

From the Visions of Road Transport in 2020, the RTD Actions Needed to an Outlook on an “Environmentally Compatible Hybrid Powertrain”

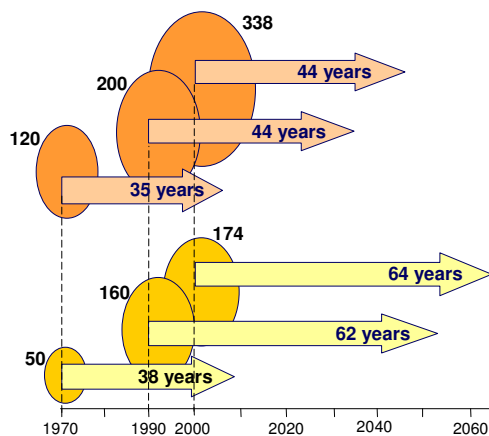
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Abstract

Recently, several technology platforms have been created on EU-level and RTD roadmaps have been worked out. According to the visions of the ERTRAC platform, the main pillars of road transport RTD have to be focused on CO₂ emission reduction as well as generally improved environmental compatibility. EARPA as the organization of research providers has established a hybrid task force, which elaborated particular RTD needs to meet the targets set by the ERTRAC platform. The results of this process are presented followed by an outlook on a possibly “ultimate” concept of an environmentally compatible hybrid powertrain.

Boundary Conditions and Scenarios for Individual Transport around 2020 and beyond:

With very high likelihood, it can be assumed that due to a continuous trend towards increased energy demand on a worldwide scale, prices for all kind of fuels suitable for mobile application will rise as well. Further a realistic assumption is the fact that fuels with larger natural reserves (Fig. 1) as well as best compatibility with alternative, bio-mass based solutions (Fig. 2) will be of common attractiveness for consumers, OEM's and fuel industry [1, 2, 3]. Hence, CNG (Compressed Natural Gas) also being compatible with bio-gas most probably will gain larger market shares.



Source: Boston Consulting Group (1 SKE = 29,3 MJ/kg)

Fig. 1: Better prospects of long term availability of natural (and bio!) gas

- Crude oil reserves in Bt of SKE
- Nat. gas reserves in Bt of SKE
- ➔ Reach = reserves / annual consumption

It can be expected that inner city areas with restricted individual transport will be extended on the one hand. On the other hand, it can be speculated that cars equipped with “green technologies” may receive exceptions from such limitations. E.g. only cars and trucks may be allowed to enter areas during some times of the day if they can be operated with extremely low noise and pollutant emissions – banning in fact the operation of internal combustion engines there. Obviously, using information technology and telecommunication, the introduction of such systems – even on a voluntary basis along and fostered by incentives - may lead to a strong market pressure towards solution best fulfilling such boundary conditions.

Finally, enhanced inter-modal transport systems, i.e. combination of different transport means (for passenger and freight transport) could lead to new requirements for road vehicles. Ultra-short- as well as trans-continental long distance trips could be provided more attractively by other modes than road transport. Thus, leading to reduced requirements for long driving ranges as well as reduced number of cold start cycles.

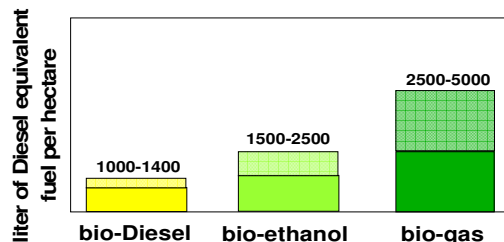


Fig. 2: Comparison of the yield per area for different bio-mass based fuels

Particularly, if parking times (at home or parking garages) are used for refilling with

whatever energy carrier, tank capacities e.g. for 400 km range could be sufficient. In the extreme case, as already discussed by some OEM's, for some part of the individual transport market, the OEM's could even provide themselves inter-modal transport systems leading to higher comfort and flexibility for the customer.

