Gas-Only Internal Combustion Engines

Project number 652816

H2020 GV-3-2014 Future natural gas powertrains and components for cars and vans

Work Package – WP 4 & 6

WP4 : Charge dilution (internal and / or external EGR) and exhaust-gas temperature management

WP6 : Dedicated after-treatment specification applied to CNG DI engine

Next CNG engine generation

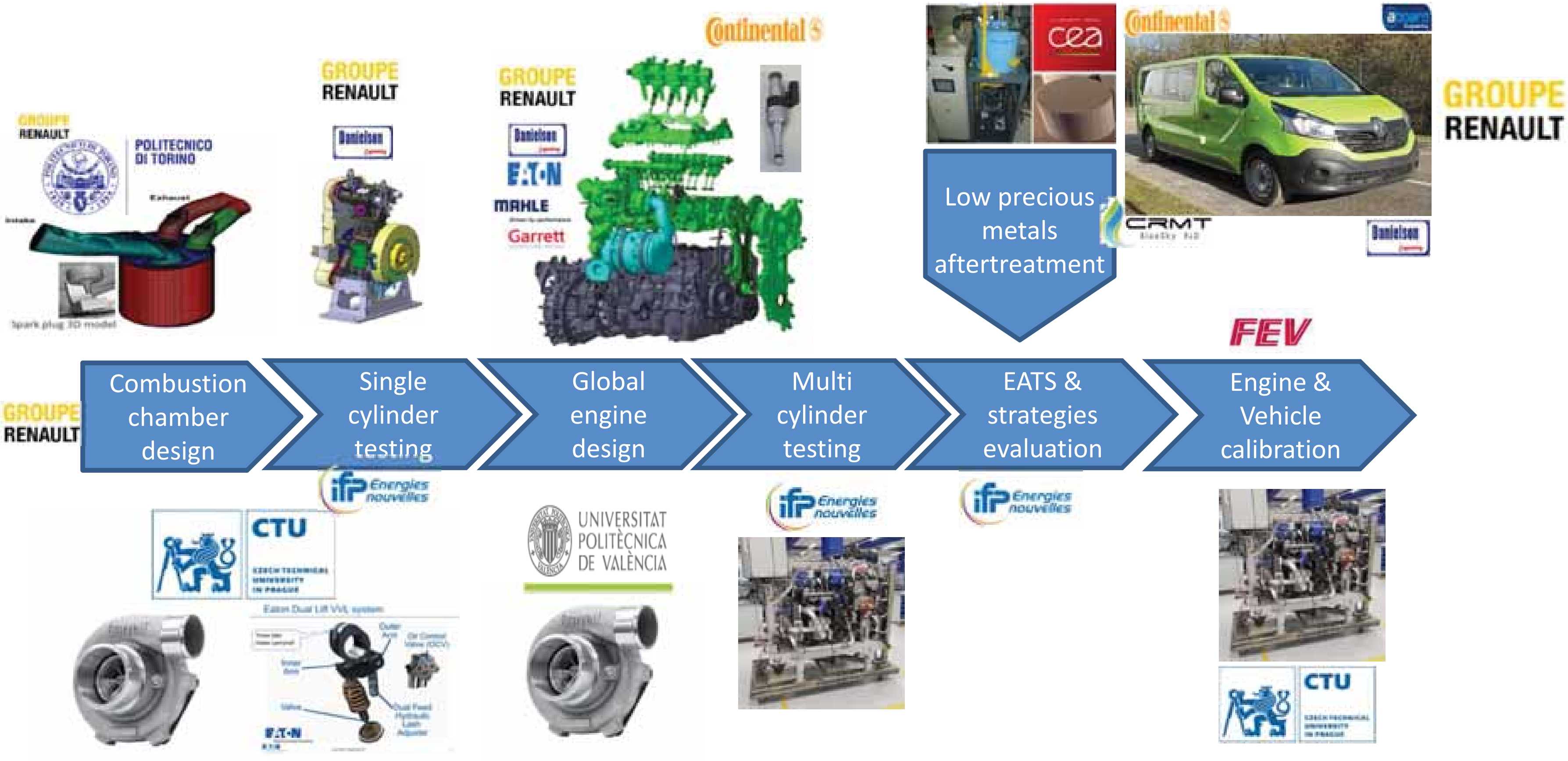
Even if current CNG technology is mature, the goal for the next generation of engines is to develop a technology exploiting all CNG benefits without drawbacks:

- offer a cost/CO_2 competitive alternative to Diesel
- improving engine efficiency for significantly lower consumption/CO_2 compared to modern Diesel engines
- Maintain or offer better drivability and low end torque compared to modern Diesel engines

WP 4 & 6 Objectives

- Increase of compression ratio for efficiency increase
- Decrease of exhaust temperature and increase of cylinder pressure at higher load to enable higher compression ratio as well as lower thermal and structural stress on engine architecture and on the after treatment system.
- Selection and optimisation of the combustion system for a dedicated CNG engine
- Optimisation of low-end torque capability to ensure down-speeding potential for better consumption
- To develop a general and low cost concept for after-treatment applied to CNG engine to help to meet possible post Euro 6 target pollutant emissions.

WP4&6 Partnership organization and process development



Main tasks

Mixing process optimisation & comnsution develomement via CFD modelling
(Politecnico Torino, Renault)

CNG DI injection system development and prototyping
(CONTINENTAL, Renault, IFPEN)

Engine & vehicle performance modeling
(Prague, CMT)

Design, prototyping, development of single & multi cylinder engine matching injection, boosting and VVA
(Renault)

Design storage system, engine & subsystems installation on demo vehicle, refinement & full assessment
(Renault)

Single & Multi cylinder engine combustion validation and strategies
(IFPEN)

Multi cylinder engine & vehicle final calibration and validation of targets
(FEV)

CVD low cost catalyst
(CEA)

