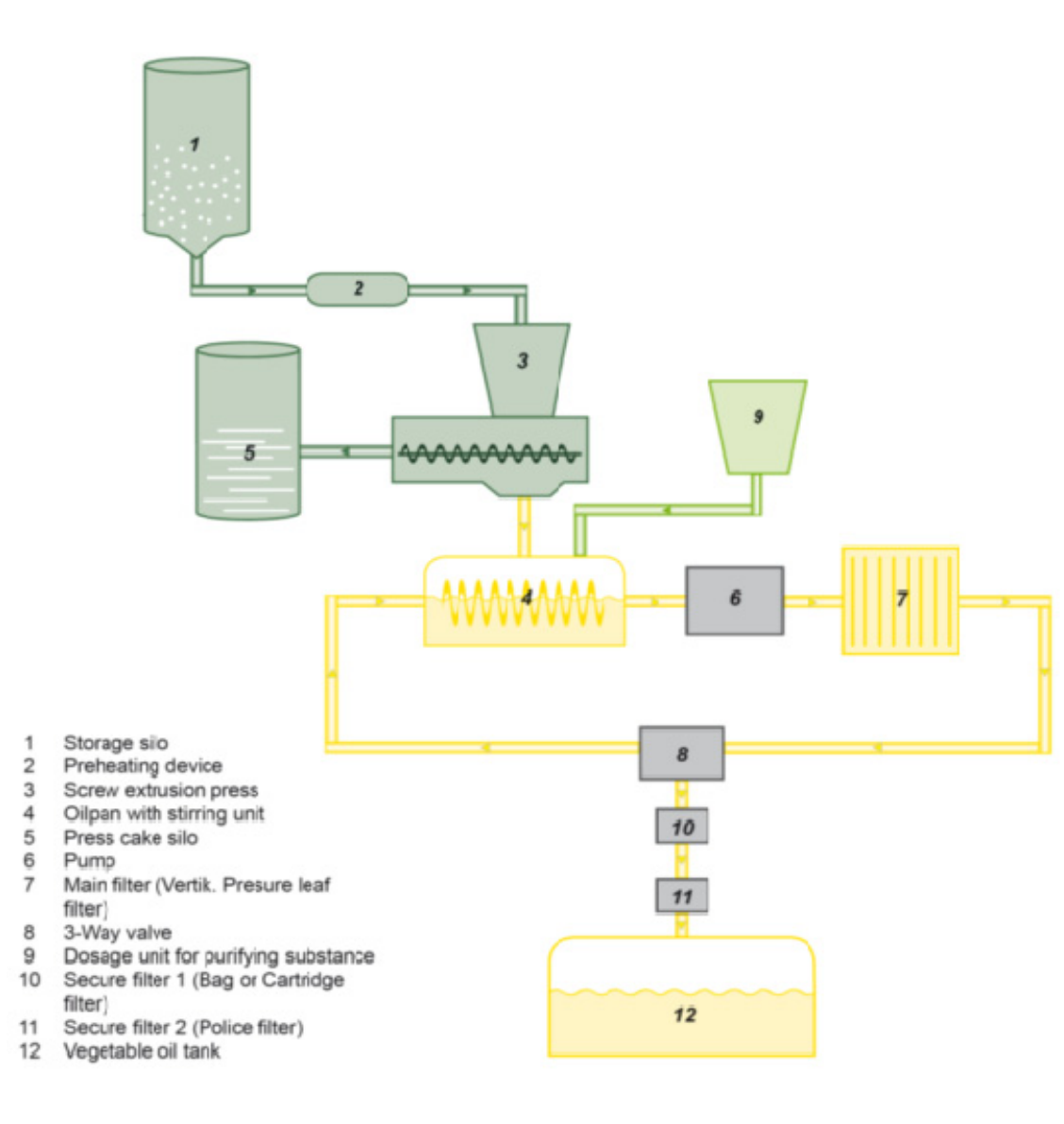


Figure 11: The Waldland purification process as used for the fuel production in 2ndVegOil

The verification, whether the cleaned pure plant oils were practically suitable for long-term use in advanced diesel engines, was conducted with two off-the-shelf combined heat and power (CHP) stations with 5.3 kW_{el} and 10.5 kW_{th} nominal loads that were adapted to pure plant oil operation in line with previously achieved results on optimum engine adaptation for rape seed oil. The CHPs are powered by a single cylinder engine with a closed particulate filter system. The engines have been operated for 500 hrs each, with four different fuels: rape seed fuel with 10 mg/kg and 1 mg/kg P+Ca+Mg and camelina sativa and maize germ oil with 1 mg/kg. The whole operation cycle of 2000 hrs was run with each engine separately. This was done to verify the impact of different contents of P, Ca and Mg on the combustion behaviour. In particular, the build-up of deposits on the injectors and the particulate filter, which have an impact on the length of the service intervals, was

monitored. Further, the aim was to check if the kind of pure plant oil is equally or less relevant than the P, Ca and Mg content. The operation showed that the content of P, Ca and Mg influences the build-up of deposits very strongly, while the type of oil has no significant relevance. The results suggested that the differences in the combustion behaviour of different plant oils could be dealt with by appropriate adaptation of the engine parameters. As a result of this finding, it was decided that the workprogramme of the 2ndVegOil project should be modified and test runs with engines, and demonstration of tractors, should be conducted with pure oils other than rape seed oil and with high instead of low blends of the former in the latter. This change represented a significant addition to the initial project's objectives.

When the tests of different plant oils with one cylinder CHP engine were made, Jatropha oil was not available in sufficient quantities. The test run with Jatropha oil was conducted afterward in April and May 2010. The 1,000 hours test run led to the conclusion that jatropha oil can equally well be used as fuel oil as the other previously tested oils.

Based on this development work, the oil mill of Öl- und Bioenergie was equipped with a dosing unit for OBEFIL and several test runs were implemented to achieve optimum oil pressing and purification at lowest possible cost. The dosing unit design was specifically developed and optimised within this work. The optimisation of the press included modifications of the filtration process. Altogether, some 327,000 liters of different oils, almost all of it with P+Ca+Mg < 1.5 mg/kg, were produced up to the end of 2011 for the engine development and demonstration work in the 2ndVegOil project. For all oils with < 3.5 mg/kg sum content of P, Ca and Mg, the name 2nd Generation Pure Plant Oil (2G-PPO) was used, but almost all the oil that was produced and used in the project had a sum content of P, Ca and Mg below 1.5 mg/kg.

A second reference press for producing 2G-PPO was set up in France. It is an innovative, mobile press, which is operated by the Cuma Verte Prairie in the region Rhône-Alpes. The press allowed the French project partners to produce the fuel for the 2ndVegOil demonstration tractors by themselves. The specific technology developed in this project can be implemented at farm level, thus permitting economic value creation and income generation in rural areas. In the course of the project, 61,000 liters of rape seed oil were processed and a sum content of P, Ca and Mg of less than 1.5 mg/kg was achieved. The second reference press was very important for the acceptance of the project among the involved farmers in France, as it demonstrated that the developed fuel concept allowed auto-supply of the agricultural sector with a fuel that is produced within closed regional economic cycles with a potential for regional value and job creation. The fact that the oil needed to be completely demineralised was strongly questioned and required comprehensive advocacy efforts, because this quality criterion looked exaggerated to the users.

