Development of a C-Segment Vehicle Dedicated to Methane Operation

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Results of the EU Horizon 2020 Project „GasOn“

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OBJECTIVES

- **EU Targets**
  - 20 % CO_2 reduction
    (vs. Best-In-Class CNG Vehicle 2014)
  - 600 km range
  - EU6+ emissions capable
- **Additional WP3 Targets**
  - Fun-to-drive (110 kW, 240 Nm)
  - 7-seater van

- FORD Grand C- Max
- CO_2 target 100 g CO_2 / km

TECHNOLOGY WALK CO_2 REDUCTION AND ENGINE TARGETS

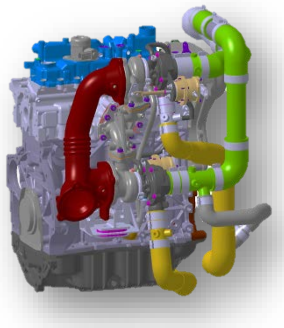
Item	MTDI Target
Fuel	Methane
CR	13 :1
Peak Power	110 kW
Low End Torque @ lowest rpm	240 Nm @ 1500 rpm
Max. Combustion Pressure Capability (avg. / peak)	p_{max} = 160 / 185 bar
CO_2 (NEDC)	≤ 100 g/km

Basis:
- 1.6l 4 Cylinder Ecoboost Engine

Generic CNG PFI Vehicle Conversion with Type 1 steel tanks: 128 g/km CO2

Downsizing:
- 1.0l 3 Cylinder Ecoboost Engine

Downsizing Enablers



Parallel Sequential Twin Turbo Boost System

Methane Direct Injection

Weight Reduction

CNG Type 4 Tanks

Exploit High Methane RON

High Combustion Pressure Capable Engine Components

Part Load De-throttling

Variable Valve Lift System (CVVA) Intake and Exhaust

High Thermal Efficiency

2 Step Variable Compression Ratio System (VCR) optional

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- Engine Design and CAE
- P&E – Dyno Calibration
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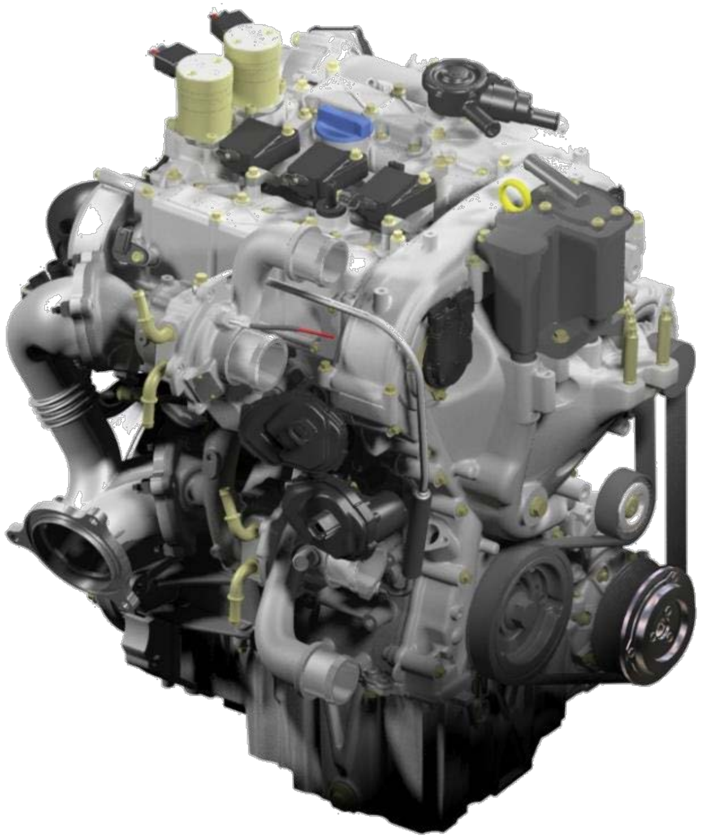
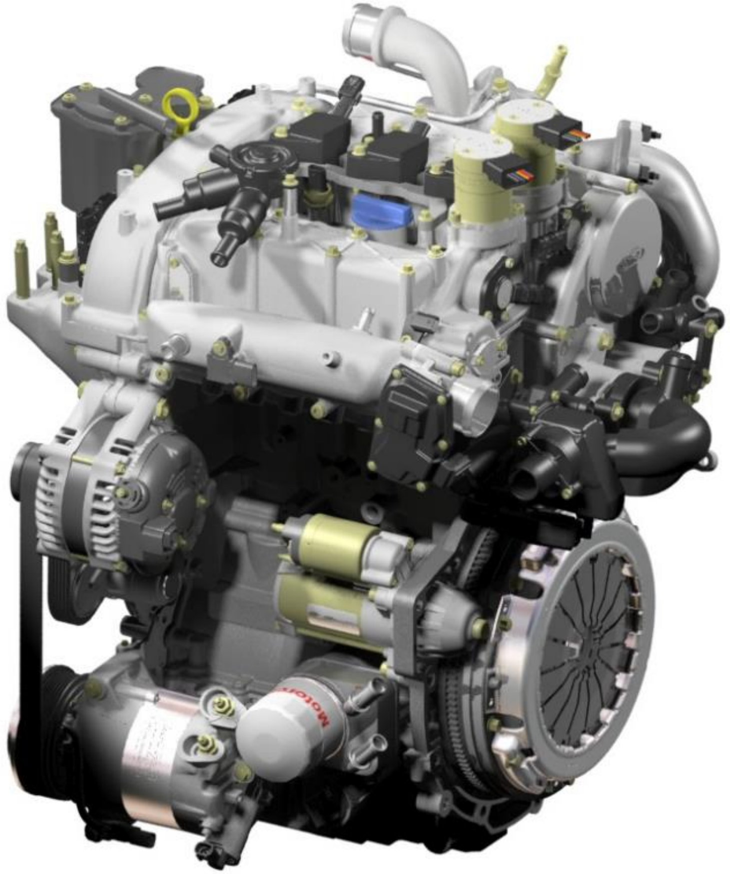
THE MTDI 1.0 ECOBOOST ENGINE – MAIN FEATURES



Front View

- Based on the new Ford 1.0L GTDI Ecoboost ® engine
- Designed to withstand very high cylinder pressures
- New combustion system dedicated to burn methane only
- CR 13
- Fully variable mechanical valve actuation of intake and exhaust valves
- Parallel sequential two-stage turbocharger system
- Methane direct injection system



Rear View

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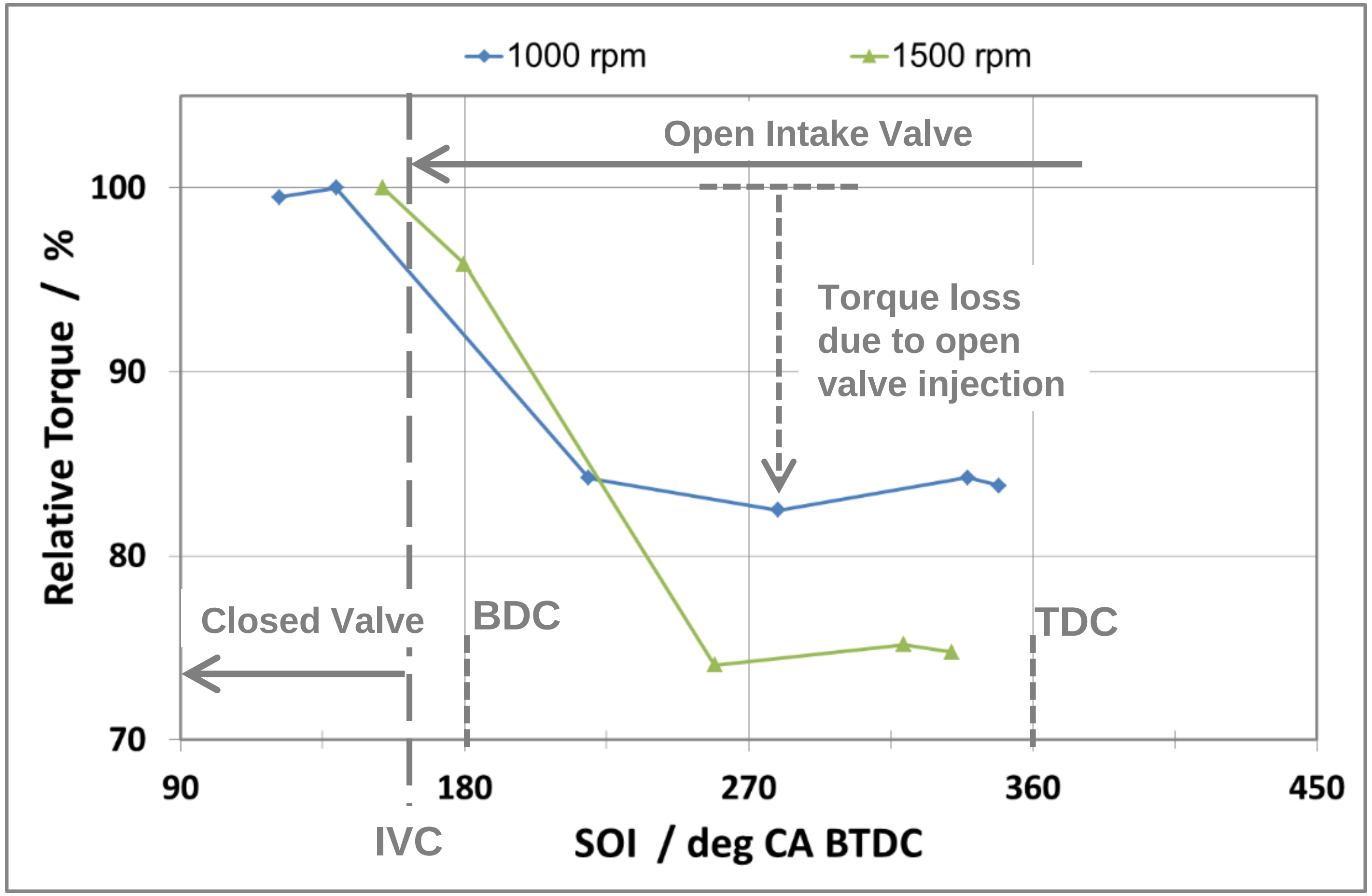
METHANE (CNG) DIRECT INJECTION