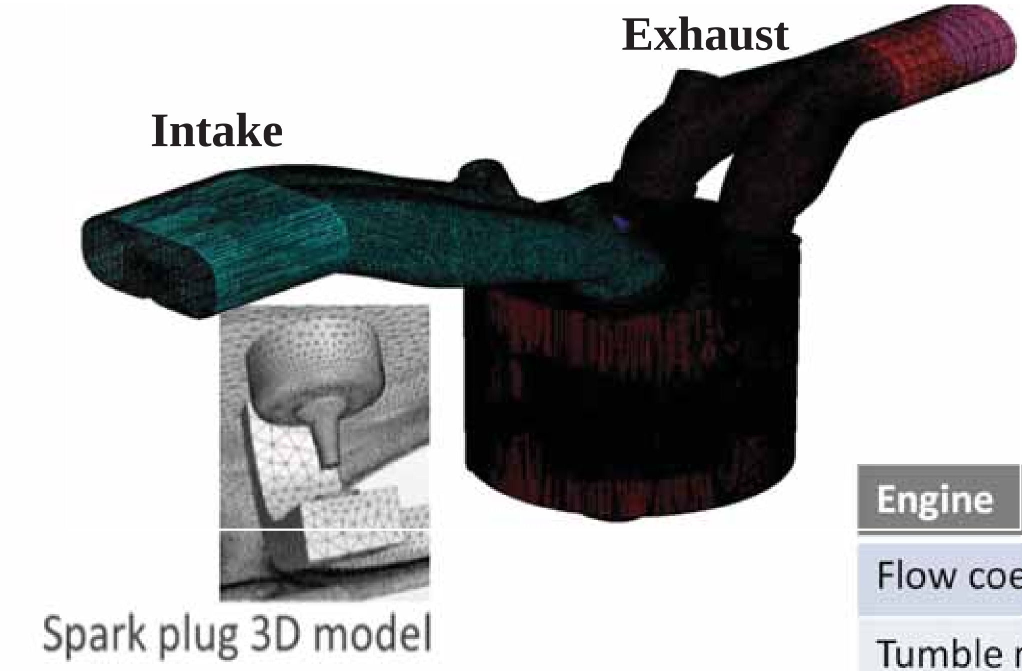
CNG demo engine - Renault

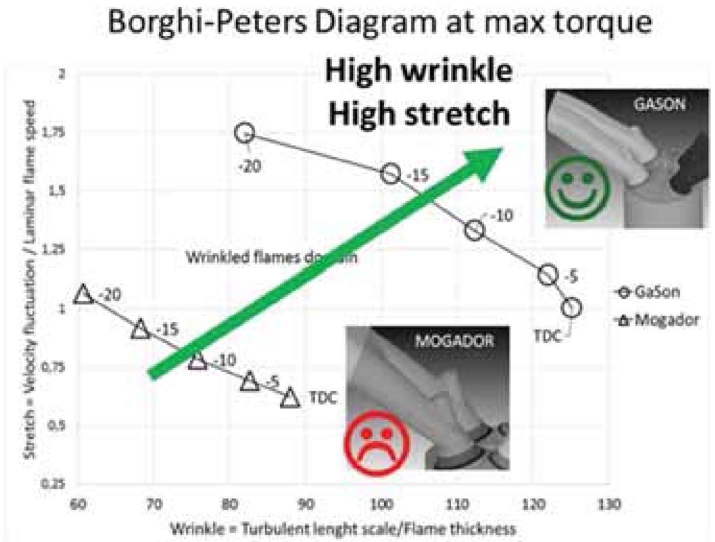
The engine selected for the investigation was a 1.6 liter turbocharged always fueled with a 100% Natural Gas (Low Heat Value 47 MJ/kg)

Feature		Metric
Displacement	1598	cm^3
Cylinders	4	-
Bore	79.5	mm
Stroke	80	mm
Compression Ratio	13:4	-
Rated power	125	kW
at engine speed	4000	rpm
Rated torque	380	Nm
at engine speed	1250 - 3500	rpm
Air management	Variable valve actuation	
Boosting	Electric Variable Gas Turbine	

Hugh turbulence CNG combustion – Strategy – POLITO/RENAULT

- **Optimization of internal aerodynamics for high efficiency combustion**
  - **Best cylinder head shape**





Engine	MOGADOR	GASON
Flow coefficient	0.09	**0.08**
Tumble number	0.98	**1.08**

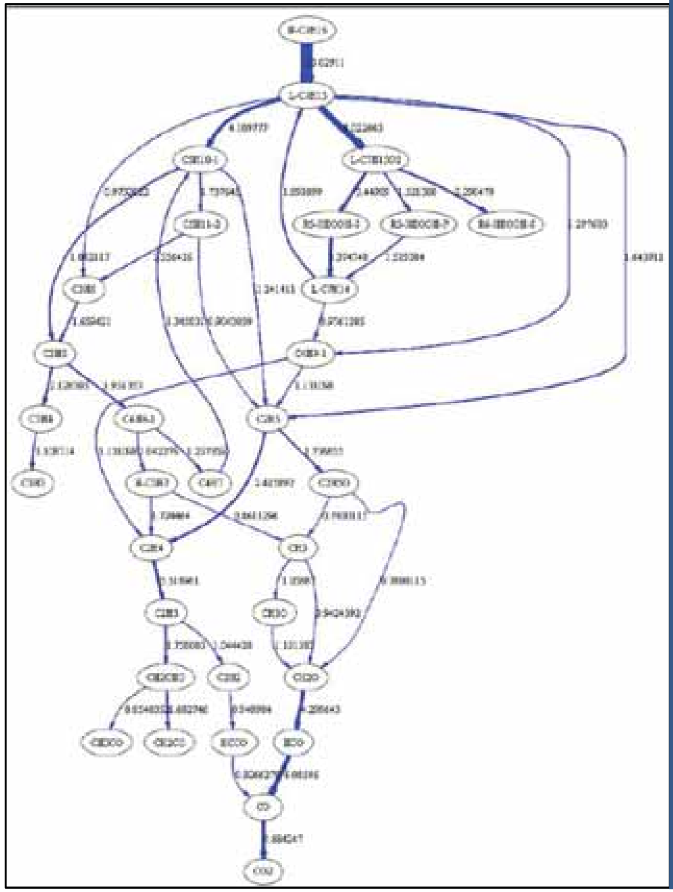
CNG combustion needs high level of turbulence without sacrifying internal flow rate

Gas-Only Internal Combustion Engines

Work Package 4&6, Charge dilution and exhaust gas temperature management

Renault, IFPEN, FEV, Continental, Politecnico Torino, Prague, CMT, CEA

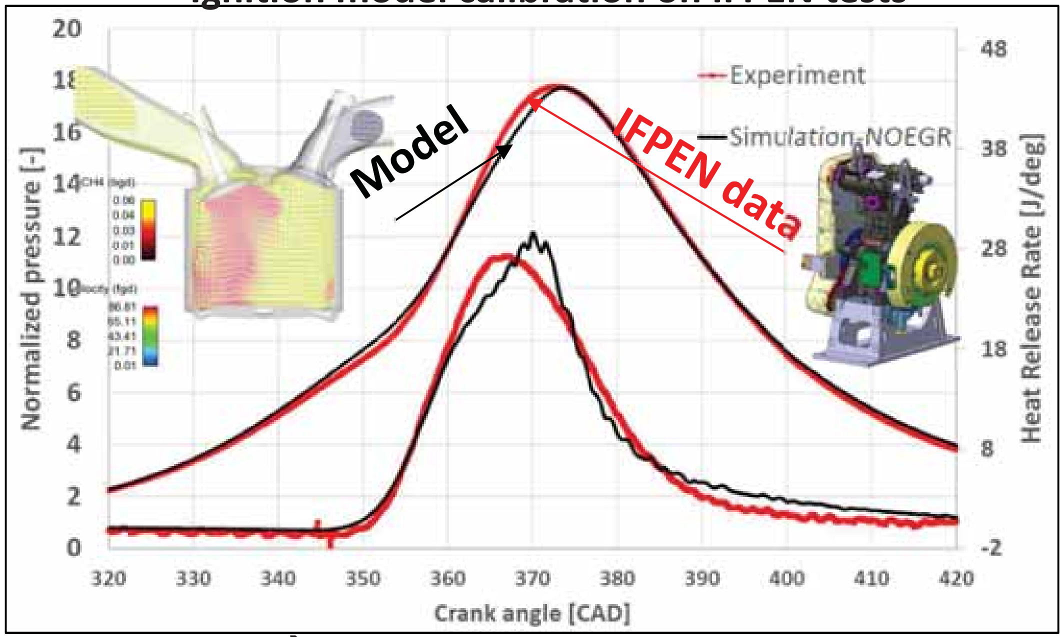
Charge dilution Laminar Flame Speed (LFS) submodel development - POLITO



Chemical implementation for LFS modeling

LFS vs EGR% modeling for different mechanisms & gas compositions

Ignition model calibration on IFPEN tests



Achievements → SAE Paper

- ✓ more accurate than correlations available in the literature
- ✓ includes the effect of EGR
- ✓ allows different Natural Gas compositions to be considered

Model ready for diluted combustion analysis

CNG DI injection system development and prototyping (CONTINENTAL, Renault, IFPEN)

Flow rate: 9,2g/s CNG @ 20bar

Design	Max no of Load cycles	Durability status
A1	<10 Mio	
A2	~30 Mio	
A3.1	60 Mio	passed

- Durability target 60 Mio LC @ ITB.
- All values above based on oiled conditions.

