European Road Transport Research Advisory Council

ERTRAC Research and Innovation Roadmaps

Implementation of the ERTRAC Strategic Research Agenda 2010

September 2011

Implementation of the ERTRAC Strategic Research Agenda 2010:

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Responding to the EU strategy for an Innovation Union[1], ERTRAC is implementing its new Strategic Research Agenda through roadmaps covering research, development, and innovation enablers. Framework conditions necessary to speed up the deployment of innovative solutions are integrated, providing content for the next framework programme, which as announced by the Green Paper[2] will be a "Common Strategic Framework for Research and Innovation", named "**Horizon 2020**".

ERTRAC roadmaps to cover all aspects of the transport system.

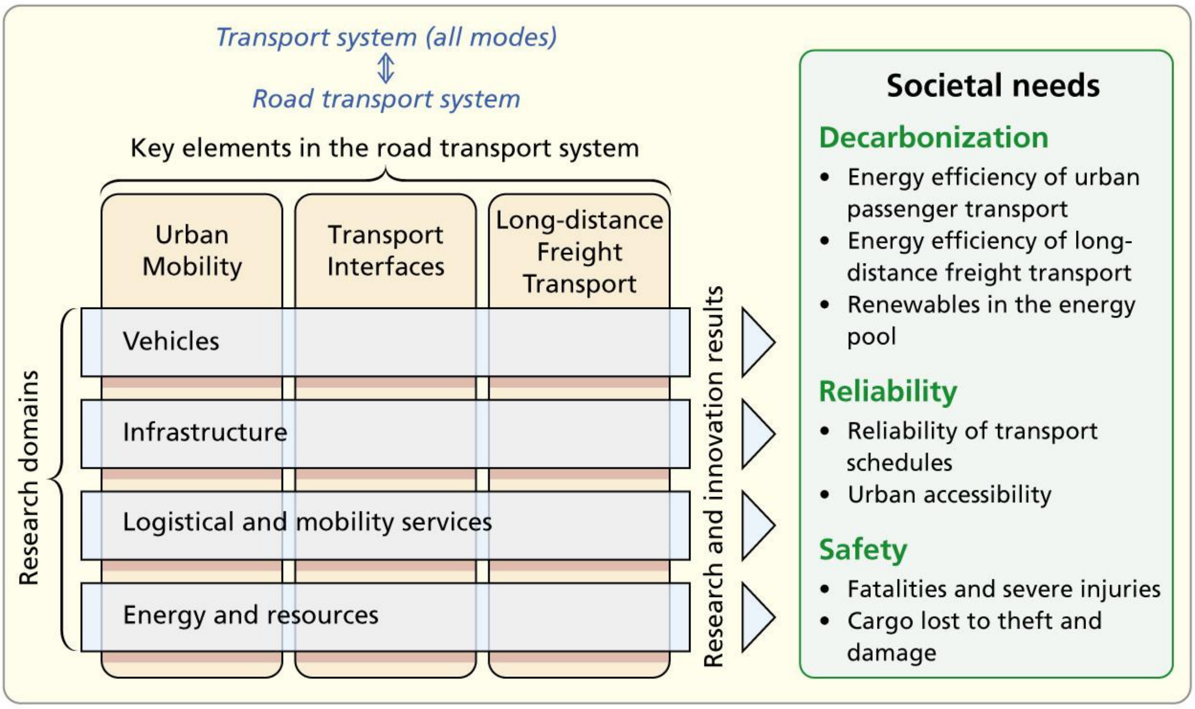

Fig.1: ERTRAC Strategic Research Agenda systems approach

As was first developed in the Strategic Research Agenda 2010, a systems approach has been used to promote innovation in the road transport system. This approach focused on the following three key elements of the transport system:

1. urban mobility;
2. long-distance freight transport; and
3. transport interfaces.

[1] COM(2010) 1161, 'Europe 2020 flagship Initiative - Innovation Union'
[2] COM(2011) 48, Green Paper 'From Challenges to Opportunities: Towards a Common Strategic Framework for EU Research and Innovation Funding'

Together, these elements provide an integrated core transport system that serves the road transport demand of more than 80% of the population (ERTRAC, 2009a), so they are of the greatest strategic significance to meeting European grand societal challenges.

Spanning these elements are four enabling research and innovation domains - vehicles, infrastructure, logistical and mobility services, and energy and resources – as shown in Fig.1. Results from research in these domains will deliver the suit of solutions to the societal challenges shown in Fig.2. The nine technology roadmaps, listed below, involve specific combinations of the three key elements and four research domains. Each will contribute significantly to at least one of the grand societal challenges.

- **Future Light-duty Powertrain Technologies and Fuels** - While the vehicle fleet will diversify over the timeframe spanned by these roadmaps, the internal combustion engine (ICE) will continue to be an important powertrain for future light-duty vehicles, either as the primary powertrain or as a supplementary powertrain in a hybrid configuration. For this reason, research and innovation leading to continuing improvements in ICEs, as well as in the transport fuels that power them, can be expected to substantially improve the energy efficiency of road transport and increase the share of renewable and alternative fuels used by road transport, in line with the decarbonisation challenges for European road transport.

- **Hybridisation of Road Transport** - Hybrid Electric Vehicles (HEV) will also play a major role in meeting the decarbonisation challenges to 2030 and beyond, not only helping Europe to reach its CO2 emission reduction targets but also its air quality standards. HEV combine the advantages of two different propulsions systems, one providing the possibility to drive for shorter distances with zero tailpipe emissions and the other providing the ability to drive for longer distances. The research needs for hybrid passenger cars, busses and trucks are considered.

- **Sustainable Freight System for Europe: Green, Safe and Efficient Corridors** - Due to its direct link with economic growth, freight transport will grow much stronger than passenger transport. The challenge is to accommodate this growth on the available infrastructure maintaining adequate service levels. This roadmap outlines the research required to enable the implementation of highly-populated, multimodal freight corridors, contributing to all three societal challenges. It includes consideration of modal interfaces, goods flow and logistics, urban interchanges, vehicle concepts, supportive road and utility infrastructures, new services and intelligent access requirements.

- **Towards an Integrated Urban Mobility System** - Recognizing that the deeper integration of the urban mobility system is a requirement to achieve greater energy efficiency and provide better accessibility, the roadmap identifies the research needed to enable the integration of the key components of the system, in particular on information, payment and pricing, network management, urban freight, interchanges.

- **Road User Behaviour and Expectations** - The objective of this roadmap is to provide guidance on the analysis of road user behaviour with respect to users' needs, preferences and future expectations to help build an improved road transport environment for passengers.

- **European Bus System of the Future** – considers new concepts of bus systems that integrate the most advanced technologies to achieve more reliable and efficient bus services.

- **Climate Change Resilient Transport** - The road transport system is vulnerable to extreme climate events, and this vulnerability will increase in future as utilisation rates go up and extreme weather events become more frequent and severe. In adapting the European road infrastructure network to ensure adequate service levels under extreme weather conditions must also take into account innovations in the other components (vehicles, services, energy & resources) of the transport system. The roadmap describes the required research on materials, components and road structures as well as management strategies and governance principles for road operations.

- **Safe Road Transport** - This roadmap covers all enabling research activities to improve road safety considering the vehicle, the infrastructure and the behaviour of drivers and other road users. All different types of safety (cooperative-preventive-active, passive and post crash) are considered, within an integrated approach. Improvements in the security of freight transport will be enabled by the research identified on both the infrastructure and the vehicle.

- **European Technology and Production Concept for Electric Vehicles (ETPC-4-EVs)** - The roadmap describes the research required to promote the global competitiveness of the European Automotive Industry with respect to the affordability of "Plug-in Hybrid Electric Vehicles" (PHEVs) and fully "Electric Vehicles" (EVs). For both vehicle types the ETPC-4-EVs roadmap places its focus on the global production of those novel technologies for EVs that are primarily responsible for the costs of the products including the necessary Supply Chain Logistics, Business Processes, as well as the needs for an effective socially compliant manufacturing infrastructure.

Contribution of the roadmaps to the objectives of the Strategic Research Agenda

The following table shows in more detail the strength of the contribution of each roadmap to each of the specific objectives of the SRA. It should be noted that although the ETPC-4-EVs is a roadmap it is shown as a row rather than a column because the developments in each of the other roadmaps will have a significant influence on what is required of the automotive industry and therefore what will be required to be competitive.

Grand Societal Challenges	**Indicators**	**Guiding objectives**	Future Power-trains and Fuels	Hybridi-sation of Road Transport	Sustaina-ble Freight System	Integrated Urban Mobility System	Road User Behaviour and Expecta-tions	European Bus System of the Future	Climate Resilient Road Transport	Safe Road Transport
Decarboni-sation	Energy efficiency: urban passenger transport	+ 80% (pkm/kWh)*	XXX	XXX		XXX	XX	XX		X
	Energy efficiency: long distance freight transport	+ 40% (tkm/kWh)*	XXX	XX	XXX		XX			X
	Renewables in the energy pool	Biofuels: 25% Electricity: 5%	XXX	XX	XX	X		X		
Reliability	Reliability of transport schedules	+ 50%*			XXX	XX	XXX	XX	XXX	XXX
	Urban accessibility	Preserve Improve where possible		XX	X	XXX	XX	XXX	XX	
Safety	Fatalities and severe injuries	- 60%*				X	X		XX	XXX
	Cargo lost to theft and damage	- 70%*			XX	X				XXX
Global Competi-tiveness	ETPC-4-EVs, European Technology and Production Concept for Electric Vehicles		XXX	XXX		X		XX		XXX

Fig.2: Roadmaps contributions to the SRA objectives (*: in 2030 compared to 2010)

These roadmaps are also linked to the roadmaps developed for the European Green Cars Initiative public-private partnership, which cover the electrification of road transport, long distance trucks, and logistics and co-modality. These roadmaps are available from the ERTRAC website www.ertrac.org or from the EGCI website www.green-cars-initiative.eu.

The roadmaps presented here should be considered as living documents that will be updated regularly in light of technical progress and evolving societal needs. The implementation of the recommended research will be monitored considering both European and national programmes. Additional roadmaps will be prepared to address further research requirements emerging.

Links to major European Commission initiatives

ERTRAC has been working closely with the European Commission services in order to deliver a mapping of priorities that replies to the societal challenges and the objectives outlined in the European policies for transport, energy, and environment, as well as by industrial policies, which have been identified in the following key communications:

- COM(2011) 144, White Paper 2011 “Roadmap to a Single Transport Area - Towards a competitive and resource efficient transport system”. ERTRAC provides roadmaps which can help the vision set up in the White Paper to become a reality. They describe for all the aspects of the road transport system how decarbonisation and energy efficiency can be implemented, and how an integrated reliable transport system can be built up. In that respect these roadmaps have also been prepared as an input to the STTP, Strategic Transport Technology Plan, drafted by the European Commission for the implementation of the White Paper.

- COM(2010) 186, “A European strategy on clean and energy efficient vehicles”. ERTRAC responds to the two pillars of this strategy, by describing efforts to be done both for the optimisation of internal combustion engines propelled vehicles and for the development of electrically propelled vehicles. ERTRAC also shares the key objective set in this strategy that Europe must stand to reach leadership positions in the development of clean mobility solutions, replying to the challenge of global competitiveness for its road transport industry.

- COM(2010) 2020, “Europe 2020 - A strategy for smart, sustainable and inclusive growth”. The ERTRAC Strategic Research Agenda and its implementing roadmaps should be seen as a major contributor to the Europe 2020 goals, considering the importance of the transport sector in Europe, its evolution towards sustainability and smart integration opening large opportunities for growth and employment.

- COM(2010) 389, “Towards a European road safety area - policy orientations on road safety 2011-2020”. Safety remaining a major challenge for road transport, ERTRAC delivers an integrated approach to allow an ambitious reduction of fatalities and severe injuries on European roads.

- Smart Cities and Communities Initiative. Sustainable mobility for people and goods in urban environments is one of the most challenging tasks in the development of the cities of tomorrow. Delivering an energy efficient, reliable and integrated transport system, is therefore fundamental and must be integrated in all urban developments.

- COM(2010) 245, “A Digital Agenda for Europe”. Connectivity and smart integration of vehicles and infrastructures is an important ground for innovation, to enable a sustainable and integrated mobility system, and ITS (Intelligent Transport Systems) are therefore included in the ERTRAC roadmaps.

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European Roadmap

Future Light-duty Powertrain Technologies and Fuels

Version August 30, 2011

ERTRAC Working Group on Energy & Environment

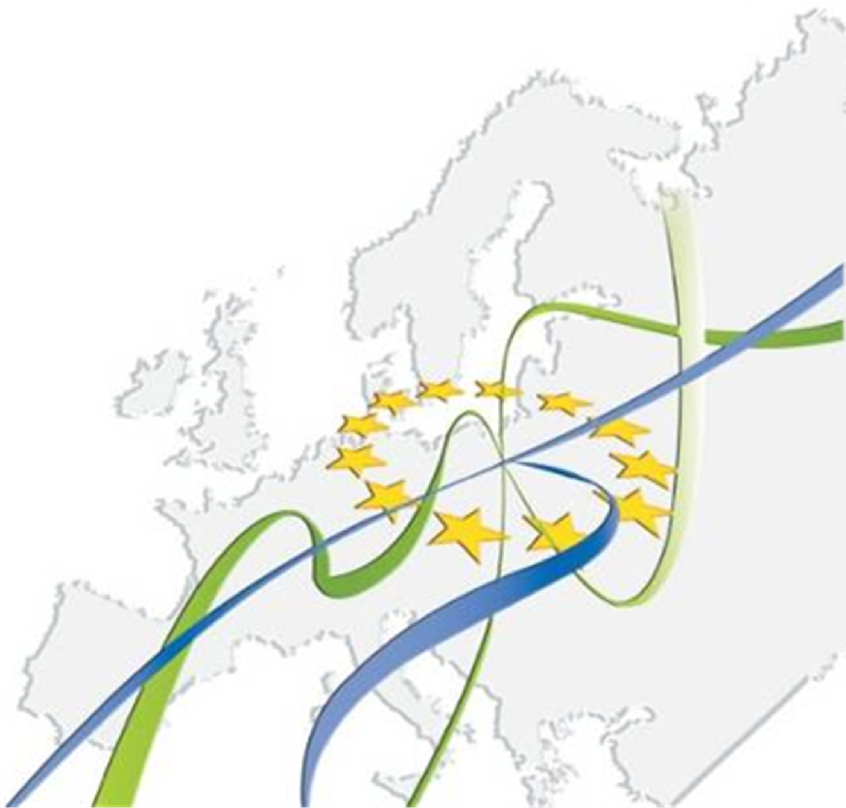


Table of Contents:

1. Executive Summary

Over the coming decades, Europe will require reliable and sustainably-produced energy for road and non-road transport as well as an energy infrastructure that efficiently utilizes and distributes this energy. Energy production must be combined with energy conservation in order to achieve ERTRAC's stated objectives for the 'decarbonisation of road transport'. In this paper, a research roadmap is presented for substantially improving the energy efficiency of road transport while increasing the share of renewable sources used by road transport.

The focus of this roadmap is future light-duty powertrain technologies based on advanced internal combustion engines (ICEs) as well as the fuels, processes, materials, and assessment tools that will be needed to enable them. Similar developments in heavy-duty powertrain technologies can be anticipated and will produce similar benefits in energy efficiency and in the decarbonisation of road transport. Meeting aggressive targets in this area will require a clear understanding of increasingly diversified energy demand and supply and the necessary innovation, research, development, and deployment activities that will be needed to meet these targets.

The advanced ICEs and fuels considered in this roadmap anticipate future demands for better transport energy efficiency, vehicle emissions, fuel flexibility, and flexible vehicle applications through:

- Light-weighting, by engine and vehicle downsizing and by structural improvements;
- Exhaust aftertreatment systems with lower impacts on engine efficiency;
- Flexible, adaptive, and predictive engine management systems for continuously optimizing engine parameters;
- Tailored operating modes, especially in hybrid and range-extended vehicle concepts;
- New demands on engine performance and competitiveness, especially in emerging markets;
- New fuels, both renewable and alternative, with consistent quality meeting market demand; and
- Scientifically-robust and reliable tools for evaluating environmental sustainability and performance.

2. Introduction

2.1 Background

A previous ERTRAC paper (ERTRAC (2010b)) presented a Future Transport Fuels Energy Pathway for Road Transport, describing an energy chain comprising primary energy, energy carrier, and application. This was a first step in describing energy scenarios for sustainable mobility that include energy demand from different road transport sectors and different transport and non-transport energy uses. A detailed view on energy production and distribution was considered beyond the scope of the previous paper and is the subject of this paper. In addition, important research needs related to the continuing development of advanced Internal Combustion Engines (ICEs) have not previously been addressed in ERTRAC Roadmaps and are included here.

Transport is a major consumer of energy. European consumers value their mobility and have a strong preference for personalized transport. Historical trends also show that there is a close relationship between the economic vitality of a country or region and its energy consumption. Without energy, a country or region will struggle to remain competitive in the world market and satisfy its consumers' demands for personal mobility.

For these reasons, the supply of energy and fuel required to meet these future demands will require a dynamic balance between aggressive energy conservation, sustainable energy production, and energy diversification. A broad range of technological and non-technological options will therefore be required, both to aggressively save energy and produce a greater fraction of energy from renewable sources in compliance with climate change and sustainable environmental expectations. At the same time, sustainable energy production must be coupled with developments in energy efficient vehicles that are attractive to consumers and can utilize a diversified energy mix while a reliable infrastructure must be in place to distribute this energy mix to where it is needed.

While the energy and fuel supply is expected to diversify in the future, advanced ICEs and powertrains will continue to play a major role for both light- and heavy-duty applications. The improvement potential for fuel consumption of advanced ICEs is still significant and continued improvements in regulated emissions performance and low overall cost are still feasible. For these reasons, advanced ICEs and powertrains will be important for meeting future consumer and regulatory demands over the near- and medium-term and they will be the pacesetter technology for alternatives like hybrid and battery electric vehicles. As such, they will be an important contributor to achieving ERTRAC's grand societal challenge for decarbonisation of transport.

Similar performance improvements can also be anticipated for heavy-duty ICEs and powertrains. In this document, similarities in research needs between light-duty and heavy-duty powertrains will be noted and differences will be the subject of additional roadmaps in the future.

2.2 Scope

This European Roadmap on Future Light-duty Powertrain Technologies and Fuels provides a perspective, including benefits, challenges, and milestones, related to the following topics:

- Advanced light-duty ICEs and powertrain technologies;
- Production and use of biofuels and advanced fuel products;
- Energy production and distribution for vehicle electrification (issues beyond those described in ERTRAC (2010b));
- Advanced materials and materials recycling for vehicles and infrastructure;
- Assessment tools (Well-to-Wheels (WTW), Life Cycle Analysis (LCA)).

2.3 Complementarities with other ERTRAC Roadmaps

This Roadmap is intended to complement other ERTRAC roadmaps focusing on Future Transport Energies, Hybridisation of Road Transport, and Sustainable Freight Transport.

2.4 Integrated approach

Increasing concerns for climate change and energy security are driving public policy while there is an ever-increasing consumer and business demand for transport and energy. Although advanced ICEs are expected to dominate road transport for several decades, especially in long-distance transport modes, the global competition for affordable energy and resources will lead to increasing diversification of energy sources, fuel types, and vehicles. This diversification will be greatest in urban environments where the transport and distance requirements are more compatible with diversified energy types and new energy distribution infrastructures. This roadmap, therefore, addresses the innovation, research, technology, and deployment needed to diversify the energy mix and infrastructure through the use of renewable fuels and advanced fuel products, including electricity, and improve the energy efficiency of vehicles and infrastructure especially through the use of advanced and lightweight materials. These changes must be accompanied by continuous improvements in road transport safety, noise, and emissions. Finally, continued development of models and assessment tools (WTW/LCA) will be needed to guide the evaluation of different fuel/vehicle combinations on a consistent and technically robust basis.

3. Contributions to the Grand Societal Challenges

The grand societal challenges addressed by the ERTRAC Strategic Research Agenda (ERTRAC (2010a)) are: 1) Decarbonisation, 2) Reliability, and 3) Safety. **Figure 1** summarizes the guiding objectives (corresponding to the main areas and indicators) of ERTRAC's 2010 SRA.

Figure 1 Guiding objectives of ERTRAC's "A Strategic Research Agenda for a '50% more efficient Road Transport System by 2030' (ERTRAC (2010a))

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'.

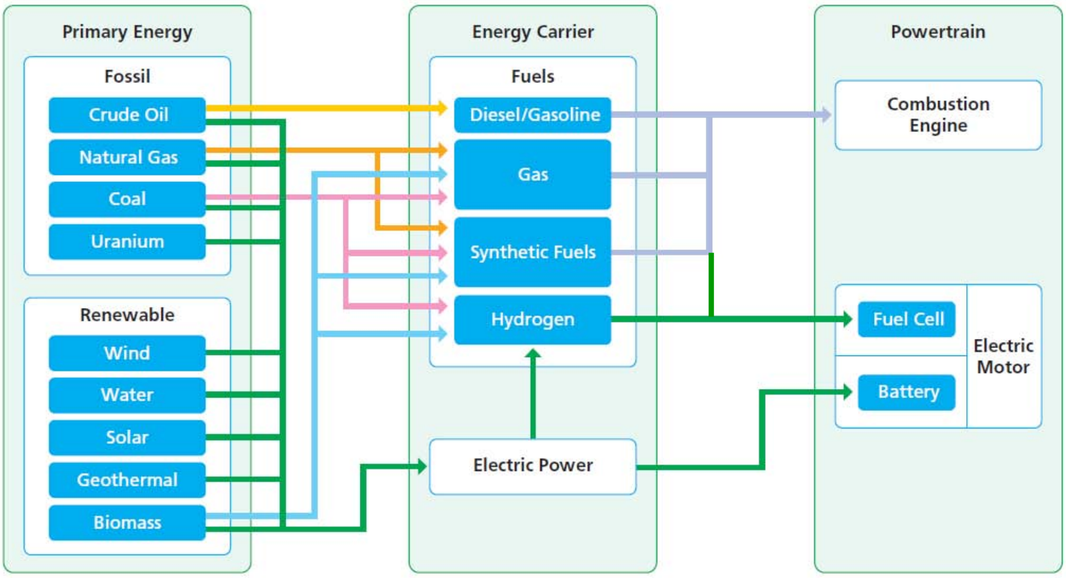
This roadmap on 'Future Light-duty Powertrains and Fuels' is specifically expected to impact the Grand Societal Challenge related to the 'Decarbonisation of Road Transport' by:

- Substantially improving the energy efficiency of road transport through an:
  - +80% improvement in the energy efficiency of urban transport;
  - +40% improvement in the energy efficiency of long-distance freight transport.
    - These will be achieved in large part through improvements in the fuel efficiency of engines, powertrains, and vehicles.
- Substantially increasing the share of renewables in road transport specifically:
  - 25% share of renewable fuels in road fuels;
  - 5% share of renewable electricity used for vehicle electrification.
    - The increasing share of renewable fuels in road fuels will require engines and vehicles that are fully compatible with the renewable fuels in the marketplace.
    - The increasing share of renewable electricity will also aid decarbonisation of road transport through the use of plug-in and battery electric vehicles which are covered in other ERTRAC roadmaps.