As a measure of the success of such new transport modes – in parallel to which, the conventional individual passenger cars will still play a dominant role – the CO2 emissions could be calculated both per distance and passenger.

ERTRAC Vision 2020:

In parallel to socio-economic scenarios sketched above, European stakeholders (ERTRAC – European Road Transport Research Advisory Council) have elaborated a very challenging vision for the time around 2020, which very particularly addresses the hurdles of today's road transport [4, 5, 6]:

- Greenhouse gas emissions and energy use from individual vehicles have been substantially reduced thanks to a wider use of highly fuel-efficient vehicles and increasing use of improved conventional, renewable and alternative low carbon fuels where beneficial to the environment. Efforts are continuing to achieve further improvements in the longer term.
- Renewable and alternative low-carbon fuels together with advanced vehicle powertrains begin contributing to environmental improvement and security of energy supply. Their large-scale availability and distribution infrastructure is still a challenge in 2020.
- The transport system has become more efficient minimizing road traffic congestion contributing greatly to reducing the energy consumption of individual road vehicles.
- Emissions other than CO2 from new road vehicles, including two-wheelers, over their entire life cycle are at levels that have negligible impact on air quality.
- Noise from the road traffic system has been reduced. Noise levels are

appropriate to individual locations including quiet zones.

- Vehicle manufacturing systems and road construction and maintenance processes are designed to maximize the extent of recycling. Advanced technologies allow a substantially more efficient use of resources and energy.
- Road transport energy use and resources approach sustainable levels.
- New approaches to the road transport system are minimizing environmental impacts on communities and natural habitats.

ERTRAC Specific Research Targets:

Following the visions assumed to be fulfilled in 2020, research targets can be defined for road transport systems on a very general basis [4]:

- Improvements in vehicle efficiency will deliver as much as a 40% reduction in CO2 emissions for passenger cars and 10% for heavy duty vehicles for the new vehicle fleet in 2020.
- Good vehicle maintenance and driving for fuel efficiency will reduce fuel consumption and CO2 emissions by at least 10% for cars and 5% for heavy duty vehicles.
- Improvements to the road infrastructure, best use of information technology systems and higher passenger car occupancy rates will contribute to further reductions in fuel consumption of passenger cars by 10-20%.
- Further reductions of carbon emissions associated with fuel production will be achieved.
- By 2020, fuel cell vehicles and low carbon / hydrogen fuels will begin contributing to carbon reduction provided sustained research efforts are begun now.
- By 2020, Euro-5 & 6 emissions standard vehicles will be well established in the vehicle fleet. The research target is to achieve these near zero emissions levels at minimum cost while still improving energy consumption and CO2 emissions.

- Transport noise will be reduced significantly through a systems approach including better indicators and improvements to vehicles, tires and infrastructure.
- Sustainable use of resources and recycling of vehicles and road infrastructure materials will also contribute to the preservation of the environment.

Consequently, by combining the scenarios, visions and related research topics, it becomes obvious the specific advantages of hybrid powertrains correspond best to some special combinations of requirements

Relevance and Importance of Hybrid Powertrain Systems as seen by the European Research Institutions

Firstly, hybrid vehicles offer possibilities to supply the market with nearly zero-equivalent emission vehicles in order to comply with more and more stringent pollution standards and to reduce the overall fuel consumption. The present voluntary agreement between the automotive manufacturers and the European Commission aims at reducing the fleet average type approval CO₂-emission of newly sold vehicles to 140 g/km in 2008/9 and to reach an average value of 120 g/km in 2012 [7]. In view of the long term Intergovernmental Panel on Climate Change it may be expected that 120 g/km will not be the end point. The proposed pathways include improving vehicle efficiency, CO₂-neutral fuels and non-technical measures (the “Integrated Approach”). With today’s state-of-the-art technologies it is unlikely to achieve the 120 g/km CO₂ goal (Fig. 3).