Durability test bench

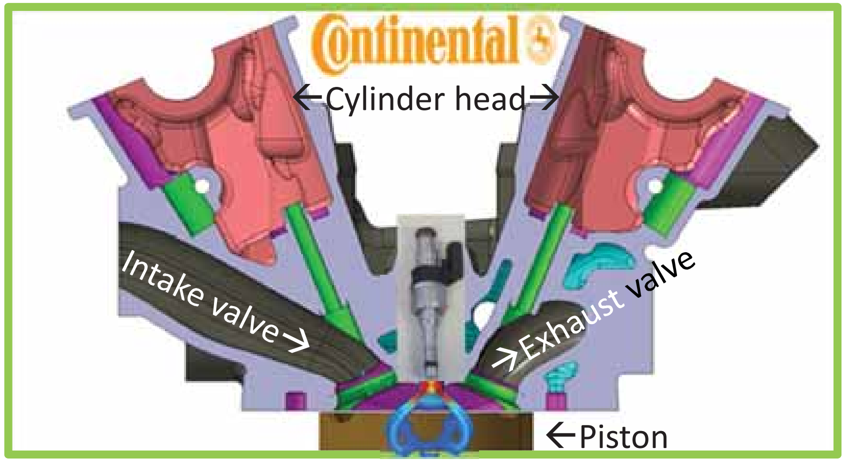
Medium:	N_2
Pressure:	20 barA
Injection Frequency:	50 (100) Hz
Injection Pattern:	single injection
Injector firing:	all injectors in parallel (not sequential)
Temperature:	Room Temperature

- DI injectors passed successfully all endurance tests
- Successful functional validation during combustion validation testing by IFPEN

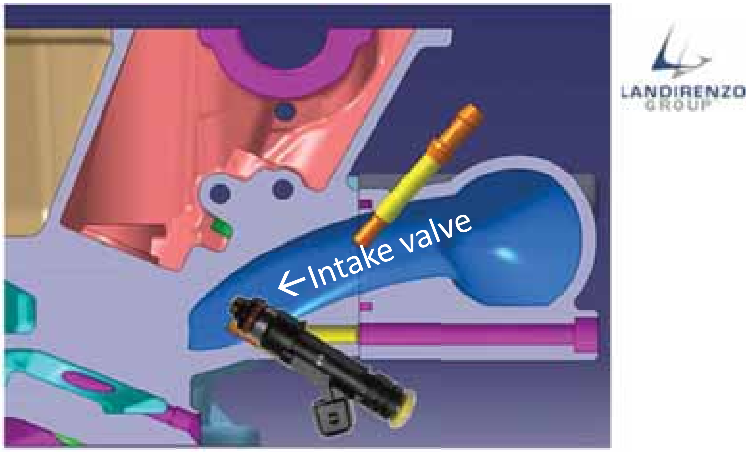
CNG DI injection system development and prototyping (CONTINENTAL, Renault, IFPEN)

- **Incident #1,#2 and #3:** Potential root cause of increased wear @ engine operation comparing to durability test bench cold operation.
- **Incident #4:** Most probably caused by high bending load applied to the hot valve (possibly during assembly into cylinder head).

Following various consecutive failures of the Direct Injector →Decision taken last April to switch to PFI



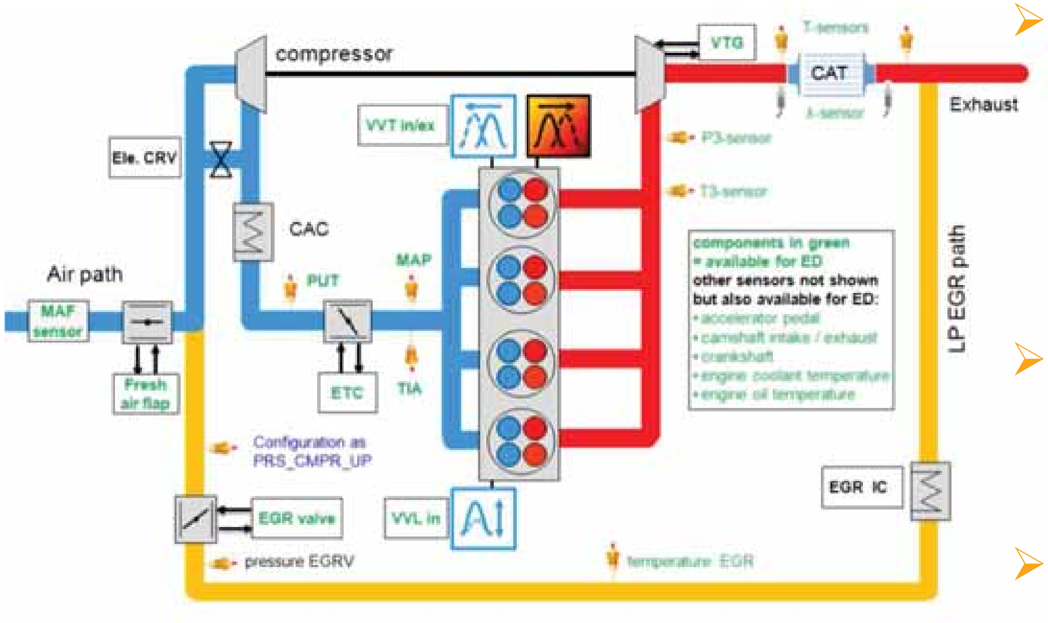
Integration of DI injection system



Integration of PFI injection system

CO_2 performances should be maintained (based on single cylinder investigation)

Control System Configuration & parts procurement - Continental



- **New and special designed main ECU to control**
  - **Fuel path**
    - CNG DI & PFI injectors
    - electronic pressure regulator
  - **Air path**
    - variable valve lift, variable valve timing,
    - Variable turbine geometry (VNT)
    - low pressure EGR system
- **New functionality and SW developed**
  - steady state engine dyno & dynamic in the vehicle
  - for exhaust gas after treatment
  - for catalyst heating
  - Change of DI to MPI injection system
- **Base calibration of functionality and continuous calibration support of IFPEN & FEV**

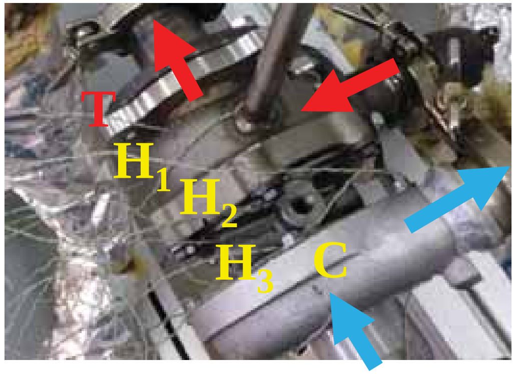
Conti components procurement

CNG DI injectors | Exhaust gas temperature sensors | NOx sensors | Intake manifold pressure and temperature sensors | Knock Sensors | Gas interface box | Main ECU

