FIAT CHRYSLER AUTOMOBILES

Advanced Engine Cooling Systems for Vehicle Application

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EDUCATION

- Mechanical Engineering Master Degree
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BACKGROUND

- (2014) FIAT CHRYSLER AUTOMOBILES EMEA - Engine Systems Unit Responsible
- (2013) FIAT GROUP AUTOMOBILES EMEA - Fuel System Responsible
- (2008) FIAT GROUP AUTOMOBILES - Cooling System Responsible
- (2006) FIAT POWERTRAIN TECHNOLOGIES - Cooling System Manager
- (2001) FIAT AUTO - Cooling System Engineer
- Association of Engineers member

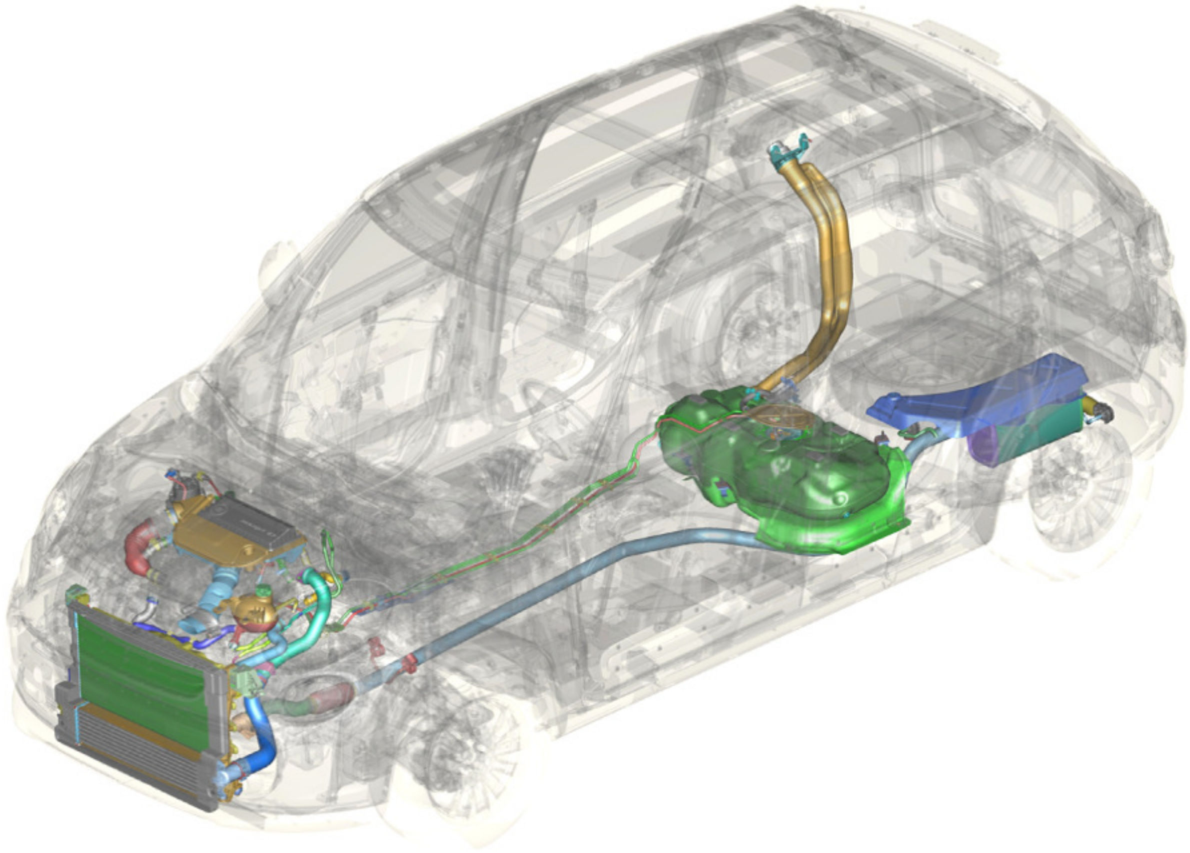
Index

- **Engine Systems: Overview**
- **Cooling Systems: the Reason and the Operation**
- **Cooling Systems: Roadmap**
- **An innovative concept: the *Smart Cooling* System**
- **Open questions**

OUR MISSION

INTAKE system

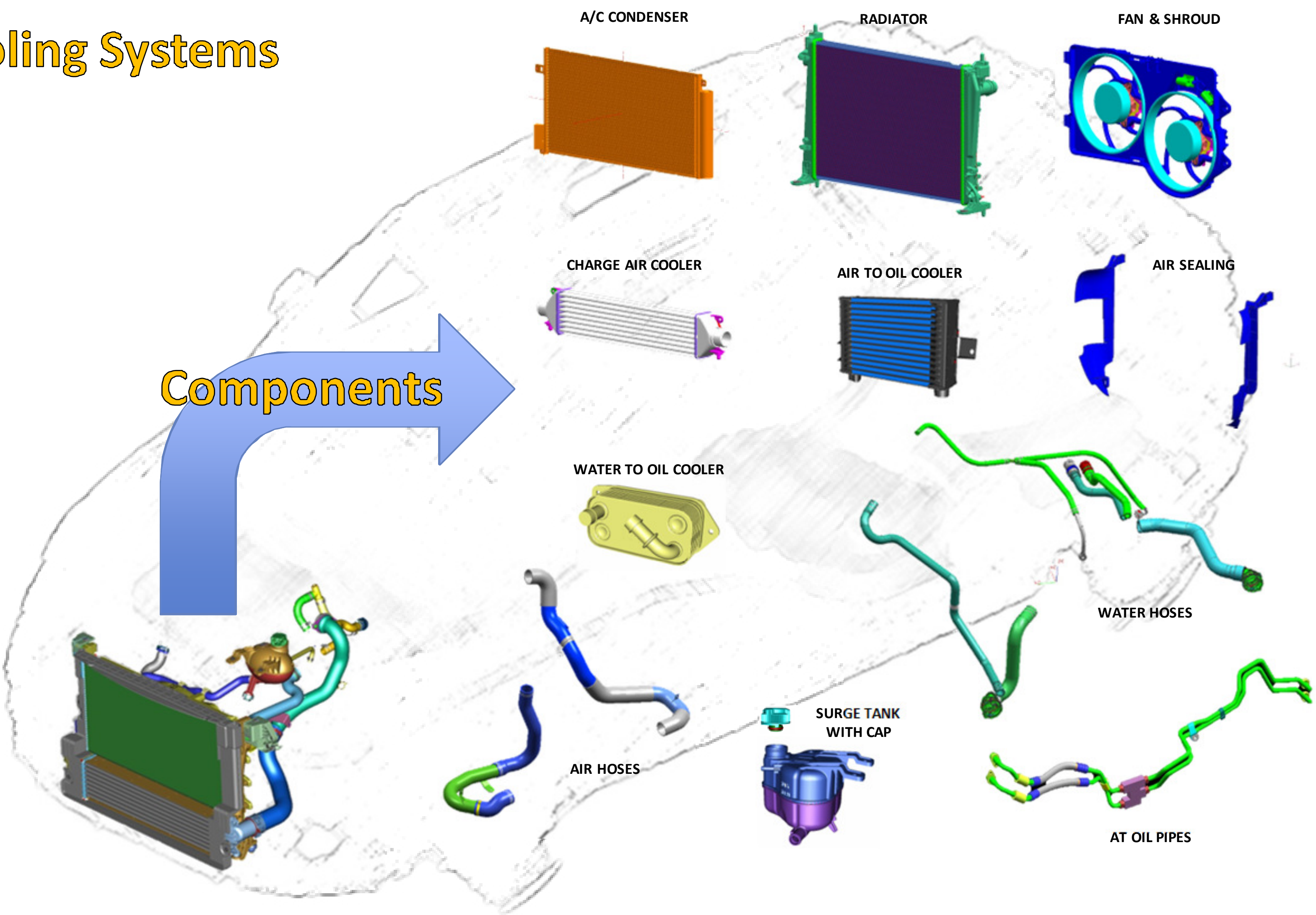
COOLING system



EXHAUST system

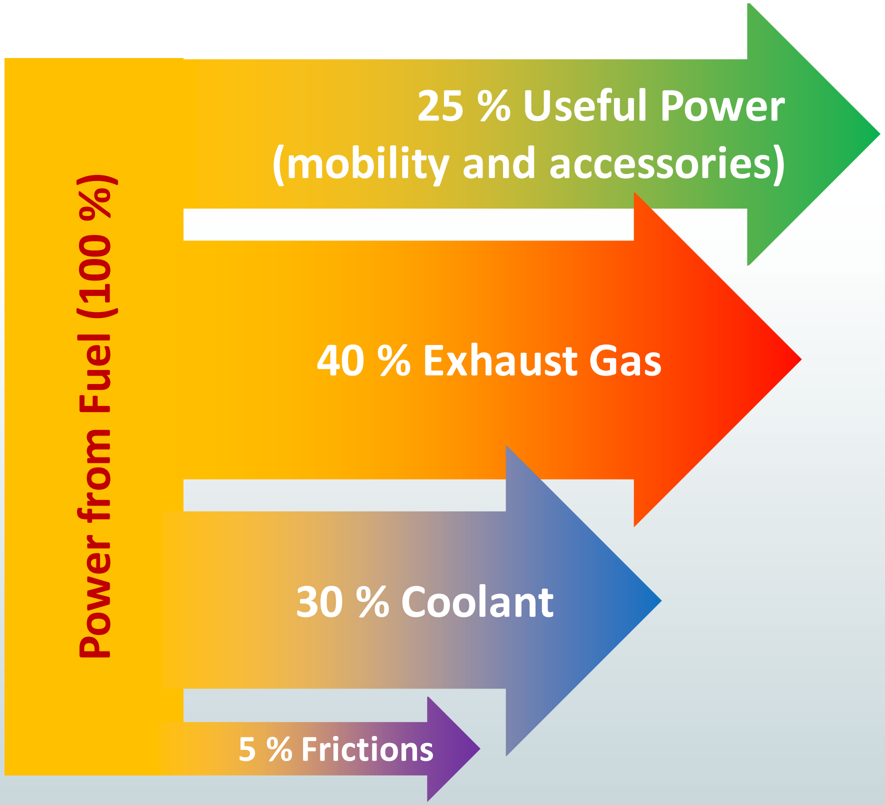
FUEL system

Cooling Systems



Cooling System: Why?

Typical energy split for a vehicle engine



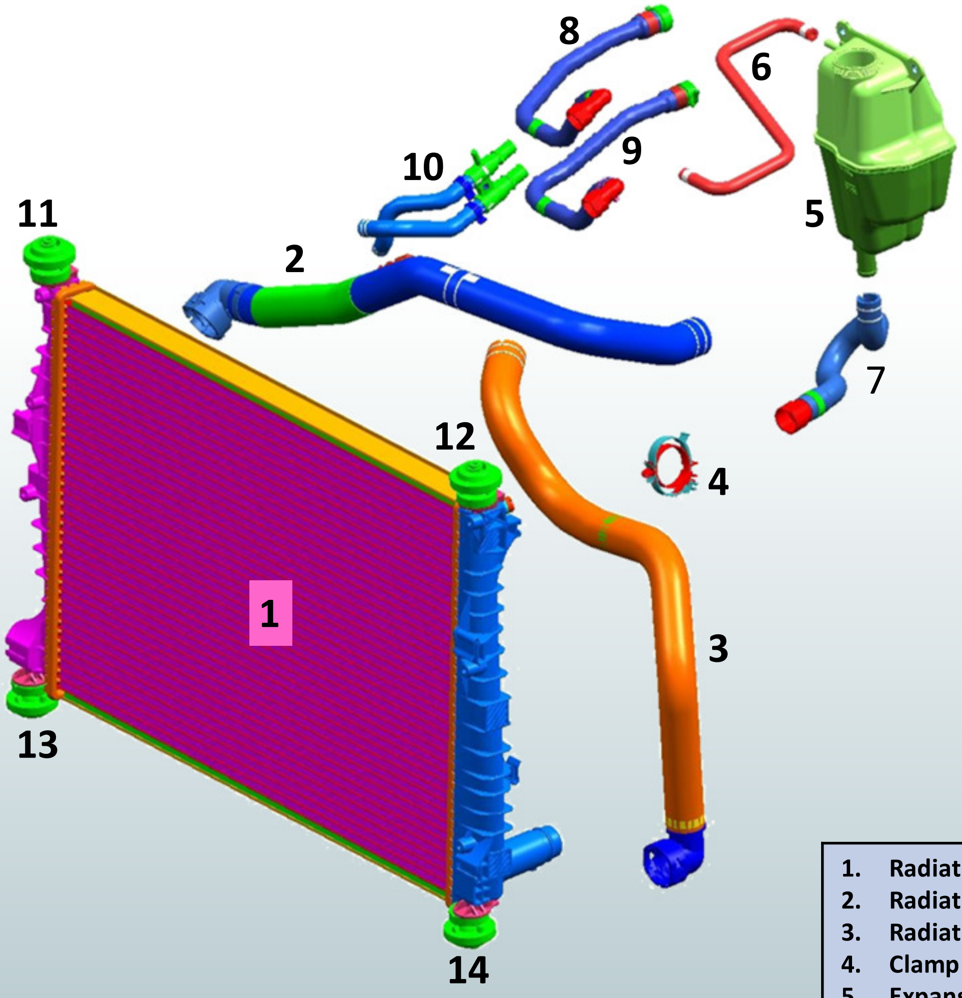
Which is the reason of a cooling system?

