

PROJECT PERIODIC REPORT

Grant Agreement number: 234032

Project acronym: POWERFUL

Project title: POWERtrain for Futur Light-duty vehicles

Funding Scheme:

Date of latest version of Annex I against which the assessment will be made:

Periodic report: 1st 2nd 3rd 4th

Period covered: from 01/01/12 to 31/12/12

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¹ Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement .

² The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate) ³:
 - has fully achieved its objectives and technical goals for the period;
 - has achieved most of its objectives and technical goals for the period with relatively minor deviations.
 - has failed to achieve critical objectives and/or is not at all on schedule.
- The public website, if applicable
 - is up to date
 - is not up to date
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator:

Date://

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism.

³ If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.

3.1 Publishable summary

1- summary description of project context and objectives

SPV2 : The aim of sub-project V2 “New CI engines with low temperature combustion and integrated aftertreatment system for alternative fuels” in 2012 is the setup of a 4-stroke 3-cyl CI engine based on the low temperature combustion (LTC) mode running on new tailored biomass based fuels. The advanced exhaust gas aftertreatment system (EATS) should be built and a control strategy and software needs to be developed.

The influence of the chosen fuel will be investigated on both, 1cyl research and 3cyl Powerful engine together with the development of LTC.

The technical approach to set up an injector for rate shaping will be demonstrated with a prototype injector and first test results show the effect of rate shaping on the combustion process.

A demo vehicle should be built. The status of the first car will be shown in the report. A second vehicle will be produced as backup solution for a different technical solution of the EATS to keep the project in the time schedule.



The subproject SP V2 is conducted by the listed beneficiaries in the shown structure:

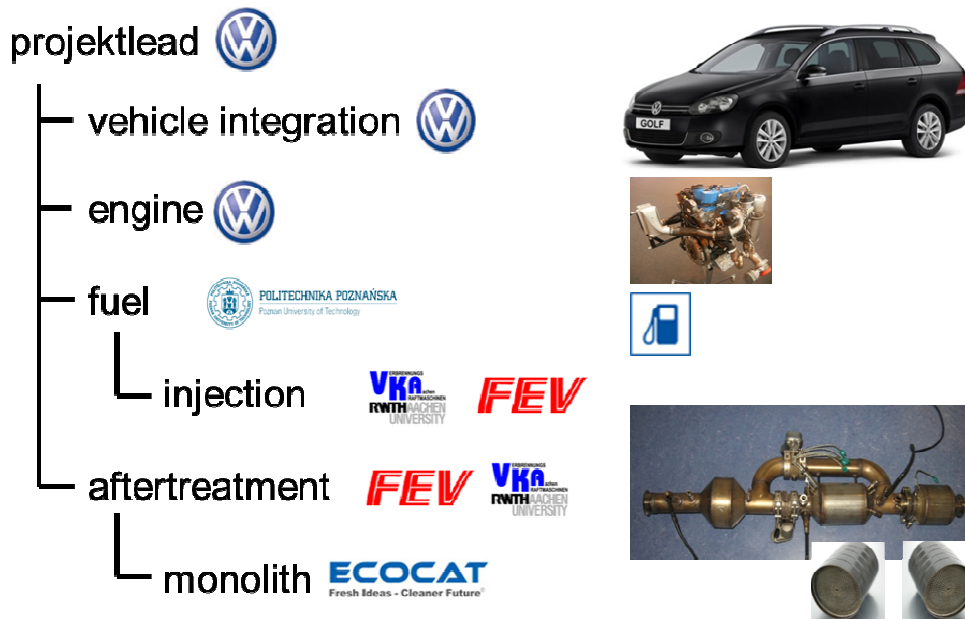
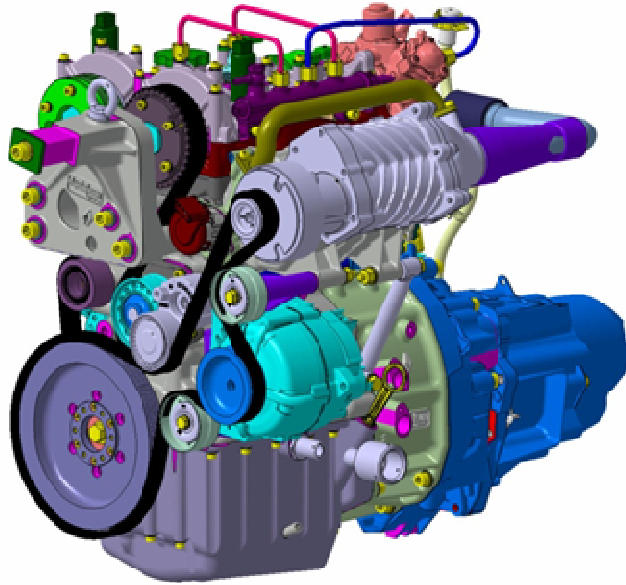


Fig: beneficiaries of SP V2

SPV3 : The first 2 years devoted to determine the best architecture of the engine and the manufacture completion of each component. The 3rd year was mainly used to optimize the subsystems which were not reaching their final target : Combustion system, airloop components (turbochargers, superchargers and air-coolers). The 3rd year has seen the design start of the demo-car with the twin-cylinder 2 stroke, and the design start of the final airloop with a dedicated after-treatment system.



K9A – 2 stroke twin-cylinder from SPV3

SPT1 : The work on vehicle modeling primarily concentrated on test vehicles and technologies of SPV1 and thus referred to SI engines. Models for two vehicles have been set up, one baseline vehicle with ‘state of the art’ technology and one with an advanced engine concept. The computer model of the baseline vehicle was primarily used as platform for a virtual integration of tribological improvements such as new materials, surface coatings and advanced lubricants for friction reduction and their projection to real world driving conditions. In regard of new engine concepts a vehicle with an advanced SI engine concept was analyzed and assessed under for various driving conditions.