4. Research Lines

As was shown previously in ERTRAC's 'Future Transport Fuels' roadmap, **Figure 2** summarizes the diversification of energy pathways from primary energy, to energy carrier, to powertrain technology. Although future pathways may increasingly lead to electric motor options, internal combustion engines are likely to be the performance and cost favourite for the near- to medium-term for light-duty applications. For heavy-duty applications, there are even fewer good alternatives so that ICEs and liquid fuels consisting of fossil and renewable fuel products will be the mainstay for some time.

Figure 2 Energy pathways for liquid, gaseous, and electric energies



4.1 Research Areas

To address the grand societal challenge associated with transport decarbonisation, the following research areas have been identified. In large part, these areas follow two main lines: increased penetration of renewable energy in the transport system (i.e. via electrification and via biofuels and alternative fuels) and drastic improvement of energy – fuel consumption of existing powertrain systems. A major research effort has also to be directed towards guaranteeing that real world performance of all systems is at the same level as during certification, closing the gap that has emerged in some cases. The main research topics are explained below.

A1) Advanced Internal Combustion Engines (ICEs)

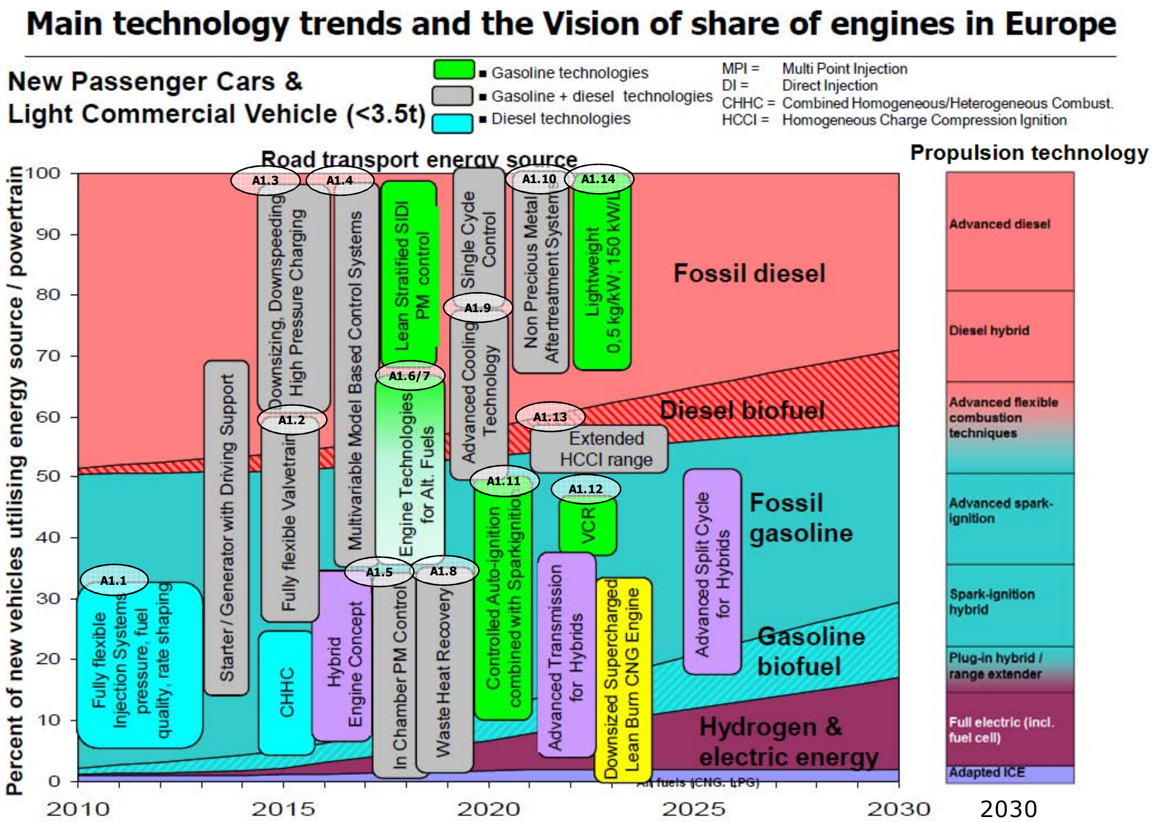
Electrification of the vehicle has already been identified as a future priority area for R&D and the research needs have been documented in another ERTRAC roadmap.

Projections for the penetration of alternative powertrain technologies over the next decades suggest that a large proportion of new light-duty vehicles will continue to use an internal combustion engine equipped with advanced concepts and technologies. ERTRAC's Strategic Research Agenda 2010

(ERTRAC (2010a)) indicated that more than half of new light-duty vehicles in 2050 will still be powered by an advanced ICE. A substantial fraction of these can be expected to be vehicles with an ICE as the sole source of propulsion while, in others, ICEs will increasingly be integrated with electric motors and batteries in a range of hybrid powertrains as described above.

Figure 3 shows the main technology trends for the light-duty powertrain over the next 20 years. Thus, there is a real urgency to address the near-term research needs while considering the medium- and longer-term technologies for 2015 and beyond. Today's ICEs have reached a very high level of maturity but they still offer significant potential for further improvement and these refinements should be exploited in future research activities.

Figure 3 Technology trends and research needs for light-duty ICE powertrains to 2030



Note: The reference numbers in this chart refer to the research needs that are described in more detail in the following section.

It is essential therefore to maintain focus on improvements to the ICE for light- and heavy-duty vehicle application, while R&D is carried out in parallel on components and systems for electrification of the vehicle. This approach will ensure the contribution of ICE technologies to sustainable mobility. Decarbonisation of the ICE itself will be achieved through efficiency improvements and the use of low carbon fuels, particularly biofuels. To achieve these advancements, further research is needed now and in the future.

A1.1) Fully flexible injection systems, pressure, fuel quality, and rate shaping

Injection is one of the most crucial parameters in modern diesel engines. The injection itself can be varied either with respect to its hardware setup (e.g. type of nozzle, number of injection holes, hole shape, targeting direction, etc.) as well as in its operational parameters. These are injection pressure, temporal variation of the injection rate (rate shaping), multiple injections, fuel quality sensing, etc. Both, hardware- and operational- parameters are strongly linked and follow partly diverging routes. At low rpm and loads, an injection rate is required that has a small gradient at the beginning and then steepens quickly. At full load, very fast injections with immediate high rates are preferred. These different targets cannot be achieved by setting only hardware design parameters but rate shaping has to contribute. Thus enabling rate shaping in the engine map offers additional potential with respect to engine emissions as well as fuel consumption reduction. Especially for the emission of particulate matter (PM) the injection system plays a key role in direct injection engines. Also for a variety of fuels different rate shaping is required respectively in order to keep “injected energy” at constant levels for different lower calorific heat levels. Closed loop combustion control and self-diagnostic systems will also be important to enable the full potential of future fuel injection equipment and strategies.

A1.2) Fully flexible valvetrains

Variable valvetrains such as camphasers on the inlet and exhaust offer the possibility of a moderate de-throttling at part load conditions as well as an internal Exhaust Gas Recirculation (EGR) capability by increased valve overlap. At Wide Open Throttle (WOT), better exhaust gas scavenging can be achieved in both naturally aspirated and turbocharged/supercharged engine types. Increasing variabilities in the valvetrain such as variable lift and variable opening duration lead to load control at part load via the valvetrain rather than via the throttle. Additionally, the response time for load jumps can be decreased. As an additional example, fully flexible valvetrains, which are completely decoupled from the crankshaft allow turbulence levels inside the combustion chamber to be adapted closer to the needs of the combustion process, e.g. via multiple opening events, etc. The latter is the enabling technology for advanced low temperature combustion. Almost all of the above mentioned aspects can be addressed by systems with discrete lifts rather than fully flexible ones but only the latter will achieve full benefits.

A1.3) Downsizing, downspeeding, and high-pressure charging

A strong trend towards downsized passenger car gasoline engines is clearly visible in the industry. The current maximum brake mean effective pressure (BMEP) reaches levels between 22 and 25 bar. The question is how to further increase the BMEP without deteriorating too significantly the engine’s thermodynamic efficiency at high loads. Similar to diesel engines, transmission ratios can be increased if the maximum engine speed (RPM) is brought to a lower value, which in turn offers the possibility to optimize the gas exchange process for a lower rpm range (downspeeding). In combination with refined applications of Miller- or Atkinson-Cycles with appropriate compression ratios further potential is to be explored. Together with increased charge motion and hence turbulence levels, cooled EGR and high pressure charging, methods how to achieve very high (up to 30bar) BMEP have to be developed for smaller displacements. Another challenging task is the development of appropriate turbo- and/or superchargers. The tradeoff will be between pressure build-up (turbo lag) and appropriate air-throughput without deteriorating full-load thermodynamics too badly due to an increased rate of hot exhaust gas remaining in the cylinder from the previous

cycle which can be caused by higher back pressures. Turbocharging systems must also overcome increasing power demands for charging if very high levels of EGR are used to enable low temperature combustion.

A1.4) Multivariable model-based control systems

Further improved combustion engine technologies are required to meet the future demands on fuel efficiency and emissions. As a consequence, the variety and complexity of controllers for both diesel and petrol engines will be increased more and more. This trend can be boosted by new sensors and increasingly powerful processors for automotive application, in particular multi core systems of high computing power. Model based controls are a potential alternative to avoid additional complexity and cost of sensors.

As vehicles are operated in a broad variety in terms of driving behaviour, road profile and operation purposes the conventional calibration based on a standardized operation pattern will not yield optimal performance concerning fuel consumption and emissions. In particular, the transient operation of combustion engines can be improved significantly.

A dedicated online-observation capability for analyzing engine combustion, powertrain and vehicle behaviour during the individual operation patterns would enable an on-road adaption of all components towards an optimized performance. Thus, individual demands from the driver on fuel efficiency or responsiveness could be accounted for as well as requirements resulting from cold start, warming-up or regeneration events of aftertreatment devices.

The real-time computing capability for engine control, e.g. via a predictive combustion model and an optimiser for the entire powertrain including electric motors and the use of route guidance systems, will maximize the benefit for both vehicle user and environment. This approach offers fuel consumption potentials up to 4% (max 2% for diesel).

A1.5) Particulate Matter (PM) control with focus on alternative fuels

New regulations related to particulate matter number assessment, in combination with the necessity to cope with a variety of biofuels, drive the need for greater understanding of processes related to particulate formation and consumption within the engine's internal combustion process. A more in-depth understanding is needed both within the diesel and gasoline engine development communities with particular emphasis on the direct injection gasoline engine. Areas that need further fundamental development include:

- Influence of fuel constituents, alternative fuels, and future fuels on combustion mechanisms related to PM;
- Influence of conventional and advanced combustion modes on PM emissions;
- Exploration of the potential of nanotechnology for development of insulating coatings of low heat capacity;
- Efficient experimental methods for characterizing PM formation and reduction during the combustion process;

- Improved computational models for combustion mechanisms related to the generation and decline of PM. Developments are needed both to predict PM levels throughout the combustion cycle and to improve the design and optimization of advanced combustion systems;

- Influence of injection system technology and specifications as well as influence of oil control on PM emissions;

- Development of charge system (boosting, EGR, and cooling) that support suitable boundary conditions for reduced PM generation;

- Maintain real life performance under varying operation conditions at the level of the vehicle certification cycle.

A1.6) Spark Ignition (SI) engine technology for alternative fuels (including downsizing)

The challenge for the development of technological solutions for a sustainable transportation system asks for high synergies between the evolution of the Internal Combustion Engine technologies and the use of low carbon alternative gaseous /renewable fuels. The innovative engine platforms based on downsizing/turbocharging/variable valve actuation enable a wide flexibility in adapting the combustion process to the specific characteristics of each fuel, thus maintaining the optimum conditions in terms of efficiency and pollutant reduction. Compared to a conventional naturally-aspirated SI engine, these new engines will provide a significant CO_2 reduction potential, close to 20%.

This approach represents the ideal way to exploit the benefit coming from the use of Compressed Natural Gas (CNG) from both fossil and renewable sources (biomethane). Moreover, from the industrial point of view the availability of such a kind of flexible engine platform is a key factor considering that other alternative fuels such as bioethanol can be also used on SI engines, depending on the local availability of the fuel. At the same time, CNG engine technology is also able to improve the introduction of hydrogen, based on renewable energy sources production, in the transportation sector via the use of natural gas and hydrogen blends for captive fleets, while for long transportation sector, Liquefied Natural Gas (LNG) is of growing interest.

A1.7) Compression Ignition (CI) engine technology for alternative biofuels

The development of process technologies for synthetic diesel by Fischer-Tropsch (FT) technology and hydrogenated vegetable oils (HVO) (as well as hydrogenated animal fats) enables a wider panel of combustion approaches thanks to the specific fuel properties of these blend components, especially higher cetane number and low aromatics composition. The availability of advanced biodiesel products at industrial scale necessitates the analysis of their impact on the powertrain technologies both from the standpoint of the combustion process and system components adaptation. Together with the evolution of the biodiesel option, blending of diesel fuel with bioethanol could also represent an option for specific applications.

A1.8) Waste heat recovery

The waste heat re-use represents a great opportunity to improve the internal combustion engine efficiency, in particular at high load operation and at heavy duty vehicle applications. Up to 70% of the combustion energy is converted to heat that is rejected in the exhaust and by the engine cooling. So, being able to re-use a considerable part of this heat means a significant overall efficiency increase

of the powertrain, evidently accounting for the passenger car constraints (dimensions, weight, and reliability) and based on technologies with a low environmental impact.

Since there are different technological solutions allowing the re-use of the waste heat, the challenge is the identification of the best solutions in terms of technology, sustainability and efficiency for small and medium passenger cars that represent the major part of the sold vehicle in Europe. To achieve these goals, it is required to develop new generation of components, systems and of powertrain able to take the maximum benefit from the waste heat re-use.

A1.9) Advanced cooling technology

Although the efficiency of modern internal combustion engines is increasing, the cooling requirements are rising due to higher demands on power output. Unlike naturally aspirated engines that eliminate heat to the environment through the exhaust gas, more rejected heat in modern ICEs will be transported into the underhood environment from heat exchangers, especially intercoolers and EGR coolers. With the underhood space already limited by passive safety and styling constraints, thermal interactions between hot parts will need to be taken into account and used more efficiently. Due to the increasing number of auxiliary systems, the cooling circuit is becoming more and more complex. This makes it very difficult to integrate and control the different components like radiator shutter and thermostat while different coolant temperatures are necessary to operate in the specified temperature range (e.g. gear box, high voltage battery, charge air cooler). Therefore research is necessary on the one hand to reduce the complexity of the coolant circuits, while on the other hand to enable advanced cooling strategies via integration of prediction tools regarding driving pattern and routing to forecast engine operating conditions.

A1.10) Non-precious metal aftertreatment systems for biofuels and alternative fuels

Global vehicle market growth and strengthened emission legislation will put a growing premium on the limited supply of platinum group metals (PGM) used in engine aftertreatment systems. Therefore, cost effective material alternatives will be needed to sustain the substantial improvements that advances in aftertreatment technology have provided in prior years. Aftertreatment technology based on close to zero or even PGM-less content will benefit from advances made in calibration and engine hardware but also from improved fuel quality as enhanced PM replacing materials gain feasibility. Areas of focus might be found specifically in PGM-less lean NOx aftertreatment technology and/or base metal only catalyzed filters. Close to zero PGM washcoat technology and/or significant platinum group metal shifts between individual PGM on oxidation catalysts and three-way catalysts will remain in focus within the industry for many years to come. PGM usage reduction in exhaust aftertreatment technologies is one enabler for other PGM consuming technologies, such as fuel cells. Finally a major challenge in this research topic is to achieve real life performance under varying operation conditions at the level of the certification cycle.

A1.11) Controlled Auto-Ignition (CAI) combined with spark ignition

A combined combustion mode, i.e. auto-ignition at low load conditions and spark ignition at high load conditions, is a promising option to reduce CO_2 while significantly reducing pollutant emissions. Advanced technologies, such as air dilution loop or EGR dilution loop, should be developed to better control the auto-ignition mode and optimising the spark ignition mode to reduce pollutant emissions.

These developments should be also combined with advanced strategies for engine control, based on technical breakthroughs on sensors or actuators.

A1.12) Variable Compression Ratio (VCR)

VCR technology allows a slight increase in overall engine efficiency and represents an opportunity to enable extreme downsizing of gasoline engines. The research target enabled by these benefits is a 15-20% improvement in overall fuel consumption and lower CO_2 emissions. Unfortunately, all of the available technologies to implement VCR on light-duty engines result in one or more drawbacks such as highly specific overall engine architecture, increased mass, higher engine friction, lower reliability, insufficient control, or difficulty in vehicle integration. There is a strong interest in pursuing research to design a reliable and efficient VCR technology that could be used as an add-on to conventional piston engine architecture.

A1.13) Extended range Homogeneous Charge Compression Ignition (HCCI)

HCCI is a combustion mode that ignites throughout the cylinder charge after activating the fresh injected fuel charge by exhaust gases that remain in the cylinder from a previous cycle. Under HCCI operation, engine-out NOx emissions may be one or two orders of magnitude lower than in a conventional engine, with an improvement in fuel consumption due to less throttling. HCCI currently suffers most from restrictions in the engine map area where it can be applied. The research target is to extend HCCI operation to a wider range, in particular low load modes. Coping with low temperatures and catalytic converter operation at low load and keeping HCCI going at low loads are other substantial tasks.

A1.14) Engine lightweighting

This is strongly interlinked with the downsizing topic. Lightweight and ultrahigh power-to-weight ratios contradict each other. The higher the specific power output of an engine will be the more demand for alternative fuels exists. Only with ethanol- or methanol-blends can the required high cylinder pressures be achieved through acceptable spark advances. This in turn requires very high strength of the components such as crankcase, connecting rod, piston, bearings, etc. which currently do not exist in conventional turbocharged engines. In diesel engines, the same problems are already being faced today. Cylinder pressures of around 200bar require special designs which in turn increase weight. The challenge is to make a step-out improvement compared to today's engine. The use of exotic materials and very smart design layouts which are considerably different from today is inevitable. Lightweighting will be especially important in hybrid and range-extended vehicles to offset additional battery weight.

A2) Production, distribution, and storage of biofuels and advanced fuel products

The demand for cleaner more energy efficient road transport is inevitable linked to the fuels employed and their properties. Advanced fuels and biofuels can and will play a very important role in achieving a more environmentally friendly and energy efficient profile. Fuel technology evolution is highly related to vehicle engine technology and exhaust aftertreatment systems development. Greater use of biofuels for transport forms an important part of the package of measures required if the EU is to comply with CO_2 reduction targets set for the near future as well as of any policy packages set up to meet further commitments in this respect. Advanced fuels and biofuels may play

an important supplementary role in vehicle electrification and the vehicle-grid integration envisaged for the next decade.

A2.1) Improve process and catalyst technology in order to improve WTT efficiency of fuel production

Biofuel production today in the large volumes required to meet ambitious EC targets is not fully sustainable because of limited availability of raw materials, high costs of production, and uncertainties about indirect land use change. New technologies should focus on fully exploiting biofuels benefits (GHG reduction, reducing dependency on oil products) while facing challenges such as widening the raw materials base towards waste products and waste biomass, developing new production processes, and reducing manufacturing costs. Process and catalyst technology improve can make a substantial contribution to making advanced biofuels socially and economically sustainable in the long term.

A2.2) Meet current fossil fuel properties using advanced biofuel products (HVO, BTL, LC Ethanol, Biomethane, DME, Hydrogen) and adapt engine technology to meet regulated limits

The main research question under this heading is: 'how do we promote the parallel development of future powertrain systems and fuels, integrating research in both fields, in order to achieve optimal performance both as regards conventional pollutants and the corresponding emission standrads as well as CO_2 emissions requirements on a WTW basis?' In this context, the following topics need to be addressed: targeted fuels for efficient ICEs having near-zero engine-out emissions, the impact of biofuel blending on combustion, the combustion characteristics of alternative fuels, adaptability of engine performance to changes in fuel quality, on-board fuel quality sensing systems, exhaust aftertreatment systems for biofuel-powered engines, powertrain calibrations for multiple fuel operating schemes, etc.

A2.3) Long-term biofuel storage systems

The development of technologies and networks for the effective promotion of new fuels and biofuels and the creation of fuel blends of custom properties and characteristics are important challenges both from a technical and a logistics and fuels distribution point of view. In this context research is required to address the following topics: In-pump blending, fuel distribution and refuelling infrastructures for long-range applications, establish conditions for compatibility of biofuels and biofuel blends with existing logistics, and the development of full biomass supply chains. From today's point of view issues related to the long term storage of current biofuels (biodiesel and bioethanol) such as microbial growth and degradation need to be specifically researched.

A2.4) Additive technology for enabling enhanced performance

Additives, added to the fuel in small amounts, are necessary to perform several functions. Among others, additives can (1) reduce emissions; (2) improve fluid stability over a wider range of conditions; (3) improve viscosity, reducing the rate of viscosity change with temperature; (4) improve ignition by reducing its delay time, flash point, and so forth; and (5) reduce wear with agents that adsorb onto metal surfaces and sacrificially provide chemical-to-chemical contact rather than metal-to-metal contact under high-load conditions. For conventional fuels and biofuel blends of low concentrations there is a wide knowledge basis of metal based additives, oxygenated additives, depressants and wax dispersants and ignition promoters. However, research is needed to further expand fuel additives as indispensable tools not only to decrease drawbacks but also to

produce specified products that meet international and regional standards, allowing the fuels trade to take place.

A2.5) Competition from other transport modes for renewable fuel products

Not all alternative fuels are equally suited for all modes of transport, and also not for all sectors within a specific mode. The needs of the different modes and the possibilities of the different fuels therefore need to be analysed for each mode separately. The suitability of a fuel for a specific transport mode depends on energy density of the fuel, vehicle compatibility and emissions performance, cost and market availability, safety during production, distribution, storage, vehicle refuelling, and use. The EC's Future Transport Fuels Report (COM (2011c)) has a suggestion with respect to the coverage of the different transport modes by the different alternative fuels. Research needs to concentrate on the specific aspects raised by each mode separately, e.g. biomass derived kerosene for aviation and biofuels for railways.

A3) Energy production and distribution for vehicle electrification

A3.1) CCS and energy production

In the EC's Strategic Energy Technology (SET) plan, the EC outlined an objective to demonstrate the commercial viability of Carbon Capture and Storage (CCS) technologies in an economic environment driven by the Emissions Trading Scheme, in particular, to enable cost-competitive deployment of CCS in coal-fired power plants by 2020 or soon after. The same technology could be used in selected refineries where the CO_2 sources support the added investment and the CO_2 transport and sequestration facilities are available. A large reduction in cost as well as an improved efficiency is necessary. The steps cover capture (pre- or post-combustion, chemical looping) and CO_2 transport and sequestration. In response to these challenges, a portfolio of demonstration projects is expected within the next five years, to test existing CCS technologies and demonstrate their long term operational availability and reliability.

