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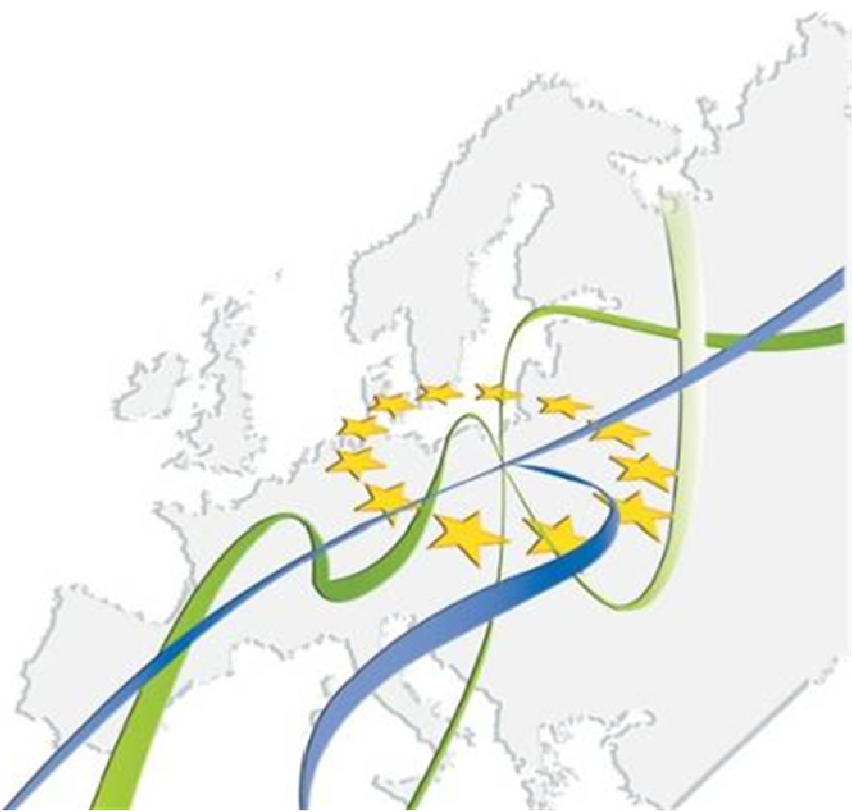
European Roadmap

Hybridisation of Road Transport

Version June 1, 2011

ERTRAC Expert Group Enabling Technologies



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1. Executive Summary

The Green House Gas emission, especially the CO_2 emission and the air quality in cities and conurbation are major societal challenges not only for road transport. ERTRAC has addressed these challenges in its new Strategic Research Agenda. But, road transport has to contribute its part because only to overcome these challenges will secure sustainable person mobility (individual mobility with the choice of your own means of transportation as well as to use all the possibilities of public transport) and goods transport for the future, a basic requirement that humans will presuppose as self-evident also in the future.
In the context of sustainable mobility the propulsion technology carry the main load to overcome the problems of environmental impact and air quality.
The electrification of vehicle drive trains is an important step to increase energy security, improvement of air quality and CO_2 reduction. The European Commission launched a set of initiatives to become leadership in the electrification technology, the Fuel Cell and Hydrogen Initiative, the Electrification of Road Transport Strategy paper developed within the framework of the Green Car Initiative, are just some to mention.
The following document 'Hybridisation of Road Transport' is based on the consensus of experts of major companies and organisations from the European Road Transport Research Advisory Council (ERTRAC) and its Expert Group Enabling Technology.

Hybrid Vehicles will play a major role for long time, well beyond 2030, they are a major enabler to reach the CO_2 targets, to reduce the Green House Gas emission in general, to enable good air quality in urban areas and to spare the energy consumption. Since Hybrid Vehicles do not have the range limitations of Full Electric Vehicles and also not the drawback of emissions like the pure internal combustion engine vehicles, they will be more in line with the consumer's needs in the future and the driving pattern of today and those for the future. **Hybrid Electric Vehicles combine the advantage of two different propulsion systems, the possibility to drive with zero emission and to drive on long distances.**
The benefits of Hybrid Electric Vehicles, no other propulsion can deliver in mid term perspective, shows very clear that they will be an important part to secure sustainable mobility:

- The decarbonisation advantage, 10%-95% CO_2 reduction potential
- The 'green car' advantage, zero emission driving in electric mode in cities and conurbation, driving without making air quality worse
- The consumer advantage, driving without limited range from city to city as well as all over the landscape, with ultra low emissions with the optimised ICE and transmission mode in the future, the use of alternative-/bio-fuels and thus reduced fuel consumption and costs in real life operation and lower emission.
- The economical advantage. With all these benefits, the use of hybrid vehicles will gain benefits on economics, jobs, technology leadership as well.

Despite all these advantages the challenges may not be forgotten:

- The relation costs versus benefits. The question will be which additional hybrid costs will be accepted by the customer, which (cost) benefits can be achieved during a reasonable time of operation
- To enlarge the ZEV range, to adapt the ICE to hybrid demands, to make hybrids lightweight, safe and more robust, to increase the durability for heavy duty application

To reach the CO_2 targets, the air quality goals and to secure sustainable mobility clear milestones and recommendations are set in this document.

Milestones for Passenger Cars

Milestone 1: 2015. **Adapted Hybrids**. The already started and ongoing introduction of hybrids into the market is based on the adaptation to existing vehicles.

Milestone 2: 2020. **Integrated Hybrids**. Vehicle & system integrated hybrids will provide efficiency gains for all consumers. Mass production of Plug-In Hybrids and Range Extender Hybrids has started.
Milestone 3: 2025. **Competitive Hybrids**. Hybrid Vehicles competitive regarding costs and benefits will conquer the market. Modular and flexible Hybrid Vehicle designs will make the market more interesting.

Milestones for Trucks

Milestone 1: 2015. **Optimised Truck**. Distribution trucks with plug-in capability and long haul trucks with tailored mild hybrid systems.
Milestone 2: 2020. **Tailored Truck**. Components tailored for high efficiency and durability w/wo Range Extender, with Plug-In capability.
Milestone 3: 2025. **Sustainable Truck**. Hybrid systems with designed for hybridisation & continuous grid connection.

Milestones for Hybrid Bus

Milestone 1: 2015. **Tailored hybrid bus** - with Plug-In capability
Milestone 2: 2020. **Light weight hybrid and full electric Bus**, w/wo Range Extender, with Plug-In capability.
Milestone 3: 2025. **Alternative energy converters systems** designed for hybridisation

To reach the milestones a lot of research expenditure is necessary mainly for the following fields:
- **Energy Storage Systems.** Batteries smaller, cheaper, lightweight, safe, more robust, long life time and with high power & energy density
- **Drive Train technologies.** New concepts for electrical machines & electro mechanical technologies, low-cost, lightweight
- **System Integration & Modular Hybrid Architecture.** To build robust, small, integrated and efficient hybrid configurations
- **Grid Integration.** Fast, contact-less, bidirectional charging infrastructure

Of course additional research efforts are to undertake in safety aspects and the integration of hybrids into the transport system and the development of solutions capable for high number of pieces (mass production).

The Hybrid Electric Vehicles are an essential part of sustainable mobility for a long time, they will support the environmental goals, without Hybrid Electric Vehicles the CO_2 and air quality targets could not be reached. Full Electric Vehicles will dominate as pure city- and short distance solutions. But, Hybrids will be the major solution for sustainable mobility, for individual mobility, for goods transport and for public transport, suitable to enter cities as well, due to there ZEV range.
The European Commission should support the benefits of Hybrids, setting the standards to get the lead, promote HEV research in the 8th Framework Programme.

2. Introduction

In its new Strategic Research Agenda, ERTRAC has addressed major societal challenges such as **decarbonisation in road transport**, reliability of the road transport system and the need for safety and security in road transports. Only **to overcome these challenges will secure sustainable person mobility** (individual mobility with the choice of your own means of transportation as well as to use all the possibilities of public transport) **and goods transport for the future, a basic requirement that humans will presuppose as self-evident also in the future.**
The future will request a mix of vehicles and the offer of more CO_2 low/energy efficient cars and trucks to secure an individual and environmentally friendly mobility freedom and ‘green’ goods transport.

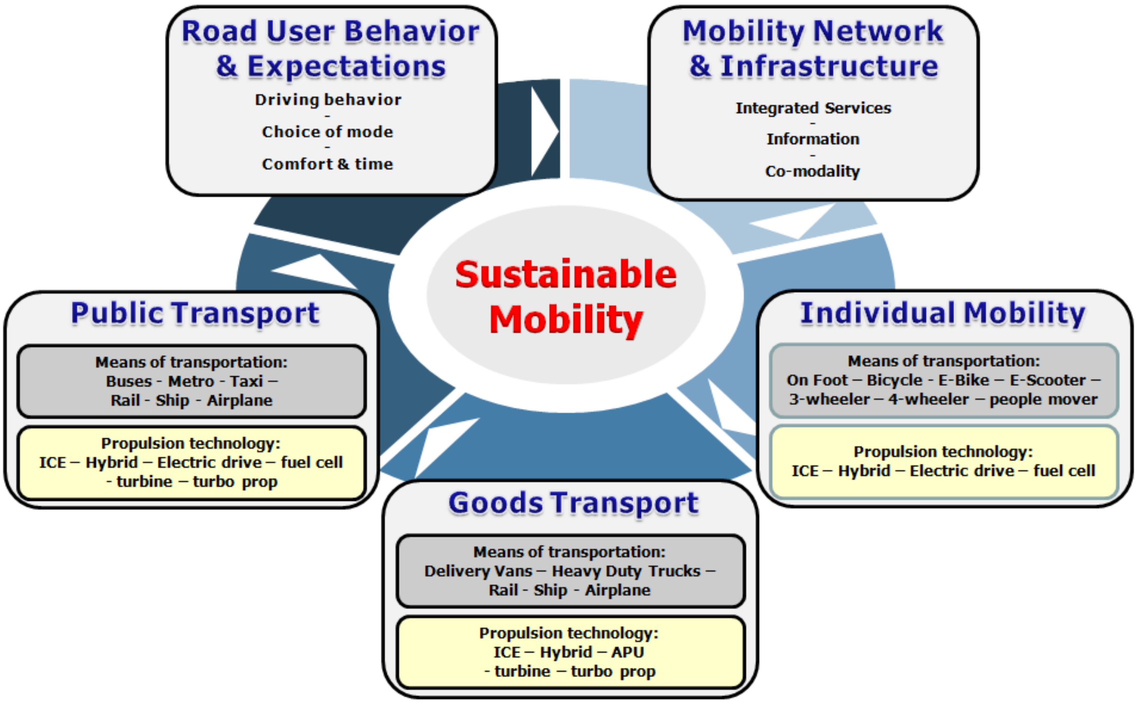


Figure 1: The context of Sustainable Mobility

In the context of sustainable mobility, with its individual mobility, public and goods transport, the propulsion technology carry the main load to overcome the problems of environmental impact and air quality. To secure mobility and goods supply in cities and conurbation will be a great problem to solve in the future. It is expected that urban zones have to accommodate more and more people.

When looking at the evolution of propulsion technologies, hybridisation appears to be a large part of the answer, even if vehicles with Internal Combustion Engines (ICE) will be the long to future solution for Long Distance Freight Transport and probably for long distance travel with family cars.

With a similar approach as the ERTRAC–EPoSS–SmartGrids roadmap **'Electrification of Road Transport'**, the aim of this roadmap on 'Hybridisation of Road Transport' is to give a consistent overview, to show the different fields of application, to explain the challenges and benefits for environment and customer, to point out the most promising configurations and to define the R&D needs on a time-line, this for passenger cars and commercial vehicles.