On the basis of the first set of achieved testing results an improvement of the developed coatings and of the selected surface treatments to enhance the friction and wear performance of the concerned engine components was carried out; in particular TEK developed a new CrN coating 20µm thick for piston ring application and applied new texturing hatches to steel and cast iron disks for camshaft and crankshaft applications. TUL developed a new a-C:Si:Cr:H coating for piston pin application. Moreover scratch test method was additionally introduced in the selected lab experiments set to assess the mechanical properties of the developed coatings (critical loads and adhesion to the substrate). Moreover the first industrial feasibility case was considered and evaluated for WC-C nanocomposite coating developed by TUL.

Concerning friction reduction by thermal management a new concept Smart Heater was installed and tested at CRF in an engine bench to demonstrate the fuel economy potential given by the system.

For the characterization of the different viscosity oils, 5W30 and 0W30 from CRF and PC1277 and PC1172 from Renault, IK4-Tekniker has selected different standard and simulation tests “stem valve-guide” and “piston ring-cylinder liner”. Moreover stress corrosion test at 400 °C in presence of corrosive gases were additionally introduced in the selected lab experiments set to assess the corrosion properties of the developed coating ZrCN (valve stem application).

Work package T1.3 focuses on road emissions testing with PEMS and has the objective to: (i) provide up-to-date technical recommendations on the design of test routes and the execution of on-road emissions tests to comprehensively characterize the fuel consumption as well as the carbon dioxide and pollutant emissions of light-duty vehicles and (ii) apply PEMS on-road testing alongside laboratory testing to characterize the fuel consumption and emissions of base-line vehicles and in a second stage of one validator vehicles equipped with a novel powertrain. The technical recommendations were provided in December 2012, while majority of experimental work in this work package is to be carried out in the final year of the Powerful project.

2- description of the work performed in 2012 and the main results achieved so far

SPV1 : In this year all the SPV1 partners worked on the extreme downsized gasoline engine. CRF designed the new engine and its new innovative components: LP-EGR, WCAC (Water Charge Air Cooler), new CR, new camshaft profile. The expected benefits are:

- Fuel efficiency increase at high loads
- Improvement of combustion cycle efficiency and transient operation
- Pumping loss reduction at part load conditions
- Emissions reductions
- No power derating thanks to intake air temperature reduction

The experimental investigations developed at the University of Genoa turbocharger test rig allowed better understanding compressor and turbine pulsating flow performance. During the third year of the project the following activities were developed:

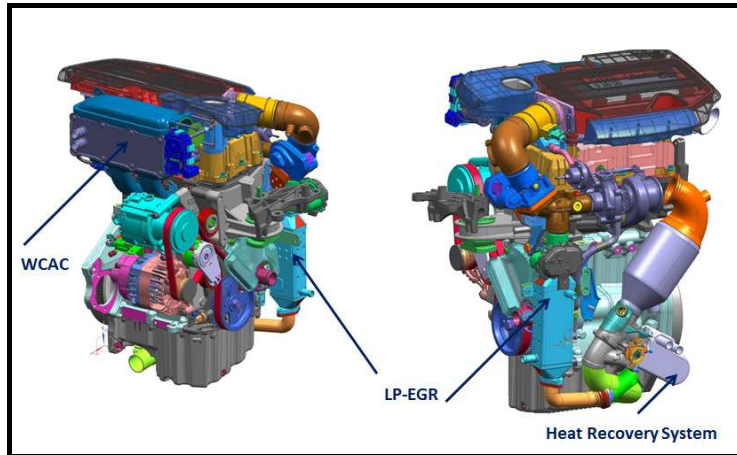
- integration of the second selected turbocharger (TC2) in a current production 2-cylinder engine intake circuit
- experimental investigation on the behaviour of the 2-cylinder engine intake circuit under unsteady flow conditions (TC2)
- measurement of turbine steady flow maps for an optimized turbine (different from the previous selected one)
- unsteady flow investigation on turbocharger optimized turbine

Thanks to the above mentioned activities, the best solution referred to the turbocharging unit for small gasoline engine application was identified by UNIGE jointly with CRF. In parallel, Magneti Marelli finalized the validation and optimization of integrated PFI+VVA+TC control strategies, and the calibrations for the 2 cyl engine, as well as the characterization of sub-systems behavior / performances, taking into account the application to the extreme downsized engine.

This work, started during the first year, led to a development and tuning of key models of physical components and strategies, to handle the main problems connected with the Integration of PFI system on a VVA+TC SI engine, in order to fully investigate the potential in terms of efficiency / CO₂, performance and emissions, (by means of definition and theoretical / experimental characterization), the optimization of injectors (and their positioning), as well as the adaptation of control system (SW) and development/implementation into the engine ECU of “integrated” control strategies.

Finally, AVL finished the set-up of the demonstrator vehicle that was equipped with electronic cylinder deactivation, electric supercharging, wide spread transmission, cooled exhaust manifold, friction reduction measures like variable oil pump and DLC shim less tappets. Besides the modifications performed directly to the engine additional CO₂ emission reduction technologies were introduced. This was an intelligent alternator control, a Start/Stop functionality (stopping the engine in idle condition) and some modifications to reduce the drag resistance of the demonstrator vehicle.

After finishing the engine and vehicle build the calibration of drivability, new ECU functionalities, fuel consumption and emissions was done. In parallel the fuel consumption and emissions were tested on a chassis dyno to demonstrate the CO₂ reduction in comparison to the base vehicle.



Extreme downsized 2 cyl gasoline engine with innovative components



Powerful – AVL demonstrator vehicle

SPV2 : The selected fuel has been investigated and used for the LTC process. The main results of LTC are a reduction of NO_x and soot, but the fuel consumption and CO₂ level have increased.

