PaREGEn

Particle Reduced, Efficient Gasoline Engines

EUROPEAN COMMISSION
Horizon 2020 | GV-2-2016 | Technologies for low emission light duty powertrains
GA # 723954

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Summary

In this report an overview of the contribution of the PaREGEn project developments to environmentally and socially important impacts is given. Further, the possible contribution of the PaREGEn project findings to improving the innovation capacity and the integration of new knowledge, strengthening the competitiveness of organisations within the European automotive industry is suggested.

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1 Introduction

Growing road traffic in Europe results in detrimental effects on the environment and public health, to a level that is becoming unsustainable despite increasingly stringent emission standards. In particular, carbon dioxide (CO_2) and noxious emissions may not be sufficiently reduced in real driving, whilst some engine technologies may have led to increases in the emissions of nanoparticles that are undetected by current certification procedures. The challenge is to develop a new generation of engine technologies that is truly and significantly more fuel efficient than the best 2015 equivalent under real driving conditions, in order to help mitigate the climate change effects of road transport, and to demonstrate pollutant emissions levels compliant with the Euro 6 real driving emissions (RDE) limits and particle number emissions measured to a 10nm size threshold.

Globally, the gasoline engine is and will remain the dominant passenger car prime mover, with between 60 to 80% of light duty vehicles using these engines (International Energy Agency (2012)). A comparison of these vehicles shows approximately 10% higher CO_2 emissions for those with gasoline engines compared to diesel fuelled vehicles (International Energy Agency (2019)). Given this basis and other projections (for example from the European Commission (2016)) that gasoline engines (including those within hybridised powertrains) remain dominant in light duty vehicles throughout the coming decade, then improvements in gasoline engines have an intrinsically greater potential to lower the passenger car vehicle parc CO_2 emissions in Europe than improvements in diesel engines (there are many more gasoline engines and the potential for improvement for gasoline engines is larger than for diesel engines). Furthermore, in Europe those passenger car vehicle classes with the higher annual mileages, namely D and E class vehicles, are often those with higher CO_2 emissions. The challenge for the automotive industry is, therefore, to develop highly fuel efficient (gasoline) engines and to improve exhaust gas aftertreatment systems, in order to meet EU legislation on emission standards and fuel economy under real driving conditions. At the same time, the European automotive industry has to improve competitiveness in order to successfully maintain substantial market volumes of high-quality cars with attractive designs, driving characteristics and fuel economy.

The PaREGEn project (supported by EC Grant No. 723954) has addressed the topic, “Technologies for low emission light duty powertrains”, GV-02-2016 of Horizon 2020 programme. The innovations therein are to be realized during the critical transition period (2020-2030) for transport, when the mitigation of climate change must be enacted. The project has been conducted realized by a seventeen-partner consortium representing all parts of the automotive industry.

In PaREGEn, further development of gasoline engines used in mid to premium sized passenger cars has been made. With the electrification of powertrains in smaller vehicles, suitable for zero emissions in urban environments, addressing mid to premium sized cars is especially important: the requirement for ultra-low emission, efficient and economic engines (whether hybridised or not) for cars regularly used for inter-urban and regional transport becomes more urgent, especially in light of the recent falling market share of diesel engine vehicles, as well as more effective to address the societal challenges of air quality, energy efficiency (decarbonization) and cost-effective mobility. Furthermore, it should be remembered that, should drop-in low carbon or net-zero carbon fuels become available in the coming decade, then it is the type of passenger car vehicles being developed in PaREGEn, that could contribute most to the additional decarbonization realisable.

As illustrated in Figure 1, through the use of state of the art development techniques, such as optical single cylinder engines, a range of modelling and simulation tools from 0D to 3D (for understanding of in-cylinder particle formation process) and the application of novel engine componentry (next generation fuel or water injection and ignition equipment, boosting systems and exhaust gas aftertreatment technology), the optimal trade-offs between ultra-low emissions and efficiency has being identified. Of special attention throughout this process is the contribution of such technologies to the reduction and control of particle numbers, including those particles between 10 and 23 nm in size. One of the most valuable contributions from this project is that the new modelling and simulation tools benefit engine design, development and control in general, long after the project has been completed.

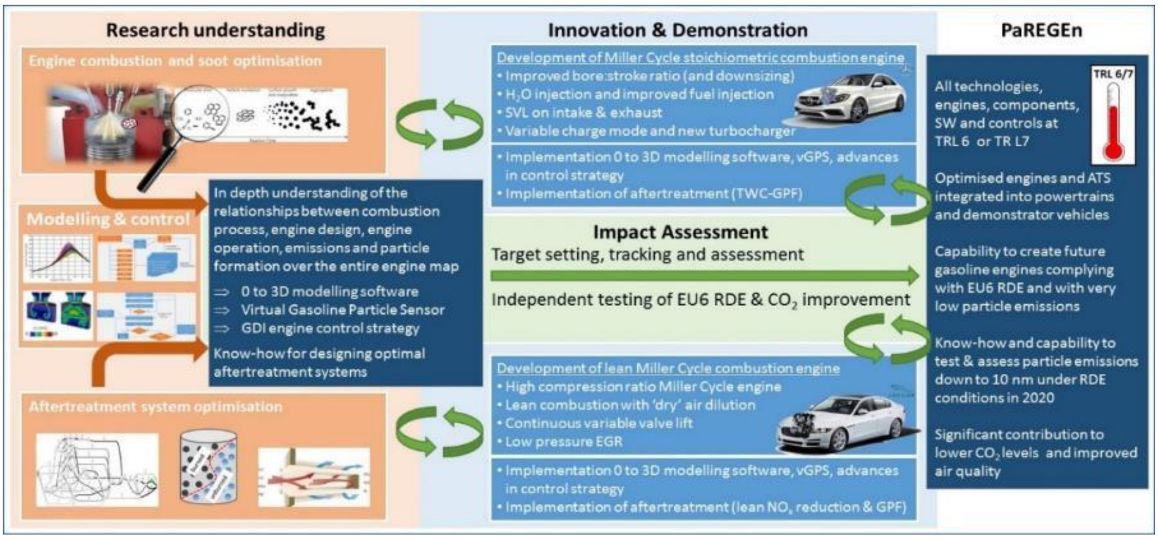

Figure 1 The project approach

This learning has been used for the generation of two demonstration vehicles. The approaches to achieving the efficiency targets have been different in each, using different combustion system, injection (fuel and water), ignition and dilutent technologies, different engine air handling systems and different aftertreatment packages. As such, progress within the project has given insight into the best way forward to meet the requirements for these gasoline engines in all vehicle classes in the coming decade. Hence the potential impact of the PaREGEn project, should its learning be exploited, is substantial, as illustrated in Figure 2.