Late SOI (Start of Injection) Torque Effect



- Significant torque enhancing effect of late injection (after IVC) at low rpm
- Avoid methane expansion in intake manifold and thus displacement of air
- Increase volumetric efficiency by utilization of CNG tank pressure

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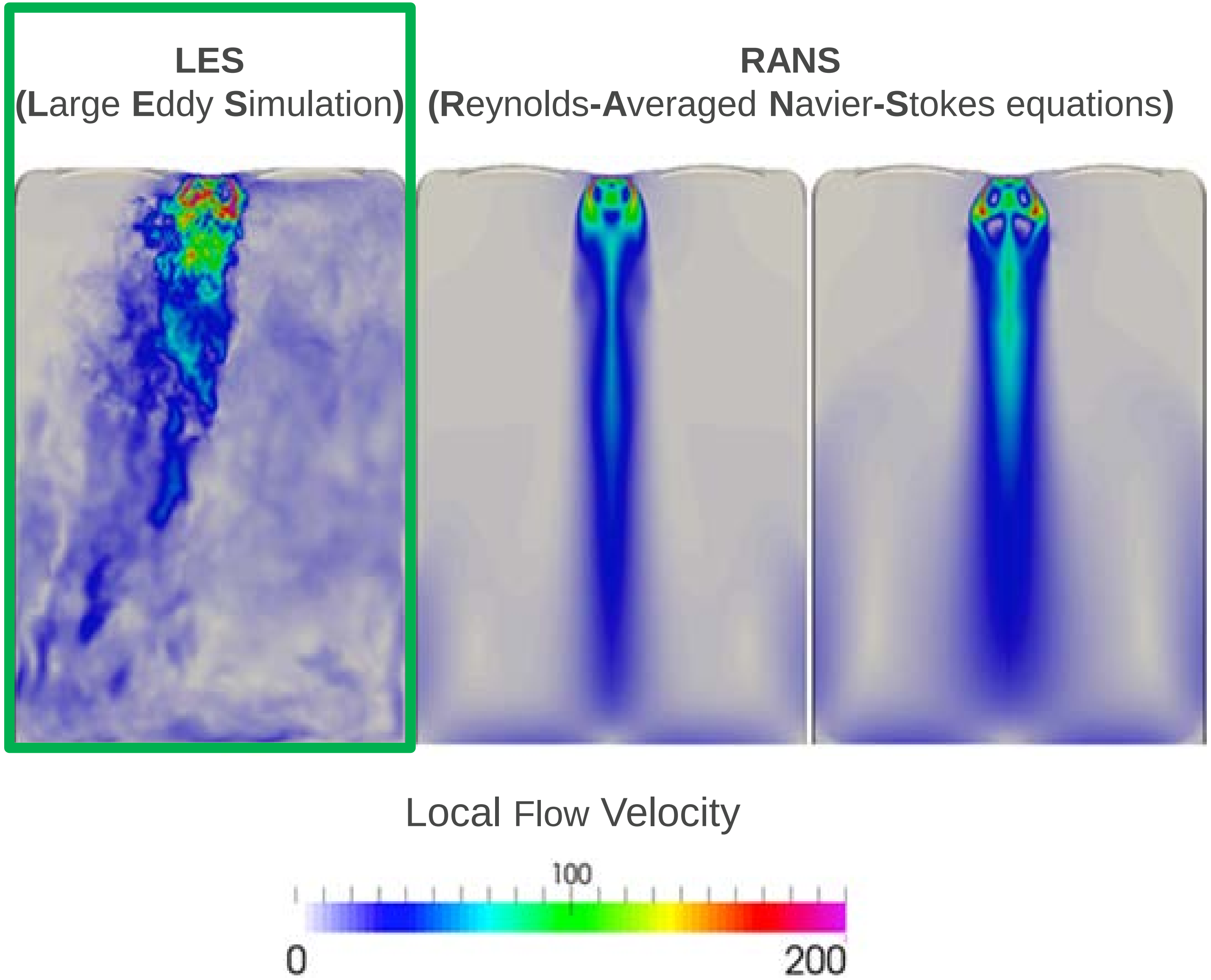
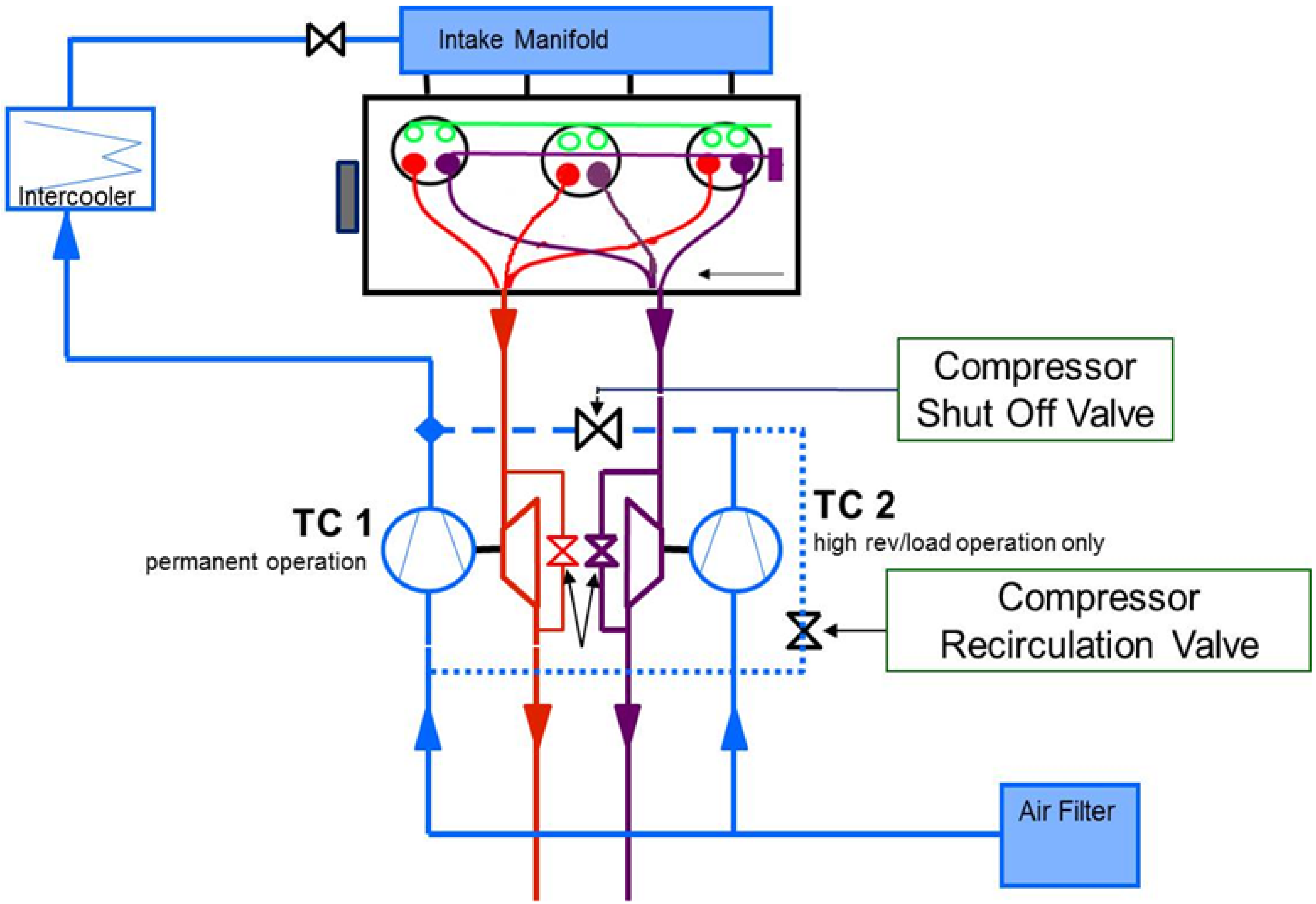
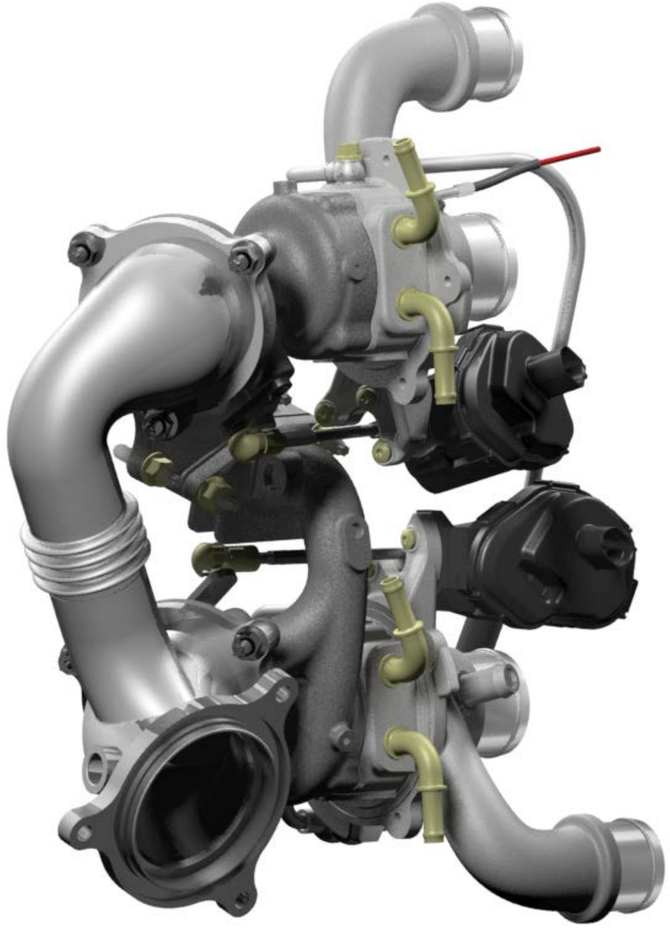
CAE-BASED OPTIMISATION OF METHANE DIRECT INJECTION PROCESS



- Mixing of two gases required extensive 3D CFD study
- Gas dynamics and momentum of CNG considerably different to liquid fuels
- Modelling techniques have been developed and tested to ensure sufficient simulation accuracy
- Most reliable results achieved via LES
- Extensive CAE support reduces development time for CNG DI injector significantly

MTDI BOOSTING SYSTEM (CONTINENTAL)





