Project no. TST5-CT-2006-031241

CLEANENGINE

Advanced technologies for highly efficient Clean Engines working with alternative fuels and lubes

Specific Target Research Project (STREP)

PRIORITY 6.2 Sustainable Surface Transport

PUBLISHABLE FINAL ACTIVITY REPORT

Period covered: from 01/01/2007 to 31/12/2009 Date of preparation: January 2010

Start date of project: 1st January 2007 Duration: 36 Months

Project coordinator name: Flavia GILI
Project coordinator organisation name: CENTRO RICERCHE FIAT SCpA

1 PUBLISHABLE EXECUTIVE SUMMARY

1.1 Summary Of Project Objectives

According to car manufacturer EUCAR consortium beyond the year 2010, the share of engines will depend mainly on:

- legislation
- **availability of mature new technologies**
- infrastructure of alternative fuels
- **availability of modified / synthetic fuels and lubricants**
- costs and **customer acceptance**

CLEANENGINE addresses 3 of these main aspects; research activities will be focused on development of modern clean motors based on:

- **liquid biofuels coming from biomass** (like biodiesel and bioethanol)
- **environmentally friendly and ash-free lubes and/or lubrication concepts**.

Impact of bio fuels and bio lubes usage on current small (ships), medium (car) and large (ship) diesel and/or gasoline engine configurations will be evaluated and compatible optimized solutions in materials, geometry and after-treatment will be developed considering lifecycle assessment methodologies.

Main effects will be:

- increasing engines efficiency (by reducing internal friction and improving combustion);
- reduce emissions at the source (very heavily in CO_2 emissions taking into account the complete life cycle of the biofuels, even up to nearly zero CO_2 emissions when using 100% biodiesel;
- reductions in NO_x, CO and PM when using mixtures of oxygenated biofuels as bioethanol;
- improve the technological and industrial practice related to the use of alternative fuels in combination with environmentally friendly lubricants;
- Increase the utilization share of biofuels;
- Reduction of the wear originated by the accumulation of biofuels in engine oils.

The advantage that can be gained in this project will:

- help in consolidating strategic knowledge for the European large industrial partners (Fuchs, Fiat, Arizona Chemicals, Guascor, Ecocat) and the SME's (Firad, Abamotor). They all will be able to compete world-wide with the results gained in this project, especially in the new emerging markets of the 'clean engines';
- guide politics for environmental legislations.

1.2 The Consortium

Due to the wide spectrum of considered technologies in the frame of the project a large number of partners is involved.

Partic. no.	Participant name	Participant short name	Country
1	CENTRO RICERCHE FIAT	CRF	IT
2	FUNDACION TEKNIKER	TEKNIKER	ES
3	FEDERAL INSTITUTE FOR MATERIALS RESEARCH AND TESTING	BAM	DE
4	AVL	AVL	AT
5	ABAMOTOR	ABAMOTOR	ES
6	GUASCOR I+D	GUA	ES
7	FUCHS Europe Schmierstoffe GmbH	FUCHS	DE
8	F.I.R.A.D.	FIRAD	IT
9	ARIZONA CHEMICALS	ARZ	NL
10	ECOCAT OY	ECOCAT	FI
11	OBR PR – RESEARCH AND DEVELOPMENT CENTRE FOR PETROLEUM INDUSTRY	OBR	PL
12	ISTITUTO MOTORI - CNR	IM	IT

1.3 The Coordinator And Contact Details

The project is coordinated by C.R.F. S.C.p.A. , Italy.

Coordinator's contact details:

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1.4 Work Performed And Results Obtained

Main results of the project can be summarized as follows:

- Development of bio-fuels (FAME and ethanol blends) according to engine manufactures specifications;
- Development and characterisation of two alternative lubes families;
- Corrosion and tribological characterization of engine materials for bio-fuels and alternative lubes compatibility;
- Application of innovative after-treatment systems to considered engines;
- Assessment of emission levels using alternative fuels, lubes and after-treatment technologies;
- LCA well to wheel study for bio-fuels and alternative lubes.

1.5 Conclusions

The project brought together many and different aspects of three complementary subjects – engines, biofuels and biolubes – with the objective to identify their interactions in view of defining those common factors allowing the achievement of the EU strategic CO2 and pollutants targets in a high competitive environment at worldwide level.

More specifically the following points were considered:

- engine sizes both for displacement and power output [small (less than 19 kW) by ABAMOTOR, medium for car application by FIAT and large size (higher than 560 kW) by GUASCOR for genset and maritime];
- biofuels (ethanol, FAME) blended with diesel fuel;
- alternative oils (ester based oil and polyglycol oils) with suitable additive packages;
- piston ring/nozzle body/valve stem metallurgies;
- after-treatment systems of different size /shape /coating;
- test procedures (transient for car engines and steady-state for small and large size engines).

Particular attention was devoted to the development of an engine technology for non-road applications that has to take advantage from what already achieved for on-road engines (see, for example, the perspective to extend to large engines, now equipped with in-line fuel injection pump, the common rail system).

A substantial effort was spent by the project in identifying and synthesizing those fuel – engine parameters really affecting exhaust emissions of engines running on biofuels and using biolubes. In establishing the most significant parameters, the project has set up the basis for future development of engines, running on conventional and alternative fuels, in front of the evolution of the non-road regulations at worldwide level as testified by a number of International regulations recently introduced or to be introduced very soon: new amendments of the EU directive 97/68, US 40 CFR part 1065, new Japanese regulation for special vehicles (i.e. non-road engines in the Japanese terminology) and the NRMM global technical regulation ECE/TRANS/WP.29/2009/118 adopted last November by the United Nations in Geneva.

2 PROJECT OBJECTIVES AND MAJOR ACHIEVEMENTS DURING THE PROJECT

2.1 Technical Objectives

The overall objective of Cleanengine project can be summarized as to optimize in terms of emission requirements and performances currently available IC engines (namely "small", "medium" and "large" sized engines) running with alternative fuels and lubes working on:

- Quality, ecotox profile and performances of bio-fuels blends, lubes and related additive packages formulations;
- Proper selection of engine components materials in respect to biofuels and oils;
- Improvement of combustion chamber shape and injection nozzle design;
- Development and/or adaptation (depending on the application) of after-treatment system.

2.2 Current State Of The tArt

Bioethanol and biodiesel are the most common biofuels used in transport worldwide. The main drivers for biofuels production and use are the security of energy supply, diversification of energy supply, reduction of oil import and oil dependence, rural development and GHG emissions reduction.

The production cost of ethanol and biodiesel declined substantially over the past years, but is still higher than that of petrol and diesel and represent a barrier to a massive introduction on the transportation market.

There are also a number of concerns about first generation biofuels (used in this project) related to their impact on the environment, biodiversity and water resources, land use changes, real GHG emission reductions and cost of CO2 avoided emissions.

Biofuel blending limits in the EU are set according to conventional fuel standards, designed to ensure a compatibility with conventional power trains and refuelling infrastructure.

In particular:

Compression Ignition Engines: The current European fuel specification for diesel fuel EN590 allows the blending of up to 5 vol.-% of biodiesel (B5) to fossil diesel. Biodiesel used for blending has to meet specification EN14214 which is the standard for neat biodiesel distributed in Europe. Biodiesel offered in Europe is mainly based on Rape Seed Oil Methyl Ester. However, other biomass sources (Soy Bean Oil, Palm Oil, Sunflower Oil) are increasingly used as are waste cooking oils in limited quantities.

B5 fuel is approved by all car manufacturers for vehicles of existing fleet and new cars. No adaptation of vehicle parts and engine are required. By contrast, for usage of B100 (neat biodiesel) vehicle adaptation is needed. The vehicle fuel supplying system has to be provided with biodiesel compatible materials. Oil change intervals have to be reduced to counteract accelerated oil aging and dilution with fuel. Even B10 fuel makes certain vehicle and engine adaptations necessary.

The impact of fuel properties of CI engine fuels on vehicle issues is still not completely known or understood. Therefore, fundamental research is essential in order to expand basic knowledge in this area.

Spark Ignition Engines: The current gasoline fuel specification EN228 allows a blending of 5 vol.-% of ethanol (E5) or 15 vol.-% of ETBE to gasoline.

E5 according to EN228 standard is approved by car manufacturers for all vehicles of the existing fleet and new cars. No adaptation of vehicle components or engine is required. E10 fuel is compatible to most of the fleet vehicles except some DI gasoline vehicles with first generation fuel injection systems provided with rails made of aluminium. The use of E85 requires adaptations of materials of the fuel supplying system and the engine. This is due to the corrosive impact of ethanol and its worse cold starting properties compared to gasoline.

As is the case for CI engines there is also a need to obtain further information concerning the interrelation between the properties of fuels used with SI engines and vehicle issues. Fundamental research is essential in order to expand basic knowledge in this area in order to provide a basis for the definition of future fuel requirements.

In this context Cleanengine project focused on a particular issue linked to the fuelling with oxygenated fuels: the detrimental effect of the bio-fuel dilution in engine oil was fought through the development of alternative oils thanks to their intrinsic properties and special additive packages formulation.

Moreover a development/optimisation of aftertreament systems was carried out to assure the emission European norms fulfilment for the three engine categories when working with bio-fuels.

3 ACHIEVEMENTS BY WORKPACKAGE

3.1 WP0 – Management

3.1.1 Objectives

Manage the activities to achieve fruitful collaboration conditions among partners and the technical success of the project by:

Manage the activities to achieve fruitful collaboration conditions among partners and the technical success of the project by:

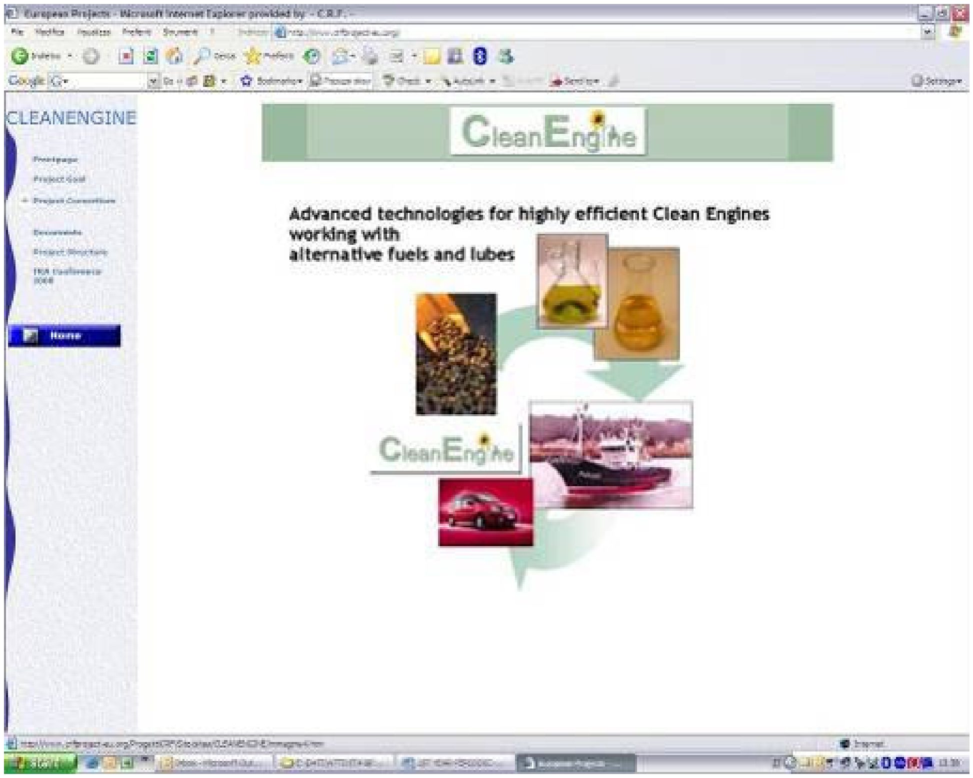
- Organization and preparation of the meetings
- Control of the progress towards the objectives of the work packages
- Organization of the production and delivery of all requested reports
- Control of all the technical reports
- Control of the financial statements submitted by the consortium members and forwarding them to the EC project supervisor
- Formulation and Implementation of the Intellectual Property policy
- Participation in inter-project meetings (i.e. CA ULYSSES)

3.1.2 Work done and final achievements

The co-ordination activities carried out during overall project are summarized below:

- Co-ordination of plenary meetings (Every 6 months)
- Compilation of consortium reports including final reports and Deliverables reports;
- Distribution of funds;
- Co-ordination and management of technical activities.

To facilitate the data and information exchanging among consortium partners, the project website published at http://www.crfproject-eu.org/ was constantly updated.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3.2 WP1 - Alternative renewable fuels

3.2.1 Objectives

To design and produce the fuels for the experiments:

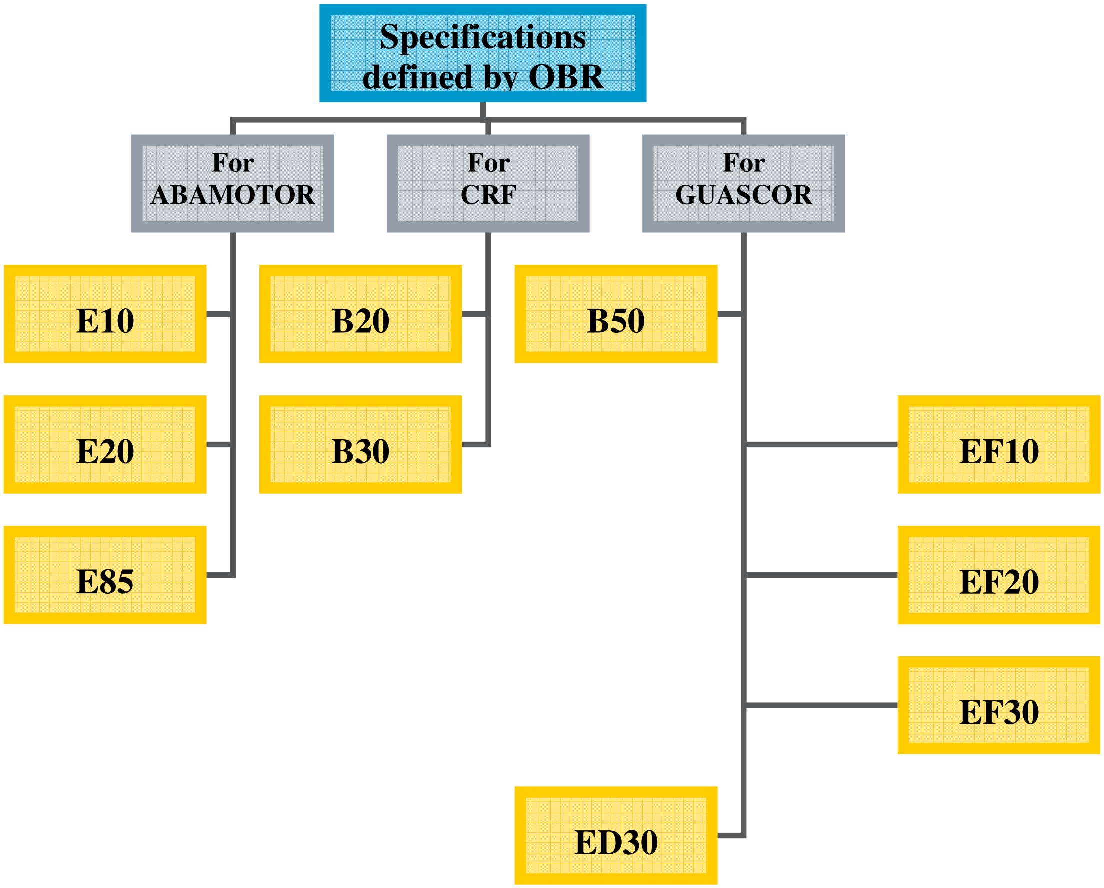
- Bio diesel + gasoil (diesel)
- Gasoil (diesel) + bio-ethanol
- Petrol + bio-ethanol
- Bioethanol + Biodiesel
- Mixtures of gasoil (diesel), biodiesel and bioethanol

To design improved lubricity, anticorrosive, biodegradability, toxicity and anti-wear additives to meet the challenging environmental requirements in low sulphur fuels and other alternative fuels and their application to engine oils.

3.2.2 Work done and final achievements

Provision of fuel specification by WP participants and biofuels formulation

At the beginning of the project, it was necessary to create database of bio-fuel blends properties for engine manufacturers To start working on bio-fuels development, it was decided among all partners that standard commercial additized fuels, FAME (Fatty Acid Methyl Esters) as well as bio-ethanol will be used for characterization and build a reference properties. The graphical scheme of work done by OBR is presented in WP1 Figure 1.



WP1 Figure 1 – Fuel blends

Bio-Diesel blends

Specifications of the qualitative parameters for FAME+DIESEL blends were defined based on :

- EN-590
- ISO 14214- 100% FAME standard
- National 20-30% FAME blends standards (Polish, Czech, Italian), and OBR's experience

For comperative studies, tests were carried out for 4 diesel fuel types: ORLEN's Diesel with commercial additives, Bluediesel (obtained from CRF, which is reference fuel chosen in Cleanengine project for medium application), Diesel with no additives, Ekoterm Plus (Light Heating Oil) that is comparable to B-Diesel specified by Guascor and FAME summer version coming from Trzebinia (Poland).