Development of engine control system

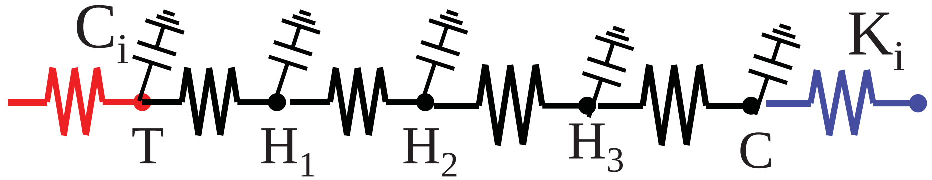
Turbocharger characterization - CMT

✓ Thermal test rig



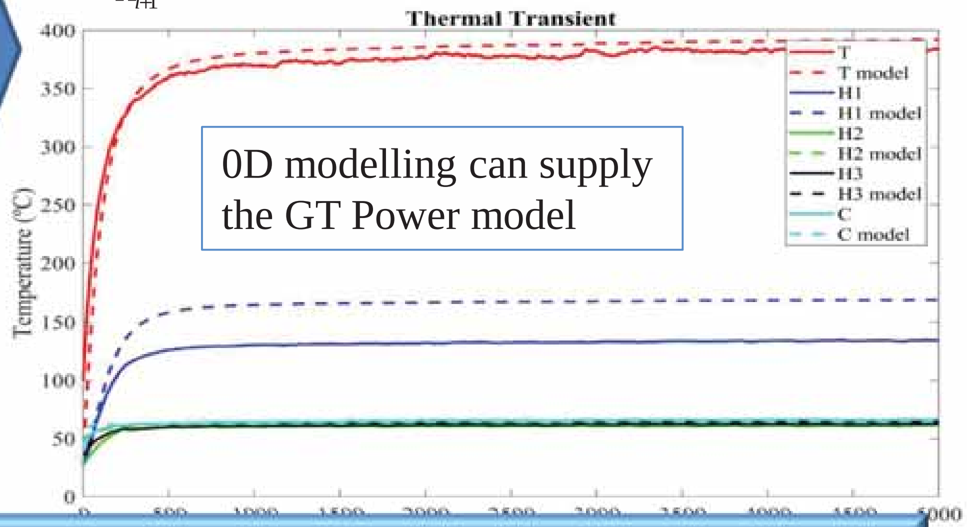
✓ Gas stand

- ❑ **Turbo thermal characterization**
- ❑ **Metal Conductance (K) and Capacitance (C)**
- ❑ **Determination of catalyst pressure drop coefficient Kcata=K(Re)**
- ❑ **Model validation with experimetal tests in gas stand and catalyst**



$$K_{Hi/Hi+1} = \frac{Q_T}{T_{Hi} - T_{Hi+1}} = \frac{Cp_T \cdot \dot{m}_T \cdot (T_{out} - T_{in})}{T_{Hi} - T_{Hi+1}}$$

$$T_{H_i}^{t+\Delta t} = \frac{\Delta t}{C_{H_{i+1}}}\left[K_{H_i/H_{i+1}} \cdot \left(T_{Hi}^t - T_{Hi+1}^t\right) + K_{H_{i+1}/H_{i+2}} \cdot \left(T_{H_{i+2}}^t - T_{H_{i+1}}^t\right)\right] + T_{H_{i+1}}^t$$



Experimental characterization turbocharger ➔ for GT Power submodeling

Gas-Only Internal Combustion Engines

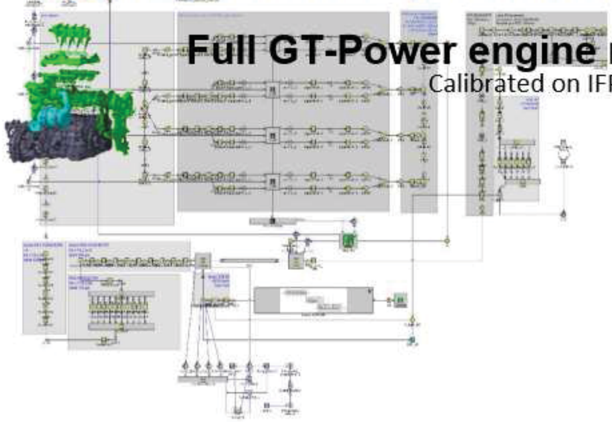
Work Package 4&6, Stoichiometric & high structural integrity small TC VVA DI engine,

Renault, IFPEN, FEV, Continental, Politecnico Torino, Prague, CMT, CEA

Engine & vehicle performance modeling (Prague, CMT)

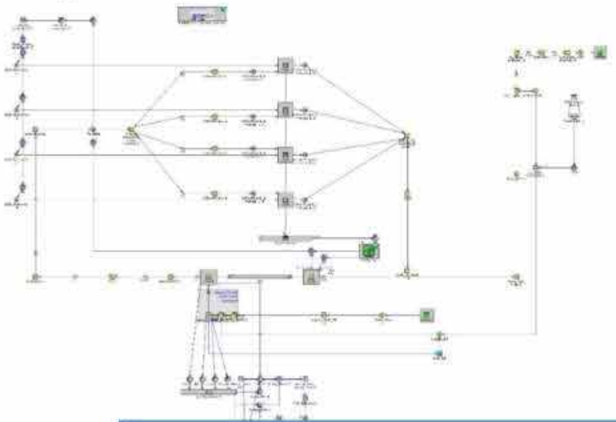
Full GT-Power engine model

Calibrated on IFPEN tests

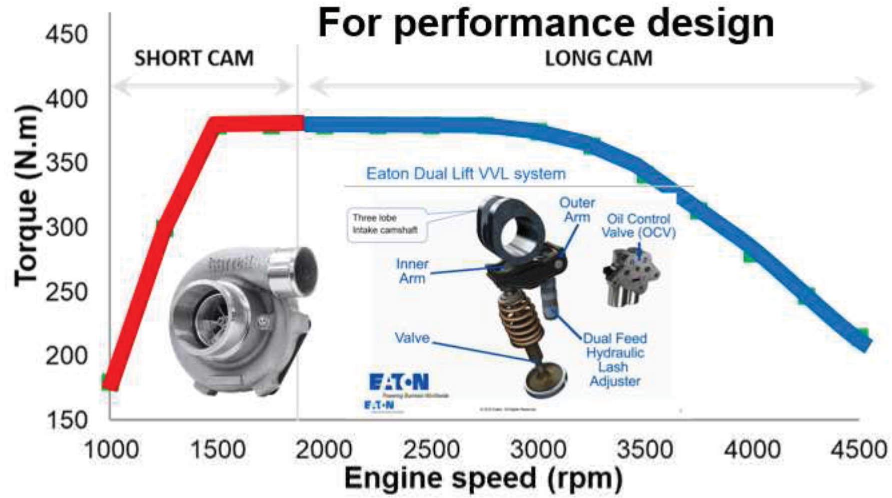


Fast Running model

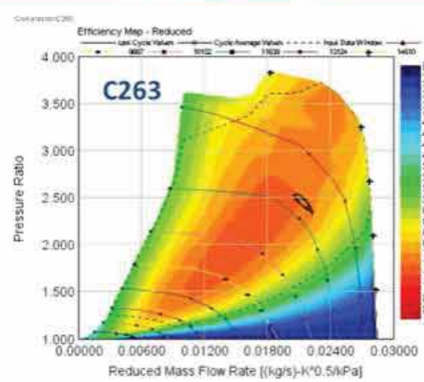
Simplified mode for vehicle transient simulation