Challenge: Smooth Transition from 1 TC to 2TC mode

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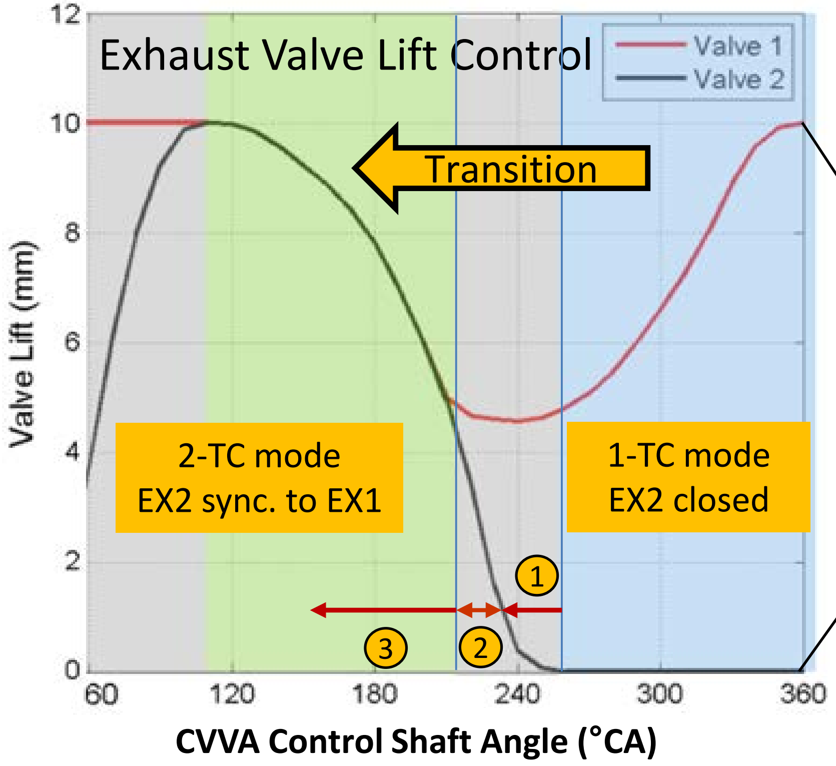
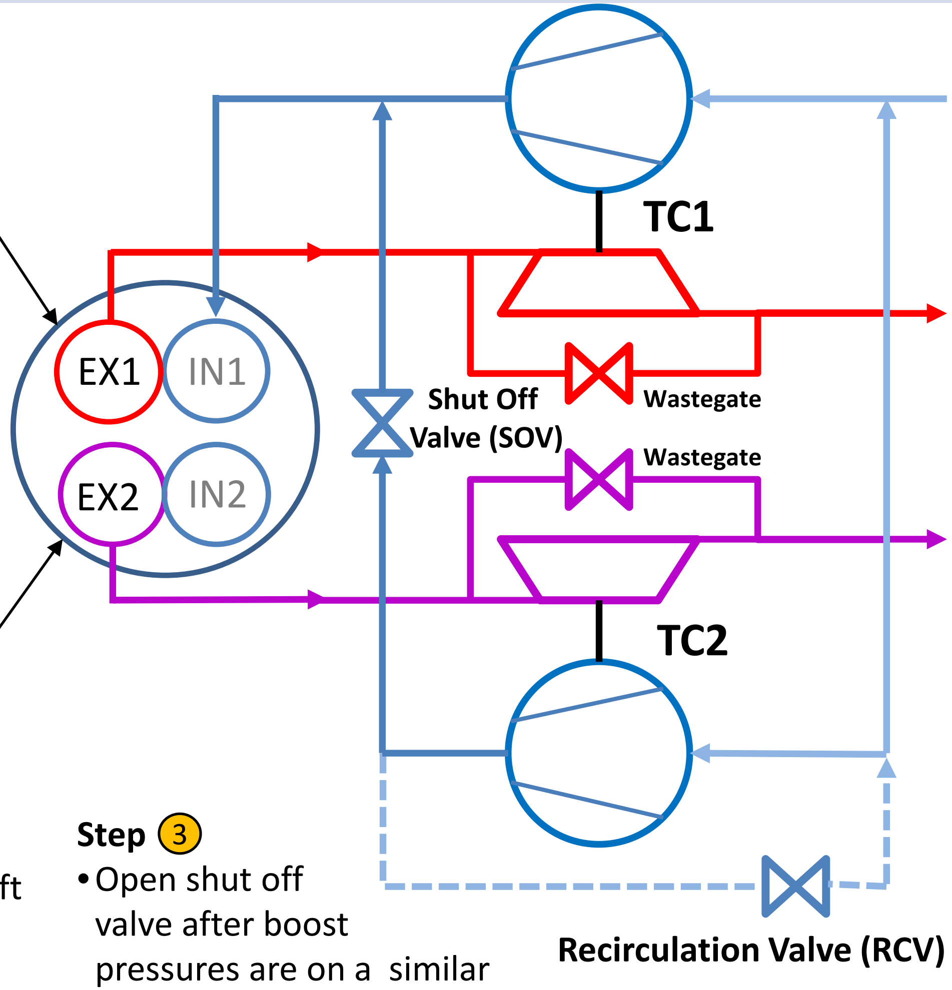
MTDI BOOSTING SYSTEM (CONTINENTAL)

Challenge: Smooth Transition from 1-TC to 2-TC mode established





Step 1
- Move EX2 to a small opening position
- Keep shut off valve (SOV) still closed
- Close waste gate of TC1 and TC2
- Open RC valve to avoid pumping of TC2

Step 2
- Variation of EX2 lift for intermediate boost pressure control

Step 3
- Open shut off valve after boost pressures are on a similar level

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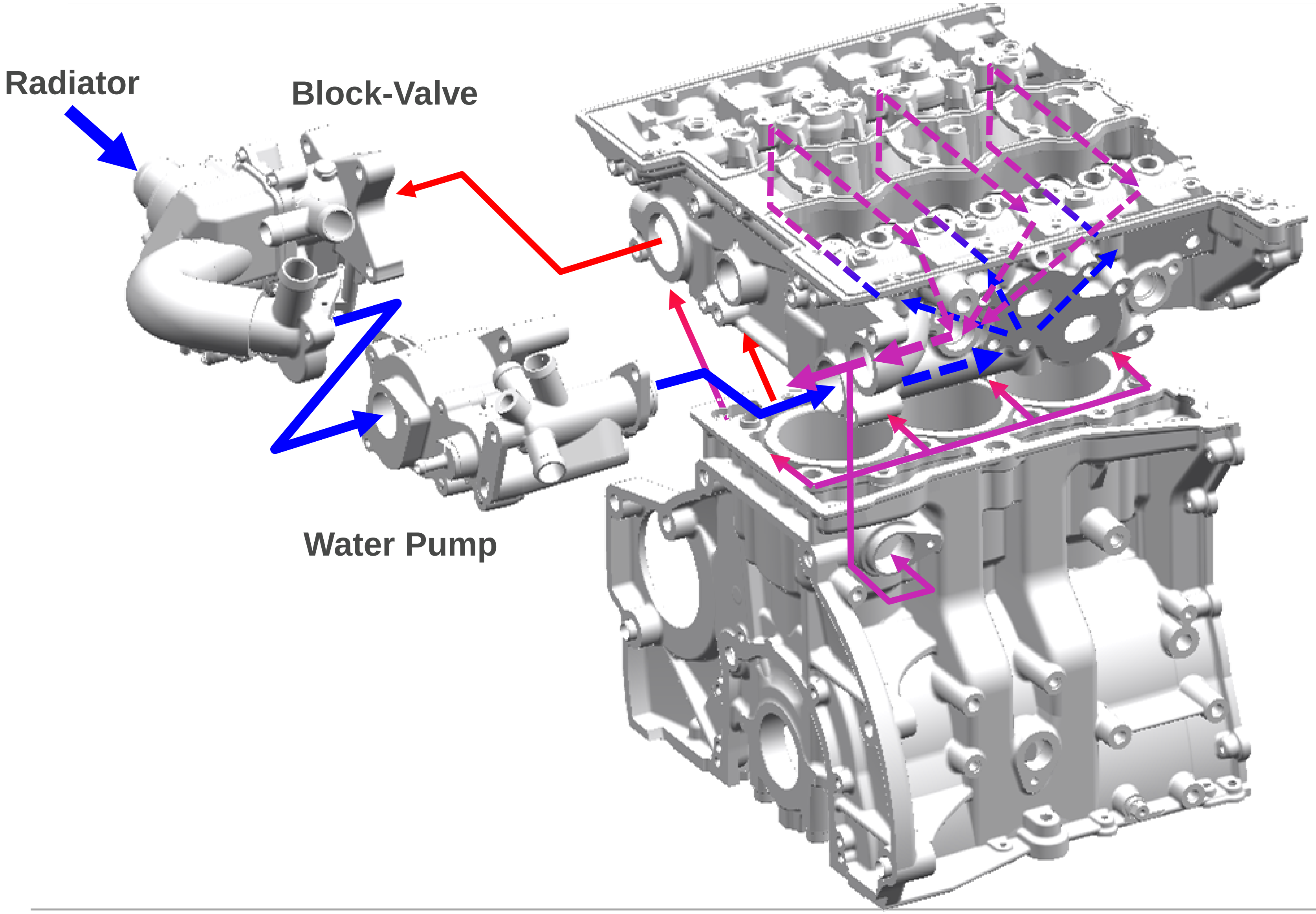
CROSS REVERSE SERIAL FLOW COOLING TECHNOLOGY



Enforced cooling capacity requested due to

- **Missing evaporation enthalpy of CNG** (no over-fueling as with gasoline)
- **Increased combustion temperatures due to high cylinder pressures caused by highly efficient CNG combustion** (no knock limitation
  → no combustion retardation as usual with gasoline)