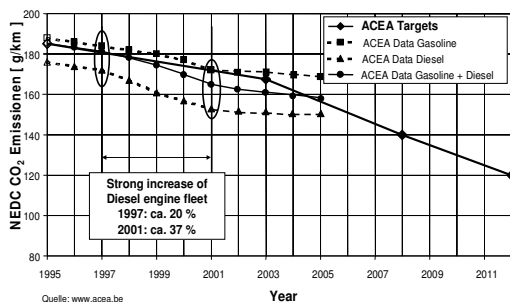


Fig. 3: Trend of CO₂ emissions from passenger cars

Hybrid vehicles are an important ingredient in the strategy for reaching 120 g/km and less:

- Mandatory add-on technology in order to achieve lowest CO₂ emissions
- Key element as bridging technology for the introduction of new powertrain technologies like pure fuel cell or improved electric vehicles.

Based on this twofold relevance of hybrid vehicles, European associations such as EARPA (European Automotive Research Partners Association) sees the future of hybrids not only as a short term solution for fuel and emission reduction but moreover as a mid to long term option for new powertrain concepts. In particular, as the technology compared to some other proposed pathways, is compatible with the existing fuelling infrastructure.

Boundary Conditions for RTD Activities in the Field of Hybrids

Many RTD (Research and Technology Development) projects have been carried out in this field in Europe and many prototypes have been developed. However, the most successful mass product is the (non-European) TOYOTA Prius. In order to enable large scale commercialization, near and mid-term RTD is required for cost reduction and system efficiency improvement. Component development and optimization, system integration and optimal control are promising research areas for cost-effective RTD investment. These research areas are emphasized by the ERTRAC Strategic Research Agenda.

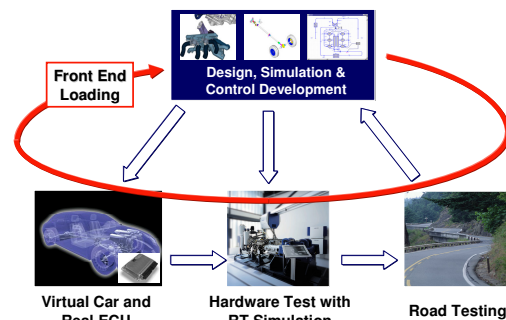


Fig. 4: Example for methods for reduction of development duration by application of simulation and component testing in a front end loading process

In EARPA’s view, the primary RTD boundary conditions for hybrid systems are:

- Cost reduction for both development and production. Significant steps can be achieved by balancing modularisation,

integration and standardisation levels of components and controls. In addition, further system optimisation provides good opportunities.

- Reduction in time to market, through advanced technologies for development processes (Fig. 4).
- Technological developments and trends both inside the vehicle and from the vehicle environment – e.g. compatibility with future Bio-fuels and common modules with future alternative propulsion systems.

Co-operative Research for Hybrid Powertrains

Research on hybrid vehicle solutions is needed to improve its competitiveness compared to conventional powertrains especially with the focus on mass production. The white spots that require further research efforts comprise from EARPA's point of view all aspects from highly tuned overall systems to component modularity along with efficient and intelligent subsystems.

Modular subsystems have to be flexible enough for the application to different types of possible hybrid solutions (full or mild hybrids; gas, diesel or fuel cells, etc.). This will allow an earlier market introduction and proof of applicability of new concepts.

Hybrid research requires a high amount of interdisciplinarity due to the combination of conventional powertrain and electric components. Only the optimal match as well as integration of efficient and intelligent (electric) components and subsystems with an overall sophisticated energy management enables the realisation of an optimised system. Due to simultaneous research efforts on system level as well as the integration of electronic and vehicle competencies, EARPA will focus its research activities on the creation of an interdisciplinary RTD platform.