A3.2) Marginal electricity production

A change of all passenger cars to electric vehicles would require a power generation corresponding to 10-20% range of current power generation (reference). An analysis of how this electricity will be generated is necessary to estimate the Well-to-Wheels (WTW) emissions of CO_2 for electrical vehicles. Some examples can be found in the electricity roadmap (ERTRAC 2009) generally indicating a positive contribution for different generation mixes while a pure fossil scenario may increase the CO_2 emissions. Most studies indicate that the marginal power will be dominated by fossil fuel until 2030. Extended studies of different scenarios for power generation are needed including an analysis of the dynamic aspects of this transition. The results of such studies depend on the size and timing of the change in supply of electricity. On the longer term it is likely that the so called "dynamic margin" consists of both fossil and renewable energy. For example the 450ppm scenario from the International Energy Agency expects significant reductions of CO_2 from EU electricity production (from ~535g/kWh in 2010 to 130 g/kWh in 2030).

The traditional definition of marginal electricity is most likely not applicable to a large fleet of electric vehicles in the future. What is of interest is the impact from a large fleet of electric vehicles and how additional electricity demand should be allocated to consumers, not the impact from limited

numbers of vehicles in an introduction phase. Given the current costs and benefits of electric vehicles, it is expected that many years will be required to reach high market shares and, during this growth period, electricity production will change in a dynamic process depending on the overall demand for electricity, regulations, pricing, taxation, etc. In the introduction phase, when there are only limited amounts of renewable electricity available, the CO_2 savings from electric vehicles will be small. However, this early introduction will facilitate a larger fleet which will operate using electricity having much lower CO_2 emissions.

A3.3) Smart Grid management (city level energy and transport demand management)

Electricity generation and distribution are likely to change in near to mid-term and trends point towards more renewable and more local power generation. Larger proportions of wind and solar power will require more balancing, and possibly also energy storage, in the grid. Information and Communication Technology (ICT) is an integral part of the Smart Grid and developments offer new opportunities for load management and communication between the users (households and other users) and the grid operators. Several European countries are enforcing new metering demands supporting this development. The increasing need for charging of electrical vehicles will benefit from this development. The power industry has accepted the cap on CO_2 as a part of the trading system and transport electrification will move transport energy within the cap. More research is needed on many levels to identify an optimised overall energy system. This includes business models, roles of different stakeholders and integration of charging infrastructure. Electricity providers are expected to play an active role here to integrate smart grids with local power generation and distribution.

A3.4) Standardisation of recharging technology and infrastructure

Standardisation of the interfaces between charging infrastructure and vehicles is essential to keep cost down and facilitate a mass market introduction of plug-in vehicles. The standardisation needs to cover the physical interface with the vehicle as well as the communication protocols and procedures related to the information flow between vehicle and grid. The significant consequences on battery ageing from different charging strategies will most likely require that the main control is governed by the vehicle management unit within the limits set by the grid. New standards are needed in all charging areas including intelligent home charging, fast charging and wireless charging. It is important that the standards developed also take more long term requirements for Smart Grid implementation (such as demand side management, time-controlled charging, and vehicle-to-grid (V2G) technology) into account.

A3.5) Continuous charging capabilities

New technologies for continuous charging (inductive and conductive) through Electric Road Systems (ERS) are emerging. The ability to pick up electric power from the road system will have a significant positive impact on the high level system cost of transportation electrification and in particular on the size of the battery required onboard the vehicle. Synergies with bus and freight distribution truck market in urban areas are of interest. In the long run, also technologies for continuous charging of long distance freight distribution are possible. Primary research areas for ERS are power pick-up systems, safety solutions and how to overcome institutional barriers.

A4) Advanced materials and materials recycling for vehicles and infrastructure

A4.1) Vehicle redesign for efficient materials recycling

In order to provide an efficient use of recycled materials as well as an optimised handling of recyclable parts, it is important to include these aspects as early as possible in the design process. Recyclable items, or parts including such, need to be mounted and assembled so that they can be easily disassembled. This needs to be taken into account when choosing joining and fastening methods. It is also important to have the correct set of requirements on materials, avoiding unnecessarily strong requirements and thereby disqualifying recycled materials.

A4.2) Infrastructure redesign for efficient materials recycling

The logistic chains as well as the complete setup of suppliers need to take into account the handling of recycled materials in the flow. This covers inbound/outbound logistics as well as in-plant material handling. From a research point of view, this increases the complexity of an already very complex system and must be investigated in order to make correct cost estimates and optimisation of the complete flow.

A4.3) Catalyst manufacturing and recycling processes

Catalysts derived from rare earth materials are regularly used in many transport-related applications, including fuel production and aftertreatment technologies. The recycling and reuse of these limited resources will be increasingly important while high-performing alternatives are identified that can be manufactured from more abundant components.

A4.4) Component technologies, such as electric machines, including lower-cost alternatives, availability of raw materials, optimised design, material demands, low-cost options

A large source of uncertainty is related to the availability of reliable and diversified supply of metals, e.g. copper and permanent magnets that are necessary to assure high efficiency and high power density (compact) electrical motors. While at a research level several solutions are pursued, it seems there is no viable industrial alternative to NdFeB for at least another decade. The move from few and critical sources of oil to a likely even more critical single source of permanent magnets should urgently address the development of both new high efficiency motors using limited weight of permanent magnets and completely new motor designs. Advanced materials are therefore required for permanent magnets and magnetic cores. This incorporates development of highly integrated motors (on-axle, in-wheel) and controls using aggressive cooling and optimized (or even non-) magnetic materials.

A4.5) Policy issues related to sustainable vehicle production

Sustainability is already at the centre of automotive R&D. Environmental challenges such as climate change and resource scarcity are the source of both constraints and opportunities for technological development. Research has to satisfy both environmental and customer needs, generating high added-value products, related processes and technologies to meet functionality requirements as well as growth conditions, public health, occupational safety and environmental protection concerns. This

means that public policies and regulations need to take into account all these aspects in a proper balance.

A4.6) Affordable technologies for producing easily recycled batteries, magnets, etc.

Cathode materials such as Lithium Iron Phosphate ($LiFePO_4$), Lithium Manganese Spinelle ($LiMn_2O_4$), are currently considered promising "new generation" electrode materials. Together with reference cobalt- and nickel-based materials, such as $Li(NiMnCo)O_2$ and $Li(NiCoAl)O_2$, these cathodes cover the main technological trends for the near future. The disposal of end-of-life batteries is a fundamental issue for all automotive application involving advances batteries. While the absence of Co- and Ni-based compounds should have a positive effect on the initial cost of the battery, it is still unclear if the recycling process for alternative chemistries is technically feasible and economically viable.

The total cost of the cell should be evaluated, for an expensive process to enhance conductivity can compensate the apparent low cost of the cell's raw components (case of $LiFePO_4$). Of course, the general performances of the cell (in terms of energy and power capability) should stand up to the car makers requirements.

A5) Assessment tools (Well-to-Wheels (WTW), Life Cycle Analysis (LCA))

A5.1) Robust WTW/LCA tools for valuing alternative fuel/vehicle pathways and further development and routine applications of LCA methodologies

Environmental sustainability will be a key driver for future technological improvements. In order to achieve this outcome, future technological innovations must be evaluated in a scientifically-robust and consistent way for their environmental impact and sustainability. LCA is a recognised approach, following guidance contained in the International Reference Life Cycle Data System (ILCD) Handbook, to achieve robust and reproducible results. Although much progress has been made on LCA methodologies in recent years, a more robust LCA methodology and software tool for vehicle design should be developed to facilitate industry decisions and enable quick and reliable 'eco-scans' that can be used to guide the environmental aspects of vehicle design. Such an LCA tool for vehicles should consider the extraction of raw materials, the manufacturing of components, vehicle assembly, and use phase (on a WTW basis) as well as maintenance, end-of-life (EoL) treatment, and recycling. A coherent framework is needed in order to compare different drive train technologies (ICEs, hybrids, battery electrics, etc.) and different fuel technologies (gasoline, diesel, compressed gases, etc.). Awareness must also be drawn to related topics such as typical vehicle utilization and associated drive cycles, interactions between electricity storage systems and the power generation grid, and the manufacturing and EoL treatment of batteries.

A5.2) LCA for vehicle materials options

The important question to address here is how to develop advanced, lightweight, cheap and eco-friendly materials from abundant resources in order to adequately fill the demands of future vehicle development and improve vehicle safety, reliability and environmental performance. In this context, it is necessary to carry out LCA of common and alternative materials, multi-fuel compatible materials including non-precious metals and catalysts, and advanced alloys aimed at the identification of materials with favorable environmental profiles.

A5.3) Models for economic and business evaluation

Economic modeling for efficient resources and production management is a key point for achieving optimal reliability and efficiency. In addition is the factor that will reveal the interactions between phenomenally unrelated technologies and practices and in the end define the viability of each technological option investigated. Modeling in this field should aim at generating and collecting data for sustainability assessment of existing and potential promising production chains and analyse possible impacts of technologies introduction in vehicle and fuels market. In addition customer behavioral analysis as well as marketable products development should also be addressed by appropriate modeling tools.

A5.4) Models for evaluation of policy alternatives

Similarly to the models for economic evaluation, models for the coherent long term policy evaluation and harmonisation are needed, capable to address topics such as investigation of joint public/private financing for R&D for biofuels introduction and vehicle-grid integration as well as demonstration of new production routes and end-use applications. Modelling can also play an important role in the development of certification systems to assure environmental sustainability of different technologies as well towards the development of indicators and coherent methodologies to assess and monitor the three dimensions of sustainability.

A5.5) Simulation tools for production design

The vehicle integration should be kept in mind from the very start of the vehicle concept design, and guaranteed throughout the development cycle. Currently, this ‘vehicle integration focus’ is typically not implemented from the very start, but instead sub-optimally synchronized during the development cycle. This brings along the risk that developed solutions and physical prototypes will remain at the level of fancy add-ons, rather than becoming integrated solutions to improve the overall vehicle performance. In future R&D, the ‘integrated vehicle design’ focus should be implemented from the very start. Modeling & simulation can play a key role in this, and novel R&D actions are needed to develop the necessary methodologies to achieve this.

5. Milestones

The objective of the next twenty years is to develop the following milestones related to Future Light-duty Powertrain Technologies and Fuels.

- **Milestone 1: (2015):**

The first milestone is intended to adapt existing technologies to increasingly impact the decarbonisation challenges. The timescale for market introduction is approximately 2020-2025.

- **Milestone 2: (2020):**

The second milestone is intended to integrate implemented technologies to increasingly impact the decarbonisation challenges. The timescale for market introduction is approximately 2025-2030.

- **Milestone 3**: **(2030):**

The third milestone is intended to achieve optimised performance from implemented technologies in order to sustainably impact the decarbonisation challenges. The timescale for market introduction is approximately 2030+.

Table 1 Milestones for Light-duty Powertrain Technologies and Fuels

	Milestone 1 (2015) Market 2020-2025	**Milestone 2 (2020) Market 2025-2030**	**Milestone 3 (2030) Market 2030+**
Milestone Concept	**Adapting**	**Integrating**	**Sustaining**
A1) Advanced ICEs			
A1.1) Fully flexible injection systems, pressure, fuel quality, and rate shaping	Increasing utilisation of advanced fuel injection system technologies	Increasing integration of system technologies to enhance performance	Full integration of system technologies to achieve optimised performance
A1.2) Fully flexible powertrains	Increasing utilisation of fully flexible powertrains	Full utilisation of fully flexible powertrains to enhance performance	Full utilisation of fully flexible powertrains to achieve optimised performance
A1.3) Downsizing, downspeeding, and high-pressure charging	Increasing utilisation of best options to evaluate commercial potential	Increasing integration of best options to enhance performance	Full integration of best options to achieve optimised performance
A1.4) Multivariable model-based control systems	Increasing utilisation of model-based control systems	Increasing integration of model-based control systems to enhance performance	Full integration of model-based control systems to optimise performance
A1.5) Particulate Matter (PM) control with focus on alternative fuels	Increasing utilisation of PM control strategies	Increasing integration of PM control strategies to enhance performance	Full integration of PM control strategies to achieve optimised performance
A1.6) Spark Ignition (SI) engine technology for alternative fuels (including downsizing)	Increasing utilisation of advanced SI technologies	Increasing integration of advanced SI engine technologies to enhance performance	Full integration of advanced SI engine technologies to achieve optimised performance
A1.7) Compression Ignition (CI) engine technology for alternative fuels	Increasing utilisation of advanced CI technologies	Increasing integration of advanced CI engine technologies to enhance performance	Full integration of advanced CI engine technologies to achieve optimised performance
A1.8) Waste heat recovery	Scale-up of best options to evaluate commercial potential	Commercial development of most promising technologies	Increasing utilisation of most promising technologies
A1.9) Advanced cooling technology	Scale-up of best options to evaluate commercial potential	Commercial development of most promising technologies	Increasing utilisation of most promising technologies

A1.10) Non-precious metal aftertreatment systems for biofuels and alternative fuels	R&D to evaluate potential for non-precious metal technologies	Scale-up of best options to evaluate commercial potential	Commercial development of most promising technologies
A1.11) Controlled Auto-Ignition combined with Spark Ignition	Scale-up of best options to evaluate commercial potential	Commercial application over limited speed/load range	Commercial application over full speed/load range
A1.12) Variable Compression Ratio	Scale-up of best options to evaluate commercial potential	Commercial application over limited speed/load range	Commercial application over full speed/load range
A1.13) Extended range HCCI	Scale-up of best options to evaluate commercial potential	Commercial application over limited speed/load range	Commercial application over full speed/load range
A1.14) Engine lightweighting	R&D to evaluate material options for engine lightweighting	Scale-up of best options to evaluate commercial potential	Commercial development of most promising technologies
A2) Production, distribution, and storage of biofuels & advanced fuel products			
A2.1) Process and catalyst technology to improve WTT efficiency of fuel production	R&D to evaluate technical options	Scale-up of best options to evaluate commercial potential	Commercial development of most promising technologies
A2.2) Advanced biofuel products and adapted engine technology to meet regulated limits	Scale-up of best options to evaluate commercial potential	Commercial development of most promising technologies	Commercial development of most promising technologies
A2.3) Long-term biofuel storage systems	R&D to evaluate technical options	Scale-up of best options to evaluate commercial potential	Commercial development of most promising technologies
A2.4) Additive technology for enabling enhanced performance	R&D to evaluate technical options	Scale-up of best options to evaluate commercial potential	Commercial development of most promising technologies

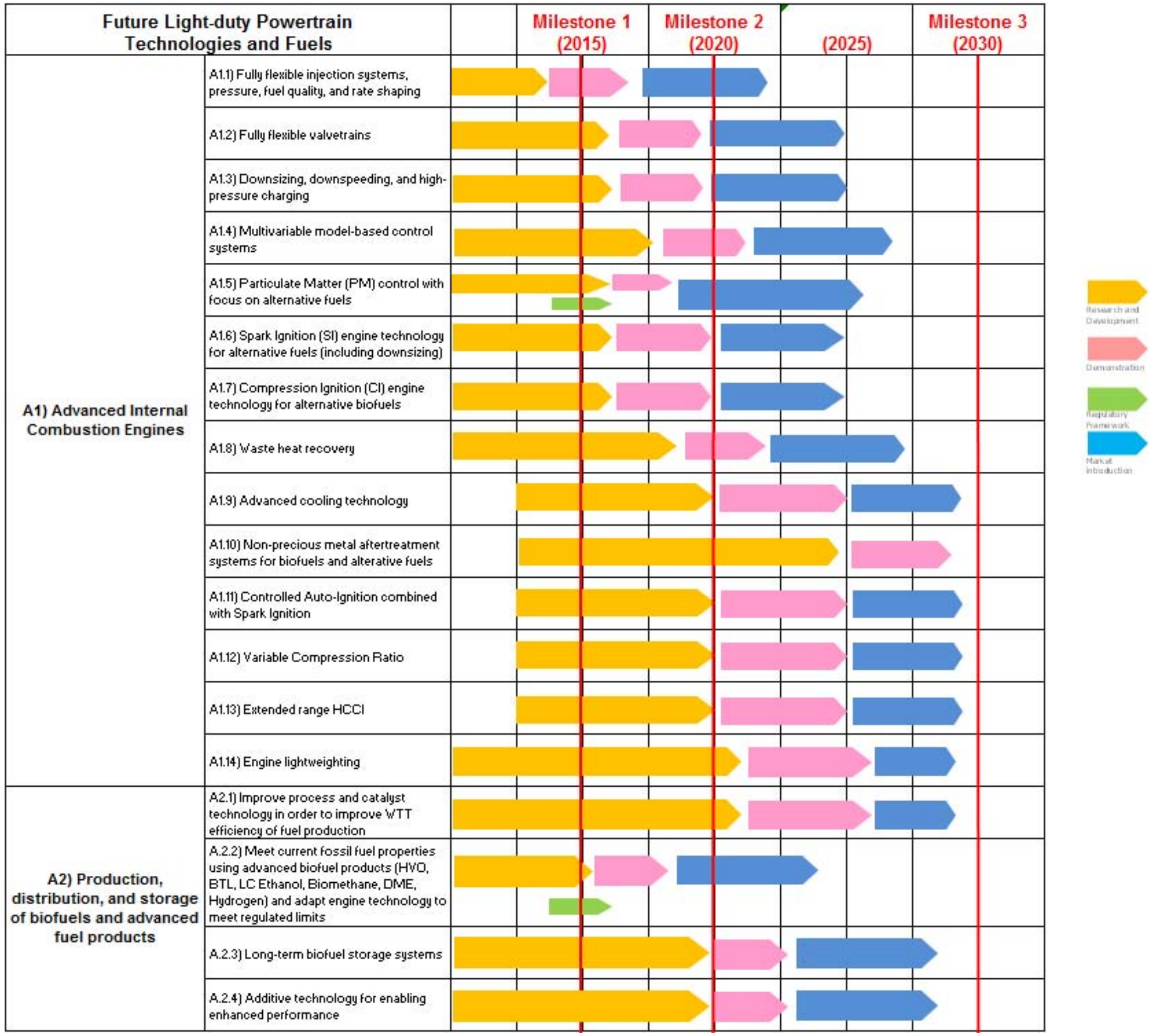
A3) Energy production & distribution for vehicle electrification			
A3.1) CCS and energy production	R&D to evaluate technical options	Pilot scale to test technical options	Scale-up of best options to evaluate commercial potential
A3.2) Smart Grid management	R&D to evaluate technical options	Scale-up of best options to evaluate commercial potential	Commercial development of most promising technologies
A3.3) Standardisation of recharging technology and infrastructure	Agreement on best options for commercial applications	Commercial implementation on limited scale	Commercial application on large scale
A3.4) Continuous recharging capabilities	R&D to evaluate technical options	Scale-up of best options to evaluate commercial potential	Commercial development of most promising technologies
A4) Advanced materials & materials recycling for vehicles and infrastructure			
A4.1) Vehicle redesign for efficient materials recycling	R&D to evaluate vehicle redesign options	Scale-up of best options to evaluate commercial potential	Commercial development of most promising approaches
A4.2) Infrastructure redesign for efficient materials recycling	R&D to evaluate infrastructure redesign options	Scale-up of best options to evaluate commercial potential	Commercial development of most promising approaches
A4.3) Catalyst production processes	Scale-up of best options to evaluate commercial potential	Commercial development of most promising approaches	Full implementation, refinement and optimisation
A4.4) Component technologies	Scale-up of best options to evaluate commercial potential	Commercial development of most promising approaches	Full implementation, refinement and optimisation
A4.5) Policy issues related to sustainable vehicle production	Small scale evaluation of best approaches to determine potential	Broader evaluation to determine potential	Full implementation, refinement and optimisation
A4.6) Affordable technologies for producing easily recycled batteries, magnets, etc.	R&D to evaluate potential for affordable technologies	Scale-up of best options to evaluate commercial potential	Commercial development of most promising and affordable technologies

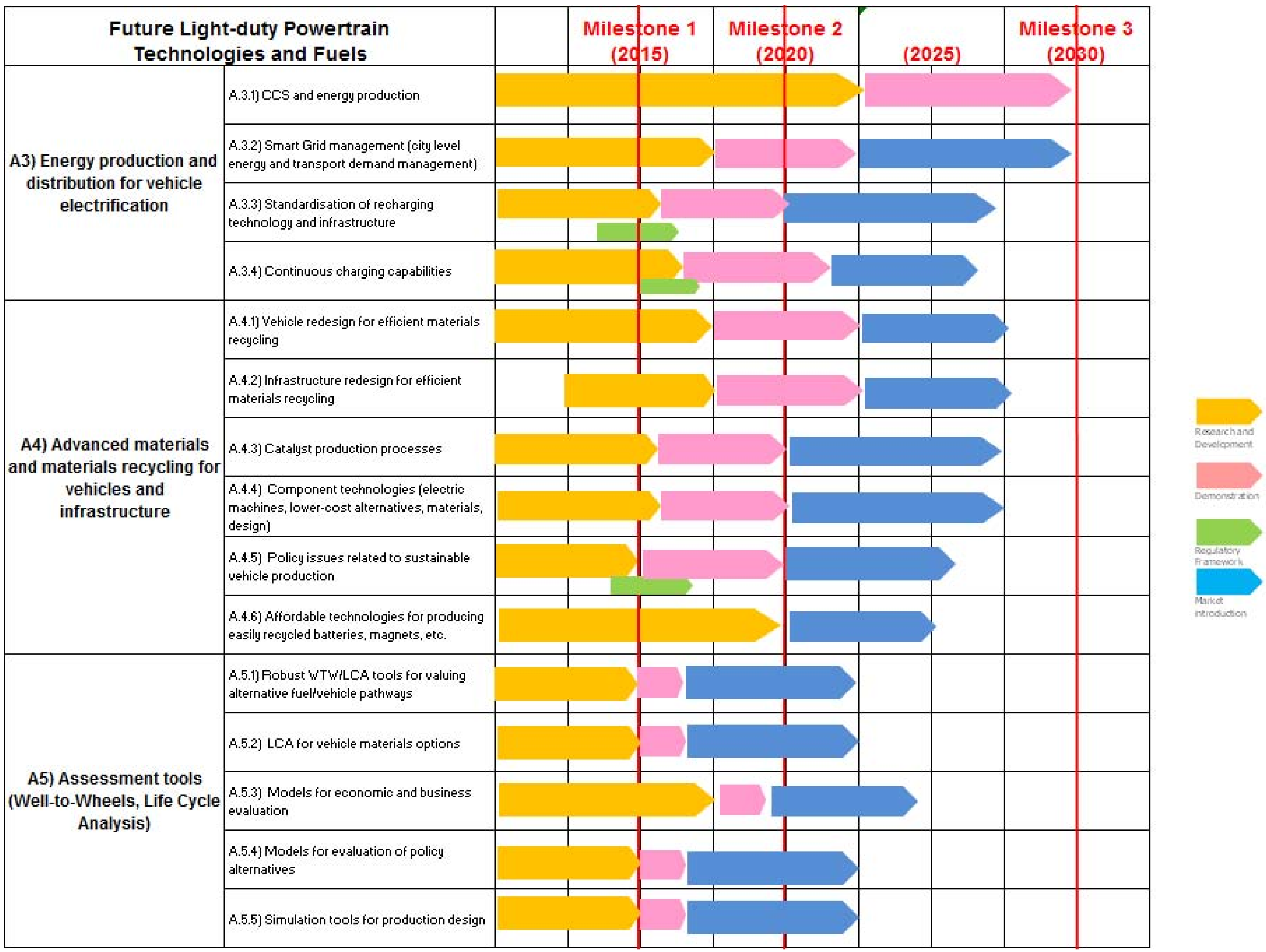
A5) Assessment Tools (WTW, LCA)			
A5.1) Robust WTW/LCA tools for valuing alternative vehicle/fuel pathways	Development of approaches to evaluate commercial applications	Implementation, refinement and optimisation to enhance performance	
A5.2) LCA for vehicle materials options	R&D to evaluate approaches for vehicle applications	Development of approaches for commercial applications	Implementation, refinement and optimisation to enhance performance
A5.3) Models for economic and business evaluation	Development of approaches to evaluate commercial applications	Implementation, refinement and optimisation to enhance performance	
A5.4) Models for evaluation of policy alternatives	Development of approaches to evaluate commercial applications	Implementation, refinement and optimisation to enhance performance	
A5.5) Simulation tools for production design	Development of approaches to evaluate commercial applications	Implementation, refinement and optimisation to enhance performance	

6. Roadmap phases and their milestones

Following the definition of milestones, this section defines the roadmap corresponding to the research needed to achieve the stated objectives. The roadmap indicates the main tasks leading to these milestones.

