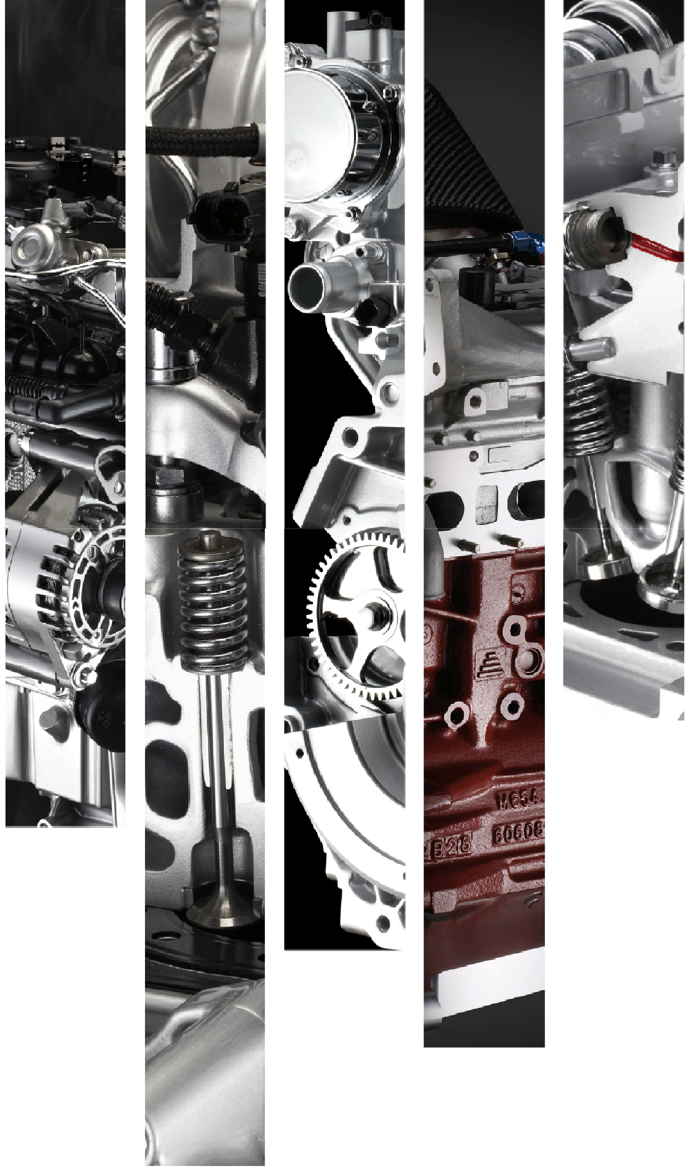
FIAT POWERTRAIN

CENTRO RICERCHE FIAT



Powertrain Evolution of the Next Years: from Conventional to Alternative

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FIAT SOCIETÀ PER AZIONI

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Contents

Introductory Remarks

- Road transportation accounts for less than 23% of global GHG emissions, but they are the ones closest to the public's everyday life.
- It is assumed that independent personal mobility will continue to be a "must" in tomorrow's society.
- When considering vehicle emissions, one has to take into account "Life Cycle" emissions, from energy production to vehicle recycling.
- Small steps in emissions reduction, but in large scale of diffusion, are more efficient for global emissions reduction than big steps in very small scales.
- As a result, affordability of a propulsion technology is a prerequisite for its impact on global emissions.
- Currently there is no single propulsion technology which can cure the global emissions problem in very short terms.
- The emissions issue, however, is actual and urgent and, therefore, every practical measure must be taken very soon.