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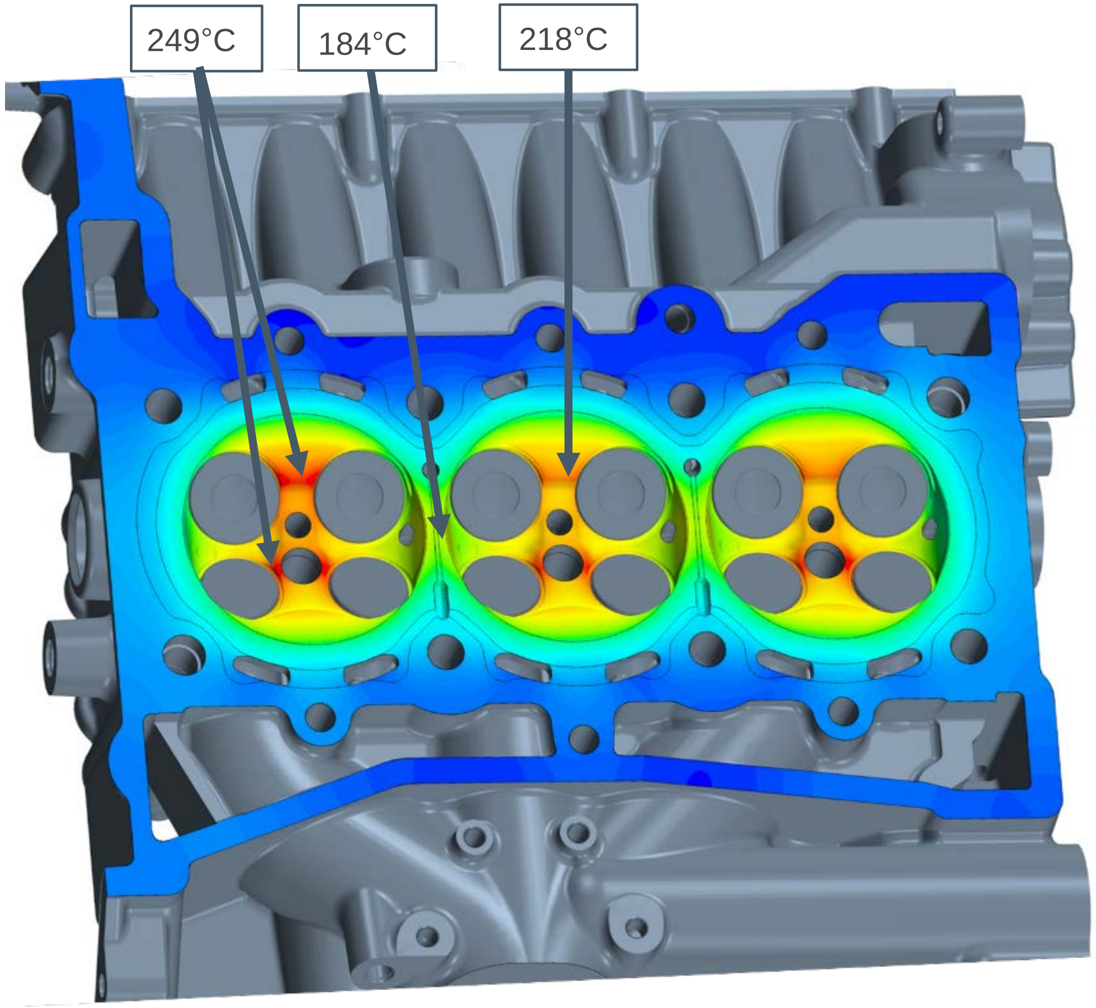
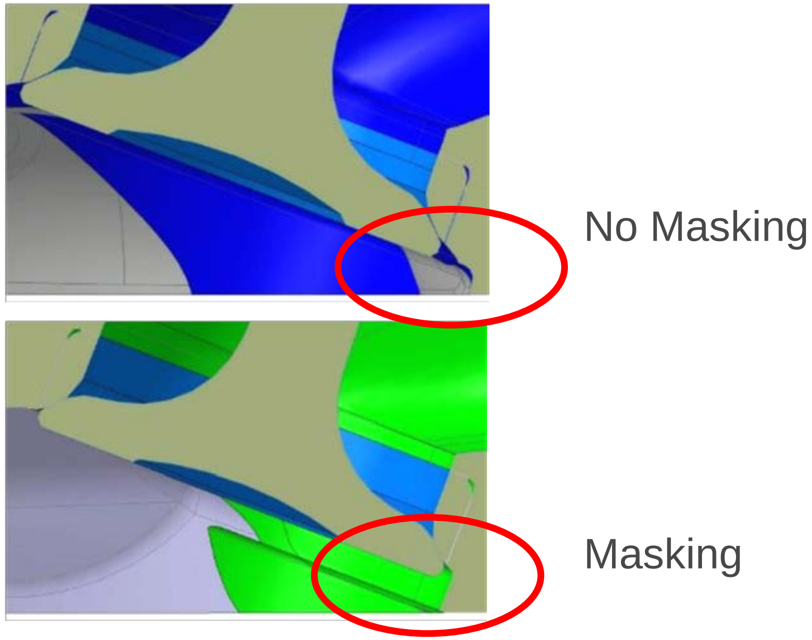
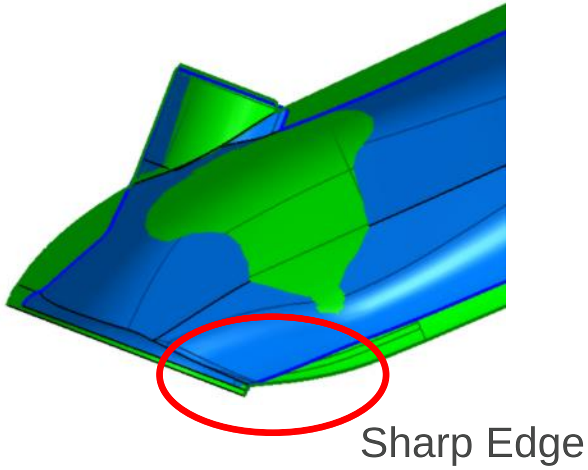
ADVANCED COOLING CONCEPT : CYLINDER HEAD MATERIAL TEMPERATURES

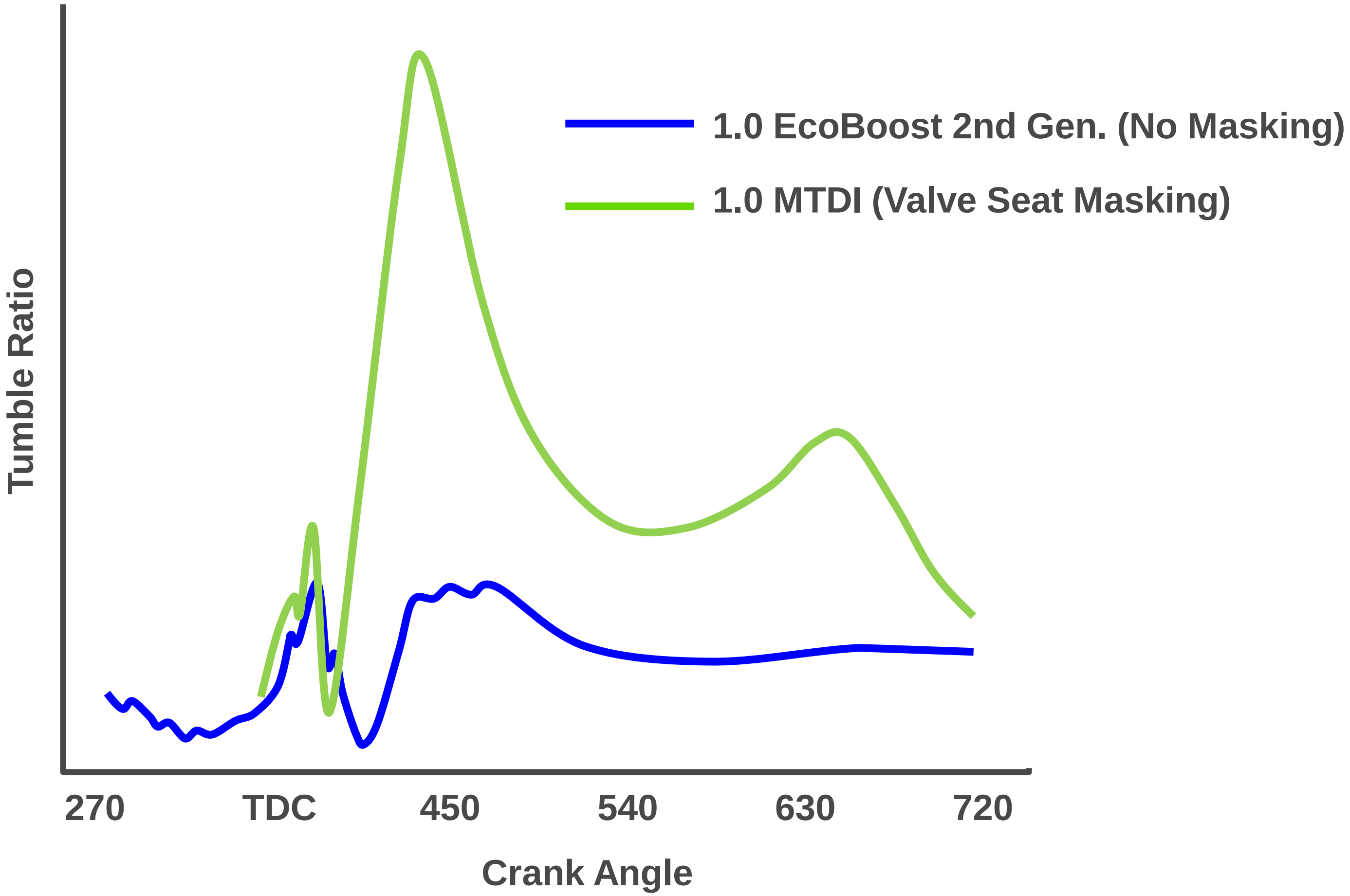


- Thermal load calculated for rated power conditions
- Limit for acceptable material temperature not exceeded
- HCF and LCF requirements met for serial production

INTAKE PORT DESIGN + VALVE SEAT MASKING FOR ENHANCED TURBULENCE







- High tumble level leads to increased turbulent kinetic energy at TDC
- Improves gas-air mixing and accelerates combustion