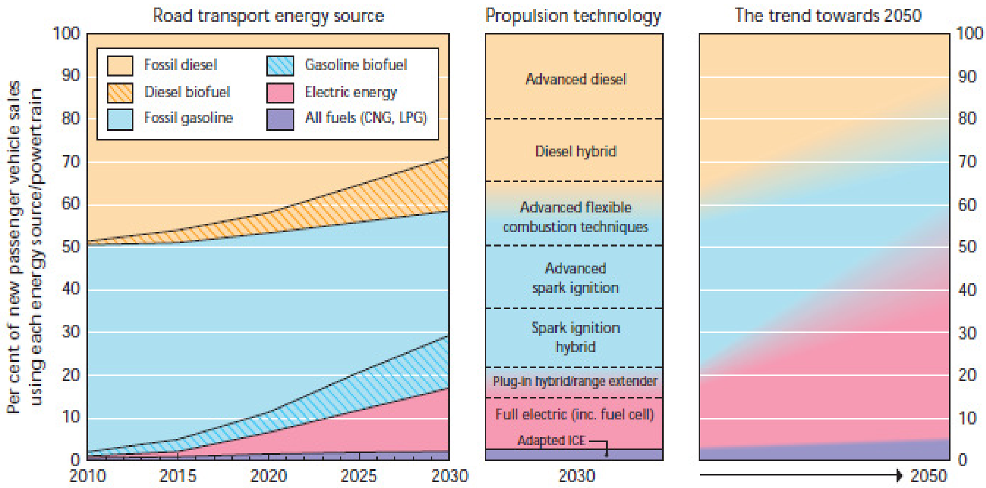


Figure 2: The evolution of passenger road transport energy source and propulsion technology, towards 2050

The electrification of vehicle drive trains is an important step to increase energy security, improvement of air quality and CO_2 reduction. Future customer demands combined with legal requirements will drive the introduction of Hybrid Electric Vehicle (HEV) technologies, increasing the energy efficiency of vehicles propelled by conventional power-trains which solely utilise fossil fuels, while developing enabling technologies for the future large scale vehicle electrification. **Without brought hybridisation, especially with Plug-In Hybrids and Range Extender Hybrids, the goals of decarbonisation could not be achieved.**

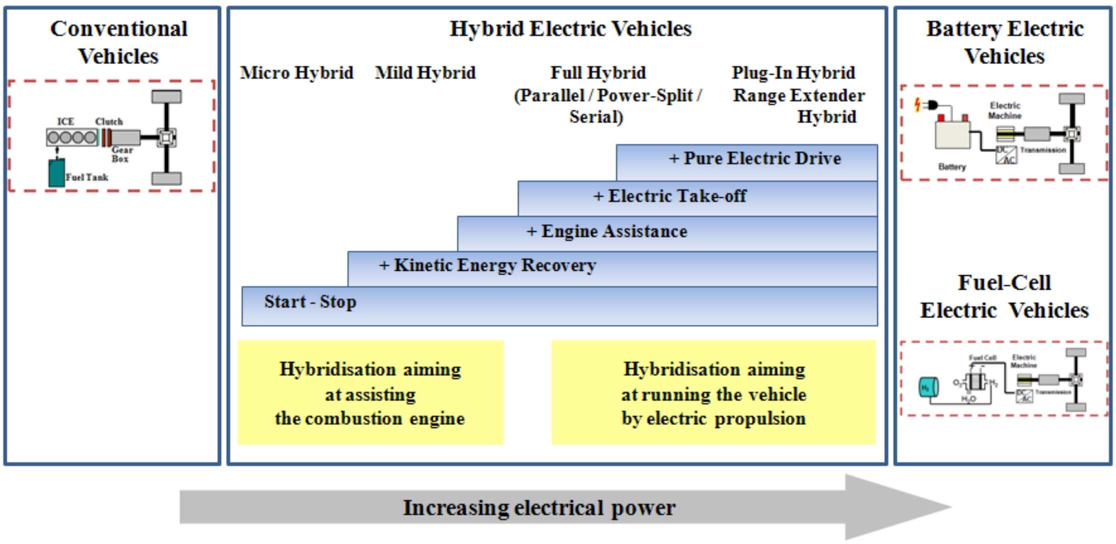


Figure 3: The classification of Hybrids

As a first step to electrification start-stop and starter-generator systems are already in a market penetration phase, pure Electric Vehicles (EV) are announced for the next years. A real series market penetration is seen after 2020.

An essential question for the moment is however, if hybrid configurations, e.g. Plug-In Hybrid, Range Extender Hybrid and other new hybrid solutions are the meaningful alternative to pure Electric Vehicles at the end. The advantage of hybrid configurations lays in the stepwise transition to electrification without giving away customer benefits.

We expect that hybrids will play a role for long time, more than today expected. Hybrids are one solution to reduce CO_2 and thus the answer for future CO_2 legislation. This demand of the future regarding sustainable mobility will show us as most build hybrid configurations the ‘Plug-In Hybrids’ as best utility for ‘allround’ cars and the ‘Range Extender Hybrid’ as a solution for conurbation.

It will be necessary to work besides pure city solutions on comfortable, affordable and environmentally friendly solutions rechargeable for short to long distance use. This will be one of the great hybrid challenges and with a proper answer a great step for future individual and sustainable mobility.
New concepts with new engine and sub-system solutions, especially for hybrid configurations are to be developed, one has to think about new hybrid means of transportation, solutions for pure short-range city traffic as well as for long distance holiday trips.
The improvement, talking in this paper will be the supplement of ICE driven vehicles with all kind of hybridisation features. We expect that most of the ICE driven vehicles are equipped with hybrid features, from start-stop up to Plug-In devices.

o Links to other roadmaps and strategic papers

Vehicles with ICE will be the main platform for road transport for long time. A lot of research effort is needed to improve the internal combustion engine. An important paper there comes from the EUCAR Work Group Powertrain, ‘**Research needs in light duty conventional powertrain technologies**’ published November 2010.

In the context of ‘Vehicles with ICE – Hybrid Vehicles – Electric Vehicles’ the ERTRAC–EPoSS–SmartGrids roadmap **‘Electrification of Road Transport’** and the roadmap **‘Long Distance Truck’**, both developed in the frame of the **European Green Car Initiative** are to mention as a important paper.
Obviously the European Commission has a great influence on the future vehicle development, papers important for road transport are under others surely:

- The Transport White Paper setting the EU transport policy: COM(2011) 144, White Paper 2011 ‘Roadmap to a Single Transport Area – Towards a competitive and resource efficient transport system’
- The strategy for clean vehicles : COM(2010) 186, A European strategy on clean and energy efficient vehicles’.

There are also links to other European Roadmaps developed by ERTRAC Working Groups, as: ‘Integrating the Urban Mobility System’; ‘European Bus System of the Future’; ‘Sustainable Freight System for Europe’; ‘Safe Road Transport’; ‘Future Transport Energies’; ‘European Technology & Production Concepts for Electrified Vehicles’ and ‘Road User Behaviour & Expectations’

3. Benefits and challenges of Hybrid Propulsion

ERTRAC has recently issued scenarios and objectives for road based transport proposing that, with the combined commitment and assumption of responsibility by all stakeholders concerned, transport efficiency should become 50% more efficient by 2030 compared with today. This target is translated into three main areas and a number of indicators with corresponding guiding objectives as shown in table 1 below.

By 2030 Road Transport is 50% more efficient than Today

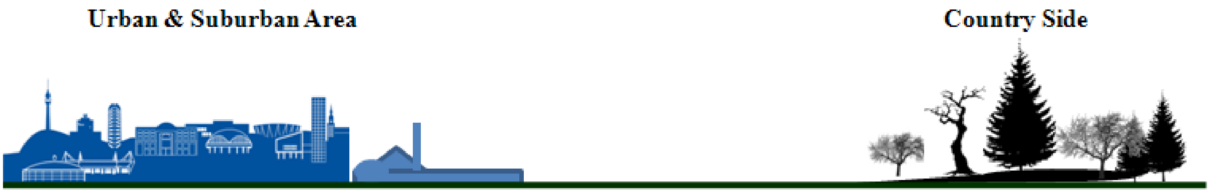
	Indicator	Guiding objective for 2030
Decarbonisation	Energy Efficiency: Urban Passenger	**+80%**
	Energy Efficiency: Long Distance Freight	**+40%**
	Share of Renewables	Biofuels: **25%** Electricity: **5%**
Reliability	Reliability of transport times	**+50%**
	Urban Accessibility	Preserve Improve where possible
Safety	Accidents with fatalities and severe injuries	**-60%**
	Cargo Lost to Theft and Damage	**-70%**

Table 1. Clear guiding objectives for Decarbonisation, Reliability and Safety in Road Transport.
The mission of '50% more efficient Road Transport' is articulated in leading indicators on Decarbonisation (3), Reliability (2) and Safety (2). Each indictor is furnished by a guiding objective for 2030 either indicating the improvement versus a 2010 baseline, indicated with '+' or '-' sign or an absolute level as is the case with 'Share of Renewables'.

Table 1: Summary of guiding objectives of 'ERTRAC Strategic Research Agenda 2010; Towards a 50% more efficient Road Transport System by 2010

The objectives for decarbonisation, set in the ERTRAC Strategic Research Agenda (SRA), are energy efficiency gains of 80% for urban traffic and 40% for long distance freight transport.

Hybrid Vehicles will play a major role, they are absolutely necessary with regard to the societal need for decarbonisation in road transport. They are a major enabler to reach the CO_2 targets, to reduce the Green House Gas emission in general. They will also play a role concerning the conventional fuel resources dependence. Not to forget that they are helpful to enable good air quality in urban areas due to the electric zero emission driving possibility. The aim of clean air in conurbation and the air quality makes it necessary to find near zero emission solutions.
Since Hybrid Vehicles do not have the range limitations of full Electric Vehicles, they will be more in line with the consumer's needs and the driving pattern of today and those for the future.



Vehicle with ICE:
- Unlimited range and speed, no ZEV range

Hybrid Electric Vehicles:
- **With ICE propulsion unlimited range and speed on the country side**
- **ZEV mode in conurbation**
- **As Range Extender and Plug-In with ZEV range up to some hundreds of kilometres**
- **Reduced CO_2 emission**

Pure Electric Vehicle:
- Limited range and speed, limited ZEV range

Figure 4: The benefits of hybrid electric vehicles

Customer expectations on Hybrid Electric Vehicle properties are even higher compared to conventional vehicles. No functional disadvantages may have the Hybrid Electric Vehicle (HEV), they should offer new and additional benefits, like to drive as Zero Emission Vehicle (ZEV). An important target is to reduce the fuel consumption in real life operation.
Hybrid Electric Vehicles combine the advantage of two different propulsion systems, the possibility to drive with zero emission and to drive on long distances. They fulfil a lot of benefits as fast highway driving, to pull supporters, they are thrifty and clean. Hybrids will be a good solution for a lot of families to choose a car they can use in areas with worse air quality, probably in the future a lot of them with restrictions for conventional cars, as well as to go on holidays.
Beside these benefits **hybrids suits a lot of vehicle configurations** – small city cars, long distance family cars, delivery vans, city-buses. Plug-In Hybrids and Range Extender Hybrids will offer a range of 400 to 500 km with optional zero emission driving in electric mode and with ultra low emissions with the optimised ICE mode in the future. An additional benefit for CO_2 reduction can be obtained when using bio-fuels from the 2^{nd} / 3^{rd} generation. Alternative fuels, especially bio-fuels offer the possibility to adapt the engine to dedicated fuel specifications. The reduced liquid fuel consumption of hybrids offer the potential to bring demand and production capacity in line without penalties for food and/or rain-forest.

The benefits shows very clear that the Hybrid Electric Vehicles will be an important part to secure sustainable mobility

- Zero emissions in cities and conurbation, driving without making air quality worse
- Driving without limited range from city to city as well as all over the landscape, with optimised ICE and transmission, the use of alternative-/bio-fuels and thus reduced fuel consumption and lower emission.

With all these benefits, the use of hybrid vehicles will gain benefits on economics, jobs, technology leadership as well.

But, the benefit of a hybrid configuration depends on a large number of influencing factors. An optimum configuration can differ significantly depending on these factors. As nearly all factors have some interrelations and due to the increased system complexity **the system design is more challenging** than for conventional ICE vehicles.

Selected optimisation tasks and their interaction to the component properties are briefly:

1) In HEVs electric motors and power electronics have to be packed. In nearly every case the available space and relation to this, the size of components is limited. Obviously, the size correlates to the component properties, leading to a trade off in design and layout.

2) At the mounting locations these components are exposed to environmental conditions i.e. temperatures and accelerations, which have to be taken into account for the design for a safe operation.

3) The control of the components is done through specific control units, which have to be connected to the vehicle communication network. The second torque source has to be coordinated with the combustion engine torque.

4) An important aspect is the correlation of the system design and thus for instance the frequency and the profile of the load of the individual components with the life time of the components. It is known, that batteries can withstand only limited numbers of charge and discharge cycles.

5) Also the power electronics, built out of materials with different extension coefficients have limited life time cycles due to the active and passive temperature cycling.

6) For the majority of the customers, predictable system reaction is a prerequisite for acceptance.

Source: 'Challenges for electric energy storage systems in hybrid vehicles'; Braunschweiger Hybrid Symposium, 21. Februar 2008

Operating at cold conditions, particularly reliable cold start behaviour is another sensitive requirement of hybrid vehicles. Since state-of-the-art battery technology is not ready to meet this completely, today a HEV suited to daily use will be equipped with an additional starter and even for Plug-In Hybrid Vehicles (PHEV) an internal combustion engine will be strongly recommended for cold conditions and as range extender.

The **challenges** to solve on the way to more sustainable electrified traffic, not only caused by the system complexity, could be summarised as:

- First of all the reduction of the hybrid system costs, especially the costs of the batteries, remains an important challenge. The energy and power density and thus the range of batteries have to be increased. The weight and volume of hybrid storage systems is to decrease, new architectures and materials for electric machines and storage systems are to develop.
- The system operating strategy optimisation. The issues of range extender and boosting, the new operation modes like start-stop function and two torque sources, adaptation of ICE to hybrid requirements, downsizing, alterative fuels and charging requires thermal management optimisation, battery and combustion optimisation. For an optimum system design, in general robust, small, integrated and efficient hybrid components and configurations are to build. For heavy duty application an increased durability is needed.
- New (fast) charging options at home, during working hours, in public areas, the needed infrastructure is to provide (type and availability of loading stations and adequate power grid, the way of data exchange between vehicle – power grid – energy provider) as well as the necessary investment in production facilities and the flexible rebuilding of production lines to react on market fluctuations.
- Hybrid solutions capable for high number of pieces are to develop.

A further challenge or impediment in market growth could be restrictions in material availability, e.g. for rare earth, magnetic materials.