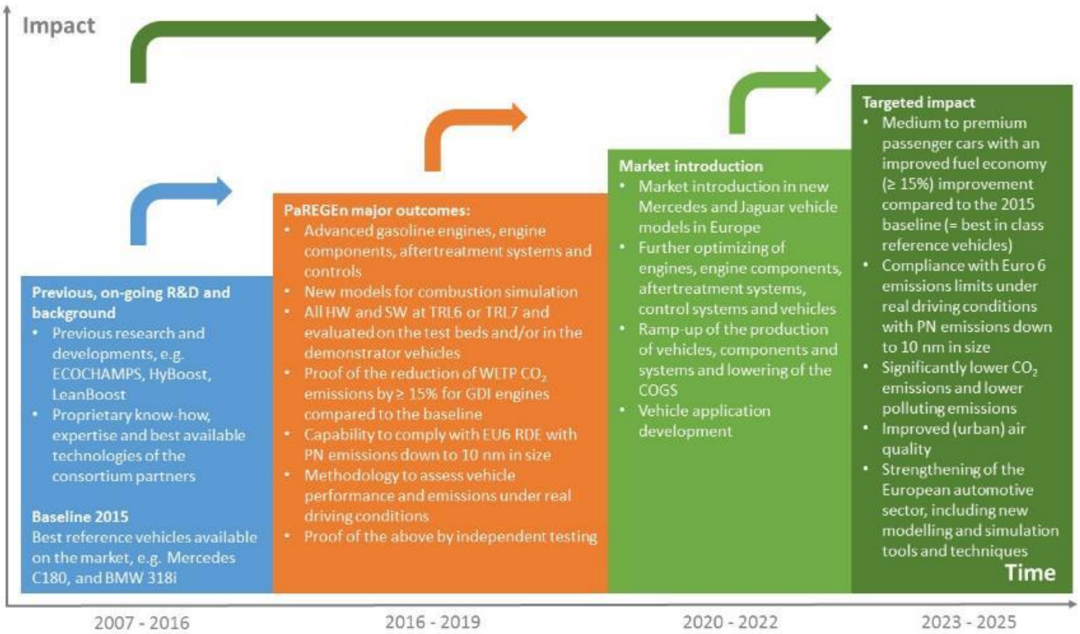

Figure 2 The project exploitation and impact overview

2 The Contribution of the PaREGEn Project to Environmentally and Socially Important Impacts

2.1 Background

During the proposal stage for the PaREGEn project the key projected outputs of the project (and how they were to be achieved) were listed in relation to the specific impacts called for in the Horizon 2020 Green Vehicles Work Programme (GV-02-2016). The specific impacts were:

- A contribution to climate action and sustainable development by
  - delivering significant reductions in CO_2 emissions (thus addressing the global warming challenge)
  - and by improving noxious emissions (thus allowing better air quality in European cities).

These impacts were proposed to be achieved by meeting the following targets:

- For a new generation of non-hybrid engines, having demonstration vehicles to prove via independent testing
  - a reduction of WLTP CO_2 emissions of 15% (based on the gasoline engines target)
  - and real driving emissions compliance to the upcoming Euro 6 RDE limits (subsequently denoted Euro 6c and Euro 6d) with particle number emissions measured with a 10nm size threshold.
- And by contributing to the establishment of a future EU Super Low Emission Vehicles standard.

How the outputs of the project related to these targets was also given in the proposal. In summary, the relevant project outputs were:

- An in-depth understanding of the relationships between engine design, engine operation, combustion processes, emissions and particle formation over the engine operating map
- The capability to effectively develop (future) efficient low emission engines having ≥15% CO_2 emissions improvement compared to 2015 best in class equivalent size and torque engines;
- The capability to improve engine and vehicle control systems significantly by the ability to optimize the instantaneous trade-off between efficiency and emissions using virtual sensors
- The know-how for designing, developing and controlling optimal future gasoline engines and powertrains complying with EU6 RDE and capable of effectively controlling sub 23nm particle emissions
- Optimal aftertreatment systems (Technology Readiness Level (TRL) 7) for highly efficient, low emission, stoichiometric and lean burn gasoline engines
- Optimised, highly efficient, low emission stoichiometric and lean burn gasoline engines and aftertreatment systems integrated into (test bench) powertrains (TRL 6)
- Proof of the ≥15% CO_2 reduction potential, with emissions compliance and PN control, by simulation, validation on the test bench with HIL systems or in demonstrator vehicles
- Optimised highly efficient low emission stoichiometric and lean-burn gasoline demonstration vehicles (TRL 7)
- Independent proof that highly efficient future gasoline vehicles can be compatible with EU6 RDE and capable of effectively reducing sub 23nm particle emissions
- Experience of testing and assessing particle emissions down to 10 nm in size under RDE conditions, providing a contribution to future possible regulation on particle emissions
- Furthermore, "unregulated species" emissions (e.g. ammonia, N_2O or NO_2) from these new engines will be considered.

These outputs have been achieved during the PaREGEn project. In the following sections, example summary results and evaluation related to the specific impacts, based upon these outputs, will be given.

2.2 Delivering Significant Reductions of CO_2 Emissions

During the PaREGEn project, two new engines, including a variety of new component hardware, together with their exhaust aftertreatment and control technologies were developed on the engine test bed and then demonstrated in two vehicles (see Figures 3 to 5 below and deliverable reports designated D3.x and D4.x from the PaREGEn project website, www.paregen.eu). The independent tracking and evaluation of these developments and demonstrations has shown the potential of the technologies to achieve the project's CO_2 emissions reductions targets (see Figures 6 and 7 and deliverable reports D5.1, D5.2 and D5.3).