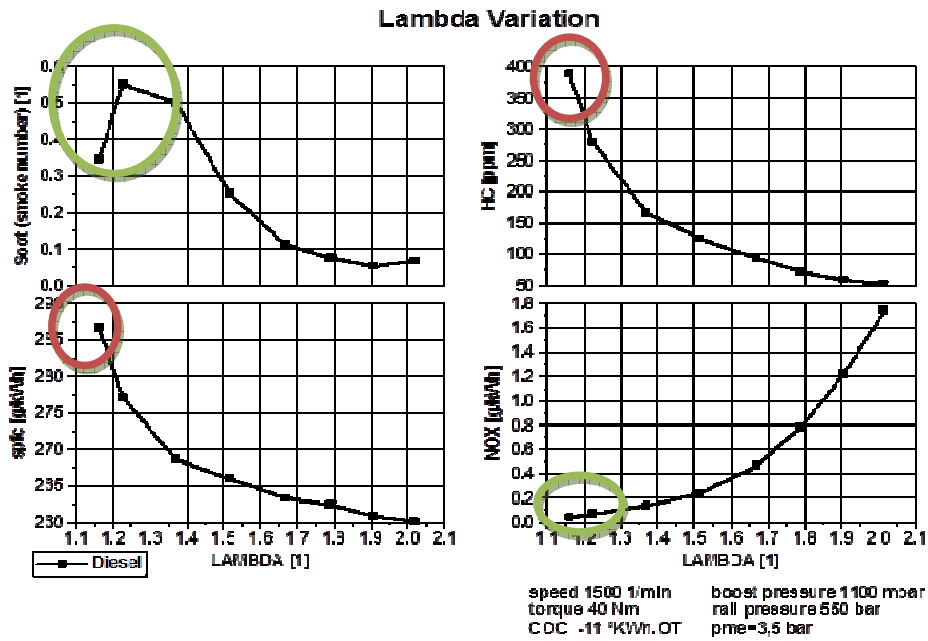


Fig: effect of LTC on emissions and fuel consumption

A prototype rate shaping injector has been tested. It shows the required pressure modulation and rate shaping capability and advantages in terms of emissions and fuel consumption.

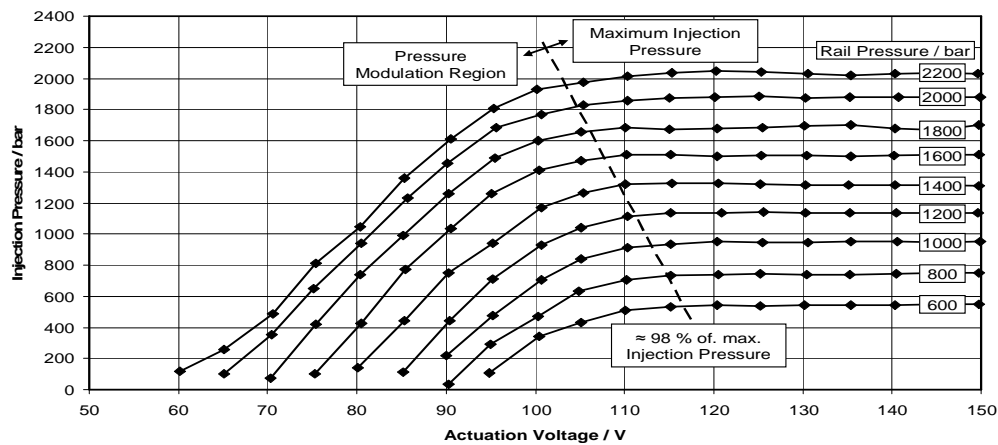


Fig: pressure modulation map of rate shaping injector

The advanced EATS was set-up including first dedicated catalysts. Tests confirmed the general function and showed promising performance. The NO_x activity could be extended towards a wider temperature range.

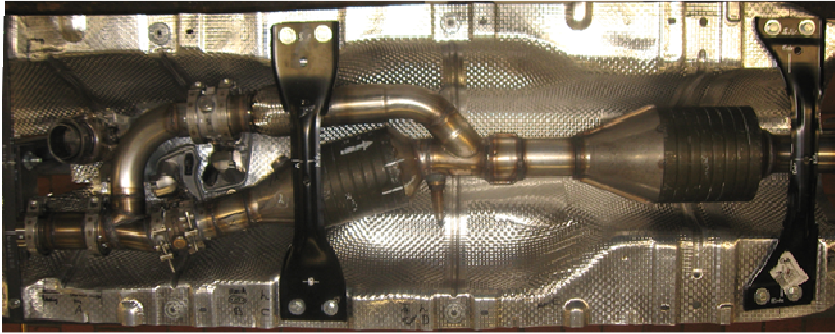


Fig: EATS hardware

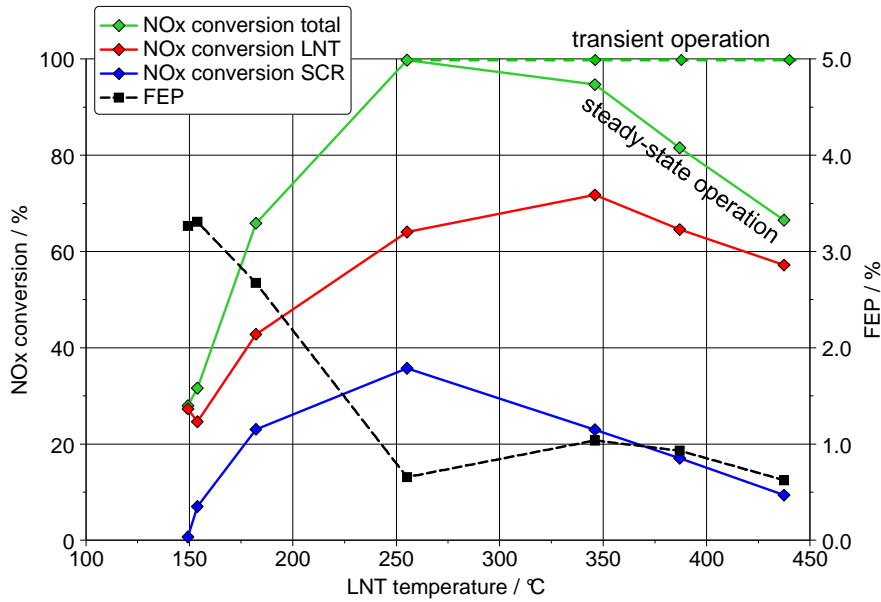


Fig: EATS NOx-conversion

New catalysts for improved low temperatures activity have been tested. The most effective materials have been identified as well as the oxygen storage capacity.