Considering the large predicted growth in their market shares, a leading position of Europe in Hybrid Vehicle Technologies is critical for the global competitiveness of the European automotive industry, for the manufacturers, the RTD providers and the entire supply chain.
The necessary investment in production facilities is to provide.

One circumstance should be considered, even if costs remains an important challenge, the question will be which additional hybrid costs will be accepted by the customer, which cost benefits can be achieved during a reasonable time of operation. The energy costs will continue to rise and concomitantly the fuel costs, which allow a higher effort for fuel reduction technologies. In addition, which sum will be equalised by burdens for conventional vehicles and/or benefits for hybrids, as e.g. tax measures, entrance-fee for cities with air quality restrictions, etc.

A brief overview on benefits and challenges for Hybrid Electric Vehicles is given in the following table.

3.1 Brief overview on benefits and challenges

Hybrid Electric Vehicles combine the advantage of two different propulsion systems, the advantages to drive with zero emission and to drive on long distances.
Benefits of Hybrid Vehicles
- The 'Decarbonisation' benefit. 10% - 95% CO_2 reduction potential, absolutely necessary to reach CO_2 targets - The 'Green Car' benefit. Cut of Green House Gas (GHG) emissions, enables good air quality in urban areas, adaptation of Hybrid ICE to designed renewable fuels. - The 'Consumer' benefit. In line with future consumer needs: possibility to drive with zero emission and to drive on long distances, with energy savings, with the permission to drive in air quality restricted areas, to drive an environmentally friendly vehicle. - The 'Market' benefit. Broad market penetration possible in a mid term perspective. - The 'Economical' benefit. Hybrids will offer benefits on economics, jobs and technology leadership.
Main challenges for Hybrid Vehicles
- The challenge of the relation costs versus benefit. Reduction of hybrid system costs (in the first place battery costs), to develop new architectures and materials for electric machines & storage systems. - The challenge of the range to drive with zero emission. Increasing the range of batteries, increasing power & energy density, to build the charging infrastructure. - The challenge of the system design. System operating strategy optimisation to new operation modes and two torque sources, adaptation of ICE to hybrid requirements, downsizing. Robust, integrated and efficient hybrid vehicle configurations. Increased durability for heavy duty application.

Table 2: Overview on benefits and challenges of Hybrid Electric Vehicles

4. Hybrid solutions in Road Transport

The definition of Hybrid Vehicles could be given in the way that hybrids have 2 different sources for the propulsion, normally they are equipped with one electrical source (battery with electric motor) and one combustion engine. In the same way the Range Extender Hybrids belongs to the hybrid family, they combine combustion engines with electric generator sets (GenSet) with a battery, to produce on-board electric power.
Normally the Hybrid Vehicles will use the ICE as drive train at full speed, on highways and on long distances, cities and conurbation are suitable for electric drive. Hybrid Vehicles thus covers a great range of sustainable driving.

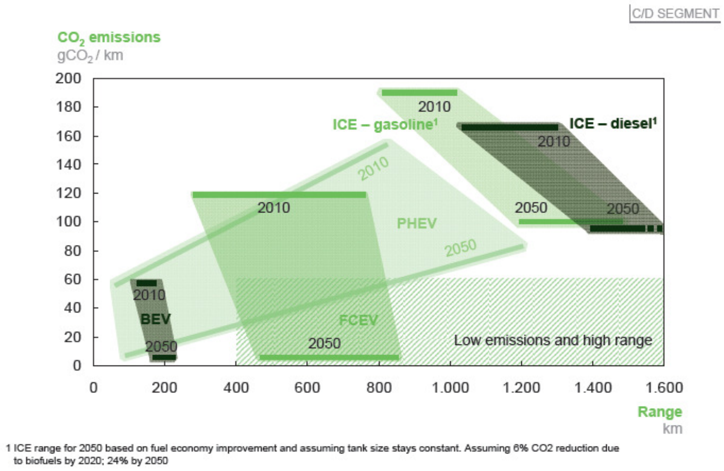


Figure 5: Driving ranges and CO_2-emissions of different passenger car propulsions (source: The role of Battery Electric Vehicles, Plug-In Hybrids and Fuel Cell Electric Vehicles; A portfolio of power-trains for Europe: a fact-based analysis, 2010)

4.1. The various Hybrid configurations for Passenger Cars

Today's situation of hybrid applications can be described as complex and with the possibility to compose nearly every configuration desired. Hybrid Electric Vehicle technology enables new vehicle operational strategies, thanks to the addition of (one or more) electric machine(s), for example:

- Start – Stop function
- Brake energy recovery
- Operating point shifting
- Boosting
- Electric driving

As shown in *Figure 3: The classification of Hybrids* we can arrange the hybrid family in

- Hybridisation aiming at assisting the combustion engine
    - The Micro and Mild Hybrids

and

- Hybridisation aiming at running the vehicle by electric propulsion
    - The Full Hybrids
    - The Plug-In Hybrids
    - The Range Extender Hybrids

In addition to this classification there are two special options.

- 'Through the Road' Hybrid
  (torque connection between e-dive and ICE via road)
  On the one hand providing the possibility for delivery vans to drive as ZEV, on the other hand to make more dynamic and the 4-wheel-propulsion available.

- 'Wheel Hub' Serial Hybrid
  This configuration used normally only for buses and special applications.

The general reach and the range as Zero Emission Vehicle (ZEV) for Full, Plug-In and Range Extender Hybrids, as well as for the option 4-wheeler, is given by the combination of battery dimension and the engine output. Nearly every customer wish could be provided, from small city vehicles up to powerful sports cars.

The impact on CO_2 reduction potential, the efficiency of the configuration and the additional costs of the hybrid propulsion depends very strongly on the configuration itself, mainly on the battery size and the demanded ZEV range. As well it is obvious that the CO_2 reduction depends on the driving conditions and behaviour.
The CO_2 reduction figures given in the following description of the hybrid families are to be seen as the indication of the potential for the hybrid system of passenger cars, the hybrid effect only, not for the optimised hybrid vehicle. Figures for a mid-size vehicle with slightly optimised drive train are given in the overview at the end of this chapter.
All figures given are based on ERTRAC experts input, they are Tank to Wheel figures.

Costs for the hybrid configurations are not given, the market is too dynamic, costs changes too fast, every figure given could be wrong a week later.

The symbols used for the hybrid family pictures:

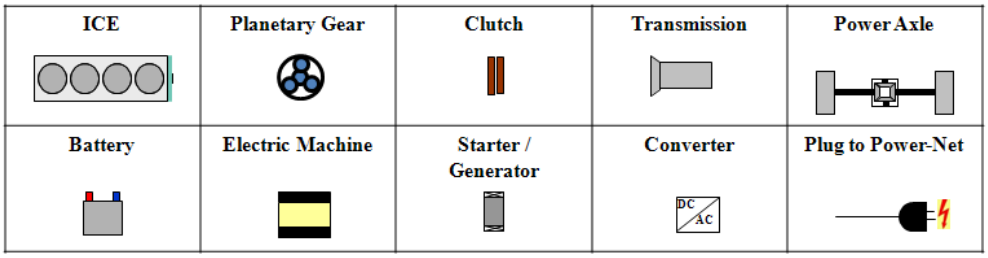


Figure 6: Symbols used in the hybrid pictures

○ The Micro and Mild Hybrid family

Micro and Mild Hybrids, with start-stop function and belt Starter-Generator, are already in market penetration phase.
In general Micro and Mild Hybrids do not have a ZEV range.

Micro and Mild Hybrid vehicles combine a start-stop functionality with some amount of regenerative braking, minimal for Micro and modest for Mild Hybrids. These two features are used to improve fuel economy and emissions:

1. The engine is automatically switched off when the vehicle is stationary and instantly restarted as soon as the driver wishes to drive off again – so there is no fuel used at idling.

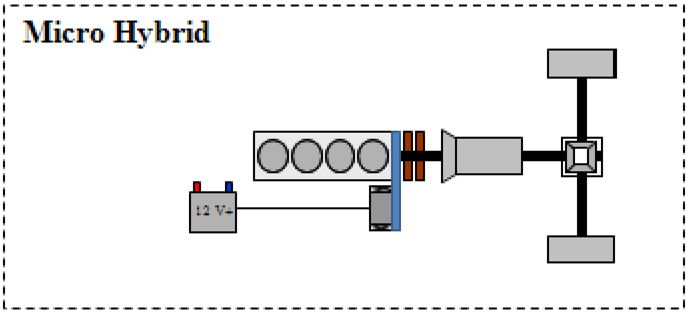
The restart can be done comfortably using a belt-driven Starter-Generator (SG) or an Integrated Starter-Generator (ISG).

2. Braking energy is recuperated via a regenerative braking control strategy – the vehicle's kinetic energy is converted into electrical energy.

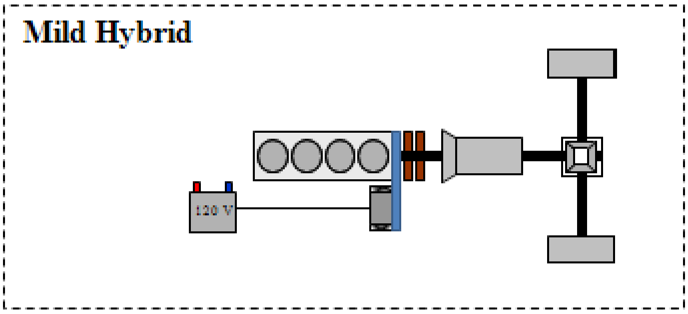
These features are believed to generate best benefit in urban driving, where start-stop rates are high and breaking events are frequent.
The given power resulting of the ICE and the Electric Machine/Motor (EM) is very application dependent.

For the start-stop function a very specific issues is to heed, the number of engine starts required in vehicle life and the additional stress on the battery due to it.

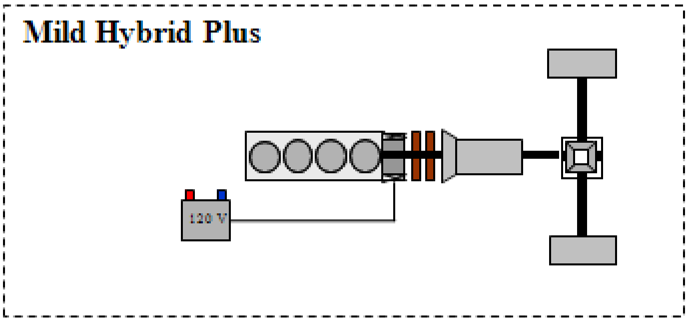
The configurations of Micro and Mild Hybrids:



14-42 V Lead-Acid Battery, 2-5 kW Belt SG, CO_2 reduction potential 3% - 7%



60V-120V medium voltage Battery, 8-14 kW Belt SG, CO_2 reduction potential 4% - 9%



60V-280V Li-Ion Battery, 8-30 kW crankshaft or fly-wheel mounted ISG, limited boost function, ICE + EM power from 80 kW up to 300 kW, CO_2 reduction potential 7% - 14%.

Even if Micro and Mild Hybrids are already in market penetration phase, there is still research need to be seen in the further development of the crankshaft or fly-wheel mounted integrated Starter-Generator and the improvement of driveability and comfort due to this start-stop system.

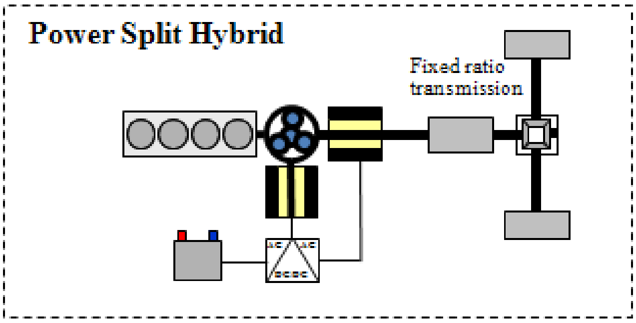
- **The Full Hybrid Electric Vehicles family**

The Full Hybrid configurations could be seen primarily as a concept to reduce fuel consumption. In addition there are advantageous as the Plug-In ones. They have a limited ZEV range of about 2 km. The electric motor is in the range of about 20-50 kW, they are equipped with a 200V-300V Li-Ion Battery of about 1.5-2.5 kWh. The total given power ICE + EM could be from 40 kW up to more than 200 kW. Some hardware is common with the Mild Hybrid Plus above and some of the Full Hybrid configurations are compatible with many conventional engine configurations.

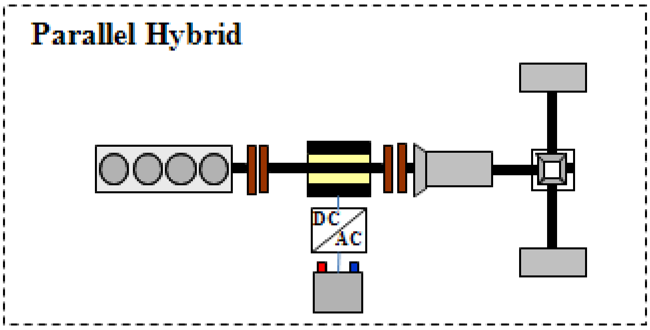
Currently the Power Split design dominates the market today followed by the Parallel Hybrid structure, whereas the Serial Hybrid has significant drawbacks due to the energy conversion losses under full power operation.