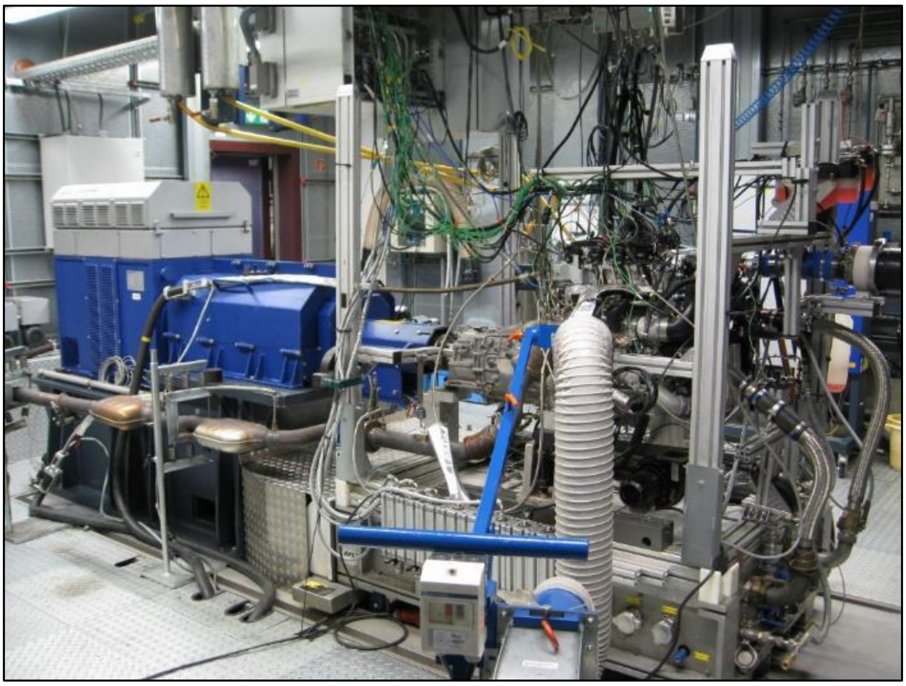

Figure 3 The Daimler PaREGEn project engine on test

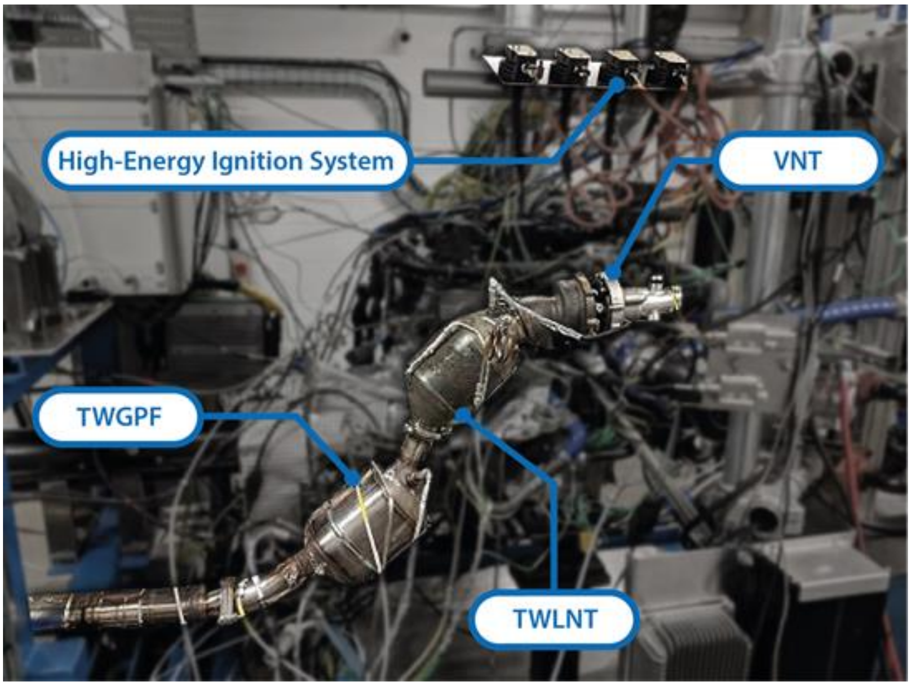

Figure 4 The Jaguar Land Rover PaREGEn project engine on test

Figure 5 The Daimler (left) and Jaguar Land Rover (right) demonstrator vehicles

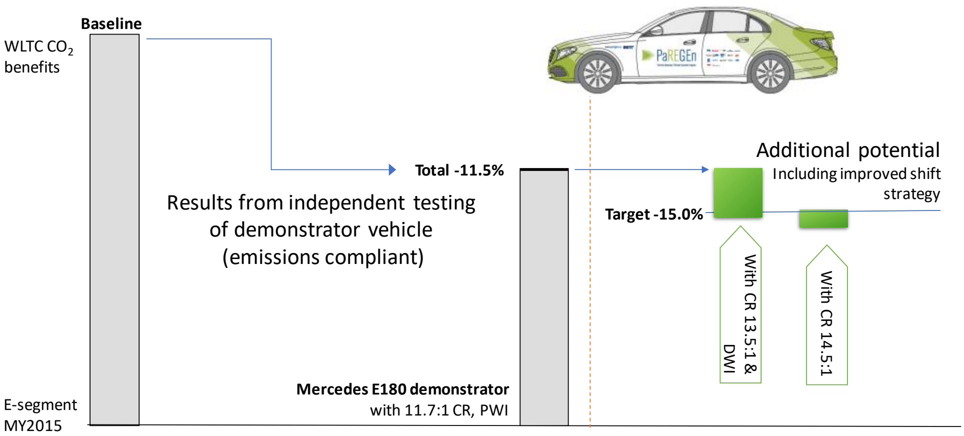

Figure 6 Daimler PaREGEn vehicle engine and vehicle CO_2 reductions waterfall diagram

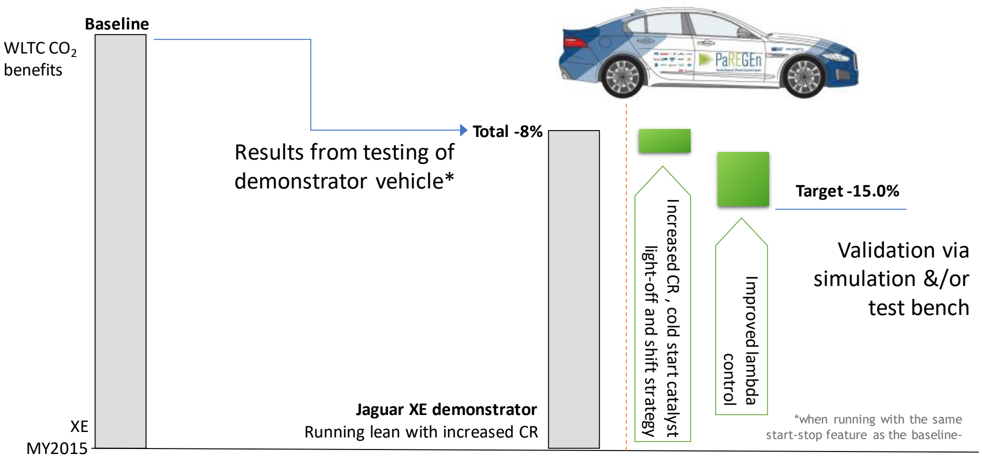

Figure 7 Jaguar Land Rover PaREGEn vehicle engine and vehicle CO_2 reductions waterfall diagram

Consequently, it has been possible to estimate the likely impact of these engine technologies on the European vehicle parc emissions over the coming years, based on a variety of assumptions related to the market introduction and uptake of these innovations (see deliverable D5.4). Within the estimations, it is assumed that the European passenger car vehicle parc will produce about 840MtCO_2 in 2020, and that this will reduce over time through technical and market developments (not immediately related to the activities of the PaREGEn project), to about 755MtCO_2 in 2030 and 525MtCO_2 in 2050.

The two demonstrator vehicles chosen within the PaREGEn project (the Mercedes E-Class and Jaguar XE) represent only a small part of the European vehicle fleet today (about 4%). However, it can be envisaged that the engine technology demonstrated within PaREGEn could be applied over time to other vehicles manufactured by the two OEMs (Original Equipment Manufacturers), which would then represent a market share, of up to 22%, depending on the size of the car (from small to large) or around 16% in total for the passenger car market. Further, it is to be expected that other OEMs, perhaps with a delay, would also adopt the technology for their non-hybrid engines, given the proven fuel economy benefits. Finally, since the technology is inherently also applicable to engines used in hybridized powertrains, a fourth scenario can be envisaged where all gasoline passenger car engines adopt the PaREGEn technologies during the time period up to and beyond 2030. Hence, given knowledge about the turnover rates within the vehicle parc, the estimates of the CO_2 impact of the PaREGEn project on the vehicle fleet emission can be made.

Should just the two OEMs involved in the project adopt the PaREGEn technologies for all of their gasoline engined non-hybrid vehicles, it is estimated that about 0.4MtCO_2 emissions would be reduced from the European vehicle parc in the year 2030. Alternatively, should all manufacturers adopt the technology benefits for all their gasoline engined vehicles, then a peak reduction of about 10MtCO_2 is expected in the year 2040. This would represent about a 2% reduction in the complete European passenger car vehicle parc CO_2 emissions in that year.