A third reference press for 2G-PPO, i.e. oil fulfilling the requirements of DIN (V) 51605 and remaining, in addition, below the limit of 1.5 mg/kg for the sum content of P, Ca and Mg was set up on the experimental farm of the Instytut Technologiczno-Przyrodniczy (ITP), formerly Instytut Budownictwa, Mechanizacji i Elektryfikacji Rolnictw (IBMER), in Poznan. The purification process is different from the one that is applied at the Austrian and French reference presses.

Finally, an investigation was made on the potential of the developed purification method to reduce the content of Na and K in addition to P, Ca and Mg. The results show clearly that Na and K are removed from the oil down to the detection limit, in the same way as P, Ca and Mg. A second issue of the investigation was to check if the use of OBEFIL for oil purification had a negative effect on the oxidation stability. The latter turned out to be true. A clear dependency of the degradation of the oxidation stability on the concentration of OBEFIL used for the oil purification could be found. It is assumed that anti-oxidants are removed during the purification process as well. In the next step, four different anti-oxidation additives were tested. The stabilizer BAYONOX Plus was found to have the best performance and was selected for the further oil production for the test fleet.



Figure 12: Oil plants from which larger amounts of 2G-PPO were produced and used within 2ndVegOil: rapeseed, sunflower, camelina sativa, maize germs, and jatropha (from left to right); minor amounts of 2G-PPO from coconut, palms and soya seeds were used for scientific field tests.

The final aim of producing 2G-PPO of a sufficient quality for fuelling advanced diesel engines with particulate filter could thus be achieved, by combining optimum oil pressing with subsequent purification of the oil with OBEFIL, and readjustment of the oxidation stability with an anti-oxidant. Clear dependencies were found that allow determination of the required concentrations of the substances for purification and additivation.

The work also showed that minor problems persist with the acid value and cetane number in the case of 2G-PPO from camelina sativa seeds (2G-PPO-CS), and acid value and water content in the case of 2G-PPO from jatropha nuts (2G-PPO-JA). The values for these parameters are not within the limits set by DIN 51605 yet.

In the case of 2G-PPO-JA, the problem can be solved if ripe nuts are used for oil production. Oil from ripe jatropha nuts has a much lower acid value and higher water content. The oil, which is commercially available in Europe, is usually produced from partially unripe nuts. A better quality control, right from the moment of harvest, would ensure a much better oil quality. Furthermore, the long transport distances are detrimental to the oil quality. Local use of 2G-PPO-JA fuel in the countries where the jatropha is grown would involve also shorter transport distances.

The acid value of 2G-PPO-CS can be improved if the camelina sativa seeds are dried at lower temperature. Drying can however, not completely be avoided, if camelina sativa is produced in mixed cultivation with other crops.

In the case of 2G-PPO from sunflower seeds (2G-PPO-SF), attention needs to be paid to removing waxes from the oil. The problem of wax fall-out from 2G-PPO-SF appeared during the scientific field tests (see after next section) and could be solved through a down-streamed cold filtering process. In the long term, the use of sunflower species with low wax content for fuel production could solve this problem from the outset.

Lubricant development

Two engine lubricants have been developed for evaluation in the 2ndVegOil project. These engine lubricants meet the ACEA E7 and E9 performance categories. Details of the engine lubricant composition are contained in Deliverables 4.1, 4.3 and 4.11 which can be downloaded from the project website². The engine lubricants chosen to be researched as part of the 2ndVegOil project were:

- OS240946 = a lubricant which is capable of meeting the ACEA E9-2008 specification
- OS241936 = a lubricant which is capable of meeting the ACEA E7-2008 specification

The ACEA 2008 nomenclature and specifications for E7 and E9 lubricants is detailed in Appendix A in deliverable 4.1. The compositions of the engine lubricant formulations (e.g. engine lubricant additives, viscosity modifiers and base oil type) used in the 2ndVegOil project are detailed in Table 1.

The Product Data Sheets for Lubrizol® 4986E, Lubrizol® 40007, Lubrizol® 7077 and Lubri-zol® 7075F are shown in Deliverable 4.11, Appendix B. These Product Data Sheets list the performance qualifications for the engine lubricant additives and provides information on the viscosity modifiers.

Sufficient quantities of each lubricant were supplied to the relevant project partners in charge of the scientific field test and demonstration and monitoring programmes throughout the project. Table 2 details the amount of engine lubricant delivered to each project partner. The relevant project partners have supplied Lubrizol with used engine lubricant samples throughout the duration of the 2ndVegOil project.

² www.2ndvegoil.eu

Table 1: Engine Lubricant Formulations to be used in 2ndVegOil Project

		ACEA E7 Engine Lubricant	ACEA E9 Engine Lubricant
Lubrizol Oil Code		OS241936	OS240946
Viscosity Grade		15W-40	15W-40
ExxonMobil AP/E 150N	Group I Base Oil	59.4	-
ExxonMobil AP/E 600N	Group I Base Oil	20	-
Chevron 220R (220N)	Group II Base Oil	-	71.1
Chevron 600R (600N)	Group II Base Oil	-	6.1
Lubrizol® 4986E	Engine Lubricant Additive	12.6	-
Lubrizol® 40007	Engine Lubricant Additive	-	16.5
Lubrizol® 7077	Viscosity Modifier	7.7	-
Lubrizol® 7075F	Viscosity Modifier	-	6.1
Lubrizol® 6662	Pour Point Depressant	0.3	0.2

Table 2: Engine Lubricant Supplied to 2ndVegOil Project Partners

Test Location	Operator	Lubricant Type	Supply Month	Lubricant Quantity
Germany	TU Kaiserslautern (Stage 4 development)	ACEA E9	October 2009	200 litres
Germany	LVK – TU Munich (Stage 4 development)	ACEA E9	October 2009	200 litres
Germany	VWP (engine conversion)	ACEA E7 ACEA E9	February 2009 February 2009	60 litres 20 litres
Germany	TFZ	ACEA E7	March 2009	60 litres
Germany	JDWM	ACEA E7	March 2009	60 litres
		ACEA E9	March 2009	120 litres
		ACEA E7	August 2009	60 litres
		ACEA E9	October 2009	25 litres
		ACEA E7	January 2010	40 litres
		ACEA E9	January 2010	40 litres
		ACEA E9	February 2011	100 litres
France	FR Cuma	ACEA E7	March 2009	120 litres
		ACEA E7	April 2010	100 litres
		ACEA E9	April 2010	60 litres
		ACEA E7	February 2011	60 litres
		ACEA E9	February 2011	40 litres
		ACEA E7	October 2011	60 litres
Austria	Waldland	ACEA E7	February 2009	120 litres
		ACEA E9	February 2009	120 litres
		ACEA E7	March 2010	130 litres
		ACEA E9	March 2010	130 litres
Poland	Contractus	ACEA E7	March 2009	240 litres
		ACEA E7	December 2009	240 litres
		ACEA E7	November 2011	40 litres

Table 3: Tractor Unit Identification, Operating Location and Engine Lubricant Used

Operating Country	TRACTOR UNIT NAME	Engine Lubricant OS NUMBER
Germany	L06930N613519	OS240946
France	L07530N613532	OS240946
Austria	L07430R604221	OS240946
Germany	CD6068R066040	OS240946
Poland	L06830G612350	OS241936
Poland	L06830K512170	OS241936
Poland	L06830K596568	OS241936
Poland	L06830K614003	OS241936
Poland	L07430K494001	OS241936
Germany	L06930N586574	OS241936
Austria	L07430R604472	OS241936
Austria	L07530N613561	OS241936
France	L06830P606579	OS241936
France	L07530K616305	OS241936

Table 3 details the tractor unit identification, operating location and the engine lubricant used in that tractor.