The framework document of the roadmap elaborated in the ERTRAC Strategic Research Agenda (ERTRAC (2010a)) defines four steps for the implementation of the actions for each roadmap. The following arrows summarize the steps that have been used in the diagrams below:


Future Light-duty Powertrain Technologies and Fuels
Milestone 1 (2015)
Milestone 2 (2020)
(2025)
Milestone 3 (2030)
A1) Advanced Internal Combustion Engines
A1.1) Fully flexible injection systems, pressure, fuel quality, and rate shaping
A1.2) Fully flexible valvetrains
A1.3) Downsizing, downspeeding, and high-pressure charging
A1.4) Multivariable model-based control systems
A1.5) Particulate Matter (PM) control with focus on alternative fuels
A1.6) Spark Ignition (SI) engine technology for alternative fuels (including downsizing)
A1.7) Compression Ignition (CI) engine technology for alternative biofuels
A1.8) Waste heat recovery
A1.9) Advanced cooling technology
A1.10) Non-precious metal aftertreatment systems for biofuels and alterative fuels
A1.11) Controlled Auto-Ignition combined with Spark Ignition
A1.12) Variable Compression Ratio
A1.13) Extended range HCCI
A1.14) Engine lightweighting
A2) Production, distribution, and storage of biofuels and advanced fuel products
A2.1) Improve process and catalyst technology in order to improve WTT efficiency of fuel production
A.2.2) Meet current fossil fuel properties using advanced biofuel products (HVO, BTL, LC Ethanol, Biomethane, DME, Hydrogen) and adapt engine technology to meet regulated limits
A.2.3) Long-term biofuel storage systems
A.2.4) Additive technology for enabling enhanced performance


Future Light-duty Powertrain Technologies and Fuels
Milestone 1 (2015)
Milestone 2 (2020)
(2025)
Milestone 3 (2030)
A3) Energy production and distribution for vehicle electrification
A.3.1) CCS and energy production
A.3.2) Smart Grid management (city level energy and transport demand management)
A.3.3) Standardisation of recharging technology and infrastructure
A.3.4) Continuous charging capabilities
A4) Advanced materials and materials recycling for vehicles and infrastructure
A.4.1) Vehicle redesign for efficient materials recycling
A.4.2) Infrastructure redesign for efficient materials recycling
A.4.3) Catalyst production processes
A.4.4) Component technologies (electric machines, lower-cost alternatives, materials, design)
A.4.5) Policy issues related to sustainable vehicle production
A.4.6) Affordable technologies for producing easily recycled batteries, magnets, etc.
A5) Assessment tools (Well-to-Wheels, Life Cycle Analysis)
A.5.1) Robust WTW/LCA tools for valuing alternative fuel/vehicle pathways
A.5.2) LCA for vehicle materials options
A.5.3) Models for economic and business evaluation
A.5.4) Models for evaluation of policy alternatives
A.5.5) Simulation tools for production design
Research and Development
Demonstration
Regulatory Framework
Market introduction

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8. References and Related Projects

- COM (2010a): COM (2010)186, ‘A European strategy on clean and energy efficient vehicles’
- COM (2010b): COM (2010) 2020, ‘Europe 2020 - A strategy for smart, sustainable and inclusive growth’
- COM (2011a): COM (2011) 48, ‘From Challenges to Opportunities: Towards a Common Strategic Framework for EU Research and Innovation Funding’
- COM (2011b): COM (2011) 144, White Paper 2011 ‘Roadmap to a Single Transport Area - Towards a competitive and resource efficient transport system’
- COM (2011c): Future Transport Fuels: Report of the European Expert Group on Future Transport Fuels (January 2011)
- ERTRAC (2009): European Roadmap: Electrification of Road Transport (ERTRAC, October, 2009)
- ERTRAC (2010a): ERTRAC Strategic Research Agenda 2010. Towards a 50% more efficient road transport system by 2030, May 2010
- ERTRAC (2010b): Future Transport Fuels: The Energy Pathway for Road Transport (ERTRAC, October 2010)
- EUCAR (2010a): Mobility and Transport in FP8. EUCAR position, November 2010
- EUCAR (2010b): EUCAR WG Powertrain: Research Needs in Light-duty Powertrain Technologies (November 2010)

9. Glossary

BMEP	Brake Mean Effective Pressure
CAI	Controlled Auto Ignition
CCS	Carbon (or CO_2) Capture and Storage
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DME	Di Methyl Ether
EC	European Commission
EGR	Exhaust Gas Recirculation

EoL	End of Life
ERS	Electric Road System
FT	Fischer Tropsch (Process)
GHG	Greenhouse Gas or Gases
H_2	Hydrogen
HCCI	Homogeneous Charge Compression Ignition
HVO	Hydrogenated Vegetable Oil
ICE	Internal Combustion Engine
ICT	Information and Communication Technology
ILCD	International Reference Life Cycle Data (System Handbook)
LC	Ligno Cellulose
LCA	Life Cycle Analysis
LNG	Liquefied Natural Gas
NG	Natural Gas
NOx	Nitrogen Oxides
PM	Particulate Matter
R&D	Research & Development
RPM	Revolutions Per Minute
SET	Strategic Energy Technology (Plan)
SI	Spark Ignition
STTP	Strategic Transport Technology Plan
TTW	Tank-to-Wheels
V2G	Vehicle-to-Grid
WOT	Wide Open Throttle
WTT	Well-to-Tank
WTW	Well-to-Wheels
XTL	X-to-Liquids (where X can be B (biomass), C (coal), G (gas), or W (waste))

ERTRAC

EUROPEAN
ROAD
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COUNCIL

European Roadmap

Hybridisation of Road Transport

Version June 1, 2011

ERTRAC Expert Group Enabling Technologies

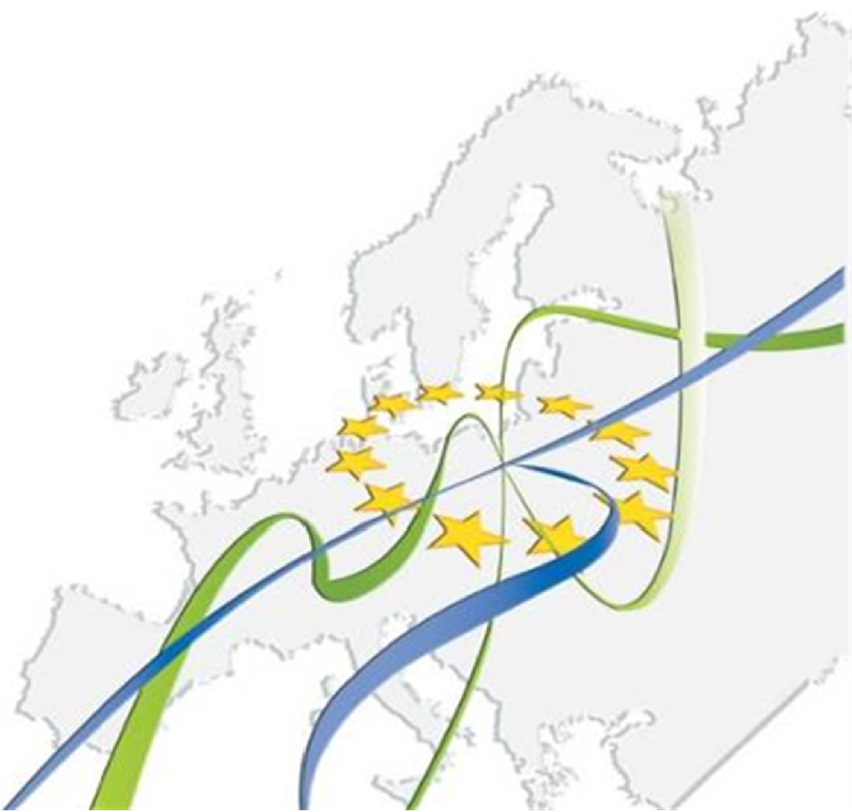


Table of Contents:

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.

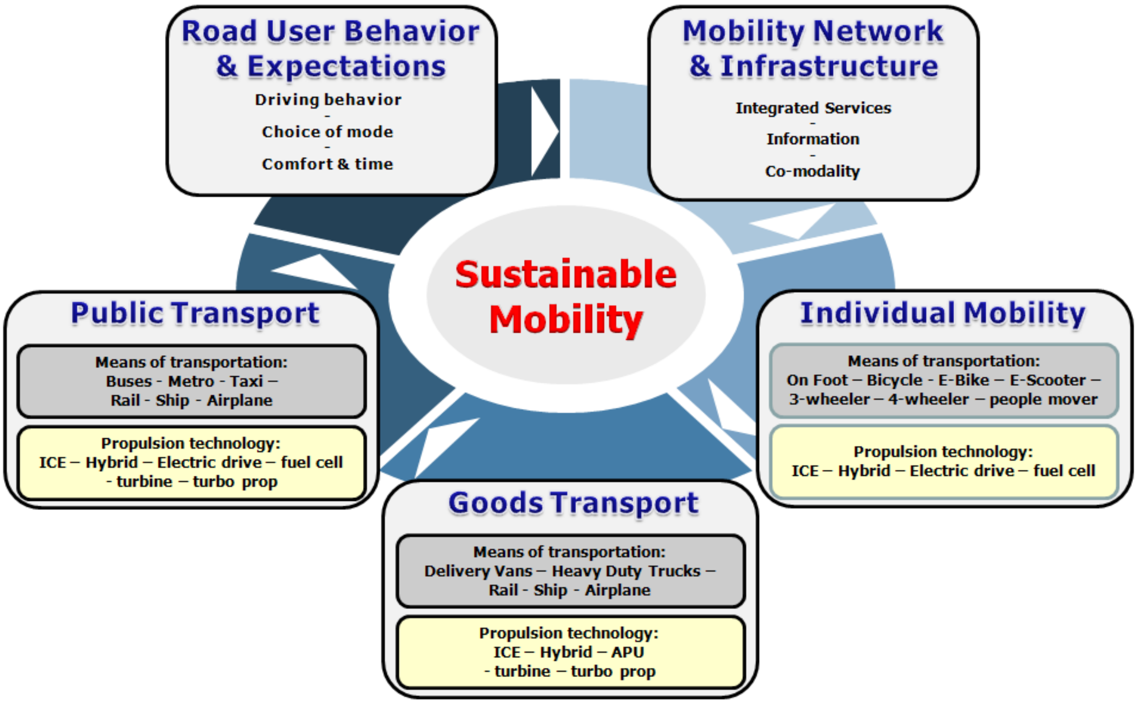


Figure 1: The context of Sustainable Mobility

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.

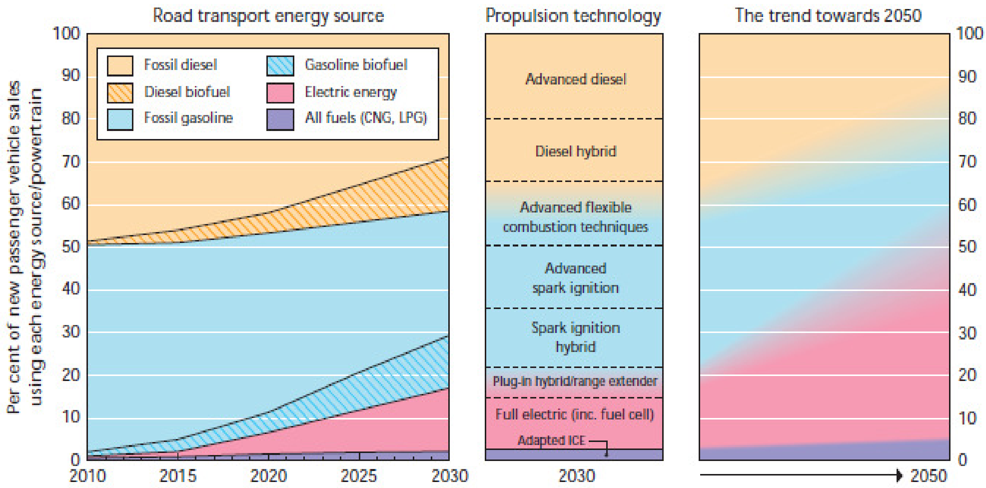


Figure 2: The evolution of passenger road transport energy source and propulsion technology, towards 2050

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.**

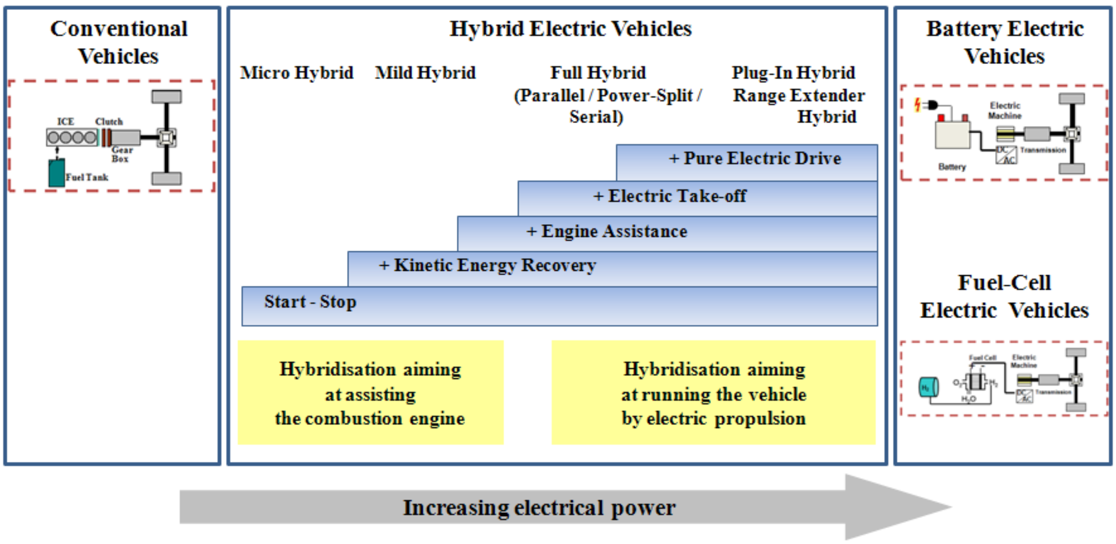


Figure 3: The classification of Hybrids

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

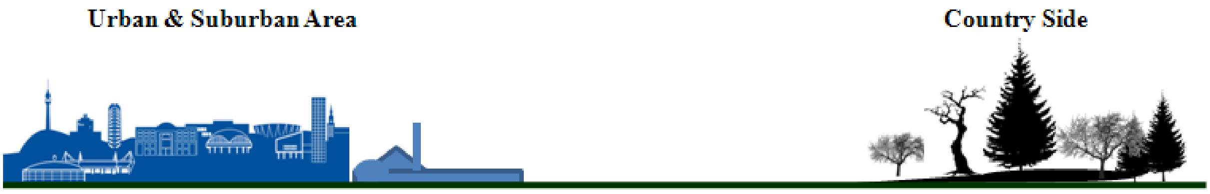
	Indicator	Guiding objective for 2030
Decarbonisation	Energy Efficiency: Urban Passenger	**+80%**
	Energy Efficiency: Long Distance Freight	**+40%**
	Share of Renewables	Biofuels: **25%** Electricity: **5%**
Reliability	Reliability of transport times	**+50%**
	Urban Accessibility	Preserve Improve where 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.

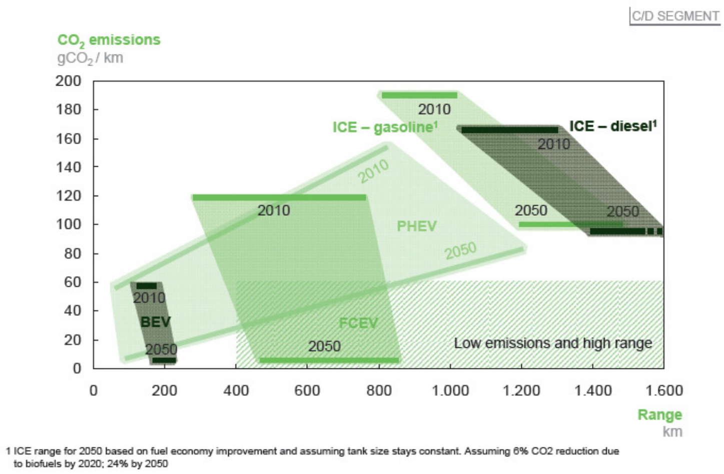


Figure 5: Driving ranges and CO_2-emissions of different passenger car propulsions (source: The role of Battery Electric Vehicles, Plug-In Hybrids and Fuel Cell Electric Vehicles; A portfolio of power-trains for Europe: a fact-based analysis, 2010)

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:

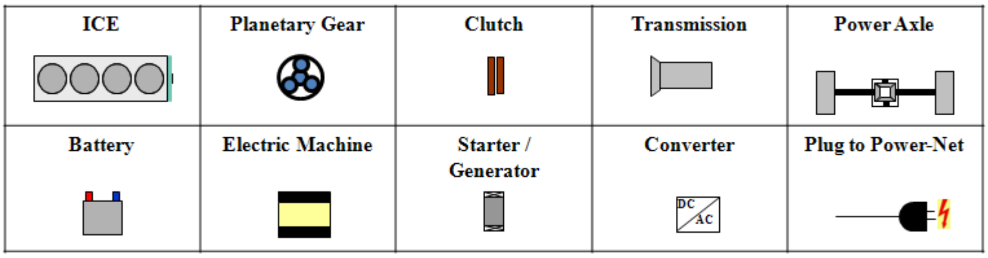


Figure 6: Symbols used in the hybrid pictures

○ 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.

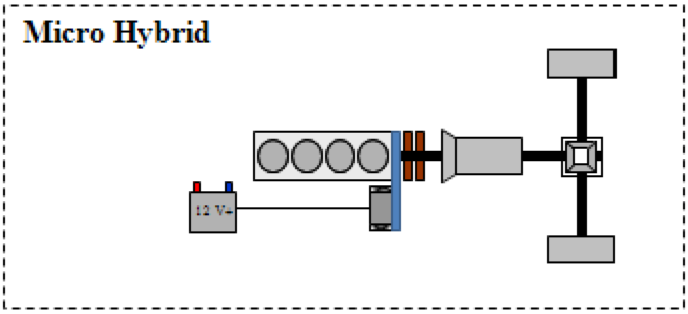
The restart can be done comfortably using a belt-driven Starter-Generator (SG) or an Integrated Starter-Generator (ISG).

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

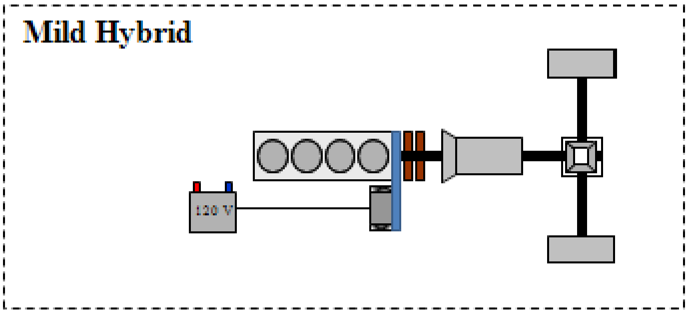
These features are believed to generate best benefit in urban driving, where start-stop rates are high and breaking events are frequent.
The given power resulting of the ICE and the Electric Machine/Motor (EM) is very application dependent.

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.

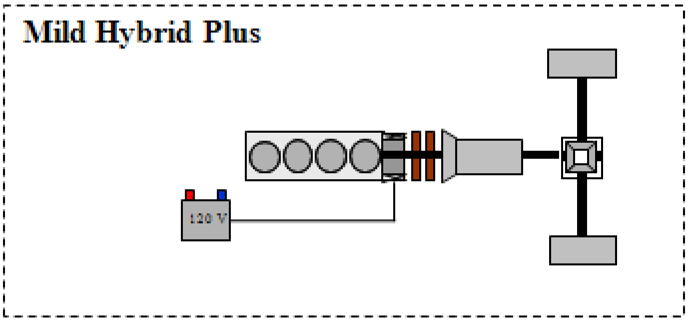
The configurations of Micro and Mild Hybrids:



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.

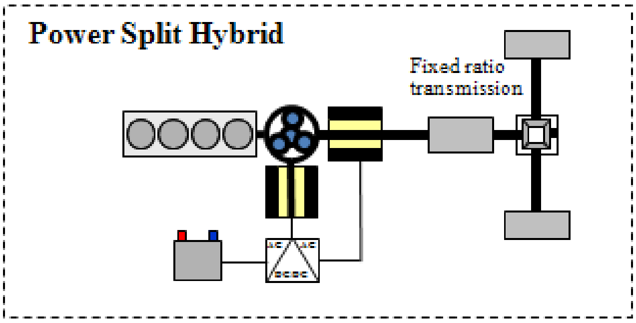
- **The Full Hybrid Electric Vehicles family**

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.

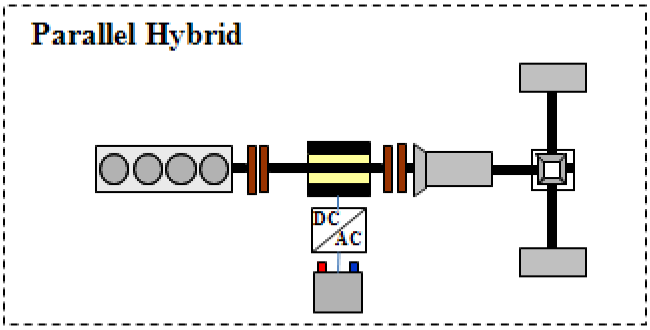
Currently the Power Split design dominates the market today followed by the Parallel Hybrid structure, whereas the Serial Hybrid has significant drawbacks due to the energy conversion losses under full power operation.