Progress of Conventional Propulsion Technologies (1/2)

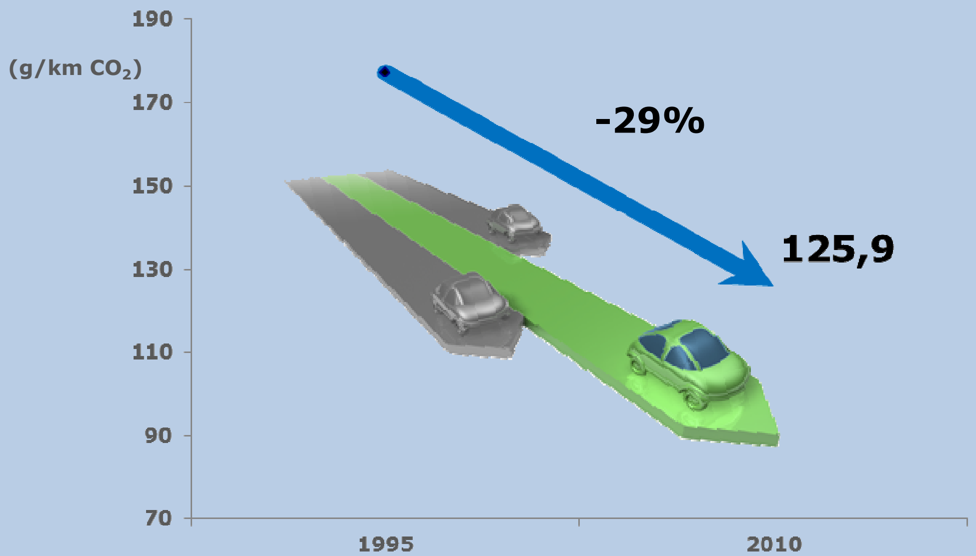
- Starting from the 90's, the regulated levels of noxious emissions are reduced by 50% every four to five years.
- As of 2014 the regulated emissions will tend to be "Fuel Neutral" in Europe as well. This means that there will be no significant difference in noxious emissions produced by Gasoline, Diesel, CNG and LPG fuelled vehicles.
- During the last fifteen years the automotive industry succeeded in reducing Fleet Average CO_2 emissions in Europe by more than 20% (Fiat Group reduction: 29%).

2010 achievement

Lowest level of CO_2 emissions in the EU

Fiat Brand ranked #1 for the 4th year in a row

- FGA: 125.9 g/km
- Fiat Brand: 123.1 g/km



Progress of Conventional Propulsion Technologies (2/2)

- The main contribution to the decrease of CO_2 emissions in Europe in the last fifteen years was mainly made by the increasing share of Diesel engines, up to 50%, and by the progressive introduction of advanced powertrain technologies for emissions and fuel consumption reduction.
- The renewal of the circulating fleet would, therefore, be the most efficient means of reducing overall emissions with an immediate effect.
- Vehicle weight and efficiency is an important factor influencing its emissions: the diffusion of small utilitarian vehicles contributes significantly in overall emission levels reduction.
- The challenge for the vehicle engineers is to meet the increasing safety and passenger comfort demand without penalizing the overall vehicle efficiency.
- City traffic control is another important factor which depends, solely, on citizen education and environmental policies.

Examples of Latest Powertrain Technologies Launched on the Market

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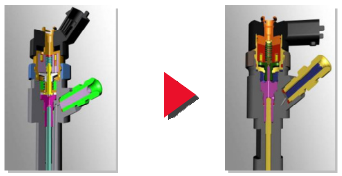
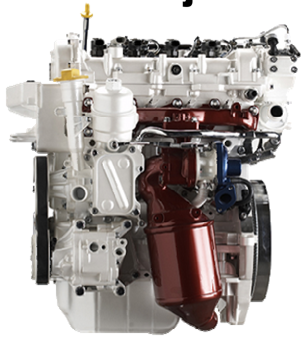
Diesel Technologies – Multijet II



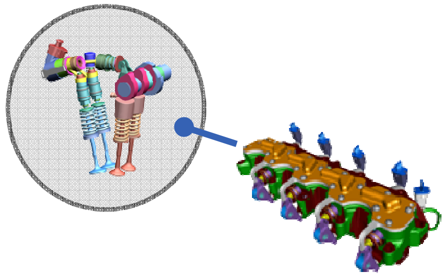
Innovative Multijet II Servovalve

Improved Common Rail injector technology for further CO_2 and NOx emissions reduction