E-gasolines

E10, E20 as well as E85 were reference fuel chosen in project for small engines. In frame of the comparison OBR has carried out test on unadditized gasoline blended with 2 various types of ethanol: denaturized with bitrex and ethyl alcohol absolut 99,8% PURE. OBR has defined specification for E10 and E20 based on requirements EN 228 and PN-A-79521 standards as well as E85 based on ASTM D 5798.

E-DIESEL and E-FAME blends

There were no existing specifications nor standards for E-diesel fuels, except for E-95 Diesel developed in Sweden and applied for specially designed engine. Similar situation appeared also in case of E-FAME blends. OBR has worked on development and characterization of this fuel types as well as preparation of their specification. OBR suggested to use FAME as a compatibilizer for summer E-Diesel mixtures.

Additives Development

OBR has formulated multifunctional additive packages for all of the biofuel types to be evaluated as part of this project. These additive packages comprise a broad range of molecules that try to address specific technical issues in these fuels. For WP1, Arizona has screened internally a range of different products that were, from a production route and cost structure point of view, the best candidates to be used as components for the additive package that OBR was creating for the different biofuels. All additives were submitted to OBR, who carried out all of the necessary performance testing according to recognised international standards.

Additive AO-305-97 was proposed to be tested as a corrosion inhibitor in Bxx (FAME + fossil middle distillate diesel) and Exx (ethanol + gasoline). Due to difficulties encountered during the synthetic work, the use of dimerized fatty acids (additive AO-305-109) and the prototype esters of partial dimer fatty acids were not considered as feasible to include in the WP1 program.

Regarding E-FAME and E-Diesel, given the particular nature of these biofuels, the intention was to test the performance of the amine salt based additives. However, due to budget related restrictions, only additive AO-305-97 was evaluated. Additives optimization for E-FAME and E-Diesel blends required additionally cetane and cold flow improver presence. OBR has developed the multifunctional additive package consisting of cetane improver, cold flow improver, anticorrosion and antioxidation additive as well as biocide and has supplied Guascor for preparation EF blends on its own.

Final Assessment

OBR's specifications, worked out on the needs of small and medium application, were fully accepted by engine manufacturers. (E10,E20,B20,B30)

Specifications for diesel/biodiesel blends, diesel/bioethanol blends and biodiesel/bioethanol blends being under OBR's development do not meet all Guascor's requirements since Spanish diesel is different from Polish one. For this reason Guascor has defined and selected the biofuel blends and its theoretical provisional specifications(Deliverable 5 and 6). Besides GUASCOR biofuel provisional requirements, GUASCOR has characterized and studied Spanish reference Diesel blended with Spanish FAME and Bioethanol delivered from Poland in order to asses biofuels standards. All these data have been obtained just after preparing the mixtures. Guascor considers very important to check some parameters during storage time. Some characteristics have not been determinate because their results do not inform more about of mixture behaviour, for example PAH or ash content. Others parameter are not possible the measure because the test conditions are not adequate for the type fuel (distillation, cetane index, lubricity test parameters, stability oxidation according with ASTM-2274).

FAME-DIESEL blends: All the mixtures fit Guascor provisional requirements. Only water content is in some cases out of specification and depending on ambient temperature cold flow improver would be necessary.

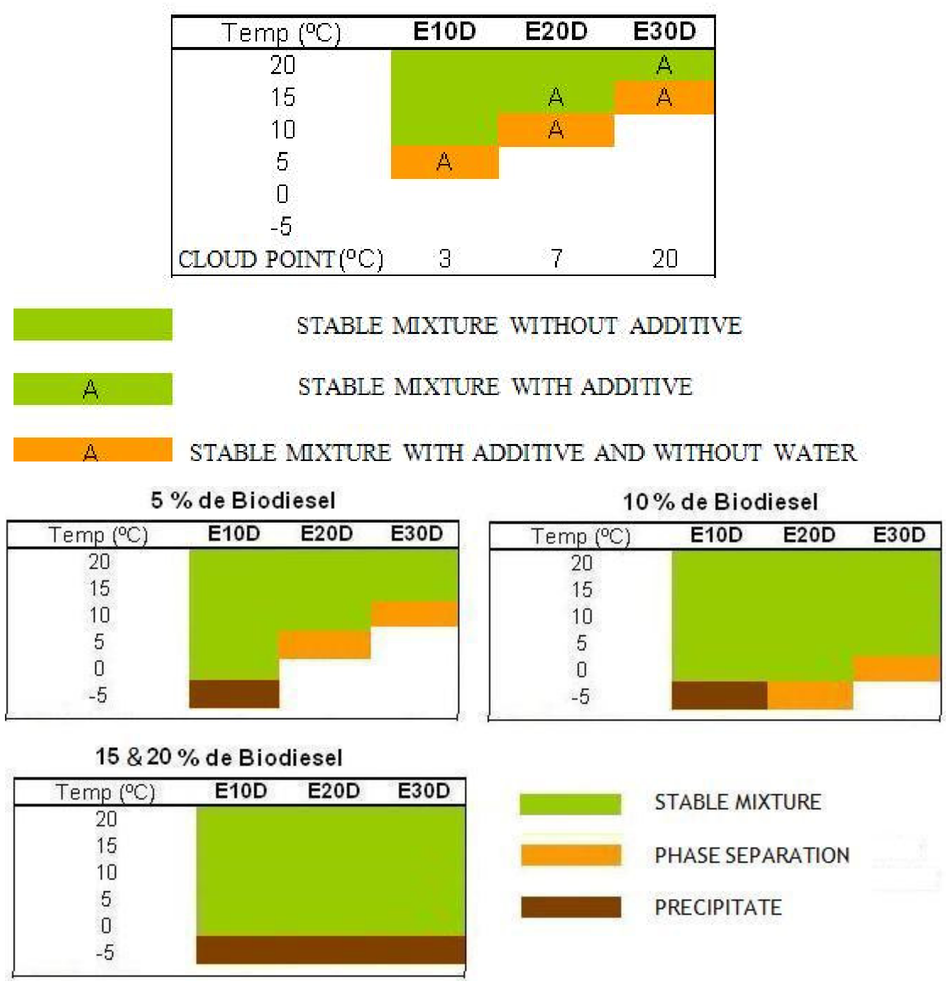
BIOETANOL-DIESEL blends:

- Blends need cetane improver in order to fit Guascor requirements.
- Depending on bioethaol % , mixtures are not stable so we need an additive that stabilizes the mixtures. Temperature and the humidity conditions cause mixture separation.
- Also the flash point is much below the limit for diesel.
- Depending on atmosfer conditions (temperature), they need cold flow improver.
- Lubricity decrease but this parameter is still on specifications.

BIOETANOL-BIODIESEL blends:

- Blends need cetane improver in order to fit our requirements.
- Depending on bioethaol % , mixtures are not stable so we need an additive that stabilizes the mixtures. Temperature and the humidity conditions cause mixture separation.

A study of the blends stability has been carried out taking into account all the factors that have an influence on it. E-Diesel Blends stability test have been run using commercial additive and/or biodiesel as emulsifier.



In conclusion, the bioethanol-diesel mixtures with more than 15% of biodiesel are stable till the temperature at which the biodiesel´s products start to precipitate; the phase separation does not occur.

In other to improve cetane number, Guascor has checked the behaivour of two different additives, one provided by O2Diesel and the other one provided by Lubrizol. The following table shows the cetane number of the E-Diesel mixtures with and without additives according to the ASTM D 613.

Mixture	% adittive	Cetane number
ED - 10	0	42,3
ED - 20	0	37,2
ED - 30	0	31,6
ED - 10	1 (O2Diesel)	45,6
ED - 20	5 (O2Diesel)	43,4
ED - 30	5 (O2Diesel)	35,6
E10/B10/D	0	42,5
E10/B10/D	0,15 (Micet-LZ)	48,9

GUASCOR will considerate the possibility of adding other additives to improve the lubricity, the corrosion and oxidation resistance, and so on.

Fuel Delivery

OBR has sent the planned shipments of ethanol to Guascor and bifuels mixtures and biocomponents for blending to ABAMOTOR and CRF in order to carry out the final engine tests there. Additionally, small quantities of FAME on partners requests were delivered by OBR during the whole project duration .

3.2.3 Deliverables

Deliverable N	Initial Deliverable title	Initial Foreseen Delivery date	Real Delivery Date	Nature	Dissemination level	STATUS
D3	Report on specifications of the biofuels for small engines (ABAMOTOR)	Mth6	Mth6	R	CO	Delivered
D4	Report on specifications of the biofuels for medium engines (CRF)	Mth6	Mth6	R	CO	Delivered
D5	Report on specifications of	Mth6	Mth6	R	CO	Delivered

	the biofuels for large engines (GUASCOR)					
D6	Report on bio fuels development, characterization and best configuration selection; contribution to standards (OBR)	Mth12	Mth24	R	CO	Delivered
D7	Report on additives packages development and content selection; contribution to standards (ARZ)	Mth12	Mth24	R	CO	Delivered
D8	Fuels supply to participants (OBR)	Mth24	Mth33	P	RE	Delivered

3.3 WP2 - Development of lubes, additives and lubrication systems to work with alternative fuels

3.3.1 Objectives

To develop, test and produce engine bio-lubricants:

- With high amount of renewable resources:
    - >50% with ester based lubricants
    - >30% with polyglycol based lubricants
    - >89% with vegetable oil based lubricants
- Low SAP (< 2000ppm S, < 0,5% ash, < 800ppm P) formulation
- Biodegradable > 60% accord. to OECD Tests and non toxic accord. to 99/45/EC
- To adapt the Plantotronic system to large size engines
- To develop lubes for the innovative lubrication concepts

3.3.2 Work done and final achievements

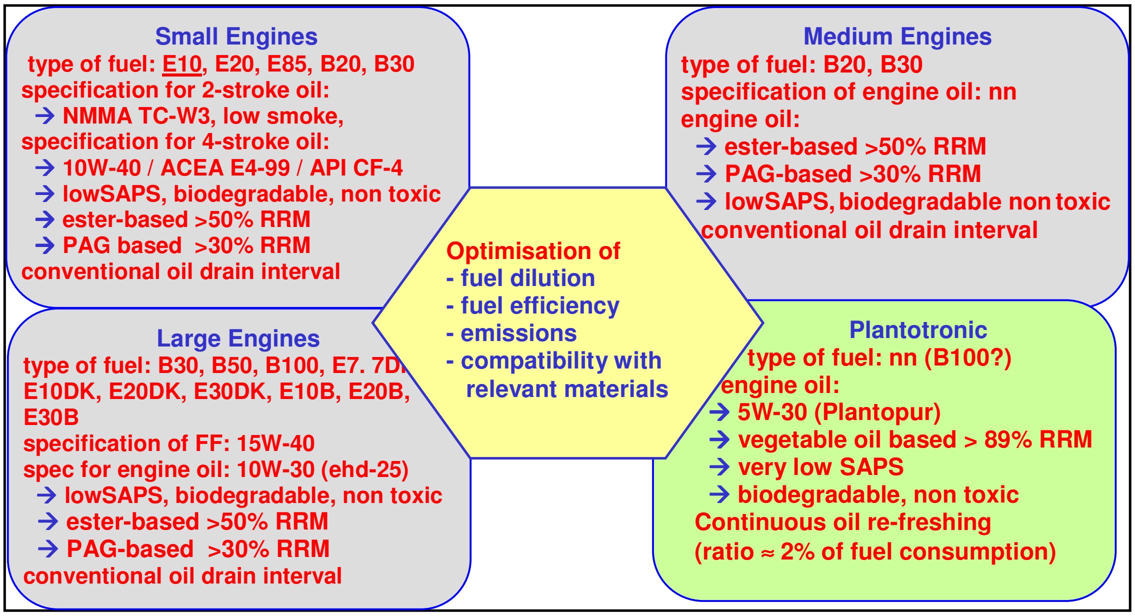
The overall objective of the WP2 is the development, production and testing of bio-based engine oils for small, medium and large engines working with alternative fuels from WP1.

The aim of WP2 is the development of lubricants, which are 'compatible' with the described bio-fuels and which are combining non-toxicity, bio-degradability and renewable resources with increased efficiency, reduced emissions and wear control. To achieve these aims the bio-lubricants should be based either on ester- or vegetable oils or on polyglycols, with a high amount of renewable resources. The minimum amounts of renewable for the different base oil categories can be found in the following table.

	Ester oils	Vegetable oils	Polyglycols
Amount of renewable resources [%]	> 50	> 89	> 30

WP2 Table 1: Percentage of renewable resources for the different base oil categories

Another approach in this project was to adapt and implement the PLANTOTRONIC system to large engines. The PLANTOTRONIC system is in principle known and is based on continuous refreshing of the used oil and offers the user an emission reduction by using pure vegetable oils and only very small amounts of additives in comparison to the today used engine oils. The PLANTOTRONIC system was developed for stationary engines and therefore the main objective in this project will be the implementation and adoption of this system for large engines.



WP2 Figure 2: Targets for bio-lubricants developed in WP 2

Four different specifications have been provided by the engine oil end-users ABAMOTOR, CRF and GUASCOR. All expect to achieve reduced emissions by the newly developed bio-lubricants and a better tolerance regarding fuel dilution and compatibility with bio-fuels. However, the different engine technologies require at least three different oils:

- 4-stroke oil for ABAMOTOR and CRF (PCMO = passenger car motor oil)
- 4-stroke oil for ABAMOTOR and GUASCOR (HDDO = heavy duty diesel oil)
- 2-stroke oil for ABAMOTOR

High fuel efficiency is another expected parameter and all oils are expected to be bio-degradable and less toxic than conventional engine oils used nowadays.
Within the Cleanengine project, engine oils were developed which are based on synthetic ester oils with an adapted additivation, both for two-stroke and four-stroke oils.

Four stroke ester based engine oils

Ester-based oils (FUCHS)

Ester oils are predestined as base oils for engine oils by combining high viscosity index, lubricity and low evaporation loss, with full compatibility with the world of mineral based lubricants and fuels. Moreover, suitable synthetic esters can be produced from renewable raw materials, e.g. by chemical modification of vegetable oils.

Within Cleanengine project, three main targets could be reached for biodiesel-tolerable engine oils:

- high amount of renewable resources: >50%
- low SAP formulation, i.e. < 2000ppm Sulfur, < 0.5% sulfated ash, < 800ppm Phosphorus
- biodegradable > 60% according to OECD 301 test, and non toxic according to EU preparations directive 99/45/EC

The additivation includes latest requirements with regard to emission limitations (after-treatment systems), and optimizing the fuel efficiency. These novel formulations combine good ageing and low temperature behaviour as well as high VI, to create best compatibility especially with biodiesel compounds and to fight against the impacts shortening oil drains.

The main impacts to engine oils by biodiesel compounds – the “oil dilution by FAME” and the “oil thickening as a result of oxidative ageing” – do not cancel each other out in general. In the case of biodiesel blends, such as the presently favoured B5 to B20 blends, these problems occur only proportionally. In the case of future B10 or B20 blends, the selective enrichment of biodiesel in engine oil has still to be examined. In some cases, an oil change is already recommended when the FAME content exceeds 6 %.

Due to the fact that biodiesel and vegetable oils are chemically special types of esters, engine oils based on synthetic esters often are discussed as “better compatible to biogenic fuels”, following the chemical maxim “like dissolves like”. There are in fact different indications of such better solubility but this only applies to corresponding additive environments. There are, without doubt, ester-based engine oils which are more and less well compatible with biodiesel:

- with special combinations of anti-oxidants to fight against ageing driven by unsaturated components of bio-fuels
- with special polymers to fight against thinning effects by alternative fuels.

		CleanEngine spec.	Ref. 1 Visco 2000	Ref. 2 M 4000	Ref. 3 Selenia WR 5W40	CEMO-17	CEMO 21
Viscosity classification		5W30	15W40	15W40	5W40	5W40	5W30
Viscosity @ 100℃	[mm²/s]	> 9.3	14.4	14.5	14.7	15.1	9.7
Viscosity Index	[-]	report	135	138	178	192	182
HTHSV	[mPa s]	> 3.1	4.0	4.2	3.7	4.1	3.1
Flash Point COC	[℃]	> 230	230	234	226	250	254
Noack Index	[%]	< 6	9.3	11.2	10.7	6.6	6.7
TBN	[mg KOH/g]	report	8.2	16.2	10.9	8.9	8.9
Sulfur	[%]	< 0.2	0.50	1.1	0.40	0.13	0.21
Phosphorus	[%]	< 0.08	0.08	0.13	0.09	0.06	0.06
Zinc	[%]	< 0.001	0.09	0.13	0.11	< 0.001	< 0.001
Chlorine	[mg/kg]	< 20	--	--	--	< 20	< 20
Sulfated Ash	[%]	< 0.5	0.9	2.0	1.1	0.8	0.8
Biodegradability	[%]	> 60	--	--	--	> 60	> 60
Algae toxicity	[mg/mL]	> 100	--	--	--	> 100	> 100
Fish toxicity	[mg/mL]	> 100	--	--	--	> 100	> 100
Renewable recourses	[%]	> 50	--	--	--	> 50	> 50

WP2 Table 2: Characteristics of the CEMO (CLEANENGINE motor-oils) types

Polyglycol (BAM)

The candidate base oils from the category of the polyglycols aim to significantly reduce the viscosities at low temperatures in order to improve the fuel economy in city driving cycles. This is achieved by means of a high, intrinsic viscosity index of the base oils, but can be further improved by VI improvers.