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%.

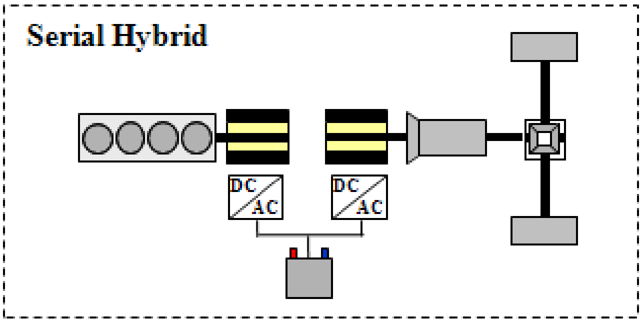


The currently most widespread alternative concept for Full Hybrids is the **Parallel Hybrid**. The Parallel Hybrid concept with an electric machine connected directly to the drive shaft of the combustion engine with one or two clutches in line before and/or after the e-motor provides benefits when being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

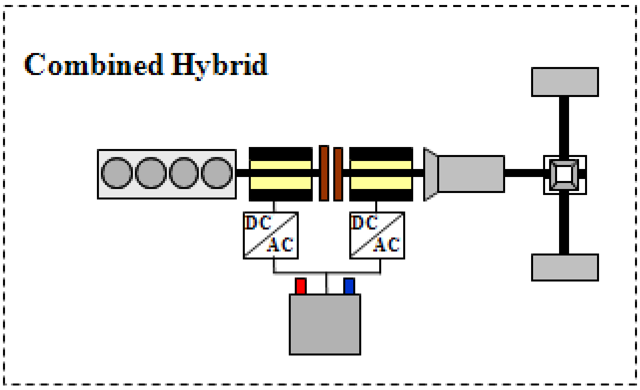


In the **Serial Hybrid** concept the Internal Combustion Engine (ICE) is mechanically disconnected from the drive train and charges the battery through a generator to overcome the limitations of the battery's energy content. This vehicle is designed to primarily operate in all-electric mode, the optimised 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.



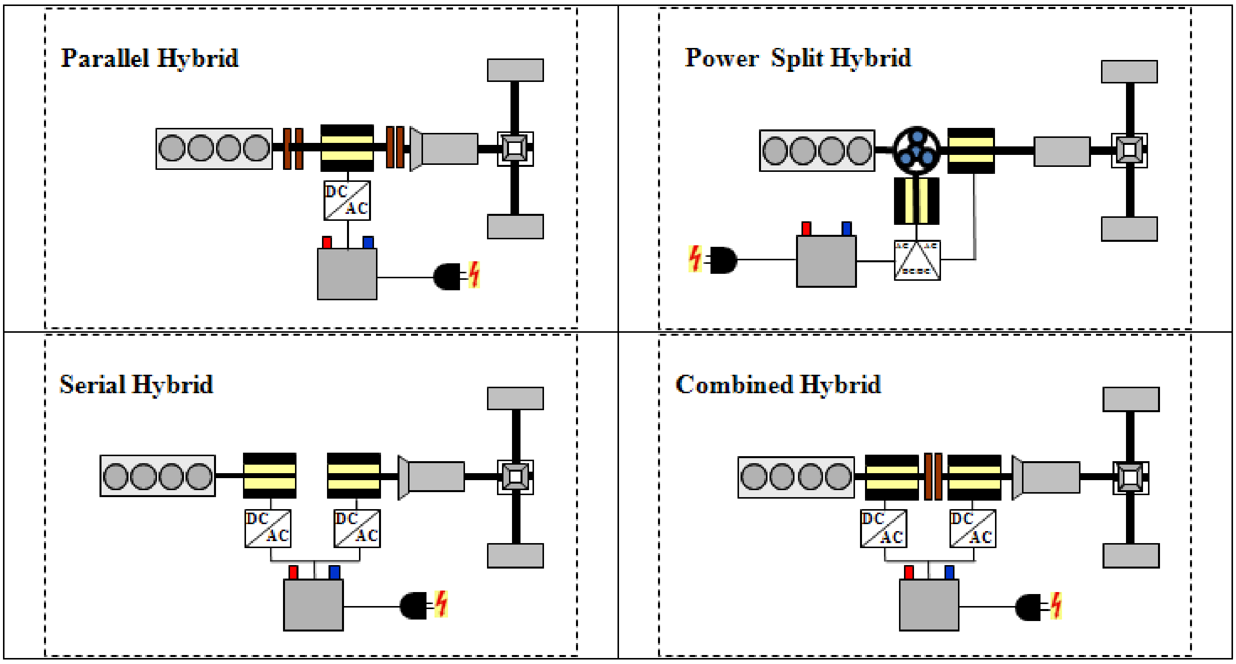
- ### The Plug-In Hybrid Electric Vehicles family

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.

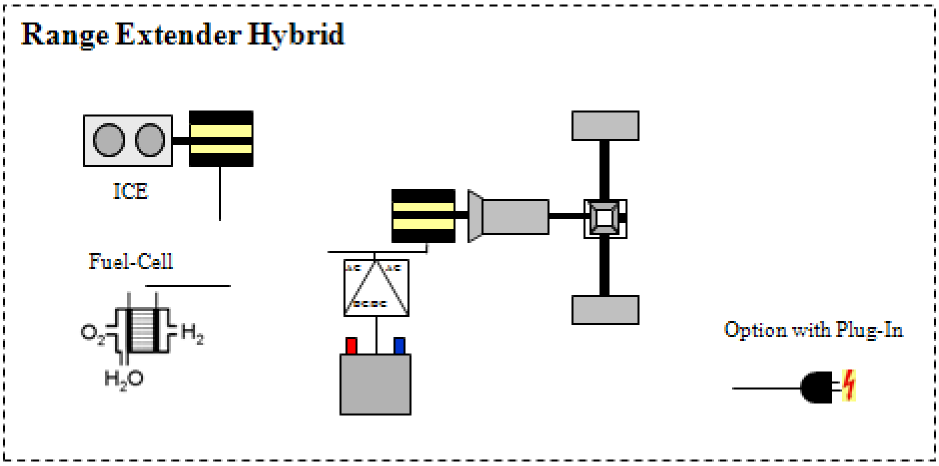
The Plug-In hybrid configurations:



○ 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:

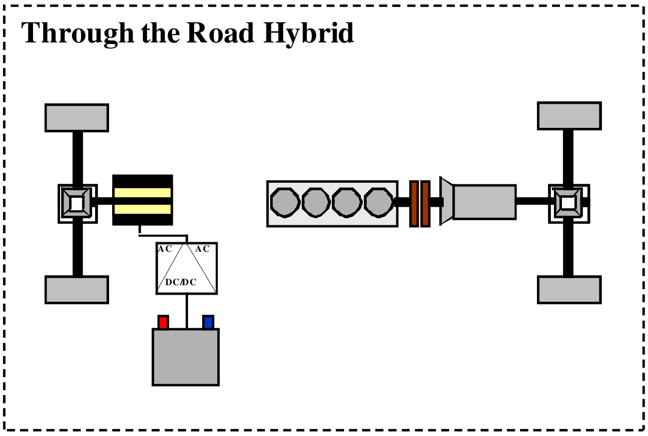
- Provide electric power when cold battery discharge power is limited, which fills the gap by enabling the vehicle to reach the same climbing and acceleration performance
- Provide electric power when hot battery discharge power is degraded.
- Provide electric power to cool the battery (with an electric 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

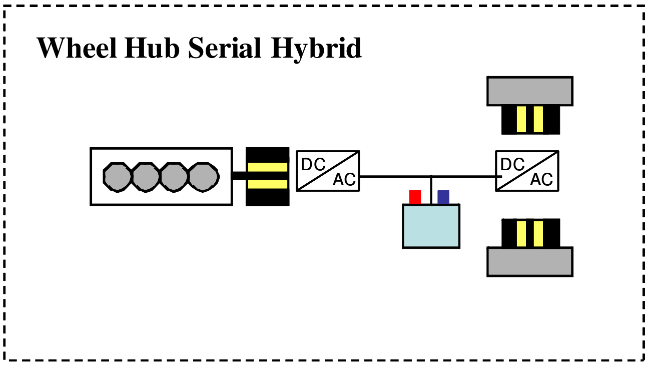
This special configuration is very convenient for present series vehicles, it could be built-up from a series vehicle with conventional ICE drive-train. An additional axis with electric motor is to built-in. Two applications are mostly built-up, as 4-wheeler or as delivery van. The 4-wheeler is the 'dynamic' 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

o 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.

o 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.

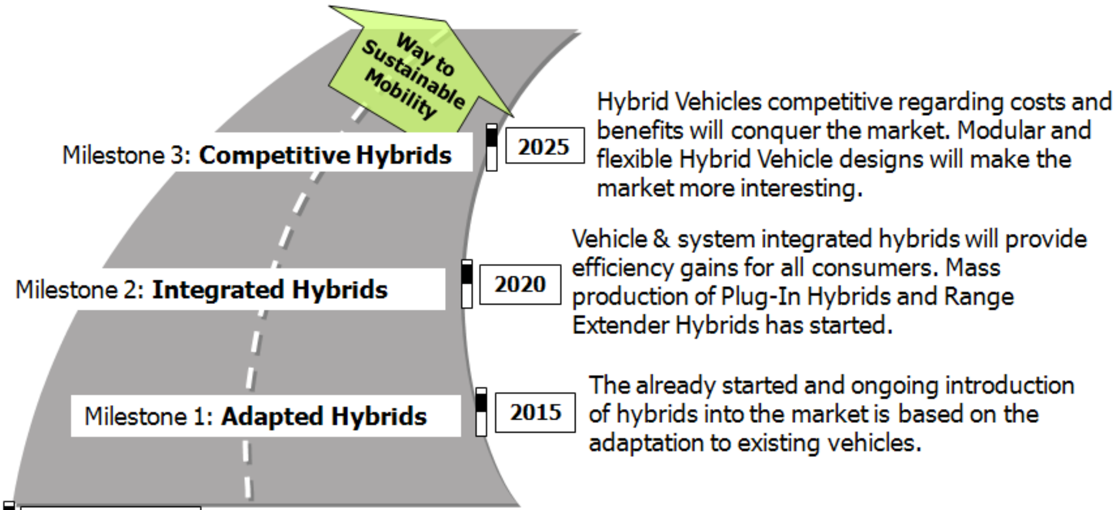
5. Milestones

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

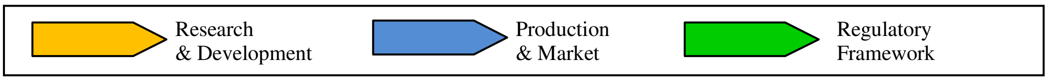
Hybrid Power-train	Further development combustion engine efficient engine with mild hybrid functions Mild hybrid concept with hybrid hotel and cargo modes / functions, focusing cost efficiency Development of enhanced durability and efficiency of ESS First generation grid plug-in charging for city distribution. 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

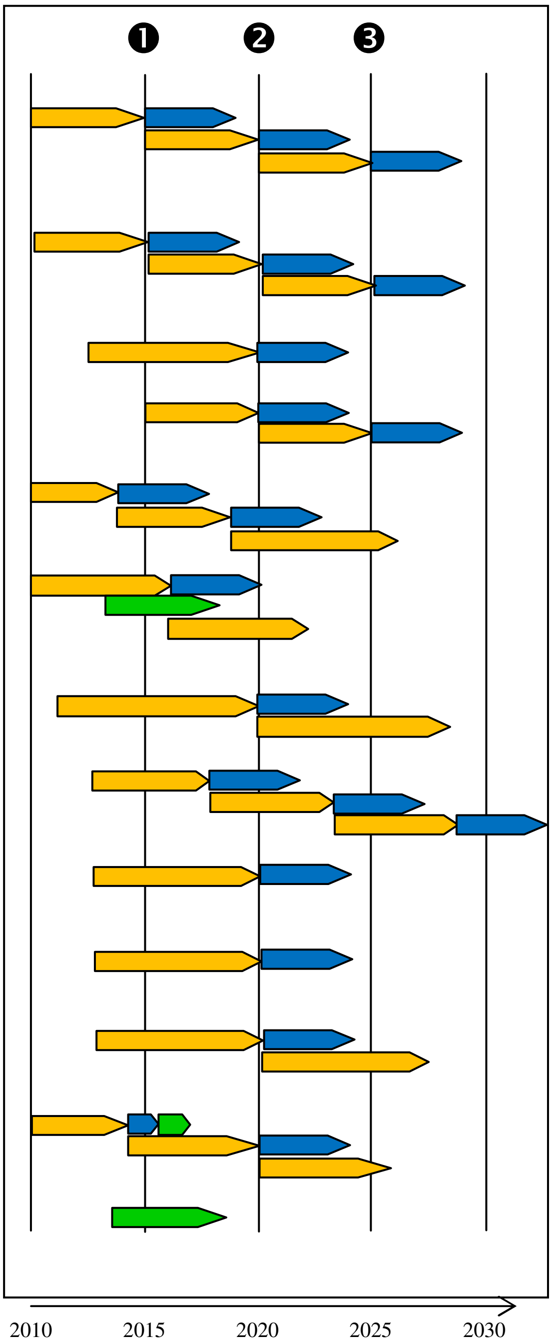
Non-electric energy storage systems

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

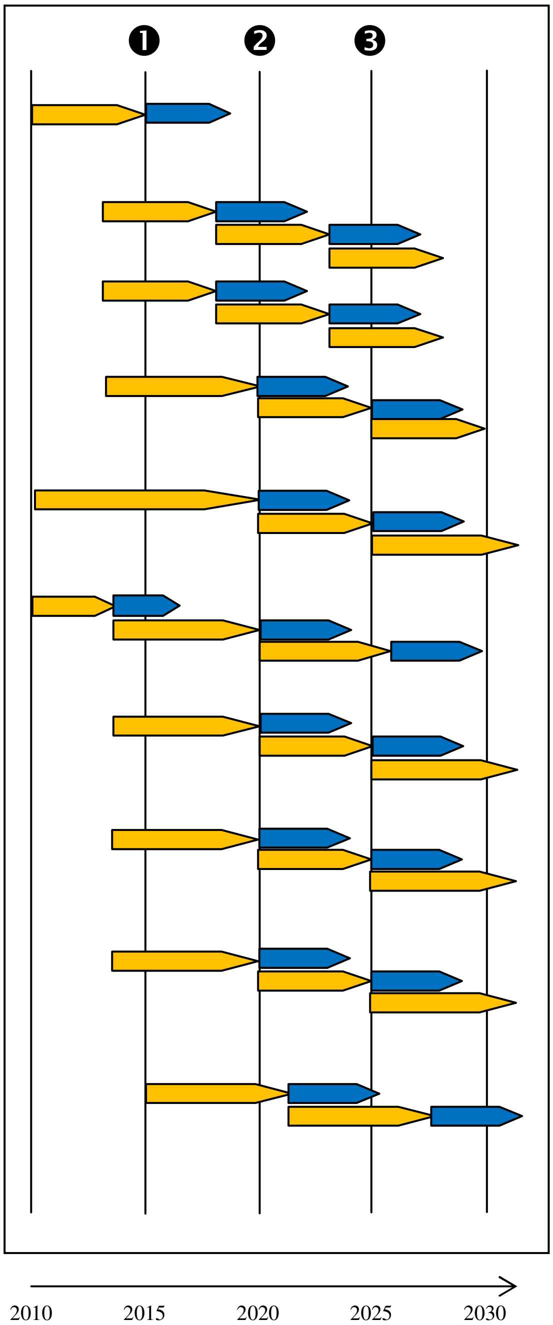
New concepts, materials for electrical machines,
low- cost & light-weight

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

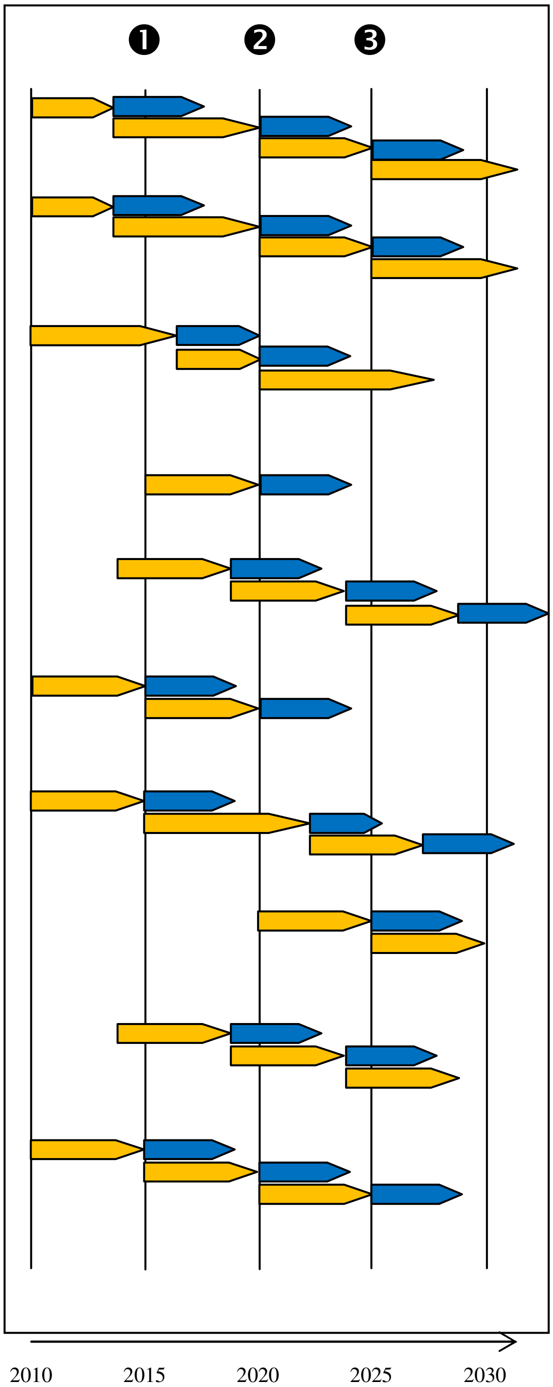
Dedicated simulation and development tools for hybrid configurations

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

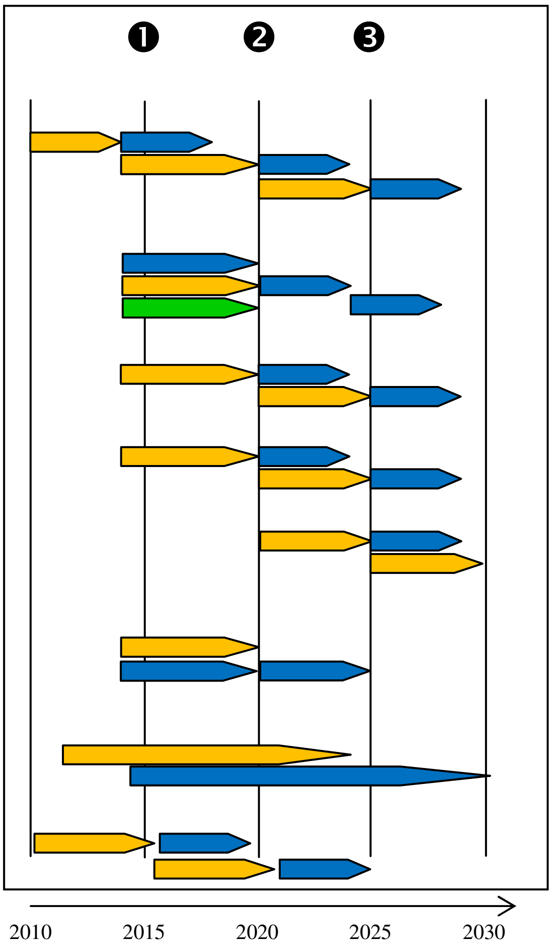
Adaptive on-board / plug-in charging devices

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

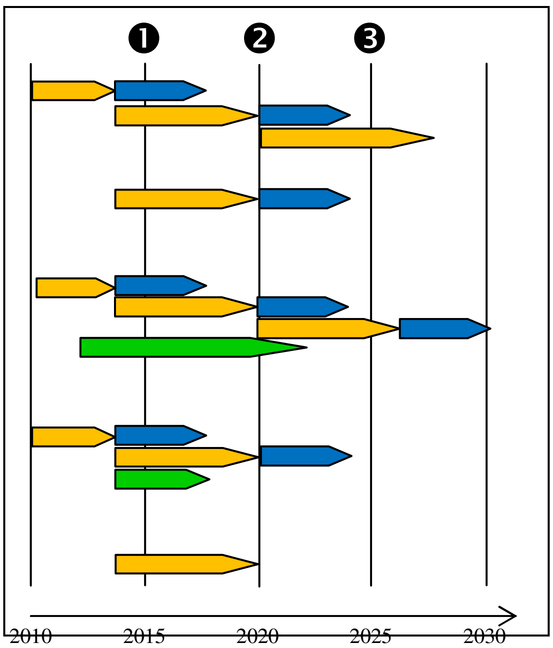
Crash compatibility and crashworthiness
of light/small and/or new vehicle concepts

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)

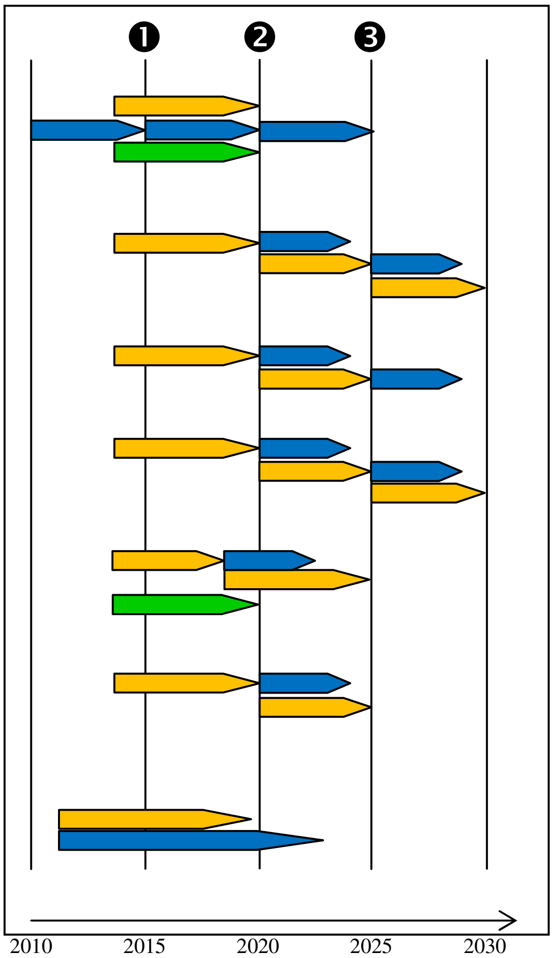
Potential of ITS for energy efficiency

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

- ***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.)

- ***Safety Aspects***

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

- ***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.