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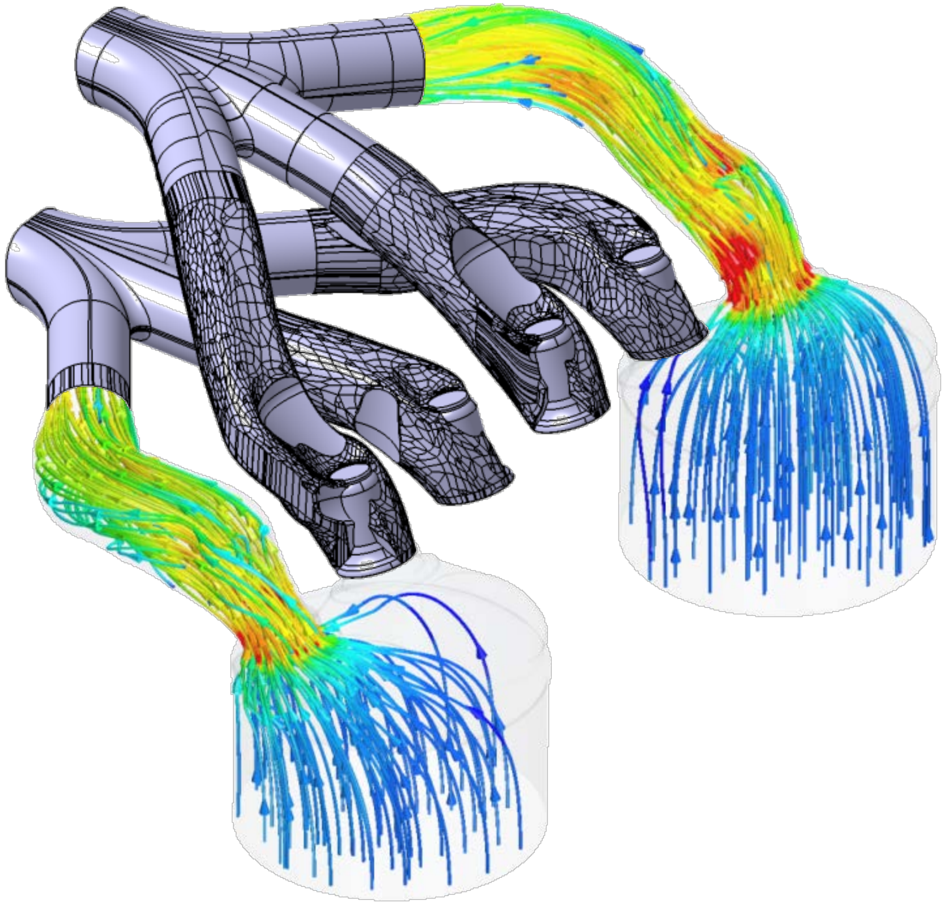
CAE BASED OPTIMIZATION OF EXHAUST PORT FLOW



- Design of all exhaust ports optimized for best mass flow rate
- New combination of CFD topology and shape optimization used
- Mass flow rate increased by 11%
- Reduced exhaust back pressure
- Improved knock behavior and fuel economy

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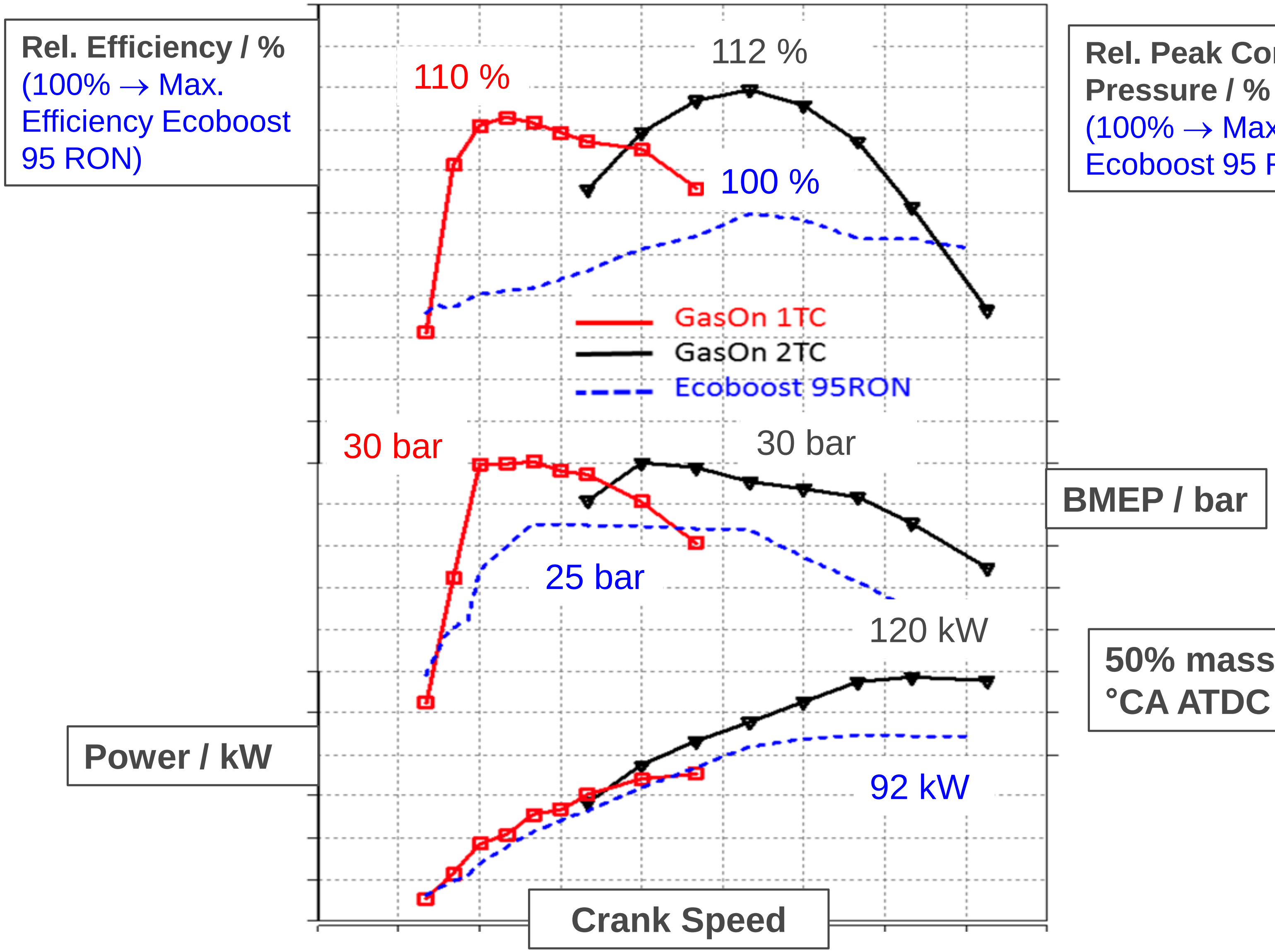
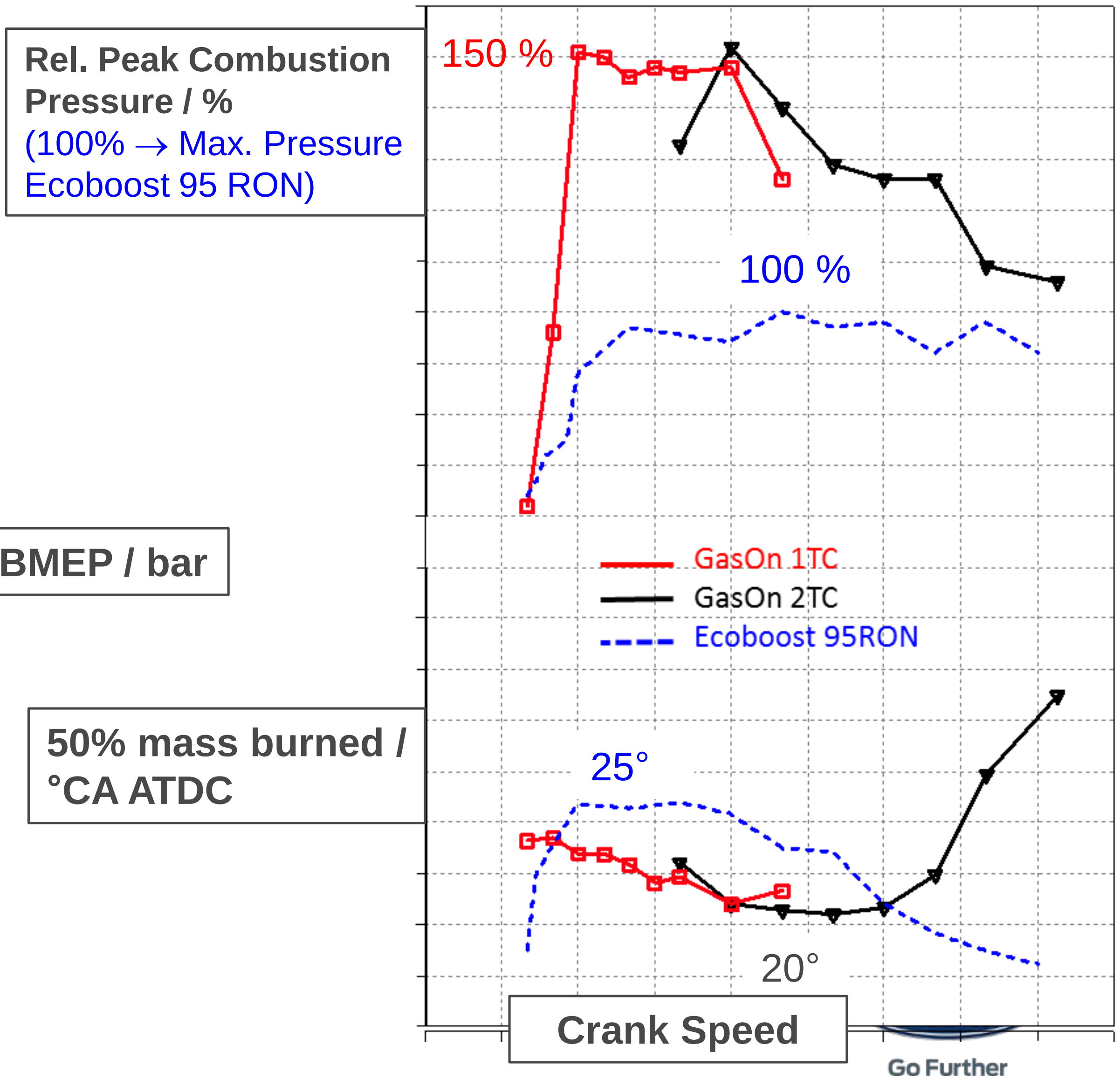
REL. EFFICIENCY, BMEP, POWER AND MAX. CYLINDER PRESSURE (CR 13)