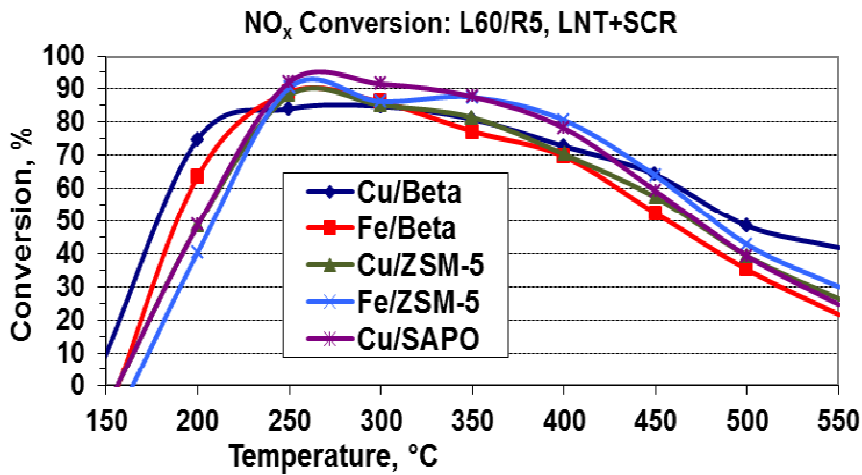


Fig: catalyst screening

A first demo vehicle has been built and is running some basic testing.



Fig: demo vehicle

Several evolutions of a 3cyl engine have been set up and tested. Most of the engine parameters have been investigated. Promising results have been found for the turbo charger, crank case and pistons.

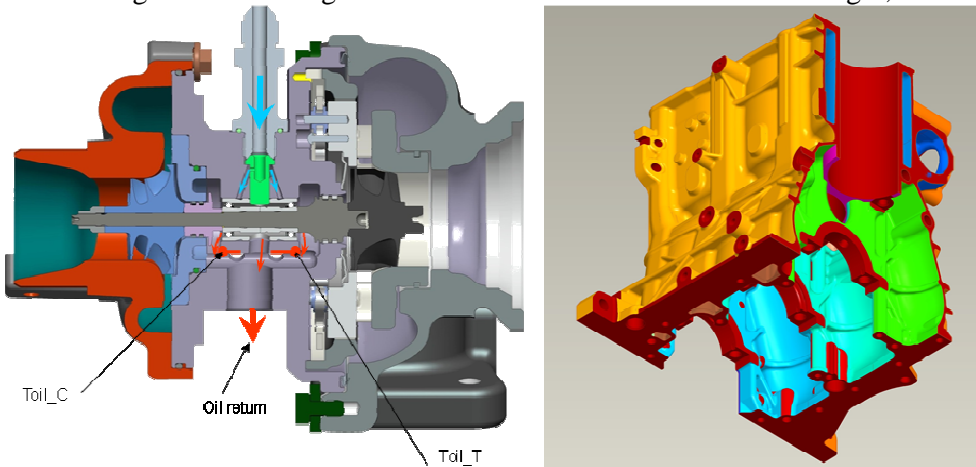


Fig: turbo charger and crank case

SPV3 : The 2-stroke engine combustion concept was optimized on single-cylinder engine with conventional combustion in order to reach ISFC and pollutant targets. The main conclusion is that the ISFC could be further improved by testing more camshafts, higher compression ratio and new injectors.

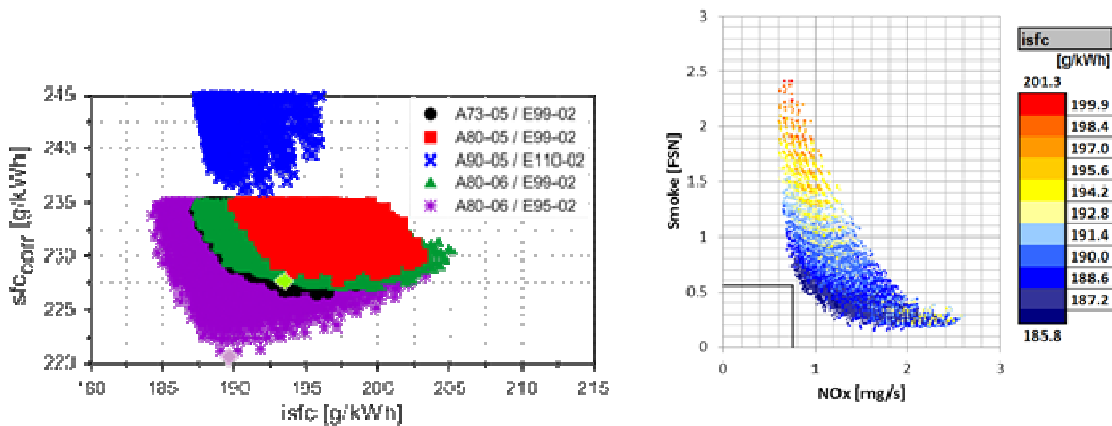


Fig. 1: Available camshaft configurations

Turbochargers were developed in order to improve the turbine efficiency and swallowing capacity. Also we decided to procure a VGT turbocharger to speed up the engine development. These were tested at IFPEN, including 3 different types of superchargers.