Looking ahead, the vehicle parc estimates suggest a reducing proportion of internally combustion engined passenger cars on the road after 2040. However, should drop-in, net zero carbon fuels become available, then the efficiency gains demonstrated within the PaREGEn project could be retained within the vehicle parc, leading to net negative CO_2 emissions from the PaREGEn technology relative to 2020, a further significant contribution of the project towards long-term GHG emission goals.

2.3 Improving Noxious Emissions

In a similar manner to the considerations for CO_2, so the impact of the PaREGEn project in relation to other emissions, especially particle (number) emissions, can be made.

In the first instance, during independent evaluation the two demonstrated vehicles showed that the achievement of the improved vehicle fuel economy (relative to the 2015 baseline) is possible whilst maintaining the most stringent current noxious emissions regulations for passenger cars in Europe (i.e. Euro 6(d), which also represents and reduction, in real driving emission terms, compared to the 2015 baseline). This is illustrated, by way of example, in Figure 8 (see deliverable D5.3).

More specifically, control of the particle number emissions, measured down to 10nm in size, was confirmed with the two demonstrator vehicles. This is represented in Figure 9, illustrating that a very significant reduction in particle numbers was possible, especially as a consequence of the gasoline particle filter developments, whilst still showing the potential to meet the fuel economy and other emissions targets.

Targets

CO_2	Standard emissions	PN
* Reduction of 15% based on the WLTC results of the baseline vehicle * Additionally: reduction of 15% based on the 2015 BIC (*) New Reg 1.43 (2020)	Compliance with Euro 6 (d) limits **RDE** Final Conformity Factor of 1.5 in case of NOx (*)	Reduction of sub-23 nm to at least 10 nm **RDE** Final Conformity Factor of 1.5 in case of PN

Vehicle-test	THC (mg/km)	NOx (mg/km)	CO (mg/km)	CO_2 (g/km)	PM (mg/km)	PN ≥ 10nm (pk/km)
Mercedes Demonstrator WLTC Low	100	60	1000	Basel Vehicle → -15 %	4.5	6.0E +11
Mercedes Demonstrator WLTC High	100	60	1000	Base Vehicle → -15 %	4.5	6.0E +11
Mercedes Demonstrator RDE	---	90	---	---	---	9.0E +11

Targets on vehicle dyno. and test bench fulfilled

Figure 8 Daimler PaREGEn demonstrator vehicle emissions test results

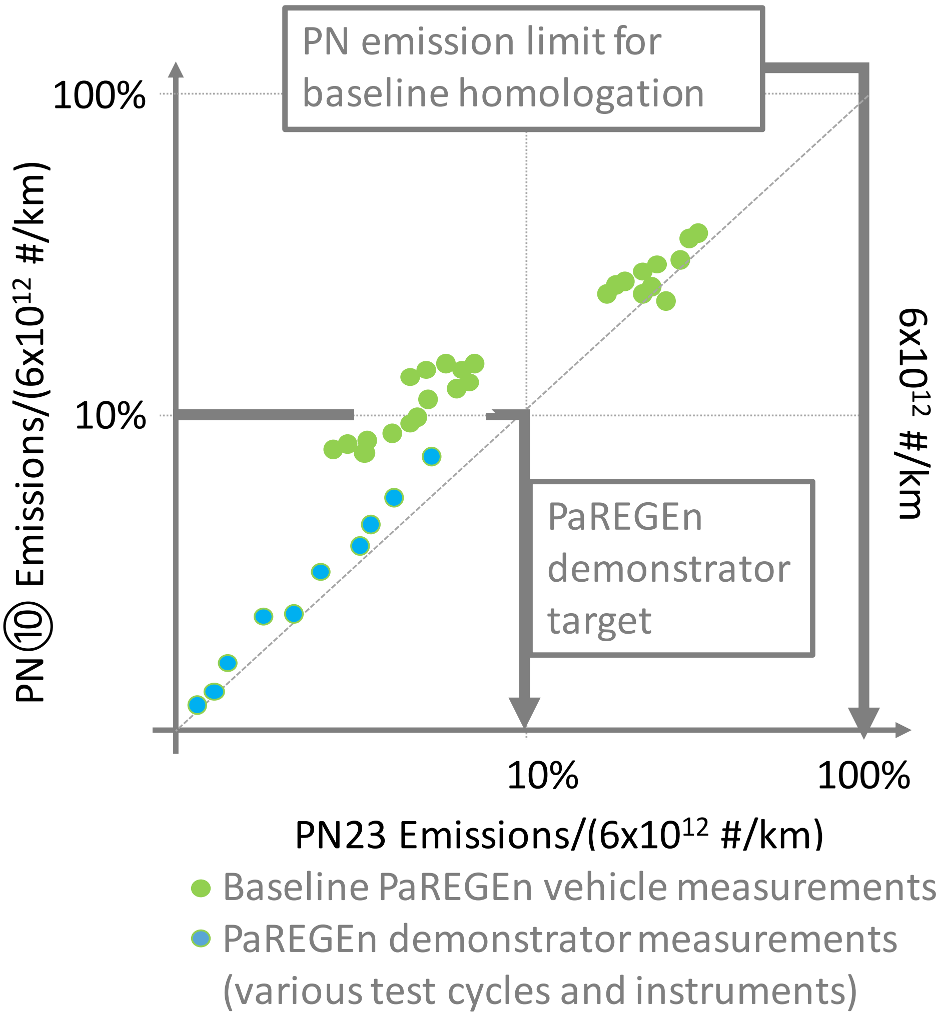

Figure 9 PaREGEn vehicle PN emissions measurement results

Further, if the particle number emissions reductions compared to the 2015 baseline (at the current 23nm size limit) are then applied to the future European vehicle parc, as has been done for CO_2 above (see deliverable report D5.4), then between a 1 to 2% reduction in particle number emissions for the parc can be envisaged by 2030. This reduction then raises rapidly, leading to a reduction of between 30% (for all non-hybrid powertrain vehicles) to 70% in the year 2050 (should the technology be applied to all gasoline engined vehicles).

At these levels of particle emissions reduction from the vehicle powertrain, then other source of such emissions, for example from the vehicle brakes or tyres, become significant for estimating the overall emissions from the European vehicle parc.

In addition, as noted above, “unregulated” emissions for the two demonstrator vehicles were measured in real time over selected test cycles. This allowed correlation factors for these emissions between different testing cycles to be estimated and used as input into the discussion for possible future EU Super Low Emission Vehicles regulation.

3 The Contribution of the PaREGEn Project to Improving the Innovation Capacity and the Integration of New Knowledge, Strengthening the Competitiveness of Companies

3.1 Background

During the proposal stage for the PaREGEn project it was recognised and recorded that the driving forces in Europe for developing technologies for fuel efficient and low emission powertrains are:

- The EU regulatory framework, i.e. the legislation stimulates car manufacturers to improve the fuel economy and the EU emission standards limiting noxious or polluting emissions: CO, THC, NOx, PM and PN
- The competitive advantage to be able to offer customers fuel efficient and low emission vehicles
- The Corporate Social Responsibility aspect, i.e. to respond adequately to societal concerns about detrimental effects of road traffic on public health due to deteriorating air quality and on the environment due to the contribution to climate change.