1.3 SDE Multijet II Euro 5

Gasoline Technologies – MultiAir

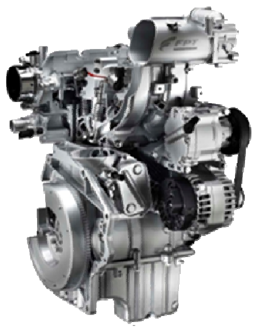


Electronic Valve Control system for Fuel Consumption / CO_2 reduction and performance improvement

1.4 Fire MultiAir TC Euro 5

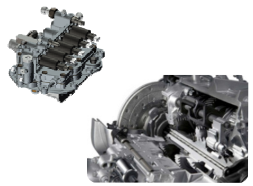
Gasoline Technologies – TwinAir

Radical Downsizing (twin-cylinder architecture) for maximum Fuel Economy exploiting Turbocharging and MultiAir technologies intrinsic synergies

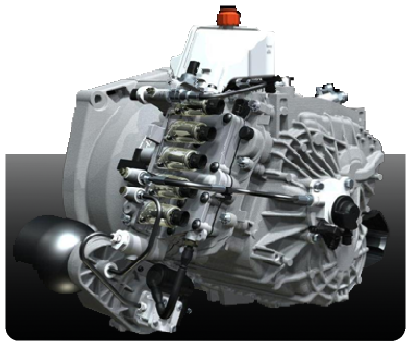


0.9L TwinAir – Euro 5 Twin-Cylinder MultiAir TC

TransmissionTechnologies – DDCT



Dual Dry Clutch Transmission technology for driving comfort equivalent to that of conventional Automatic Transmissions with lower cost and superior Fuel Economy



C635 Dual Dry Clutch Transmission

Conventional Propulsion Technologies and CO_2 Emissions

- The most efficient thermodynamic cycle currently used for vehicle propulsion is the Diesel one, with ~20% better efficiency (and CO_2 emissions) than the alternative Otto cycle (e.g. gasoline engine).

- The lowest carbon-content, readily available, fuel is the Natural Gas (>95% Methane – CH_4) which results in ~23% lower CO_2 emissions compared to Gasoline when used in conventional, Otto-cycle, engines.

- New Gasoline engine technologies, such as Electronic Valve Control, Downsizing, Direct Fuel Injection and Turbo-charging, render the modern Gasoline engine very competitive in terms of CO_2 emissions with the Diesel and Natural Gas (CNG) engines.

- The introduction of these, available, new Spark-Ignition engine technologies in CNG-fuelled vehicles further increases its intrinsic low-carbon benefit.

- Hybrid Gasoline/Electric propulsion, lately introduced in the market, is not necessarily more efficient than other modern conventional technologies particularly when vehicle mission and Life Cycle emissions are taken into consideration.

Alternative Fuels
Benefits and Issues (1/2)

- **HYDROGEN:** Hydrogen is the Ideal Fuel but, unfortunately, cannot be found free in the nature. It is produced with high energy cost, depending on method and electric energy source mix. Its use in combustion engines is critical and in electric energy producing Fuel Cells prohibitively costly. Distribution Network and Safety issues are also extremely difficult to address.

- **NATURAL GAS:** This is a freely available natural fuel, the closest to hydrogen in terms of chemical structure. It is characterised by large reserves (e.g. shale gas), very low extraction energy cost, near-zero heavy hydrocarbon emissions and can be used in conventional internal combustion engines.