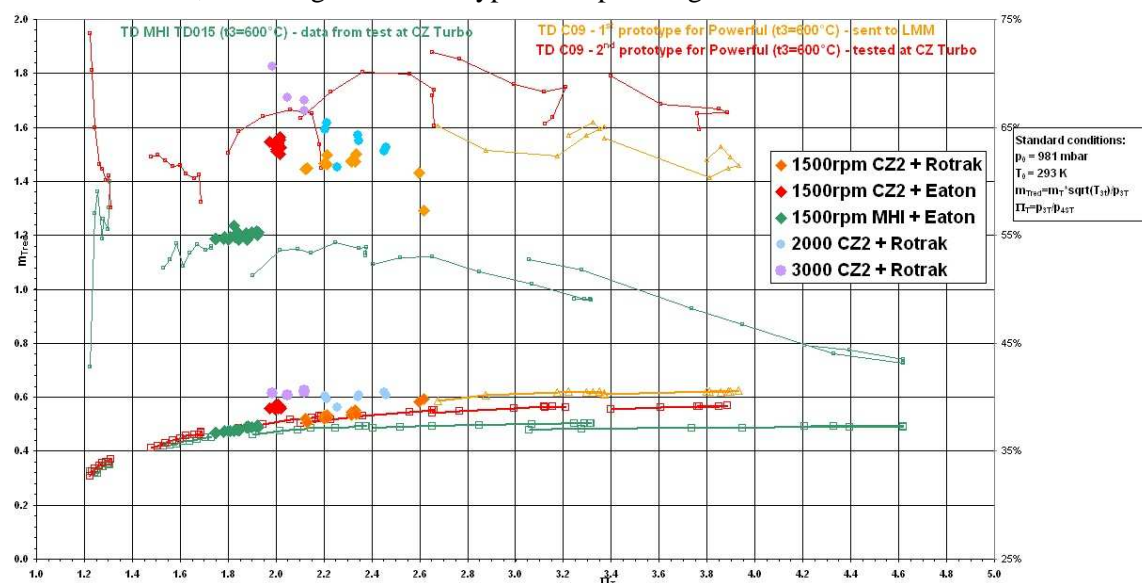
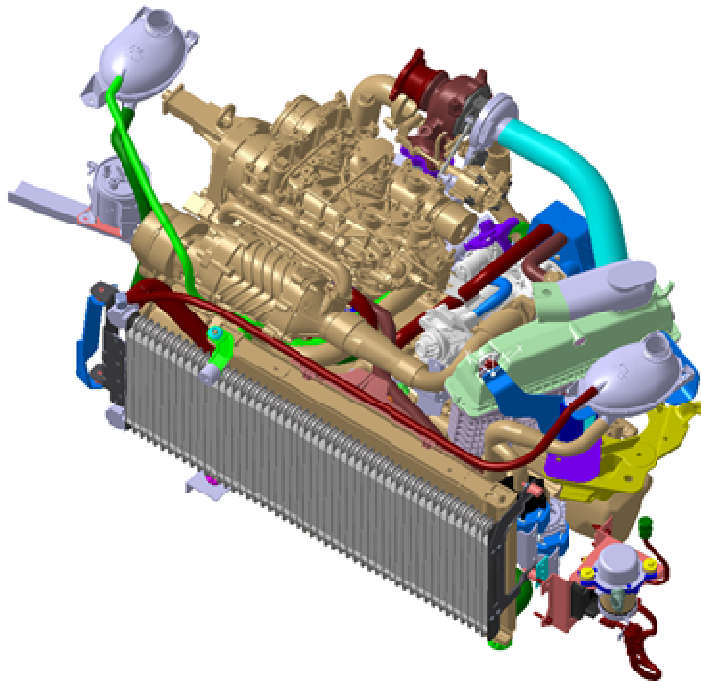


Figure 1: Global comparison of MHI and both CZ C09 turbine prototypes data and turbine operating points resulting from the engine testing on IFPEN test bed. The good agreement between CZ tests of both turbines is evident while the MHI manufacturer map (black lines in Erreur ! Source du renvoi introuvable.) is far from the reality.

The detailed implementation of the engine into a Twingo chassis was complete, including all the, including the design of the dedicated after-treatment system. The friction reduction program was started with the help of T1 sub-project



SPT1 :

T1.1: New simulation tools and powertrain integration

This work package applies various models for simulation of engines, drive trains and vehicles which depict the innovative aspects of the individual concepts. All technology routs refer the improvements to specific baselines vehicles. These are modern, commercially available passenger cars. They are modeled on the basis of stationary engine maps. Experimental data such as chassis dynamometer tests (e.g. NEDC) and on-road vehicle measurements with PEMS are used to calibrate the model parameters. To date, this method has been evaluated as an example.

The quasi-stationary models are exclusively used for representation of reference figures for CO₂ emissions under various operating conditions (“real world driving”) and drivability. In order to cover all innovative aspects of Powerful the models must depict the vehicle characteristics in much greater detail and thus include the thermodynamic engine cycle, friction losses, the warm-up characteristics (as friction depends on temperature), the energy consumptions of auxiliaries (coolant and lubricant pumps, alternator), gear ratios and friction of drive train. Consequently, the models must reach a corresponding level of sophistication which includes all influencing factors of turbocharging, combustion, friction, cooling and lubrication. This is a necessary prerequisite for the analysis of concepts and their projection to real life operation. Figure S1 shows the scheme of a comprehensive simulation platform. The individual boxes can be individually developed and calibrated, then they are coupled and applied to various boundary conditions.