- **Only a fraction of the fuel power is usable**
- **The main part is rejected through the exhaust line or is rejected as heat**
- **The cooling system is used to transfer the heat in excess to the ambient and to keep the engine temperature within the limits**

The cooling system is composed by several subsystems:

- ✓ **Water**
- ✓ **Fan & Shroud**
- ✓ **A/C condenser**
- ✓ **Charge air**
- ✓ **Oil**

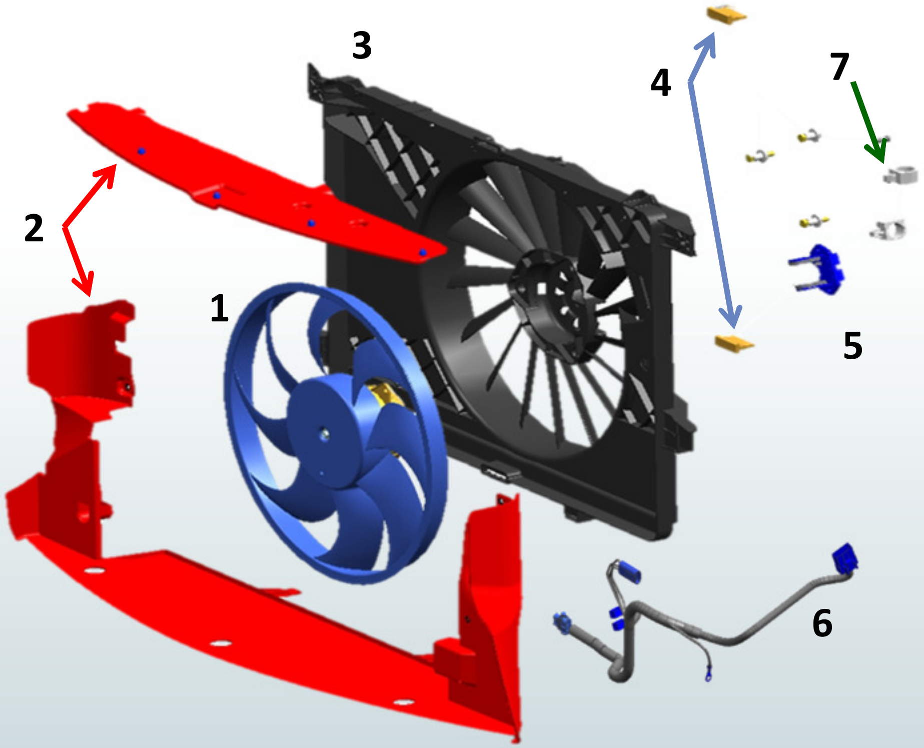
Components of the water system



- The excess of engine heat is transferred from the engine metal structure to the coolant, which through the heat exchanger (radiator) installed in front of the vehicle is cooled by the ambient air
- A centrifugal pump, usually driven by the engine shaft, circulates the coolant
- Usually the coolant liquid is a water/ethylene glycol mixture with specific cleaning and anticorrosion agents
- This mixture presents the following advantages:
  - High specific heat (and heat capacity)
  - Low viscosity, so low pressure losses and good heat exchange
  - No significant variation of the physical properties along the time and a wide range of temperature
  - High latent heat of evaporation
- Ethylene glycol is added to lower the water freezing temperature below -30 °C
- The radiator is the main component of the system. Its size may impact the complexity and the cost of the whole system integration

1. Radiator	7. Filling pipe
2. Radiator inlet hose	8. Cabin heater inlet hose
3. Radiator outlet hose	9. Cabin heater outlet hose
4. Clamp	10. 4-ways heater inlet/outlet
5. Expansion tank	11-14. Radiator fixation parts (with rubber insert)
6. Degassing pipe	

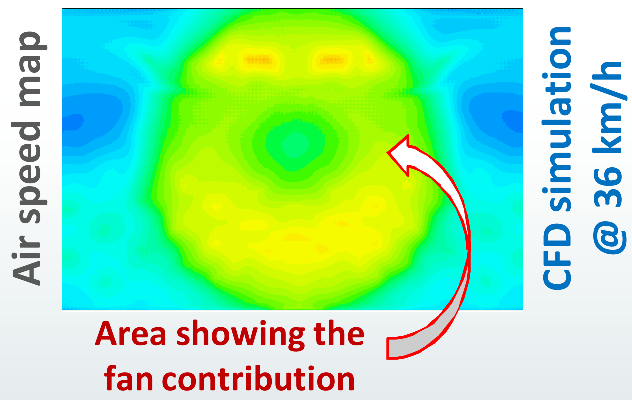
Components of the fan & shroud system



1. Fan 2. Air conveyor 3. Plastic shroud 4. Elastic plug	5. Resistor 6. Wiring harness 7. Wiring harness fixation

The main goal of the Fan & Shroud system is to guarantee the needed amount of cooling air through the cooling module

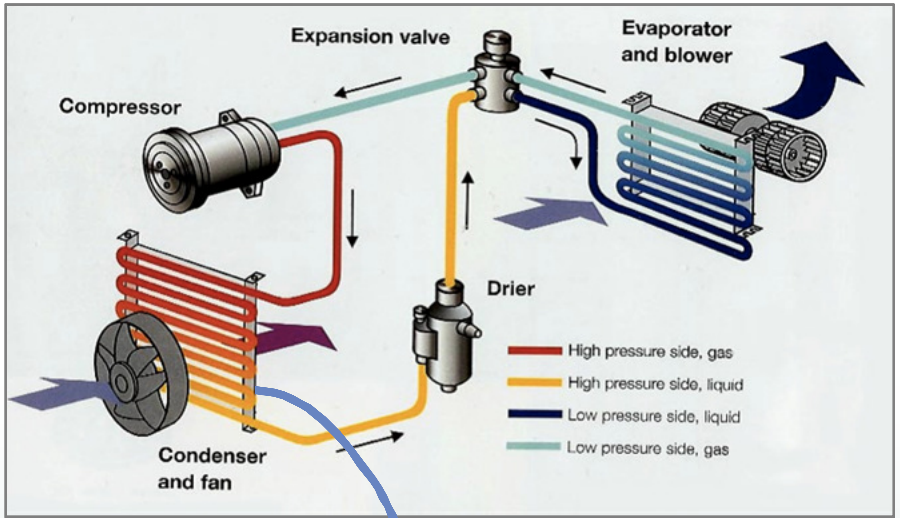
At low vehicle speed the fan contribution is fundamental to increase the air flow



The main constraints are:

- The heat exchange according to the vehicle thermal balance
- The packaging limitations inside the engine bay, the installation constraints and the safety requirements
- The maximum allowed electric power
- The noise emissions and component vibrations

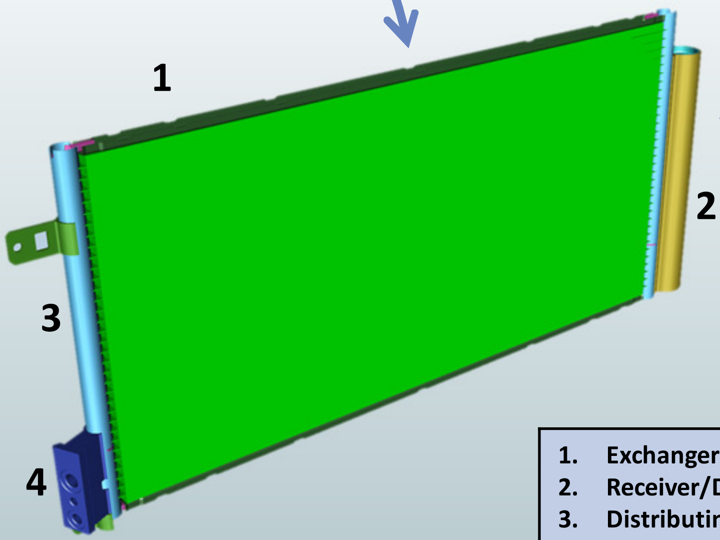
A/C Condenser



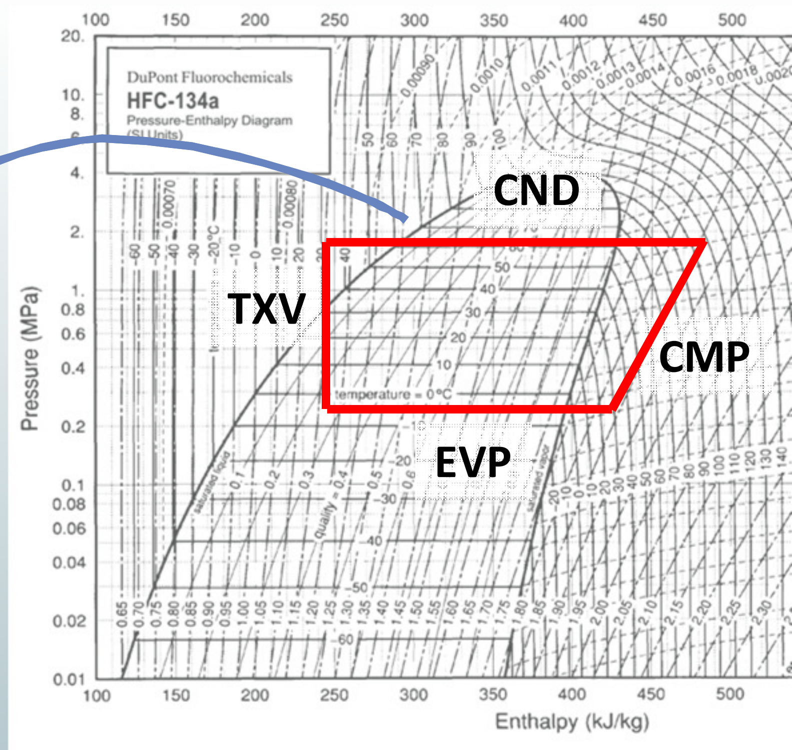
The goal of A/C condenser is **to reject the heat of the A/C evaporator and A/C compressor** in order to assure the cabin thermal comfort

The **main constraints** are:

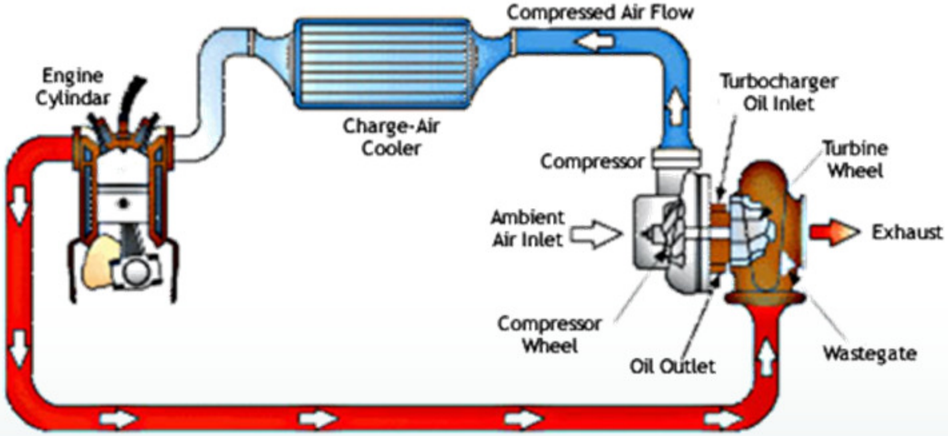
- The heat exchange according to the HVAC requirement
- The packaging limitations inside the engine bay, the installation constraints and the safety requirements