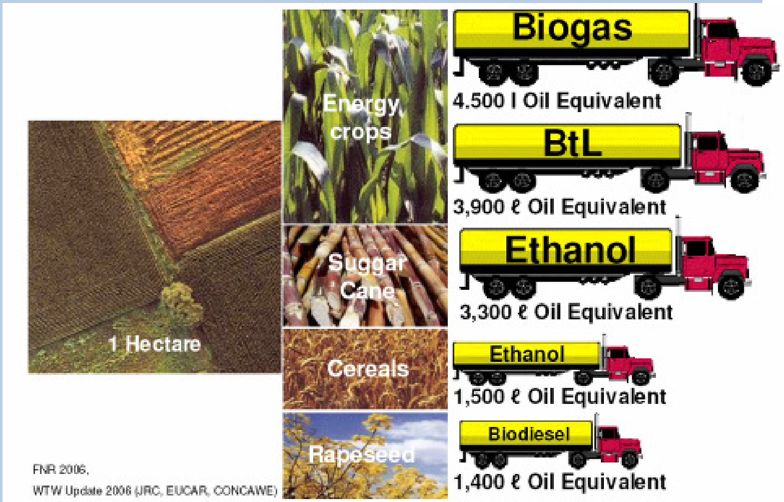
- **LPG**: Liquefied Petrol Gas. This is an alternative to Gasoline or Diesel fuel but it remains a fossil fuel, product of crude oil distillation. It can be used in conventional Otto cycle engines with significant savings in terms of CO_2 emissions and operating costs. However, since it is a petroleum derivative, it cannot be considered as a "future alternative" fuel.

Alternative Fuels
Benefits and Issues (2/2)

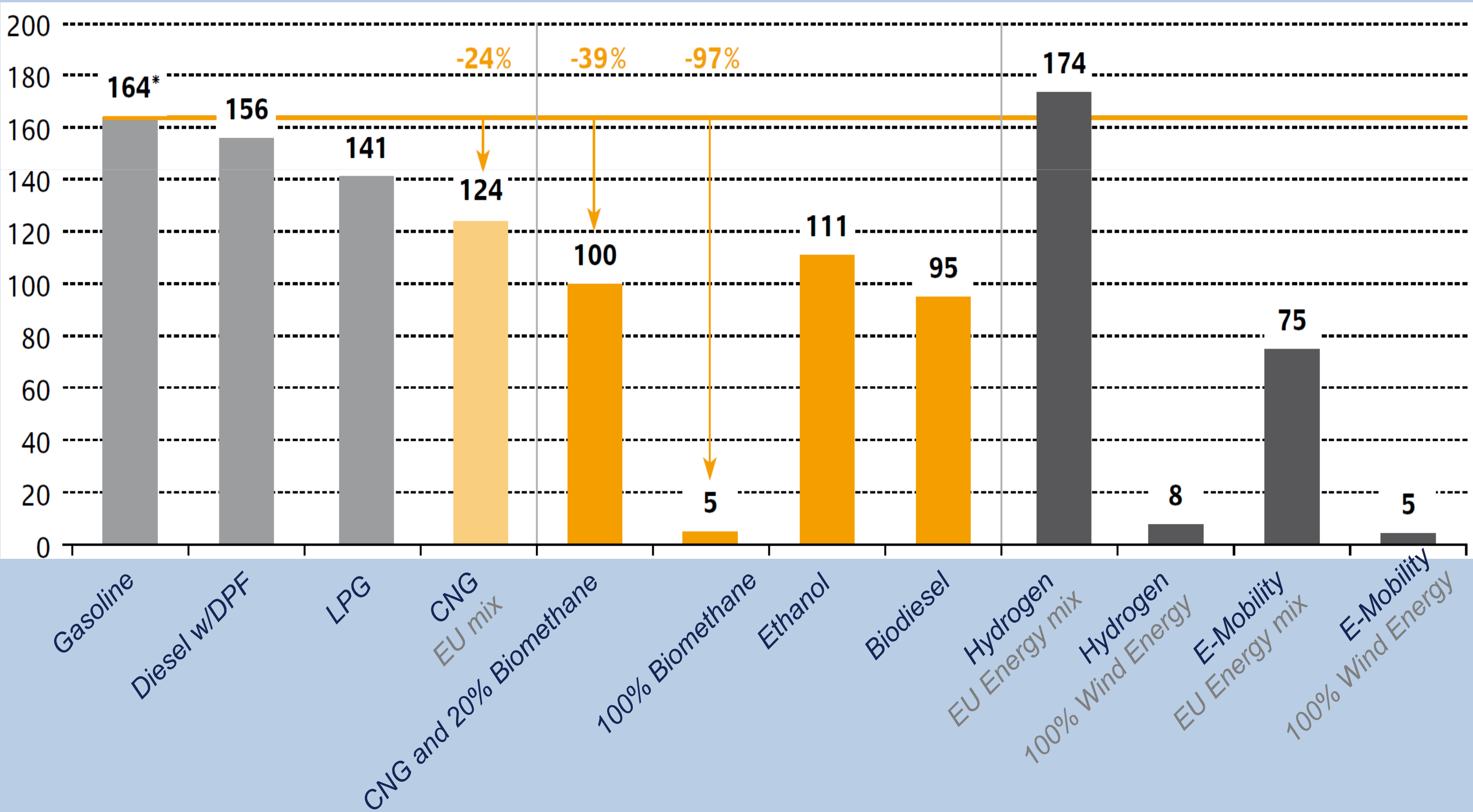
- **NATURAL GAS – HYDROGEN MIXTURES:** Up to 30% Hydrogen, if and where available, can be blended with Natural Gas with significant CO_2 emissions benefits and minor implications on the conventional combustion engine and storage system. This approach can be used as a step towards the future "Hydrogen economy" by incentivizing the formation of the relevant distribution infrastructure.