They offer a lean burn behaviour and reduce polymeric deposits on the intake valves in direct injecting engines, as they are polymer-free. Second, as they polyglycol-based formulations are ash-free, they not increase the back pressure of the particulate filter over time. Third, they are metal-free, thus not deteriorating the lambda-sensor and catalysor.

In order to study the solubility of alcohol and biodiesels as well as to address the different oxidation and degradation reactions of these, polyglycols with different backbone compositions, namely:

a. polypropylene glycols) (PPG B48).
b. polyalkylene glycols (PAG D23) and
c. fully hydrocarbon soluble polyglycol (PBG 20), were used.

It is believed, that the PPGs are better suited for the dilution of biodiesels and the PAGs for the alcoholic-based biofuels. A fully hydrocarbon soluble prototype polyglycol (PBG) may bridge between both fuel types.
The fully oil soluble polyglycol targets also the two-stroke applications of ABAMOTOR.

The ecotoxicological properties of the base oils and the delivered polyglycol formulations were evaluated by TEKNIKER. As the PAG D21 and PPG B46 failed in respect of the daphnia toxicity (See Figure jj), one additive determining the anti-corrosion properties in the presence of bio-fuels and supposed to deteriorate the toxicological properties, was substituted. The third formulation trial for the formulations PAG D23 and PPG B48 were inline with the bio-no-tox-criteria. An additive enhancing the corrosion resistance of the polyglycols, when biofuels and their oxidation products are diluted in engine oil, needed to be chemically modified.

Lubricants	NOACK %	Ash %	VI	Pour point °C	η_{40} mm²/s	η_{100} mm²/s	η_{150} mm²/s	HTHS at 150°C mPa·s	OECD 301 B/F %	Aquatic toxicity algae daphnia fish OECD mg/l 201	202	203
Selenia WR 5W-40	10,8	1,15	175	-40	89,9	14,5		3,8	~30		>100	
Polyalkylene glycol (PAG)												
PAG D21 b.o.	5,9	0	169	-30	62,99	11,9	4,95	4,21				
PAG D23	2,5	0,1	160	-30	68,5	11,5	5,00	4,81	>60	>100	211	
Polypropylene glycol (PPG)												
PPG B46 b.o.	20,2	0	185	-39	45,88	9,11		3,85				
PPG B48	3,9	0,04	172	-39	48,1	9,05	4,80	3,59	>60	>100	136	
Fully oil soluble polyglycol												
PG B20	3,2	<0,01	133	-36	66,12	9,90	5,43	3,61	>60	>100	>1.000	

WP2 Table 3: Characteristics of the polyglycol formulations

Oil soluble polyglycols and having a content of renewables were evaluated (See Table cc). They are not commercially available. This will be achieved by using

a. monopropylene glycol initiators derived from renewable glycerine,
b. incorporation of renewable alcoholic back bones (chains of C_{14}, C_{16}, C_{18}) in the polyglycol molecule resulting in polyglycolesters.

Two stroke engine oils

Different ester base oils with different viscosities have been used for the formulation of the CLEANENGINE 2-stroke oil semo (= small engine motor oil). An ash-free formulation was developed with a special additive for the “low-smoke” performance of the 2-stroke-oil. These formulations were adapted to the special needs of bio-fuels. The AO performance of these formulations was enhanced, also the compatibility with bio-fuels. The reference 2-stroke oil was REPSOL 2T which is mineral oil based and not ash-free.

The following table shows the developed 2-stroke candidate oils in comparison to the reference lubricant REPSOL 2T. There was no specific requirement regarding viscosity for the bio-2-stroke lubricants.

			Clean Engine spec.	Reference Repsol 2T	semo-10	semo-36
Viscosity @ 40 °C	ASTM D 445	[mm^2/s]		59.5	45.8	113.3
Viscosity @ 100 °C	ASTM D 445	[mm^2/s]		8.6	8	18.3
Viscosity Index	ASTM D 2270	[-]		117	147	181
FP, COC		[°C]		120	260	218
S- Content		[mg/kg]		3.100	135	<5
P- content		[mg/kg]		<5	<5	150
Biodegradability	OECD 301B, F	[%]	> 60	--	> 60	> 60
Algae toxicity	OECD 201	[mg/mL]	> 100	--	> 100	> 100
Fish toxicity	OECD 202	[mg/mL]	> 100	--	> 1000	> 1000
Renewable recourses	Calculation	[%]	> 50	--	> 50	12

WP2 Table 4: Characteristics of small engine motor oils (semo)

For 2-stroke engines it is obvious that in the tank the lubricant is mixed with fuel. Thus, it is essential to ensure a perfect mixture. Therefore all developed semo versions were tested regarding the general compatibility with petrol and the bio-fuel E85. Furthermore the miscibility with fuel was tested according to a standard FUCHS in-house test at room temperature (Ratio lubricant/fuel: 9/1. Under these conditions all 'Small Engine Motor Oils' for Abamotor (SEMO) were miscible with EN 228 gasoline and bio-fuel E85. The reference 2-stroke lubricant only was miscible in EN 228 gasoline, but not with E85.

Primarily this method was evaluated for the use with EN 228 gasoline and – as the result has shown – cannot be easily transferred to E85. To evaluate this – and to investigate the possibility of a miscibility gap – all semo 2-stroke oils were tested in the real mixture ratio of 2% lubricant in the fuel. The result was totally different, and the miscibility in E85 was no longer given for SEMO-10. A miscibility gap with E85 seems to be given.

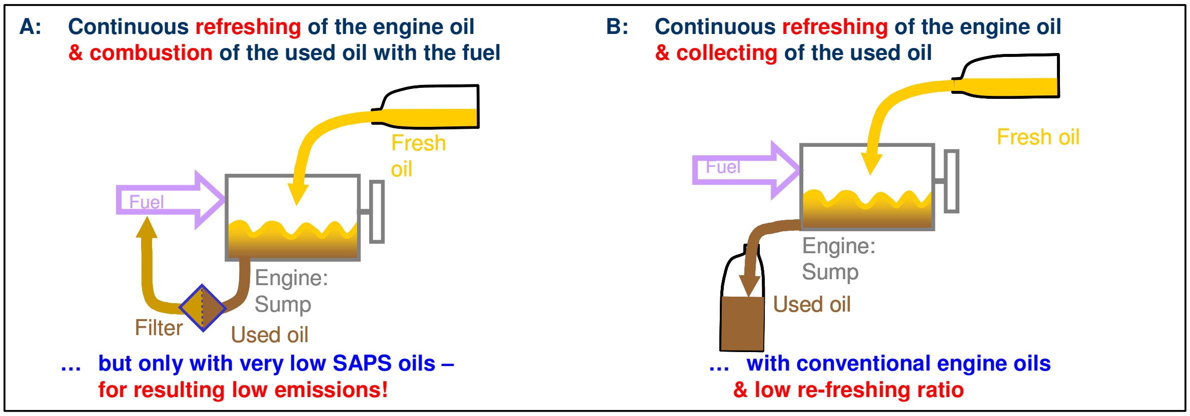
These effects required a new 2-stroke oil concept which leads to the development of semo-36. Semo-36 fulfils both requirements and is completely miscible with EN228 gasoline and E85 bio-fuel.

Adaptation and implementation of the PLANTOTRONIC system

The PLANTOTRONIC concept is based on a continues refreshing of the oil and offers surprising emission reduction opportunities by allowing the use of a very low additive concentration and even vegetable oils for engine lubrication.

The principle of the PLANTOTRONIC system is that the used oil generated by the refreshing method is mixed with fuel and burned without detriment to emission. The continuous refreshing allows the use of pure vegetable oil with a low oxidation stability caused by the unsaturated fatty acids. This bio-engine oil is therefore very good biodegradable and due to the very low additive concentration (very low SAP) it is also non-tox. Furthermore an automatic oil change is done which is very interesting for stationary engines and therefore the main objective in this project will be the implementation and adoption of this system for large engines.

First step for the implementation by GUASCOR should have been a manual refreshing of the oil without combustion and the collection of the used oil (Figure 3 B). This method seemed suitable to study the general feasibility of the system. The fuel should be bio-diesel and/or pure vegetable oil and the engine oil cemo-17.



WP2 Figure 2 - Manual oil refreshing system

Due to the fact of limited test bench capacities, GUASCOR was not able to carry out the promised engine test with the adapted Plantotronic system. In this task the scope of work was reduced to the economical evaluation of installation of the Plantotronic system. Fuchs supported a cost calculation sheet and calculation data of different alternative lubricant concepts for Plantotronic.

Alternative oils properties

Biodegradability and toxicity of alternative engine oils

A basic requirement of the newly developed alternative oils is their environmental compatibility, evaluated by biodegradability and the toxicity tests proposed by OECD international organisation. Oil formulations as CEMO and PAG types were up-graded for compliance with OECD301F, OECD 201 and OECD 202 tests. The ecotox test results of the reference oil vs. "Cleanengine" oils are summarised in the corresponding tables. The examples unveil that both the base oil selection and the additivation play key roles for ester- and polyglycol-based formulations in order to meet the ecotox-criteria.

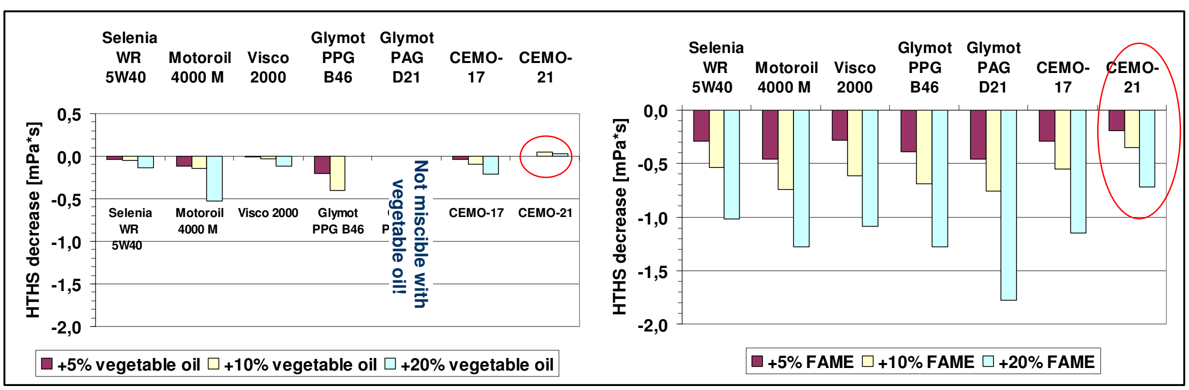
Impact of bio-fuel dilution on viscosimetrics

Fuel dilution is a general factor in diesel engine operation, both for diesel fuel and FAME. The specific FAME problem is the accumulation of fuel (including some additives used in FAME), which does not evaporate under common engine operations and ends up in a long-term dilution of the engine oil.

There are three primary causes for this:

- Compared to equi-viscous hydrocarbons, ester fluids have powerful penetrating properties and solvencies. This leads to the greater dilution of unburned FAME into the engine oil.
- Today's diesel engines with particle filters (DPF) often use a filter regeneration system which involves the periodic injection of a small quantity of fuel which burns. This increases the exhaust temperature to a point at which the carbon "burns-off". This procedure however, leads to the increased drag-in of unburned fuel in the engine oil.
- Due to a distillation curve of FAME shifted by ~100 K to higher temperatures compared to diesel fuel, the FAME in engine oil accumulated in the oil and leads to long-term dilution.

A number of tests have shown that at the end of a conventional oil drain interval, up to 20 % FAME can be found in the engine oil but normally between 5 and 10 %. This figure is also dependent on the wear status of the engine. The result of oil dilution is a drop in viscosity with the accompanying danger of increased wear and failure. In Figure 3 HTHS viscosity values decrements are shown for standard hydrocarbon oils and ester-based (CEMO) & polyglycol-based (PAG and PPG) formulations.



WP2 Figure 3: Effect of FAME-dilution on HTHS value of standard hydrocarbon based oils and hydrocarbon/ester-&polyglycol-based formulations

The decreasing in the HTHS viscosity in percentage of the alternative engine oils is lower than the conventional reference oils.

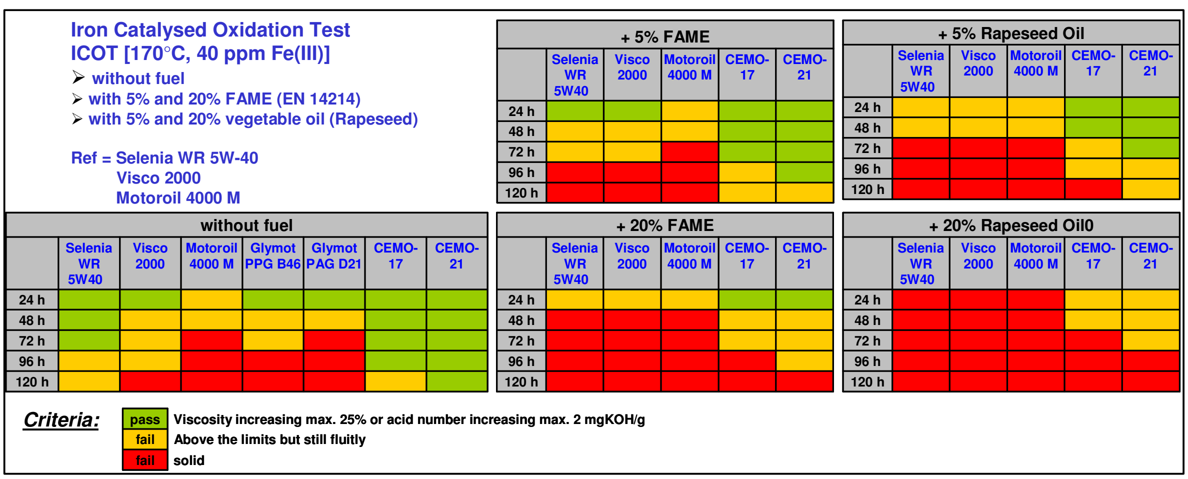
A totally other path to reduce the drop in viscosity in biofuel-operation may represent the use of pure vegetable oils, like rape seed oil and Jatropha oil, which has a complete distinct and higher HTHS value from FAME.

With respect to second generation fuel technologies, Jatropha oil is considered as a substitute for hydrocarbon-based diesel fuel, either as resource for bio-diesel production or fuelled directly.

As the HTHS viscosities of FAME with 0,89 mPas and of Jatropha oil with 3,0 mPas differ significantly, it is more likely that chemical interactions originate the increases in wear rate rather than changes in viscosimetry. The effect of additions of FAME and vegetable oil into the polyglycol- and ester-based formulations support this hypothesis.

Influence of fuel dilution to the ageing stability

The oxidation stability with and without bio-fuels was also tested in comparison to the reference lubricants from ABAMOTOR, CRF and GUASCOR.



WP2 Figure 4: Influence of fuel dilution to the ageing stability

The ageing stability of the ester based engine oils CEMO-17 and CEMO-21 was significantly better than the one of the reference oils. This behaviour is even enforced with increasing biofuel contamination.

Due to this development, the risk of aging effects like oil thickening as a consequence of biofuel contamination (especially with pure vegetable oils) could be minimised. Additionally longer drain intervals (that means: nearer to the conventional drain intervals known for operation with diesel fuel) could be achieved.

On-line oil quality measurement by infrared sensor

To compensate the Plantotronic system testing activity an experimental activity of Vis-NIR sensor developed in Teknier was set-up for a Guascor gas engine.

The aim of this work was to obtain, through the measurements Vis-NIR sensor installed in a Guascor gas engine, regression models to predict different oil quality parameters as Total acid number, Total base Number, Insoluble in pentane and Viscosity (40ºC).

Results of this activity showed that it is possible to perform the oil condition monitoring with Vis-NIR sensor. All the regression models achieved with the majority requirements established so all the models have a correlation higher or equal than 0.90.

3.3.3 Deliverables

Deliverable N	Initial Deliverable title	Initial Foreseen Delivery date	Real Delivery Date	Nature	Dissemination level	STATUS
D9	Report on the specifications of the lubricants for small engines (ABAMOTOR)	Mth6	Mth6	R	CO	Delivered
D10	Report on the specifications of the lubricants for medium engines (CRF)	Mth6	Mth6	R	CO	Delivered
D11	Report on the specifications of the lubricants for large engines (GUASCOR)	Mth6	Mth6	R	CO	Delivered
D12	Report on lubes development, characterization and best	Mth18	Mth33	R	CO	Delivered

	configuration selection					
D13	Report on economical evaluation of installation of Plantoronic and on-line oil quality measurement by infrared sensor (GUASCOR)	Mth12	Mth33	R	CO	Delivered
D14	Report characterization and testing for selection of lubricants (TEKNIKER)	Mth12	Mth12	R	CO	Delivered
D15	Lubes supply to participants: Ester-based, Polyglycols, other (FUCHS, BAM)	Mth24	Mth24	P	CO	Delivered

3.4 WP3 - Study of materials for engine components

3.4.1 Objectives

- To evaluate the tribological impact of usage of bio fuels and environmentally friendly lubes on currently applied materials;
- To develop improved component materials for optimizing the coupling between alternative fuels and lubes with engine materials;
- To optimize next Generation Lubes in Tribological Tests with Existing Component, Triboreactive and low friction Materials;
- Identification and tribological testing of suitable triboactive surface coatings to replace certain additives in poly-glycol and ester based engine oils.