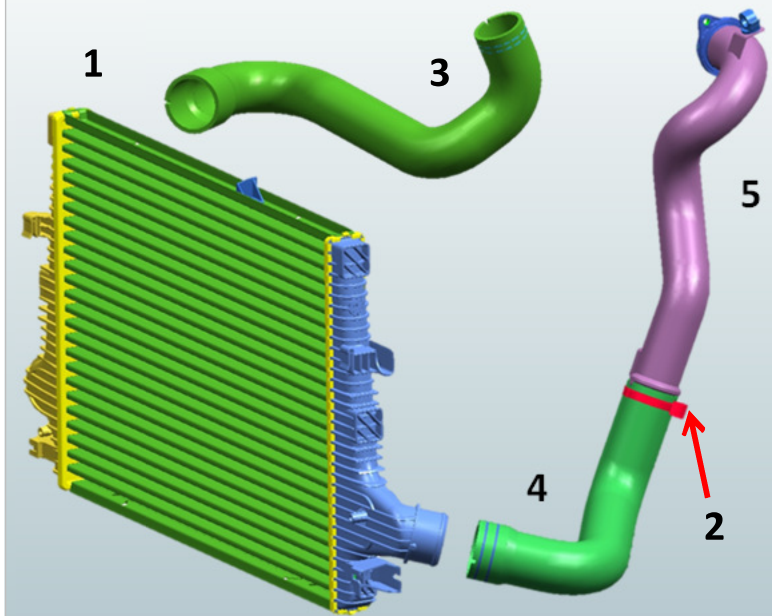


1. Exchanger core
2. Receiver/Dryer
3. Distributing tank
4. Block joint



Components of the charge air cooling system





The main goal of the Charge Air cooling system is to **decrease the temperature of the pressurized air** after the turbocharger

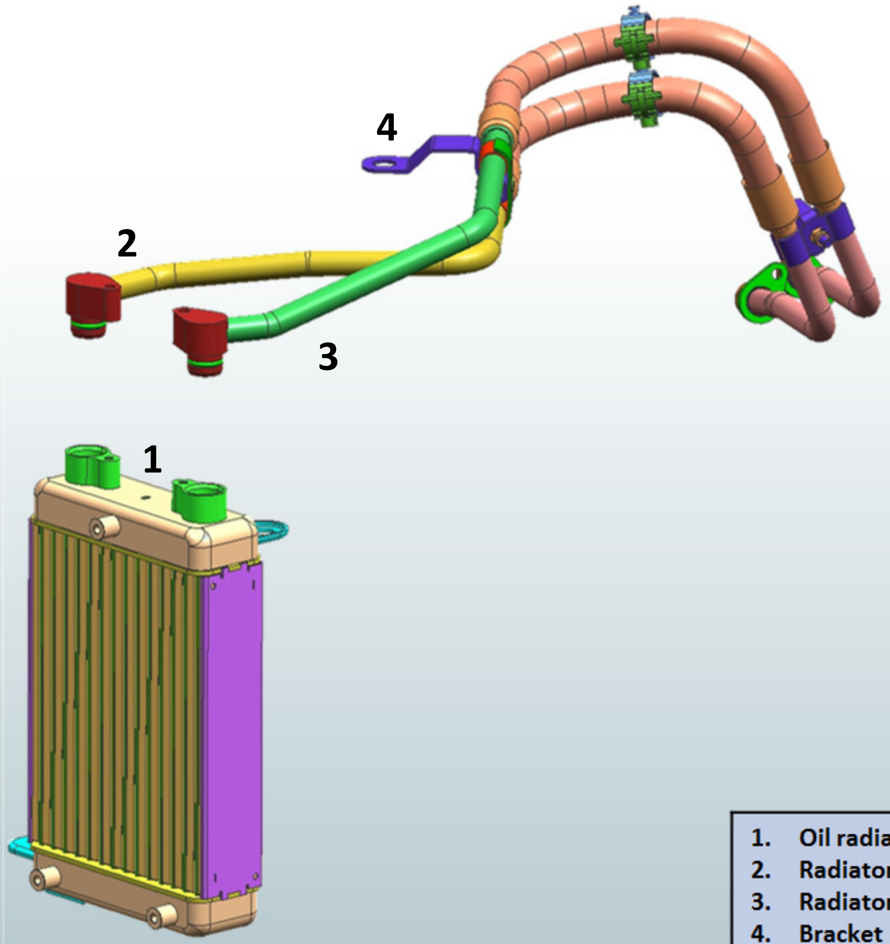
- A low air temperature guarantees a good combustion inside the engine, lowering the pollutant emissions and the fuel consumption
- Also, the system should assure the best trade-off between pressure drop and air volume from compressor outlet to the intake manifold to enable an optimal power supply

The **main constraints** are:

- The heat exchange according to the vehicle thermal balance
- The packaging limitations inside the engine bay, the installation constraints and the safety requirements

1. Charge Air Cooler (CAC)
2. Clamp
3. CAC inlet flexible hose
4. CAC outlet flexible hose
5. CAC outlet rigid hose

Components of the oil cooling system



The main goal of the Oil cooling system is to limit the oil temperature, in order to:

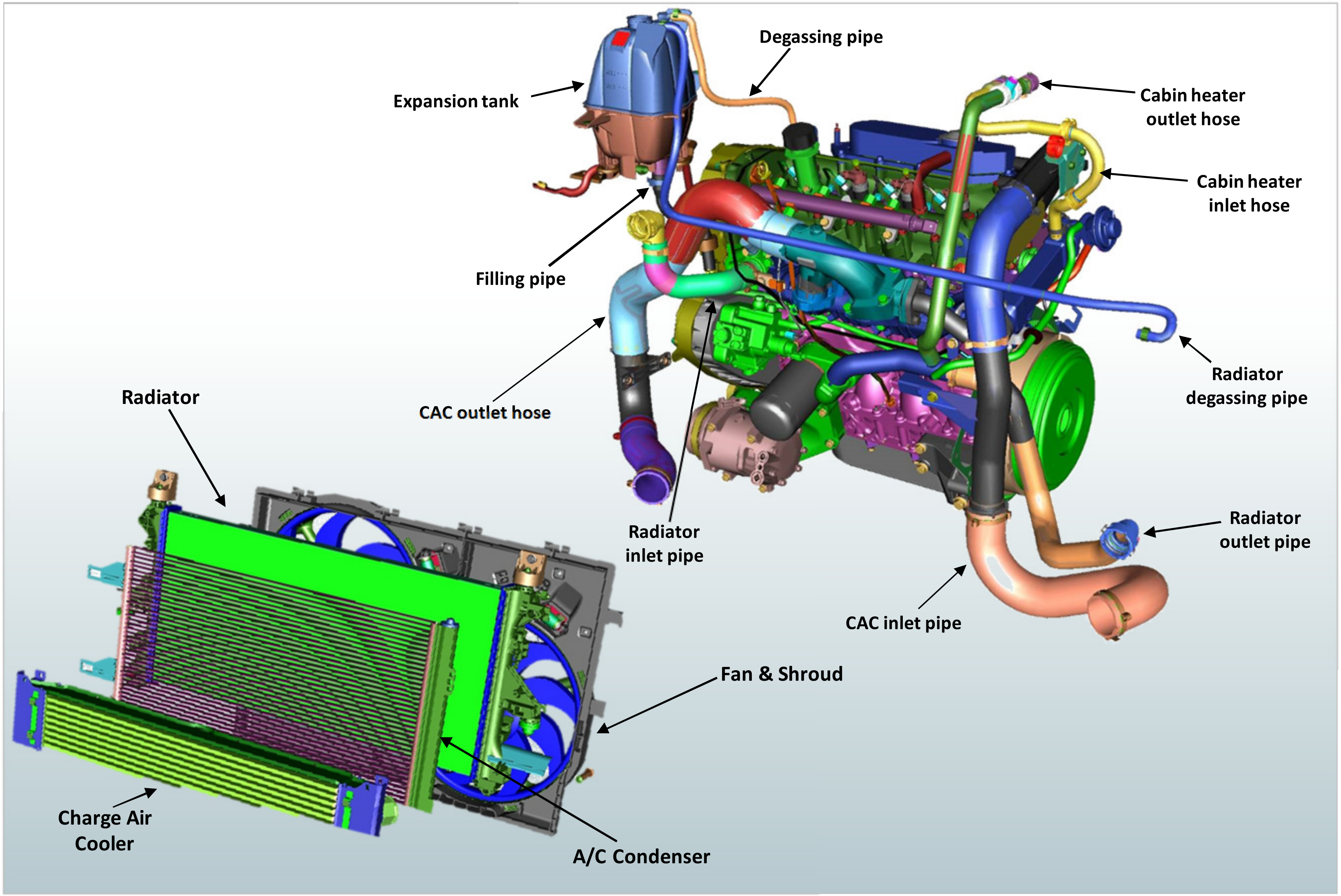
- reduce the cracking risk
- optimize the engine/gearbox oil temperature during warmup
- reduce the engine frictions
- guarantee the maximum temperatures of the engine moving parts (cylinders, valvetrain, pistons…)

The main constraints are:

- The heat exchange according to the vehicle thermal balance
- The layout packaging inside the engine bay, the installation constraints and the safety requirements

1. Oil radiator
2. Radiator inlet pipe
3. Radiator outlet pipe
4. Bracket

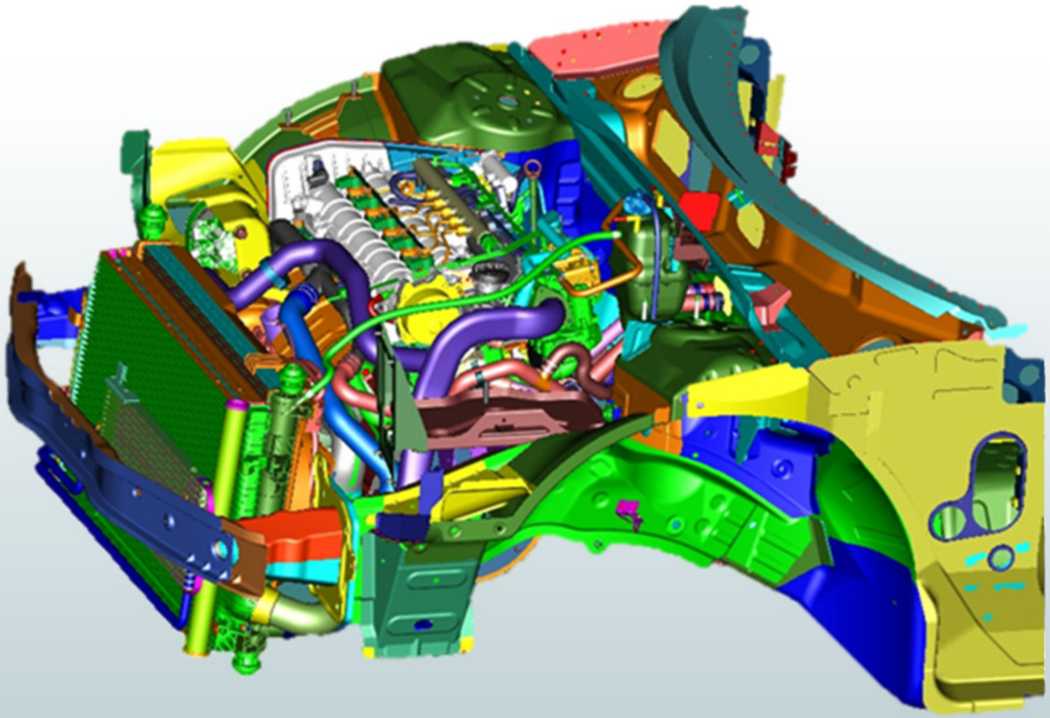
Cooling System – Components Lay-out



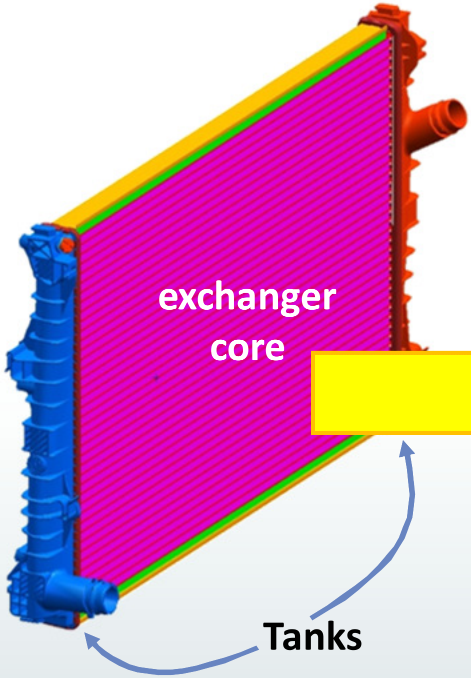
Cooling System – Engine Bay Integration

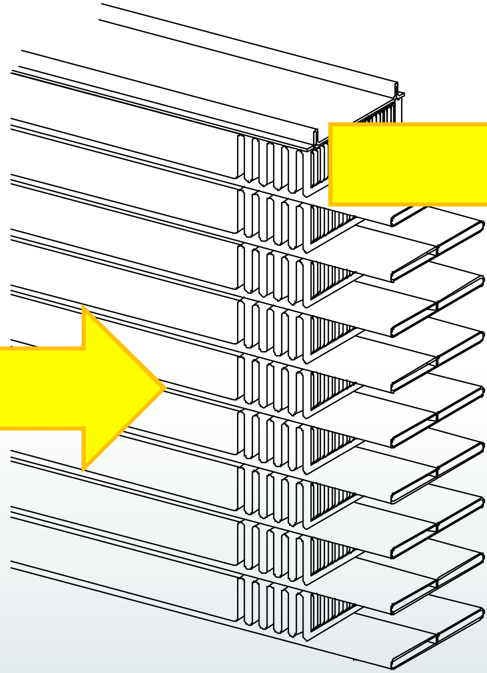
The packaging study of the cooling system components shows the interactions with the engine bay:

- **engine**
- **crash cross beam**
- **mounting/fixing**



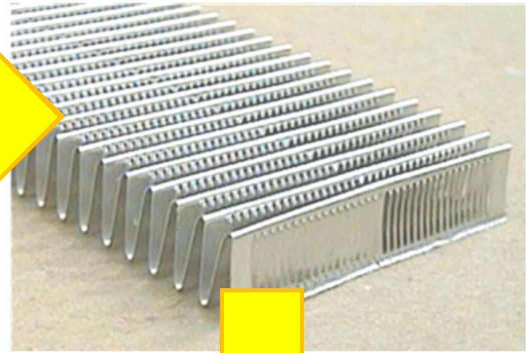
Cooling System Components: Radiator

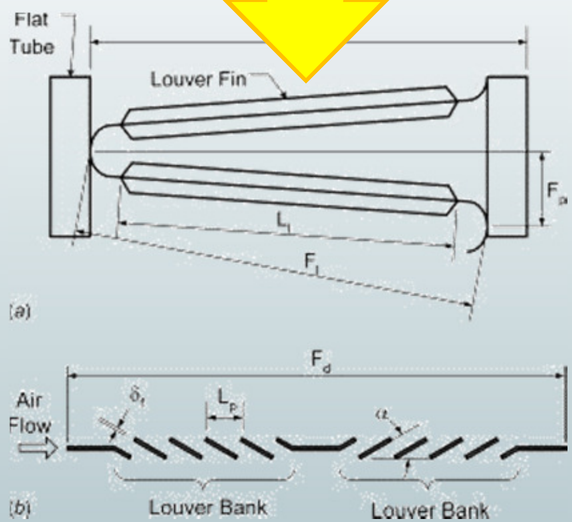




Tubes and fins assembly

Radiator fins with louvers





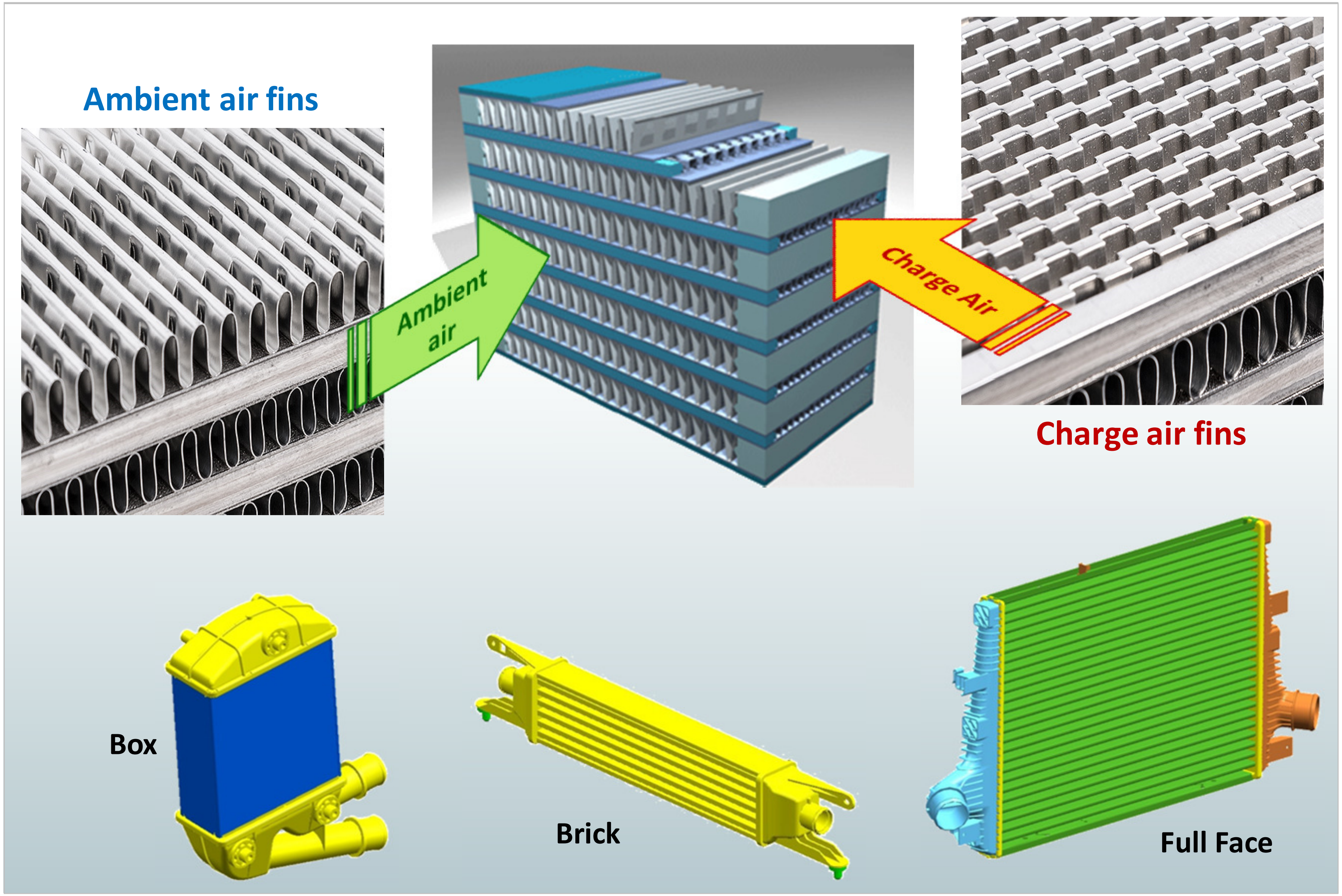
Typical materials:

- Aluminum for the core
- Plastics for the tanks

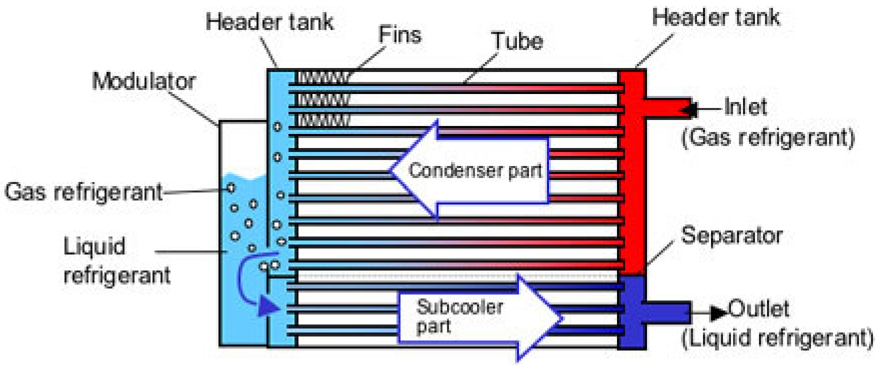
The main parameters are:

- Core technology (mechanical or brazed)
- Size and weight
- Heat exchange per surface unit
- Air and coolant side pressure drop
- Structural resistance

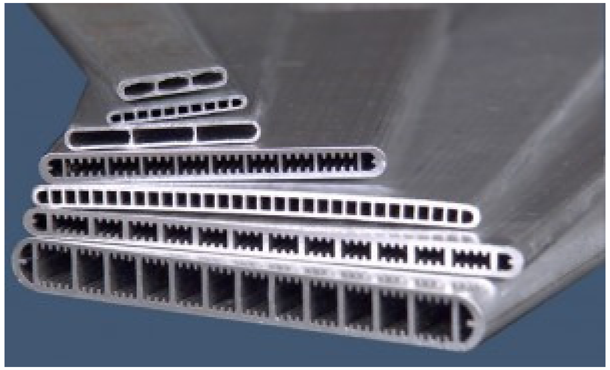
Cooling System Components: Charge Air Cooler



Cooling System Components: A/C Condenser



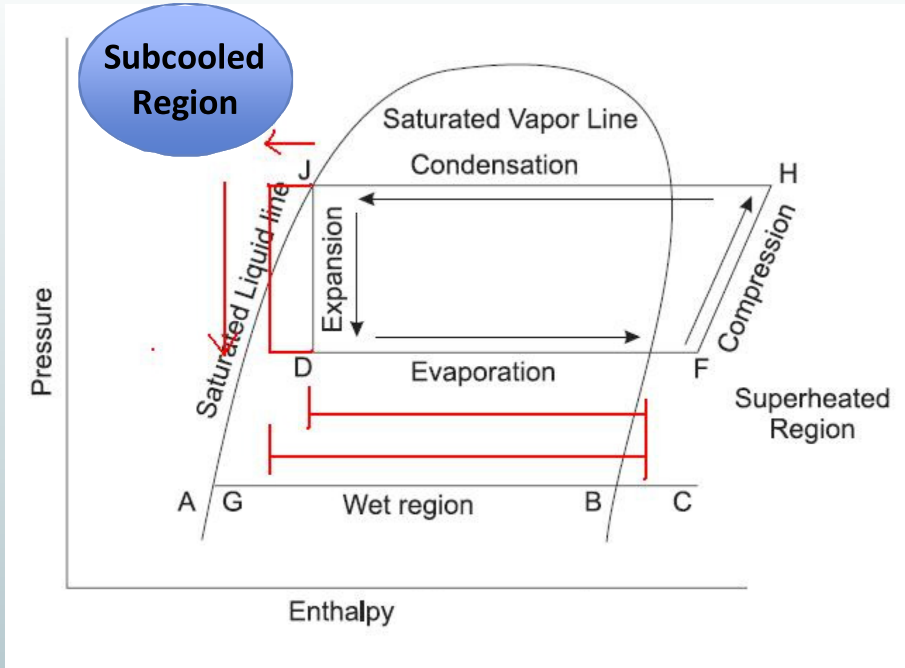
Extruded tubes for condensers



Inside a condenser, a **phase transition** occurs.

To improve the heat exchange, **several tubes are dedicated to the subcooling**, a process decreasing the temperature when the refrigerant is already in the liquid phase.

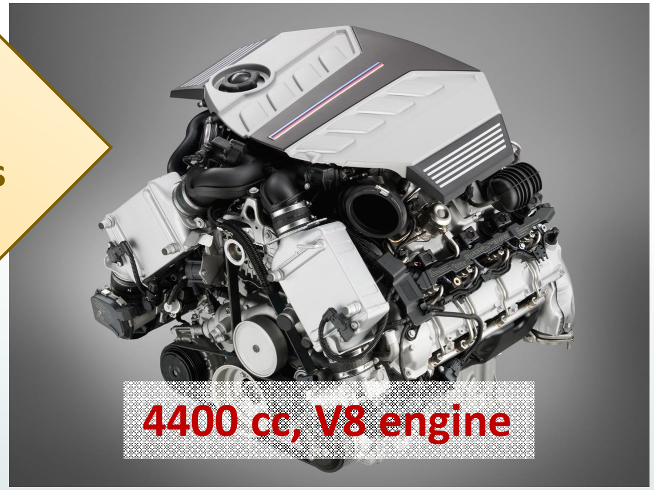
The exchanger core assembly is similar to the radiator one, but **tubes are extruded**.



Cooling Systems: Roadmap

As general trend, all the carmakers are introducing **secondary loop circuits** working at lower temperature than the engine cooling loop. This “cold” coolant circuit can be used **to serve several auxiliaries**, mainly the **charge air cooler**.

