1. FINAL EXECUTIVE SUMMARY

1.1 Summary of Project Objectives

The present project aims at the selection, test and assessment of a novel, fully integrated active aftertreatment system, aimed to allow compliance with future regulations, based on the use of activated chemical agents, generated on purpose, to enable and maximise the pollutant compounds abatement capabilities with particular reference to NO_x emissions from Diesel engines.

Two approaches towards these goals will be pursued:

- Catalyst based approach: the activated chemical agents will be produced by reforming diesel fuel, using an auto-thermal reforming device (hereby addressed as Catalytic Fuel Processor, CFP). Such activated chemical agents will be injected in the exhaust line, upstream a main catalyst, in charge to exploit the activated agents: such device will be called in the following Catalyst based AfterTreatment Device (CATD).

- Energy based approach: two devices are included in this system concept; the first one is an Energy based Fuel Processor (EFP), using corona discharge generated plasma to reform the fuel in active species. The second is a microwawe resonance based cold plasma generator, used as Energy based exhaust elaboration AfterTreatment Device (EATD): this device will work on the main exhaust gas stream, acting directly on gaseous (HC, CO, NO_x) and solid (PM) pollutants. The processed gases, mixed with the activated agents stream from EFP, will be finally treated by an Auxiliary Catalyst, in charge of exploiting the reactive compounds to complete pollutants abatement.

It is intended to carry the two technological routes up to the application on engine bench: after that, a collegial decision of the partnership will select the most promising technological route for the final vehicle test campaign.

1.2 The Consortium

The radically innovative integrated technology pursued in the TOP-EXPERT project is developed with a proper balance of fundamental research carried out by academic partners and research institutes under an industry-driven development perspective ensured by leading industrial partners (component and system manufacturers; end-user). These developments would not be possible in the time and budget constraints of a STREP project, if the starting points were not the expertise of the partners (see the following table) as well as their attitude to cooperate together, proven in previous major projects in the aftertreatment field.

Participant name	Participant short name	Country
Centro Ricerche Fiat	CRF	IT
University of Leoben	MUL	AU
Politecnico di Torino	POLITO	IT
University of Liverpool	UNILIV	UK
Aerosol & Particle Technology Lab. APTL CERTH-CPERI	APTL	GR
EMCON technologies	EMCON	GE
Johnson Matthey	JM	UK

1.3 The Coordinator and Contact Details

The project is co-ordinated by C.R.F. S.C.p.A. , Italy and the co-ordinator's contact details are provided below:

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The CRF combined expertise and knowledge in the aftertreatment and materials development field and business issues will facilitate the rapid development of the technology into a demonstrable prototype within the three year lifetime of the project.

1.4 Work Performed and Results Obtained to Date

The first part of the project has been focused to provide the guidelines for an effective development work. The systems specification requirements defined at the beginning of the project has been used for the whole project duration to properly compare the effectiveness of the innovative aftertreatment systems developed. In this task, a state of the art engine and vehicle have been selected and characterized as study case for the systems application (Figure 1);

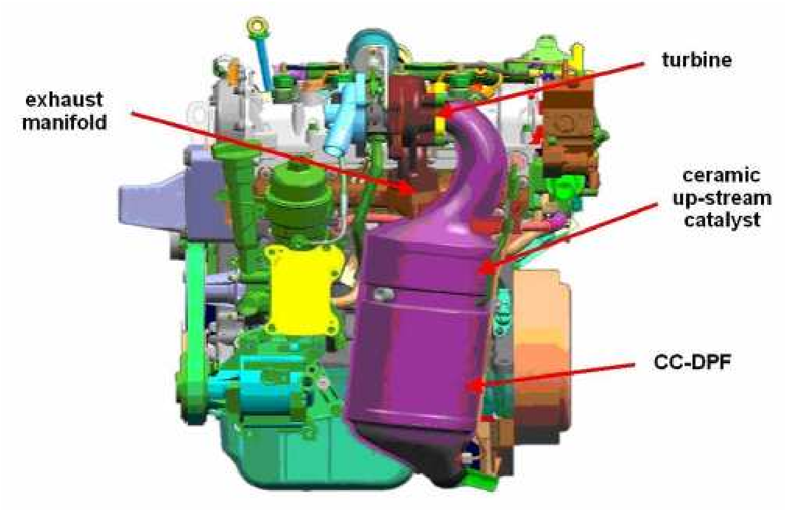

Figure 1: target system architecture (close-coupled).

The information collected from the study case characterization has been then provided in to the partnership, to start with the definition of the systems specifications for the two aftertreatment concepts: the chemical and electrical based approach.

The second task was focused on the fuel processor devices development, needed for the on board production of activated species for NOx reduction; the device to be developed in this task are:

- Catalytic fuel processor (CFP).
- Electrical fuel processor (EFP).