3.4.2 Work done and final achievements

In WP 3 tribological performance of alternatives lubes developed in WP2 and the effect of bio-fuels dilution were evaluated; alternative coatings were tested to counteract the negative effect of bio-fuel dilution. Also the corrosion effect of bio-fuels on some engine components materials was evaluated.

Tests @ TEKNIKER

<u>Tribological tests:</u>

Application 2 Stroke engine oils: Ester Based Bio-lubricants were evaluated by Basic Tribological Tests (SRV tribometer) and Semo 10 and 36 base ester oil have the best tribological behaviour; additional tests were run by DIN 51834-2 Friction and wear test "Cylinder Liner Piston Ring": Semo 10 and 36 confirmed the previous result: friction behaviour was improved and similar wear mass lost as reference oil were measured.

Large DIESEL engine application GUASCOR: DIN 51834-2 Friction and wear test was used: all alternative oils Cemo 17, Cemo 21, PPG B48) showed similar friction behaviour and polyglycol oil has a bit low ball wear scar than reference oil. Then a special test configuration for Stem valve guide was applied for Guascor 4 stroke engine and Cemo 17 and PPG B48 oils demonstrated to be a good alternative.
Additionally new CrDLC and WC/C coatings applied to valve stem could be an alternative of Cr20µm ref.

Small DIESEL engine application-4 Stroke engine ABAMOTOR: Basic Tribological Tests according to DIN 51834-2 and Friction and wear Piston Ring Cylinder Liner Simulation Tests were used; these tests demonstrated it is possible to improve wear and friction properties from the selected oils (Cemo 17, 21 and PPG B48 oils) against reference phosphated and chromated piston rings materials; also extreme pressure properties are improved by using the new Cemo 21 oils against reference piston ring.

In conclusion Cemo 17, 21 and PPG B48 oils are a good alternative.

Medium engine application FIRAD. Nozzle Simulation: Basic SRV Tribological Test Friction and wear test (based on cylinder/disk configuration) were run using Reference Standard diesel and B50. Ti DLC coating developed by Tekniker has a good alternative for nozzle application.

Corrosion tests:

The corrosion resistance of alternative coatings was analyzed and compared with the electrochemical response of the current coatings and materials used in valves for heavy engines and nozzles for medium engines.

Application	Materials/coating	Icorr (µA/cm^2)
Stem valves	Chromed Ref	6.53
	CrN(PVD)	**0.02**
	Cr-DLC(PVD)	**0.13**
	Ti-DLC(PVD)	**0.58**
Nozzles from FIRAD	X82WMo Ref	18.50
	DLC (FIRAD)	**0.003**
	Cr-DLC (PVD)	7.99
	Ti-DLC (PVD)	**0.18**

CrN coating by PVD offered in stem valves the lower corrosion current but Cr-DLC coating exhibit non porous behaviour isolating completely the substrate. In nozzles application the alternative based on Ti-DLC (PVD) reduced significantly the corrosion current in relation to the substrate and exhibit a passive behaviour at anodic potentials in the electrolyte used. This coating had also very good tribological properties.

Tekniker carried out the Compatibility Test (ASTM D471) for seals materials (cellulose fibre based and elastomeric) for ABAMOTOR Application. Standardized immersion test (absence of light) was used to evaluate the comparative ability of rubber, rubber-like compositions and polymers to withstand the effect of following fuels and oils mixtures :

- 1st mixture: Petrol 95 (without lead) + 4% Reference oil (Ref. 2 stroke engine oil)
- 2nd mixture: Petrol 95 (without lead) + 4% SEMO 10
- 3rd mixture: Ethanol 85 + 4% SEMO 36

The tests revealed: No changes in appearance and dimensions, significant variations in mass, hardness, density and volume in some seals, SEMO 36 + Ethanol 85 caused the worst effect (changes in density).

Tribological Tests @ BAM

BAM test method: Piston ring/cylinder liner simulation tests were performed under mixed lubrication conditions in different lubricants: the reference couple was grey cast iron liner CKS36® ring lubed by reference oil Selenia WR 5W-40 that displayed an extraordinary and outstanding wear resistance which is deteriorated by biofuel dilution. The dilution of 10 wt.-% of FAME or Jatropha increases the wear rate of the grey cast iron liner by one to two orders of magnitude. FAME and Jatropha oil also favoured higher coefficients of friction.

By the same tests it was demonstrated that this adverse effect of biofuels to the grey cast iron liner wear resistance (mated with CKS36® rings) can be compensated by the application of Cleanengine new formulated oils (CEMO ester-based and polyglycol oils) and novel, triboactive ring coatings, like

a. nitrogen alloyed DLC thin films or
b. thermally sprayed Ti_nO_{2n-1} coatings.

Extreme pressure by SRV: The EP test results of fresh blends of hydrocarbon/esters and polyglycols (without bio-fuel dilutions) respecting the bio-no-tox criteria indicated that the prototype formulations exhibit much higher Hertzian contact pressure until seizure than the state-of-the-art reference oil Selenia WR 5W-40. Thus, they exceed the tribological demand. Under a stroke of 2 mm, the blends of hydrocarbon/esters (Cemo) gave still higher contact pressures, even those of the polyglycols were already above P0Mean of >3.000 MPa. The extreme load carrying capability of the Cemo oils is much easier deteriorated by the biofuel dilution, than for the polyglycols or the FL Selenia WR 5W-40 oil.

***Slip-rolling* resistance** of cam/follower/shim tribosystems of two DLC-type thin film coatings lubed by polyglycols and two factory fill engine oils (BMW SAE 0W-30, HTHS= 3,0 mPas and Selenia WR 5W-40, HTHS= 3,8 mPas) was evaluated by using a twin disk arrangement. The calculated initial oil film parameter λ of ~0,043 indicates the friction regime of boundary lubrication. The wear rates of the Parker DLC coating were much smaller, when lubed by the polyglycols.

In contrast to the wear situation of the grey cast iron liners, a DLC-coating lubricated with polyglycol B20 + 10 wt.-% FAME

a. showed an unaffected slip-rolling resistance and
b. presented an improved wear resistance for the DLC coating.

The polyglycols presented a wear reducing effect on the uncoated counterparts slip-rolling against the DLC-type thin film coatings.

The DLC thin film responded in terms of wear rate positively to the 10 wt.-% FAME dilution and the wear rate of the uncoated steel counterpart wasn´t increased

Fully formulated “Cleanengine”-type polyglycol-based engine oils seem not to have a frictional benefit, when lubricating DLC thin film coatings in highly concentrated tribo-contacts, but the friction was not affected by the dilution of 10 wt.-% of FAME, as well as the wear of the DLC coatings and the uncoated mating steel counterpart.

Ester-based oil were not considered in this testing program and a comparison can not be done.

Entrained valve train tests @ CRF

To test newly developed oils applied to real parts, CRF run the motor driven engine head bench based on FIAT Diesel engine 1.900 ccm and 8 valves; five oil formulations were tested: reference Selenia WR 5W40, ester based CEMO21, polyglycols: PPG B46, PPG B48, PBG B20. A new engine head was used for each oil under testing. The testing conditions correspond to normal engine head working environment both in terms of temperature and pressure. The overall duration of each test 250h is equivalent to 60.000 km of driving.

The friction torque of CEMO 21 and polyglycol-based alternative oils showed a very good behaviour, registered values are sensibly lower than the reference oil, especially for PPG B48 and PBG B20 at higher velocity regimes.

In the starting phase at 900 rpm PPG B48 and PBG B20 friction torques are higher than those of the CEMO 21 followed by a strong running-in with a decrease down to ~2,8 Nm. A saving at 900 rpm of 1,7 Nm is achievable through alternative engine

Wear length was evaluated through cams height measurement before and after the test. The highest mean value (among 8 cams) in height reduction corresponds to reference Selenia WR 5W40 oil.

Lower wear values were measured for CEMO21 and PPG B48 oils. the sum of cams wear was for both, CEMO 21 and PPG B48 oils, about -15% lower and for the PBG B20 of about -42% lower than for the reference oil. Overall, no significant wear was detectable on tappets.

3.4.3 Deliverable

Deliverable N	Initial Deliverable title	Initial Foreseen Delivery date	Real Delivery Date	Nature	Dissemination level	STATUS
D16	Delivery of reference materials (CRF)	Mth1	Mth1	P	RE	Delivered
D17	Delivery of advanced materials for laboratory testing (BAM)	Mth6	Mth6	P	CO	Delivered
D18	Delivery of advanced materials for component testing (TEKNIKER)	Mth12	Mth12	P	CO	Delivered
D19	Report tribological and corrosion compatibility of standard materials on samples (ABAMOTOR)	Mth12	Mth12	R	CO	Delivered
D20-D22	Report on tribological and corrosion compatibility of materials in engines (BAM, Tekniker)	Mth 30	Mth 33	R	CO	Delivered

3.5 WP4 - Combustion and Injection process characterization and development

3.5.1 Objectives

- To evaluate the impact of usage of bio fuels in comparison with standard fuels on present injector configuration, injection strategy (post-injection) and engine geometries;
- To design improved engine combustion systems (chamber shape, position and number of nozzle holes) and post injection strategies for selected bio fuels and bio lubes;
- To validate and optimize combustion system and injection strategies in close interaction with engine test bed studies for selected bio fuels and bio lubes.

3.5.2 Work done and final Achievements

Injector flow/fuel spray analysis & optimization

AVL:

Code modifications:

For performing the calculations within this project some modifications needed to be done in the CFD code. This mainly concerned property data, which have not been available before for the bio-fuel types relevant for the CleanEngine project. Since none of the partner organizations could deliver the necessary data, a literature survey has been done in order to find descriptions of properties of the liquid and gaseous phase and implement them into the FIRE software.

Conclusions from the injector flow calculations:

Simulations have been set-up and performed for a Diesel engine injector for the two fuels ‘Diesel’ and ‘FAME’. It could be shown that the influence of the fuel type is quite small. The principal behavior of the injector stays the same for both fuel types. Also the amount of fuel which enters the combustion chamber does not differ too much.

IM-CNR:

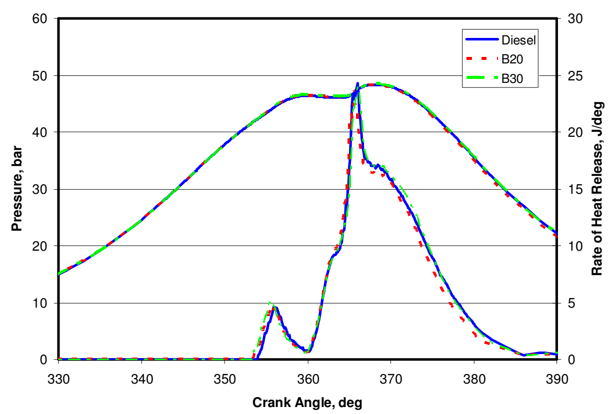
Tests on the optical engine showed that the different fuels have a spray penetration in the bowl very similar among themselves. Therefore the addition of FAME to the reference fuel doesn’t have an effect on the injection system and the spray characteristics in the bowl. Differences in the in-cylinder soot evolution among all the fuels were detected confirming the strong benefit of FAME addition to the fuel in terms of soot formation reduction.

Due to the way the blends were made, that, as suggested by OBR, contain the 20% in mass of FAME for B20 and the 30% in mass of FAME for B30, the volumetric heat content of fuels has little differences. The heat content decreases only of about 2% and 3% per volume unit.

Combustion chamber/injection system analysis and development

AVL:

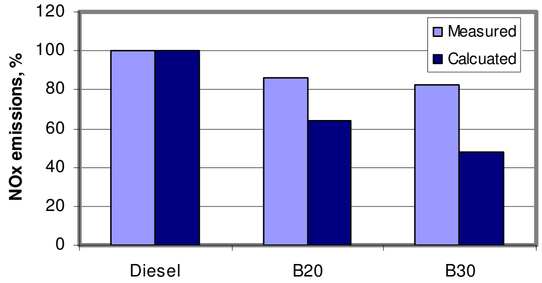
Within this sub task AVL set-up and performed calculations for the engines of IM-CNR, GUASCOR and ABAMOTOR. In the following some results are presented for the IM-CNR engine, which is a passenger car size modern common rail diesel engine. Investigations have been done for several operating conditions and for different blends of diesel and bio-diesel (e.g. B20 and B30) Figure WP4 Figure 1 shows the pressure and rate of heat release curves for diesel and the two different fuel blends B20 and B30.

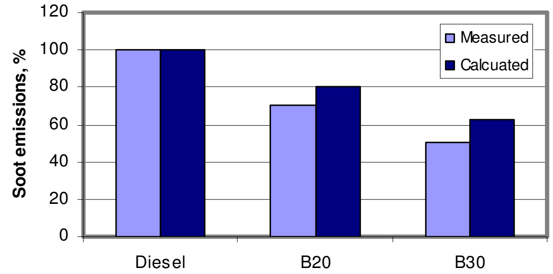


WP4 Figure 1: Mean cylinder pressure for the different fuels and for the test case at 1500rpm @ 3.7bar IMEP

No big differences between the behavior for the different fuels concerning the pressure trace and rate of heat release can be observed.

When looking at the emissions in WP4 Figure 2 we can observe that in this operating point NOx as well as soot emissions decrease with an increasing amount of bio-diesel.





WP4 Figure 1: NO_x and soot emissions for different fuels and for the test case at 1500rpm @ 3.7bar IMEP

Both, simulation and measurement show the same trends here, although the NO reduction is slightly over predicted and soot reduction is a little bit under predicted by the simulation.

Conclusions from engine calculations:

The calculated and the measured data reveal the fact that the addition of up to 30% bio-diesel to fossil diesel does not very much alter the combustion behavior. The rates of heat release are very similar between the fuel blends. The emissions though show the expected behavior, which means that especially soot is reduced due to different chemical and physical reasons. The fuel consumption slightly increases with the addition of bio-diesel, because simply bio-diesel contains less energy.

IM-CNR:

Independent of the applied method, the results of all investigations reveal that in principle standard hardware equipment can be used to operate a diesel engine with the relevant fuel blends. The blending of FAME up to 30% in diesel fuel has only a very small effect on the injection system behavior. The impact of higher viscosity on injection velocity disappears with higher temperatures measured on the engine.

Engine tests for simulation assessment:

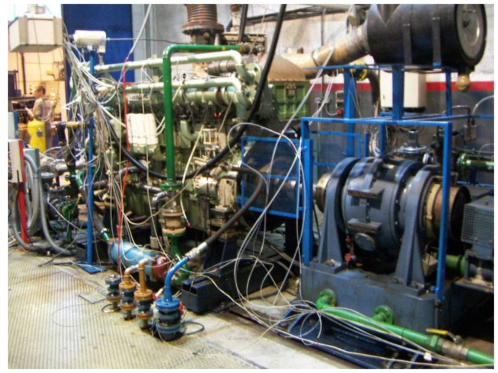
- ***GUASCOR:***

Guascor defined and selected the engine, its configuration and the performance test for the characterization of actual diesel engine to compare its behavior using ethanol-biodiesel blends.

The field test was designed in order to study the performance of reciprocating internal combustion engines according with ISO 3046: standard reference conditions, declarations of power, fuel and lubricating oil consumptions, test methods, test measurements, speed governing, torsional vibrations…

Exhaust emissions measurement were also described according to ISO 8178: Carbon monoxide, nitrogen oxides, hydrocarbon, and particles.

The engine characteristics:



- Engine: SF240TA
- Cylinders: 8 Line 24lt
- Diameter: 152 mm
- Stroke: 165 mm
- Compression Ratio: 14:1
- Revolution rating: 1800 rpm

Test conditions are have been:

SPEED	POWER	
1500	100%	510
	75%	383
	50%	255
	25%	128
	10%	51
1800	100%	577
	75%	433
	50%	289
	25%	144
	10%	58

<u>Diesel -FAME (Biodiesel) mixtures:</u>

Tested mixtures are:

- 100% Diesel (as base data).
- 25% FAME - 75% Diesel
- 50% FAME – 50% Diesel
- 100% FAME

The effect of adding biodiesel to diesel:

- Fuel consumption: Biodiesel higher than diesel, 11%
- Cylinder Pressure: Biodiesel higher than diesel, aprox 3%
- Wight of injection: Biodiesel higher than diesel, aprox 6%
- Start of injection: Biodiesel similar than diesel

Emissions:

- SO_2: Biodiesel lower than diesel aprox 80-90%
- CO: Biodiesel lower than diesel aprox 40-50%
- Smoke: Biodiesel lower than diesel aprox 70-80%
- CO_2: Biodiesel similar than diesel
- NOx: Biodiesel higher than diesel aprox 10-20%
- THC: Biodiesel higher than diesel aprox 85%

Ethanol-diesel mixtures:

Tested mixtures are:

- 100% Diesel (as base data).
- 5% Ethanol - 95% Diesel
- 10% Ethanol - 90% Diesel
- 20% Ethanol - 80% Diesel
- 20% Ethanol - 80% Diesel+Cetane Number improver additive
- 20% Ethanol - 70% Diesel-10% Biodiesel
- 20% Ethanol - 70% Diesel-10% Biodiesel + Cetane Number improver additive
- 20% Ethanol - 60% Diesel-20% Biodiesel
- 30% Ethanol - 70% Diesel

The effect of the different ethanol percentage in the E-diesel blends:

- Thermal efficiency: Similar with all fuels
- Fuel consumption: Increase with the ethanol percentage in the E-diesel blend, it is 6% higher in the case of E20-diesel
- Cylinder Pressure: Decreases with the increase of ethanol in the blend at low loads and it is similar at high loads.
- Wight of injection: Delay respect to diesel as the percentage of ethanol increases in the blend, E20-diesel presents a 3º delay.
- Start of injection: Similar to diesel at high loads and 3º delays at low loads.
- Start of combustion: Delays respect to diesel. E20-diesel presents a 6º delaying respect to diesel at low load and 1º at high loads.
- Emissions: At maximum load E-diesel NO_x, THC, CO, CO_2 and smoke emissions decrease respect to diesel and SO_2 emissions are similar but at low load THC and CO emissions increase.