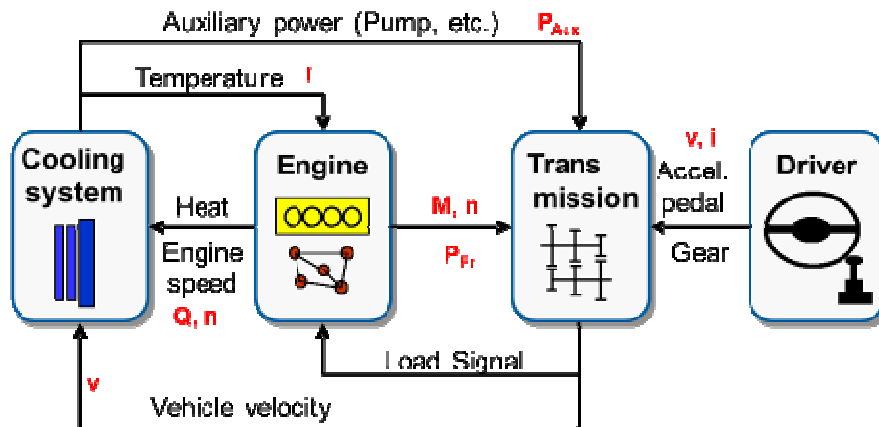


Fig. S1: Scheme of a complex vehicle simulation platform

Within the first two project years various exemplary models have been set up. Besides the coupling of existing software tools also new models (primarily for friction and wear) are specifically developed within these platforms. This approach has well advanced with a model for a Fiat Punto which represents the reference vehicle for modeling activities. This car is an excellent example for the big volume of passenger cars with 1000 -1100 kg weight and SI engines.

Another activity of the second project year concentrated on a detailed friction model for the Fiat Punto (piston rings, crankshaft bearings etc.). In addition, the engine friction was experimentally analyzed (by a “strip down” analysis) and these data were used for calibration of the model. This model has been successfully used for the simulation of the NEDC test cycle and various concept investigations have been carried out.

In the third project year two vehicles were modeled with very high levels of modeling sophistication. These include the thermodynamic cycles of the combustion engines, the drive trains, the cooling and lubrication systems, auxiliaries and also detailed tribological models for sliding surfaces within specific component groups of the engines. One vehicle refers to typical 'state of the art' technology of Euro 5 vehicles and thus represents a baseline for the assessment of various improvements. This model was primarily used as platform for a virtual integration of tribological improvements such as new materials, surface coatings and advanced lubricants for friction reduction and their projection to real world driving conditions. In regard of new engine concepts a vehicle with an advanced SI engine concept was analyzed and assessed under various driving conditions.

T1.2: Friction reduction

WP concerning friction reduction includes four different tasks. Work performed in first project years concentrated especially on tasks related to enhancement of surfaces friction performances and application of low viscosity lubricants. The starting point was the preparation of a friction contact pairs map in IC engine to identify the most relevant mechanical losses sources due to friction. After that a tribological test plan was prepared to simulate the selected contact pairs at lab scale in order to evaluate the friction and wear performances of the standard surfaces compared with the performances of engineered surfaces, in particular coated or treated by IK4-Tekniker and Lodz University participants. Tribological tests included in the plan were referred to: piston ring/liner, piston skirt/liner, valve/valve guide, crankpin/sliding bearing, camshaft/head supports, piston pin/piston. Results depend on the application and the related lubrication regime in real operating conditions: nc-WC/a-C coating developed by TUL revealed very good properties in starved lubrication condition and with high applied loads (i.e. piston pin application), ZrN/ ZrCN coating developed by IK4-Tekniker demonstrated to be very effective at extreme pressures when a corrosive environment is present (exhaust valve stem application). Laser texturing developed by IK4-Tekniker is currently under investigation as an optimization phase of laser dimples geometry and distribution on the surface is ongoing. The application of the low viscosity lubricants reduces both the friction and the wear.

T1.3: Real life emissions investigations with PEMS

The objective of the first part of this work package is to develop a protocol for measuring on-road emissions of light-duty vehicles with PEMS, including the design of suitable test routes, the selection of test parameters to be measured, and the definition of test modalities. This objective has been achieved in Deliverable DT 1.10. To comprehensively characterize the CO₂ and pollutant emissions requires complementing laboratory tests over the NEDC, WLTC, and Artemis with on-road emissions tests. The emission tests on the road should cover shares of urban, rural, and motorway driving to cover as far as possible the range of normal driving conditions. The on-road emissions testing in the Powerful project is closely related to the work of the Real-Driving Emissions of Light-Duty Vehicles (RDE-LDV) working group of DG Enterprise that currently develops a complementary test procedure for light-duty vehicles.

The test protocol specified in DT 1.104 has been applied to two baseline vehicles until the end of 2012 and will be applied in 2013 to one validator vehicle equipped with a novel powertrain

⁴ Note that deliverable DT 1.10 specifies the best-practice scenario. The WLTC was not yet available in 2010; the first baseline vehicle (Fiat Punto) could thus not be tested on this cycle.

technology. The PEMS activities of this work package are scheduled to be completed by the end of the POWERFUL project in 2014.

Already in the first project period between 1 January 2010 and 31 December 2010, JRC and CRF have developed a test protocol for applying PEMS to light-duty vehicles. This work was closely related to the PEMS light-duty vehicle test campaign conducted at the JRC. Following the predefined test protocol, PEMS was used to measure the on-road emissions of the first baseline vehicle, i.e., a Fiat Punto equipped with a gasoline engine provided by CRF. The PEMS tests were conducted on two test routes around Turin and Ispra, respectively, representing urban, uphill/downhill, and motorway driving. Tests on each route were replicated three times. The on-road PEMS tests were complemented by extensive laboratory emissions testing at different ambient and engine temperatures based on the New European Driving Cycle (NEDC, 18 tests), the Artemis driving cycle (11 tests), the Worldwide Harmonized Motorcycle Test Cycle (WMTC, 2 tests) and a newly designed driving cycle designed at the JRC based on driving patterns identified during PEMS on-road emissions testing (8 tests).