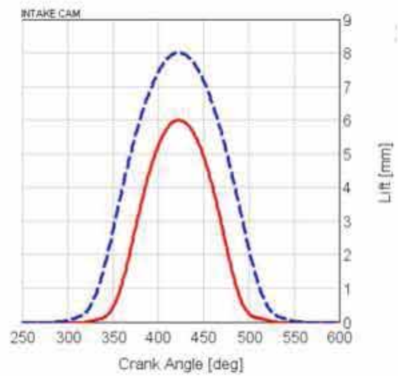
For performance design



For Turbo matching



For valve lift optimisation



GT-Power ENGINE 1D MODEL DEVELOPMENT

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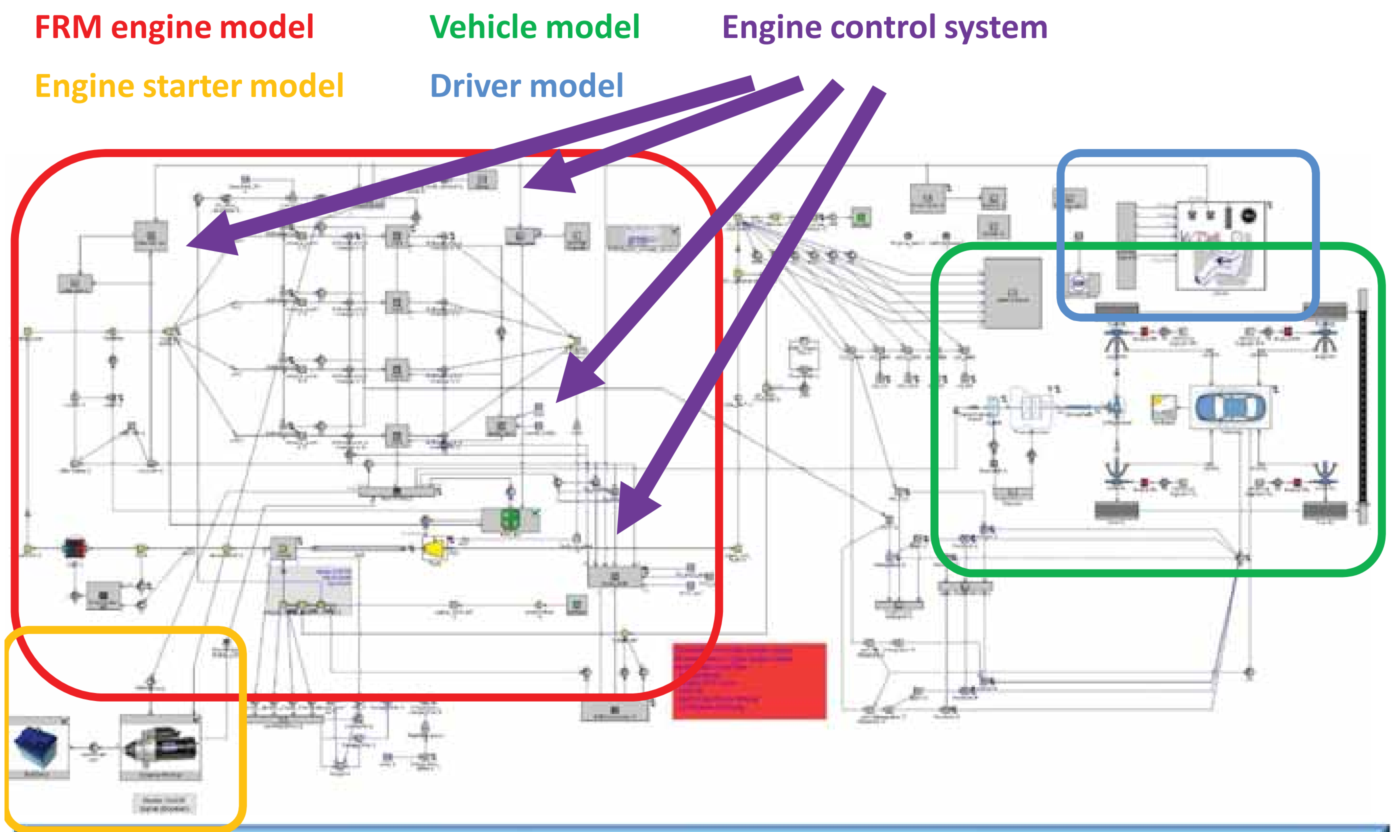
Work Package 4&6, Charge dilution and exhaust gas temperature management

Renault, IFPEN, FEV, Continental, Politecnico Torino, Prague, CMT, CEA

Engine & vehicle performance modeling (Prague, CMT)

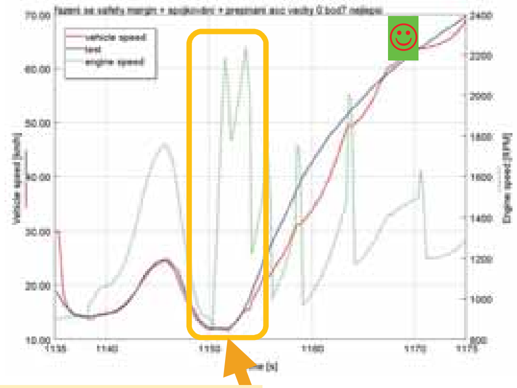
Development of full vehicle model for drive cycle evaluations



GT Vehicle Model with Engine Start & Stop functionality

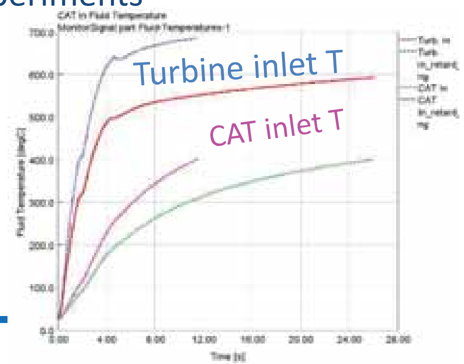
Example : Recommendations for dynamic vehicle calibration for FEV

Example : Acceleration control system correction



Combustion setting:
- Ignition/injection timing
- Intake/Exhaust Valve Open *timing* & profile choice
- **clutch control**

Thermal transients: Engine and CAT warm-up calibrated by experiments



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Work Package 4&6, Stoichiometric & high structural integrity small TC VVA DI engine,

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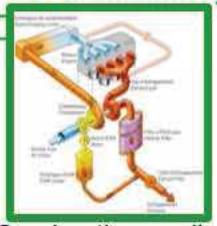
Design, prototyping, development of single & multi cylinder engine matching injection, boosting and VVA (Renault)

GROUPE RENAULT

- **GasOn specific**
  - → **High turbulence cylinder head**
    For combustion boosting
  - → **very high CR piston 13.4** MAHLE
    For efficiency
  - → **direct injection**
    For performance
  - → **variable valvetrain**
    For performance