The CFP is essentially a fuel reformer catalyst based on noble metals supported onto inorganic metal oxides; an extensive lab-scale experimental campaign has been carried out to optimize the catalyst formulation and select the most suitable reformer volume using a wide span of real-like parameters, to assess the CFP functional capabilities, and the strategies to drive the device itself in different situations, considering in particular the start-up and the engine transients.

The CFP design and manufacturing phases have been accomplished through a series of many different concepts; the basic idea has been to place the CFP as a by-pass of the main exhaust line and integrate in a compact system all the needed components to properly control the reforming reaction:

- Flow control valve;
- Fuel vaporizer;
- Fast ignition system;
- High efficient reformer catalyst on a specific substrate;

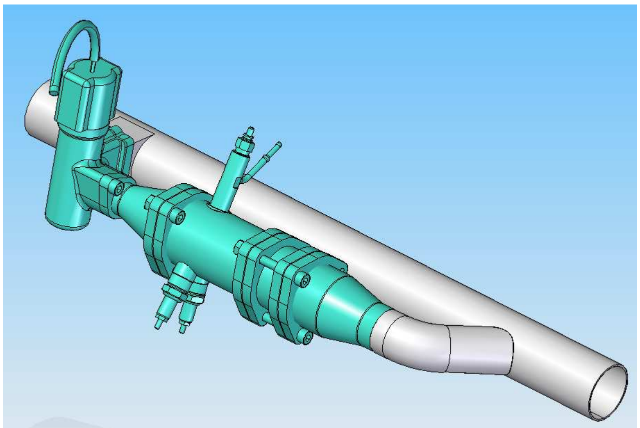

Figure 2: CFP prototype.

All these components have been assembled and optimized in order to manufacture the full scale CFP system. In the same way, it has been designed and developed the EFP to electrically reform the fuel and produce active species to reduce the NOx over a specific catalyst. This device exploits a corona discharge, generated by an appropriate power supply, to dissociate a controlled quantity of fuel into a stream of activated species.

The performance of the EFP as stand-alone system and combined with a catalytic reformer has been investigated; the test campaign covered many aspect of the plasma technology: steady state conversion efficiency, side products especially short chain hydrocarbons, time dependence (on-off cycles) with cold and warm system and influence of fuel composition on the reforming process.

Figure 3: EFP prototype.

All these aspects have been considered in order to find out the pros and cons of the plasma fuel reformer system. In general, the EFP showed a good capability to convert fuel into a hydrogen rich gas; the hydrogen production efficiency for the EFP alone seems to be not enough to produce the required quantity of hydrogen. Using an additional reformer catalyst the hydrogen production significantly increases, but the space requirements and the weight are still big issues for the EFP and the down-sizing possibilities are very limited due to the system complexity.

To achieve the requested emission reduction, the production of active species by means of the fuel elaboration devices must be exploited in a specific aftertreatment device capable to actively reduce the NOx levels. The catalyst definition has been carried out according to the specs and boundary conditions and in particular considering the actual working parameters (exhaust temperature, gas composition, conversion efficiency, etc.); the selected catalyst will be the same for both the fuel elaboration devices (CFP and EFP). A numbers of base experiments have been carried out to explore different catalyst solutions capable to exploit the active species produced by the fuel processors; among some potential catalysts formulations (i.e. NOx storage catalysts based on Pt, Ba, Rh, HC SCR catalysts based on Ag/Al_2O_3, Cu/ZSM5 or Pd/TiO_2), the most appropriate considering the operative temperature range has been an H_2-SCR catalyst capable to reduce the NOx at very low temperature and less sensitive to the NO/NO_2 ratio.

In parallel to the NOx aftertreatment device, it is needed an appropriate catalytic system capable to comply with the target emission limits and with the following functionalities:

- Oxidation of CO and HC present in the exhaust gases;
- Soot particles reduction;
- Elimination of possibly harmful activated species slip over.

Even for this task two parallel solutions have been considered: the chemical based approach and the energy based approach. For the chemical based approach, a flow-trough DOC and a catalyzed wall-flow DPF have been selected and the most appropriate catalyst type and formulation has been adapted to fit with the specific boundary conditions (temperature and pollutants levels) and it must guarantee an adequate sulphur poisoning and ageing resistance for the requested mileage. This system has been then tested on a Euro 5 representative vehicle in order to evaluate its performance over the homologation cycle in terms of CO, HC and PM (particulate matter) reduction in fresh and aged conditions.

Concerning the Energy based aftertreatment system, it has been developed, manufactured and tested a full-scale EATD (exhaust elaboration aftertreatment device) system based onto an high efficiency heat exchanger capable to increase the exhaust gas temperature (thanks to an heather and a heat recovery system) in order to better oxidize CO, HC and increase the NO_2 level to improve the CRT effect onto the DPF.