The results indicate that PEMS is applicable to light-duty vehicles and yields reliable measurements of on-road NO_x (nitrogen oxides), CO (carbon monoxide), THC (total hydrocarbon), and CO₂ (carbon dioxide) emissions (Figure S2). Route-average on-road emissions of the tested base-line vehicle stay well below Euro 5 emission standard; NO_x as well as CO emissions may, however, exceed Euro 5 emission standard if emissions are averaged over shorter sub trips. Likewise, pollutant emissions as measured in the laboratory stay below Euro 5 emission standard; emissions measured based on the NEDC are generally lower than both emissions measured on the road as well as with the more aggressive Artemis and WMTC driving-cycles (Figure S3). The average on-road CO₂ emissions of the tested baseline vehicle amount to 158 ± 12 g/km and deviate by $27 \pm 1\%$ from emissions measured during NEDC testing (124 g/km). Low temperature testing in the laboratory indicates substantially increased THC and CO emissions. Based on the on-road emissions testing conducted so far, we conclude that PEMS provides reliable results and presents an important tool to comprehensively characterize vehicle emissions.

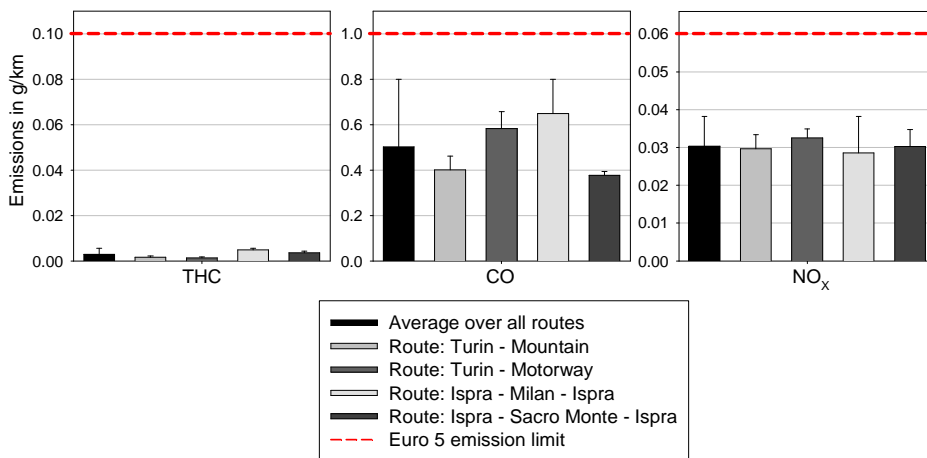


Fig. S2: Route average on-road emissions of the Fiat Punto baseline vehicle as measured on the road with PEMS

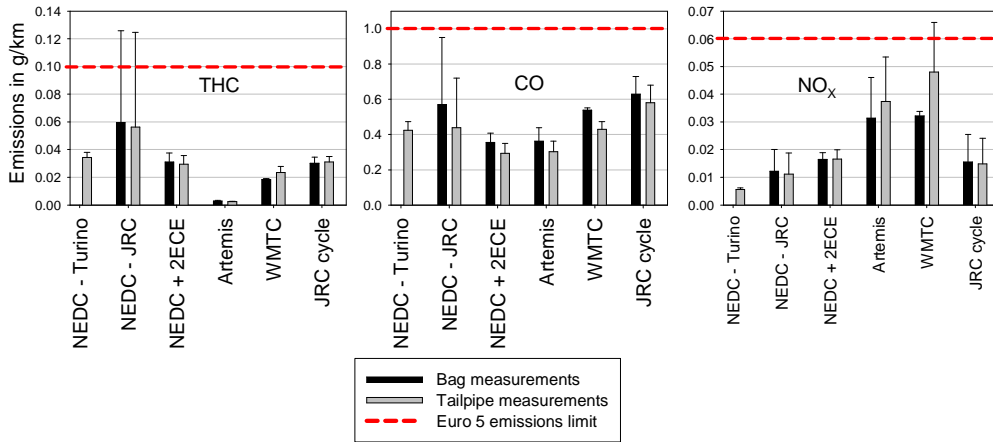


Fig. S3: Average laboratory emissions of the tested Fiat Punto baseline vehicle

By December 2012, the JRC has also tested in 2012 another base-line vehicle (Renault Twingo,) in the laboratory. The laboratory tests were carried out as for the Fiat Punto at 20-30 degrees Centigrade ambient temperature by using various driving cycles (NEDC, WLTC, Artemis). Tests over the NEDC and WLTC were conducted as cold-start tests. The test vehicle was preconditioned with three repetitions of the extra-urban part of the NEDC followed by a 10 min soak period prior to all tests over the Artemis cycle. The laboratory tests will be complemented in Spring 2013 by on-road emissions testing with PEMS.

3- The expected final results and their potential impact and use (including the socio-economic impact and the wider societal implications of the project so far),

SPV2 : The tailored fuel leads to a reduction of CO₂ emission and to an extended load limit to use LTC.

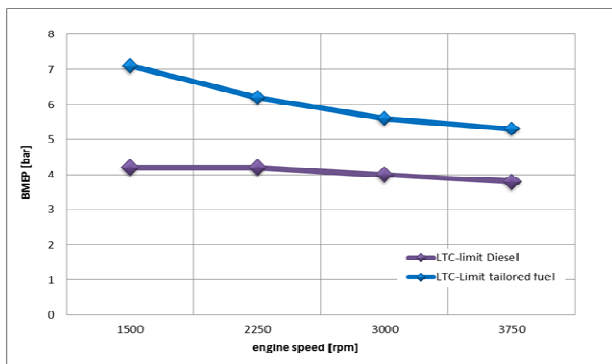


Fig: LTC load limits with Diesel and Powerfuel

LTC's fuel penalty has to be compared to the fuel penalty of the on-board reforming of the EATS. It is a challenge between those two technologies and their efficiencies, but a certain fuel penalty seems inevitable for the given boundary conditions.