- **BIO-METHANE:** It is a product of the natural decomposition of organic waste. Once refined, it can be used "as is" or mixed with Natural Gas in conventional engines. It does not affect the food chain and its use ensures reduction of the Green House Gas emissions which would result if it were not used.

- **ELECTRICITY:** A very convenient energy carrier produced in a variety of ways, starting from coal or heavy oil burning stations all the way to renewable wind or solar energy plants. Assuming "clean" electric energy production, which is not feasible for use in large scale, the problem of on-board electric energy storage remains a roadblock for its diffusion in road transport.



Well – to – Wheel CO_2 Emissions Various Fuels



(*) Reference Vehicle : Gasoline – CO_2 emissions (Tank-to-Wheel) : 140 g/km
Source : Concawe & DENA – German Energy Agency

Hybrid Propulsion
Benefits and Issues (1/2)

- Hybrid Propulsion solutions, which combine Internal Combustion Engines with e-motors, will represent for the next decades a significant transition phase from the conventional propulsion technology to the electric one.

- In this scenario Hybrid solutions will become more and more important and popular as a function of their ability to improve the environmental-energy issues without sacrificing the typical end user needs, with affordable additional costs.

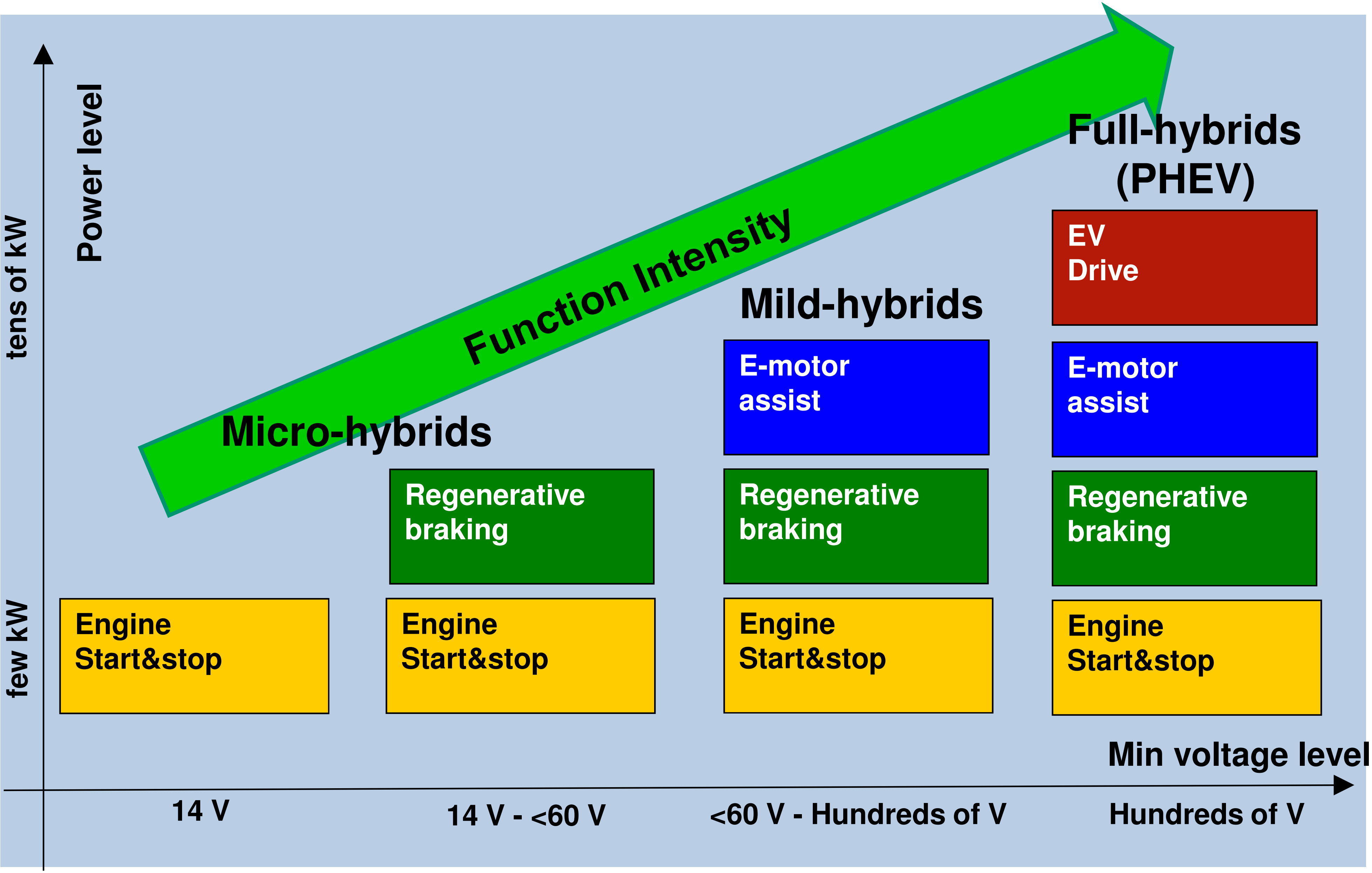
- **HYBRID :** The Hybrid Electric Vehicle (**HEV**) propulsion systems reduce energy waste in particular city traffic conditions. Their benefit is significantly reduced in generic vehicle missions and when used with low-efficiency internal combustion engines. They are characterised by high costs (at least two engines / e-motors and two energy / power storage systems).