The Full Hybrid configurations:

A **Power Split** concept (as used in the Toyota Prius) features a planetary gear set to split the power of the combustion engine into a power flow directly to the wheels and another power flow to the generator. The generated electrical energy is either stored in a battery (mostly NiMH) or is used to power a traction motor mechanically connected to the wheels. The layout allows electric driving and brake energy recovery at high efficiencies. Moreover it introduces an electrical Continuous Variable Transmission (CVT) function, which enables the combustion engine to operate close to the optimal fuel economy trajectory in the operation map. Additionally it makes a conventional transmission obsolete and thus reduces mechanical complexity. The CO_2 reduction potential is about 15% - 28%.

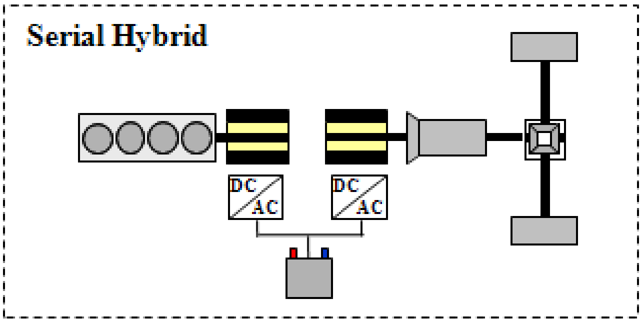


The currently most widespread alternative concept for Full Hybrids is the **Parallel Hybrid**. The Parallel Hybrid concept with an electric machine connected directly to the drive shaft of the combustion engine with one or two clutches in line before and/or after the e-motor provides benefits when being added to an existing conventional vehicle unit. A CO_2 reduction of 15% - 27% could be achieved.

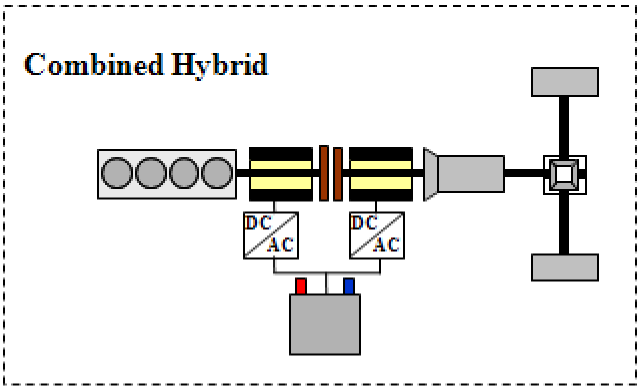


In the **Serial Hybrid** concept the Internal Combustion Engine (ICE) is mechanically disconnected from the drive train and charges the battery through a generator to overcome the limitations of the battery's energy content. This vehicle is designed to primarily operate in all-electric mode, the optimised on-board electric power generator set is used only for extending the range of the vehicle once the battery is depleted beyond a predefined limit. The CO_2 reduction is about 10% - 27%.

The Serial Hybrid is equipped with 2 electric motors in a range of 20-100 kW each. The electric motor belonging to the ICE side could be smaller than the second one, normally they have the same performance. The electric motors must provide the whole vehicle performance which could be easily 100kW.



The combined or serial-parallel configuration is equipped with 2 electric motors and a between-switched clutch, which allows to switch between serial and parallel driving mode. The **Combined Hybrid** configuration offers a lot of operation modes, electric drive, boosting for acceleration, recuperation and battery loading.
The advantage of this configuration is to be seen clear therein that in the range of middle- to high-speed the mechanical energy could be brought directly to the power-axle, to the wheels, without energy conversion losses. A CO_2 reduction of 10% - 28% could be achieved.



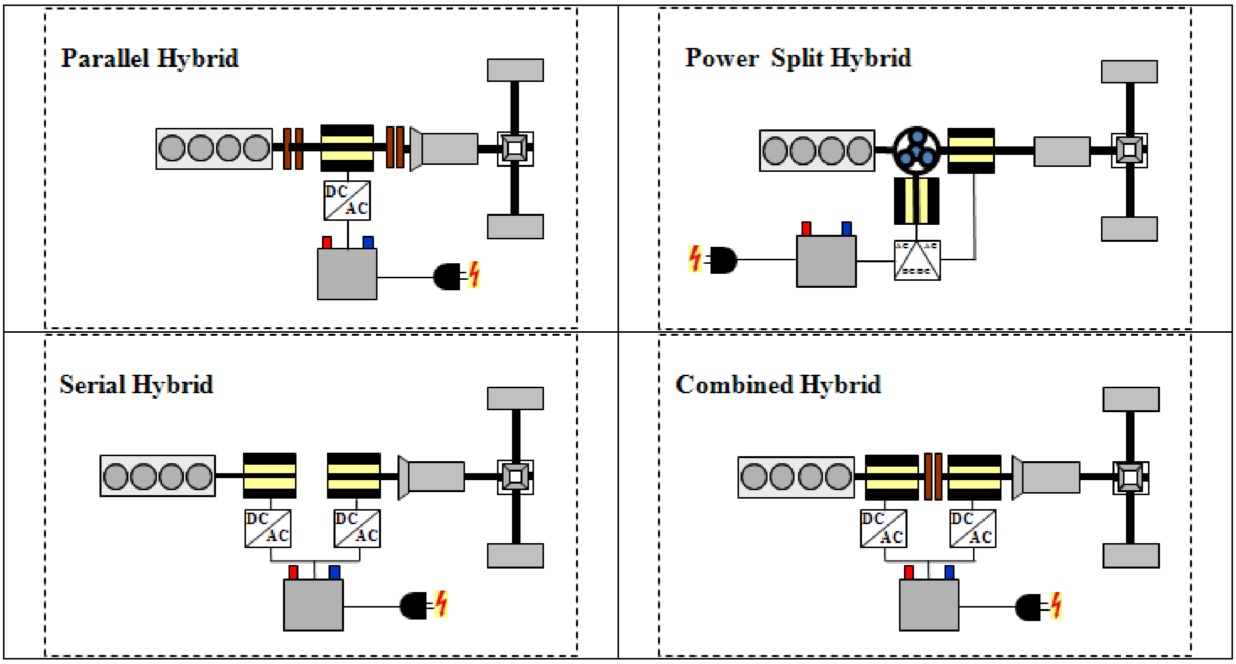
- **The Plug-In Hybrid Electric Vehicles family**

The Plug-In Hybrids are from the technical side equal to the Full Hybrids, apart from the Plug-In device. The difference lays in the application, in the functionality: The aim of the Full Hybrids could

be described to gain fuel consumption. High 'power density' batteries are in use. The Plug-In Hybrids aim to drive in electric mode, they need batteries with high 'energy density'. The optimal battery capacity (and the electric driving range) may vary by market and consumer group. The willingness to pay for additional battery capacity (and additional range) could be a key determinant.
Plug-In Hybrids can be combined with all of the well known base structures of Hybrid Vehicles.
An increasing degree in electrification can now be achieved through two methods. First, a larger battery size is capable of storing more electrical energy and power. This introduces the Plug-In feature, which utilises off-board charging strategies from the grid. Secondly, a high power electric motor can provide the required propulsion for the vehicle.
The degree of electrification increases from Parallel Hybrid to Power Split and to Serial Hybrid. This is mainly a question of battery size and performance, the more electric power the less mechanical devices. With a higher degree of electric power the possibilities for smaller and/or downsized internal combustion engines increases.
Thus the Plug-In Hybrid family shows the greatest potential for the future, these vehicles are the 'all-round' cars. They allow high speed on highways as well as adequate zero emission range. They could be built up as small city cars, as 'family cars' to go to holidays as well as to build up and used in delivery vans. Home recharging will be a prerequisite for most consumers as well as the recharging options during working time; the public recharge infrastructure has to ensure the adequate driving range.
The CO_2 reduction potential is in a range of 10% - 85%. The reduction potential depends strongly on the use case, the duration of electric driving. With a high electric driving part the CO_2 reduction potential could be up to 85%, on long highway runs it will shrink to 10%.
The ZEV range is about 20 - 80 km, depending on electric motor and battery size. The electric motor is in the range of more than 30 kW, the Plug-In Hybrids are equipped with a battery of about 5 to 15 kWh, nominal voltage range could be up to 400V.

Integrating the larger batteries together with the hybrid drive train represents a big challenge in Plug-In Hybrids. Currently the approach to overcome this challenge is to realise a hybrid system with a downsized combustion engine.

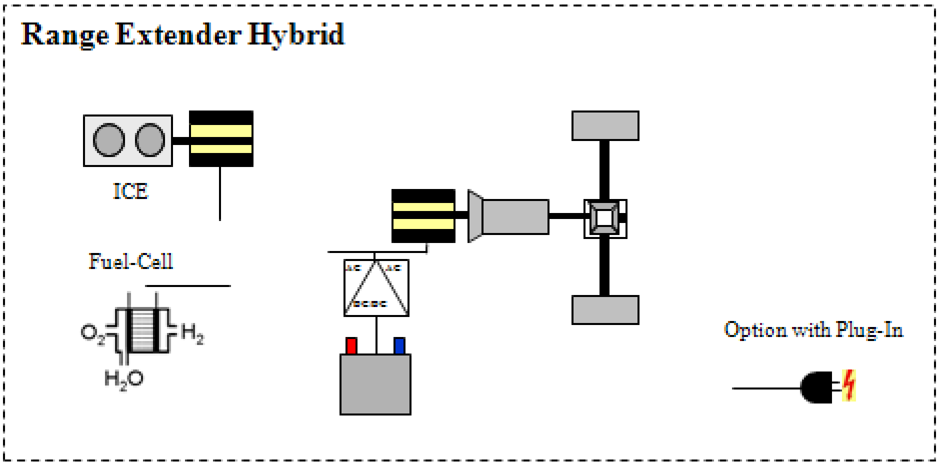
The Plug-In hybrid configurations:



○ The Range Extender Hybrid Electric Vehicles

Range Extender Systems combine (small) combustion engines (or may be fuel-cells in the future) with electric generator sets with a relatively large battery, to produce on-board electric power. As Serial or Combined Hybrid they can have, but do not necessarily need a mechanical link to the wheels. The option as Plug-In version is given.

The Range Extender Hybrids seem to be a proper construction for future city solutions with sufficient electric reach of 80 to 120 km and a CO2 reduction of 10% - 95% is realistic.



The electric energy supply consists of 1st the battery and 2nd the range extender. If the battery fails, the range extender could provide a minimum of propulsion, but could not deliver full performance. The range extender modules can provide the following benefits:

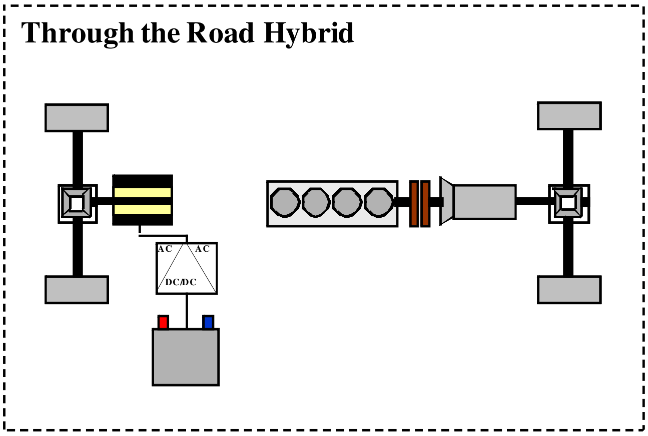
- Provide electric power when cold battery discharge power is limited, which fills the gap by enabling the vehicle to reach the same climbing and acceleration performance
- Provide electric power when hot battery discharge power is degraded.
- Provide electric power to cool the battery (with an electric A/C cooling system), when the battery is to hot to charge
- Delivery of thermal energy to heat up the battery, when it is too cold to charge or discharge the battery
- Extend the vehicle driving range significantly beyond the energy capacity of the battery
- Reduce the overall vehicle drive-train and energy storage system costs

The range extender module offers the possibility to reduce the battery size to reasonably optimised dimensions. Due to this reduction in size, statistically meaningful specifications in terms of electric driving distance, cost, integration and other benefits can be met.
Moreover, this approach allows implementing optimised range extender systems that can overcome the battery shortcomings.

A major gap is still to be seen in a suitable combustion engine and/or in alternative GenSet systems.

○ The 'Through the Road' Hybrid Vehicle

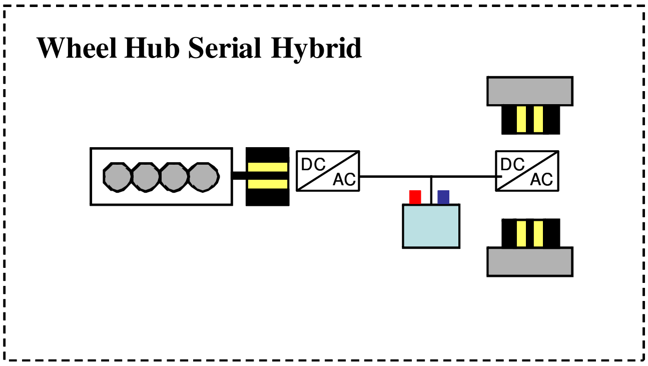
This special configuration is very convenient for present series vehicles, it could be built-up from a series vehicle with conventional ICE drive-train. An additional axis with electric motor is to built-in.
Two applications are mostly built-up, as 4-wheeler or as delivery van. The 4-wheeler is the 'dynamic' version for passenger cars, using high power density batteries. The benefit as delivery vans is to drive as ZEV. The battery type is of high energy density.