9. References

ERTRAC Strategic Research Agenda 2010; Towards a 50% more efficient road transport system by 2030, May 2010

ERTRAC, EPoSS, SmartGrids; **European Roadmap Electrification of Road Transport;** Version 3.7, 24 September 2010

Dr.-Ing. Daniel Kok, Ing. Don Kees, Dr.-Ing. Engbert Spijker, Dr.-Ing. Lutz Gaedt, Dr.-Ing. Eckhard Karden; **High-Volume Micro-Hybrid Electric Vehicles;** 14. Aachener Kolloquium Fahrzeug- und Motorentechnik 2005

Dipl.-Ing. Hans Kemper, Dr.-Ing. Thomas Hülshorst, Dr.-Ing. Christoph Bollig, Dr.-Ing. Karsten Wittig, Dipl.-Ing. Andreas Sehr, FEV Motorentechnik GmbH, Aachen; **E-Vehicles with Range Extender – Properties and Potentials;** 18. Aachener Kolloquium Fahrzeug- und Motorentechnik 2009

Dipl.-Ing. Hans Kemper, Dipl.-Ing. Oliver Rütten, FEV Motorentechnik GmbH, Aachen; **System Integration – Challenge for Hybrid Electric Vehicles**; Braunschweiger Hybrid Symposium, 14. Februar 2007

Prof. Dr.-Ing. Wolfgang Steiger; Volkswagen AG, Wolfsburg; **twinDrive – Concept for Electrification of Powertrains**; 21th International AVL Conference "Engine & Environment", September 10th, 2009, Graz, Austria

Dr.-Ing. L. Hofmann, Prof. Dr.-Ing. J. Leohold, Dr.-Ing. W. Steiger, Dr.-Ing. T. Böhm; Volkswagen AG, Wolfsburg; **twinDrive – Ein Schritt in Richtung Elektromobilität**; VDI-Tagung Innovative Fahrzeugantriebe, Dresden 06.-07. November 2008

Peter Prenninger, AVL; **Research Priorities for Hybrid Electric Vehicles and Advanced Electric Components**; EARPA Workshop – 03 November 2010, Brussels

Dipl.-Ing. Hans Kemper, Dr.-Ing. Ernst Scheid, Dipl.-Ing. Oliver Rütten, Dipl.-Ing. Peter Janssen; FEV Motorentechnik GmbH, Aachen; Director Soo-Won Lee, Dipl.-Ing. Hyun-Ok Kim, Dipl.-Ing. Jong-Nam Park, Dipl.-Ing. Dong-Woo Kang; Ssangyong Motor Company, Seoul; **New Diesel Hybrid Drivetrain, Properties & Potentials;** 14. Aachener Kolloquium Fahrzeug- und Motorentechnik 2005

Dr. Christoph Bollig, FEV Motorentechnik GmbH, Aachen; **Range Extender Concepts for City Cars**; Ulysses Workshop, May 6th, 2010

Dr. Christoph Bollig, FEV Motorentechnik GmbH, Aachen; **Perspektiven individueller (Elektro)-Mobilität;** Verbraucherzentrale Düsseldorf, 29.01.2009

EGCI Ad-hoc Industrial Advisory Group of the European Green Cars Initiative PPP; **Multi-annual roadmap and long-term strategy;** November 2010

Study of more than 30 stakeholders, McKinsey & Company the management consultancy; A portfolio of power-trains for Europe: a fact-based analysis, **The role of Battery Electric Vehicles, Plug-In Hybrids and Fuel Cell Electric Vehicles**; 2009

EUCAR Work Group Powertrain; **Research needs in light duty conventional powertrain technologies;** November 2010

ERTRAC Expert Group Enabling Technologies; **Future Transport Fuels, The Energy Pathway for Road Transport;** 14 October 2010

Prof. Dr.-Ing. W. Steiger, Volkswagen AG, Wolfsburg; **Technical, social and political framework for future mobility;** 31. Internationales Wiener Motorensymposium 2010

Nick Owen, Ricardo UK Ltd; **EARPA's Vision for Integrated Road Transport Research;** EARPA Workshop on Automotive Technology Answering Grand Societal Challenges, 3 November 2010

European Automotive Research Partners Association aisbl; **EARPA Position Paper on Urban Mobility;** 18 October 2010

Dipl.-Ing. Hans Kemper, Dr.-Ing. Thomas Hülshorst, Dipl.-Ing. Olaf Elsen, FEV Motorentechnik GmbH, Aachen, Prof. Dr. rer. Nat. Dirk Uwe Sauer, Elektrochemische Energiewandlung und Speichersystemtechnik, ISEA, RWTH Aachen; **Challenges for electric energy storage systems in hybrid vehicles;** Braunschweiger Hybrid Symposium, 21. Februar 2008

Dipl.-Ing. Gereon Hellenbroich, FEV Motorentechnik GmbH, Dipl.-Ing. Thomas Huth, Institute for Combustion Engines (VKA), RWTH Aachen University; **New planetary based hybrid automatic transmission**; 19th AachenColloquium, October 5th, 2010

P. Wolters, M. Pischinger, T. Hülshorst, J. Ogrzewalla, H. Kemper, FEV Motorentechnik GmbH; **An E-tractive City-Car Concept on the Road**; 19. Aachener Kolloquium Fahrzeug- und Motorentechnik 2010

Dr. Lars Hofmann, Dr. Wolfgang Steiger, Dr. Tobias Böhm, Jürgen Willand, Volkswagen AG, Wolfsburg; **Technology and Benefits of the Volkswagen Full Hybrid Concept**; 14. Aachener Kolloquium Fahrzeug- und Motorentechnik 2005

European Commission; COM(2010) 1161, 'Europe 2020 flagship Initiative - Innovation Union'.

European Commission; COM(2011) 48, Green Paper 'From Challenges to Opportunities: Towards a Common Strategic Framework for EU Research and Innovation Funding'.

European Commission; COM(2011) 144, White Paper 2011 'Roadmap to a Single Transport Area - Towards a competitive and resource efficient transport system'.

European Commission; COM(2010)186, 'A European strategy on clean and energy efficient vehicles'.

European Commission; COM(2010) 2020, 'Europe 2020 - A strategy for smart, sustainable and inclusive growth'.

ERTRAC

EUROPEAN
ROAD
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European Roadmap

Sustainable Freight System for Europe
Green, Safe and Efficient Corridors

Version May 26, 2011

ERTRAC Working Group on Long Distance Freight Transport

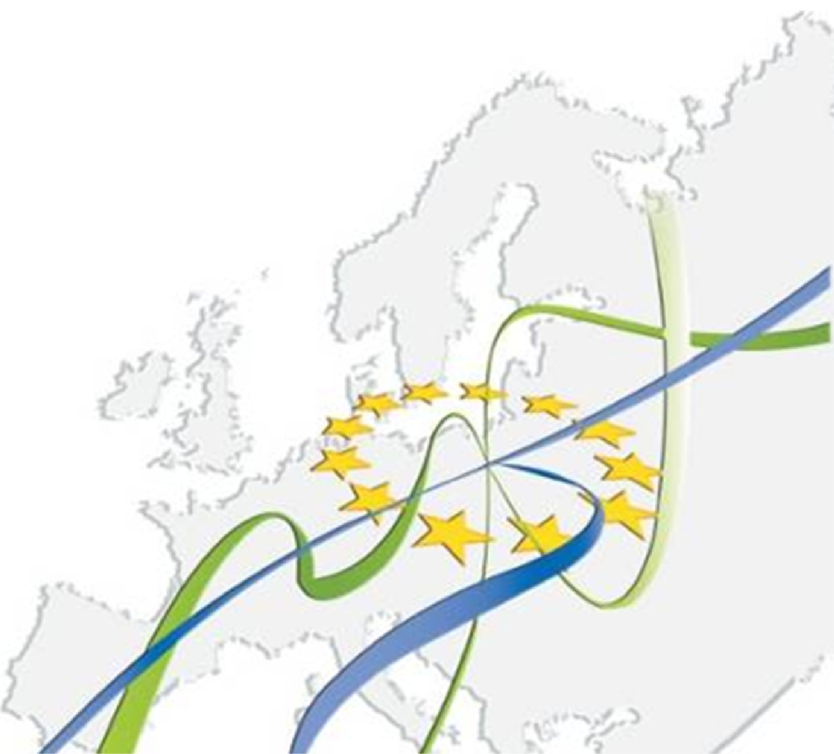


Table of Contents:

1. Introduction

The transport industry at large is responsible for generating 7% of European GDP and 5% of employment. In an increasingly global market place, the wider economic development and competitiveness of Europe also depends on an effective and efficient transport and logistics system. The mobility of people and the flow of goods to, from and within Europe must be cost effective, safe and environmentally sustainable.

Despite efforts to decouple growth in freight transport from growth in GDP during the last decade, demand for freight transport has increased annually on average by 2.7% whereas GDP increased with 2.5%. This should be compared with passenger transport that grew at a pace of 1.7% during the same period (ibid). The European transport sector is not yet on a sustainable path in several aspects. Transportation is responsible for most of the increase in oil consumption during the last three decades, a trend that is expected to increase. In the EU transport is responsible for the emission of 23.8% of green house gases and 27.9% of CO_2. The sector is 97% dependent on fossil fuels so the environmental concerns are well aligned with efforts to improve energy security and globally the transport sector is responsible for more than 50% of all liquid fuel consumption. Hence, the entire transport sector, and particularly road freight transport, has been identified as a main policy area

where further environmental and overall efficiency improvements are critical for a sustainable future in Europe.

To ensure sustainability and global acceptance in the future, the transport system requires the development of systems that reduce the dependence on oil and minimise the emission of greenhouse gases. The transport system would benefit from a substantial restructuring and reorganization. Transport emanates from the needs of private citizens, business and public organisations to get goods and people moved from one geographic location to another. To accomplish that, a number of modes with their individual infrastructures and traffic operations are available. For each mode there are different types of sub-mode with separate and common infrastructures and traffic operations. Between and within the modes there are hubs making it possible to consolidate and change mode for the transport “packages”. Furthermore, transport and traffic “packages”, carriers, vehicles, drivers, flows, infrastructures, etc are connected to a varying degree through wireless communication infrastructures. The transport operations are planned and managed with different cycle times from hours to months. The effectiveness of the transport system as a whole is gradually increasing but there is an untapped potential for further improvement, particularly in relation to its sustainability, safety, and reliability. Achieving these objectives will need new business concepts and new technologies as well as pan-European standards and regulations developed in collaboration between the public and private sectors.

One example of a new business concept, also identified in the ERTRAC Scenario document, is the ‘green corridor’ concept which could be introduced and used for highly-populated multimodal corridors in Europe by 2030 (see figure 1). This roadmap document is primarily intended to show the likely path to develop and implementing such transport corridor concepts and developing measures to improve the safe and clean usage of transport infrastructure. It will give a consistent overview including benefits and challenges:

- Interfaces and interoperability between different transport modes
- Logistics design; Goods flow optimization
- Interface and interoperability with local/urban network.
- Vehicle concepts
- Intelligent corridor access requirements
- Corridor specific services
- Infrastructural support measures

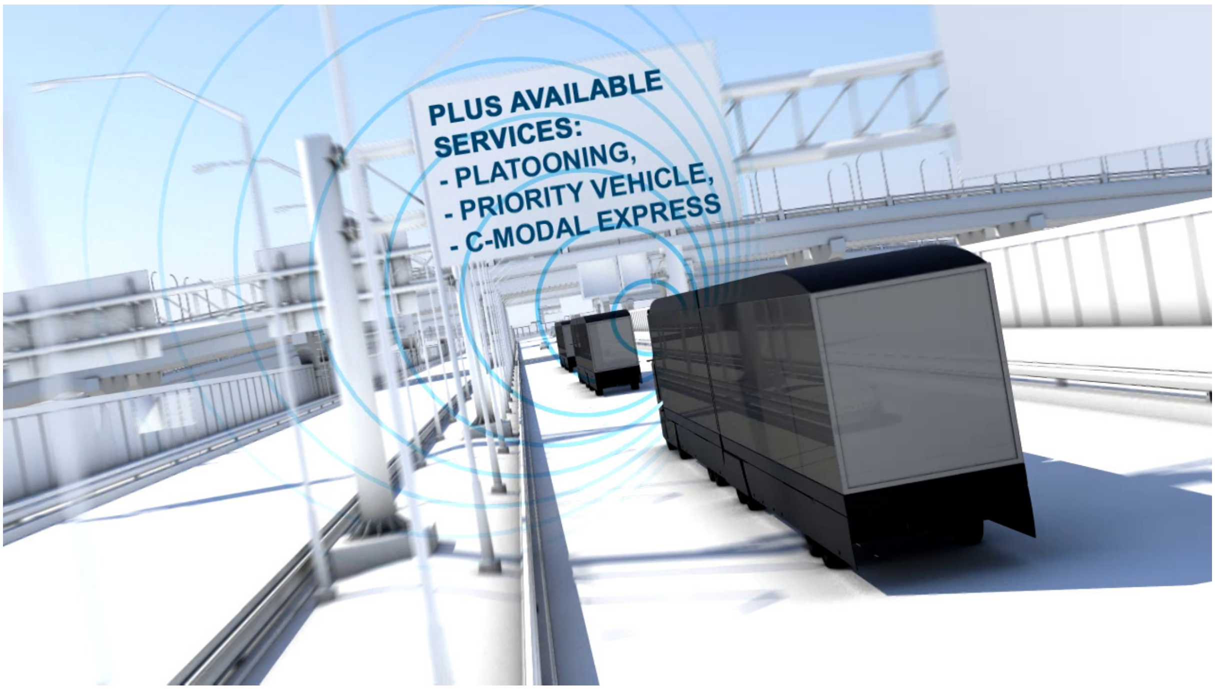


Figure 1 Possible services available in a future transport corridor.

This road map does not cover safety aspects. We refer to and adopt the ERTRAC road map "Safe Road Transport".

This road map addresses the interface and connection with between urban and long distance transport. It is therefore coordinated with the ERTRAC road map "Towards an integrated urban mobility system".

2. General Expectations and Approaches for green, safe and efficient corridors

Capacity limitations mean that all transport modes will need to work in seamless coordination in order to increase the level of efficiency. 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 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 figure 2 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'.

Figure 2. Summary of Guiding objectives of ERTRAC's "A Strategic Research Agenda aiming at a '50% more efficient Road Transport System by 2030". (ERTRAC, 2010)

A number of important research, innovation and policy challenges, that will contribute towards these targets and gain from a pan-European approach, have been identified.

This roadmap contributes to the following objectives set by the ERTRAC SRA:

1. The societal target for Long distance freight transport efficiency, as indicated by (volume and/or) weight of freight transported per kWh is an increase of 40 % by 2030 compared to 2010. By increasing the amount of sustainable energy sources CO_2 emissions can be decreased even further, sometimes demanding new carriers and converters.

2. The emissions of air pollutants and noise will be in compliance with existing policies
3. The societal need for Reliability of transport schedules, as measured by average time loss, (scheduled time vs. real travel time). The target is to increase the reliability by 50 % by 2030 compared with today, 2010.

Today many bottlenecks in the road, rail, sea, and air transportation "infrastructure" exist where it is not possible to create new links. The concept of green corridors is intended to help solve this problem by, for example, increased utilization of the available capacity through different means requiring a systems approach involving vehicle, trailer and load carrier manufacturers, infrastructures, logistics operators, etc. Furthermore significant improvements within the transport corridors are expected in the area of safety, reducing accidents and fatalities.

Another resource that should be made more effective is the concept of novel and highly advanced co- and intra-modal hubs to enhance further optimisation of the available modal mix. By co-utilisation between different freight forwarders and by speeding up transfer times, land resources can be freed. In both cases vehicles, load carriers and the equipment for transferring loads must be optimised to work in these new physical environments.

In general, consolidating loads on full vehicles enables the highest level of transport effectiveness and the fewest number of freight movements, thus minimising the contribution of freight transport to congestion. However, many companies aim to minimize the amount of stock they hold in storage, which means that frequent, flexible, and rapid deliveries are required. This can sometimes make it difficult to consolidate freight in large vehicles. This situation can be improved significantly by implementing intelligent logistics solutions including the optimisation of e-freight initiatives and the concept of bundling freight flows controlled by goods operators, which necessitates common platforms for information and business exchange. Research, innovation and policy development are needed to adequately resolve the difficulties that can arise, in addition to focusing attention on business models, service platforms & databases, ICT & protocols, modularised goods carriers & vehicles, etc.

Following this approach has important implications for both vehicle and infrastructure. While respecting the limitations on vehicle size imposed by the road infrastructure, it should be possible to tailor vehicles and load carriers for a better match with the goods transport assignment. Correspondingly focused research is required on the layout and design of vehicles which are optimised for a more specific mission profile and better overall efficiency. In the longer term it should be possible to convert large trucks into smaller vehicles, and vice versa.

The current interest regarding electricity as the energy carrier especially for cars operating in urban areas will be explored also with respect to commercial vehicles. Electrification will open up for a transfer to sustainable energy sources such as wind, hydro, solar and biomass and improved supply security. Key is solving the current limitations in energy storage capacity and energy transfer speed which will require considerable investments in the whole energy supply infrastructure. It is important to emphasize, however, that CO_2 neutral liquid fuels and combustion engines are the basic energy conversion concept for the foreseeable future.

3. Challenges and Prospects for green, safe and efficient corridors

In the 2006 mid-term review of the White Paper 2001 of the European Commission, goods transport (tonne kms) in Europe is projected to increase by 50% between 2000 and 2020. The TERM report (EEA, 2010) suggests that road transport accounts for about 75% of goods transport on land today, and continues to develop rapidly, not least because of its transport and quality characteristics. Regardless of the future scenarios chosen to meet this challenge it is evident that goods transport on European roads will have to absorb the lion's share of the increasing transport demand, as indicated in Figure 3.

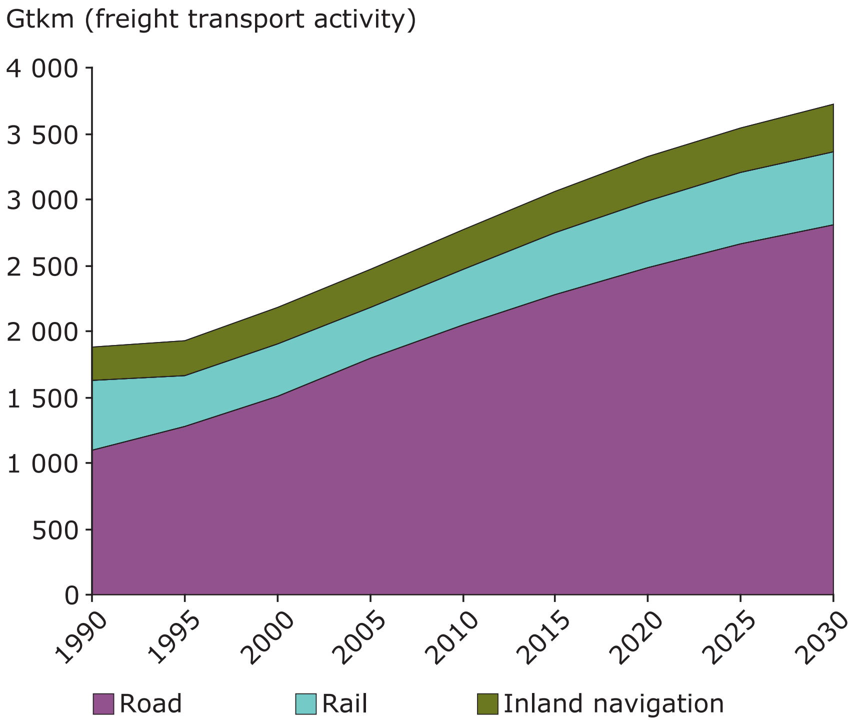


Figure 3. Freight demand projection for the EU 25. Source: The TERM report (EEA, 2009)

Road transport will remain the most important mode. Modal shift from road to rail, short sea shipping and inland waterways are of course put forward as more efficient alternatives to road freight but the potential is intensely debated. What is clear is that these other modes represent only a relatively small proportion of total freight so to produce energy efficiency improvements comparable to the potential of those within the road freight transport system would require very large growth in modal share. A variety of factors such as the infrastructure capacity and quality, investment, competitiveness and the balance between passenger and freight traffic will affect the ability of alternative modes to grow. A study in the UK (McKinnon & Piecyk, 2010) based on a Delphi survey of 100 logistics specialists has suggested that mode shift could potentially decrease roads share of the freight market by 14% (from 64% of tonne-kms to 50%) by 2050. Studies in Sweden have indicated the potential to move freight from road to rail and sea is around 10% (SIKA, 2008). While

these changes are significant and important, the forecast growth in freight transport demand suggests that, Europe will probably still be heavily reliant on long distance trucks to maintain a competitive transport system.

A key factor for the transport sector is its adaptability to dynamic changes in the transport patterns. Complexity and flexibility of logistics will need to increase considerably because of the emergence of new trading partners, increasing integration of the order and production process with transport and delivery, and changing transport corridors, e.g. road and rail transport between Asia and Europe.

One major challenge in road transport is congestion. One measure intended to help meet this challenge is, for example, the concept of green corridors which could, in principle, be applied in both inter-urban and urban environments. This concept will give a strong incentive to the development of more effective vehicles, standardised load carriers and supporting ITS/ICT systems.

The potential for increasing the efficiency and safety of transport corridors is structured into five main areas in which timely R&D, demonstrations, production, market introduction and regulatory framework development are illustrated in a roadmap format.

3.1 Vehicle Technology

It is considered vital for the road transport sector to develop new smart concepts such as modular load-carriers and innovative complete vehicle solutions (including the trailer) contributing to adaptable, tailored, efficient and seamless transport.

Overall transport efficiency will also benefit from optimising the aerodynamic design, reducing rolling resistance and internal friction, and introducing lighter truck and trailer concepts and efficiently designed and controlled auxiliaries.

To increase the efficiency of the vehicles operating within the corridors, then it will be important to consider, for example, optimised vehicle specifications that better tailor truck and trailer components, weight and length of vehicle combinations, increased level of modularity and innovation in the trailer market (e.g. the uptake of light weight high volume low bed trailers) and also more efficient operation of the truck by the driver.

3.1.1 Vehicle technically specified for running in corridors

For efficient transport operation within Green Corridors the vehicle parameters need to be optimized. The vehicle should be adapted to its operation and to the freight it is carrying.

3.1.2 Vehicle dimensions for optimized load capacity within corridors

As freight transport operators are likely to require even more flexibility in the future, accessibility to a set of tailored vehicles or to vehicles able to adapt to different operations is crucial. Today, single vehicles are often used for many different tasks, often inefficiently. Trucks built to carry 40 tonnes will often only carry 20 tonnes because they are carrying low density goods and are full on volume not mass. In these cases a large quantity of “dead” weight is transported, therefore the vehicle load carrying ability would need to be “upsized” to the absolutely maximum volume but “downsized” both from a structural mass and powertrain point of view. Research as well as internationally agreed

and harmonized standards are needed to determine present load factors/fill rates, to make data collection cost efficient and unambiguous and to agree on realistic targets.