In conclusion, the EARPA Hybrid Task Force requests a parallel, double-track RTD approach:

1. In-depth integration of the development and production process of hybrid powertrain components and systems to reduce the development cycle times and the production costs

- Standardization of mechanical, electrical and thermal interfaces and characteristics of the components in view of a cost and time effective development process (Fig. 5)

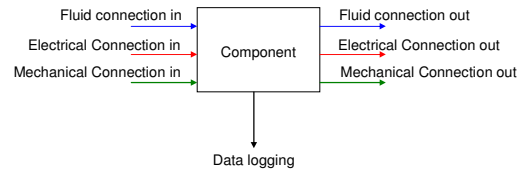


Fig. 5: Commonly accepted standard development modules with predefined interfaces

- Well defined work flows including information transfer enabling a seamless co-operation between working partners or different suppliers.
- Creation of a de-centralised development environment [8] for hybrid powertrain components and systems including software- and HIL-(Hardware-In-the-Loop) testing for (Fig. 6):
 - Establishment of a unique position of the European automotive industry
 - Alignment of RTD on component level with research for entire systems and vice versa.

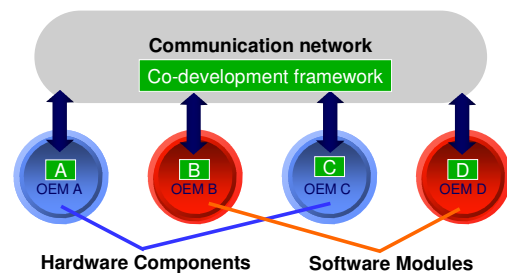


Fig. 6: De-centralized development environment for numerical and HIL simulation

2. Technology development in view of higher function integration in hybrid subsystems along with identification of modular components
 - Higher integration of functions on component level in order to reduce the costs
 - Introduction of modularity on a basic component level enabling an “of-the-

shelf-synthesis” of highly integrated customized subsystems.

In order to validate the results of component research, we suggest to cluster research activities around a demonstration project which covers several propulsion concepts and, consequently, help to answer different questions:

- What is the most effective level of integration of systems and controls?
- What is the best way to supply electricity on board: External electric charging, Electric Generator, Fuel cell?
- How is it possible to more widely couple electrical and mechanical power for highly different applications?

The EARPA Hybrid Task Force sees the requirement to carefully identify research topics on a European level in close co-operation of all relevant stakeholders.

Components and Subsystems for Future Hybrid Powertrains

Considering the fact that currently three very big OEM's are jointly developing a common hybrid transmission subsystem, which will be used in the future in cars of all of these OEM's at least. Further is well known that Toyota is ready to license its hybrid system as developed for the Prius. Moreover, particularly two recent European Integrated Projects, the IP HySys and the IP HiCeps are elaborating and searching for synergies among hybrid powertrains, i.e. between

- fuel cell – battery – e-drive and ICE – battery - e-drive systems, as well as
- hybrid system components for passenger car and light duty truck applications.

Considering these developments, it can be concluded, the a large number of components are widely accepted as typical supplier's sub-systems. These are on the hardware side:

- batteries and supercapacitors
- inverters
- components of e-motors

- electrically driven powertrain and vehicle auxiliaries
- cooling systems
- air and fuel management components

In contradiction, the primary energy converter, either the ICE or the fuel cell may be regarded even for a longer time in the future as the core competence of the OEM.

On the software side, i.e. the powertrain and vehicle controller algorithms, there are also functions, which could be shared between different powertrain concepts and types of vehicles:

- battery controller
- e-drive controller
- brake controller
- controller for inverters
- controller for auxiliaries

Also the hybrid vehicle controller, which is a master controller for several sub-system controllers, could be shared at least between different vehicles of an OEM. However, since the character of a hybrid powertrain and, thus, of the vehicle highly depend on the functions and calibration of the hybrid controller, detail may remain intellectual property of the OEM's in the future.