From small…
…to big engines



WCAC adoption benefits

Performance:

- reduced air pressure drop & volume
- improved air cooling
- charge air thermal management (control of the air charge temperature)

Emissions:

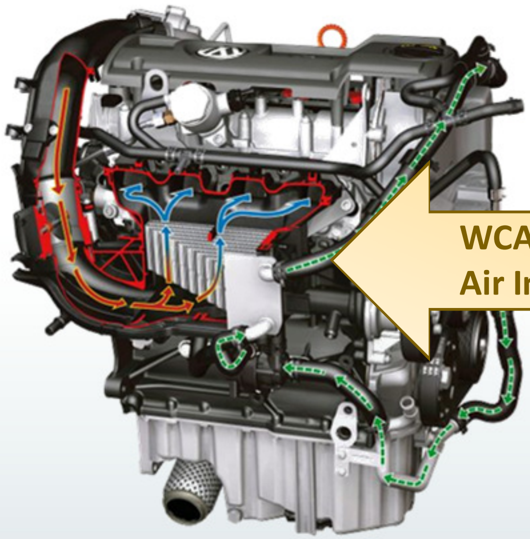
- charge air thermal management (control of the air charge temperature / density)
- with LP EGR: possibility to avoid icing and condensation
- with LP EGR: EGR rate setpoint reached more quickly

Packaging/Integration

NVH improvements

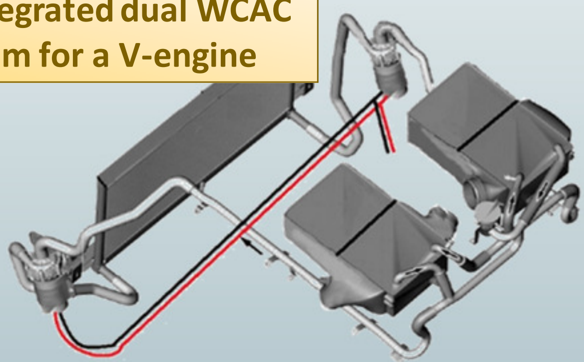
From the Air Cooled to Water Cooled heat exchangers

Charge Air Cooler →
Water Charge Air Cooler (WCAC)



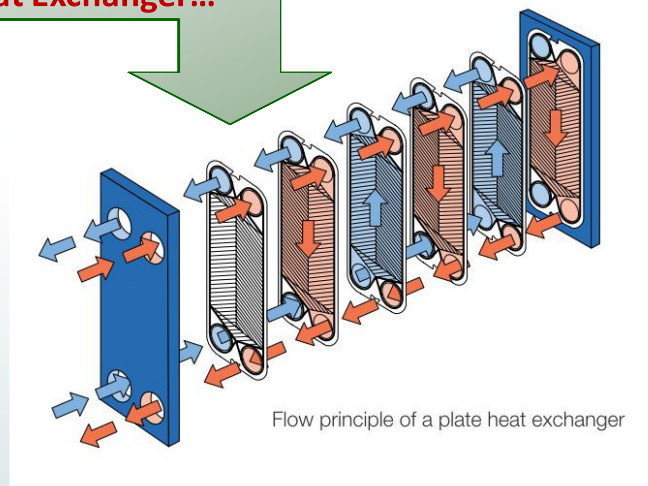
WCAC integrated in Air Intake Manifold

Not integrated dual WCAC system for a V-engine

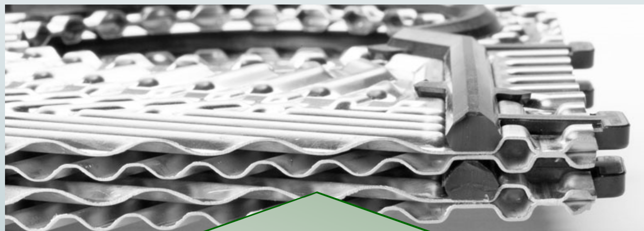


Condenser →
Water Condenser (WCND)

WCND is a
Plate Heat Exchanger…



…sized to fit in engine bays



Fins and louvers are replaced by shaped plates

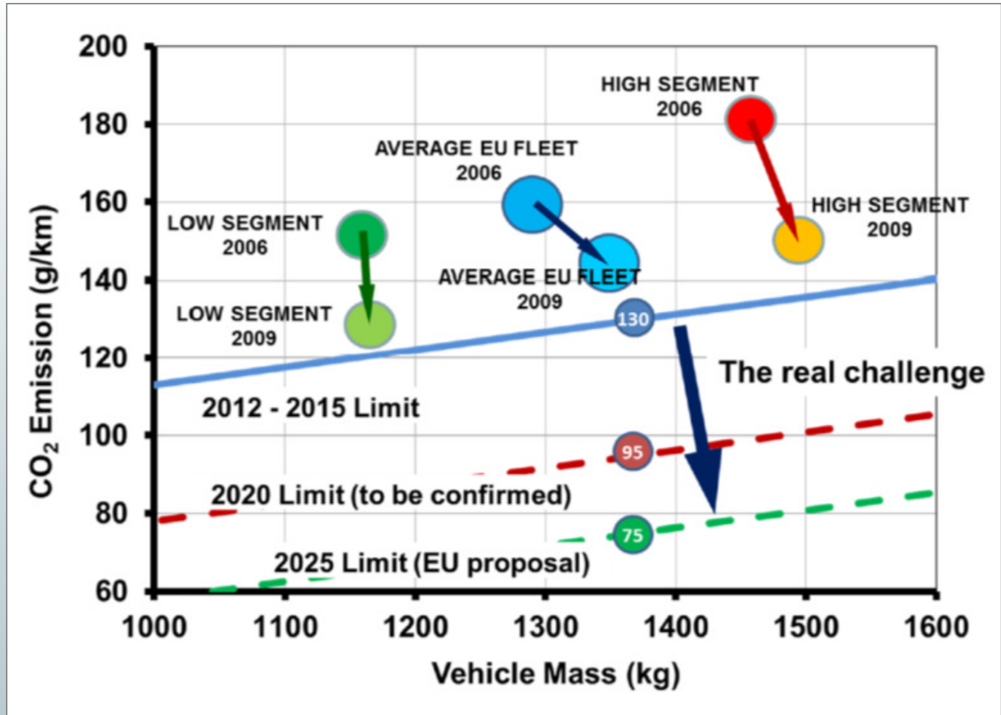
Smart Cooling System

- Scenario
- Approaches to heat rejection
- Dual Level Cooling application
  - Alfa Romeo "Giulietta" 1750 QV
  - Fiat "Punto Evo" 1.3 DS MultiJet
  - Alfa Romeo "Mito" 1.4 MultiAir QV
- Dual Level Cooling: experimental results
  - Engine cooling
  - A/C performances
  - Fuel consumption
- Dual Level Cooling: packaging
- Conclusions

Scenario

- The **European Commission** is promoting the **reduction of the CO_2** and GreenHouse gases emissions of road transports (EC 443/2009).
- The target should be achieved with effective and sustainable solutions
- Also in NAFTA market, OEMs are interested in gain **CO_2 credits** using "off-cycle" technologies or improved air conditioning systems

The **onboard thermal management** system is becoming more and more relevant to assure the **engine performance improvement** minimizing the impact on the **vehicle layout, cooling drag** and **cost**.

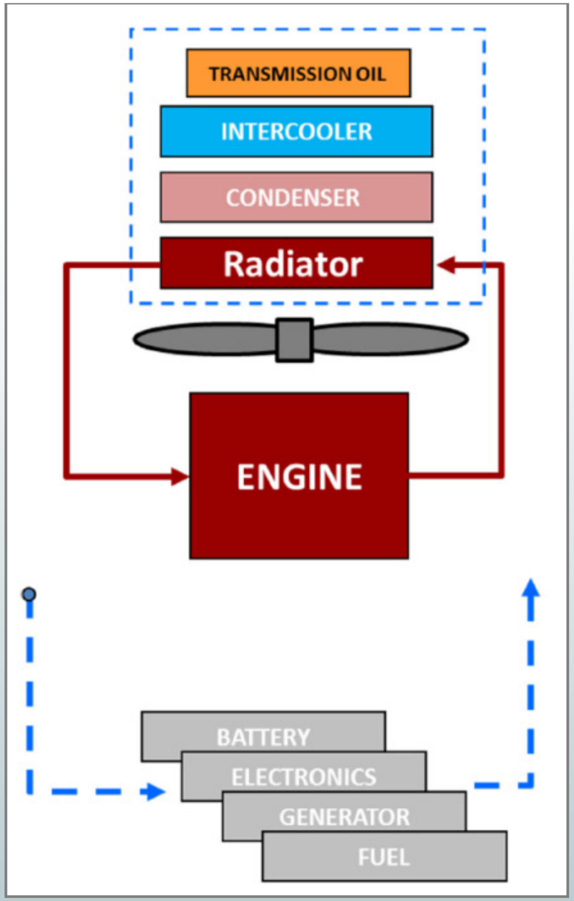


Heat rejection: the standard approach

Each subsystem (i.e. water, A/C condenser, charge air cooler, transmission oil…) **has its own cooling system** bringing the fluid to be cooled on the front of the vehicle and then back to the engine bay

This implies that:

- **The front thermal module is not standard**
  (it depends on engine and optional equipment)
  ➔ **difficulties in optimizing the aerodynamics**
- **All the subsystem share the same cooling fan, activated on a single system need**
  ➔ **energy demand**
- **New subsystems** (e.g. electronics, e-motor, batteries…) **require additional heat exchangers**
  ➔ **negative impact on cooling drag**
- **Small accidents damage several heat exchangers**
  ➔ **fluids are dispersed into the environment**



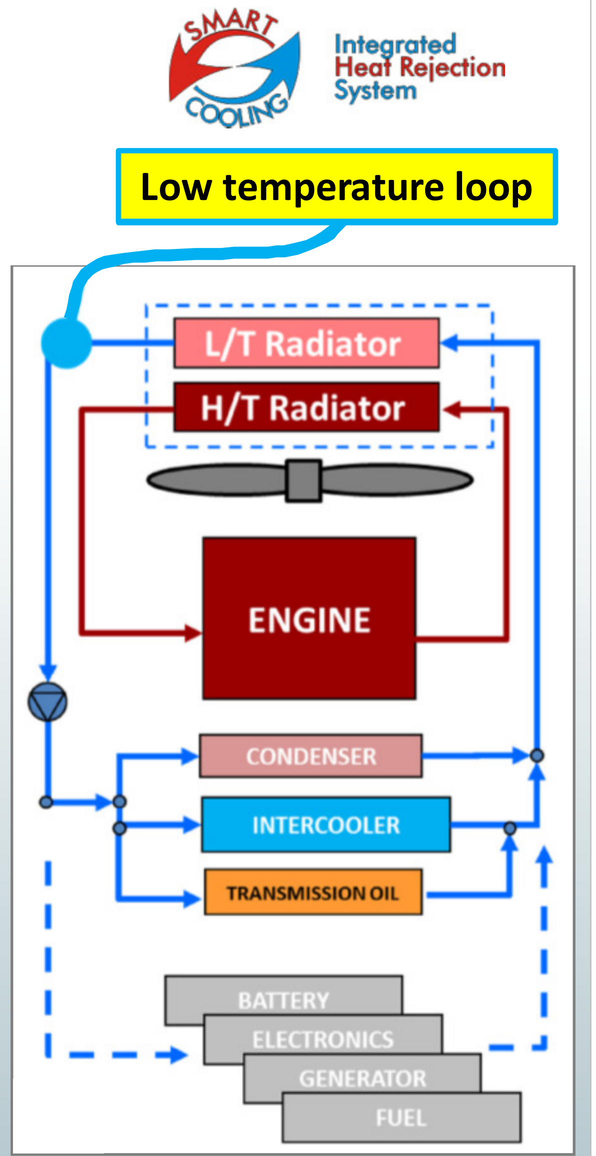
Heat rejection: *Smart Cooling* System

A **secondary loop** with coolant at **lower temperature** than engine coolant is used to locally cool all the subsystems