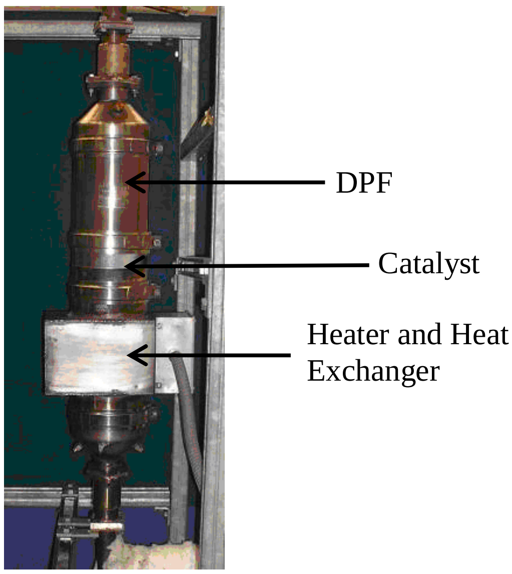

Figure 3: The EATD System

The system has been tested onto the engine test bench and showed interesting performances; heat-up performances of EATD indicated an effective heat recuperation from heat exchanger, however the thermal inertia and the pressure drop generated by the system are still high.

Once collected all the information coming from the test campaigns carried out onto the developed systems, it has been selected the most promising technology for the final implementation on vehicle; the selected technology was the CATD (Catalyst based aftertreatment device) in two different configurations: CC (Close-coupled) and UF (Under-floor) systems.

The two CATD systems have been successfully implemented on the selected demo vehicle (new Lancia Delta 2.0Mjet Euro5) with some minor modifications; moreover, a specific control box and software have been developed and installed onto the vehicle in order to properly control the CFP.

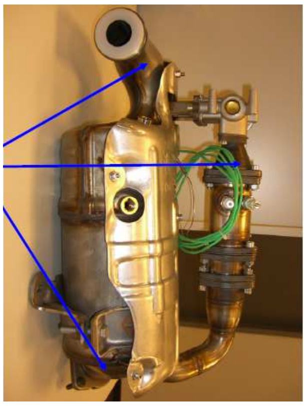

Figure 4: Close-coupled system.

Figure 5: demo vehicle.

Figure 6: Under-floor system.

The CATDs have been tested over a wide range of working conditions: on the road in real driving conditions, stationary driving conditions over the roller test bench, European homologation cycle (NEDC). It has been demonstrated that the CFP is able to work in many driving conditions and the reforming reaction can be effectively controlled and maintained; the Close-couple system performances in stationary conditions are interesting but not fully compliant with the expectations; while the Under-floor system demonstrated an higher reliability in all the testing conditions reaching instantaneous NOx conversion efficiency up to 85%. During the NEDC cycle the UF system was able to reduce the overall NOx emission below 0.08 g/km; the main drawback of such a system is the high level of the secondary emissions (mainly CO) generated during the reforming process. Another weak point of the TOP EXPERT system is the fuel penalty which is still higher than the expected target.

Finally, over the project duration has been developed a specific simulation tool. The full-scale CATD model has been successfully implemented as well as the injection and ignition models; moreover, the reaction models for ignition and reforming processes have been set-up to simulate the fuel vaporizer and the reformer catalyst and evaluate the H_2 production. The new solver has been validated by means of simulation runs on a 3D bypass-model. The mesh of the whole aftertreatment-system has been refined with a specific clean-up activity in order to avoid problems during transient simulation runs (non-orthogonal cells); the computational model has to account for 3 different filter regions – each with its own reaction scheme – as well as for the combustion of the injected fuel, which sums up to a total number of 11 species and 9 reaction rate equations. The chemical reaction rate constants for the individual filter regions were calibrated using an optimisation algorithm. Then, the simulation of the whole TOP-EXPERT geometry has been carried out and the calculated reaction products for the whole system match quite well with the experimental data from CRF. The developed model is in good agreement with experimental data obtained from the 3D TopExpert geometry achieved with the newly adapted filter solver are in good accordance with the experimental data delivered from EMCON and CRF.

1.5 Conclusions

The main objective of Top-Expert project was the development of a novel, fully integrated active aftertreatment system based on the use of activated chemical agents, used to abate the pollutant compounds with particular reference to NOx emissions from Diesel engines. During the project two approaches have been evaluated: catalyst based approach and energy based approach.

The two technological routes have been developed and tested up to the application on engine bench: after that, the catalyst based approach (CATD) has been selected as the most promising technological route for the final vehicle test campaign. The final test campaign demonstrated that the CATD systems are able to work over a wide range of engine conditions controlling and maintaining the on-board diesel fuel reforming reaction, are compatible with the engine and vehicle systems and fully transparent to the vehicle user and the systems operation. The UF system demonstrated better performances than the CC one either in stationary conditions or over the homologation cycle. The main drawback of both the systems is anyway the high level of the secondary emissions (CO, HC and soot) which should be solved in order to exploit as much as possible the system performances.

Finally, the preliminary cost benefit analysis showed that in comparison to a standard SCR system (HN_3 based), the costs for the both the systems should be competitive and a further cost saving is expected with some improvements in the manufacturing process.