In responding to these forces, the stakeholders within the industry naturally need to continuously innovate and integrate new knowledge into their products and processes. In the following sections, examples of how the PaREGEn project and its partners produced results which contribute to these aspects will be given in summary.

3.2 Contributions to Improving the Innovation Capacity and the Integration of New Knowledge

The PaREGEn project has contributed to the innovation capacity by taking a lead in advancing gasoline engine technology and aftertreatment systems, resulting in the ability to offer customers, in future, fuel efficient and low emission vehicles in line with legislation on fuel economy and emissions. The PaREGEn consortium is a vertical consortium in which all key stakeholders are represented, ranging from research experts, Tier 1 and Tier 2 suppliers (developers and/or manufacturers of key components, systems or software tools) to OEMs, each with a broad range of vehicle classes in their portfolio. As such, through practice and realisation within the project, the results of research, occasionally invention, have been able to be transferred into new processes and products, that is innovation.

For the universities and research institutes (UDE, RWTH-VKA, ETH, UOB and JRC): the delivery of specific innovative components and analysis tools or tests across the applications has increased awareness of industry needs, particularly in relation to engine components, aftertreatment systems and controls. This has led to new tools, techniques and improved education for students looking at a career in the automotive industry. Furthermore, the dissemination of new knowledge to the public as achieved through multiple peer reviewed and open access publications, is a fundamental aspect of the universities' mission. For example, the papers release on the open access platform Zenodo at the time of the project completion were the following (more are expected in 2020):

- Edwards S., Verhagen E. (2018). Particle Reduced, Efficient Gasoline Engines: A First-Year Report on the PaREGEn Project DOI; 10.5281/zenodo.1483250
- Geiler J. N., Grzeszik R., Quaing S., Manz A., Kaiser S. A., (2017) Development of laser-induced fluorescence to quantify in-cylinder fuel wall films DOI; 10.1177/1468087417733865
- Edwards S., (2018) PaREGEn; Particle Reduced, Efficient Gasoline Engines - Workshop Presentation DOI; 10.5281/zenodo.3459091
- Edwards S., (2018) PaREGEn; Particle Reduced, Efficient Gasoline Engines - ERTRAC ECGVI EC #H2020RTR18 DOI; 10.5281/zenodo.3459269
- Jüngst N., (2018) Multi-diagnostic imaging of evaporating fuel wall-films in combustion as a source of PAH and soot DOI; 10.5281/zenodo.3546086

- Jüngst N., Kaiser S., (2019) Visualization of soot formation from evaporating fuel films by laser-induced fluorescence and incandescence DOI; 10.5281/zenodo.3546100
- Jüngst N., Kaiser S., (2019) Experimental and numerical analysis of evaporating fuel films DOI; 10.5281/zenodo.3546124
- Jüngst N., Kaiser S., (2018) Imaging of Fuel-Film Evaporation and Combustion in a Direct-Injection Model Experiment DOI; 10.4271/2019-01-0293

By way of further example, as part of the work to try and understand the cause and effect relationships of particle formation (see Figure 10 and deliverables denoted D1.x), the use of four colour Laser Induced Fluorescence (LIF) together with Laser Induced Incandescence (LII) undertaken at UDE, together with partners, (see Figures 11 and 12) is the first known application of these techniques to a gasoline engine. It has enabled the temporal and spatial variation of soot (hence particle emissions) precursors in a combustion system to be visualized, helping to generate ideas and guidelines as to how such precursors can be reduced or controlled in future engine designs. Additionally, the data derived in these investigations is now being used to validate software tools beyond the remit of the consortium partners, multiplying the impact of the knowledge gained through new possible offerings from the engineering service providers and software suppliers.

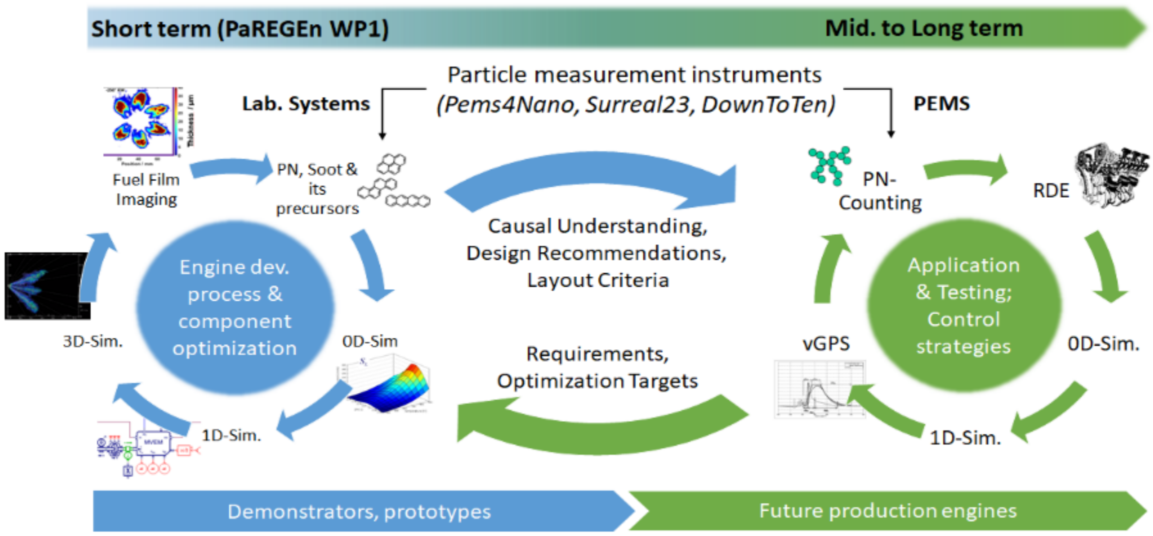

Figure 10 An overview of the particle formation cause and effect relationships investigations

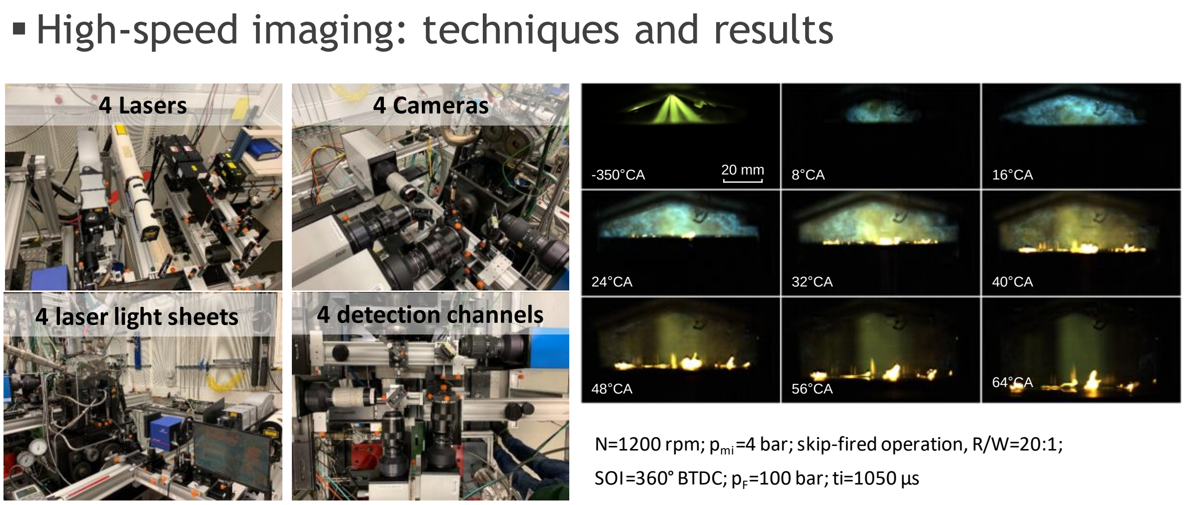

Figure 11 The optical engine four colour laser-based combustion imaging arrangement and example results