The used engine lubricant samples were taken at approximately 250 hour intervals (when the engine lubricant was changed for fresh lubricant) apart from tractors running in Germany with identifications of L06930N586574 and L06930N613519. These tractors operated under a different engine lubricant sampling regime and engine lubricant drain interval. They were analysed by standard industrial lubricant analysis techniques:

- Total Base Number (TBN by ASTM method D4739)
- Total Base Number (TBN by ASTM method D2896)
- Total Acid Number (TAN by ASTM method D664)
- Kinematic Viscosity (tested at 100°C by ASTM method D7279)
- Wear metals measured by Inductive Coupled Plasma (ICP)
- High Temperature High Shear viscosity (by CEC Test method L-36-A-90)
- Percentage soot measured by Thermogravimetric Analysis (TGA)
- Oxidation and Nitration (by method DIN 51453)

The measured Total Base Number (by ASTM D4739 and ASTM D2896) shows that the basic reserve of the engine lubricant was being depleted due to the acidic nature of the combustion gases, however this change in basic reserve is considered to be acceptable as is demonstrated by only a small increase in the Total Acid Number (measured by D664).

The measured Kinematic Viscosity at 100°C (measured by ASTM D7279) and High Temperature High Shear Viscosity (measured by CEC test method L-36-90) showed that, throughout the field trial, the

kinematic viscosity of the engine lubricants had stayed within the SEA J300 specification for SAE 40 engine lubricants and the high temperature high shear viscosity had changed very little compared to the fresh engine lubricant. One lubricant sample did show a very low viscosity, but no cause could be identified and contamination of the sample could not be ruled out. This highlights that the engine lubricants' viscosity had stayed within the formulated viscosity grade throughout the field trial. The viscosity performance of both engine lubricants is therefore considered satisfactory.

The copper wear levels (as measured by ICP) showed that six samples exceeded the John Deere (JD) warning limit of 20ppm (max.). However the samples that showed high copper either came from the tractor which had the low viscosity result (which could have caused the high copper wear) or from tractors which were operating on an extended engine lubricant drain cycle. The iron level follows a similar trend to copper with a reasonably low level of iron wear for all samples apart from the sample from Poland (which had the low viscosity) and the tractors operating in Germany on the extended lubricant drain interval. The level of iron wear for all samples falls within the JD warning limit of 0.5 ppm / hour max.

In summary both lubricants have performed satisfactorily during the field trial. The engine lubricants developed for the 2ndVegOil project seem appropriate for 2G-PPO fuels in advanced engines when the lubricant drain interval is 250 hours. An extension to 500 hours seems possible, but requires further investigation of the reasons for the high copper wear levels in some lubricant samples.

Engine, fuel and lubricant demonstration

The developed engine concepts, 2G-PPO fuels with selected additives, and two appropriately formulated lubricants were subjected to comprehensive demonstration in four European countries (Germany, France, Austria and Poland). 16 tractors were tested in the field, under a broad range of operating conditions, with 8 different 2G-PPO fuels, for a total of 24,000 operating hours. Zero total failures were reported and all minor failures that were attributed to the use of 2G-PPO instead of diesel as fuel could be traced back to fuel contamination and/ or inappropriate fuel storage or to the use of other fuels than 2G-PPO. Hence, the proof of concept was provided for the developed combinations of modified diesel engines, 2G-PPO fuels with additives, and lubricants.

This was achieved through scientific field tests of five tractors (n° 3, 8, 14, 15 and 17) under close supervision of JD and the Bavarian Technology and Support Centre (TFZ) in Straubing / Germany and a fleet demonstration and monitoring programme for a further 11 tractors that were tested under a broad range of real operating conditions. The fleet demonstration and monitoring programme was conducted by the project partners IBDI and VWP, with the support of the project partners ITP, Waldland, and FRCuma. Two of the tractors used for the scientific field tests (n° 3 and 8) joined the fleet demonstration and monitoring programme in the middle of the project period, thus increasing the demonstration fleet to a total of 13 tractors, out of which 5 were run by ITP in Poland, 5 by Waldland in Austria, and 3 by FRCuma in France. The duration of the demonstration

and monitoring was 26 months for tractors n° 1-2, 4-7, and 9-12, respectively 15 months for tractors n° 3, 8 and 16.

15 out of the 16 JD tractors used for scientific field tests and demonstration were 6830 Premium (85 kW), 6930 Premium (96 kW), 7430 Premium (103 kW) and 7530 Premium (114 kW) series models that were converted to 2G-PPO operation. They were chosen because they were the largest and most powerful tractors produced at the JD production facility in Mannheim/ Germany, thus offering the highest potential economic benefit when being fuelled with 2G-PPO. All four models are powered by the EU Stage 3A compliant 6068 PowerTech Plus engine at different power levels. The 6830 Premium and 6930 Premium models have got the CD6068HL481 engine and the 7430 Premium and 7530 Premium ones the CD6068HL482 engine. The different power levels are implemented by different engine control software settings. The 6068 PowerTech Plus engines use four-valve technology with a high pressure common rail system for fuel injection. They are turbo-charged and have an external exhaust gas recirculation (EGR) system including a cooler to reduce NO_x emissions. Through retrofitting with an SCRi[®] system (Selective Catalytic Reduction integrated) from Emitec in the middle of the project period, 4 of them achieved compliance with EU Stage 3B emission level. The conversion to 2G-PPO operation implied modifications of the pre-heating system, fuel lines and filters, fuel pressure pumps, and the electronic control unit (ECU) settings.

One tractor (n° 17), a pre-series 6210R model, complied with EU Stage 3B emission level from the outset. Compared to the EU Stage 3A compliant models, it uses a diesel oxidation catalyst (DOC) and a diesel particulate filter (DPF). The DPF is regenerated by injecting fuel into the exhaust system prior the DOC. This causes a rise of the exhaust gas temperature, which leads to a combustion of the organic particles held back by the DPF. The conversion to 2G-PPO operation differs from the conversion concept for the Stage 3A compliant tractor models as to the fuel pre-heating system. In the course of initial testing, the engine fuel supply was separated from the DPF regeneration fuel supply and separate diesel fuel storage was installed. For the DPF regeneration, diesel fuel was continued to be used instead of 2G-PPO.