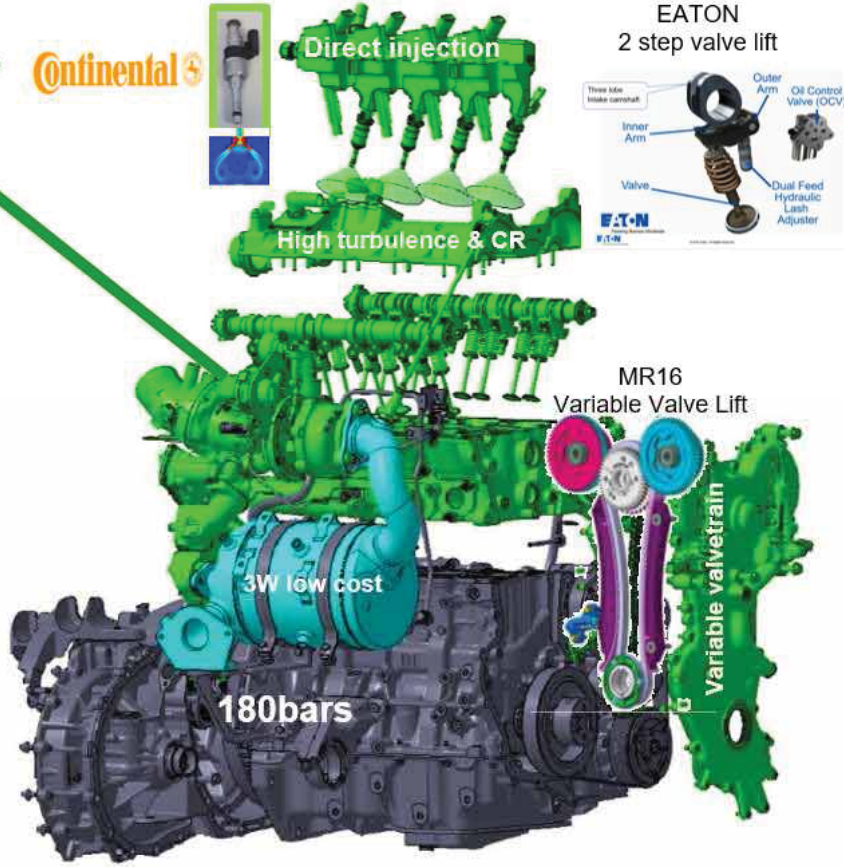
Garrett
e-Variable Gas Turbine

Cooled Exhaust Gas recirculation



Combustion cooling

EATON
2 step valve lift



→ **3W Catalyst** → For low Precious Metals

- **Diesel base engine**
  For high thermal efficiency

Design of the multi cylinder engine

Gas-Only Internal Combustion Engines

Work Package 4&6, Charge dilution and exhaust gas temperature management

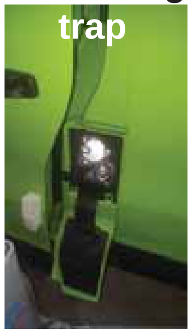
Renault, IFPEN, FEV, Continental, Politecnico Torino, Prague, CMT, CEA

Design storage system, engine & subsystems installation on demo vehicle, refinement & full assessment (Renault)

GROUPE RENAULT

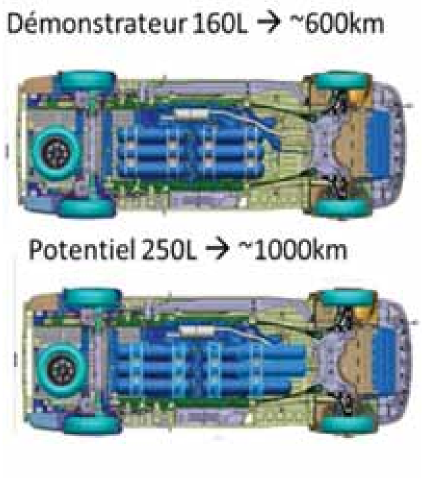
Composite Type 4 CNG Tanks

CNG filling trap



Engine integration

Trafic Demo Car

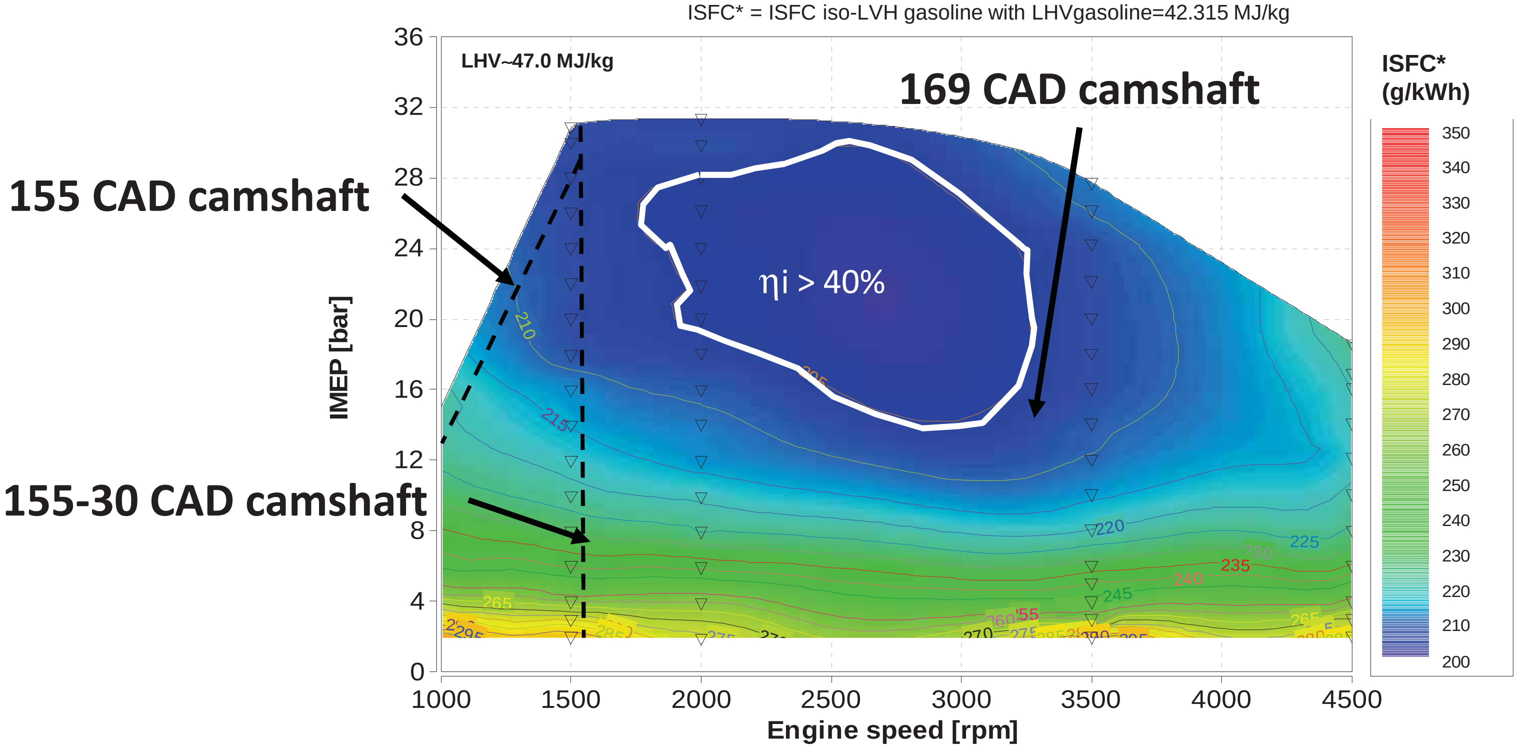


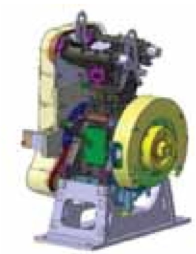
State of the art R110 standard CNG conversion