- **PLUG-IN HYBRID :** The Plug-in Hybrid Electric Vehicles (**PHEV**) behave as the HEV's but allow some vehicle autonomy in electric mode. The energy storage system is more costly than an HEV's and they require electric energy re-charging facilities (public or private).

Hybrid Propulsion
Benefits and Issues (2/2)

- The main bottleneck for a wider market penetration of the HEV solutions is their related additional cost. For the Passenger Car applications, depending on the segment, there are two main scenarios:
  - Small and compact cars: the end user purchasing criteria are strongly influenced by the purchasing price. In Europe hybrids have to compete with Diesel solution reference.
  - Medium and upper segment cars: other complementary criteria become increasingly important (i.e. performance, comfort, driveability, green image,…) lessening, but not eliminating, the purchasing extra price issue.
- Considering the European car market mix, the small and compact cars segment is the key one for a diffusion of Hybrid vehicles significantly contributing to CO_2 emissions reduction. The CO_2 reduction vs the additional cost is the main index to be considered for the economical evaluation and feasibility of the selected HEV configurations.
- In this view it has to be preferred an add-on approach (avoiding as far as possible devoted solutions with minor synergies with the conventional powertrain) and therefore the selection of powertrain / e-motor coupling solutions with limited modifications in respect of the base configuration.