As a result of the conversion, the engine power was slightly lowered. This was due to the lower calorific value and the different injection behaviour of 2G-PPO compared to diesel. It would have been possible to convert the engines such that the same power would have been reached with 2G-PPO as with diesel before the conversion. However, the power would then have exceeded the allowed limits in case that an operator decided to fuel the tractor with diesel instead of 2G-PPO. As no automatic fuel detection device was installed yet that would have allowed switching the ECU settings automatically between a “2G-PPO mode” and a “diesel mode”, the lower power with 2G-PPO was considered to be an acceptable compromise.

At first, four JD EU Stage 3A compliant tractors, n° 3 and 8 of the 7530 Premium model, and n° 14 and 15 of the 6930 Premium model, were converted by VWP to 2G-PPO operation in October 2008 at JD in Mannheim. After the conversion, the tractors’ performance and system functionality was assessed on test benches at JD. The tractors were then used for comprehensive scientific field tests with 2G-PPO-RS (2nd Generation Pure Plant Oil based on Rape Seed) fuel from May 2009 on. Tractor n° 8 was retrofitted with an SCRi[®] system in April 2010 and further tested by the project partner FRCuma until July 2011 in the framework of the fleet demonstration and monitoring programme.

Tractor n°3 was further tested by the partner Waldland from May 2010 until July 2011. It was retrofitted with an SCRi® system in July 2010. The tractors n° 14 and 15 continued to be used for scientific field tests by JD and TFZ until July 2011. They were retrofitted with an SCRi® system in spring 2011.

Ten further JD EU Stage 3A compliant, 6830, 7530 and 7430 Premium model tractors (n° 1-2, 4-7, 9-12) were converted to 2G-PPO operation and checked on the test bench at the beginning of 2009. They were demonstrated and monitored in Poland, Austria and France from spring 2009 until mid summer 2011. The tractors n° 3 and 8 joined the demonstration and monitoring programme in spring 2010 as well as a further EU Stage 3A tractor (n° 16, 7430 Premium model).

The JD EU Stage 3B compliant tractor (n° 17, pre-series 6210R model) was converted to 2G-PPO operation and checked on a test bench at JD in autumn 2010. It was used for scientific field tests from spring until midsummer 2011. It was further converted to EU Stage 4 through installation of an SCRi system in August/ September 2011 and tested during 10 operation hours on JD internal testing field near Mannheim with a cultivator.



Figure 13: Converted EU Stage 3B compliant tractor

It should be noted that, due to changes in the course of the project, the tractor identification number 5 does not exist. Hence, the numbers run from 1 through 17, leaving 5 out, and altogether 16 tractors were tested in the field and/ or demonstrated and monitored.

All field test and demonstration tractors were initially planned to run on 2G-PPO-RS fuel and on low blends of other oils with 2G-PPO-RS. It was after the scientific field tests and demonstration and monitoring had already started that the unexpected result of the engine and fuel development work was found that other 2G-PPO than 2G-PPO-RS could also be used, without blending, in suitably adapted engines without encountering any problem,

power deficit or increased emission levels, if the oils were completely demineralised. As a consequence, the test and demonstration plan was changed in October 2009 and it was decided that larger amounts of 2G-PPO-SF (2nd Generation Plant Oil based on SunFlower seed), 2G-PPO-CS (2nd Generation Pure Plant Oil based on Camelina Sativa seed), 2G-PPO-JA (2nd Pure Generation Plant Oil based on Jatropha seed), and 2G-PPO-MG (2nd Pure Generation Plant Oil based on Maize Germ) would be used as fuel. So tractor n° 3 ran with 2G-PPO-SF (since June 2010), tractor n° 5 with 2G-PPO-CS (since July 2010), and tractor n° 15 with 2G-PPO-MG (April to June 2010) and 2G-PPO-JA (since November 2010) in addition to 2G-PPO-RS fuel.

After production, the 2G-PPO was stored in Intermediate Bulk Containers (IBC) of 1,000 liters each. The fuel was delivered to the partners in an IBC. Special fuel stations were used at the demonstration that could be connected directly to the IBC. The whole supply chain was designed to avoid any contamination with dust or water as long as the correct procedures were followed.

Additives supplied by JD, or developed and produced by Lubrizol prior to the project, were mixed into the demonstrated 2G-PPO fuels. These additives were so-called keep-clean (JD) and multi-functional diesel additives (MFDA) (Lubrizol). They optimize the combustion and prevent combustion residuals deposition in the injection system. The lubricants used for the field tests and demonstration were the E7 and E9 called lubricants developed within 2ndVegOil.

Figure 14: shows the tractor masterplan which provides details of the scientific field tests and the demonstration and monitoring programme within 2ndVegOil. Tractor n° 15 was also tested with a small amount of 2nd generation coconut, palm and soy oil in the framework of a linked research project.

The tractor fleet demonstration and monitoring was conducted jointly with farmers, who operated 11 out of the 13 tractors in their normal farming operations. Two tractors were operated by ITP on the institute's own experimental farm in Poznan/ Poland. The local JD tractor dealers in Poland, Austria and France were involved in the demonstration and monitoring, and provided local support. In general, the tractor operator bought a tractor from the local dealer who ordered it at JD in Mannheim. The tractor was then converted to 2G-PPO operation in Mannheim and delivered to the operator via the local dealer. The aim was to operate each tractor at least 500 hours per year and all tractors 700 hours per year on the average.


Tractor operators and dealers underwent comprehensive training by the project partner VWP, and were supported by specifically prepared technical documentation and operating instructions that were established in English (master version), German, Polish and French. Operator contracts were concluded between the tractor operators and the respective national project partner (ITP in Poland, Waldland in Austria and FRCuma in France). The contract regulated the duties of the tractor operator with regard to the proper operation and monitoring and supported him with comprehensive technical guarantees and support. The first point of contact for the tractor operators in case of technical problems or questions was the respective local dealer. If there was any suspicion that the problem was due to 2G-PPO, VWP was contacted.

The fuel was delivered by the first reference press at Öl- und Bioenergie GmbH in Austria and the second reference press at the Cuma Verte Prairie in France. The quality of the oil from the third reference press at the experimental farm of ITP in Poznan, Poland, could not be stabilised at a sufficiently high level during the demonstration fleet operation and was therefore not used as fuel in 2ndVegOil.

The demonstration and monitoring aimed at establishing a comprehensive database on the tractor engine power, durability and the condition of the engine lubricant. For that purpose, measurements were made and monitoring logbooks were kept. Measurements were made of the engine power, the quality of the fuel oil and the lubricants. The quality of the fuel oil was assessed by laboratory analysis of samples of the produced oils. Samples of the lubricant were subjected to laboratory analysis (see above).

For testing the tractors after conversion to 2G-PPO operation, a stationary dynamometer in a fully instrumented test cell at JD in Mannheim was used, as well as a mobile Power-Take-Off (PTO) dynamometer. FRCuma and ITP used local PTO dynos. Each 350 OP the tractors were measured with the PTO dyno.

The monitoring logbooks were set up in four languages. They were to be filled in by the tractor operators on a daily basis. Figure 15: shows a sheet of the logbook.