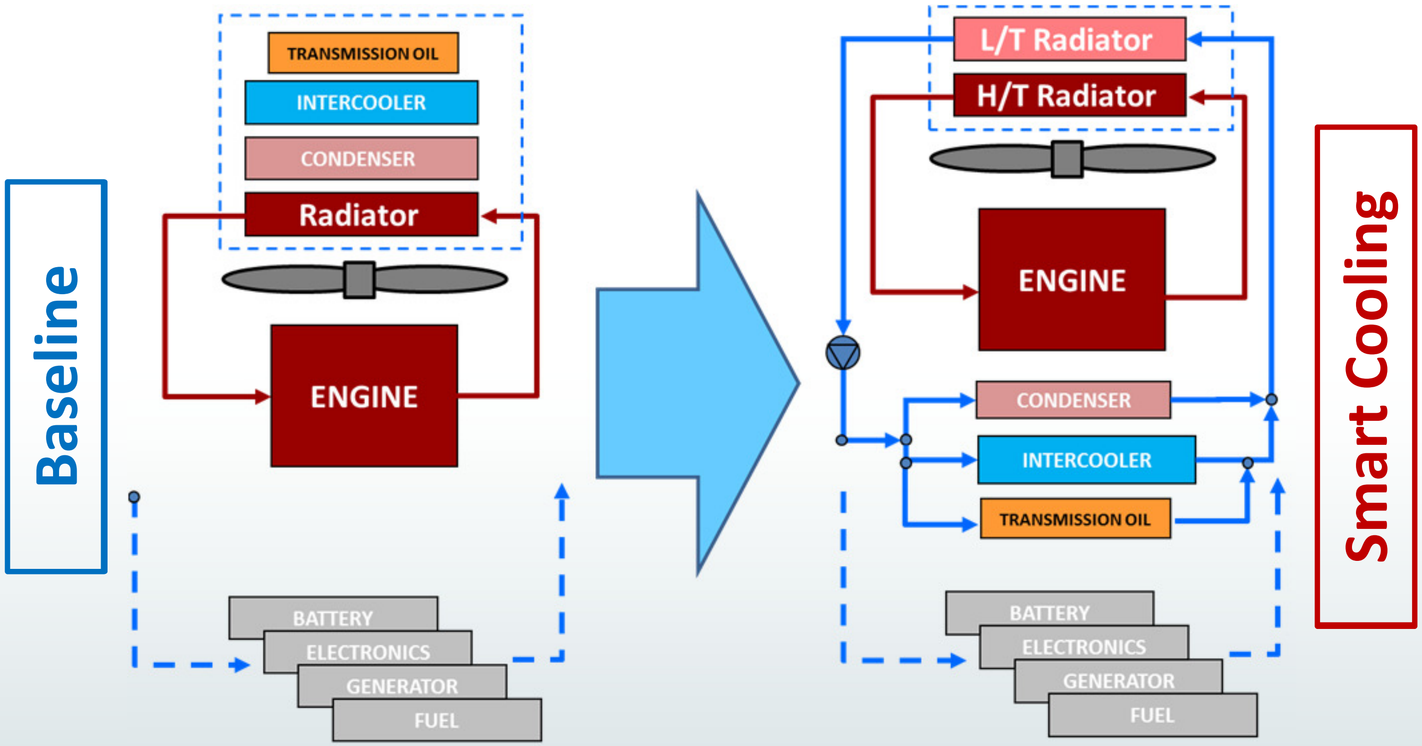
This concept brings to:

- **Standardize the front thermal module**
- **Simplify the front aerodynamics optimization**
- **Reduce the fan energy demand buffering the heat rejection needs**
- **Reduce the fluid to be cooled amount** (e.g. charge air or A/C refrigerant)
- **A modular approach simplifying the integration of additional systems** (e.g. batteries, e-motor…)
- **Achieve a higher integration level** (e.g. the charge air cooler placed inside the air intake manifold)

We refer to this system as "Smart Cooling"



From baseline to *Smart Cooling* System



- A low temperature cooling loop allows to cool all the vehicle and subsystems locally (e.g. charge air cooler, condenser, oil cooler…)
- This simplifies the front thermal module that is constituted by only two exchangers, allowing to make the vehicle and engine subsystem more compact and more efficient.
- The low temperature loop acts as a sort of “**buffer of cold**” reducing the need of forced ventilation (front fan) and related power demands.

Smart Cooling System: Results

All the investigated vehicle application gave the following results:

Engine cooling

- Compliant with FCA requirements
- Better charge air cooler performances

Air conditioning

- Better A/C performances also in very hot climate
- A/C overconsumption reduction

Fuel economy

- Benefits thanks to the lower air intake temperature
- Benefits in “real life” (with A/C ON)

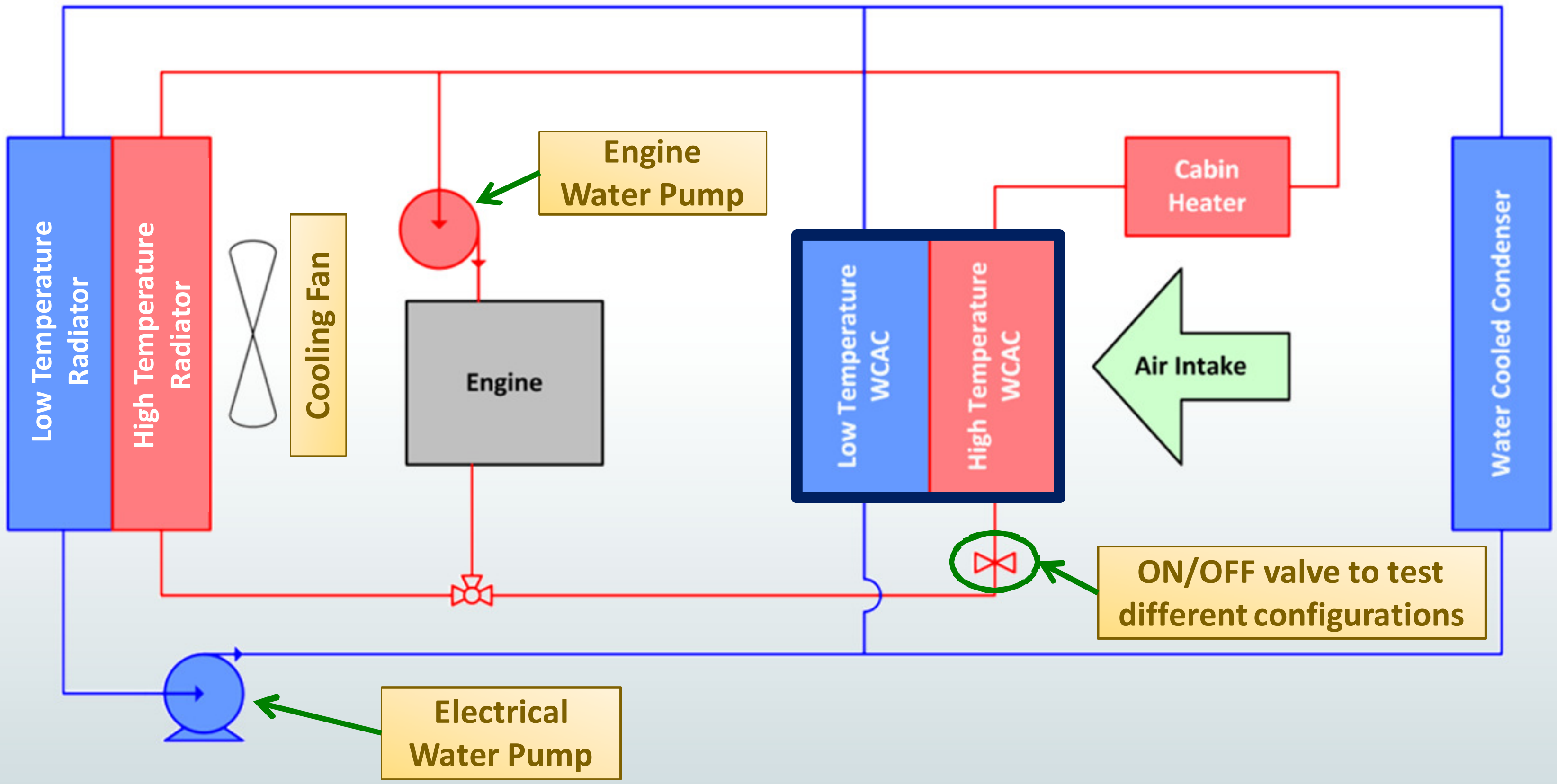
Packaging

- Simpler and more compact layout

Smart Cooling System:
Application on Alfa Romeo "Giulietta"

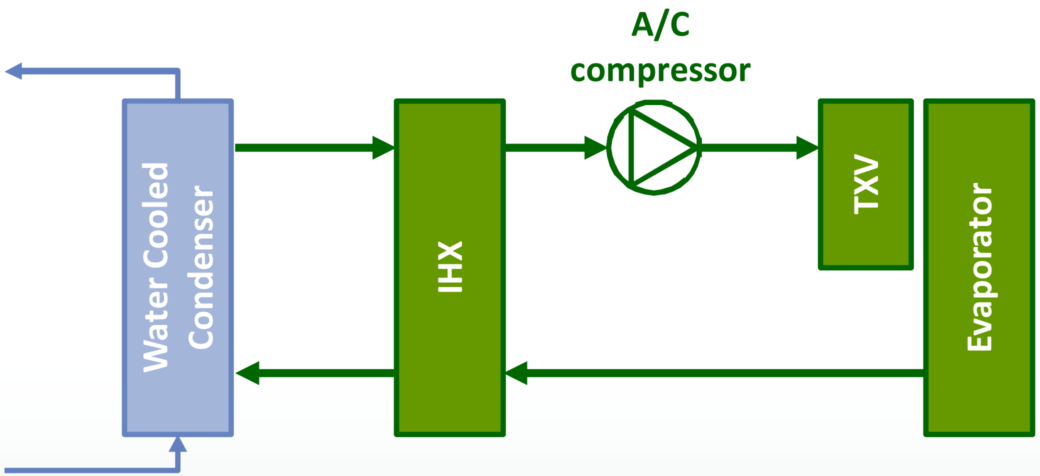
Reference vehicle:	Alfa Romeo Giulietta 1750 QV
No. of cylinders:	4
Max. Power:	173 kW @ 5500 rpm
Max. Torque:	340 Nm @ 1900 rpm
Displacement:	1742 cc
Max. speed:	242 km/h
Other features:	turbocharger, fuel direct injection, scavenging

Smart Cooling System: Overview and system scheme

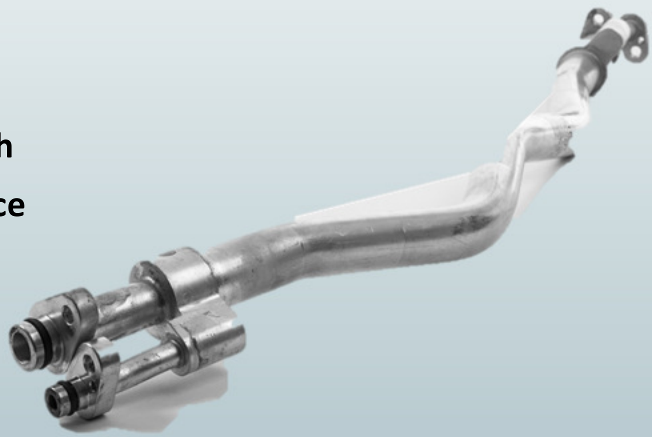


- The water cooled charge air cooler (WCAC) allows to cool the intake air first with the engine coolant, than with the secondary loop, reducing the thermal load on the low temperature loop (cascade WCAC)
- Water cooled condenser compliant with C/D segment requirements