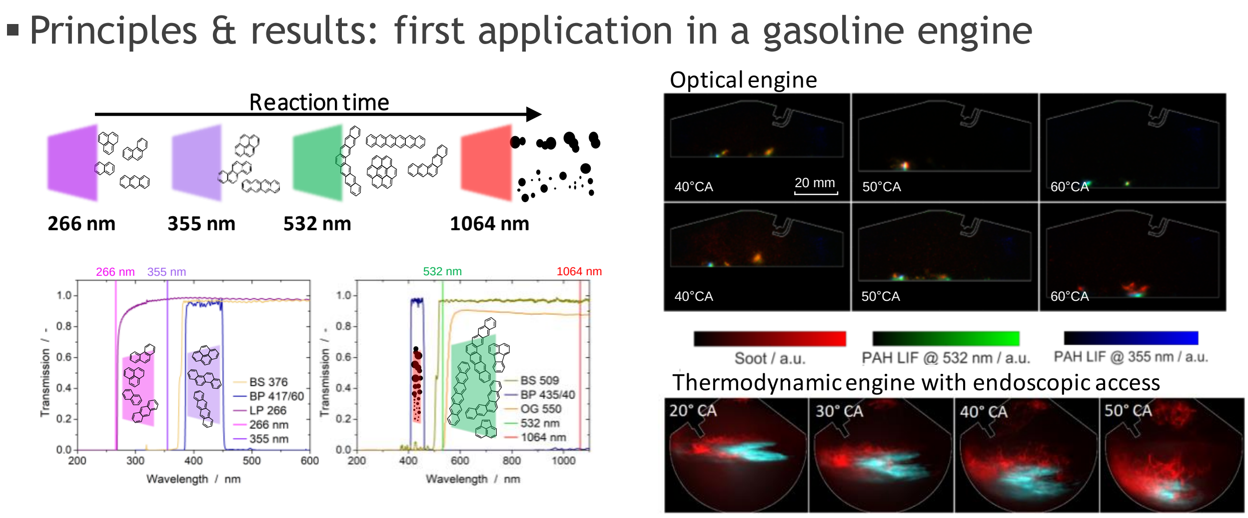

Figure 12 The four colour visualisation of particle precursors during the combustion process

For the engineering service providers (Ricardo, FEV and IDIADA), specifically: the delivery and reporting of analyses and tests across the wide range components, systems and vehicles has enhanced their capability to provide rapid, reliable and comprehensive support to the industry. This has realized improved competitiveness through proprietary know-how, patents, improved services offerings through new tools (including software), techniques and increased awareness of the client's (OEMs and suppliers) needs, leading to further consulting services and R&D service contracts. Again, by way of example, the detailed investigation by FEV, together with partners, into the potential of water injection, either port or direct in-cylinder, in order to improve the performance, economy and emissions trade-off of gasoline engines (see Figure 13 and deliverable reports D3.2 and D3.7) has led to a patent application covering the use of such systems in future engines.

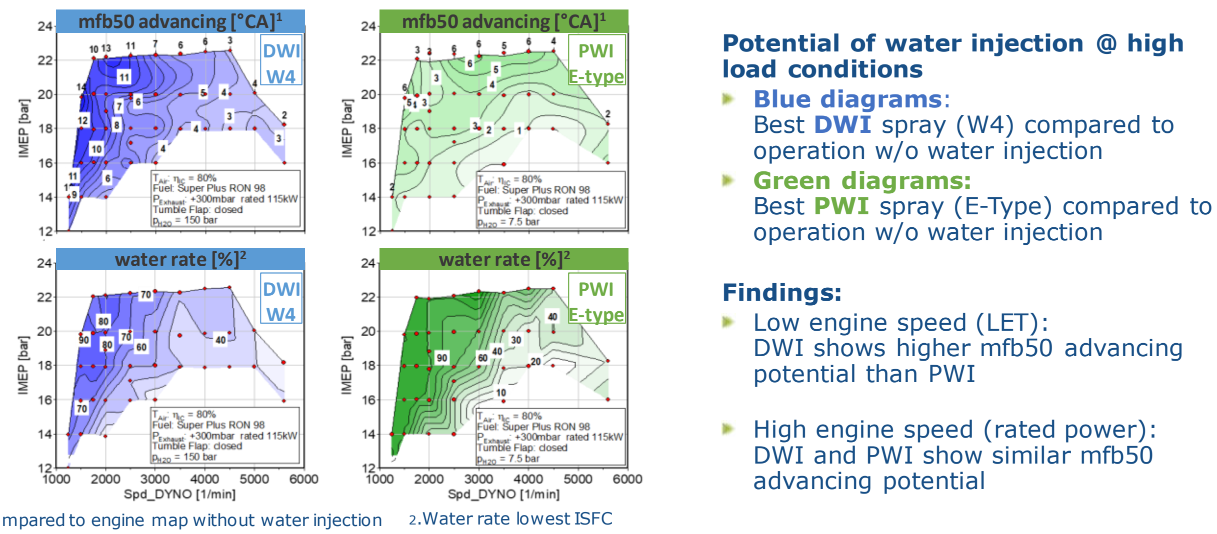

Figure 13 Results of detailed investigation into water injection by FEV and partners

For the suppliers (Bosch, Johnson Matthey, Garret, UFI, LOGE and Siemens): the delivery of new engine components, aftertreatment systems and control systems has enhanced the knowledge to design, analyse, build and test components viable for future market requirements. This enhancement has realized improved competitiveness through specific proprietary know-how, at least two patents, increasing cost effectiveness through increased production volumes of standardized components, an awareness of the needs to be able to economically manufacture these products and increased component sales through more attractive product offerings. An example of the results is the new Spark Ignited engine Mean Value Engine Model (MVEM) with new emissions (gaseous and soot) capabilities as well as new coupling capabilities with research models for crank angle resolved engine models (see Figure 14 and 15 and deliverable report D1.11). The new combustion and emissions modelling software techniques, from LOGE, are already being offered commercially. Further, the new MVEM models will be industrialized and commercialized as part of the automotive commercial Siemens Amesim offer. Other examples are the new gasoline particle filters from Johnson Matthey (see Figure 16 and deliverable reports D2.x) and the recovered water filtration and treatment ideas from UFI (see Figure 17 and deliverable report D3.6): in both cases some of the technology is now protected by patent applications.