VWP <small>VERNEHME HILFSTÄTTEN FÜR PFLANZLICHTECHNOLOGIE</small>				Operation Log				JOHN DEERE			
Customer-Name:				Tractor-type:				Tractor Serialnumber:			
date	status op-hrs	refuel amount (liters)		oil level (mm)	engine oil (liter)		operating mode *)	remarks / features / maintenance / repairation			
		rape seed oil	diesel fuel		oil change	refilled					
1	2	3	4	5	6	7	8	9			
01.02.2009											
02.02.2009											
03.02.2009											
04.02.2009											
05.02.2009											
06.02.2009											
07.02.2009											
08.02.2009											
09.02.2009											
10.02.2009											
11.02.2009											
12.02.2009											
13.02.2009											
14.02.2009											
15.02.2009											

Operating mode *)

No	Work
1	Plough
2	Cultivator
3	Disc harrow
4	Transport (on road)
5	Spreader
6	Sprayer
7	Power harrow
8	Seeder
9	Baler
10	Mower
11	Tedder, windrower
12	Forage loader
13	Slurry tank
14	Manure spreader
15	Front loader work
16

WP 5
2nd vegoil
S.Innerhofer_V1_8_en

Please send diary entries monthly to:
EU-Partner / Fax

VWP
Am Steigbühl 2
D - 90584 Allersberg

Figure 15: Sheet of the operation logbook

For evaluating the tractors’ fuel consumptions and to make them comparable among each other, 16 operation modes were defined, of which 15 corresponded to defined field works, and were arranged in four different load level groups. The 16th mode served as a category for activities that the tractor operator could not allocate otherwise. The operation mode was noted in the logbook,

together with the operation hour status, fuel consumption, lubricant level and events such as lubricant drain and ECU failure codes.

All but one tractor reached the scheduled minimum of 500 annual operation hours per year. Altogether, the tractors were operated 20,117 hours under the demonstration and monitoring programme. The rate of documentation (operation mode recorded) was 90%, the average load 70% and the average fuel consumption was 13.5 liters per operating hour. At the end of the demonstration and monitoring programme, some tractors were partially disassembled and submitted to thorough inspection in order to check the engine condition after 2G-PPO use. This was done notably with those tractors that had been operated with other oils than 2G-PPO-RS.

The scientific field test programme involved only five tractors and shorter operation periods, but was slightly more comprehensive than the tractor fleet demonstration and monitoring programme with regards to the assessed parameters, degree of detail of measurements, and additional tractor investigations. In particular, emissions were measured for the tractors n° 14 and 15. The EU Stage 3B compliant tractors were submitted to an endoscope inspection of the DPF after each regeneration cycle. The scientific field test programme covered the operation with 2G-PPO-MG and 2G-PPO-JA. It was linked to another research project within which small amounts of 2nd generation coconut, palm and soy oil were tested.

The five tractors were operated by JD on their test field near the factory in Mannheim. Two tractors joined the demonstration and monitoring programme halfway through the project. Two further tractors were operated by farmers in Bavaria under the close supervision of TFZ, one starting in May 2009, and one in March 2010 on. Altogether, the tractors were tested for 5,701 operation hours within the scientific test programme, including 10 successfully completed operating hours of an EU Stage 4 compliant tractor. Contrary to the demonstration and monitoring programme, special operations (mode 16) accounted for a significant part of the total operation time.

The scientific field tests and the tractor fleet demonstration and monitoring have shown that tractors with advanced engines that are converted to 2G-PPO operation can run on different kinds of 2G-PPO, with a stable and good engine performance and with very low emission levels. The PTO measurements were found to be a good method to observe the tractors condition over the testing period. No catastrophic technical failure, such as engine destruction, occurred during the project, and only minor technical problems with fuel filters and injectors were found to be related to 2G-PPO. For instance, a few cases of power loss could be traced back to fuel impurities and solved by cleaning the injectors or the fuel supply system. Fuel impurities can be traced back to contaminations due to irregular handling of 2G-PPO or use of other fuels. This underlines the paramount importance of adhering to storage requirements when using 2G-PPOs.

Concerning lubricants, both tested lubricants achieved a good performance. Regarding fuel additives, it could be seen that the Lubrizol additive more often led to technical problems, such as power loss, than the JD Protect 100. It is assumed that this is due to too low dosing of the Lubrizol additive compared to JD Protect 100. Last but not least, the tractor operators' feedback was positive in terms of the tractor performance, and several tractors will continue to be operated with 2G-PPO by the same operators.

Fuel standard development

A major dissemination effort as part of the 2ndVegOil project was to draft an acceptable text proposal for a standard that can be accepted by all the Member States of the European Standardization Committee (CEN). The resulting European Norm (EN) needs full product and test method assessment and correlation of field experience regarding distribution systems and engines. The project duration, the application of, and experience with the product around Europe was not adequate to achieve that goal. As an intermediate step, a proposal for a so-called CEN Workshop was made.

The Workshop was accepted and initiated by CEN in 2009. Additional experts other than the project partners were sought and found. After a kick-of meeting in April 2010, the group continued to work with 12 organizations on a fuel specification. After the sixth meeting, the text was concluded and presented to CEN for publication as a so-called CEN Workshop Agreement. It has been published on 7 December 2011 as CWA 16379:2011, *Fuels and biofuels — Pure plant oil fuel for diesel engine concepts — Requirements and test methods*. It is publicly available as a reference document from the CEN Members National Standard Bodies (see: <http://www.cen.eu/cen/News/PressReleases/Pages/biodiesel.aspx>).

Table 4: Threshold values of new draft standard (CWA 16379:2011)

Property	Unit	Limits			
		Direct processed		Improved quality	
		PP01 minimum	PPO1 maximum	PPC2 minimum	PPO2 maximum
Visual aspect	--	Free from visible contamination, sediment and free water			
Density at 15 °C	kg/m ³	910,0	940,0	910,0	940,0
Flash point	°C	101	–	101	–
Lower heating value	kJ/kg	36 000		36 000	
Sulfur content	mg/kg	–	10,0	–	10,0
Water content	mg/kg	–	750	–	750
Total contamination	mg/kg	–	24	–	24
Oxidation stability at 110 °C	h	6,0	–	6,0	–
Acid value	mg KOH/g	–	2,0	–	2,0
Phosphorus content	mg/kg	–	12,0	–	1,0
Ca + Mg ^g	mg/kg	–	20,0	–	1,0

The final document specifies the minimum properties of pure plant oil that are necessary to achieve smooth deployment of this fuel in diesel engines, with or without exhaust gas after-treatment, compatible for pure plant oil combustion. In the CWA, two pure plant oil fuel classes are defined. These are effectively tailored towards use in diesel engines without, and diesel engines with exhaust gas after-treatment (catalyst, filter). Both classes are intended for, but not limited to, use in heavy duty vehicles. This is also due to

the fact that all field data was taken from tractors under the 2ndVegOil project.

The CWA will be usable on a voluntary basis for engine clearance, fuel acceptance and where necessary fuelling station allowance, supporting both local regulations and international trade. In the longer term, further work in this area, including steps towards a more formal standard, will depend on whether pure plant oil and the adapted engines become available as a general automotive concept.