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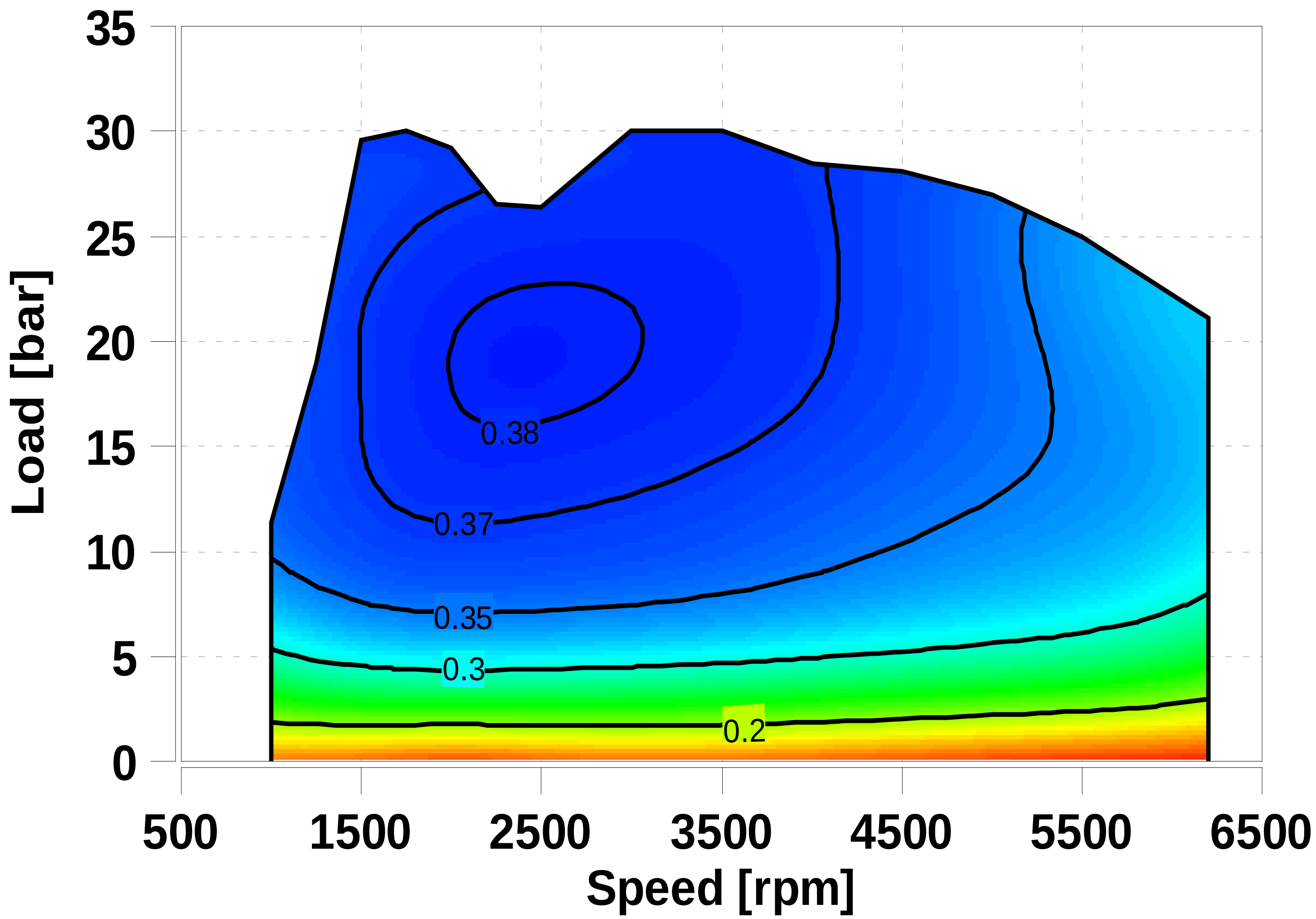
THERMAL BREAK EFFICIENCY MAP (NON-VCR ENGINE CR 13)



- Peak efficiency of 38 % measured
- High efficiency over extremely wide engine map area (> 30 % efficiency above 5 bar BMEP ≅ 17 % of max. load)
- Main contributors: high CR, knock resistant fuel and de-throttling through CVVA
- NEDC cycle simulation predicts 93 g CO_2 for a 1590 kg Vehicle
- WLTP cycle simulation predicts 120 g CO_2 for a 1830 kg vehicle

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VEHICLE INSTALLATION

- 4 bottles underbody replace the original gasoline tank
- 1 bottle below trunk
  (vehicle body modified, spare wheel well removed).
- 6th mounted in the trunk behind 3rd seat row.
- 7-seater capability maintained
- range approx. 650 km

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VEHICLE INSTALLATION

- Perpendicular CNG tank packaging
  → new exhaust system required,
  → releasing the exhaust gas sideways

- New dedicated catalyst (special CNG coating, high PGM, increased volume)

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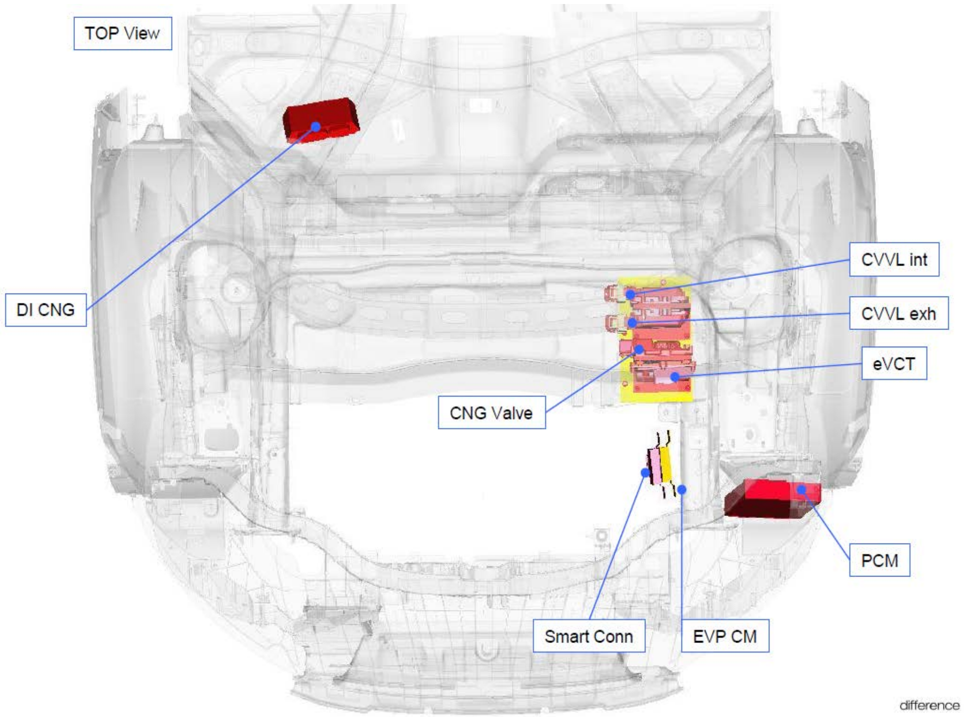
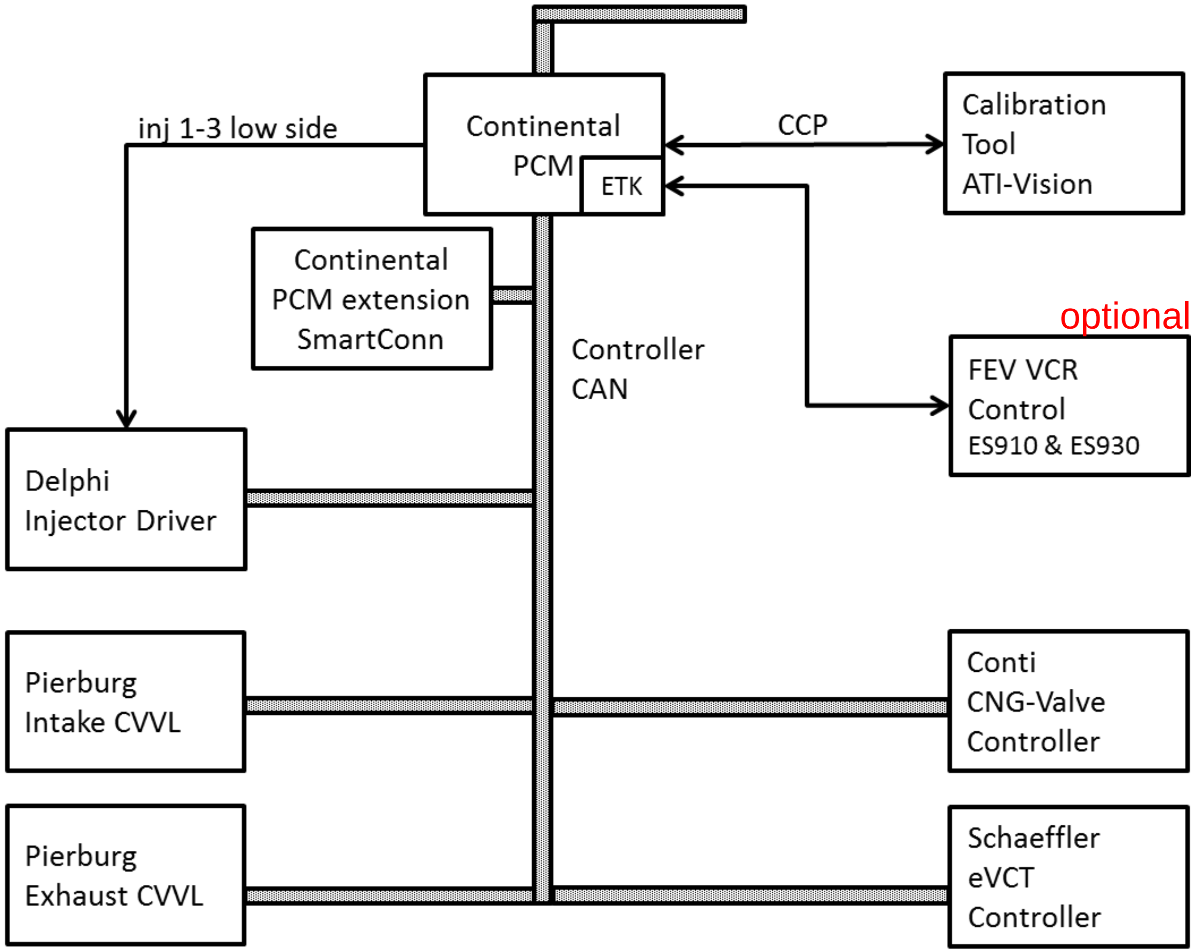
VEHICLE INSTALLATION – CONTROLS SYSTEM

Engine design with high degree of freedom, requires complex interaction of 7 control units and development of new software functionalities.