This is a cheap and simple option for the hybridisation of existing series vehicles, possible for front-wheel or rear-wheel propulsion.

○ The Wheel Hub Serial Hybrid

This configuration has the drawback of big unsprung mass on the wheels, used normally only for buses and special applications.



o Overview Hybrid Passenger Car configurations

The following part will give a brief overview on the different hybrid options with information on electric driving range and an indication on the CO_2 reduction potential. The figures given are based on the expertise of ERTRAC experts, given for a mid-size vehicle with a weight of approximate 1500 kg with slightly optimised drive train - some downsizing, transmission optimisation and vehicle measures.
Furthermore the ZEV range and CO_2 reduction depends strongly on the relation of battery size (power & energy), electric motor power and the ICE dimensioning as well as on the driving conditions and driving behaviour. As it is a big difference to go for a short distance with mainly electric drive, like it is possible in cities, or to go for a long distance trip using mainly the ICE, the numbers for CO_2 reduction are subdivided into the savings in the New European Driving Cycle (NEDC) and a presumed city driving with long phases of electric driving and frequent start-stop. The ranges are to be seen as today's expert knowledge.

- The Micro and Mild Hybrid family

A simple and cheap solution for conurbation with many start-stop actions, to reduce fuel consumption and emission.

- The Full Hybrid Electric Vehicles family

A solution mainly to reduce fuel consumption. The Power Split Hybrid dominates the market today, it introduces a electrical CVT function and reduces mechanical complexity through fixed ratio transmission. The Parallel Hybrid offers benefits when added to an existing conventional engine. The Serial Hybrid has drawbacks due to the energy conversion losses under full power operation.

- The Plug-In Hybrid Electric Vehicles family

The best configuration for 'All-Round' Cars. Two methods to increase the degree of electrification and thus reduce the mechanical devices and increase the possibilities for downsized engines:
1. A larger battery size introduces the Plug-In feature with off-board charging.
2. A high power electric motor provides the required propulsion.
The degree of electrification increases from Parallel to Power Split and to Serial Hybrid. The Serial Hybrid is designed to primarily operate in all-electric mode.
The Plug-In Hybrids allows high speed on highways as well as acceptable ZEV range.
As Combined Hybrid with clear advantages in the range of middle- to high-speed.

- The Range Extender Hybrid Electric Vehicles

Proper solution for city and conurbation traffic. Offers a minimum of propulsion with reduced performance if the battery fails. The Range Extender system can overcome the battery shortcomings.

Hybrid family	Configuration	ZEV range (km)	CO_2 Reduction (%)	
			City	NEDC
Micro & Mild Hybrid	Micro	0	4-7	3-5
	Mild		5-9	4-7
	Mild Plus		7-14	7-12
Full Hybrid	Power Split	~ 2	18-28	15-25
	Parallel		17-27	15-25
	Serial		12-27	10-23
	Combined		12-28	10-25
Plug-In Hybrid	Parallel	20 - 80	17-85	15-80
	Power Split		18-85	15-80
	Serial		12-85	10-80
	Combined		12-85	10-80
Range Extender Hybrid	Range Extender	80 - 120	12-95	10-80

Table 3: Overview about an indication of ZEV range and CO_2 reduction potential of Hybrid Passenger Cars

4.2. The Hybrid options for Commercial Vehicles

○ The hybrid options for the bus

The city buses are in the fore front in utilising the hybrid technology. The hybrid technology is very well suited for city bus driving with frequent stops. City bus fleets in Europe have recently entered a transition mode to hybrid technology. The state of art hybrid technology has a proven potential of reducing the fuel consumption with at least 30%. This technology has with future development the potential to meet the long term European goal of an 80% CO_2-reduction.
The bus population is producing more passenger kilometres then the aeronautic sector, but is receiving just a friction of the development support. We are therefore convinced that investments in this segments technology development could be a very cost efficient way of reducing the CO_2 emissions and at the same time improve the energy efficiency.
Independent which fuel is used or for that matter which energy converter is used. It is equally important to have an efficient vehicle. Hence, is the hybrid system valid in most cases.

Technology development in this segment is very rapid outside Europe. In China are large governmental subsidies feeding a rapid transition to this technology. The US have today passed Europe when it comes to market penetration of this technology. 30% of the transit market in US is populated by hybrids. China and US are today in the lead regarding battery development for hybrid applications. Further development towards cost reduction and towards the transient demands of hybrid applications are essential.

In order to fully utilise the potential of the hybrid technology for city and intercity buses, dedicated transmission development is needed. Other hybrid technologies related to city bus applications are energy efficient system integration, Plug-In technology including novel concepts based intermittently transferred electricity from grid, focusing interactive high power transfer. Light weight technology and other requirements for new vehicle architectures, are important development areas as well as Range Extender Hybrid technologies for climate or emergency propulsion energy. Intelligent climate system that can also fully developed and utilised in the frame of a hybrid city bus energy system.

When designing hybrid technology for city buses the specific operational conditions of this transport mode have to be taken into account:

- Compared to passenger cars which normally run in average only a short time every day, city buses run 16-20 hours daily.
- Due to optimised operational use on bus lines, city buses normally do not return to the depot during the day. This has an influence on the design/concept of additional charging of energy (electricity) which should be realised during operation.
- Many start-stop cycles due to operation in very dense urban areas with frequent stops for boarding/alighting of passengers
- Introduction/running of new technology should not result in slowing down travel speed of bus services which is a very important factor for attractiveness and comfort for passengers

For line haul and coaches is system- and component development closely linked to trucks. It is of this reason highly likely that coaches will copy the truck road map.

○ The hybrid options for the long distance and distribution trucks

Future long-haul and distribution truck power-trains will include an increasing degree of hybridisation as important part of improving fuel efficiency and for improved transport operations in urban areas. Dedicated system and component research activities are needed on advanced development on e.g. engine and complete power-train designs for Hybrid Truck operation, featuring start-stop capabilities, advanced transmission systems, brake energy recovery, efficient auxiliary mode operation and hotel mode functions. The utilisation of hybrid technology in the truck segment, ranges from focused Mild Hybrid solutions for long distance vehicles to Full Hybrid applications for urban distribution trucks. For smart total vehicle energy management are especially important, also including advanced systems for the hotel mode are crucial research topics for reducing total HD Mild Hybrid Vehicle energy consumption. Both the energy management of the cab comfort, the ability to for e.g. refrigeration, as well as handling of cargo, can benefit from an advanced hybrid technology system on the vehicle in the hotel mode.

A new generation of hybrid control architecture development are also needed which is prepared for future types or degree of Plug-In possibilities or concepts based intermittently transferred electricity from grid. Local demands in lager cities or the potential local development of “green corridor” road net work will requires a large degree of flexibility of the control system even for the long haul segment. Driving environment and Global Positioning System (GPS) linked information development will also improve the control system potential of the hybrid system utilisation.

The complete engine system needs to deliver high efficiency in the defined hybrid driving modes which may differ considerably depending on the type of hybrid application. A full integration of the power-train with the hybrid system including all other sub systems, including after-treatment is therefore paramount. Both series or parallel or a combination system may be applicable for long haul Mild Hybrid Vehicles. Specifically for HD truck is the requirement for high voltage development solutions, due the high demand of power in these hybrid vehicles.

Several steps of energy efficiency and cost reduction actions can be applied for engines dedicated to be operated in combination with a mild hybrid power-train with or without any kind of grid energy transfer. Engine transient operation requirements will e.g. be possible to reduce significantly, which opens up for engine simplifications and further essential improvement of the engine efficiency and potential alternative fuel utilisation. High efficient combustion modes, like e.g. different derivatives of Homogeneous Charge Compression Ignition (HCCI), may then be developed and realised, due to reduced transient requirements. This is also valid for the after-treatment and waste heat recovery solutions, although different fuel need special after-treatment considerations. Special attention is to be taken of how to start and stop the engine in an efficient, silent and durable way.

A key element in cost and performance is electric energy storage systems where development in the passenger car market will be an enabler to achieve the volumes necessary. However the specific durability demand on e.g. long haul transport systems set a specific attention on the development towards robustness of these systems. Battery cost, weight and durability predictions are currently a limiting factor for the future for this segment. Additional dedicated hybrid related research is therefore crucial on these topics. However, mild hybridisation opens also for new features which contribute to improve the energy efficiency on the total vehicle operation. Examples are kinetic or electro-kinetic systems which in certain applications can be an efficient additions or parts of the total hybrid concepts. These have the advantage to be independent from battery development.
In summary 3 different energy accumulators or additional energy providers should be considered:

- Electric systems batteries or super capacitors to provide energy for propulsion or retrieve kinetic energy, focus on high energy density (battery, fuel cells)
- Hydraulic systems to provide energy for propulsion or retrieve kinetic energy & store energy in pressurised gas tanks or hydraulic fluids.
- Kinetic systems use of flywheels to retrieve energy and use energy for electric generation or direct propulsion

	Bus Configuration	ZEV range	CO_2 reduction (%)	
			City	Inter city
Micro Mild	Parallel or serial	**0**	**-**	**4-5**
Full Mild	Parallel or serial	**0**	**35**	**20-25**
Plug-in	Parallel or serial	**60% of total**	**75-80**	**-**

	Truck Configuration	ZEV range	CO_2 reduction (%)	
			City	Inter City
Micro Mild	Parallel or serial	**0**	**-**	**4-5**
Full Mild	Parallel or serial	**0**	**15-25**	**10-15**
Plug-in	Parallel or serial	**30% of total**	**30-40**	**-**

Table 4: Overview of CO_2 saving for Bus & Truck Hybrid. Basically the same hybrid topologies as for light duty is relevant also for heavy duty.

4.3 Non electrical hybrid systems

Although electrification is the established method for creating a hybrid power-train, other types of system exist and may be attractive in some applications. These alternative systems, sometimes known as "mechanical hybrids", store energy using mechanical principles such as compression of air or the spinning of a flywheel. Their potential advantages are reduced cost (compared with current battery and electrical system prices) and better performance in aggressive duty cycles. These technologies are generally less mature and well known, but Europe possesses significant strength in the technologies required to make them viable.

- **Hydraulic Hybrids**

A Hydraulic Hybrid uses a hydraulic pump/motor to force fluid into a pressure accumulator under braking, or provide extra torque to facilitate the launch of the vehicle. Performance is similar or slightly better than that of a "Strong Mild" Hybrid, and the system has found favour in prototype garbage trucks which have a need for repeated cycling between stopped and a low movement speed. More advanced variants of the technology employ digitally controlled pumps and motors to create a series or power-split drive, and have been demonstrated as prototypes in cars and commercial vehicles. The system is usually integrated into the final drive, but other configurations including hydraulically variable transmissions are possible.

- **Flywheel Hybrids**

A Flywheel Hybrid stores recovered kinetic energy in a high speed flywheel. Rotating at speeds of up to 60,000 rev/min (to give good energy density), the flywheel is contained in a vacuum to minimise losses. Drive to the vehicle can be via a shaft with seal, a magnetic coupling to an external shaft (both requiring a variable transmission to connect to the driveline), or an electric machine built into the flywheel. Performance is again at just above the level of the “Strong Mild” hybrid (a passenger car system stores up to 0.2 kWh of energy, but can supply 30 kW of power), and again the system performs well on aggressive duty cycles. The system can be integrated in a number of ways, including mechanical linkages into the transmission or driveline, and electrical connection into an electric machine positioned in one of the electrical hybrid configurations described above. There is less recent field experience of this type of system, but prototypes of all the types described have been demonstrated, and a European OEM has used such a system in sports-car racing.

- **Comparison to electrical systems**

The cost of electrical hybrid systems is dictated by the underlying cost of batteries, power electronics and motors, which employ materials of high value (Lithium, Copper, Refined Silicon). In contrast, mechanical hybrid systems are mostly made from more common engineering materials. Carbon-fibre is often used for hydraulic accumulators and flywheels, but the most costly grades are not required. Those who promote such systems claim a potential cost of half that of an equivalent electrical hybrid.

The losses in an electrical hybrid system increase with the square of current, so performance on more aggressive duty cycles is compromised. Mechanical systems also experience higher losses with high power flows, but not to the same extent; hence their suitability to the aggressive start-stop regime of buses, garbage trucks, delivery vans and urban traffic.

Unlike the electrical hybrid, there is no direct route to the use of electricity as a fuel (Plug-In Hybrid, Range Extender Hybrid or pure Electric Vehicle). However, a mechanical system can be combined with a battery-electric drive, allowing the battery cells to be optimised for a slow discharge rate and high energy density (which facilitates a significant cost reduction).

Typical performance of some Flywheel systems, based on recent research, is as shown in the table below. A hydraulic system would have similar performance.