Project assessment

The development and demonstration activities in 2ndVegOil were accompanied by a project assessment in line with the PREMIA assessment framework. The latter is a common assessment framework for demonstration actions of alternative motor fuels in transport. It was developed within the EC FP6 project “PREMIA - R&D, Demonstration and Incentive Programmes Effectiveness to Facilitate and Secure Market Introduction of Alternative Motor Fuels (AMF)”. Though it was first applied in a project dealing with hydrogen fuel for passenger cars, it is general and flexible enough to allow assessing the other alternative transport options, too.³

The PREMIA assessment framework allows comparison of the use of alternative motor fuels according to different aspects, but does not include a complete life cycle analysis (LCA). As 2ndVegOil dealt with tractors, instead of passenger cars, an adaptation of the PREMIA assessment framework was made. For this purpose, a reference system and a 2ndVegOil system were defined. The PREMIA classification system of assessment parameters was adopted, but an adjustment was made of the assessment parameters and the way they are determined.

Among the various parameters that are proposed to be assessed by the PREMIA assessment framework, the focus of the work was aimed at the potential for greenhouse gas emission (GHGE) savings. The latter was calculated by using (1) the BioGrace GHG tool⁴, which is free software that has been developed in the frame of the Intelligent Energy for Europe (IEE) project BIOGRACE and (2) an in-house mathematical model, which has been developed in parallel to the 2ndVegOil project. Both methods are equivalent, and allow calculating GHGE in line with the EU Renewable Energy Directive (RED) (2009/28/EC)⁵ and the EU Fuel Quality Directive (FQD) (2009/30/EC)⁶. This ensures that the results obtained are comparable with other assessments in the field of biofuels that comply equally with the two mentioned directives.

A first major finding was that using 2nd Generation Pure Plant Oil from Rape Seeds (2G-PPO-RS) as fuel in the cultivation of rape seed that is used for 2G-PPO-RS production, raises the GHGE savings from the standard value of 57% to above 60%, i.e. above the minimum value that is imposed by the RED and FQD from 2018 on.

Even higher GHGE savings can be obtained with 2nd Generation Pure Plant Oil from Camelina Sativa seeds (2G-PPO-CS) that are produced in mixed cultivation with wheat for instance. The key parameter is the lower heating value to GHGE ratio of the cultivation (HER), i.e. the ratio of the lower heating value of the co-produced crops to the GHGE related to the cultivation. Wheat has a better HER than 36.79 MJ/g CO_{2-eq}, which was found to be the minimum value for a crop mixture, achieving a GHGE saving of 60%, if the oil crop is processed in a manner equivalent to the standard rape seed oil production process (see black horizontal curve for a fictitious mixture where both components have a HER of 36.79 MJ/g CO_{2-eq} in Figure 16:). The minimum HER is different if

³ (Pelkmans, Van Poppel, & Govaerts, December 2006)

⁴ www.biograce.net (Biograce - Harmonised Calculation of Biofuel Greenhouse Gas Emissions in Europe, 2011)

⁵ (Renewable Energy Directive (RED), 2009)

⁶ (Fuel Quality Directive (FQD), 2009)

deviations occur from the standard production process that is underlying the RED and FQD (e.g. different oil yield during pressing), but the difference is small in most cases. Hence, for a wide range of mixtures, the high HER of wheat compensates the low HER of camelina sativa. If the latter was combined with a crop X that has the same HER as camelina sativa, the GHGE saving would remain below 60% for all mixtures (see CS-X curves in Figure 16:).

Mixed cropping has allowed the production of higher yields for the crop fractions than would be expected from linear interpolation of the monoculture yields^{7,8}. For this reason, the yields have been interpolated not only linearly, but also by a square function that fits with literature values. The non-linear curves in Figure 16:, compared with the linear ones, show the effect of this square function interpolation, i.e. the effect of the higher yields obtained by mixed cropping compared to monocultures. There is a gain of a few percent of GHGE saving. Hence, mixed cropping is an effective option for optimizing the GHGE saving. The decisive parameters are the HER and the parameters that describe the mixing effect. With these parameters, suitable mixtures of oil crops with accompanying crops can be selected.

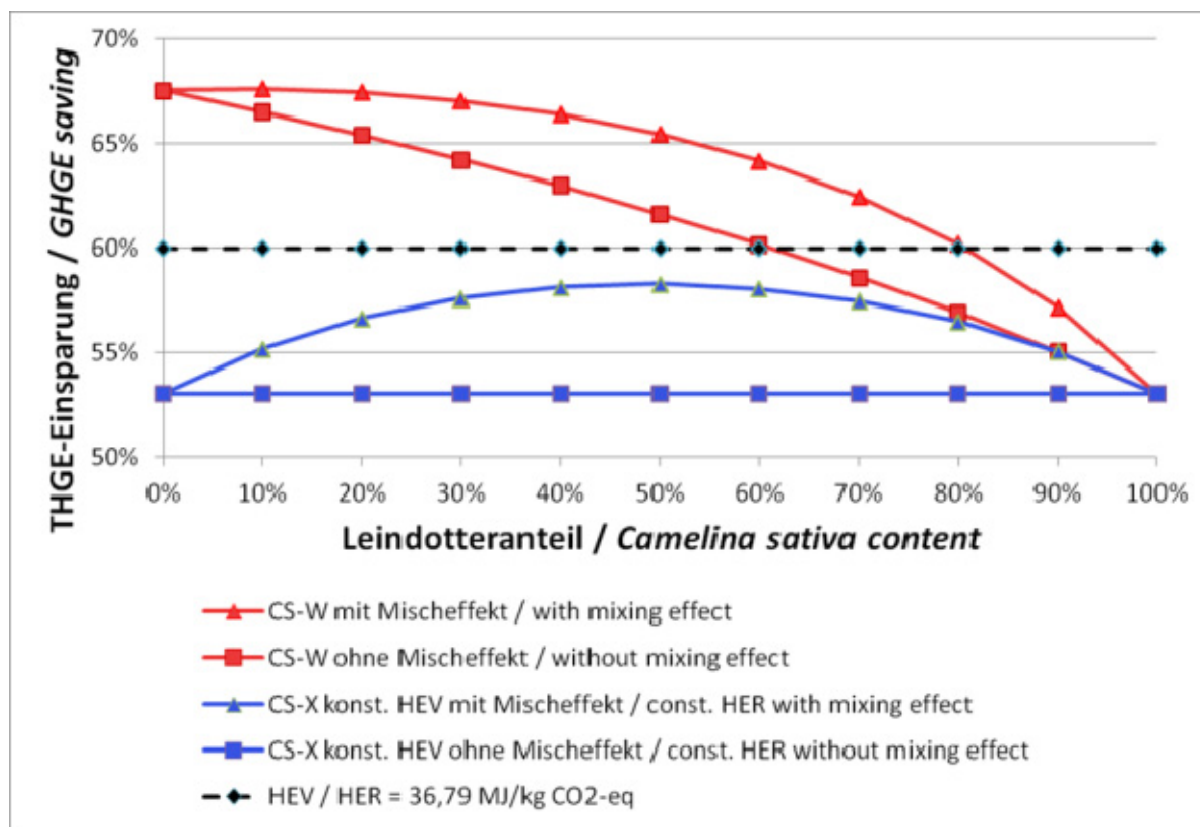


Figure 16: GHGE saving as a function of the camelina sativa (CS) content in mixtures with wheat (W) or a fictitious grain crop (X) with the same HER as camelina sativa

⁷ (Paulsen)

⁸ (Gollner, 2010)

It was further found that the contribution of N₂O from the combustion process to the overall GHG emissions is probably very small. However, this contribution could become very large if NO_x reduction strategies fail in completely reducing NO_x to N₂, and major parts of NO_x are reduced to N₂O only. Future work is needed to determine exactly how much N₂O is released during the combustion process and how the amount of N₂O is influenced by different NO_x reduction strategies.