Enabled Functions vs. HEV Typologies



BEV - Battery Electric Vehicles
Benefits and Issues

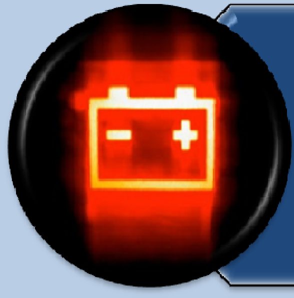
- As mentioned before, Electric traction will be an optimal solution in terms of environmental sustainability, non only on a local scale, but on a global one as well, only if electricity will come mainly from non-fossil sources.

- Moreover, the widespread introduction of Electric Vehicles is presently hindered by the Battery Technology:

  - Poor specific energy, entailing a limited vehicle range
  - High costs
  - Long times for the complete recharge
  - Energy intensive manufacturing from raw materials

BEV – Battery Electric Vehicles
Battery Issues

LIMITS:
- Specific energy: today no more that 150-180 Wh/kg (at cell level)
- Usable power : drastically reduced in cold conditions (by 40÷50% at 0 °C)
- Recharging time: normal recharge : some hours - fast recharge: around 30 minutes



PROBLEMS to be further investigated (particularly for Li-ion):
- Safety : high temperature (> 80°C), overvoltage, crash
- Reliability : for large scale applications
- Lifetime : compliance with the **10 year** target
- Fast recharge : effects on lifetime

COSTS:
- Mass production volume estimates range around **200-250 €/kWh**
- This leads to a cost of **4 to 5.000 € for a typical City Car** using a 20 kWh battery system (100 km range)

A Proposal for a Sustainable Mobility Scenario in the Short – Medium Term (1/2)

- **GASOLINE TECHNOLOGY :**
  - It will maintain its prevalence in private generic mobility but its use must be limited to small cars which should adopt all modern fuel consumption reduction measures (Downsizing, Valve control, Turbo-charging, Stop&Start, …).
- **DIESEL TECHNOLOGY :**
  - Modern Diesel technologies can be as “clean” as their Gasoline counterpart, but with higher costs.
  - Suitable for private and public transportation involving heavier vehicles with prevailing extra-urban and motorway mission profiles.
- **NATURAL GAS TECHNOLOGY :**
  - Ideal for public transportation vehicles (buses, taxis, delivery vans, public utilities…) which can be refuelled centrally at the end of their daily mission. The future can see the use of bio-methane and hydrogen blends without significant technological impact.
  - Suitable for private generic mobility where the fuel distribution is widespread. The bi-fuel version is a bridge to this future scenario.

A Proposal for a Sustainable Mobility Scenario in the Short – Medium Term (2/2)

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- **HYBRID TECHNOLOGY :**
  - Very attractive for small City Cars when combined with technical solutions which reduce the additional mass and cost.
  - This technology is particularly recommended for Light Commercial Vans used for door-to-door distribution. Combined with efficient modern Diesel Engines ensures an advantage of 25% in CO_2 emissions at affordable cost, given their annual mileage and initial cost.
  - This technology can be combined with Natural Gas engines with further CO_2 emissions benefits.
- **ELECTRIC PROPULSION :**
  - Very suitable for public utility vehicles with pre-defined, short, city mission profiles (urban cleaning, post office,…) which allow maintenance and re-charging at the vehicle's base.

Conclusions

As a Summary of the considerations made so far it can be stated that a realistic scenario for the near future mobility should be characterised by:

- Smaller and lighter city cars with efficient modern conventional powertrain.
- Modern Diesel-fuelled vehicles for private use in prevalently extra-urban mission.
- Public and generic private transportation based on the use of low-carbon fuels, such as Natural Gas, enriched with bio-methane and hydrogen, according to availability.
- Diffusion of Hybrid electric vehicles for city applications, particularly those of door-to-door delivery vans and, eventually, small city cars.
- Adoption of Electric vehicles for specific, public utility, city missions.

It is clear that there is no single technology which can technically and economically cure in a short term the transportation emissions issues. An intelligent mix of available and affordable technical solutions can, however, guarantee a significant leap forward.