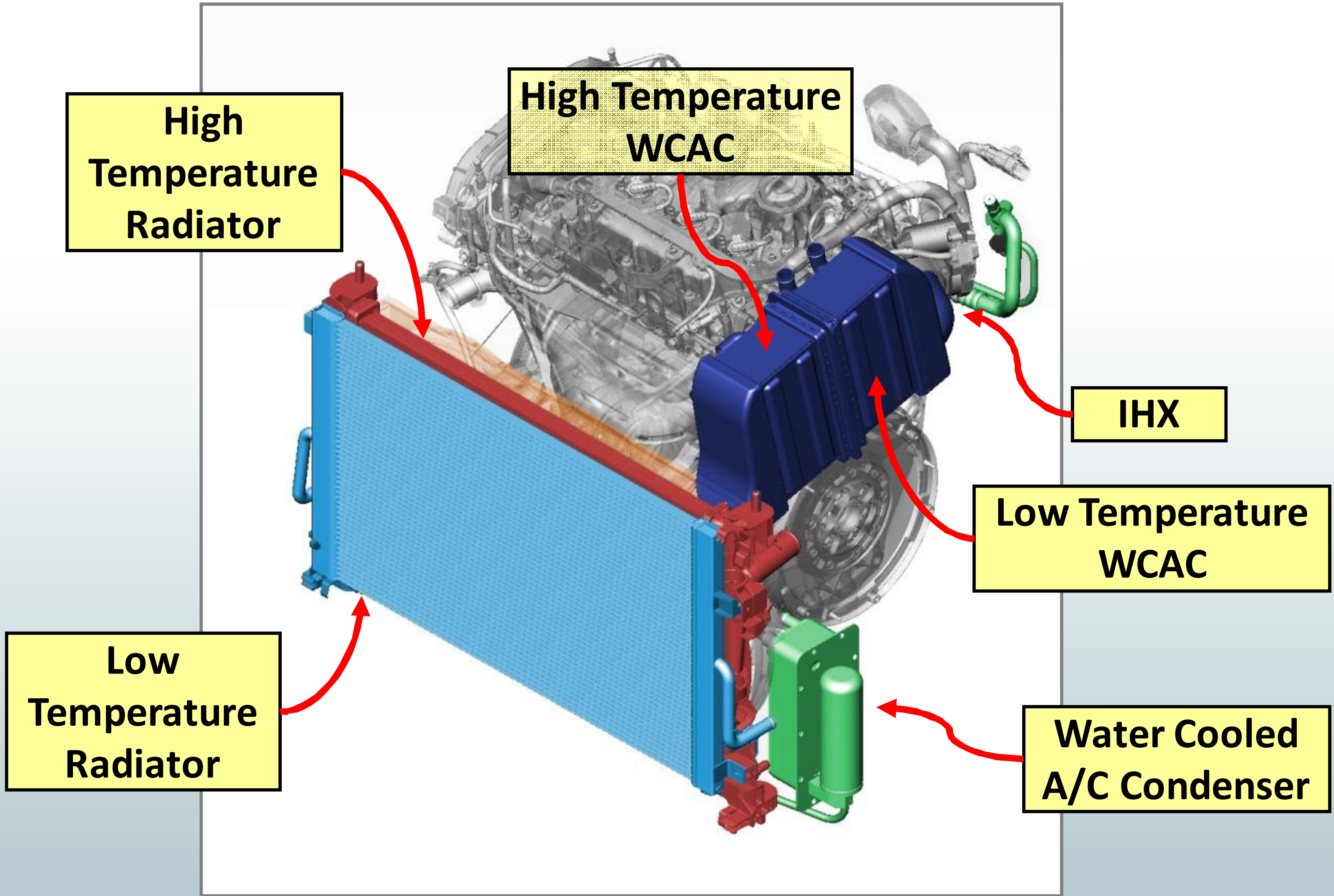
Smart Cooling System:
A/C loop layout and Water Cooled Condenser



- Standard refrigerant-to-air condenser is replaced by a water cooled condenser (WCDS)
- WCDS is a plate heat exchanger
- Subcooling is guaranteed by the intermediate heat exchanger (IHX)
- IHX is a coaxial tube minimizing the refrigerant pipes length
- IHX is usually used in order to improve the A/C performance



Smart Cooling System:
Alfa Romeo "Giulietta" on board installation



Smart Cooling System:
Engine cooling results on Alfa Romeo "Giulietta"

Small vehicles too!

Benefits of the WCAC system on the charge air temperature:

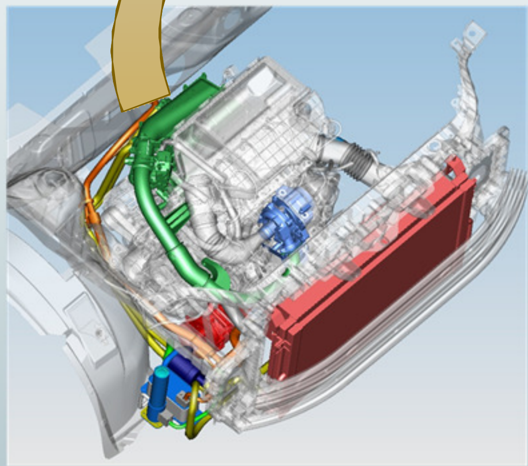
- **Uphill:** **- 8 K vs baseline**
- **Max speed:** **- 9 K vs baseline**
- **Towing:** **- 34 K vs baseline**

Smart Cooling System:
Fiat "Punto Evo" 1.3 DS Multijet Application

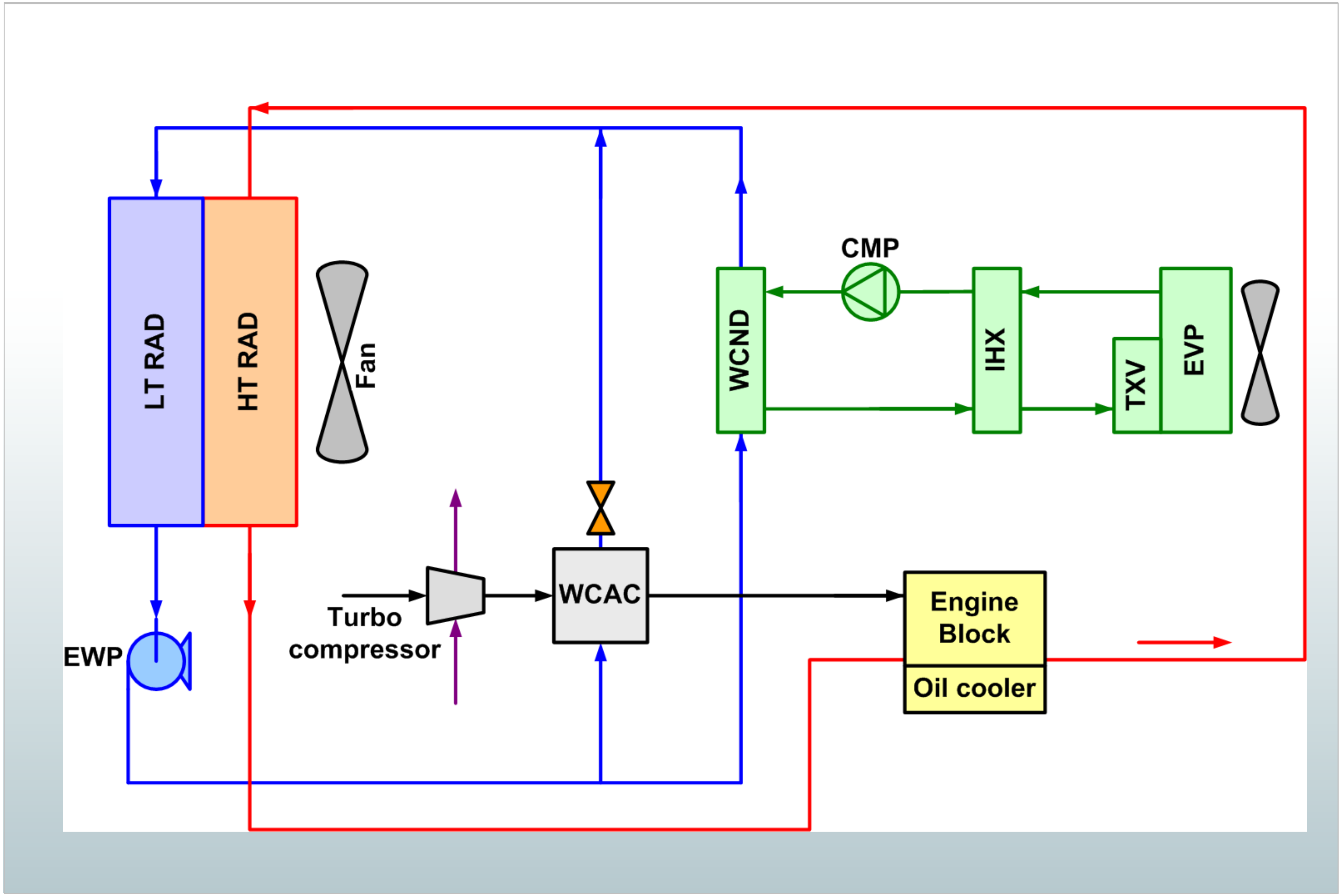
Reference vehicle:	Fiat "Punto Evo" 1.3 DS MultiJet
No. of cylinders:	4
Max. Power:	70 kW @ 4000 rpm
Max. Torque:	200 Nm @ 1500 rpm
Displacement:	1248 cc
Max. speed:	175 km/h

Front cooling module

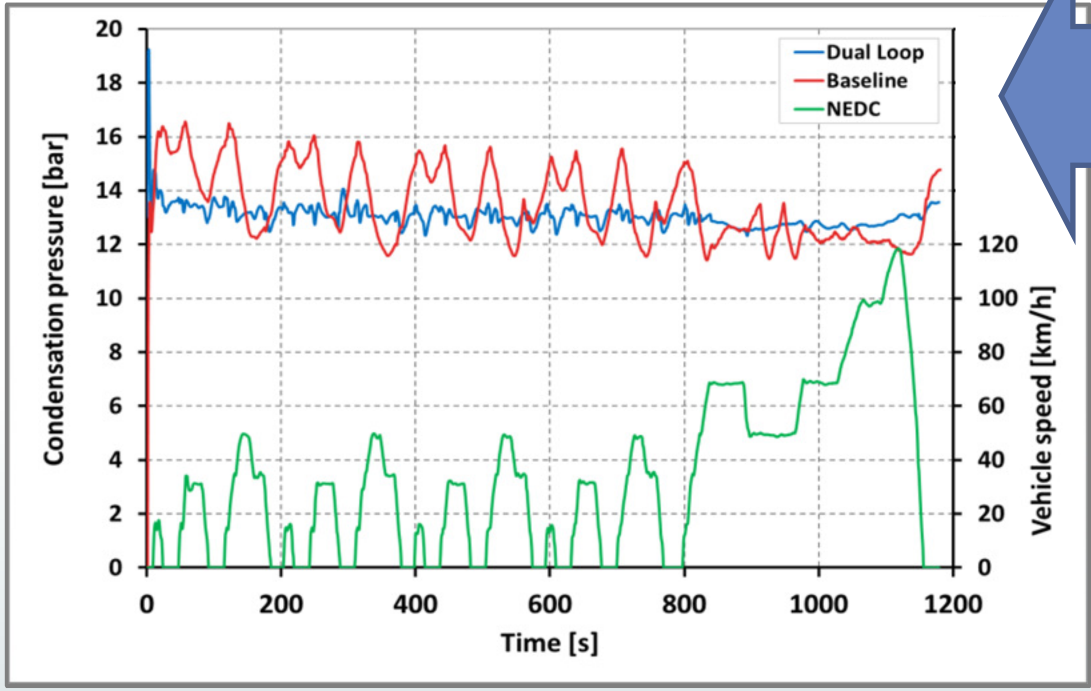
Charge air pipe



Smart Cooling System:
Fiat "Punto Evo" 1.3 DS Multijet Application



Smart Cooling System: A/C performances on "Punto Evo" application



NEDC driving cycle*

Ext. temperature: 28 °C

A/C setpoint: 22 °C

A/C mode: Fresh air

* procedure developed within the **B-COOL EU** project (2008) to assess the impact on the A/C fuel consumption

"Real life" conditions:

- Lower condensation pressure and PWM fan control bring to **lower A/C overconsumption**
- Shorter refrigerant lines and smaller condenser permit to **reduce** (up to -30%) **the refrigerant charge**