Table 5: Calculation of land use for 2G-PPO production

Term	Symbol	Source/ Formula	Number	Unit
Energy yield in rape seeds per cultivation area	e_{rapeseed}	BioGrace GHG tool	73.975	MJ/ha
Fraction of energy in rape seeds that arrives as oil fuel in the tank	$f_{\text{energy,PPO}}$	BioGrace GHG tool	58,22%	MJ/MJ
Fraction of total cultivation area allocated to oil fuel in the tank	$f_{\text{area,PPO}}$	own considerations	61,25%	ha/ha
Energy yield in rape seed oil in the tank per allocated cultivation area	e_{PPO}	$= f_{\text{energy,PPO}} / f_{\text{area,PPO}} \cdot e_{\text{rapeseed}}$	70.313	MJ/ha
Cultivation area per MJ of rape seed oil in the tank	a_{PPO}	$= 1/e_{\text{PPO}}$	1,42E-05	ha/MJ
Cultivation area per kWh of rape seed oil in the tank	a_{PPO}	$= a_{\text{PPO,MJ}} / (3,6 \text{ kWh/MJ})$	3,95E-06	ha/kWh
Efficiency of engine	η_{engine}	2ndVegOil Del 2.3 vs2 ^{*)}	36,70%	kWh/kWh
Cultivation area needed per kWh energy delivered to shaft	a_{shaft}	$= a_{\text{shaft}} / \eta_{\text{engine}}$	1,08E-05	ha/kWh
Cultivation area needed per kWh energy delivered to shaft	a_{shaft}	$= a_{\text{shaft}} \cdot 10^5 \text{ m}^2/\text{ha}$	0,11	m²/kWh

*) The efficiency of the JD PowerTech PVX engine is confidential. Here, the efficiency of the JD 6068 PowerTech Plus engine is used instead as a good approximation.

Concerning the land use, the figure has been calculated for 2G-PPO-RS and amounts to 0.11m²/kWh, where the area allocated to the oil (as opposed to the area allocated to the oil cake) is expressed in terms of mechanical energy delivered by the engine crankshaft. The values for other 2G-PPO still need to be determined, and then a comparison needs to be made with other biofuels. It is assumed by the project consortium that 2G-PPO have generally a better land use performance than several other biofuels, because 2G-PPO is produced jointly with a valuable by-product, oil-cake, which is rich in proteins and a valuable fodder.

Concerning most parameters that are related to vehicle performance, operation and use, the differences between the reference and the 2G-PPO case are almost negligible.

6. Outlook

Exploitation of results

The project has paved the way towards the series production of a pure plant oil fuelled tractor and other heavy-duty machinery. The project partners, particularly John Deere, will continue fine-tuning the achieved developments to make them ready for series production. The market is not yet ready to allow a business case for a pure plant oil fuelled tractor, but the situation can change quickly if the fuel price continues to rise. In the meantime, the market is limited to a smaller number of customer designed agricultural and other heavy-duty equipment that is adapted to pure plant oil operation with the technology developed in this project.

The CWA 16379:2011, *Fuels and biofuels — Pure plant oil fuel for diesel engine concepts — Requirements and test methods*, will be usable on a voluntary basis for engine clearance, fuel acceptance and, where necessary fuelling station allowance, supporting both local regulations and international trade. In the longer term, further work in this area, including steps towards a more formal standard, will depend on whether pure plant oil and the adapted engines become available as a general automotive concept.

Potential impact

Contribution to biofuel supply in the EU

This project has widened the range of plant oils that can be made suitable for use as transport fuel by proper pressing, blending and additives. E.G. camelina sativa alone can contribute to a few percent of the total fuel demand of the EU, without needing much extra land for being grown, if mixed cultivation is applied to cereals and fodder pea cultures in the EU. As a side effect, this would enable a nearly complete switch of the agricultural areas concerned to organic agriculture, thereby strongly enhancing the sustainability of agriculture in the EU.

Due to the high flame-point and the total harmlessness for soil and water, plant oils are very safe and environmentally friendly fuels and are perfectly suitable for environmentally sensitive areas and for vehicles operating in agriculture. They are therefore a very valuable element of a comprehensive bio-fuel supply strategy.

Within the mix of different bio-fuels, which have the potential to reduce the EU's dependency on imported fossil fuels, plant oil fuels are potentially the most compatible with food and raw material production. Oil seeds have two products: oil and oil cake which can be used as protein-rich animal food or even human food. In addition, the straw of oil plants can be used for biogas generation.

Contribution to engine development

This project has allowed plant oil fuel and engine technology to make a big leap forwards by making fuel-engine concepts available that fulfill the forthcoming Euro 6 norm which is valid since 1 January 2012. This is a quantum leap, bearing in mind that even many engine specialists have never heard about engine concepts, which enable the currently permitted emission levels to be achieved when fuelling the engine with plant oil fuel.

The strategy pursued in this project, to go ahead with tractor engine development and demonstration, as long as no hybrid vehicles are available in sufficient number for conducting a medium-scale demonstration, anticipated the forthcoming development of high efficient and low-emission hybrid vehicles. Thanks to an additional comprehensive activity on hybrid engine development, this project has prepared the ground for a quick implementation of plant oil use in hybrid engines, as soon as these come onto the market.

Contribution to standards

With the publication of the CWA 16379:2011, Fuels and biofuels — Pure plant oil fuel for diesel engine concepts — Requirements and test methods, on 7 December 2011, 2ndVegOil has provided a significant contribution towards a more formal standard, whose final formulation will depend on whether pure plant oil and the adapted engines become available as a general automotive or agricultural concept. The CWA will then be a stepping stone for a revised specification or for other standards.

Contribution to overall sustainable development

Plant oils have, until now, not always been considered as a fully sustainable alternative to fossil fuels. The reason is that mainly rape seed oil has been used so far, and rape seed can hardly be cultivated organically. In addition, the low yield of oil per hectare, compared to the yield of biogas per hectare of energy plants that are digested or to synthetic bio-fuels still under development is frequently cited. This project has shown that the reported area need has to be corrected at least by taking the energy content of the co-produced oil cake into account. If plant oils are produced as a co-product of a main crop in mixed cultivation, the additional area need is much smaller again. This widens the range of options for sustainable fuel supply.

Promoting plant oil as a fuel, this being the purpose of this project, in fact makes a strong contribution to sustainability. This applies firstly economically and socially, because it provides new economic opportunities for SMEs and farmers in rural areas, and secondly with regard to the environment, because it has a very good energy balance in production and features the lowest risks for the environment.

This project has thus contributed to increasing environmental sustainability; first, by developing very low emission fuel-engine concepts, and secondly, by considering oil plants other than rape seed, which have an even better environmental performance.