WP4 Final results:

- *Performance gain vs Diesel*
- *Engine efficiency enhancement due synergic effects of innovative technologies*
- *Vehicle driving range*
- *CO_2 reduction*
- *Final calibration pending*

SINGLE CYLINDER RESULTS Specific fuel consumption & performances - IFPEN





- High efficient combustion chamber design
- Performance target was achieved
- Engine settings defined for MCE application

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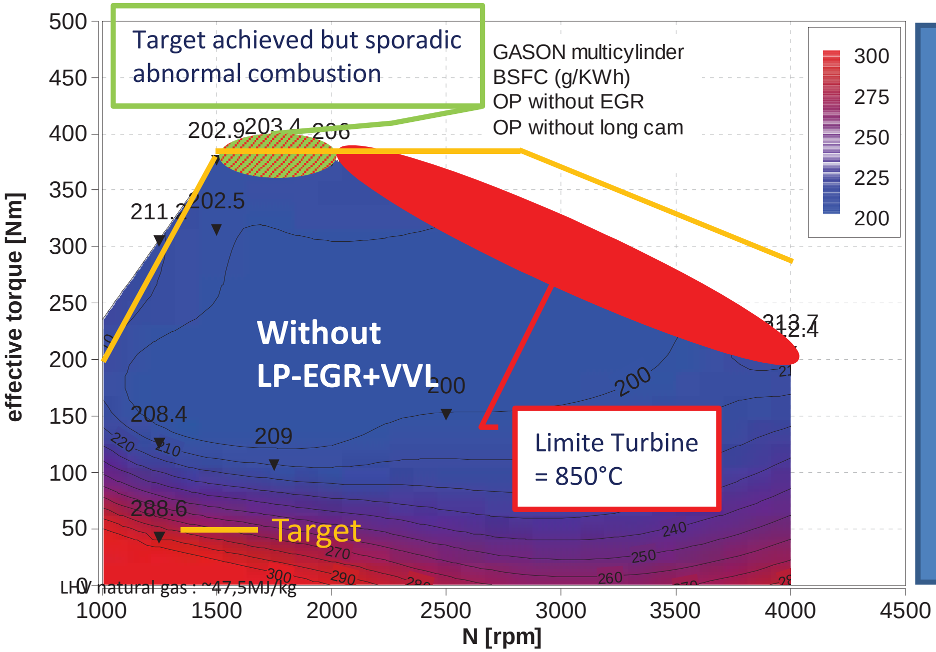
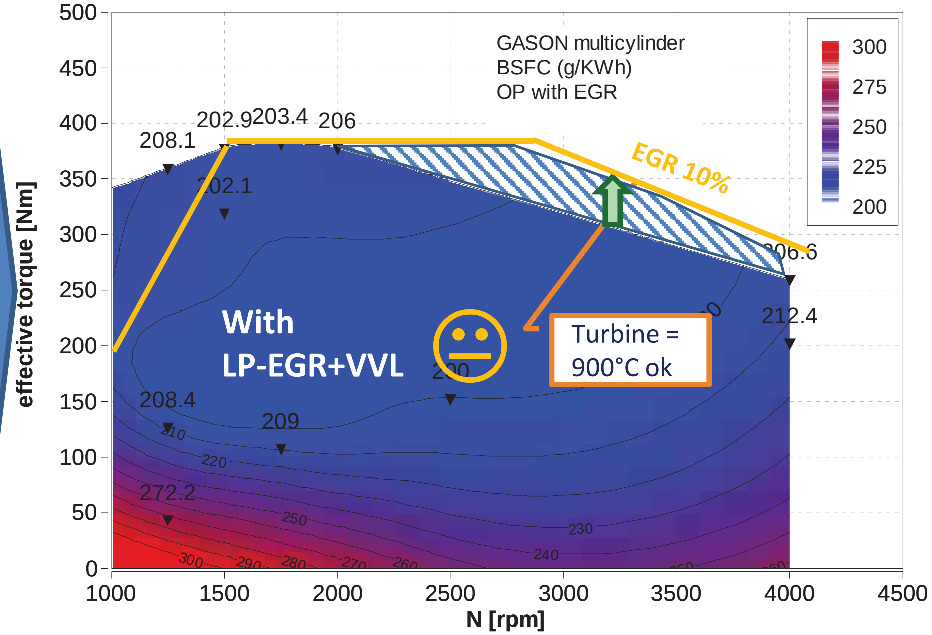
Multi cylinder engine combustion validation and strategies (IFPEN)





- Confirmed the combustion chamber behaviour
- Confirmed the Performance at low/medium rpm & potential at high rpm
- Defined the Engine settings for MCE calibration

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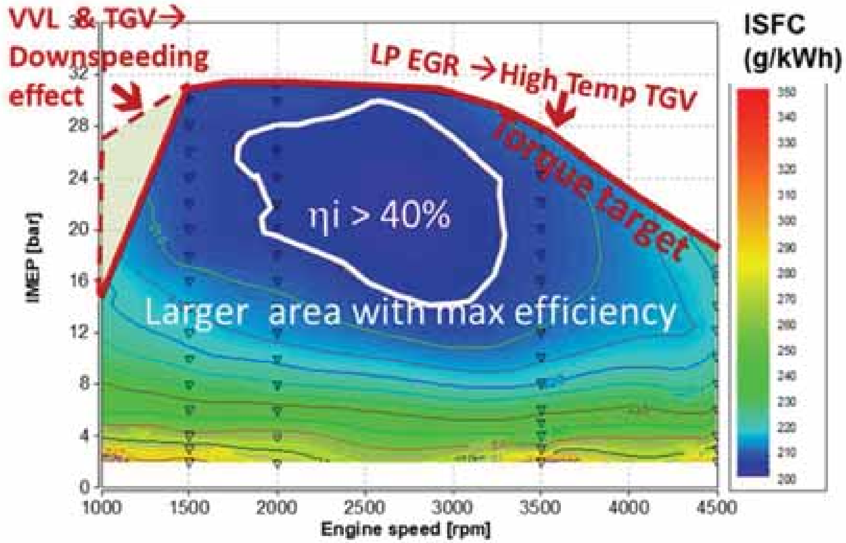
Engine efficiency enhancement due synergic effects of innovative technologies

CO_2 Reduction technology	Enabling Technology	Measured
Downsizing and external EGR benefit	Advanced boosting	12% tbc
	CNG Direct Injection (CNG DI)	
Compression ratio increase	High peak pressure capable engine architecture	5% tbc
	High Compression ration (13.4)	
Dethrottling and/or advanced air management	Advanced variable valve actuation	1% tbc
CNG system weight reduction with downspeeding and further vehicle measures	Light weight CNG tank system	
	Downspeeding with longer final drive to trade performance (gained by weight reduction) against fuel economy	7% tbc
TOTAL – Measured on test bench engine and vehicle silulation (NEDC)		25% tbc
TARGET on NEDC		16-22%



High Torque curve → Downspeeding effect → Long final drive for CO_2 and consumption reduction

- Downsizing and external EGR allowing advanced boosting and injection schemes → +12% BTE (Brake Thermal Efficiency)
- Compression ratio 13:4 versus 10:1 improves BTE of 5% without any knocking phenomena due to high octane number (130)
- Advanced variable valve actuation allowing dethrottling and high low end torque → +1% BTE
- Advanced boosting and external EGR allowing downspeeding diesel like low end torque → +7% by using Diesel gear box