An optimized match of vehicles to the tasks will contribute to improving the efficiency of transport. For the operator to be able to adapt to changing operational conditions it is important to look at aspects such as access to the vehicle that best matches the needs and/or vehicle adaptation strategies to freight/cargo composition (weight, volume, shape, sensibility etc) and to its operational environment in the corridor.

An increased level of modularisation of load carriers (e.g. pallets, ISO containers etc) is crucial for freight inter-modality and efficiency. The experiences from the aviation industry handling ULD´s should be taken into consideration. Common standards need to be agreed and implemented for the design, dimensions of freight modules (load carriers) in order to optimize the intermodal vehicle. Automated operation and coupling/decoupling of the freight modules as well as built in intelligence e.g. cargo on board monitoring, tracking and distribution are interesting areas for research. Inter-modal shipping involves the movement of freight by multiple modes, preferably in a single freight module (container). The freight modules have to be flexible enough to fit all modes and handling, loading and unloading needs to be efficient and flexible. In other words; a level of increased operational flexibility is needed to be able to implement an efficient inter-modal transport system.

The use of (internationally agreed) modular concepts for pallets, swap-bodies, containers, etc will result in increased efficiency of transport in general and road transport in particular. Standardised load modules give high flexibility and an opportunity to standardize vehicles which are adaptable to different situations, and to use optimised combinations.

The use of modular concepts throughout Europe could have a positive effect on transport efficiency and on the environment, and could also support intermodality. Initiatives to agree on standards and facilitate the implementation of modular concepts in which industry, authorities and policy-makers collaborate are vital. In order to support the setting of this regulatory framework, extensive impact assessments will have to be performed, taking into consideration the whole transportation system, and analyzing the impacts on the environment, on safety, and on mobility aspects (e.g. congestion, user's acceptance, etc.).

According to McKinnon & Piecyk (2010), we can expect several developments over the next forty years promoting consolidation of freight loads into larger and heavier consignments to make better use of the vehicle capacity.

To meet these expectations vehicle design needs to be optimized. Research areas important are:

- mapping and predicting the quantities of different types of load that are carried by trucks on the road
- impact and consequences of road vehicle mass and dimensions on transport efficiency
- modal split
- infrastructure capacity
- strategies to optimize pay load
- chassis control (braking, handling, traction)
- modular vehicle architecture

Other areas important to look into are:

- automatic load factor and weight control
- modularity for load units
- modularity for loading

The weight and length of the vehicles needs to be optimized and flexible as well as technically adapted to performance based standards within the corridor.

3.1.3 Vehicles and infrastructure matching each others

The concept of intelligent vehicles and transport services needs to be supported by matching intelligence in the road infrastructure. Increasingly the level of road based automation will be able to support freight transport through cooperative systems. Whereas to a large extent such systems serve all road users, on selected corridors the systems are expanded or adapted serve efficiency in freight transport. These corridors need to be selected and roll-out strategies should take in consideration that a full scale deployment of the green corridors concept involves many border crossing and will involve cooperation and collaboration of a multitude of road authorities.

3.2 Driver environment

3.2.1 Driving efficiency

The behaviour of the driver has a substantial effect on the vehicle fuel consumption, and thereby its emissions. By combining cooperative systems using vehicle-infrastructure communication, there are potential fuel savings and reliability improvements to be made.

Drivers' driving behaviour is a key-issue for eco-driving/fuel efficient driving. Today, eco-driving can result in 10-12% fuel savings with the use of Driver Coaching Systems (DCS). DCS are technologies that help drivers and fleet managers to improve fuel efficiency. The DCS on market today are based on technologies that record information generated by the vehicles and display information directly to the driver to encourage better driving and/or deliver post-trip reports to drivers and fleet managers.

As described in the "Safe Road Transport" roadmap, DCS are also strongly applicable in the road safety domain and, in the near future, fuel-efficiency- and safety-related DC will merge into common applications. The key challenge for future development of driver coaching concerns the implementation and deployment strategies where a critical issue will be effective incentive schemes to motivate long-term behavioural change. For commercial fleets, it may be foreseen that driver coaching will to an increasing degree form part of general safety/efficiency management strategies, and be combined with other measures, such as driver education and training. Technologically, driver coaching system will merge with other driver support systems including cooperative system technologies. For private driving, new business models for DC will emerge involving incentives, possibly linked to tax reduction and dynamic pricing (e.g. pay-as-you-drive). Finally, as driving becomes increasingly automated, future DCS may focus more on strategic aspects of driving performance (rather than vehicle control).

Related, important, research areas are:

- advanced HMI supporting the driver
- HMI-based information on cargo
- smart loading based on intelligent goods
- automated customs processes
- automated handling of cargo

3.2.2 Drivers safety and comfort

In the corridor it is important to secure a high level of security and efficiency services for the driver, vehicle, and cargo supporting reliability of transport times. Important research areas are:

- safe and secure bookable parking spaces
- smart driver cabin
- driver villages offering high level of services for the driver and his/her vehicle
- driver monitoring system
- driver villages connecting all transport modes
- cargo and driver security systems
- augmented vision. The driver operates in an increasingly complex setting that challenges the human capabilities. Augmented vision can help the truck driver in enhancing the key features in the traffic situation. This will provide good support to the driver, in particular when driving in the night or under extreme conditions that impair a clear view on the traffic situation (rain, snow, fog).

3.3 Logistics and intermodality

The Green Corridor concept has strong links with the business sector, in particular with logistics services. They are driven by an optimised use of all transport modes and network planning based on existing and forecast traffic flows.

3.3.1 Corridors logistic performance

The provision and generation of information from transport activities that can be used to better plan and coordinate other transport activities requires substantial new solutions in information management, data processing, real time planning, data capture technology, and monitoring and evaluation, both by business and by public authorities. More effective provision of information will not only, for instance, match loads to capacity more efficiently, but information availability will also enable government agencies (customs, police, …) to improve their performance in supervising business activities, increase their hit-rates, and remove administrative bottlenecks.

Another important development is to standardise the measurement frameworks on transport performance, environmental footprint and negative transport effects, and, more importantly, develop ways to feed these measurement frameworks with actual, real time data feeds obtained from ongoing transport and logistics operations. The facilities used to support Green Corridors can be made increasingly complex (e.g. enhanced ITS support) once the logistical and market conditions are

identified, under which these corridors can operate in a sustainable way. Understanding this part of the performance of Green Corridors is an essential objective of the private and public business case.

Important research areas are:

- overall performance requirements
- vision on the dimensions and capabilities of Green Hubs and Corridors
- logistic and sustainability key performance indicators
- identification of Green Corridors and Hubs based on sound logistics concepts
- logistics footprint and energy consumption measurement and reduction, quick-wins
- seamless Integration of corridors and hubs into networks
- connection between long distance and urban freight transport

3.3.2 Co-modality and intermodal seamless interoperability

An important development is a regulatory framework in which partners in the supply chain are allowed to exchange and share information between and amongst existing shared information or supply chain management networks, without facing immediate claims of violating anti-trust regulation, or other impediments.

An important challenge is to identify and select candidates for the “green” hubs and corridors and to integrate them into a European network of green corridors. A first step is to develop an intermodal corridor pilot. To succeed a common framework of national initiatives with similar standards is needed.

Other areas of importance are:

- real time optimization of co-modal routes (traffic information, cargo monitoring)
- efficient (cost, energy, footprint) transhipment between modes, quick-wins
- interoperability between modes & networks increasing intermodal capability and energy efficiency
- extended intermodality and network integration

3.3.3 Logistics and supply chain business models

Collaborative planning can allow for a reduction of empty running and improve load capacity utilization on all modes of transport. Therefore, the development of green corridors should also involve the evolution and assessment of new business models based on collaborative arrangements across partners in supply chains and due to the experimentation of innovative approaches in the regulatory framework of transport.

Areas to look into:

- logistic companies prepared for green corridors business models
- business models for logistic collaboration including information sharing
- load factor improvement
- benefits of off-peak and night time driving
- performance based organizations operating in the supply chain

- real time optimization models to select mode and plan loads
- green logistics business models integrating energy consumption and footprint in decision making
- business plans supporting convergence of technologies and regulations
- performance based services

3.3.4 Intelligent logistics system, optimising e-freight

Existing infrastructure and vehicles can be used more efficiently by developing sophisticated logistic chains and networks, which use advanced information and communication technologies. This management requires data that needs to be generated to a much larger extent than is currently the case. Efficient supply chain management or intelligent logistic systems therefore have a twofold bonus: security and carbon footprint reduction.

Integrating e-freight initiatives at the European level are required to reap the full benefits and achieve real progress on the targets specified above. This requires not only a push on IT investments and choices for the right architectures, standards and approaches, but also the explicit recognition of the similarities and differences in the governance and government supervision of logistics activities across Europe.

The creation of improved supply chain operations will have great repercussions for the demand for service quality and volume of transport systems. With the advent of RFID and similar identification technology in the supply chain the development of Intelligent Cargo systems at the European level is within reach. In addition, possibilities for horizontal collaboration between shippers and increasing responsiveness needs will drive shippers increasingly to develop hybrid distribution channels. A major advantage of these channels is that they allow further bundling of freight between firms. However, this efficiency gain will only materialize if shipper and carrier information systems are sufficiently interconnected and interoperable. This extends the e-freight roadmap towards synchronization between transportation, inventory and production schedules between firms.

Areas for research are:

- implementation of current ITS and e-freight solutions targeting interoperability & intermodality through corridor based multimodal transport management systems
- internet based common management platform
- e-freight pilots
- synchromodality: ITS solutions for the integration of transport and supply chains including electronic booking, dynamic mode allocation and capacity management.
- Information community development and system adoption (logistics operators and service providers)
- cargo units interacting with the system and self optimizing
- enhanced security of goods. Reduction of stolen and damaged goods
- paper less and electronic flow of information
- full internet e-freight transport

3.4 Infrastructure

The Infrastructure component of the Green Corridor concept involves all aspects of road operations involved with green, safe and efficient freight transport. The enabling research and innovation includes the materials, components and physical integration to the road structures as well as the operational strategies for traffic and maintenance management and, on the highest system level, the policy and governance principles that set service levels to the road user (e.g. asset management and liveability issues).

To enable the green, safe and efficient corridors, the supporting road network needs to be highly adaptable, automated and climate resilient in order to accommodate for changing demands and conditions, to enhance the implementation of ITS and intelligent road operations, and to ensure adequate service levels under extreme weather conditions. As the latter research and innovation challenge is covered in a separate roadmap, this green corridors roadmap will focus on the research and innovation that enhance the adaptability and automation of road operations.

The enabling research and innovation solutions need to be proven in the practice of road operations. Moreover, as the green corridors concept is highly integrated and complex the RAMS (Reliability, Availability, Maintainability and Safety) of the solutions need to be proven in practice through full-scale systems field operational tests i.e. on full-scale corridors, and by established RAMS analysis.

Finally, it should be noted that many of the technical solutions already exist and are proven on a 'single technology' level, in specific situations and context. This is the case for the basic materials and components as well as for many ITS solutions. The challenge for the next 15 years will be the testing of the existing solutions in other contexts and situations in the short term (by 2015), followed by proving the integration of the tested solutions in larger scale systems such as city rings on the medium term (by 2020) and ultimately the full-scale corridors (by 2025) (see illustration in figure 4).

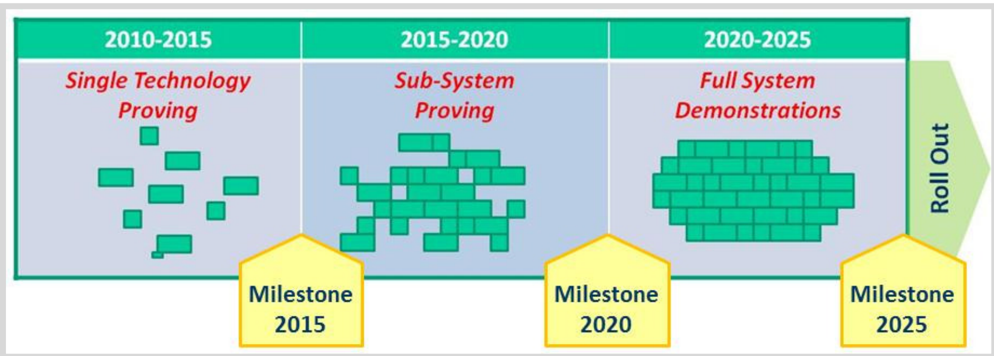


Figure 4. Corridor implementation roll out.

3.4.1 User friendly Design & Construction

For the road user/truck driver the traffic situation becomes more complex. Conditions become more critical to error or failure. Therefore research is needed into improving user friendliness of the road infrastructure to better fit the requirements, expectations and behaviour of the user.

Here the research and innovation topics are concerned with self-explaining and forgiving design of road structures and management systems as well as to provide secure and highly furbished service stations ('driver villages') at well located spots in the network. Self-explaining and forgiving design will improve the ease of instantaneous appreciation of the driver, and the tolerance for erroneous behaviour. Measures involve better lay-out of the road plan, signage and information systems as well as innovative applications of the vehicle-infrastructure communications ranging from basic driver support to augmented vision. The focus is on improving safety hot-spots and other complex, highly integrated locations on the road network.
The service stations should be integrated with the corridor over the entire stretch as to allow ITS facilities such as advanced booking of parking lots in compliance with driving time regulations.

3.4.2 Durable and integrated Pavements, Bridges, Tunnels & Structures

The durability of the road structures (pavements, bridges, tunnels) should be designed to service high volumes of freight traffic. Freight traffic imposes a heavy burden on the road structures and without the proper innovations in durability of the materials and components this will lead to increasing levels of maintenance interventions (e.g. resurfacing), reducing the network availability. Therefore, research and innovation should aim at better technical and functional durability of the surface components in road structures (e.g. long lasting overlays, expansion joints), including self-healing properties. Particular focus is on improving the life span of the pavement surfaces on bridges and the expansion joints. Climate change will also place a heavy burden on the highway, including extremes of heat, precipitation and associated impacts on the sub-soil. Whilst, research topics are covered in a separate roadmap, the research requirements should not be considered in isolation.

3.4.3 Advanced Utility, Sensory and Communication Systems

Advanced road based utility, sensory and communication systems are indispensable for the desired high service levels on the green freight corridors. Such road based systems serve three distinct objectives:

- Automation of the road availability and maintenance e.g. to safe guard against strongly non-linear road surface deterioration phenomena under the intensive freight transport loads
- Enhancing full grade ITS in road transport, integrating the user, vehicle, service provider and operator. For full co-modality this should be connected to the traffic control of the other modes
- Enhancing the penetration of new propulsion concepts in the road transport system, including the supporting alternative energy and fuel supply system

3.4.4 Intelligent Traffic Management strategies

One objective of intelligent infra management is to optimise the utilisation of the available road network within the service levels set by policy and governing principles (reliability, availability, maintainability, safety). Although on a transport system level, this is set in the context of co-modality, here the focus is on road operations. Another important area would be an operation and traffic control-management by e.g. ITS and that provides all actors within the freight transport with a variety of advanced options for efficient and flexible seamless freight shipments.

The user, i.e. the driver and the vehicle, will be supported through these cooperative systems (milestone 2020), as such systems already are under tests, in view of automated driving on the longer term.
The infra management systems are robust in the sense that they allow for maintenance interventions, incidents and disasters as well as for extreme weather conditions. The latter will be addressed in a separate road map. From the viewpoint of European corridor management, the solutions ultimately will allow for high degrees of trans-national remote operation of the road network.
The systems should support advanced information, operation and management concepts to support the user on the road, requiring high levels of accuracy, dependability and operation in real time. Research should also target dynamic real time lane management concepts with the focus of on-line servicing freight transport on the best available infrastructure in a manner that is compatible with the other road users (passenger transport). On specific sections of the corridor, this would include the creation of dedicated lanes for freight transport through targeted reconstruction projects. As an alternative, dedicated lanes for LGV and passenger traffic can be considered, freeing up available capacity for HGV.
Finally the relations between advanced concepts for demand management such as dynamic pricing on the one hand, and capacity allocation measures such as dynamic slot management on the other, need to be better understood. The opportunities for improved asset management and specifically PPS in infrastructure development should be looked into as they can accelerate the implementation of infrastructure needed for Green Corridors.

3.4.5 Freight Corridor Governance

The green freight corridors will be key assets to Europe. Their management must be fitted with an adequate toolbox of data, models & methods to allow adequate risk based evaluations and decisions on the desired performance/service levels by the different road administrations involved in the selected pilot corridors. Governance decisions and the resulting service level agreements should be developed across connected service areas and supported by common toolbox for operational network management and asset management. This tool box can only succeed when based on a harmonized set of compatible data, models and methods. The challenge is to agree on the common architecture and parameters, and to harmonize the different national and regional datasets that concern the pilot corridors. The result will be a Road Asset Observatory/Building Information Model (BIM) in which the pilot corridors are represented in terms of the constituting objects that are described by consistent parameters and relations to the other objects in the corridor.
Furthermore the research and innovation should produce reliable forecasting methods for the highly non-linear phenomena in road operations (e.g. degeneration of pavements, dynamic traffic processes). This would in turn improve (risk-driven) decision supporting models.

Figure 5. Possible design of a sustainable corridor

3.5 ICT in corridors

ICT is one of the key enablers for creating a safe, sustainable and efficient transport system. To create economical sustainable solutions some of the main challenges for ICT is interoperability and harmonisation as well as roll out of those systems compared to the stand alone solutions.

Stakeholders are basically divided into vehicle, driver, logistics/ co-modality and infrastructure. ICT solutions are a transversal input, affecting these areas. The research and innovation activities in all areas should start with collating existing ITS solutions to assess the needs for further research and requirements for integration of individual technologies in to sub-systems and full-scale systems.

3.5.1 Communication infrastructure (X2X)

Areas of importance:

- Interoperable, harmonized V2V, V2I communication creating awareness about vehicle surrounding enabling e.g. traffic safety, automation and eco-mobility services
- Adoption of EU-wide regulations for management of data exchange and storage.
- Increased position, integrity and authentication (GNSS) solutions
- Open Service Platforms for robust, secure, safe and efficient service management
- Connectivity, vehicles "fully connected" with other vehicles, infrastructure, road operator and their logistic provider
- Demonstration and deployment projects in selected corridors

3.5.2 Sustainable transportation (X2X)

Areas of importance:

- Accurate Real-Time traffic data: Creating accessible, harmonised, accurate in real-time traffic data for all users enabling e.g. optimisation of real-time route planning and control and efficient travel time estimation

- Solutions to detect and communicate incidents and accidents
- Sustainable Traffic management solutions
- Harmonized Access Control solutions to prevent access to corridor for non-compliant vehicles
- Demonstration and deployment projects in selected corridors
- Methods and services for transport utilization optimization
- Solutions enabling pay for performance and polluter pays services

3.5.3 Automated driving (X2X)

Areas of importance:

- ICT for speed and distance control (V2V)
- Europe wide standardisation regarding vehicles dimensions, communication systems for automated driving
- Interaction vehicle + infrastructure towards automated driving
- ICT considering infrastructure limitations for automated driving such as bridges (weight limits), tunnels
- Demonstration projects in selected corridors
- Automated driving demonstrations in all existing corridors. By 2030 automated driving "business as usual" in all corridors
- Review and harmonisation of policies and regulations
- Sustainable business models and methods for platooning

4. Milestones

- Milestone 1: Supportive corridor, 2015
- Milestone 2: Interactive corridor, 2020
- Milestone 3: Mass market corridor, 2025

	Milestone 1: 2015 **Market 2018-2020**	**Milestone 2: 2020** **Market 2023-2025**	**Milestone 3: 2025** **Market 2028-2030**
Corridor concept	**Supportive corridor**	**Interactive corridor**	**Mass market corridor**
Main elements	Some selected corridors with dedicated lane and dynamic lane management	Selected international cross border corridors Interactive corridors (v2v and v2i	Automated driving Extended intermodality Seamless integration

	National initiatives with similar standards, open for further standardisation International Cross border initiatives (Additional value as testbeds) One road corridor intermodal with one rail corridor Harmonised enabling legislation in place Vehicles dedicated for corridors Flexible fuel platform support Safe and secure bookable parking spaces Interoperability management platform (future internet PPP) Implemented (already known and available) ITS+logistics solutions, some targeting interoperability & intermodality Proposed business models for logistic collaboration	communication) User oriented Multimodal traffic and travel information services Common road operation and management systems and processes (remote operation, Incident and Calamities Management) Performance (standard) based services Technological initiatives on standardised electrified infrastructure concepts validated (i.e. proof of concept but not extensive rollout) Vehicles optimised for corridors and its operation incl. hybrid and electric vehicles Extended modularity for vehicles and cargo units Implementation of 'intelligent cargo units' – enhanced	of urban mobility and long distance transport Adaptive vehicles incl. aerodynamics Driver villages connecting all modes Full E-freight within the corridors Alternative energy & fuel recharging fully supported along the pilot corridors, some level of standardised electrification Automated Asset Condition Monitoring and forecasting along the pilot corridors Integration of Alternative Energy sources and utility functions I Implemented business models for logistic solutions targeting e.g. cost and load factor efficiency Cooperative systems along pilot corridors

	solutions for e.g. load factor improvement E-freight pilot Reliable Infrastructure with maintenance and management regimes Monitoring and enforcement of efficient driving, vehicle weight and dimension	security in terms of no stolen goods, no damage Implemented business models for logistics: Collaboration info sharing Cooperative systems: Automated monitoring and operation enabled; Decentralized, local traffic management tested; Regulatory framework adapted. Interaction vehicle + infrastructure towards automated driving Driver villages offering high level of services for the driver and his/her vehicle	

	Milestone 1: 2015 **Supportive corridor**	**Milestone 2: 2020** **Interactive corridor**	**Milestone 3: 2025** **Mass market corridor**
Vehicle Technology			
Vehicle technically specified for running in corridors	Optimized vehicle parameters for efficient transport operation within transport corridors	Vehicles fully adapted to its operation and freight Modularity Intermodal efficiency	Optimized vehicles dedicated and tailored to its operation