Contribution to promotion of SMEs and farmers

Plant oil can be produced by farmers and SMEs, who profit from the whole value creation chain. This distinguishes plant oil notably from bio-ethanol and, in particular, from synthetic fuels, which are produced by the thermo-chemical pathway. The latter requires large production units in order to achieve an acceptable overall efficiency, at least if the produced fuel is the main product and not just a co-product of electricity and heat generation. Thus, plant oil offers the most comprehensive chances for the promotion of SME and farmers.

In this project, a focus was put on methods for producing 2nd generation plant oil fuels in small decentralised oil presses. The reference oil presses, which were built to supply the demonstration fleet, are owned by SMEs. The concept and technologies to produce very high quality oil, decentralised in small oil presses, will be further disseminated by the project consortium beyond the end of the project. Owners of small oil presses are the main target group of the dissemination activities.

Vehicles running on plant oil offer new opportunities for small mechanical workshops to enter in the business of engine conversion and maintenance of plant oil fuelled vehicles. In this project already, local workshops in the target areas in France, Austria and Poland were trained on the basics of engine conversion and maintenance.

Proposals concerning the political framework

In the course of this work, the consortium noticed an inconsistency in the use of the Green House Gas Emission (GHGE) reference value for diesel fuel within the Fuel Quality Directive (FQD) and its implementation. The consortium requests that this be corrected in the forthcoming revised FQD and suggest to use, in the case that a bio-fuel is replacing diesel fuel, 87.64 g CO_{2-eq}/MJ instead of 83.8 g CO_{2-eq}/MJ as fossil fuel comparator, i.e. the value, which is also used in the public version 4 of the BioGrace GHG Tool for the GHGE of diesel when diesel is used as auxiliary fuel in a bio-fuel production process. This will slightly increase the calculated GHGE savings of bio-fuels that replace diesel fuel.

The consortium also advocates a threshold for the consideration of carbon stock changes caused by indirect land use changes (ILUC factor) for bio-fuels, which are produced by an agricultural enterprise and used for own use, or consumed within the local region. For further specifying this criterion, a limit could be set at 10% of the agricultural portion of an area that is used for the production of bio-fuels for own use or for consumption in the local region.

If pure plant oil from agricultural production is used by the agricultural enterprise itself, the thus produced fuel should be exempted from any tax. The exemption should also apply, if part of the production, e.g. the oil pressing, is conducted by another enterprise.

For greater reliability in assessing differences in GHGE that are due to regional characteristics, and to ensure that conditions are met for the non-consideration of indirect land use changes, cooperation is recommended with regional marketing initiatives such as UNSER LAND, which certify the regional origin of products and similar criteria, very often in relation to sustainability aspects. The use of typical regional values for the GHGE calculations for bio-fuels could be legitimised by a certification of such bio-fuels by accredited certification systems of regional marketing initiatives.

Further RTD to be done

The following development work needs still to be done before series production of pure plant oil tractors of EU Stage 4 emission class can start:

- In terms of 2G-PPO injection, further scientific research is required to better understand the complex behaviour of fuel injectors.
- The complex mechanism of deposit formation in internal combustion engines fuelled with PPO needs to be investigated.
- The use of 2G-PPO also for the regeneration of the DPF needs to be developed.
- The long-term exhaust gas cleaning performance needs to be investigated, in particular for EU stage IV.
- A fuel detection and automatic switching of the ECU between 2G-PPO and diesel operation is needed.

Concerning the fuel development, further research is needed to develop farming practices for mixed cultivation of camelina sativa with cereals and other field crops. The research might also be extended to other new oil crops that are found to be suitable companions for mixed cultivation.

Further need for research exists, also with regard to the functional relationships of N₂O field emissions, nitrogen fertilisation, soil conditions and climate/ weather. This work has also shown that GHGE calculations with European average values can lead to big differences to actual GHGE under real cultivation and production conditions. Here, further research is needed about the possibilities to conduct more precise regionally differentiated calculations with a reasonable effort.

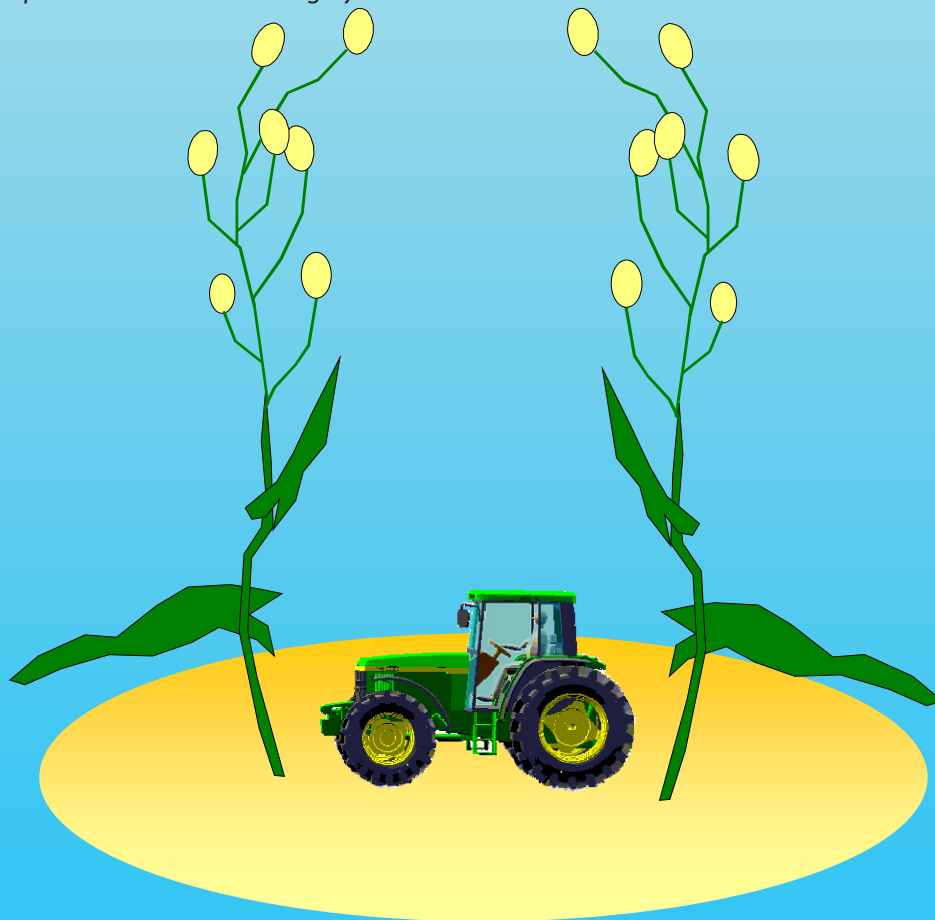
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The term "pure vegetable oil" (PVO) which figures in the title of the project was decided to be abandoned in the course of the project and was replaced by "pure plant oil" (PPO). The latter is the expression which is used among others in the European Standardization Committee (CEN) Workshop Agreement CWA 16379, Fuels and biofuels — Pure plant oil fuel for diesel engine concepts — Requirements and test methods, which is one of the major outcomes of this project. For this reason, the term "pure plant oil" is used thoroughly within this document.



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