Configuration (Baseline = Standard vehicle, without stop-start)	CO2 reduction %	
	City	NEDC
Flywheel Hybrid + Stop-Start, no post-run energy recovery, applied or retro-fitted to carry-over powertrain	15-25	10-15
Flywheel Hybrid + Stop-Start + Post-run energy recovery into 12v battery; carry-over powertrain	17-30	12-20
Flywheel Hybrid + Stop-Start + Post-run energy recovery to 12v battery + down-sized engine	20-35	15-25
Comparison: Electrical Strong Mild Hybrid (section 4.1), carry-over powertrain	7-14	7-12
Comparison: Electrical Full Parallel Hybrid (section 4.1), carry-over powertrain	17-27	15-25

Table 5: Overview of CO_2 saving potential for non electrical hybrid systems.

4.4 Requirements for energy storage systems

The resulting requirements on the hybrid system are mainly dependent on the hybrid concept. The hybrid topology and the target performance values (e.g. electric driving range) will define the main requirements like voltage range, power and capacity of the battery.

The energy storage systems between pure Battery Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV) are different in their requirements. Pure Electric Vehicles requires systems, normally batteries, with high energy density. Hybrid Electric Vehicles requires electrical energy storage systems with high power density (battery, fly-wheel, supercap), application mainly on boosting as well as with high energy density (battery, [in special applications a fuel-cell]), application mainly for electrical operating range.

In general, electrical energy can be stored in different forms; compressed air (pneumatic), flywheels (kinematic), thermal storage (heat), hydrogen and (chemical), but battery energy storage has the ability and can combine best energy capacity (Wh) and power output (W) needed for a certain application.

Battery systems should be distinguished from other storage devices because they are flexible and can be adapted to high power and/or high energy demands during use. When correctly selected or tailored, they are highly efficient, both during use and at stand-by. Batteries are highly recyclable and infrastructures for collection and recycling already in place over Europe, moreover, they use a high proportion of secondary materials.

Electric energy storage systems for HEV enables new additional functions. Storing is not only a matter of capacity only but the ability to fulfil other functionalities (start-stop function, brake energy recovery, operating point shifting, boosting, electric drive, bi-directional charging) typically related to the charge/discharge models in the vehicle.

A broad range of different electrochemical battery technologies exist. However, lead, nickel, lithium and sodium based battery technologies are the four major families which are usually considered as those technologies that can effectively contribute to the efficient and sustainable use of electrical energy storage, the selection of one depending on the requirements of the different vehicle architectures. Giving the diversity of possible operating modes, there is no single storage system or technology covering the entire range of needs.

Apart from Energy storage systems in the vehicles, batteries will also contribute to the infrastructure to improve charging and bi-directional energy flow management in the future electricity grid.

Regarding future technologies for plug-in HEV and EV development: in medium term indicating Li-S and Li-Silicon, on the longer run possibly Li-Air and hybrid battery-storage technology.

- **Heavy Duty energy requirements**
  - New Materials and Cell Design for improved HD Life, Cost, Safety
  - Improved robustness by improved & tailored control and electronic solutions for HD vehicles
  - Improve SOC (state-of-charge), SOH (state-of-health).
  - Improved Super Capacitors with improved energy density for specific power intensive applications, and brake recovery systems
  - Power and energy optimized batteries combination for improve discharge and fast charging performance
  - Technology solutions and standards for Fast-charging of HD plug-in systems

- **The fuel-cell as storage system**
  - Focus on high power density and high energy density due to a separate source of energy (i.e. fuel-cell with hydrogen tank):

As a visionary possibility for the future one can imagine hybrid configurations with fuel-cells instead of batteries.

All of the topics relevant for fuel-cells are addressed in the multi annual implementation plan of the fuel cells and hydrogen joint undertaking (MAIP of FCH JU) of the EU.
For most of the former technical bottlenecks of fuel cell systems such as cold start ability (sub zero °C) and durability, solutions are identified. Main challenges of today and for the upcoming years are the cost reduction on component and system level as well as the creation of a sufficiently dense hydrogen supply network. In parallel, basic research is and will be ongoing regarding new materials, which should help to further improve system efficiency, simplify the operation, improve the reliability and reduce the costs.

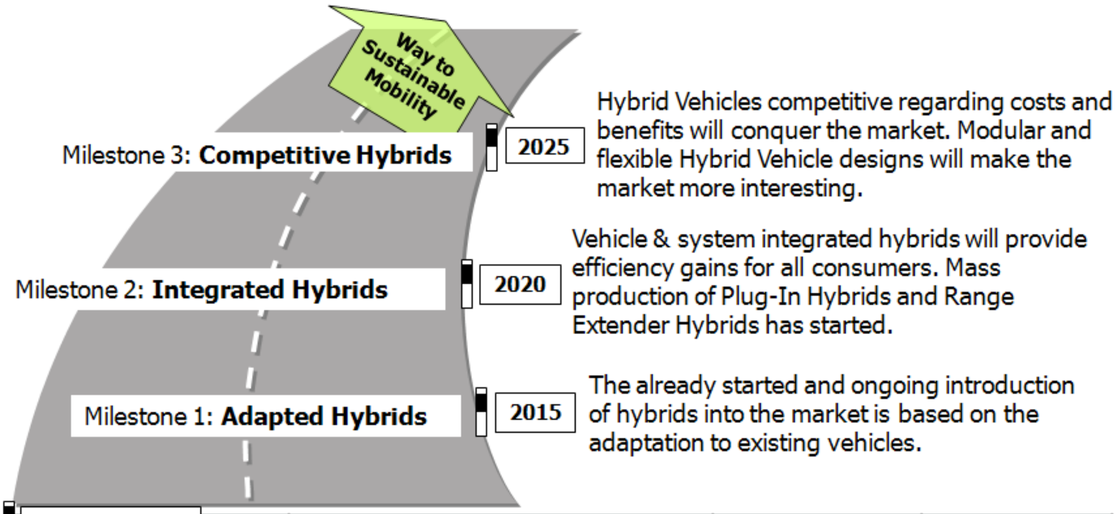
5. Milestones

5.1. Milestones for Passenger Cars

In response to the mentioned needs, the involved ERTRAC stakeholders have combined their knowledge and experience, coordinated with the European Roadmap 'Electrification of Road Transport', in order to assess which benefits of the hybrid configurations can be achieved by when, and what actions will be required to master the challenges of Hybrid Vehicles at large scale.

As a kernel for the roadmaps a scenario for passenger cars based on the expected future hybrid configurations was considered with a brief excursion to commercial vehicles and buses. Separate detailed roadmaps may be developed for buses, delivery vans and light duty trucks, two wheelers, heavy duty freight transport, road infrastructures as well as for a Hybrid-City-Vehicle concept. In addition a 'Technology & Production Concept for the Electrification of Road Transport' will be developed for the industrial mass production.

To strengthen and extend the European competitiveness in the field of Hybrid Vehicles, the 'European Roadmap Hybridisation of Road Transport' has defined the necessary milestones and recommendations.



2011 Potential	Application	ZEV range (km)	CO_2 reduction potential
Plug-In Hybrid	Best application for 'All-Round' cars	20 km – 80 km	15% - 90%
Range Extender Hybrid	Proper solution for city traffic	80 km-120 km	10% - 95%

Figure 7: Overview of research milestones

Even if the milestones are settled for a clear near future (2015, 2020, 2025) with a market introduction expected after another 3 years of series development, it is obviously clear that research and development of hybrids is necessary to go on after 2025.

The milestones are structured according to the following system:

1. The general description of what should be achieved at this milestone followed by a description with the goals to reach at this milestone for each of the different hybrid configurations
2. The description of the milestones for the major technology fields is shown in Table 2

- **General milestone description**

  - **Milestone 1: Adapted Hybrids (2015)** [Market 2018-2020]

The already started and ongoing introduction of hybrids of EU car makers (passenger and industrial vehicle) into the market is based on the adaptation to existing vehicles. The conversion of existing vehicles into Plug-In Hybrids and Range Extender Hybrids will increase. First fleets will evolve for niche applications like, e.g. taxis, car sharing systems, delivery services and other bigger fleets. For Plug-In Hybrid and Range Extender Hybrid vehicles, specific standards for safety, data communication and billing will be developed. At the same time a charging infrastructure will become available. Continuous cost reduction and a first level of integration at sub-system level is needed for market penetration for hybrid system applicability on most vehicle segments including small vehicles. A keen market assessment definition is mandatory to exploit the market penetration of this new technology for cost targets, based on benefits for customers.

Configuration	Milestone 1 Goals
Micro / Mild Hybrid	Improvement ISG; Subsystems integration and smart control strategies for efficient and cost effective hybrid power-train;
Full Hybrid Plug-In Hybrid	Optimisation of conventional ICE and hybrid transmission concepts; Improved thermal management; Modification of breaking systems; Definition of simulation tools to find optimal hybrid configurations; Define a standardised development and manufacturing process; Establish safety standard processes;
Range Extender Hybrid	Definition of specific ICE configurations for Light Commercial Vehicles (LCV) with optimal Range Extender functionality. Establish the baseline (NVH, weight reduction, alternative fuels) for the next generation of Range Extender Unit.

  - **Milestone 2: Integrated Hybrids (2020)** [Market 2023-2025]

Base technologies for the generation of vehicle & system integrated hybrids will provide efficiency gains for all consumers, more system integration and high performance storage systems including batteries for bi-directional charging. The charging infrastructure allows the dissemination of Plug-In Hybrids and Range Extender Hybrids over various cities and regions. Mass production of Plug-In Hybrids and Range Extender Hybrids has started. First business models for charging and grid stabilising will be in place.

Configuration	Milestone 2 Goals
Micro / Mild Hybrid	High level fitment in passenger cars; further improvement of cost, efficiency and performance.
Full Hybrid Plug-In Hybrid	Full integration of hybrid power-train components at vehicle level; Intelligent energy management; Definition of specific vehicle architecture for hybrids.
Range Extender Hybrid	Advanced thermal engine technologies for further alternative fuel application.

- **Milestone 3: Competitive Hybrids (2025)** [Market 2028-2030]

  Dedicated Hybrid Vehicles competitive regarding costs and benefits will conquer the market. Highly integrated, but flexible components and systems, small, light and efficient batteries will allow the enlarged mass production of Hybrid Vehicles, fully established in Europe. Modular and flexible Hybrid Vehicle designs will make the market more interesting.

Configuration	**Milestone 3 Goals**
Micro / Mild Hybrid	No further research needed, systems well accepted by the market
Full Hybrid Plug-In Hybrid	Products available at price attractive for the consumer and profitable for the manufacturers; Fully integrated optimised power-train for Hybrid scalable architecture; Fully optimised vehicle architecture for Hybrids;
Range Extender	Fully integrated optimised drive train for Range Extender Hybrid scalable architecture;

For Hybrid Vehicles, similar to the Electric Vehicles, major technology fields can be defined. The following table summaries the milestones considering the following major technology fields:

- Energy Storage Systems
- Drive Train Technologies
- System Integration & Modular Hybrid Architecture
- Grid Integration
- Safety aspects
- Integration into the Transport System

- **Milestones for the major technology fields**

	Milestone 1: 2015 [Market 2018-2020]	**Milestone 2: 2020** [Market 2023-2025]	**Milestone 3: 2025** [Market 2028-2030]
Energy Storage Systems	Availability of suitable energy storage components for hybrids. Availability of affordable "Power" batteries for Mild Hybrids.	Advanced long life, safe and cost competitive energy storage systems. Availability of batteries providing tripled energy density, tripled lifetime at 20-30% of 2009 cost and matching V2G.	Small, light and efficient batteries competitiveness for mass production. New battery technology available
Drive Train Technologies	Drive train components with increased efficiency and capability of energy recovery.	Manufacturing of range extenders and update of optimised electric motors.	Implementation of power-train systems providing unlimited range at sharply reduced emissions. Range extender optimised combustion engines and GenSet.
System Integration & Modular Hybrid Architecture	Establishment of an interdisciplinary development (& production) environment for cost and time efficient development, testing and production of hybrid and electric power-trains.	Solutions for safe, robust and energy efficient interplay of power-train & energy storage system. Optimised control of energy flows based on hard- and software for the electrical architecture.	Fully adapted power-train to the hybrid architecture; optimised vehicle architecture to customer needs, dedicated HEV configurations for city-cars, LCV and family cars. Lightweight vehicle structure.
Grid Integration	First charging infrastructure in construction. First business models for charging.	Charging adaptive to both user and grid needs. Bi-directional and enhanced speed charging.	Quick, convenient and smart charging. Easy to understand business models for charging cost bill.
Safety aspects	Hybrids meeting same safety standards as conventional cars.	Implementation of solutions for all safety issues specific to mass use of hybrids and road transport based on it.	Maximum exploitation of active safety measures for hybrid vehicles.
Integration into the Transport System	In some states the promotion of hybrids is regulated.	Sponsorship and regulations for cities and conurbation with restrictions because of air quality extensively established. First battery changing stations on highways.	Free entrance in Europe to restricted areas for Hybrids with ZEV range. Legislation and tax incentives are established in Europe. Network of battery changing stations exists.