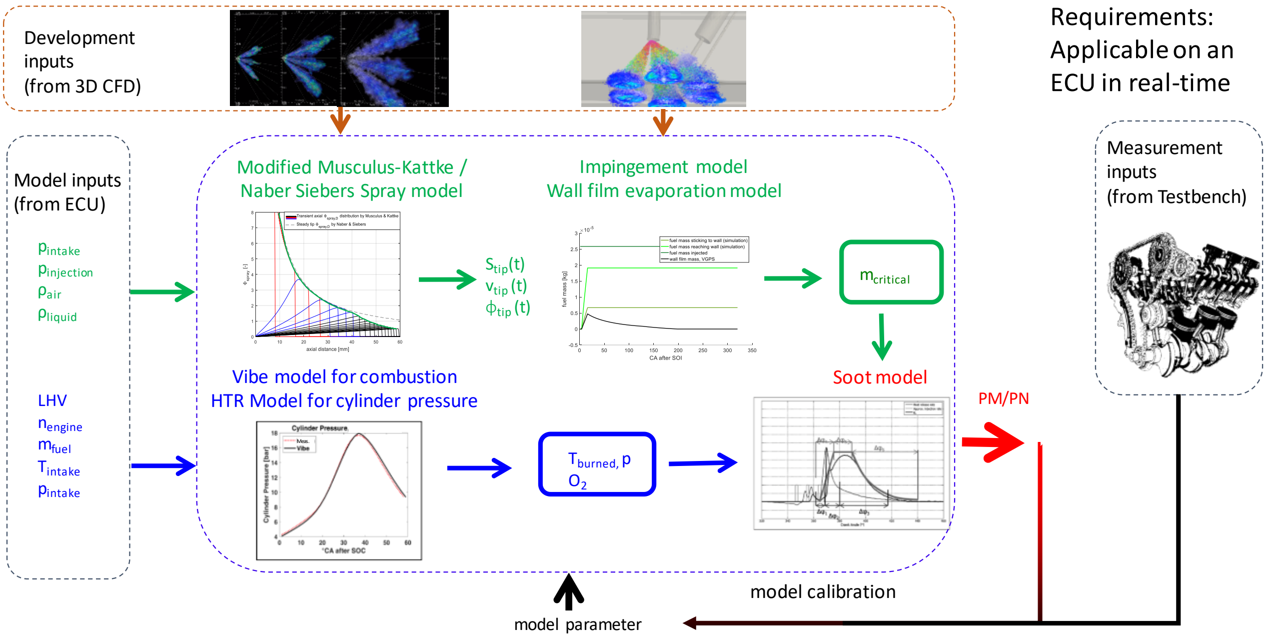

Figure 14 An overview of the arrangement of the virtual gasoline particle sensor (vGPS) development

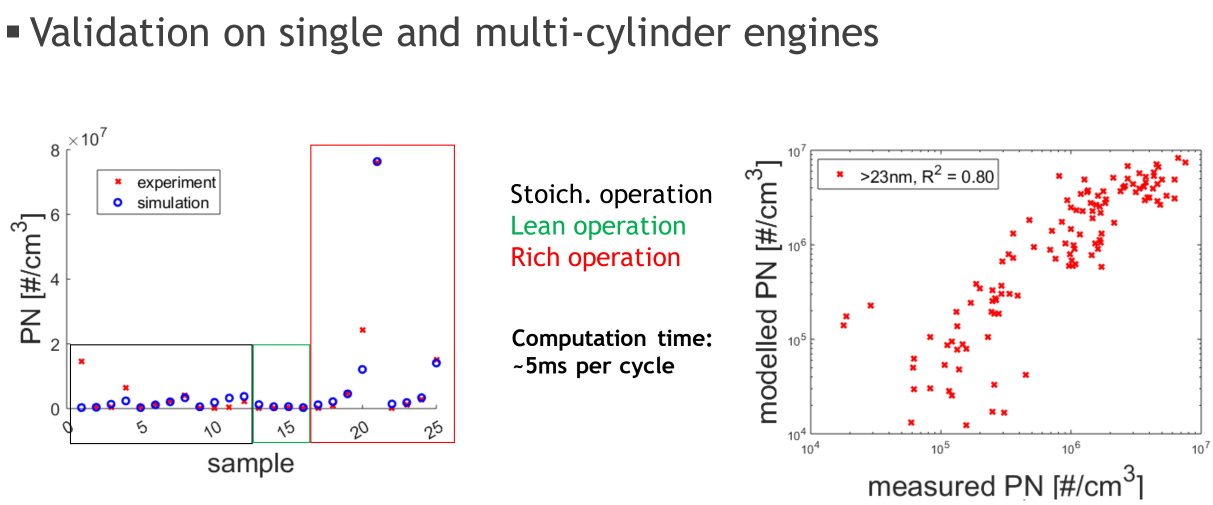

Figure 15 Validation of the vGPS during engine testing within the PaREGEn project

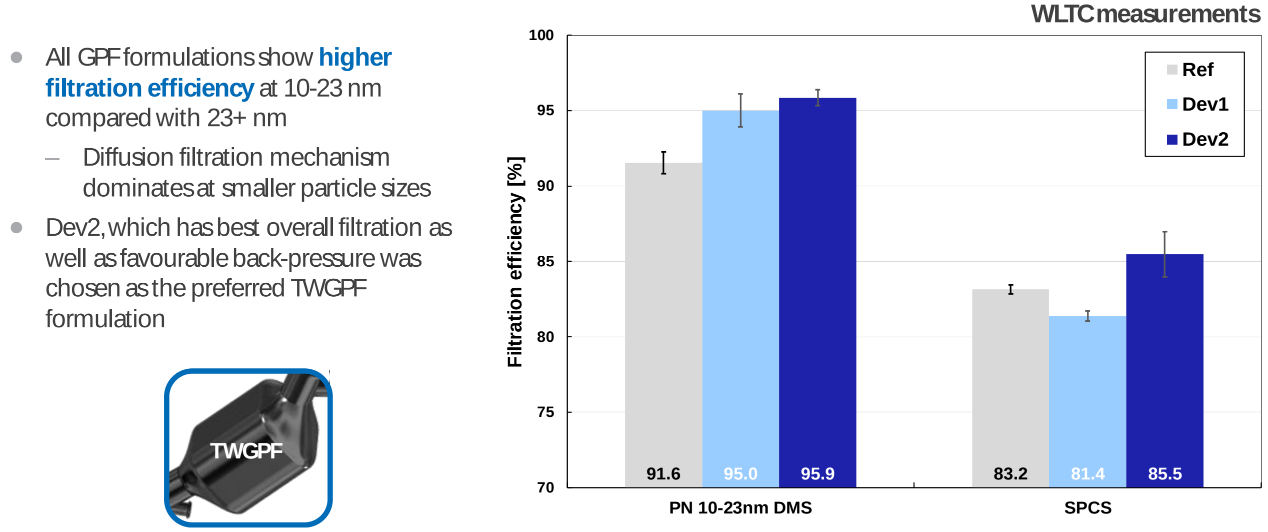

Figure 16 JM Three-way gasoline particle filter filtration efficiency for ultra-fine particles