The effect of a Cetane improver additive in the E20-diesel blend:

- Thermal efficiency: Similar with and without Cetane improver
- Fuel consumption: Similar with and without Cetane improver

- Cylinder Pressure: Similar with and without Cetane improver
- Wight of injection: Reduces around 1º delay respect to diesel with Cetane improver additive. At high load it is similar with and without additive.
- Start of injection: Reduces a little bit its delay respect to diesel with the Cetane improver at low loads. At high load it is similar.
- Start of combustion: Reduces 1-2º delay respect to diesel with Cetane improver.
- Emissions: SO_2 and CO_2 emissions are similar with and without additive. CO and THC emissions are lower with the additive at low loads. NOx emissions are similar with and without additive at low loads; however, at high loads they are higher with the additive maybe due to the additive composition. Smoke decreases with the Cetane improver.

Guascor Conclusions:

The addition of bioethanol to diesel, decrease the cetane number of the blend; as a consequence of it, CO and smoke emissions decrease at full load but increase at low load. Also, the fuel consumption, efficiency and other characteristics (density, lubricity, viscosity, flash point,..) increase when you add ethanol to diesel.

The addition of additives to the mixture as cetane improvers, improves the combustion properties which makes CO and THC emissions are reduced at all loads while NOx increased at high loads due to the nature of the additive.

On the other hand the addition of biodiesel to the mixture as an additive, in addition to improving the stability of the mixture and its lubricity, enhances cetane number also.

The result is a mixture with improved lubricity and stability properties and whose emissions of SO2, CO and smoke decrease, whereas there is an increase in NOx emissions and fuel consumption.

In order to select the best biofuels mixture, bioethanol-biodiesel mixture engine test had been carried out in WP6.

- ***ABAMOTOR:***

The objectives from Abamotor for WP4 has been fully accomplished:

- Improvement of the emission measurement installation with the setup of the air and water cooling system and insonorization.

- Study of the modification of the diesel engine to reduce emissions, reaching EPA 2 specifications
- Study of the modifications of the combustion chamber using B20 and B30 in 4 stroke small engine
- Study of the effect of the pressure in the chambers when using bioethanol in 2 stroke small engine.

A new test bench for emissions measurements have been installed in ABAMOTOR Energía. The testing bench has been insonorized and it has been adapted an air and water cooling system in order to control temperature and noise.

The combination of a new injection pump in the diesel engine controlling the gap allows reducing NOx emissions keeping the rest of the emissions on the same level. It can be observed in the next table that it has been possible to reduce the emissions, reaching EPA 2 requirements.

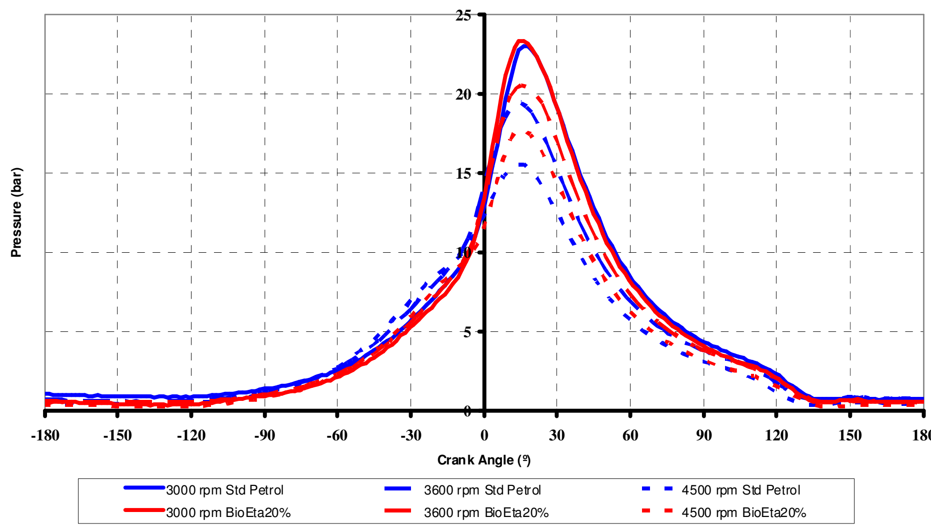
Test nº	Gap	CO	NOx	HC	NMHC+NOx	Particles
9	1.4mm	4.46	7.72	0.60	8.32	0.49
10	1.7	4.56	7.18	0.86	8.04	0.51
11	1.9	4.89	6.93	0.84	7.77	0.46
12	2.2	5.13	6.32	0.89	7.21	0.49
Límits EPA 2		8			7.5	0.8

As it can be seen in the next table, a slight increase in the fuel consumption and power is produced with the delivery timing delay.

Test nº	Consumption(kg/h)	Maximum Power (kW)
13	1.53	5.94
14	1.58	6.09
15	1.61	6.16
16	1.64	6.11
17	1.66	6.28

Study of the effect of the pressure in the chambers when using bioethanol in 2 stroke small engine.

It has been measured the pressure in the combustion chamber of the 2 stroke petrol Minsel engine from Abamotor comparing the pressure with standard gasoline and bioethanol E20 and it has be seen that the pressure in the combustion chamber increases with Bioethanol E20.



Overall conclusions

The metal engine tests show small differences among fuel blends. Emissions are similar or even slightly better. The fuel consumption though is becoming slightly worse for all the cases.

3.5.3 Deliverables

Deliverable N	Initial Deliverable title	Initial Foreseen Delivery date	Real Delivery Date	Nature	Dissemination level	STATUS
D23	Report on injection fuel spray optimization by simulation (AVL)	Mth18	Mth18	R	CO	Delivered
D24	Report on combustion phase optimization simulation (AVL)	Mth18	Mth18	R	CO	Delivered
D25	Report on engine test results on small engines (ABAMOTOR)	Mth24	Mth24	R	CO	Delivered
D26	Report on test results on medium engines (IM)	Mth24	Mth24	R	CO	Delivered
D27	Report on performance engine test results on large engines based on different ethanol/diesel/biodiesel mixtures (GUASCOR	Mth24	Mth 30	R	CO	Delivered

3.6 WP5 - After treatment systems development for alternative fuels

3.6.1 Objectives

Development of a catalytic system (diesel oxidation catalyst (DOC), particulate oxidation catalyst (POC), DPF (diesel particulate filter) and NOx technologies adapted to bio fuels and lubes to comply with:

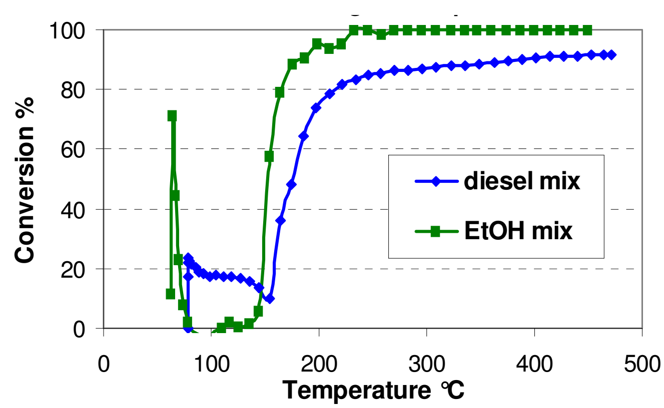
- EURO 5, EPA 3 target for cars with optimized catalyst;
- EPA2 and next Stage 3 for small engine targets with cost effective catalyst;
- Blue Sky Series Voluntary emissions standard for GUASCOR engines.

3.6.2 Work done and final achievements

Based on data in emission measurements with bio and diesel fuels, samples and prototypes were prepared for small diesel engine (Abamotor), passenger car (CRF) and large diesel engine applications (Guascor). Ecocat made a wide review about the studies made with aftertreatment systems in lean and stoichiometric applications: effect on emissions, changes related to three-way, oxidation, NOx trap, SCR catalysts and particulate filters.

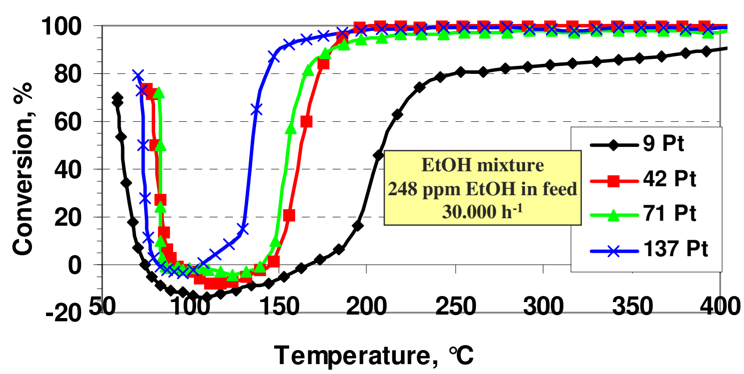
Biofuels consist usually of bio-ethanol or oxygenated hydrocarbons. The laboratory experiments were conducted to study the effects of Pt, Pd and Pt-Pd as active metals in oxidation catalyst for the reactions of ethanol, nitrogen oxides and carbon monoxide in lean conditions. The catalyst reactions with simulated emissions from ethanol-diesel and ethanol-gasoline fuelled engines were investigated. The acetaldehyde (AA) formation and oxidation as a side reaction with ethanol (EtOH) was also studied. The use of ethanol matches also to experiments made in the engine applications of partners.

The reactivity of EtOH and acetaldehyde was investigated as a function of active metals (Pt, Pt-Pd or Pd) in lean exhausts. Ethanol is found to be more reactive to be fully oxidized to harmful CO2 and water than typical HCs in diesel exhaust gases (WP5 Figure 1). Pd containing catalysts are quite active as hydrothermally aged at 700°C to oxidize ethanol but the selectivity to acetaldehyde was higher and the durability of Pd-rich catalysts in real exhaust is lower than with Pt-only or Pt-rich oxidation catalysts. The net acetaldehyde conversions were best for Pt catalyst, because it showed no aldehyde formation at 80-170°C.



WP5 Figure 1: HC conversion in exhaust gases by fuel type in light-off experiments on hydrothermally aged (700°C/20h) 70 g/cft Pt catalyst. 496 ppm C_1 as HCs in lean mixture.

The increase in Pt loading enhanced directly EtOH oxidation reaction (Fig. 2). The level about 40 g/cft Pt was enough to reach lower light-off temperatures.



WP5 Figure 2: Effect of Pt loading (g/cft) on EtOH conversion on hydrothermally aged (700°C/20h) Pt catalyst.

The reactions in the presence of ethanol in exhaust gas can be described by the following reactions:

$2\ C_2H_5OH + 6\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$	EtOH oxidation	(1)
$2\ C_2H_5OH + O_2 \rightarrow 2\ C_2H_4O + 2\ H_2O$	AA formation	(2)
$2\ C_2H_4O + 5\ O_2 \rightarrow 4\ CO_2 + 4\ H_2O$	AA oxidation	(3)
$2\ NO + C_2H_5OH + 2\ O_2 \rightarrow N_2 + 3\ H_2O + 2\ CO_2$	EtOH- SCR	(4)

The potential of HC-SCR catalysts (silver/alumina) was also investigated in the presence of oxygenated hydrocarbons. NOx conversions were above 60% at 280 – 470°C on Ag catalyst with 1000 ppm EtOH (30.000 h-1). In practise, the additional fuel injection correlating to about 4 - 5% fuel penalty is usually needed to reach higher NOx conversions above 40%. However, the HC-SCR activity is too low to be applied in large diesel engine application (Guascor), where fuel economy is essential and urea-SCR is the main stream aftertreatment for NOx removal.

Based on these studies Pt and PtPd based DOCs and DPFs have been prepared for application in CRF and Abamotor. PtPd has shown a good thermal durability which promotes its use in filter applications, where temperature may increase during PM regenerations.

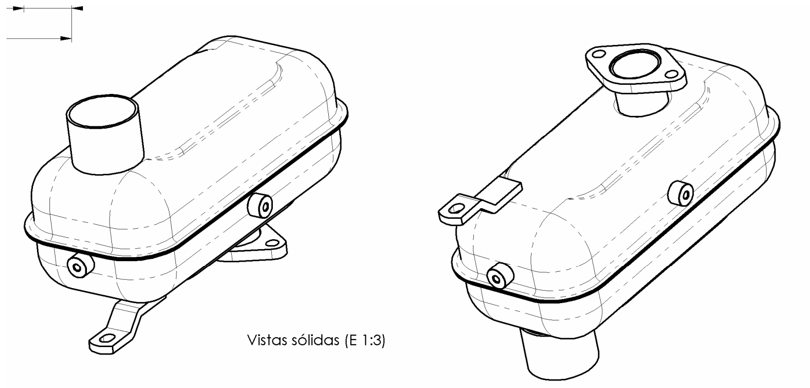
The activity and selectivity of the thermally aged PtRh and PdRh TWC catalysts was examined in simulated laboratory mixtures. The increase of EtOH amount in feed decreased the light-off temperature of emission compounds. The base activity of aged PtRh catalyst was better than of PdRh catalysts with the same loading of 40 g/cft (5:1). The light-off temperature difference has an effect on emissions during the first 200 seconds from the gasoline engine start-up. Based on these catalyst studies, PtRh catalysts were selected for small engine applications with ethanol blends in Abamotor.

Ecocat had also presentations about project results in EuropeCat 9 meeting in Spain in August 2009 (REF: Maunula, T., Pienipaavola, L., Ahola, J. and Kinnunen, T., Effect of biofuels on the efficiency of diesel oxidation catalysts, Oral presentation at EuropaCat 9, Conference at the 30th Aug-4th Sept 2009, Salamanca, Spain) and SAE meeting in San Antonio USA in November 2009 (REF: Maunula, T. and Kinnunen, T., Effect of oxygen containing biofuels on the emissions with exhaust gas catalysts, SAE Paper 2009-01-2737).

Small engine after treatment system development

Abamotor used in this project a small diesel engine (0.43L, 4-stroke engine with biodiesel B20 and B30) targeting to EPA Tier 4 emission limits (CO 6.6 g/kWh, NMHC+NOx 7.5 g/kWh and PM 0.4 g/kWh). Durability requirement is 3000 hours. The raw emissions were first measured. It was found a need to decrease NOx and HC/CO emissions.

The use of urea-SCR or even HC-SCR with active fuel injection is not reasonable for NOx reduction in this kind of small engine applications. Based on raw emission analysis, the target was to decrease HC and CO emissions with a small oxidation catalyst. The same catalyst might have a slight NO reduction by HC-SCR reactions with natural hydrocarbons present in exhaust gas. The small catalyst converter should be integrated to a part of the silencer (WP5 Figure 3).



WP5 Figure 3. Abamotor diesel engine silencer structure where to assemble aftertreatment systems.

A simple catalyst design is the most practical in this kind of engines to limit pressure drop changes, to keep the original muffler structure and keep additional costs low. The silencer tubes and perforations are design to control the flow rates and therefore combustion stoichiometry.

Several alternatives were proposed to be integrated into the original muffler. It is possible to install small honeycomb catalyst inside inlet tube or in modified inlet tubes. It is also possible to coat the perforated inlet and/or outlet tubes which catalyst coatings. It is possible to wrap wire mesh type catalyst over outlet or inlet tubes. These possibilities were considered and it was decided to prepare a wire mesh catalyst wrapped over outlet tube.

A small 0.16 L gasoline engine was the other application in Abamotor. The emissions were measured with standard muffler and catalyzed muffles which looked visually the same. THC emissions decreased with catalyzed muffler over 85%, NOx emissions over 60% but CO emissions increased due to low λ value with standard carburettor calibration. Experiments were conducted to reach higher CO conversions but the adjustments to higher λ values resulted in a decrease in NOx emissions and other drawbacks. Thus, the final concept included the catalyzed muffler with wire mesh type 3-way catalyst, which actively removed odorous hydrocarbon and NOx from exhaust gas.