Table 5: milestones considering the major technology fields for passenger cars

5.2. Milestones for Commercial Hybrids

- **Milestones for Hybrid Bus**

Hybrid Bus	**Milestone 1: 2015** Market 2018-2020 Tailored hybrid bus - with Plug-In capability	**Milestone 2: 2020** Market 2023-2025 Light weight hybrid and full electric Bus, w/wo Range Extender - with Plug-In capability	**Milestone 3: 2025** Market 2028-2030 Alternative energy converters systems designed for hybridisation
Improved passenger transport efficiency Hence, substantially reduced energy consumption			
Hybrid power-train for buses	Second generation Hybrid propulsion concepts, focusing cost efficiency. Development of enhanced durability and efficiency of ESS. Developed dedicated hybrid transmissions. Novel concepts based intermittently transferred electricity from grid. Focusing interactive high power transfer. GPS based bus operation.	Dedicated full electric propulsion concept with a range Extender. New ESS that combines both good energy and power performance. Advanced electric motors, e.g. hub-motors and compact and efficient power electronics.	Novel energy conversion concept as main propulsion unit, with fuel flexibility. Second generation concepts for intermittently or continuously transfer of electricity from grid.

Table 6: milestones for Hybrid Bus development

- **Milestones for trucks**

- Hybrid distribution truck **-Mild to full hybrid long haul trucks**	**Milestone 1: 2015** Market 2018-2020 **Optimised Truck** Distribution trucks with plug-in capability and long haul trucks with tailored mild hybrid systems	**Milestone 2: 2020** Market 2023-2025 **Tailored Truck** components tailored for high efficiency and durability w/wo Range Extender - with Plug-In capability	**Milestone 3: 2025** Market 2028-2030 **Sustainable Truck** hybrid systems with designed for hybridisation & continuous grid connection

Improved city and inter city goods transport
Hence, substantially reduced energy consumption

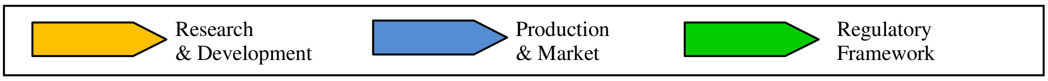
Hybrid Power-train	Further development combustion engine efficient engine with mild hybrid functions Mild hybrid concept with hybrid hotel and cargo modes / functions, focusing cost efficiency Development of enhanced durability and efficiency of ESS First generation grid plug-in charging for city distribution. Developed dedicated hybrid transmissions GPS based hybrid operation	Tailored hybrid energy optimized combustion engine Dedicated truck mild and full hybrid high efficiency and components, with essential steps taken in storage technology solutions, in terms of cost and durability. First generation concepts for intermittently transferred electricity from grid.	Novel energy conversion concept as main propulsion unit designed for hybrid usage, with fuel flexibility First generation concepts for continuous transfer of electricity from grid.

Table 7: milestones for hybrid power-train of city and long distance trucks
(Source: Multi-annual roadmap and long-term strategy, prepared by the EGCI Ad-hoc Industrial Advisory Group of the European Green Cars Initiative PPP, November 2010)

6. Roadmaps

Following the definitions of milestones, the involved companies and organisations from ERTRAC agreed on actions to be taken in order to achieve the stated objectives. Considering phases of R&D, production and market introduction as well as the establishment of regulatory frameworks, dedicated roadmaps were drafted. Those indicate what has to be done when for a well-timed move of Europe towards the hybridisation and thus the electrification of road transport.

The explanation of the arrows used in the roadmaps of figure 4 is given below:



Energy Storage Systems

Battery development for passenger car hybrids
(Small, robust, safe, fault tolerance, Low cost, High rate power & energy density); "Power" batteries for Mild Hybrids

Battery development for commercial vehicle applications
(robust, very high number of charging cycles and extensive operational conditions)

Batteries for bidirectional charging

Increase battery lifetime to be equal to the lifetime of the vehicle

Advanced battery management systems

Optimisation & standardisation of battery packs
Development & standardisation of battery swap

Integrate batteries into vehicle structure

Advanced chemistry cell technology

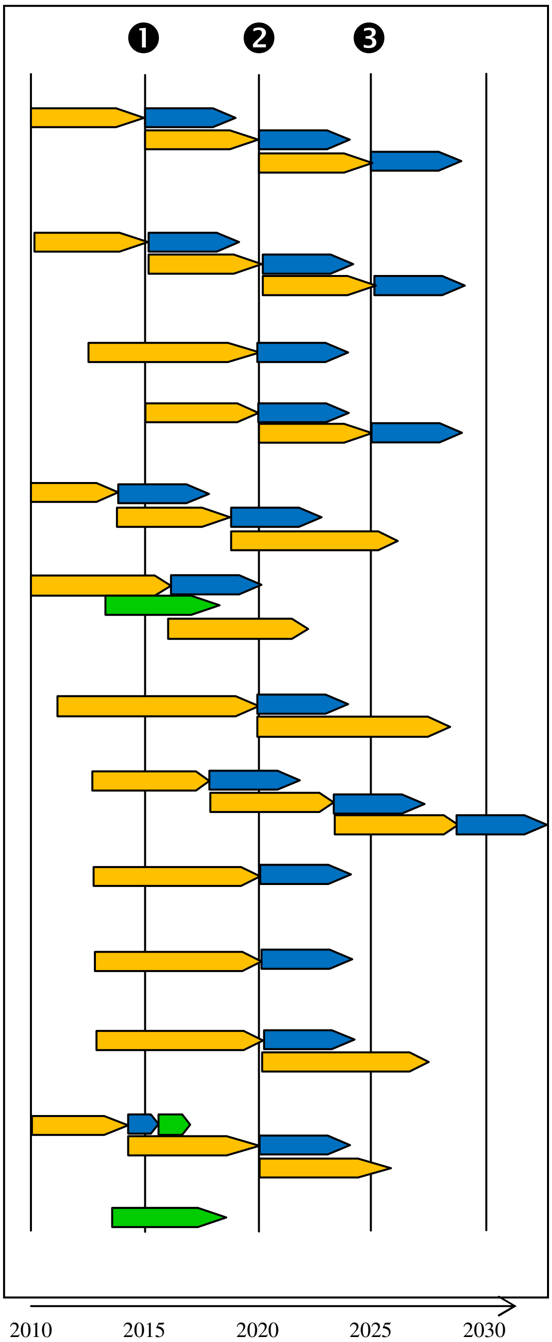
Non-electric energy storage systems

New technologies for brake-energy recovery

Supercaps development

Recycling processes and second-life solutions for batteries

Set European guidelines for battery lifetime



Drive Train Technologies

Next generation of electric motor for Mild Hybrids;
Electric in Wheel Motor to allow new vehicle architecture

Hybrid suitable combustion engines

High efficiency optimisation of downsizing

Complete power-train management concepts
(including E-drive, e-sources, e-storage systems)

Integration of hybrid-electric
transmission architectures and concepts

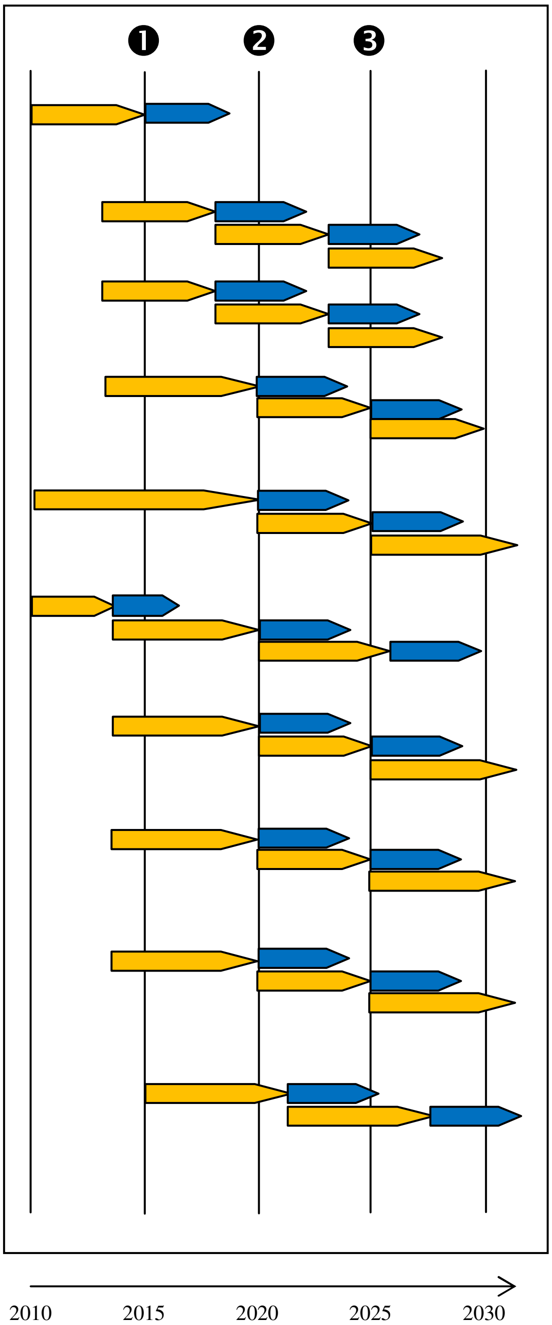
New concepts, materials for electrical machines,
low- cost & light-weight

New architectures, materials for electro-mechanical &
storage devices, low- cost & light-weight

High efficient-, high voltage-, high temperature-
electrical power systems, compact & robust

Range extender modules / generator sets,
high integration of sub-/systems

Investigations in the compatibility with future CO_2-neutral
fuels and with future common modules of alternative
and conventional propulsion systems for an optimal
use of these energies.



System Integration & Modular Hybrid Architecture

Increased system efficiency with existing components

Control strategies for electric components & vehicle energy management

Thermal systems & technologies for advanced power electronics and electric machines, for heating, venting, cooling

On-demand auxiliaries and vehicle functions

Modularisation of subsystems and standardisation of component features and interfaces, in hard- & software

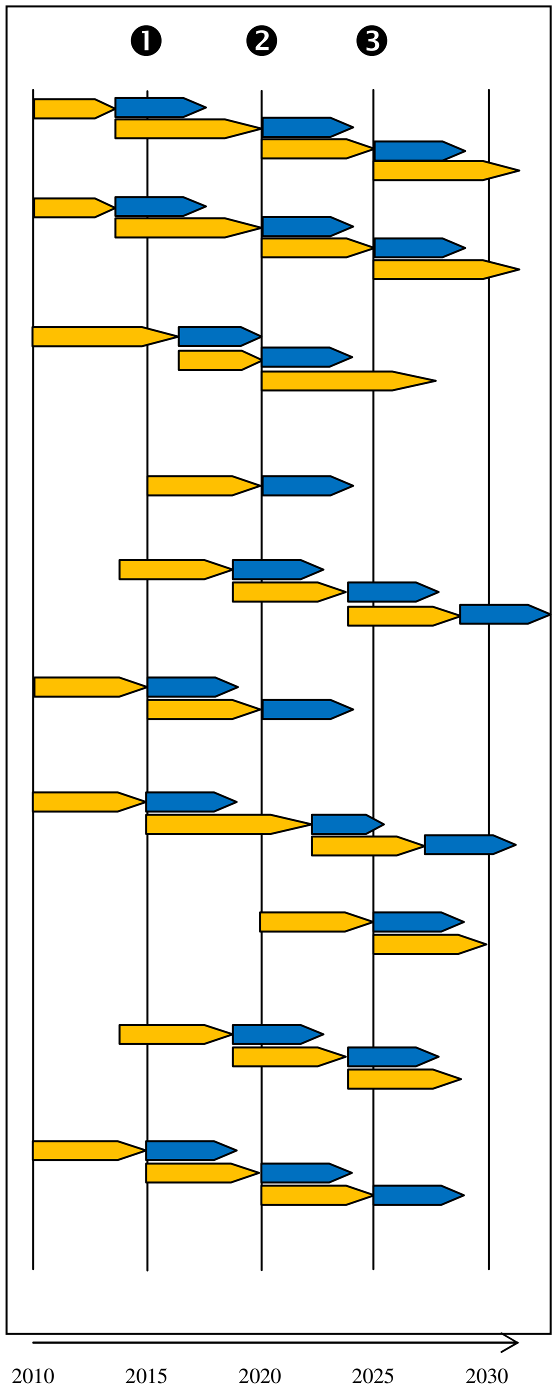
Dedicated simulation and development tools for hybrid configurations

HEV architectures for smaller vehicle classes for wider market penetration

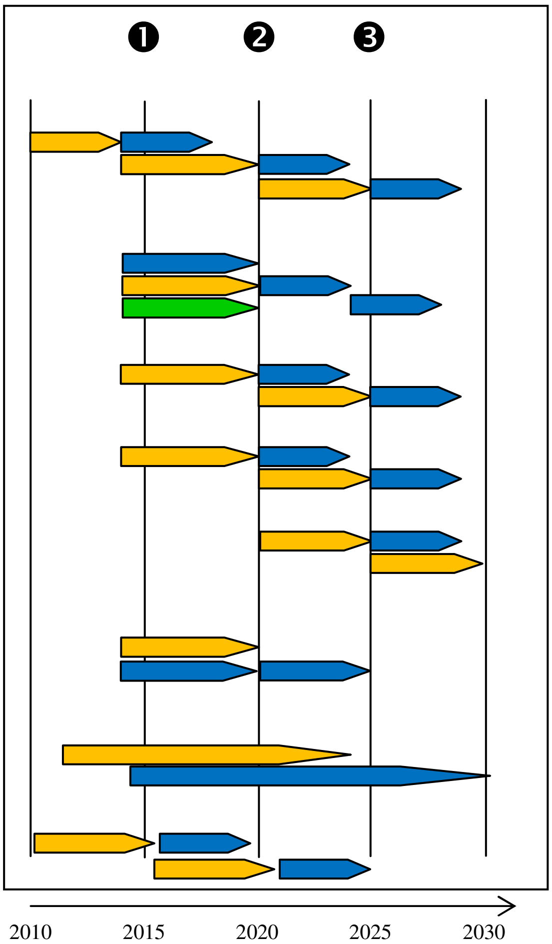
Flexible vehicle architecture for sales fluctuations between conventional ICE or hybrid vehicles