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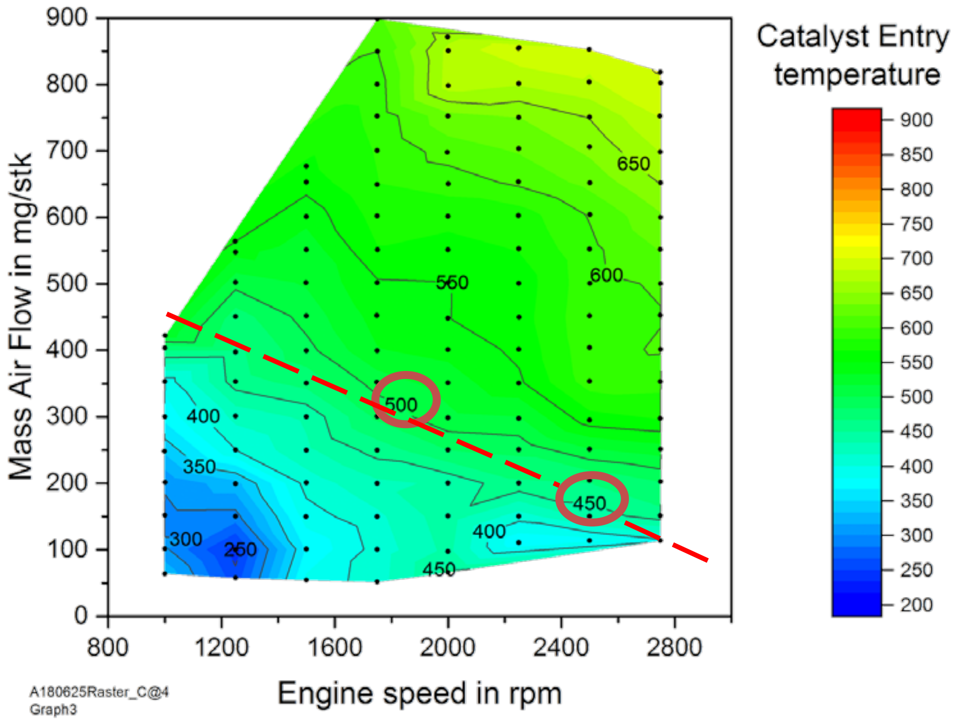
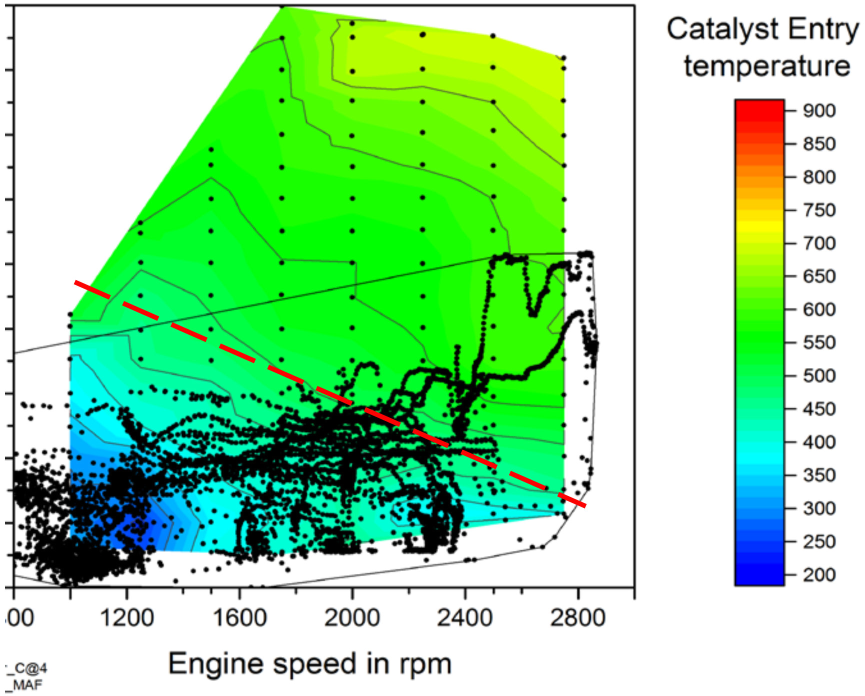
VEHICLE CALIBRATION - CATALYST HEATING REQUIREMENTS

- CH_4 conversion requires min. catalyst temperatures of 450 – 500°C
- Catalyst temperature not sufficient for CH_4 conversion in most parts of NEDC
- Countermeasure: Implementation of "Lambda Split Function" (2 cylinders rich and 1 cylinder lean)
  → de-balancing increases generation of CO
- CO oxidation in the catalyst generates additional heat directly in the catalyst (no heat losses).





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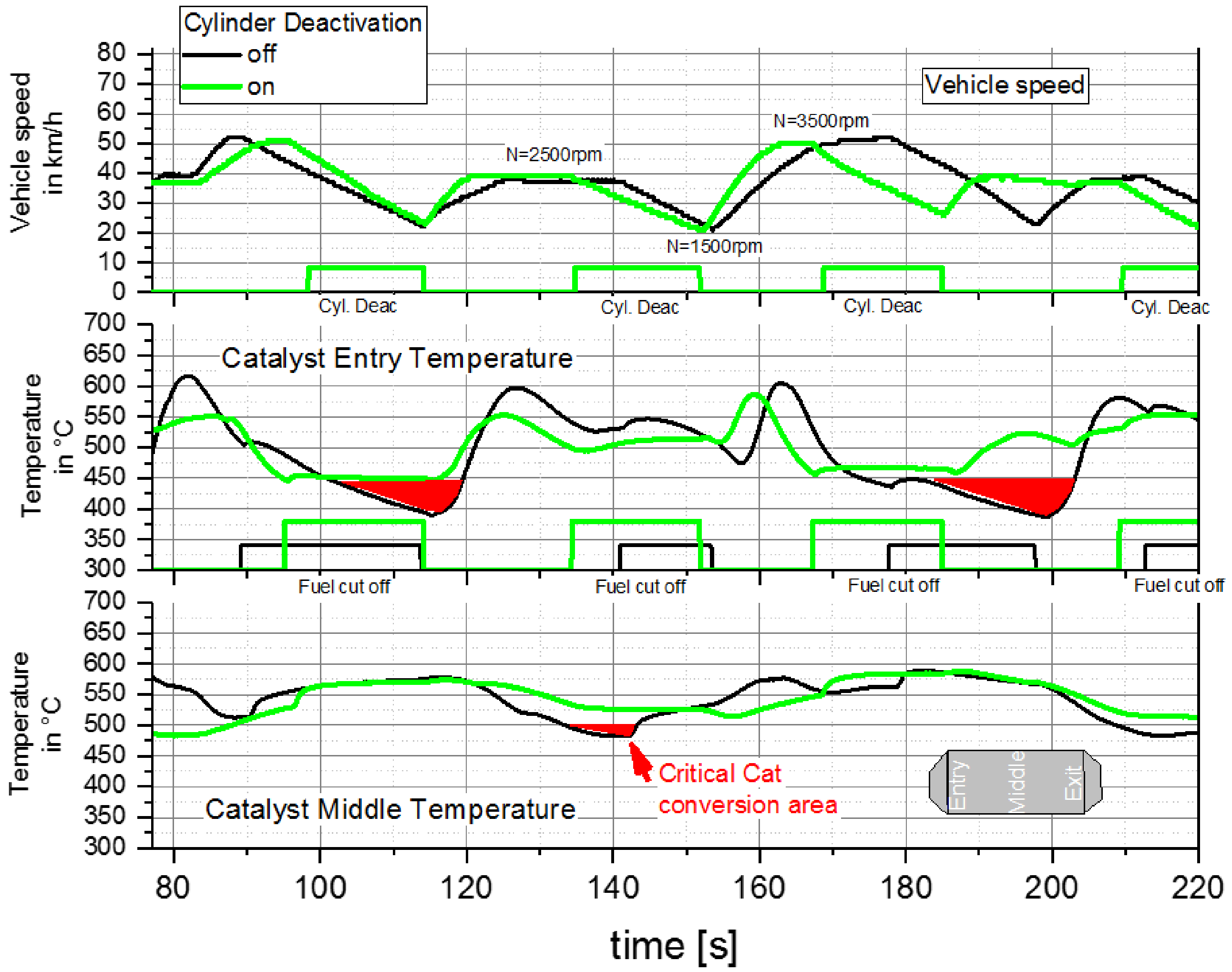
VEHICLE CALIBRATION – CYLINDER DEACTIVATION

Cylinder deactivation during fuel cut off introduced to reduce HC emissions



- CVVA system on intake side offers cylinder deactivation
- Cylinder deactivation used in order to prevent catalyst cooling at engine motoring and fuel cut off phases
- Reduction of HC peaks after fuel cut off phases due to higher catalyst temperature