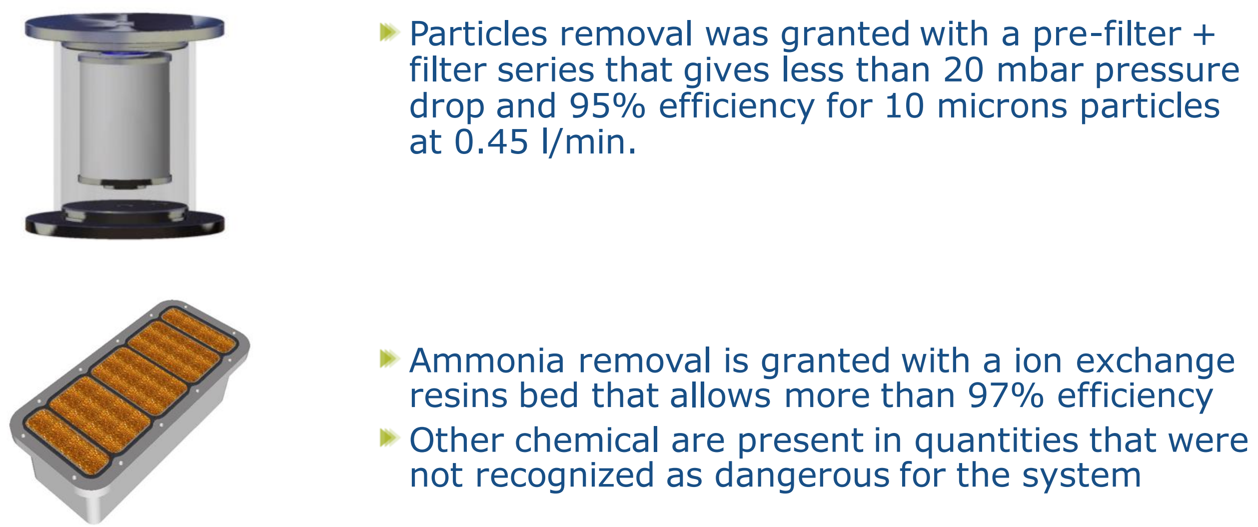

Figure 17 UFI water recovery filtration and treatment devices

For the OEMs (Daimler and Jaguar Land Rover): the delivery of the two demonstrators has enhanced their knowledge to design, analyse, build, test and certify vehicles viable for future market requirements. This enhancement has been realized through improved competitiveness through specific proprietary know-how, an awareness of the needs to economically manufacture these products and may increase vehicle sales in future through more attractive sector offerings.

3.3 Strengthening the Competitiveness

The project work on the gasoline engine technology, modelling and control, aftertreatment systems and system optimization has strengthened the competitiveness of different parts of the industry:

- European vehicle manufacturers
- European automotive technology and component suppliers (Tier 1 & 2)
- European universities and research institutes, and
- European companies and institutes specialized in gasoline engine, powertrain and vehicle development, or the software, simulation, control and testing thereof.

The examples given above plus more from the PaREGEn project, show how proprietary know-how, trade secrets and intellectual property has been variously generated in organisations within each part of industry (reference can be made to the full set of presentations and posters shown at the project Final Event, as available via www.paregen.eu). Since these organisations are European based, European industry competitiveness has been strengthened, to a small part, through the running of the PaREGEn project.

The achievement of the project targets is facilitating future investments in the production of new engines, engine components, control, software and aftertreatment systems, since financial and operational risks have been lowered to some extent, such that the return on investment and payback times may be more favourable than and the outset of the project.

4 Conclusions

The PaREGEn project has demonstrated technologies, both product and process related, that have the potential for environmentally and socially important impacts. Further, the possible contribution of the PaREGEn project to improving the innovation capacity and the integration of new knowledge, strengthening the competitiveness of companies within Europe has been suggested.

5 Appendix A – Acknowledgement

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

Project partners:

#	Partner	Partner Full Name
1	RIC	RICARDO UK LIMITED
2	DAI	DAIMLER AG
3	JLR	JAGUAR LAND ROVER LIMITED
4	BOSCH	ROBERT BOSCH GMBH
5	FEV	FEV EUROPE GMBH
6	JM	JOHNSON MATTHEY PLC
7	HON	HONEYWELL, SPOL. S.R.O.
8	JRC	JOINT RESEARCH CENTRE – EUROPEAN COMMISSION
9	UNR	UNIRESEARCH BV
10	IDIADA	IDIADA AUTOMOTIVE TECHNOLOGY SA
11	SIEMENS	SIEMENS INDUSTRY SOFTWARE SAS
12	LOGE	LUND COMBUSTION ENGINEERING LOGE AB
13	ETH	EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZUERICH
14	UDE	UNIVERSITAET DUISBURG-ESSEN
15	RWTH	RWTH AACHEN UNIVERSITY
16	UFI	UFI FILTERS SPA
17	UOB	UNIVERSITY OF BRIGHTON
18	GARR	GARRET MOTION CZECH REPUBLIC S.R.O.

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6 Appendix B – Abbreviations / Nomenclature

Table B-1 List of Abbreviations / Nomenclature.

Symbol / Short name	
0D or 3D	Zero Dimensional or Three Dimensional
ACEA	European Automobile Manufacturers' Association
BEV	Battery Electric Vehicle
BTDC	Before Top Dead Centre
CO	Carbon Monoxide
CO_2	Carbon dioxide
COGS	Costs of Goods and Services
CR	Compression Ratio
DWI	Direct Water Injection
EEA	European Environment Agency
EC	European Commission
EF	Emissions Factor
EU	European Union
GDI	Gasoline Direct Injection
GPF	Gasoline Particle Filter
HEV	Full Hybrid Electric Vehicle
HW	Hardware
IMEP	Indication Mean Effective Pressure
ISFC	Indicated Specific Fuel Consumption
JLR	Jaguar Land Rover
LET	Low Engine Torque
LII	Laser Induced Incandescence
LIF	Laser Induced Fluorescence
mfb	Mass Fraction Burned
MHEV	Mile Hybrid Electric Vehicle
MVEM	Mean Value Engine Model
MY	Model Year
NEDC	New European Driving Cycle
N_2O	Dinitrogen Oxide
NO_2	Nitrogen Dioxide
NOx	Oxides of Nitrogen
OEM	Original Equipment Manufacturer
PAH	Polyaromatic Hydrocarbon
PC	Passenger Cars
p_F	Fuel Pressure
PFI	Port Fuel Injection
PHEV	Plug-In Hybrid Electric Vehicle
PM	Particulate Matter
PWI	Port Water Injection
PN	Particle Number

RDE	Real Driving Emissions
R+D	Research and Development
SCE	Single Cylinder Engine
SOI	Start of Injection
SUV	Sport Utility Vehicle
SW	Software
TF	Total Fleet
THC	Total hydrocarbons
t_i	Injection Duration
TRL	Technology Readiness Level
TWC	Three Way Catalyst
VNT	Variable Nozzle Turbine
WLTC or WLTP	World Harmonized Light-duty Vehicle Test Cycle or Procedure