Fuel consumption with A/C ON: -5%

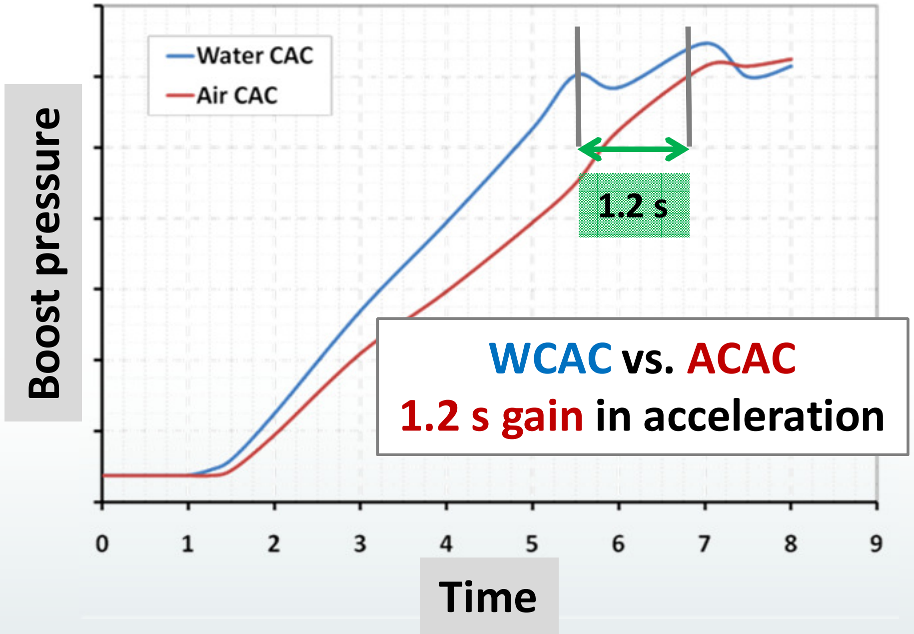
A/C overconsumption: -20%

Cool down conditions: Lower condensation pressure than baseline vehicle

Severe conditions: The system works efficiently also in very hot conditions

Ext. temp. 49 °C, R.H. 19%, 1100 W/m² sun load

Smart Cooling System: Alfa Romeo "Mito" 1.4 MultiAir 170 hp QV Application



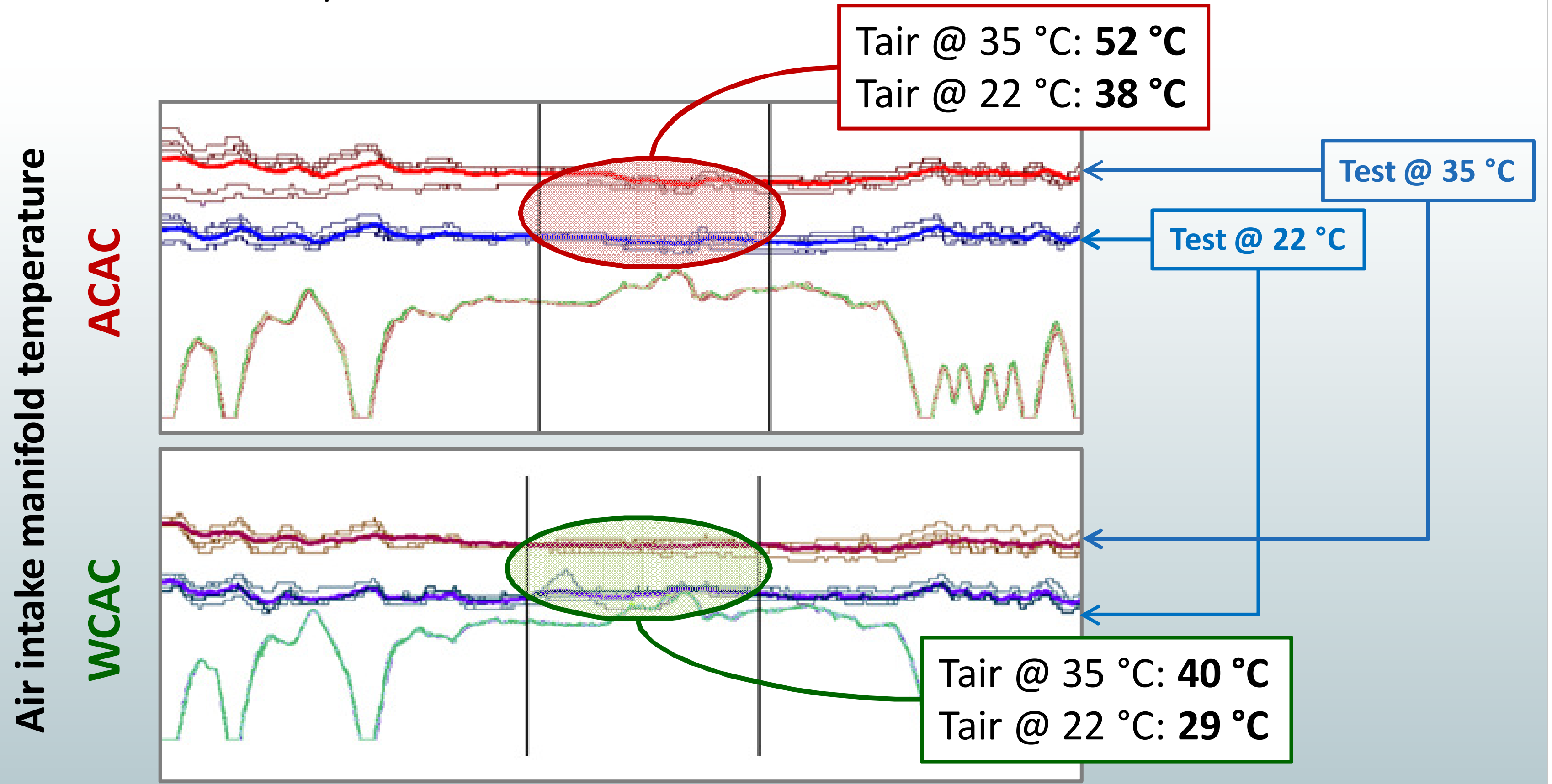
Reference vehicle:	Alfa Romeo "Mito" 1.4 MultiAir QV
No. of cylinders:	4
Max. Power:	125 kW @ 5500 rpm
Max. Torque:	250 Nm @ 2500 rpm
Displacement:	1368 cc
Max. speed:	220 km/h

Smart Cooling System:
Air intake temperatures on "Mito" application

The vehicle with air cooled charge air cooler (**ACAC**) has been compared with the one equipped with water cooled charge air cooler (**WCAC**)

SFTP-US06 driving cycle has been performed at **two different ambient temperatures:**

- **22 °C** – ordinary temperature in EU
- **35 °C** – hot temperature in EU



Smart Cooling System: Fuel consumption expected benefits

External temperature	Manifold temperature		WCAC vs. ACAC
	ACAC	WCAC	
22 °C	38 °C	29 °C	-9 K
35 °C	52 °C	40 °C	-12 K

$$P_e = MEP \cdot V \cdot \frac{rpm}{60} \cdot \frac{2}{\tau}$$

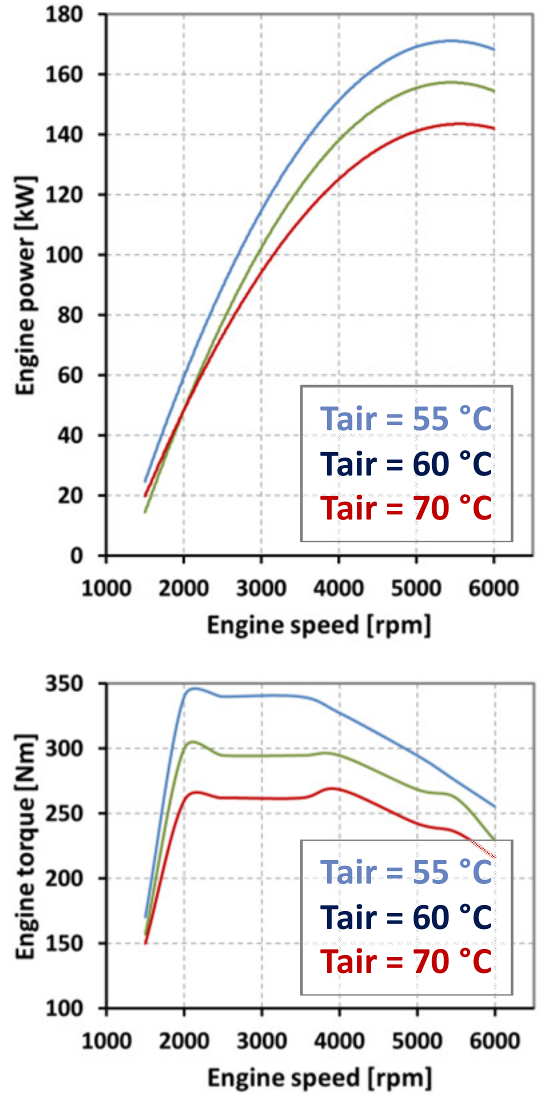
$$MEP = \frac{\lambda_v}{\alpha} \cdot \frac{\rho_c}{C_s}$$

$$\rho_c = \rho_a \cdot \frac{p_c}{p_a} \cdot \frac{T_a}{T_c}$$

$$P_e = C \cdot \omega$$

Engine power and Torque decrease when air intake temperature T_c increases

$$P_e \propto \frac{1}{T_c}$$



Homologation:

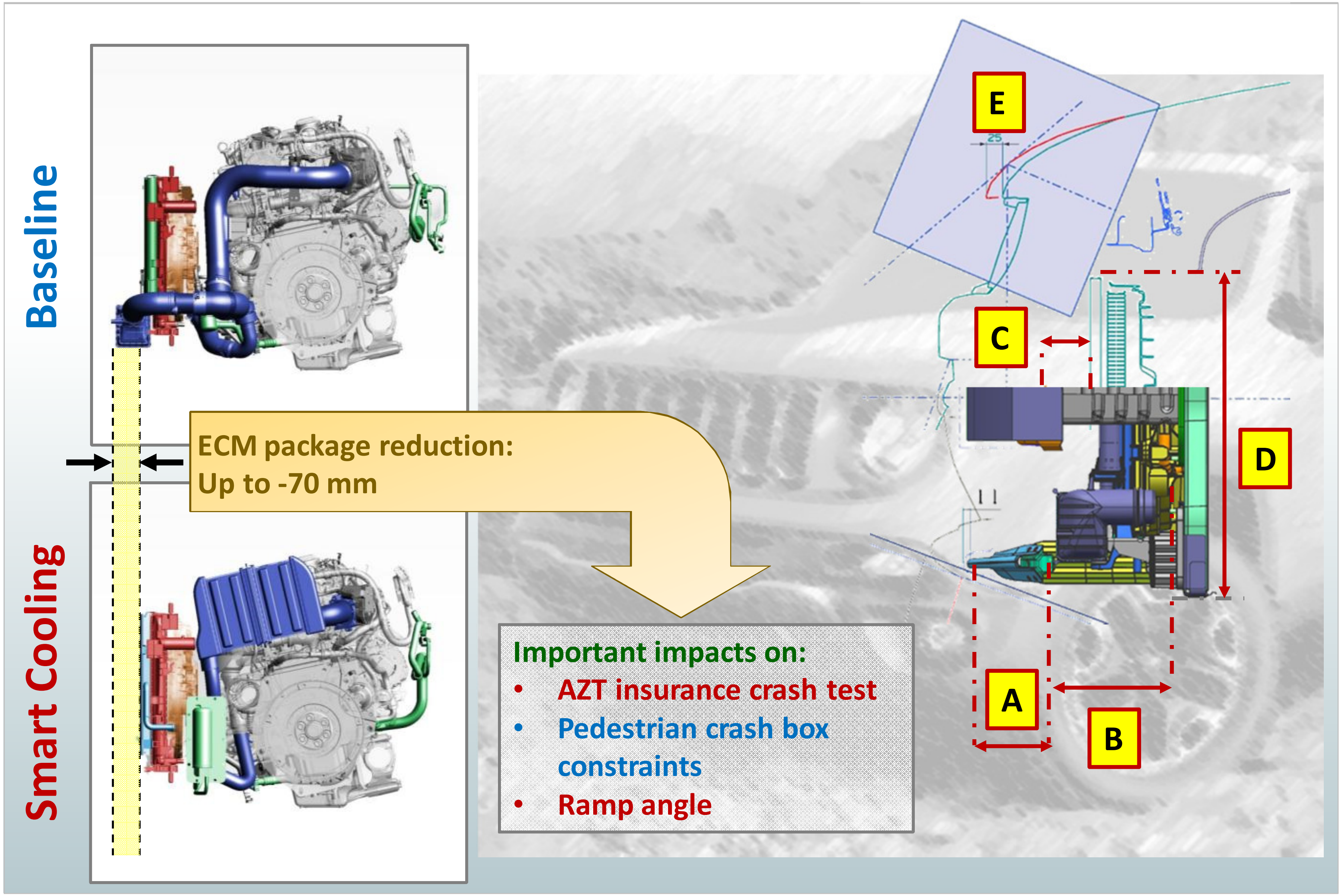
- A WCAC system guarantees lower air intake temperature
- A specific calibration taking into account this opportunity promises fuel economy advantages

➔ **Expected fuel consumption benefit: -2% on SFTP-US06 cycle**

"Real life" (with A/C ON)

- Fuel consumption **-5%** on NEDC cycle @ 28 °C, 50% r.h.

Smart Cooling System: Layout advantages



Smart Cooling System: Conclusions

The *Smart Cooling* System achieves:

- Good engine cooling performances
- Better air intake cooling at high load conditions
    - around -10 K vs. baseline vehicle
- Improved air conditioning performance
    - lower condensation pressure vs. baseline vehicle
    - A/C operation guaranteed also in severe ambient conditions
- Fuel Economy improvement
    - -2% expected with new engine calibration
    - real life: -5% with A/C ON
- NVH improvement
    - Lower A/C compressor noise
- Benefits from layout and packaging
    - reduced turbolag (> 1 s improvement)
    - A/C refrigerant charge reduction
    - thinner front thermal module (up to 70 mm on the "Giulietta" application)
        - Possible overhang reduction
        - Better insurance class
        - Better ramp angle
    - safer use of flammable refrigerant because the front module contains only the water/glycol mixture