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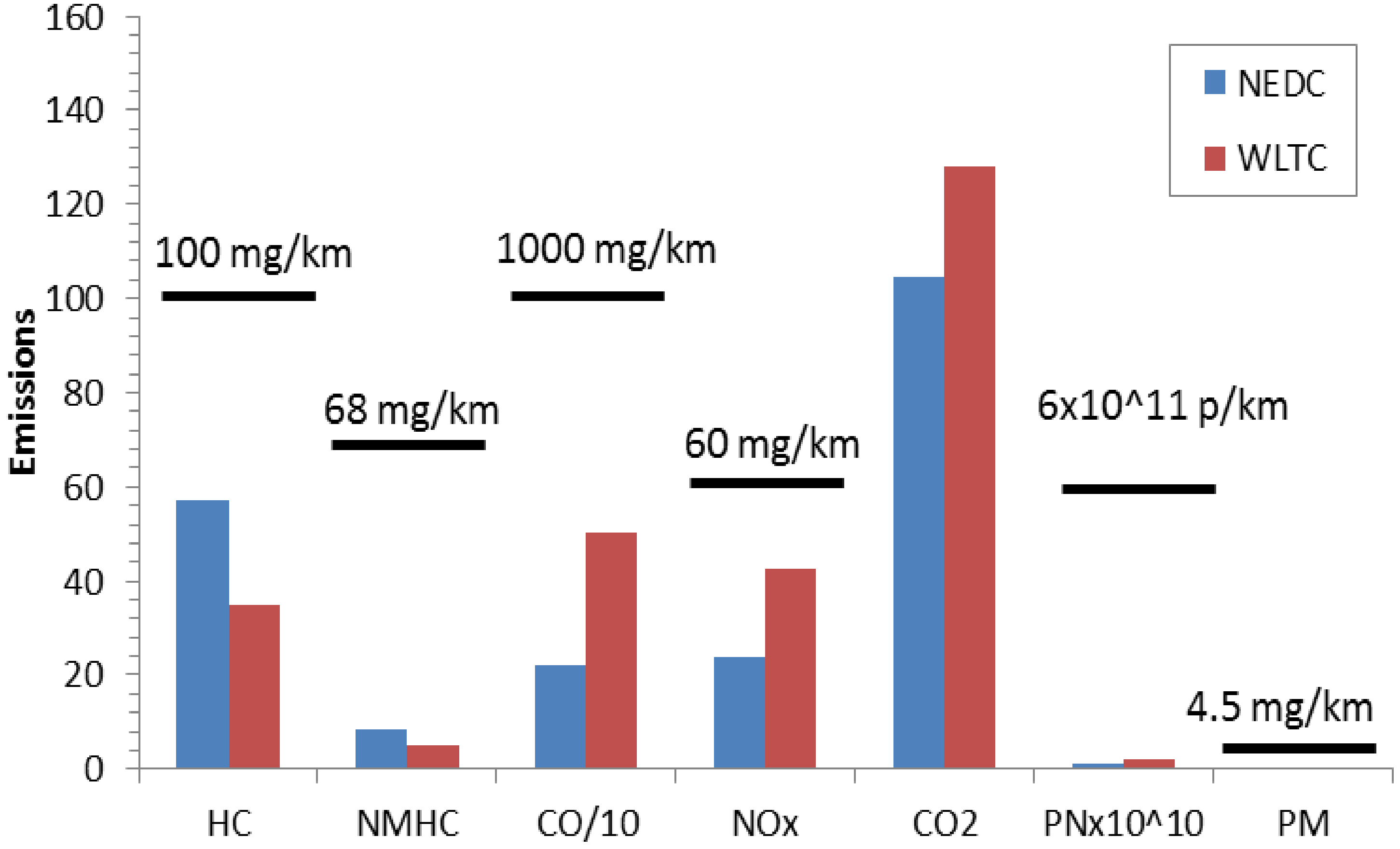
VEHICLE CALIBRATION – NEDC/ WLTC CONFIRMATION BY JRC

- JRC* confirmed emission capability in NEDC and WLTC.
- All emissions significantly below limits in NEDC and WLTC
- Very low PN without any particle filter



*JRC: Joint Research Centre of the EU

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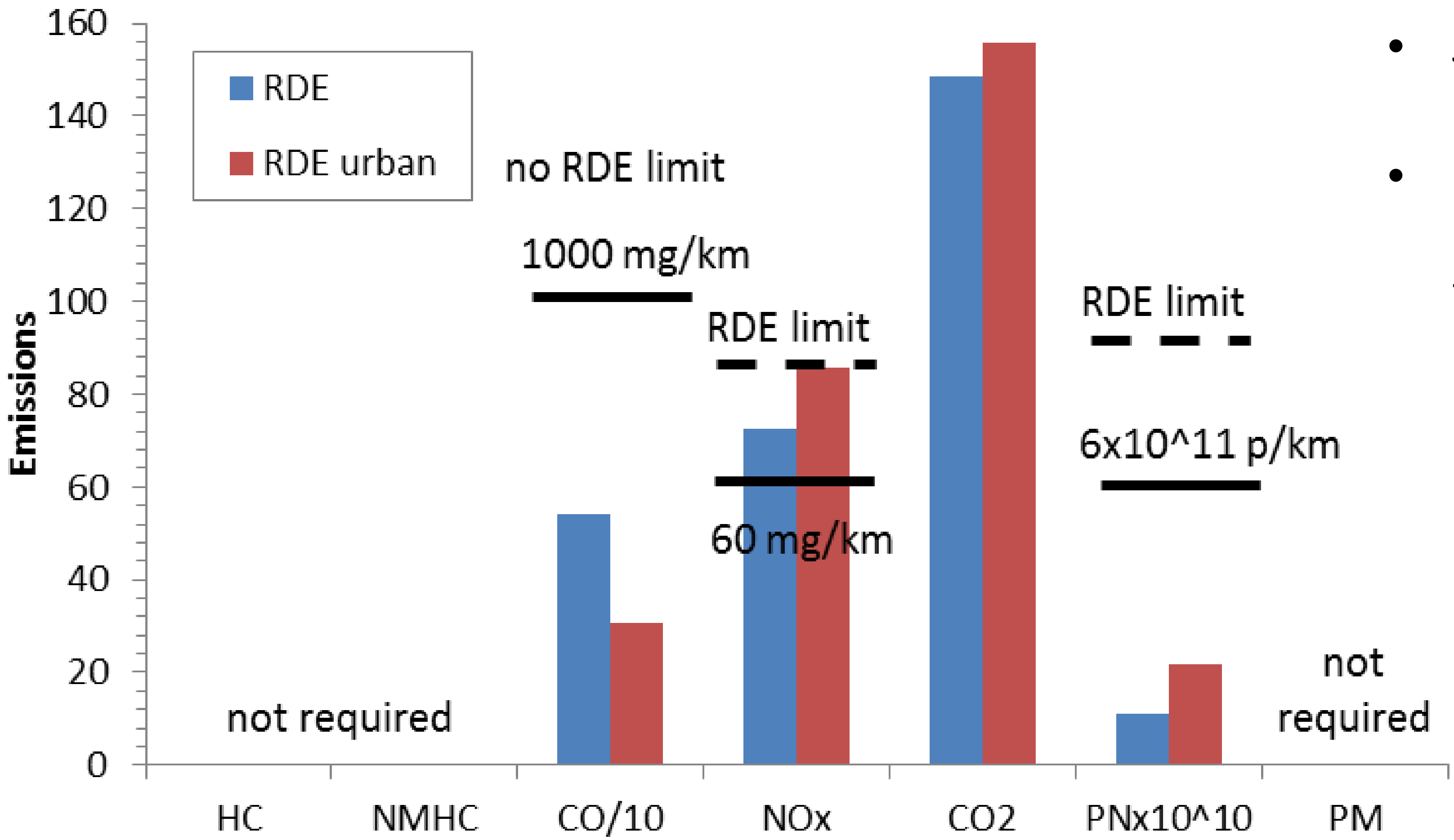
VEHICLE CALIBRATION – RDE CONFIRMATION BY JRC

JRC confirmed emission capability in RDE for EU6d limits.



- JRC on-road results for RDE compliant route with PEMS
- Lines give the laboratory Euro 6 limits. Dashed lines show the 2020 RDE limits, which are subject to annual revision

VEHICLE CALIBRATION – SUMMARY OF EMISSION RESULTS

- All NEDC, WLTP and RDE emissions - CO, NOx, PN, THC, NMHC below EU6 limits
- CO_2 target (> 20 % below BIC 2014 CNGV in NEDC) achieved

~1% CO2 reduction for homologation fuel G20/G25, since tests were carried out with pump fuel (approx. 95 % CH_4 and 5% C_2H_6). Replacement of 7 ECUs by 1 integrated ECU would lead to additional 0.5 – 0.7 gCO2/km reduction by reduction of electrical load

	Bag	HC	CO	CO2	Corrected CO2	NOx	NMHC	HC + NOx	Fuel econ.	Particulate	PN
		[mg/km]	[mg/km]	[g/km]	[g/km]	[mg/km]	[mg/km]	[mg/km]	[m3/100km]	[mg/km]	[1/km]
	Limits EU6	100	1000			60 84 (RDE)	68			4,5000	6,00E+11
Testbench CONTI	**NEDC**	62,5	188,5	100,5	99,0	34,5	8,5	97,0	5,6		7,47E+09
	WLTP	31,1	467,3	121,7	120,0	43,4	1,9	74,5	6,8	0,2	1,62E+10
	RDE - aggressiv	59,3	613,9	161,0	159,0	76,0	2,6	135,3	9,0	3,0	5,84E+10
Testbench JRC	**NEDC**	57,0	220,0	105,0	103,5	24,0	9,0				1,30E+10
	WLTP	35,0	510,0	128,0	126,5	43,0	5,0				2,20E+10
	RDE		540,0	148,0	146,5	73,0					1,10E+11
	RDE Urban		310,0	156,0	154,5	85,0					2,20E+11

VEHICLE CALIBRATION – CO_2 VS. GASOLINE/DIESEL

- WLTP CO_2 approx. 20% better than diesel and approx. 40 % better than gasoline (without any electrification)

For comparison:

Ford Grand C-MAX (MY 2019)	WLTC CO_2: g/km	WLTC CO_2 Difference to GasOn
GasOn CNG 1.0 l (120 kW)	120 … 126	reference
Gasoline 1.5l Ecoboost (110 kW)	169 … 172	34 … 43 %
Diesel 2.0l TDCi (110 kW)	146 … 152	16 … 27 %

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SUMMARY

- New combustion engine concept - based on the new Ford 1.0L GTDI Ecoboost ® - dedicated to operation with methane fuel (CNG)

- Engine structure for very high combustion pressures up to 185 bar
- Engine cooling system adapted to significantly increased thermal load
- Fully variable mechanical valve actuation (CVVA) system for intake and exhaust valves
- Parallel sequential 2-stage turbo charger system
- Methane direct injection system

- Maximum power output of 120 kW and 30 bar BMEP over a wide engine speed range achieved

- NEDC CO_2 reduction > 20 % (NEDC) vs. best in class CNG vehicle 2014 (and today 2019 !)
- WLTC CO_2 reduction ~ 20 % vs. Diesel and ~ 40 % vs. Gasoline

- EU6 emission limits met in NEDC, WLTC and RDE with a single 3-way-catalyst.
- PM and PN are extremely low without any particulate filter.

- Type 4 CNG storage system ensures a full driving range of ~650 km (with only ~ 80 kg on-weight) while 7-seats are kept

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ACKNOWLEDGEMENTS

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Q & A

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