Interdisciplinary development & production environment for hybrid global commodity management

HEV design for commercial vehicle application



Grid Integration



Develop advanced charging solutions & connection devices
(Quick, contact-less, bidirectional)

Establish European wide Business Models
(For charging, bidirectional trading, standardise Billing-concepts)

Protocol / devices for V2G communication

Adaptive on-board / plug-in charging devices

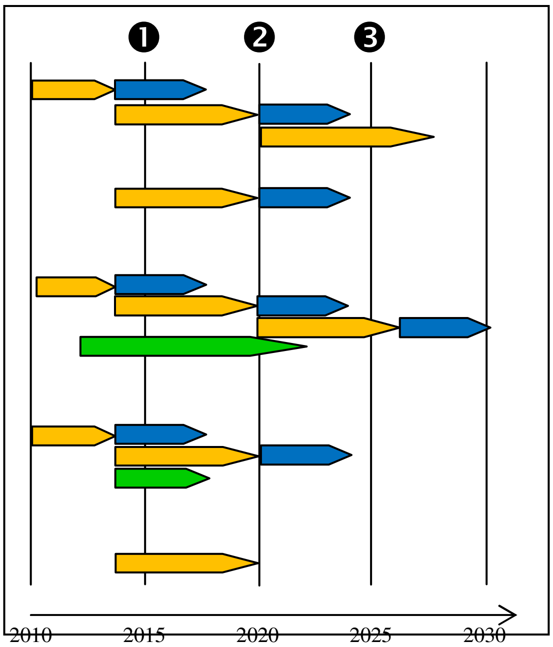
Integration of vehicle-infrastructure interface

Develop suitable charging infrastructure
(Network of quick-/charging stations, regulate coverage with charging spots)

Suitable charging infrastructure (quick charging)
for commercial vehicle application (specific conditions)

Fast charging demand for heavy duty vehicles

Safety Aspects



Crash compatibility and crashworthiness
of light/small and/or new vehicle concepts

Acoustic perception of electric drive

Integrated safety hybrid concepts

Develop battery safety for fire, acidity, etc.
Post-crash safety (batteries, high voltage lines)

Examination of electro-magnetic aspects

Integration into the Transport System

Promote green image of hybrid vehicles
(New concepts for parking / space use,
Regulations for air-quality restricted areas,
Tax advantages for Green Hybrids)

Matching hybrid vehicles to tasks
(customised, modular, flexible, variable design)

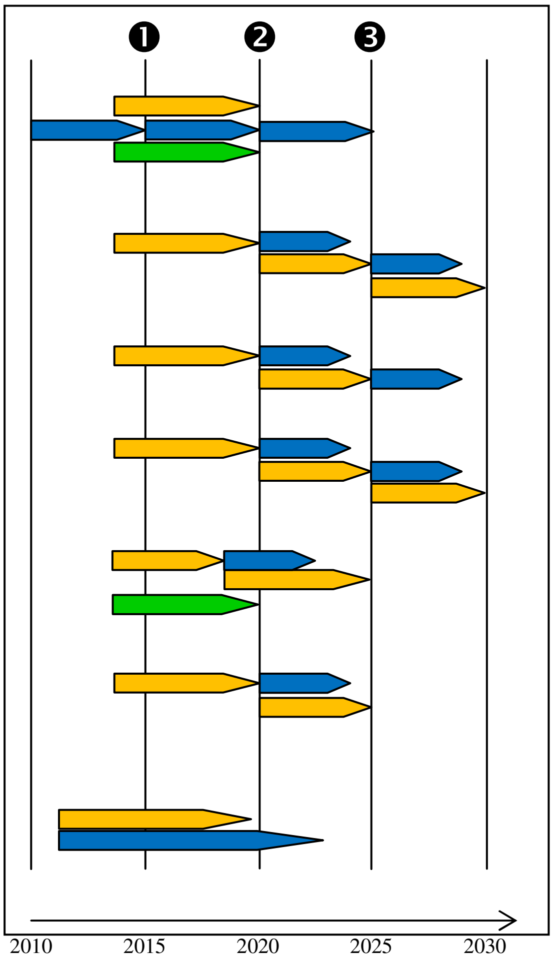
Potential of ITS for energy efficiency

Highly accurate range prediction for electrified vehicles based on navigation systems with advanced digital maps

Optimised certification processes for HEV to utilize a new technology (passenger cars & commercial)

Life cycle and Well to Wheel analysis for vehicle and energy path

Maintenance of hybrid technology in commercial vehicle application (design of maintenance centres, staff training etc.)



7. Recommendations

As it has become clear that Europe will take leadership in CO_2 reduction, it should also be the place to launch HEVs and EVs large demonstration projects. Where Mild HEV with start-stop functions are already at mass production, storage systems should still be further improved to fit the evolution of new vehicle architectures, including the further progress on the Internal Combustion engine to switch of the engine and restart when needed.
In order to strengthen and extend the competitiveness of European automotive industry in the field of hybrid and electric vehicles, continuous R&D efforts are required.
The today's given recommendations could be further developed into more detailed recommendations according to upcoming EC work-programmes and specific strategic papers.

> **For Hybrid Passenger Cars:**

All different configurations of hybrid propulsion and vehicles applications will be seen in the future.

- The Micro and Mild Hybrids with start-stop function and some boosting. A first hybrid step and a cheap solution for conurbation with many start-stop opportunities.
- The Full Hybrids as a very good solution to reduce the fuel consumption
- The Plug-In Hybrids as the best configuration for so called 'All-Round' Cars and as 'Combined' Hybrid with clear advantages in the range of middle- to high-speed.
- The Range Extender Hybrids as best solution for city and conurbation driving and even 'All-Round' Cars as long as their maximum speed is limited.

> **For Hybrid Commercial Vehicles:**

Hybrid is a very important technology for Heavy Duty (HD) Vehicles especially in transient operation cycles, which has and will prove a strong CO_2 reduction potential. HD Vehicle (especially busses) can also accept the high capital cost, due to a high degree of utilisation and a longer payback time.

General requirements for commercial vehicles

- Highly energy hybrid systems with system robustness durability
- Efficient and compatible high and low voltage driveline components
- Tailored energy accumulator systems for HD applications:
- Grid connection systems tailored for HD vehicle usage.

Most important, further development towards cost reduction and towards the transient durability demands of hybrid HD truck applications are essential for this segment, since the impact is less than for bus application but still a very important technology for CO_2 improvement and for the total environmental impact of the HD truck operation spectra.

❖ **Research needs**

Research funding and an innovative environment are crucial and it is important to build on what is happening in the Member States, which have taken interesting initiatives to promote electric mobility.

Develop second generation for both “Energy” and “Power” batteries. Battery monitoring is a must for all Hybrid Electric Vehicles. The system operating strategy optimisation is needed to respect the battery system limits (voltage, current, temperature, isolation). The operation strategy has to minimise battery energy throughput to meet target battery life time. Further battery and system operating strategy research (fundamental and demonstrations) should always be focused on a

specific vehicle architecture to improve the effective specific energy (Wh/kg or Wh/litre), the battery weight, the battery efficiency (during charge/discharge and in stand-by), the ambient temperature condition range, the cycle life duration (in function of the depth of discharge) combined with long calendar life, the maintenance free level, the battery management system, the State of Charge (SOC) and the Sate of Health (SOH) indications, the environmental impact, the recyclability of the materials. It is not only the cost of the battery during one lifetime but also about the cost per delivered kWh electricity throughput.
We should develop other opportunity under FP8 for battery research, both basic research in materials as well as in deployment of batteries in projects to look at the commercialisation of electro-mobility. Further fuel consumption reduction by hybrids will be dependent on the progress made in the area of battery technology.

Based on the indications given in the roadmaps and as general recommendations, **research efforts must be undertaken mainly for the following fields:**

- ***Energy Storage Systems***

  For all Hybrid configurations:
  - Batteries smaller, cheaper, lightweight, safe, more robust, fault tolerance, with long life time and with high power & energy density
  - Batteries for fast & bi-directional charging and discharging
  - Advanced chemistry cell technology, beyond Li-Ion (e.g. Li-S, Li-air and new ones)
  - Recycling of materials and batteries, develop second-life solutions for batteries
  - New technologies for brake-energy recovery

  For Passenger Cars especially:
  - Robust batteries for start-stop function
  - Robust "Power" batteries for Mild Hybrids

  For urban commercial vehicles, especially city buses:
  - Robust batteries for very high number of charging cycles and extensive operational conditions (16-20 hours operation per day)

- ***Drive Train Technologies***

  For all Hybrid configurations:
  - Smart control of driveability and comfort, "super Starter", "smart Generator"
  - Complete drive-train & thermal management concepts
  - New concepts for electrical machines & electro mechanical technologies, low-cost, lightweight
  - High efficient & high temperature power electronics
  - Suitable combustion engine or alternative GenSet system

  For Micro & Mild Hybrid:
  - Development of crankshaft or fly-wheel mounted integrated Starter-Generator
  - Development of highly efficient and compact cylindrical motor

- ***System Integration & Modular Hybrid Architecture***

  - To build robust, small, integrated and efficient hybrid configurations. Overcome the challenge to integrate larger batteries and drive-train in Hybrid Vehicles

- Control strategies for electric components (e.g. battery monitoring), vehicle energy management
- Modularisation of subsystems and standardisation of component features and interfaces in hard- & software
- HEV architectures for smaller vehicle classes
- Dedicated simulation and development tools for hybrid configurations
- Flexible vehicle architecture to manage sales fluctuations between ICE and Hybrid Vehicles

o ***Grid Integration***

- Adaptive on-board / plug-in charging devices
- To establish charging options and surface covering infrastructure (fast, contact-less, bidirectional)
- Establish European wide business models

For urban commercial vehicles, especially city buses:

- Charging infrastructure taking into account specific operational conditions (quick charging concepts at bus stops, in depots etc.)

o ***Safety Aspects***

- Improvement of integrated safety hybrid concepts
- Development of batteries safety for fire, acidity, etc

o ***Integration into the Transport System***

- Development of solutions capable for high number of pieces (mass production)
- Matching hybrid vehicles to tasks (customised, modular, flexible, variable design)
- Accurate range prediction based on navigation systems
- Maintenance of hybrid technology in commercial applications including design of maintenance centres and training of maintenance staff, e.g. in bus companies
- Training of professional drivers for operation of hybrid commercial vehicles

Non-electrical Hybrid technologies are relatively immature, and their research needs reflect this:

- Validation of new energy storage concepts on rigs and in vehicles
- Improvement of components (flywheels, pressure vessels, hydraulic drives, CVTs, bearings and seals etc) for durability, safety and low losses
- Development of manufacturing processes for lower cost and higher volume
- Exploration of “two element” hybridisation / electrification, combining a mechanical peak-lopping system with a reduced cost, low power electrical system

A significant reduction of costs for all components remains an important challenge with research needs. The costs of hybrids have to be competitiveness to conventional vehicles, this under consideration of fuel savings and the benefit of ZEV driving.
Dedicated competitive hybrid vehicles with highly integrated components and systems, small, light and efficient storage systems will conquer the market and will allow the mass production of hybrid vehicles.
In addition, non-technical measures to support market uptake of vehicles with hybrid propulsion systems will be needed. Governments should be able to phase in and phase out economic incentives in a timely fashion.

In coordination with the ERTAC Working group 'Global Competitiveness' and their roadmap on '**European Technology & Production Concept for Electric Vehicles'** research needs will be addressed on:

- Interdisciplinary de-centralised development & production environment enabling the cost and time efficient development, testing and production of hybrid and electric power-train components and subsystems.

8. A brief look beyond 2030

The years beyond 2030 and in the long term, we see Hybrid vehicles in all configurations and different applications as the 'normal' vehicle. The Internal Combustion engine, through further development very efficient, is adapted to the hybrid configuration for less CO_2 emission and best interplay as hybrid. The so called 'conventional' ICE passenger car is mainly supplemented with hybrid components, nevertheless the ICE will stay as main propulsion component and the need for further development is still there. Plug-In will became standard.
For Heavy Duty Trucks the Diesel ICE is still seen as the dominating propulsion, still with research needs and development potential.
Most big cities and big conurbation are still fighting with bad air quality and congested streets. Thus pure Electric Vehicles will dominate as pure city and short distance solutions. But, Hybrids will be the major solution for sustainable mobility, for individual mobility, for goods transport and for public transport, suitable to enter cities as well, due to there ZEV range.
The connection between grid and electrified vehicle is fully available in cities and conurbation as well as the connection between transport modes, guaranteed e.g. through hubs for goods and people. Services will allow the consumer to choose the best transport mode.

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