Outlook on an “Environmentally Compatible Hybrid Powertrain” of the Future

After having analyzed the requirements for future road vehicles and, thus, for hybrids, discussed the research needs in this field as seen by major stakeholders on a European level and compiled the chances for cost reduction by development and use of common components and subsystems, the paper should be closed with an outlook on a hybrid vehicle of the future:

Starting with the fuel, this vehicle will emit 30-35% less CO₂ because its fuel is a mixture of natural and bio gas stored at high pressure (350 bar – leading to a range of 600 km). 20% of this fuel is produced from biomass and, therefore, CO₂-neutral [9]. The low C-content of the natural gas reduces the CO₂-emissions also by approx. 10-15 %.

The hybrid vehicle is equipped with a direct injection gas engine, highly supercharged with a VGT turbocharger. The high

knocking stability of the fuel and modern combustion systems [10] allow to operate the engine at higher compression ratios (up to 14:1) and very high BMEP's – exceeding 35 bar (Fig. 7). The high power density allows a remarkable downsizing and at part load, the very stable combustion system accepts high EGR rates, which result in CO₂-emissions at part load in the range of today's Diesel engines (partly also because of lower friction losses of the gas engine compared to a Diesel engine) – i.e. -20% CO₂ emission compared to modern gasoline engines.

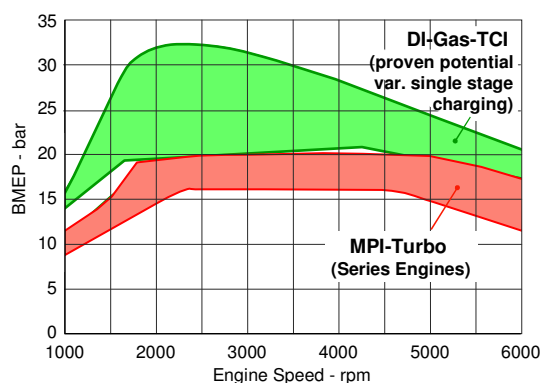


Fig. 7: BMEP (Break Mean Effective Pressure) potential of turbocharged DI-gas combustion systems

A special methan-3-way catalysts enables the fulfillment of even strictest emission limitations.

An automated single- or double-clutch 6-speed transmission is attached to the engine including a powerful electric motor-generator. The reverse gear is eliminated by using first gear and running the e-motor in backward rotation. Both, the gear box and the engine in fully integrated in the thermal system of the engine and well insulated to the ambient, thus widely eliminating high cold start friction losses. The automated transmission allows to shift the operating points into the area of best engine efficiencies providing together with the hybrid components a CO₂-reduction potential of another 15-20%

A lithium-ion battery is used to store braking energy as well as to provide the power and energy for enabling a 10 km zero-emission driving range of the vehicle. The user of the vehicle has also the possibility to recharge the battery at home or at parking garages over night with base load electricity produced by CO₂-emission free power plants. Further, at low states of charge of the battery, the charge mode of the powertrain is activated particularly

when the ICE is operated at lower efficiencies and loads than the point of best efficiency.

The vehicles are running on roads (in combination with suitable tires) providing reduced rolling resistances. The traffic is controlled via intelligent on-board navigation systems connected to traffic information and control systems in such way that the braking events are minimized (Fig. 8).

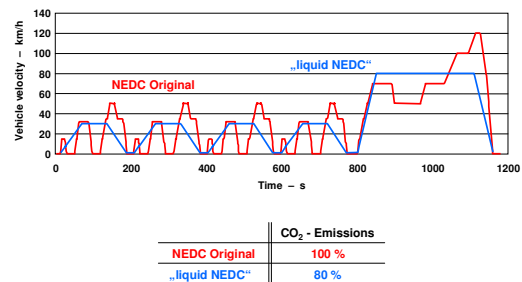


Fig. 8: Example of reduction of CO₂-emissions due to reduced braking events

As a consequence, a vehicle with this **“Environmentally Compatible Hybrid Powertrain - EC-HyP”** concept could emit only approx. 1/2 of the CO₂-emissions for a trip from A to B in a typical European city compared to current state of the art, although the vehicle load carrying capacity is not reduced compared to a similar of today's vehicles.

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