Gas-Only Internal Combustion Engines

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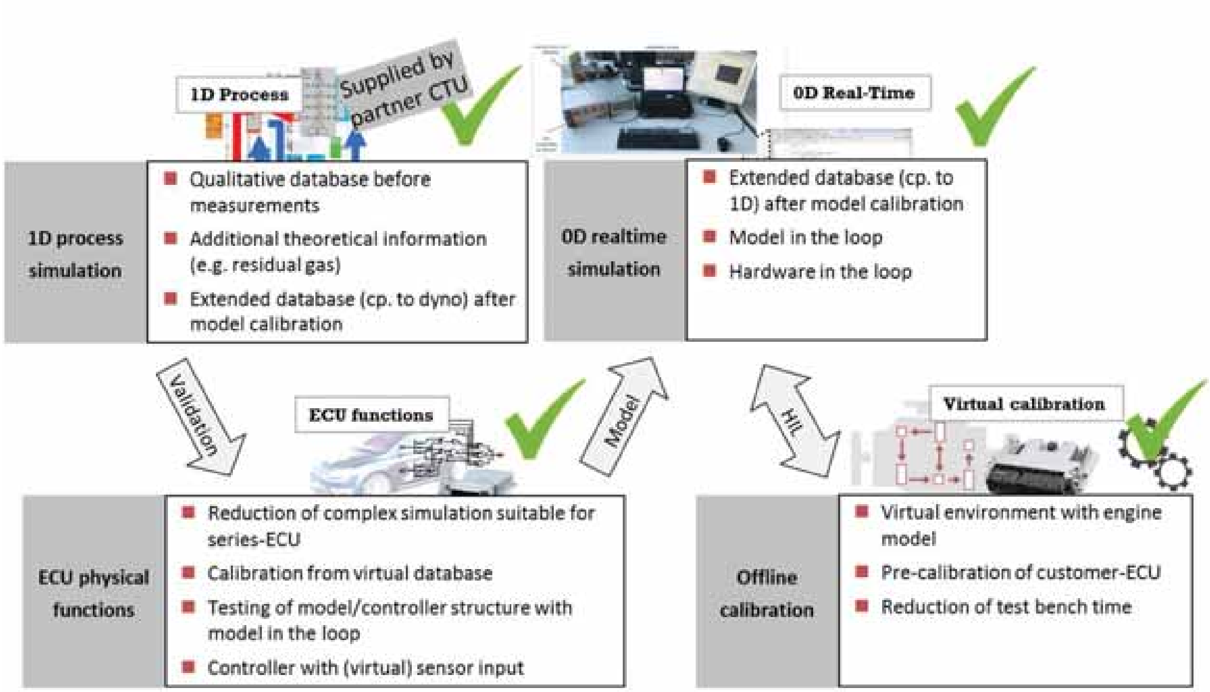
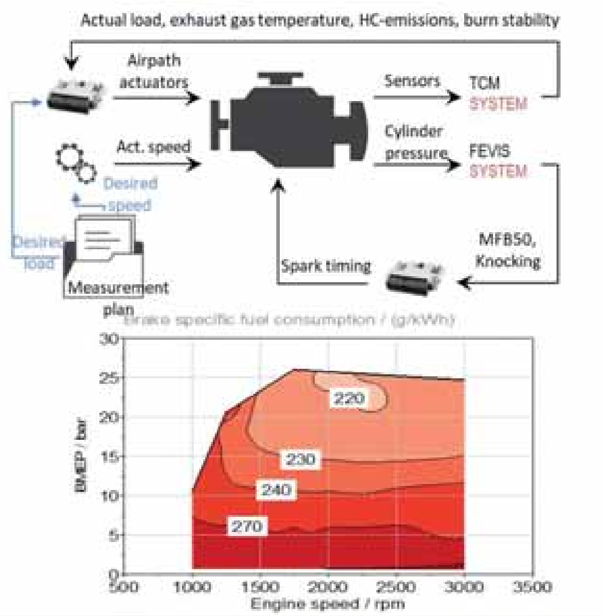
Multi cylinder engine & vehicle final calibration and validation of targets (FEV)





Virtual calibration – Enabler for shorter test bench time

Automated test bench operation

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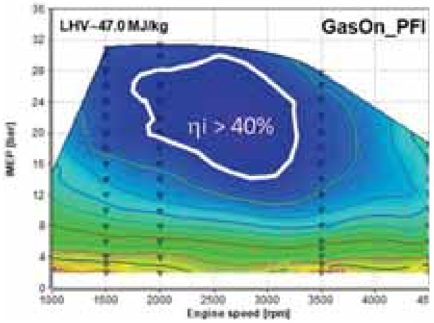
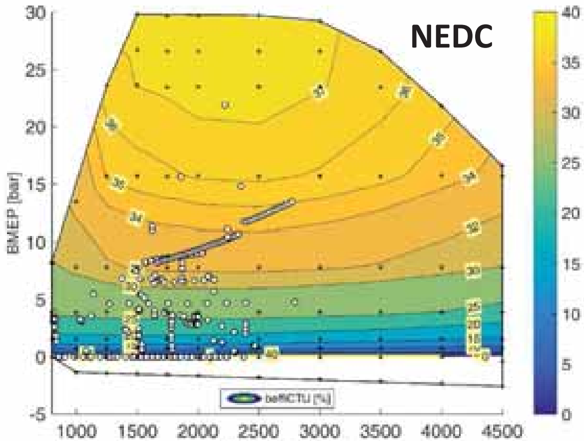
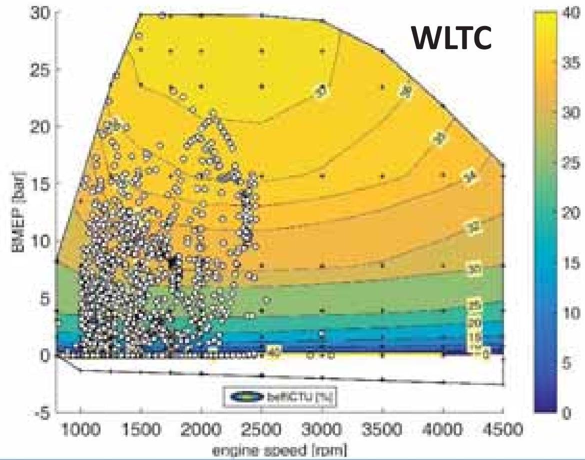
GT Vehicle & Engine Model with Engine Start & Stop functionality - CTU
Drive cycle simulation results







Drive cycle	Simulations with transients
GasOn/NEDC	128
GasOn/WLTC	*135*
Target M9R -22%/NEDC	132

Simulations based on test bench results confirmed the potential of up to 25% CO_2 reduction

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GAS ON

Conclusion	
At engine level, the synergic adoption of external EGR with advanced boosting system, variable valve actuation and high compression ratio allows to achieve the same rated torque and power of high output Diesel engine	√
Fuel & CO_2 saving is consolidated at 25% on various cycles based on test bench results and calibrated vehicle simulation models	√
Upgraded CNG storage system ensures a full driving range close to 600 km without trunk/payload penalty	√
Final calibration for CO_2 & emissions	ONGOING
CO_2 validation by JRC	RESULTS JUNE