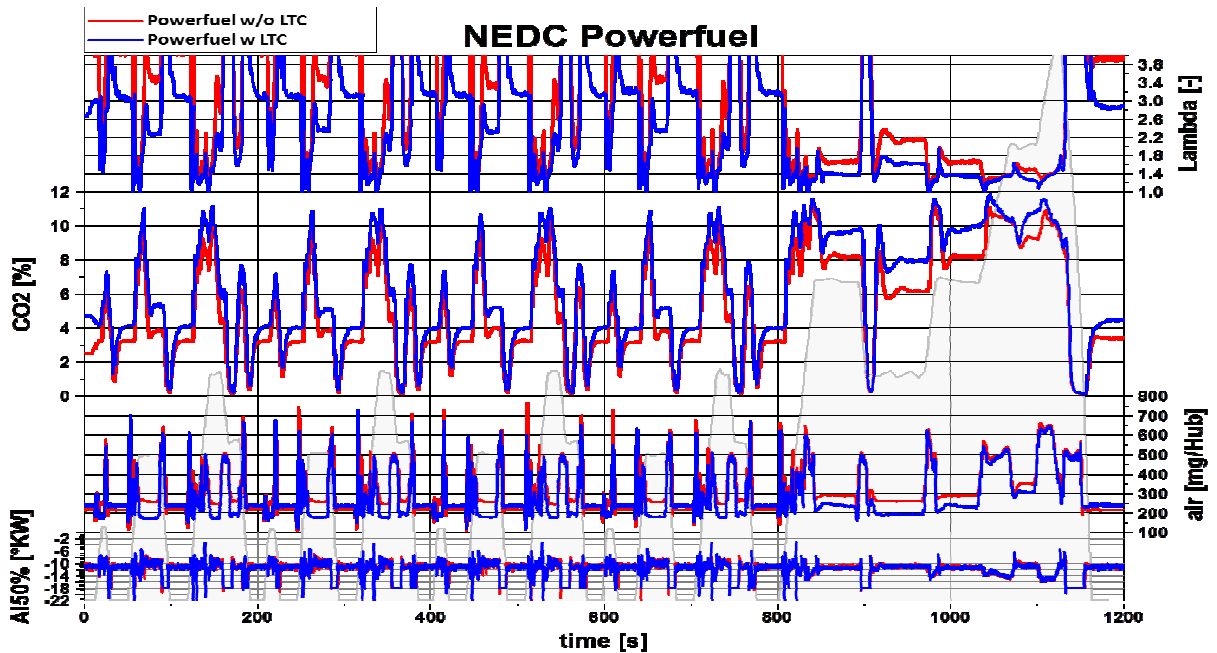


Fig: NEDC comparison with/ without LTC, Powerful

The engine design has made the main progress in this period and the results are discussed with other departments inside VW. Some of the technical aspects will be followed up also after the end of the project and will have a positive effect to series technology.

The potential of rate shaping needs to be investigated beyond the given results. If the increase of fuel efficiency can be confirmed in further tests this technology will contribute to lower CO₂ levels. New chemical approaches for LNT and SCR catalysts especially for low temperature activity will be useful for automotive industry due to the direct impact in daily vehicle use.

SPV3 : Diesel two-stroke engine for small and medium vehicles is a significant breakthrough and high promising answer to keep the best compromise between CO₂ saving and low emissions target. The results of the third year of the project gave the confirmation that the combustion system was doable. However more work is needed to get right the reliability of the supercharger and the efficiency of the turbocharger.

The work team mixing OEM, research institutes and universities demonstrate the potential of cross-culture teamwork.

SPT1 : The work on friction reducing technologies follows a systematic, fundamental and comprehensive approach. The focus is on sliding contacts which depict highest potentials for the reduction of energy losses due to friction. Even though a wide spectrum of measures is investigated it is likely that the work will be completed as planned. The expected result is a comprehensive catalogue of measures for friction reduction.

Computer models are used for projecting the effects of new technology concepts to real world driving conditions. Thus, reference vehicles are defined on the issues of the vertical subprojects and adequate modeling platforms are set up. This approach has well advanced with a model for a gasoline fuelled vehicle. A detailed model for a vehicle with CI engine is currently in development.

Past emissions tests conducted at the JRC and the emissions tests of the two baseline vehicles conducted in the context of the POWERFUL project indicate that the NEDC is insufficient to characterize the real-world fuel consumption and pollutant emissions of light-duty vehicles. Type approval based on the NEDC may thus not accurately capture the efficiency and emissions performance of light-duty vehicles. Work package T 1.3 contributes to the development of methods to comprehensively characterize the emissions behavior of vehicles. Up-to-date guidelines on how to conduct on-road tests, including the selection of test routes and the handling of analytical equipment are provided in Deliverable DT 1.10- The proposed combination of laboratory tests and on-road emissions testing with Portable Emissions Measurement Systems (PEMS) allows capturing vehicle emissions under a wide range of operating conditions. We consider the proposed method suitable to reliably evaluate the performance of baseline vehicles and the validator vehicle within the POWERFUL project. The work within WP 1.3 in POWERFUL is closely linked to the development of a complementary real-driving emissions test procedure for light-duty vehicles, which will be based on the application of PEMS. The procedure will be gradually implemented by the European Commission from 2014 onward and is anticipated to substantially reduce the on-road NOX emissions of light-duty diesel vehicles in Europe. The procedure will thereby contribute to reducing air pollution levels throughout urban environments in Europe.