Passenger car after treatment system development

The emissions were measured in CRF engine laboratory using a Fiat Croma Euro 4 and the new DOC and catalyzed DPF samples. Ecocat aftertreatment system showed the same emission values (g/km) as the original system with standard and B30 fuels in measurements in 2007-2008. Ecocat catalysts was very cost efficient due to lower volumes and PGM loadings: DOC 1.0 L/75 g/cft Pt versa 1.1L/PtPd(4:1) and catalyzed DPF 4.0 L/25 g/cft Pt versa 3.2L/10 g/cft Pt. The same systems were also tested in Artemis cycles.

Artemis cycles showed high NOx emission and very low HC and CO emissions (compared to NEDC values obtained during the first analysis campaign). No important differences were found on mass soot emission between NEDC and Artemis.

Bio-diesel blends (up to 30% blend tested) gave differences in most cases not appreciable.

Based on the results with Fiat Croma Euro 4 vehicle, a new aftertreatment system was designed for Euro 5 application (Fiat Lancia Delta 2.0 D, 110 kW). In Euro 5 calibration NOx had to be decreased but raw CO and HC emissions were supposed to increase slightly. Therefore, improved oxidation activity might be necessary for Euro 5 application. In the new system, the same Pre-DOC and catalyzed DPF were applied but to enhance the oxidation activity the loading of DOC was increased from 70 g/cft PtPd (4:1) to 100 g/cft Pt or 100 g/cft PtPd (4:1) with the same converter dimensions (Brazed metallic, 500 cpsi, 1.3 L, coating 40 g/m2).

The effects of engine lubricant and additives on aftertreatment system were analyzed by CRF. In general, the combinatory effects of fuel and lube oil have been analyzed. The Euro 4-5 solutions for diesel passenger cars contain usually both DOC and wall-flow DPF. Filters plugging tendency can be improved by lube oil ashes. The ash compounds can also shorten after-treatment system life (chemical action) by catalyst deactivation or filter substrate corrosion at high temperature. Therefore, in the development of bio-based lub oils or additive, it is important to study the ash/poison formation and plugging tendency on particulate filter.

A laboratory experimental methodology was set-up at CRF to evaluate the HT filter substrate corrosion effect due to peak temperatures in regeneration events; methodology was applied to lubes (reference and ester-based oils) and DPF substrates considered in Cleanengine Project. The filter in test matrix contained 5 particulate filters with the cell density of 200-300 cpsi (SiC, cordierite and aluminium titanate were used as filter materials).

By optical microscopy no evident interaction was detected between ash and substrates up to 1200°C. Partial pores occlusion can be hypothesized without impact on filtration performance. SiC substrates, including ECOCAT, were not damaged at all peak temperatures but ashes penetrated into pores and disappeared from substrate surface at 1250°C. Cordierite showed important damage (especially with 5W40 ash); as a consequence filter correct functionality could be affected. Aluminum Titanate is the least reactive. CEMO21 ash demonstrated to be the least reactive.

Large engine after treatment system development

The experiments with biofuels were continued by using diesel-FAME and FAME-EtOH blends. 6-cylinder engine (18 L, type SF180TA) was used for endurance test with ethanol blend (WP5 Figure 4).

WP5 Figure 4: Guascor SF180TA 18 L diesel engine used in ethanol blend studies.

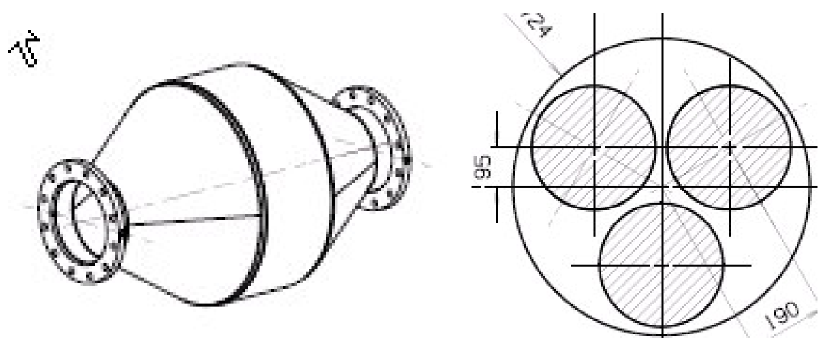
Based on various fuel blend studies, NOx removal was seen necessary to reach EPA 2007 in future applications. The potential NOx removal methods were analyzed for off-road applications. HC-SCR is not possible due to lower HC emissions, fuel penalty and low durability reasons. NOx trap application is also not fuel economy friendly solution and will be destroyed in exhaust with high sulphur concentrations in fuels even if S-free biofuels are blended with diesel fuel. The only practical solution is urea-SCR. Urea-SCR has been used successfully in power plants combusting solid, liquid or gaseous fuels since

1970's in Japan and USA. Vanadia based SCR catalysts are durable in the presence of high SOx and ash concentrations but the cell density of SCR catalysts should kept low in the dirty exhaust gases. The designed SCR catalyst had a typical composition: V2O5 on TiO2 stabilized with WO3.

The conditions for SCR catalyst ageings and requirements for catalysts were the next:

- Pressure drop max. 18 mbar (very low value compared to on-road applications)
- Ethanol-FAME blend
- Ageing in an engine point or a combination of points (1500 rpm, max. power)
- No urea dosing equipments

It was not possible to make SCR catalyst studies with urea injection within time schedule and project funding. Thus, it was planned to make ageings in real biofuel blends and then to study the activity and accumulated poisons later in 2010. Because the potential testing facilities of catalysts for 18 L engine were limited, it was planned to build a modular SCR catalyst converter having three parallel SCR units (WP5 Figure 5). Then, it will be possible to test a single unit with a smaller diesel engine (6-8 L) after ageing. The total catalyst volume was about 38 litres and a volume of a single unit 12.7 L. The SCR catalyst volume per engine volume (L/L) was in ageing tests about 2.1 and it was about 1.8 with a 6.9 L engine.



WP5 Figure 5: Design of modular SCR catalyst for SCR ageing experiments.

The activity of SCR catalyst was measured as fresh before the planned ageings in Ecocat with 6.9 L engine, which was equipped with commercial Bosch urea dosing system. The criteria NOx conversion is a way to detect parallel NOx conversion and NH3 slip. Criteria NOx conversion is the conversion value when NH3 slip is reaching the concentration of 20 ppm, when urea/NOx is increased in experiments. The initial activity was above 90% over a wide operation window. The aged catalyst will be analyzed after this project in 2010.

3.6.3 Deliverables

Deliverable N	Initial Deliverable title	Initial Foreseen Delivery date	Real Delivery Date	Nature	Dissemination level	STATUS
D28	Report on development of catalytic system small engines (ECOCAT)	Mth30	Mth33	R	CO	Delivered
D29	Report description optimized catalytic system medium engines (ECOCAT)	Mth30	Mth33	R	CO	Delivered
D30	Report description optimized catalytic system for large engines (ECOCAT)	Mth30	Mth33	R	CO	Delivered
D36	Report lab test simulation of bio-fuel emission and interaction with catalysts (ECOCAT)	-	Mth33	R	CO	Delivered

3.7 WP6 - Technologies implementation and evaluation in engines

3.7.1 Objectives

To apply developed technologies to real engines working with selected bio fuel and bio lubes

3.7.2 Work done and final achievements

Small Engine Application – ABAMOTOR

2 stroke engine

Different technologies have been implemented in small 2 stroke MINSEL engines:

1. Implementation of biolubricants for petrol 2-stroke engines
2. Implementation of the bioethanol E10 and E20 for petrol 2 stroke engines
3. Implementation of the SEMO 36 biolubricant for E85 in 2 stroke engines.
4. Implementation of an ECOCAT catalyst for 2 stroke petrol engines

1. Implementation of the biolubricants for petrol 2 stroke engines:

The Semo 10 oil provided by FUCHS has been tested by ABAMOTOR Energía, SL in order to check their suitability for 2 stroke engines. The Minsel M165 engine manufactured by ABAMOTOR has been tested using a mixture oil/petrol in a ratio of 2%. Scuffing tests have been performed in hard conditions in order to check the resistance to seizure. The biolubricant presented a clean combustion but there is a risk for seizure if we use this oil in a ratio of 2%. A higher concentration (eg. 4%) should be recommended.

2. Implementation of the bioethanol for petrol 2 stroke engines:

The objective of this task has been to check the viability of using bioethanol E85, E20 and E10 in a 2 stroke petrol engine and check their effect in emission reduction. An engine Minsel M165 from ABAMOTOR has been used and different percentages petrol/bioethanol have been tested in the engine.

The test protocol consists of scuffing engine tests carried out in severe conditions in order to detect the risk of seizure in the engine. The mixture of bioethanol/oil has been of 2% using the reference oil Repsol Motor.

E85 mixture resulted to be not miscible nor with reference mineral oil neither with SEMO10 ester-based oil.

Scuffing and Emissions Tests Results are summarised in WP6 Table 1:

	Emission tests results					Engine status after scuffing test
Oil Type and %	Power (CV)	Consume (gr/CVh)	NOx (g/Kwh)	HC (g/Kwh)	CO (g/Kwh)	
SH3 Limit Normative			5,36	161	603	
Petrol/Ref. Oil 2%	5,46	397	1,469	139,8	333,2	
BioE10 2% Ref. Oil	5,44	385	1,573	124,1	314,8	No scuffing, not abrasion in the cylinder and the inside of the piston was quite clean
BioE20 2% Ref. Oil	5,5	382	2,29	128	251,5	Engine is cleaner and not sign of seizure or abrasion can be detected
Bio E85 2% Ref Oil Not miscible	4,8	427	2,29	109,8	43,11	

WP6 Table 1 – Emissions and Scuffing Test results with E10, E20, E85 blends

Conclusions

The bioethanol E10 and E20 are compatible with mineral oil, but the E85 is not miscible. The bioethanol up to 20% concentration shows a cleaner combustion and improves scuffing behaviour. The CO emission is considerably reduced when increasing the bioethanol concentration, the HC are slightly reduced and NOx seems to increase. The power is maintained when using E10 and E20 and significantly reduced when using E85. The oil consumption is also similar when using E10 and E20, but increase when using E85.

3. Implementation of SEMO 36 biolubricant for bioethanol E85 2 stroke engines:

A mixture of 2% of bioethanol E85 and Fuchs Semo 36 has been shacked and leave deposit during 24 hours, checking that after this period, there is no separation between bioethanol and oil. The ratio fuel/oil used has been 2% with the oil Fuchs Semo 36. It can be seen that the use of bioethanol E85, suffers a loss of power. The graphite surface treatment got very good result with the bioethanol, probably due that the power during the test has been lower and consequently the Engine combustion temperature also lower. The piston is cleaner with the bioethanol also due that the SEMO 36 is miscible with bioethanol and the power is lower. The head of the piston is very clean and the front of the piston is also absolutely clean. Aspiration cylinder is also clean without marks. In the exhaust part there are a small number of marks, quite superficial.

The emission test results are summarised in WP6 Table 2:

Oil Type and %	Power (CV)	Consume (gr/CVh)	NOx (g/Kwh)	HC (g/Kwh)	CO (g/Kwh)
SH3 Limit Normative			5,36	161	603
Bio E85 Semo 36 2% Miscible	4,3	478	0,689	119,5	32,93

WP6 Table 2 – Emission Test Results with E85 + 2% SEMO36

Conclusions

The combination of Bioethanol E85 with Semo 36, have good performance from the point of view of scuffing and emission, but the power is reduced and the consume is slightly increased.

4. Implementation of an ECOCAT catalyst for 2 stroke petrol engines

A Minsel M-165 engine has been used in different working conditions and the catalysed muffler provided by Ecocat was installed.

The backpressure with the std muffler and with the catalysed muffler has been measured:

	4500 rpm	3600 rpm	3000 rpm
STD muffler	5,12 Cv / 30 mmHg	4,70 Cv / 24 mmHg	4,1 Cv / 18 mmHg
Catalysed muffler	4,97 Cv / 36 mmHg	4,55 Cv / 32 mmHg	3,90 Cv / 28 mmHg

WP6 Table 3 – Measured backpressures

The conclusions were:

1º The power reduction using the catalysed muffler is from 3% at high rpm to 5% at low rpm (3000 rpm).

2º The back pressure increases with the reduction of the engine speed. At 4500 rpm the back pressure with the catalysed muffler is by 16% higher than the back pressure with the std muffler. At 3600 is by 25% higher with catalysed muffler and at 3000 rpm is by 35% higher.

Concerning emissions the Catalysed muffler abated especially the HC emissions. As NOx emission increases when the mixture is poorer the best to reduce the emissions is to keep the carburettor with the usual screw setting. It has been possible to achieve the requirements of Phase 2 of the Directive 2004/26.

4 stroke engine

Different technologies have been implemented in small 4 stroke diesel engines:

1. Implementation of the biodegradable oil CEMO 17 based on esters and polyglycol from BAM in four stroke engines
2. Implementation of an ECOCAT catalyst for 4 stroke petrol engines
3. Implementation of Biodiesel in 4-stroke
4. EPA 2 achievement when using Biodiesel in four stroke engines
5. Pressure in combustion chamber measurements in four stroke engines with biodiesel

1. Implementation of the alternative oils CEMO 17 based on esters and polyglycol from BAM

The engine used in this test is the Minsel M540 engine: emission and scuffing tests were run, if scuffing is successful an endurance test lasting 50 hours at full load test is performed.

Both CEMO17 and polyglycol oils passed scuffing test; duration test has been carried out for17 hours with Cemo 17 oil and only for 5 hours with Polyglycol oil, but it can be drawn the conclusions.

Scuffing and durability test with Fuchs CEMO 17: The cylinder and the piston were in very good conditions, little fine coal was noticed near the compression ring caused by the high temperatures in this area. Maybe the oil does not support such high temperatures. Scuffing and durability test with BAM POLYGLYCOL: With polyglycol oil there is more fine coal than using CEMO 17 oil. This indicates that this oil support worse the high temperatures near the piston head. In this case the test duration was 5 hours, if more working hours would be run probably working problems could occur for the engine.

Emission tests were run for: CEMO 17 + Diesel B, Polyglycol + Diesel B, Polyglycol +B30 F

Using Cemo 17 oil we obtain better results than using Polyglycol oil, the difference is by 9 % better in CO emission and by 12 % better in HC emission.

The best results are obtained using Biodiesel B30, comparing these results and the results using polyglycol and Diesel B, it is produced 25% lower CO emission and 50% lower HC emission.

These oils formulations improve the fine coal production, characteristics at high temperatures should be improved especially for Polyglycol oil.

2. Implementation of an ECOCAT catalyst for 4 stroke petrol engines

A silencer with catalytic converter provided by ECOCAT was installed on M430 enigne and tested for emissions assessment. Looking from outside it is like the standard silencer one but it contains catalyst material inside.
Two different fuels were used: Diesel A + Ecocat silencer, Diesel B + Ecocat silencer, Diesel B + Standard silencer configuration were tested.

It is possible to point out that the catalytic converter introduction improves consistently the CO emission, allowing thinking about the oxidative behaviour of the catalyst, even if the decrease of the CO emission does not involve modification in the CO2 generation. An improvement in NOx and HC specific emission was also noticed.

The catalytic converter has been able to reduce significantly the CO emissions, slightly the HC emissions, being no big the effect in NOx emissions.

3. Implementation of Biodiesel in 4-stroke diesel engine

ABAMOTOR received from OBR 70 litres of biodiesel B20 y B30 for their test in their Engine Minsel M-430 to determine how it can vary the emissions in relation to diesel B.
The engine used for the tests is equipped with a standard injection equipment. The pump is Stanadyne with reference 656-023 and the injector used has 4 holes with 0.25 mm. It has been used also an injection equipment with higher pressure called EPA, which pump and injector are from New Diesel company with references NPFR 1K and 15450/2 respectively and the injector has 5 holes of 0.21 mm. The cam gear is in this case with 8mm length, when the standard is 7mm length. The injection delay is in all the cases of 25º. The emissions can be reduced when using biofuels B20 and B30 using the standard injection system. The EPA 1 Injection system present similar emissions with Biofuels B20 and B30 and Diesel.

4. EPA 2 achievement when using Biodiesel in four stroke engines

The configuration of the above engine (standard injection system) modified with a time delay 12º was able to reach EPA 2 mission requirements also when using biodiesel:

Test nº	Fuel	CO	NOx	HC	NMHC+ NOx
12	Diesel	5.13	6.32	0.89	7.21
15	B20	5.35	5.80	0.93	6.73
16	B30	5.15	5.67	0.97	6.64
Límits		8			7.5

WP6 Table 4 – Measured emissions for B20, B30

In this conditions the fuel consumption was a 6,4% higher.

5. Pressure chamber measurements in 4 stroke petrol engines for biodiesel

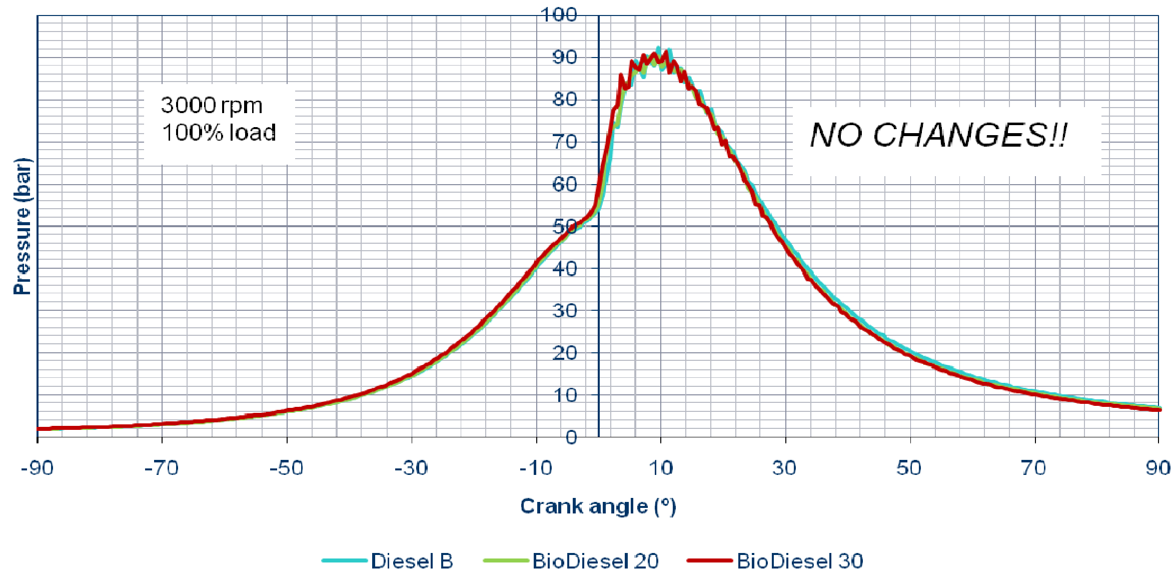
The KISTLER 6061B sensor was mounted perpendicularly to the combustion chamber wall (Front sealing sensor mounting). P ≈ 8.0 CV

It was verified that the recessed installation of the sensor diaphragm does not influence measurements.

	Velocity (rpm)	Injection delay before the TDC (mm)	Cylinder head gasket (mm)
Diesel B	3000	Standard	0.1
BioDiesel 20	3000	Standard	0.1
BioDiesel 30	3000	Standard – A1 – 12º	0.1 – 1.0 – EPA

WP6 Table 5 – Measured emissions for B20, B30

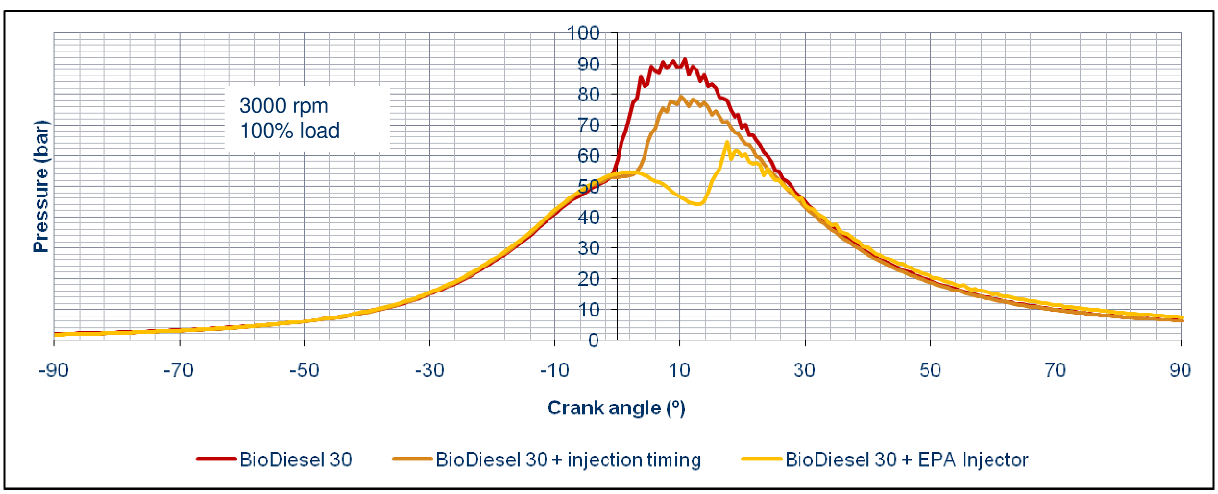
It could be observed that no changes in pressure were observed when changing from Diesel to Biodiesel B20 and B30. This effect was also observed in car engines.



WP6 Figure 1 – Measured pressure in combustion chamber

Also it could be observed that the shortest delay occurred when the delay period included the top center.

Later injection results in longer delays: the longest delay is with the latest injection, where average pressure during the delay period is the lowest.



WP6 Figure 2 – Measured pressure in combustion chamber

Medium Engine Application – CRF

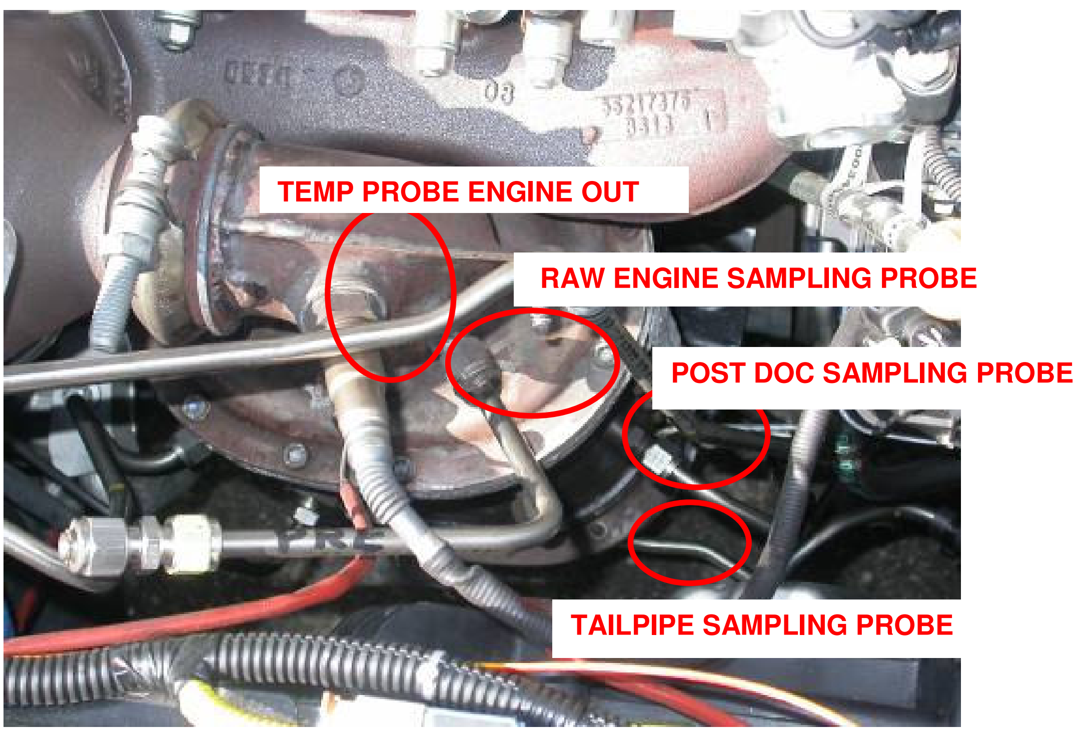
Based on the results with Fiat Croma Euro 4 vehicle, a new aftertreatment system was designed for Euro 5 application (Lancia Delta 2.0 dm^3 Mjt 121 kW). In this case the

DOC+DPF positioning in the exhaust line is in closed coupled configuration. Moreover, compared to Euro 4 layout, the precat catalyst is removed.

In reducing NOx emissions, raw CO and HC emissions was supposed to increase slightly. Therefore, improved oxidation activity was supposedto be necessary for Euro 5 application. In the new system, the same DOC and catalyzed DPF were applied but to enhance the oxidation activity the loading of DOC was increased from 70 g/cft PtPd (4:1) to 100 g/cft Pt or 100 g/cft PtPd (4:1) with the same converter dimensions (Brazed metallic, 500 cpsi, 1.3 L, coating 40 g/m2). Two alternatives were prepared to have an alternative DOCs with Pt-only or PtPd versions but only the Pt-Pd version was tested on roller bench, in order to direct compare the results with the NP system.

A new demountable canning was prepared for installing Ecocat DOC and DPF.

The AT system was installed on Lancia Delta vehicle: in WP6 Figure 3 the engine van and the sampling probes for modal analysis are shown.



WP6 Figure 3 – Assembled system and probe points

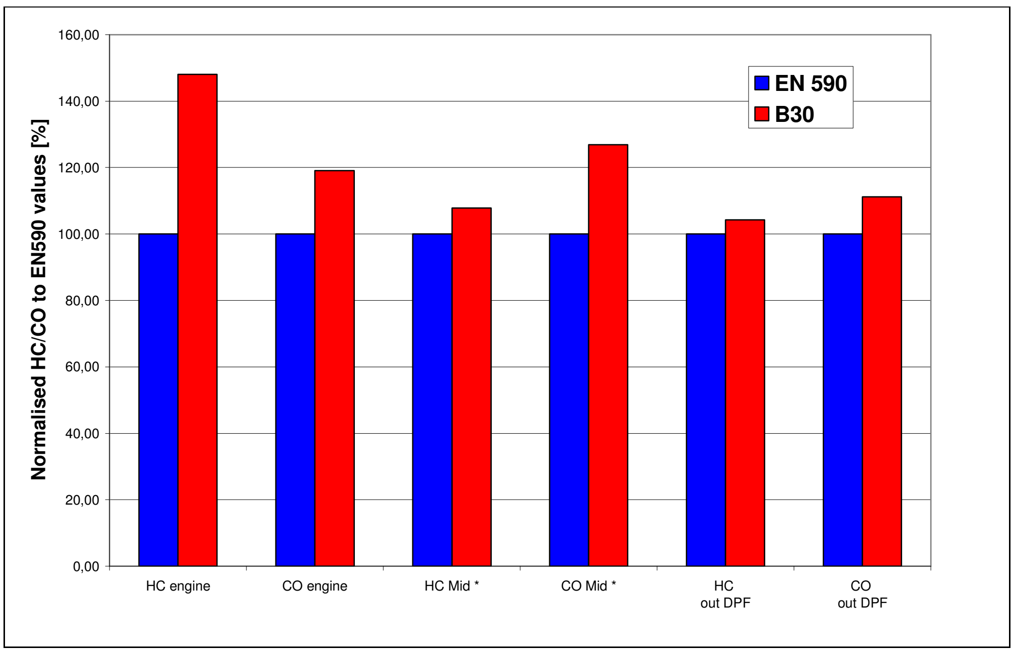
The NP and the ECOCAT designed systems were compared over NEDC driving cycle (cold) @ roller bench. EN590 and B30 fuels effects on gaseous emissions were measured. Both modal and bag analyses were carried out.

Main differences between Ecocat and NP exhaust lines can be summarised as:

- Metallic vs ceramic substrate for DOC;
- SiC vs Cordierite substrate for CPF;
- demountable canning vs NP canning;
- different shape DOC/DPF inlet pipe (leading to a different gas flow distribution on Ecocat catalysts).

Due to above listed reasons, a different pressure drop is expected as well as a different thermal distribution. So both CO, HC bag analysis emission results for Ecocat system are higher than NP values. The discrepancy between the NP and the Ecocat system behaviour is mainly due to the differences in the two assembled systems listed above; it is important to notice B30 generated higher HC and CO emissions in both cases.

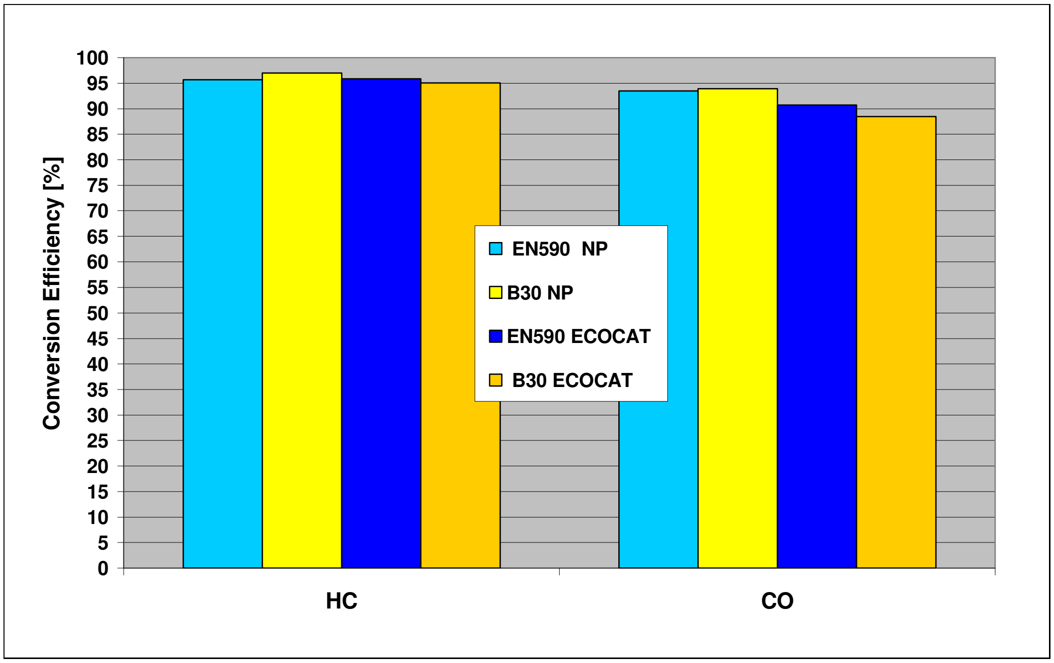
This can highlighted looking at emissions measured for NP exhaust line working with EN590 and B30. This result is confirmed by literature data that report higher CO and HC values for engines fuelled with bio-diesel blends working at low load points.



WP 6 Figure 4 – Normal Production Euro 5 Exhaust line NEDC Emissions modal analysis data comparison EN590/B30 normalised @ EN590

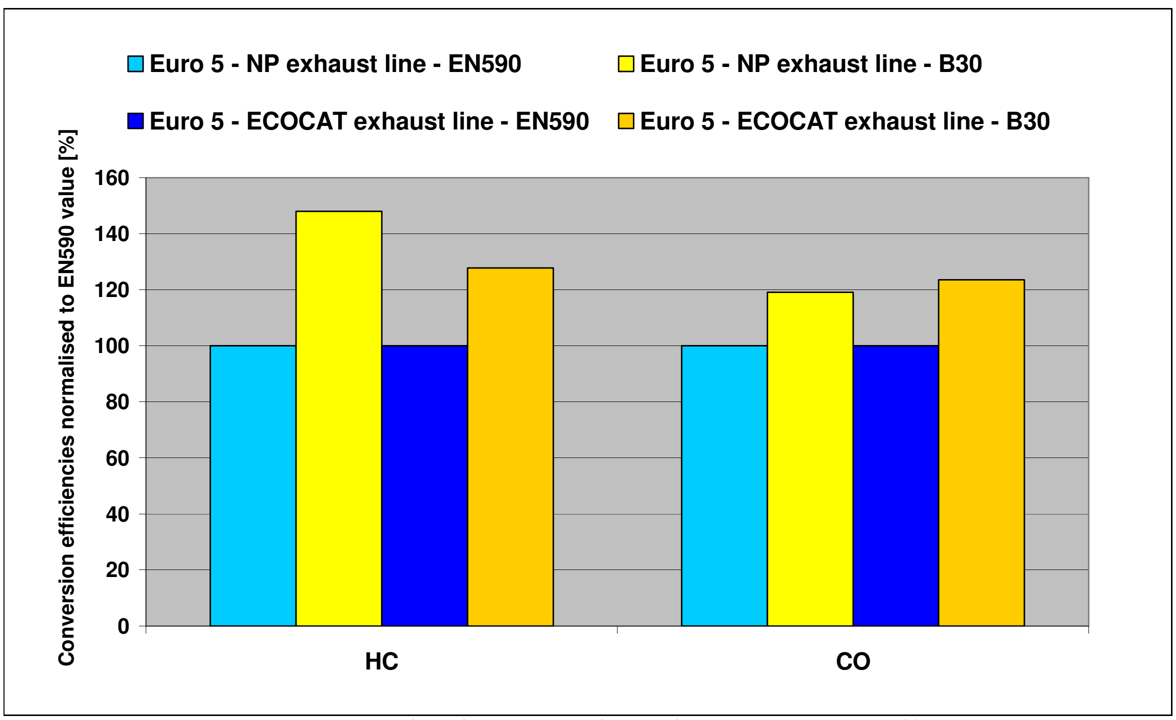
Concerning CO_2 emission a decrease was observed for Ecocat exhaust line: probably a lower pressure drop value due to the different filter substrate was the origin of this result.

As a direct comparison of the two systems by absolute emission values was considered not to be reasonable because of the two systems differences, conversion efficiencies values were considered to be the most proper way of comparison. Results are included in WP6 Figure 5.



WP6 Figure 5 – Euro 5 Exhaust lines Conversion efficiency

If conversion efficiency values are normalised to EN590 a clear improvement can be appreciated with B30 fuel with both systems that are able to recover the increase in engine raw emissions (WP6 Figure 6).



WP6 Figure 6 –Normalised Euro 5 Exhaust lines Conversion efficiency

Large Engine Application – GUASCOR

PERFORMANCE TESTS

Following the work done on WP4, Guascor run engine performance test with 20% Ethanol - 80% FAME biofuels mixture.

Guascor defined and selected the engine SF240TA (see details in WP4), its configuration and the performance test for the characterization of actual diesel engine to compare its behaviour using ethanol-biodiesel blends.

The field test was designed in order to study the performance of reciprocating internal combustion engines according with ISO 3046: standard reference conditions, declarations of power, fuel and lubricating oil consumptions, test methods, test measurements, speed governing, torsional vibrations…

Exhaust emissions measurement were also described according to ISO 8178: Carbon monoxide, nitrogen oxides, hydrocarbon, and particles.

Results:

Engine efficiency: The engine can offer the same power with E-fame mixture. However, the engine needs more amount of biofuels to offer the same power comparing to diesel base-fuel; in consequence the fuel consumption increase. This behaviour is directly linked to the lower heating value. In the case of ethanol it is half of diesel. When the effect of biodiesel and ethanol is combined, as in E20-biodiesel mixture; the fuel consumption is even higher, 18% higher comparing to diesel.

Engine combustion: The cylinder Pressure is similar to diesel with at high loads. At low loads, it is lower for the ethanol containing blend around 12 bars.

The ethanol containing mixture start of injection is similar to diesel at high load. However, it delays around 3º at low loads. This delay can be attributed to the lower viscosity of the ethanol blends respect to diesel, which makes more difficult to manage the injection pressure.

The addition of ethanol to biodiesel increases the fuel consumption, so the wight of injection for E20-bioidesel delays 3º comparing to diesel.

The start of combustion for E20-biodiesel mixture presents 2-3º advance respect to E20-diesel. This advance is related to the higher Cetane number of the biodiesel respect to diesel; which advances the ignition of the E20-bioidesel comparing to E20-diesel.

Engine emissions: On the one hand, the addition of ethanol to biodiesel reduces its Cetane number. The ignition of the E20-biodiesel delays respect to biodiesel, as a consequence of the reduction of the Cetane number. This delay takes time to the vaporization of the fuel mixture after being injected in the combustion chamber. The combustion efficiency for E20-biodiesel mixtures is higher comparing to biodiesel due to this air-fuel vaporization-mix time, but the combustion quality is worse. The ignition delay involves a reduction of the combustion time, so there is not enough time to burn the water and the CO2 resulting from the combustion, increasing CO, particles and THC emissions.

However, the lower viscosity of the E20-biodiesel comparing to biodiesel enhances the combustion quality. A lower viscosity means lower drop diameter, which leads to a more homogeneous air-fuel mixture improving the combustion quality.

E20-biodiesel CO, CO2 and SO2 emissions increase due to the Cetane number effect. And THC and NOx emissions decrease respect to biodiesel and smoke emissions are similar probably because of the viscosity effect.

On the other hand, the Cetane number of biodiesel is higher comparing to diesel. So the E20-biodiesel mixture ignition is faster comparing to E20-diesel. Furthermore; the extra O2 provided by the fatty acid methyl esters to the combustion process leads to a better combustion quality with fewer emissions for the E20-bioidesel.

E20-biodiesel THC, smoke, CO, CO2 and SO2 emissions decrease respect to E20-diesel. Only E20-biodiesel NOx emissions increase respect to E20-diesel; probably due to the higher viscosity of the E20-biodiesel comparing to E20-diesel.

Conclusion:

- As it can be seen in the next table, the results obtained in the performance test carried out in the WP4 and 6 shows that Guascor engine does not fulfill the EPA 2007 with Bioethanol mixture. It is necessary a cataliyt to fulfill the EPA 2007.

	rpm	kW	NMHC g/Kwh	NOx g/Kwh	+ g/Kwh	CO g/Kwh
EPA 2007					**4,00**	**3,50**
DIESEL	1500	***511***	0,29	11,22	11,51	3,73
nov	1500	***511***	0,35	13,10	13,45	**1,95**
	1800	***575***	0,28	10,31	10,58	**2,35**
E20D	1500	***510***	0,22	10,58	10,80	**2,53**
	1800	***578***	0,56	8,81	9,37	**2,10**
E20BD	1500	***511***	0,24	11,76	12,00	**1,69**
	1800	***575***	0,60	10,33	10,92	**1,07**
Biodiesel	1500	***509***	2,96	14,62	**17,59**	1,02
	1800	***576***	3,02	12,24	**15,26**	0,77

- The selected blend for the endurance test is E12BD, 88% FAME + 12% Bioethanol.

ENDURANCE TEST

Guascor carried out the endurance engine test during 500 hours with the selected fuel blend E12BD: 12% ETHANOL (by OBR) + 88% FAME (UNE EN 14214).

Guascor has defined and selected the engine and its configuration and the endurance test for the characterization of actual diesel engine using biofuels. The endurance test will let us verify the engine correct behaviour with biofuels (materials compatibility, fuel and oil consumption, exhaust emissions, etc.); and it leads to a maintenance schedule.

The engine characteristics:

- Engine: SF180TA
- Cylinders: 6 Line 18lt
- Diameter: 152 mm
- Stroke: 165 mm
- Compression Ratio: 14:1
- Revolution rating: 1500 rpm

Test conditions are next:

- Time: 2000 h
- Speed: 1500 rpm
- Power: 100%, 350 kW

The engine setup based on diesel engine, all the components were studied and optimized in some cases due to their critical behaviour with biofuel.

- ✓ Refrigeration system of the engine test cell was optimized in order to operate with the defined temperatures during the test time, adding auxiliary refrigeration systems as aerorefrigerators.
- ✓ Lubrication circuit injection pump was isolated in order to avoid oil dilution.
- ✓ The filter body was painted with a specific paint for biofuels in order to study its behaviour.
- ✓ Injection tubes were reinforced in order to avoid fuel leakage.
- ✓ Fuel feed circuit filter system was modified in order to adapt it to the biofuel blend.
- ✓ Engine control unit was adapted to operate with low heating value lower than Diesel.
- ✓ Bearing materials applied by vacuum deposition are compatible with biofuels. These materials are able to resist high engine charge and pressure, moisten better the oil rubbish and resist the corrosion.
- ✓ Forced lubrication cylinders head were assembled in compensation to the lower lubricity and higher corrosion power of biofuels comparing to diesel.

Results:

- *Emissions:*

TEST	hour	295	310	322	352	367	383	383	405	413	422	437	450	462	498
POWER	kW	337	337	341	355	339	338	334	340	340	340	342	340	342	340
SO2	ppm	4,9	1,8	4,4	3,5	5,3	5,00	5,50	5,10	4,50	5,00	4,7	6,5	5,3	4,6
CO2	%	7,31	7,4	7,3	7,3	7,0	7,16	7,18	7,31	7,36	7,20	7,4	7,46	7,3	7,14
CO	ppm	99,1	87,2	84,1	81,9	78,9	89,90	87,80	94,80	98,70	85,60	109,5	110	96,4	78,7
O2	%	10,8	10,8	10,9	44,0	11,2	11,10	11,04	10,84	10,95	11,06	10,7	10,7	10,9	11,2
THC	ppm	50,5	50,4	50,1	45,2	39,9	43,90	46,90	50,60	41,56	44,90	52,2	65,8	47,6	42,21
CH4	ppm	6,19	-19,8	-21,5	-22,8	-12,6	-32,22	-32,54	-22,92	-30,47	-14,54	-16,5	-34,9	-23,4	-36,6
NO	ppm	1117	1256	1260	1254	1185	1199	1199	1198	1262	1232	1186	1216	1176	1250
NOx	ppm	1148	1328	1323	1339	1201	1258	1246	1248	1354	1295	1244	1278	1222	1308

- *Fuel consumption:* The fuel consumption was calculated taking in account the low heating value of the test blend, the power generated and the fuel flow. The fuel consumption shows a significant increase at 30 hour and 120 hours of engine test. At 30 hours, the injection tube broke and the injection pump filter broke; and at 120 hours, this filter broke again. The fuel consumption media was 215.66 g/Kwh.
- *Oil analyse:* The first oil charge maintained its properties. In spite of isolating the injection pump, the viscosity decreased due to the fuel content.
- *Problems found during the test:*
  - Principal water pump gasket leakage
  - Storage tank impulsion pump failure
  - Storage tank content measure float failure
  - Storage tank content measurement stick accident
  - Injection pump filter failure
  - Injection tubes leakage
  - Nozzle deposits

Conclusion:

With this engine test Guascor get a first evaluation about the engine behaviour working with E-Fame blends in the long term, taking in account the possible performance degradation and engine components live effect, mainly on injection system, piston-ring, cylinder liner, overhead valves, lubricant oil life effect, an so on. The endurance test let to Guascor know how to optimize the maintenance standard for this kind of biofuels.

It is clear that it is needed a strongest lubricant which should be able to maintain its properties in spite of suffering fuel dilution.

About the emissions, it is necessary a catalyst in order to fulfil the EPA 2007.

It is necessary to find a filter system which should be able to improve the water separation.

Finally, it is also necessary the nozzle design and materials optimization.

3.7.3 Deliverables

Deliverable N	Initial Deliverable title	Initial Foreseen Delivery date	Real Delivery Date	Nature	Dissemination level	STATUS
D31	Report application of developed technologies to small engines (ABAMOTOR)	Mth36	Mth36	R	CO	Delivered
D32	Report application of developed technologies to medium engines (CRF)	Mth36	Mth36	R	CO	Delivered
D33	Report on endurance engine test results on best selected bio-fuels mixtures (GUASCOR)	Mth36	Mth36	R	CO	Delivered

3.8 WP7 - Life cycle analysis

3.8.1 Objectives

To determine the lifecycle environmental impact and cost of the introduction of advanced technologies (design combustion chamber, after-treatment, advanced lubrication systems,..) to introduce alternative biofuels and biolubes.

3.8.2 Work done and final achievements

The main concern of this LCA study is the question as to whether or not the system running with bio-lubricants and bio-fuels and the new developments of the project, what we have called "CLEANENGINE system" is comparable to the current system "Standard system" running with conventional mineral lubricants and fuels, from an environmental point of view.

Based on the available data and using the Eco-indicator 99 H/A method, several conclusions have been drawn. However, it is important to keep the following limitations well in mind:

- Data limitations: inputs and outputs of all stages of the life cycle have been inventoried based on literature, company specific data and available databases. Where possible, company specific data was used. If such data was not available, data has been used from publicly available LCA-databases, from LCA-studies or from other sources of relevant literature. When possible, data for Western Europe and for recent years was used, but for many processes older or less suitable data had to be used. In some instants no data could be found, so data for similar processes had to be used and/or own assumptions had to be made.
- Methodological limitations: the Eco-indicator 99 methodology is widely spread and well accepted, but methodological limitations still exist.
- Subjectivity: ISO has set strict rules for the publication of comparative LCA's. According to ISO standards, normalising and weighting in order to obtain one final environmental index is only allowed for comparative LCA's which are not made public. For comparative assertions disclosed to the public, "subjective" weighting is not allowed. In chapter 4, the subjective weighting step is included.

A parallel study was run for passenger car application: Boustead sw and CML method were used for bio-diesel production phase, a Fiat internal developed sw was applied for usage phase. This second study is affected by the same limits. Conclusions were similar.

Keeping these limitations in mind, the following conclusions have been drawn.

PRODUCTION PHASE

Fuels

- The main environmental impacts in the **bio-ethanol** production are due to the **wheat farming operations** (43 % of the total impacts). These impacts are mainly due to the use of fertilizers and also due to the on farm fuel use.
- The **natural gas** used in the bioethanol synthesis process has also a very impact (40,4% of the total impact)
- In the **bio-diesel** production the main impacts are due to the rapeseed oil and methanol used in the esterification process. The rapeseed oil impacts are mainly due to the farming operations.
- When **comparing biofuels** (bio-ethanol Vs gasoline and Biodiesel Vs Diesel) in both cases the "bio" fuels have lower environmental impact.

Lubricants

- In the **TMP ester** manufacturing process most of the environmental damages are due to the manufacturing of the refined rapeseed ester (about 44% of the total impact) and the TMP manufacturing process (around the 38%). The environmental damages caused by the production of the refined rapeseed oil can be traced back to the machinery operations and the use of fertilizers for the cultivation of the rapeseeds. Most of the environmental damage caused by the TMP ester is to the depletion of fossil fuels, but effects on human health caused by emissions of inorganic substances are also important damages.
- The main environmental impact from the manufacturing of the **mineral lubricant** is the depletion of fossil fuels caused by the use of crude oil.
- The **TMP Ester** (from rapeseeds) has lower environmental impact than the **reference mineral lubricant**

USE PHASE

An **evaluation** of the systems under study (tiller, 2-wheels tractor,6 cylinder in-line engine, 4 stroke engine of a passenger car), has been performed using the Eco-Indicator-99 methodology.

In each of the application two systems have been studied: the conventional system (running with conventional mineral fuel and mineral lubricant) and the Cleanengine system (running with biolubricants and biofuels).

- The environmental impacts produced by the manufacturing and use of lubricants is almost negligible when comparing with environmental impacts produced by the needed fuel manufacturing and the emissions produced during fuel combustion
- The main environmental impact is due to the **fossil fuel consumption**, for that reason the use of **bio-fuels represents an environmental benefit**.
- Taking into account all the limitations it can be said that in all the systems studied **the cleanengine system** (where biolubricants and biofuels have been introduced) produces **lower environmental impact** than the **conventional system** (running with conventional lubricants and fuels)
- It is interesting to remark that in the tiller application the CLEANENGINE system II (running with BIOE85+SEMO36 biolubricant) produces higher impact than the CLEANENGINE system I (BIOE85+mineral lubricant). This is because of the higher consumption (oil and fuel) of system I.

3.8.3 Deliverables

Deliverable N	Initial Deliverable title	Initial Foreseen Delivery date	Real Delivery Date	Nature	Dissemination level	STATUS
D34	Report well to wheel small and large engine application /TEKNIKER)	Mth36	Mth36	R	CO	Delivered
D35	Report well to wheel medium application (CRF)	Mth36	Mth36	R	CO	Delivered

4 APPENDIX 1 – Final Plan For Using And Disseminating Knowledge

SECTION 1 – Exploitable Knowledge And Its Use

Exploitable Knowledge (description)	Exploitable product(s) or measure(s) Sector(s) of application	Timetable for commercial use	Patents or other IPR protection	Owner & Other Partner(s) involved
Bio-fuels optimisation	Fuels for IC engines for industrial and transportation use	2010 - Optimised blends application in Guascor and Abamotor engines	NO	GUASCOR, ABAMOTOR
Ester based and polyglycol lubricants development	Lubricants for IC engines for industrial and transportation use working with bio-fuels	2010 - Starting application tests in passenger car diesel/gasoline engine	NO	BAM, CRF
Coatings development for improving resistance of engine materials working with bio-fuels	Coatings for engine components working in engines for industrial and transportation use working with bio-fuels	Not defined	NO	TEKNIKER, BAM
After-treatment systems development for EU emission norms compatible engines feed with bio-fuels	After-treatment systems for IC engines for industrial and transportation use working with bio-fuels	2010 - Starting SCR application tests in GUASCOR diesel engine	NO	ECOCAT, GUASCOR

SECTION 2 - Dissemination Of Knowledge

Nr.	Date	Type	Type of audience	Countries addressed	Size of audience	Partner responsible
1	February 2007	Project web-site	General	World wide	NA	All
2	February 2007	ULYSSES CA web-site	General	World wide	NA	CRF

3	October 2007	ULYSSES CA Workshop, Catania (IT)	R&D	Europe	50	CRF
4	June 2008	Congress LUBMAT2008, San Sebastian (ES)	General	International	~250	FUCHS, TEKNIKER, BAM
5	December 2008	Workshop FITSA: Impactos y oportunidades de las nuevas propulsiones en los componentes del automóvil, Madrid (ES)	General	International	250	TEKNIKER
6	March 2008	Article in Motortechnische Zeitschrift (MTZ)	Automotive	International	NA	FUCHS
7	March 2008	Presentation Technische Arbeitstagung Hohenheim, Stuttgart	Lubricant experts	Germany		FUCHS
8	April 2009	Advances in Boundary Lubrication and Boundary Surface Films, Seville (ES)	Scientists and companies	International 30 countries	100	TEKNIKER CRF
9	June 2009	Ecotrib2009 Conference, Pisa (IT)	General	International	200	CRF, FUCHS, TEKNIKER, BAM
10	September 2009	ICE 2009 9th International Conference on Engines & Vehicles, Capri (IT)	General	International		IM-CNR, AVL
11	September 2009	EuropaCat IX Congress, Salamanca (ES)	General	International		ECOCAT
12	November 2009	SAE Powertrains Fuels and Lubricants Meeting, San Antonio (TX-US)	General	International		ECOCAT
13	January 2010	17th Int. Coll. Tribology, TAE Esslingen, Plenary paper	General, lubricants producer	World wide	~800	CRF, FUCHS, BAM, TEKNIKER
14	January 2010	17th Int. Coll. Tribology, TAE Esslingen, Plenary paper	General, lubricants producer	World wide	~800	BAM
15	April 2010	OERG Meeting	R&D	International	25	TEKNIKER, ABAMOTOR, FUCHS