Vehicle dimensions for optimized load capacity within corridors	Vehicle optimized length, weights and design for corridors Weight & dimensions Truck technically adapted to performance based standards within the corridor	Vehicle optimized for all corridors Improved aerodynamics for complete vehicle (incl. trailer) Load factor and weight control Modularity for load units and vehicles Modularity for loading Flexible weight and dimensions, optimized for performance based standards	Efficient transformable vehicle for all corridors Adaptable exterior vehicle geometry Automatic load factor and weight control Optimized and flexible weight & dimensions, for performance based standards
Vehicles and infrastructure matching each other	Vehicle technologies and road infrastructure are supporting each other in the corridor Rollout strategies for selected regional corridors	Rollout strategies for border crossing corridors	Rollout strategies for all corridors
Driver Environment			
Driving efficiency	Advanced HMI supporting the driver: e.g. smart route planning, coaching for efficient driving, information on the corridor and intelligent	Intelligent goods: HMI between driver cabin and cargo (paperless and electronic flow of information, see also Logistics)	Translational freight transport: automated customs processes (no stop at borders) Automated driving Automated handling

	communication with back office and customer	Smart loading of cargo (reducing time to load and unload by 50%)	of cargo at driver villages and hubs
Driver safety and comfort	Safe and secure bookable parking spaces Smart driver cabin: Multi-use driver cabin	Driver villages offering high level of services for the driver and his/her vehicle (e.g. maintenance and repair) Driver monitoring systems	Driver villages connecting all modes: seamless flow of goods Cargo and driver security systems: reducing incidents by 90%
Logistics and Intermodality			
Corridors logistics performance	Developing a vision on the dimensions capabilities of Hubs and corridors Define corridors logistics key performance indicators Identification of Corridors and Hubs Reduction of logistics footprint.	Integration of Hubs and Corridors.	Seamless integration of urban mobility and long distance transport
Co-modality and intermodal seamless interoperability.	Pilot one road corridor intermodal with one rail corridor National initiatives with similar standards, common	Optimize transhipment between modes Optimized interoperability between modes,	Extended intermodality and network Integration

	framework open for further standardisation Harmonised enabling legislation in place to reach physical interoperability	networks and opportunities	
Logistics and Supply Chain Business Models	Logistic companies prepared for green corridors business models Proposed business models for logistic collaboration solutions for e.g. load factor improvement	Business models for green hubs and corridors Performance (standard) based services Implemented business models for logistics, collaboration and info sharing	Extended logistics collaborative business models for logistic solutions targeting e.g. cost and load factor efficiency
Intelligent logistics Systems, optimising e-freight	Implemented (already known and available) ITS and e-freight solutions some targeting interoperability & intermodality Interoperability management platform (future internet PPP) E-freight pilots Information community development (logistics operators and service providers) for	Implementation of 'intelligent cargo units' capable to interact with the systems and self-optimize Enhanced security in terms of no stolen goods, no damage Paperless and electronic flow of information.	Full internet E-freight within the corridors Paper free transport Large demonstration projects

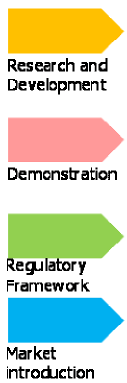
	information system adoption. New legal and regulatory framework for e-freight implementations		
Infrastructure			
Corridor scope	Pilot Corridors Agreed & Assessed Stakeholders engaged & corresponding Programmes Aligned	Impacts Assessed Ex-Ante Common Regulatory Framework agreed	Impacts Assessed Ex-Post European Roll-Out Plans Agreed
User friendly Design & Construction	First demonstrations of 'advanced driver villages' concept (bookable parking spaces, full information services) Self-explaining and forgiving design demonstrated in safety hotspots	Roll-out strategy for Advanced driver villages agreed	Roll-out strategy for self-explaining and forgiving design agreed
Durable and integrated Pavements, Bridges, Tunnels & Structures	Self-Repairing Abilities 50 % improvement of current lifespan (asphalt overlays)	100% improvement of current lifespan (asphalt overlays)	Self-Repairing Abilities standard in asphalt overlays Non-bituminous, durable overlays
Advanced Utility, Sensory and Communication Systems	Vehicle Recharging Systems demonstrated in several service locations along the	Roll-out strategy for vehicle recharging systems agreed Automated Asset Condition Monitoring	Alternative energy & fuel recharging fully supported along the pilot corridors Automated Asset

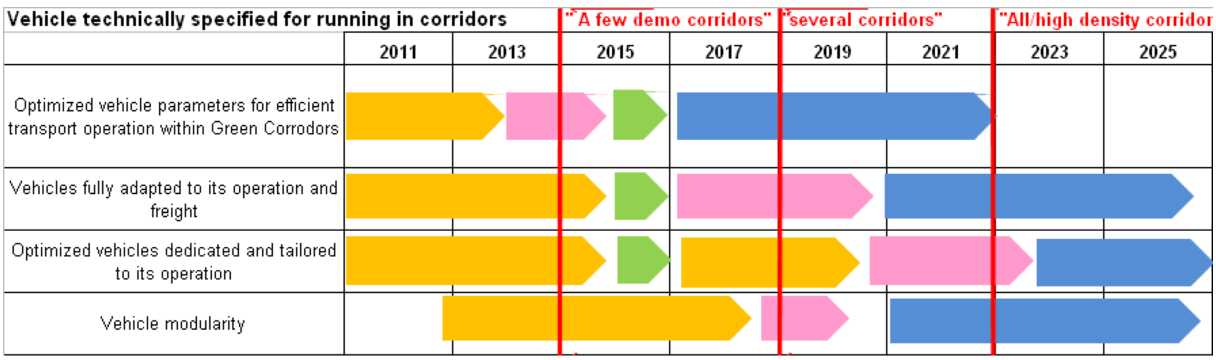
	pilot corridors In-Built & Wireless Sensors demonstrated Open Standard Interfaces agreed	and forecasting Roll-out strategy for sensory systems agreed	Condition Monitoring and forecasting along the pilot corridors Integration of Alternative Energy sources and utility functions
Intelligent Traffic Management Systems	Cooperative systems locally enabled. Impact assessment and cost/benefit finished; Business models available; Deployment plans with other cooperative stakeholders coordinated Dynamic traffic management enabled	Cooperative systems: Automated monitoring and operation enabled; Decentralized, local traffic management tested; Regulatory framework adapted. User oriented Multimodal traffic and travel information services demonstrated on national sections Common Remote Operation along corridor Common Incident and Calamities Management Systems and Processes	Cooperative systems along pilot corridors. Automated Roads demonstrated locally (e.g. platooning, intersection control). Liability issues settled. User oriented Multimodal traffic and travel information services demonstrated along pilot corridors
Freight corridor governance	Asset Management toolbox demonstrated on national network (SLA, Road Network planning & Asset Observatory)	Asset Management (Multi-Modal SLA; national/regional sections, Risk/Performance Management) Common Cost-Benefit Evaluation/LCC	Asset Management (Fully optimised for pilot corridors on basis of a common set of performance indicators, Road Asset Observatory/ BIM, Reliable Operations

		calculation tools operational on pilot corridors	Forecasting) Common dynamic traffic forecasting models operational on pilot corridors Common advanced risk driven decision support models operational on pilot corridors
ICT			
Communication infrastructure (X2X)	Adoption of EU-wide regulations for management of data exchange and storage Increased position, integrity and authentication (GNSS) solutions Open Service Platforms for robust, secure, safe and efficient service management	Interactive transport within corridors (V2V and V2I communication) for high energy efficiency Construction of safe, secure, robust and efficient X2X infrastructure in any location of the network	Vehicles "fully connected" with other vehicles, infrastructure, road operator and their logistic provider
Sustainable Transportation	Optimisation of real-time route planning and control ICT solutions integrating all transport modes	V2I and V2V avoiding bottlenecks in a corridor Solutions to prevent access to corridors for non-compliant vehicles Vehicle status monitoring.	Methods and services for transport utilization optimization Deployed harmonized pay for performance and polluter pays services

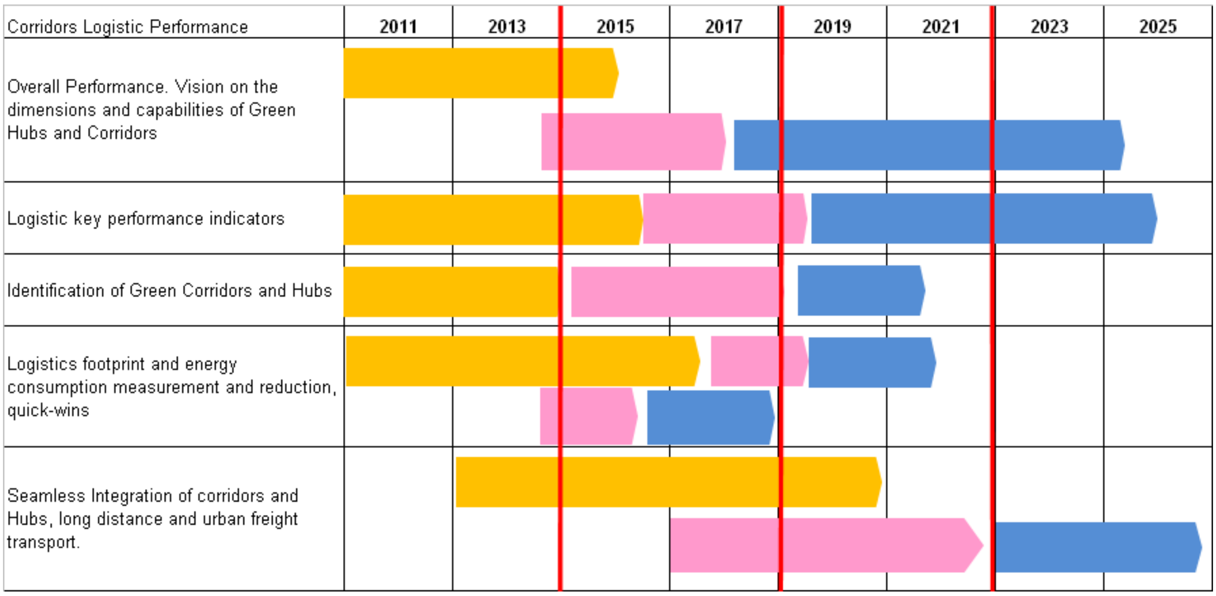
Automated driving (X2X)	ICT for speed and distance control (V2V) Europe wide standardisation regarding vehicles dimensions, communication systems for automated driving	Interaction of vehicle and infrastructure towards automated driving. ICT considering infrastructure limitations for automated driving such as bridges (weight limits), tunnels Demonstration projects in selected corridors	Automated driving demonstrations in all existing corridors. By 2030 automated driving "business as usual" in all corridors.

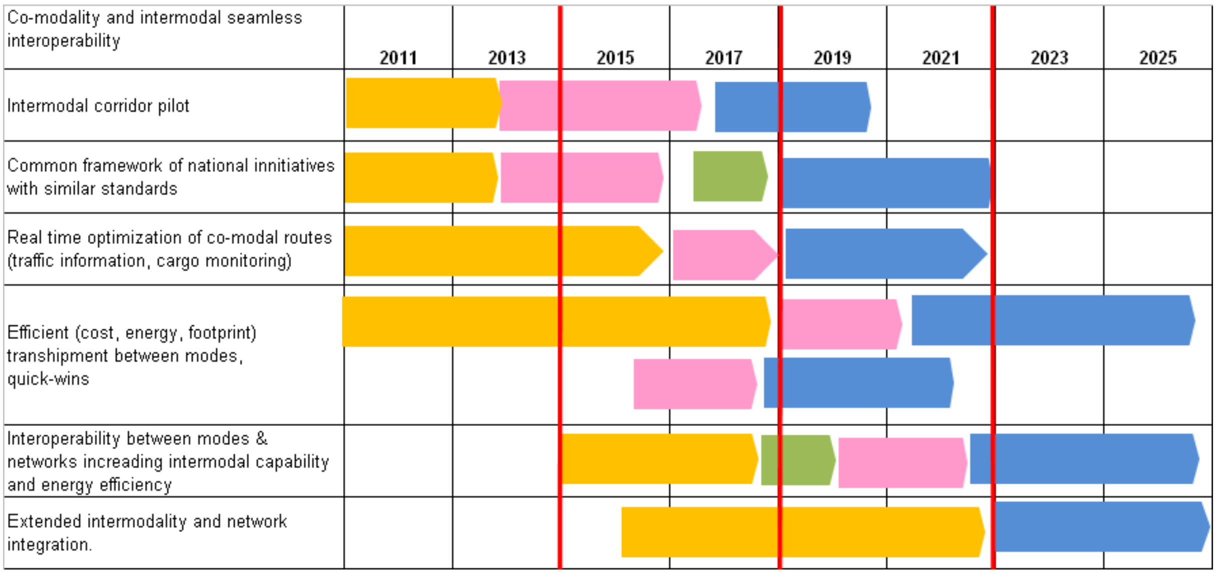
5. Roadmaps

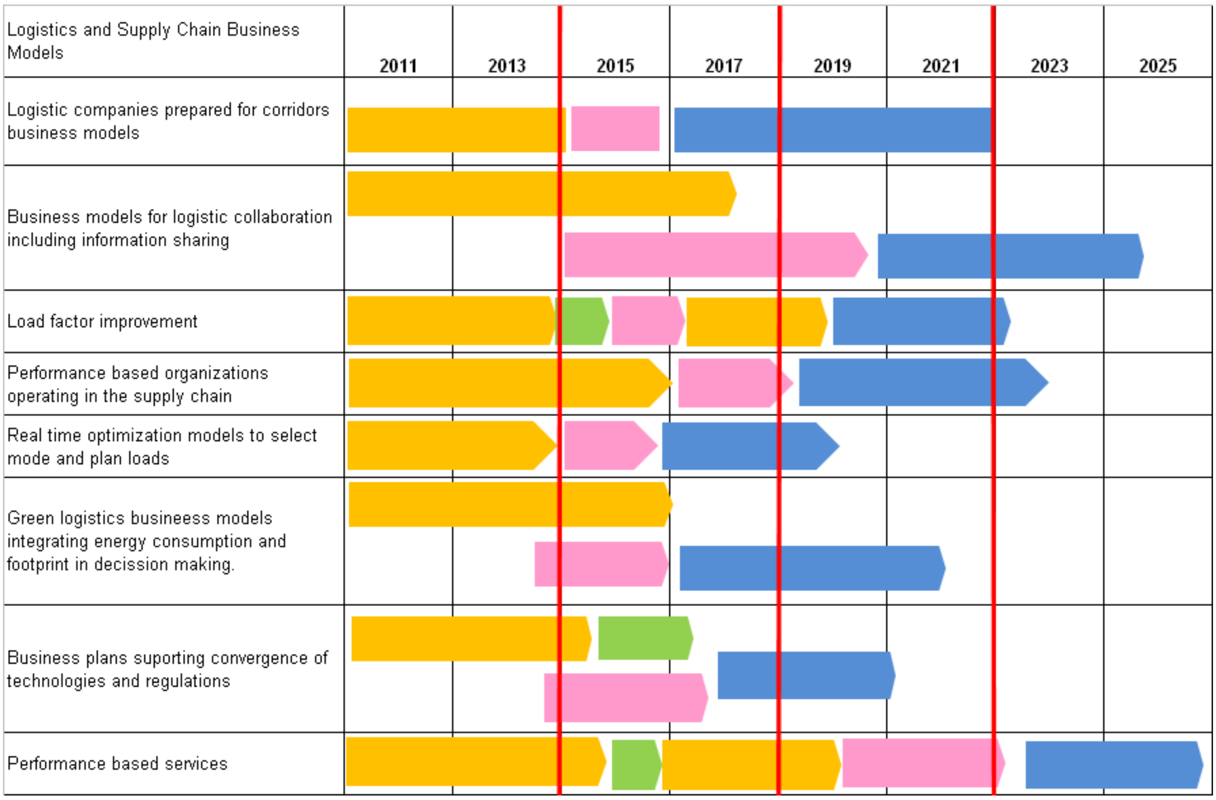




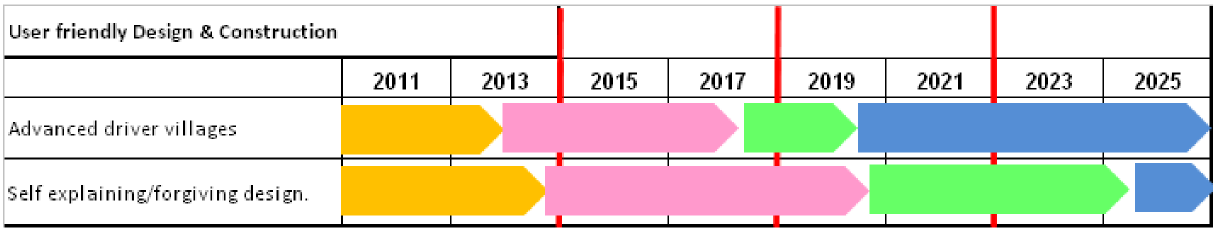

Vehicle dimensions for optimized load capacity
"A few demo corridors"
"several corridors"
"All/high density corridor
2011
2013
2015
2017
2019
2021
2023
2025
Vehicle optimized length &weight for corridors
Vehicle optimized for all corridors
Efficient transformable truck for all corridors
Automatic load factor and weigth control
Modularity for load units
Modularity for loading
Weight & dimensions, vehicle technically adapted to performanced based standards within corridors
Vehicles and infrastructure matching each others
"A few demo corridors"
"several corridors"
"All/high density corridor
2011
2013
2015
2017
2019
2021
2023
2025
Vehicle technologies and road infrastructure are supporting each other in corridors
Rollout strategies for selected regional (national) corridors
Rollout strategies for border crossing corridors, and for all corridors
Driver efficiency
2011
2013
2015
2017
2019
2021
2023
2025
advanced HMI supporting the driver
HMI-based information on cargo
smart loading based on intelligent goods
automized custom processes
automated handling of cargo
Drivers safety and comfort
2011
2013
2015
2017
2019
2021
2023
2025
safe and secure bookable parking spaces
smart driver cabin
Driver villages offering high level of services for the driver and his/her vehicle
driving monitoring system
Driver villages connecting all modes
Cargo and driver security systems

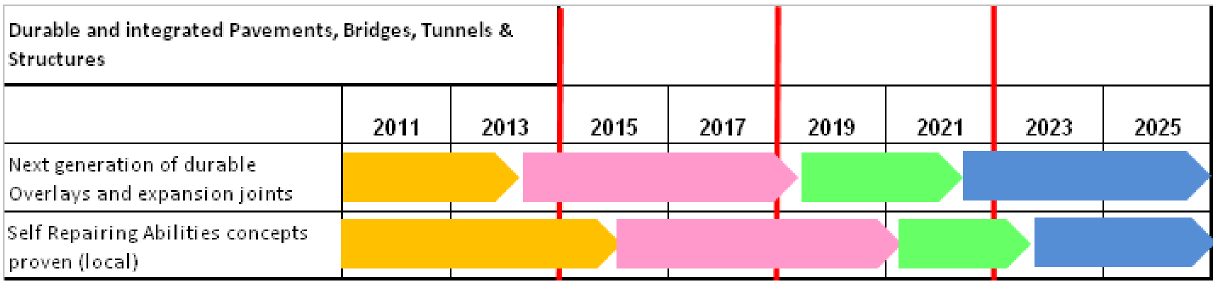

Corridors Logistic Performance
2011
2013
2015
2017
2019
2021
2023
2025
Overall Performance. Vision on the dimensions and capabilities of Green Hubs and Corridors
Logistic key performance indicators
Identification of Green Corridors and Hubs
Logistics footprint and energy consumption measurement and reduction, quick-wins
Seamless Integration of corridors and Hubs, long distance and urban freight transport.

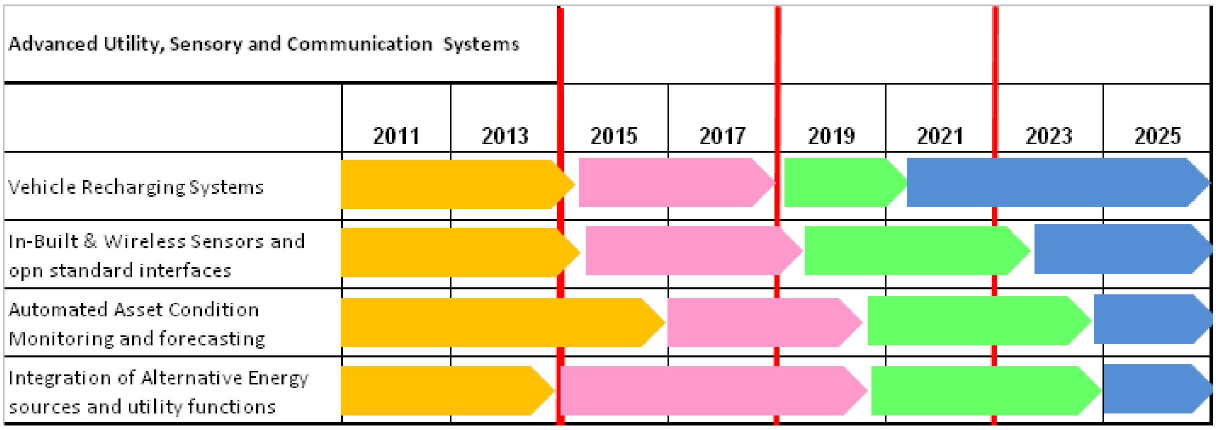

Co-modality and intermodal seamless interoperability
2011
2013
2015
2017
2019
2021
2023
2025
Intermodal corridor pilot
Common framework of national innitiatives with similar standards
Real time optimization of co-modal routes (traffic information, cargo monitoring)
Efficient (cost, energy, footprint) transhipment between modes, quick-wins
Interoperability between modes & networks increading intermodal capability and energy efficiency
Extended intermodality and network integration.

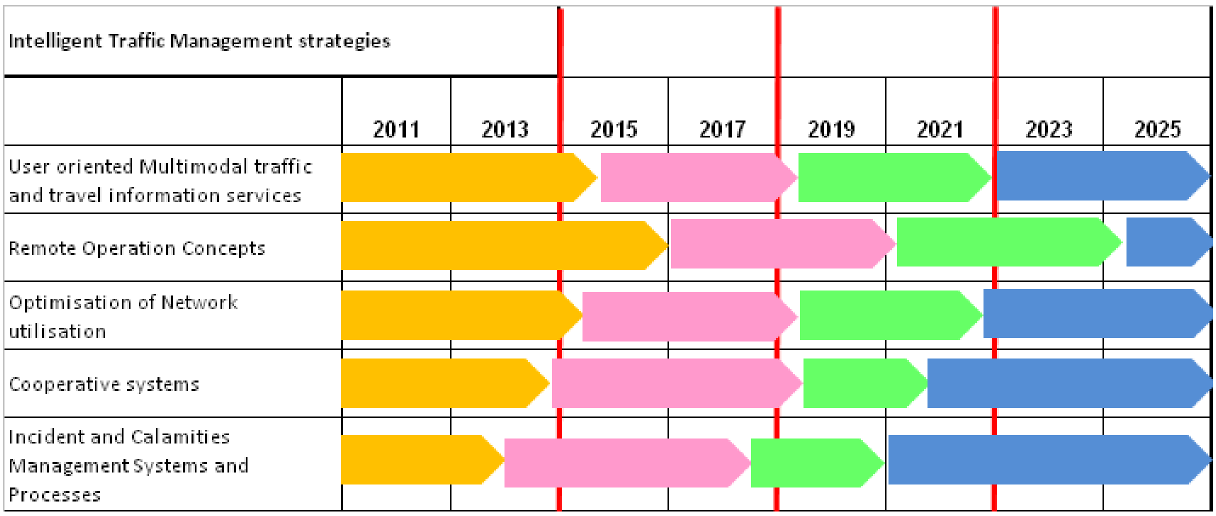

Logistics and Supply Chain Business Models
2011
2013
2015
2017
2019
2021
2023
2025
Logistic companies prepared for corridors business models
Business models for logistic collaboration including information sharing
Load factor improvement
Performance based organizations operating in the supply chain
Real time optimization models to select mode and plan loads
Green logistics busineess models integrating energy consumption and footprint in decission making.
Business plans suporting convergence of technologies and regulations
Performance based services

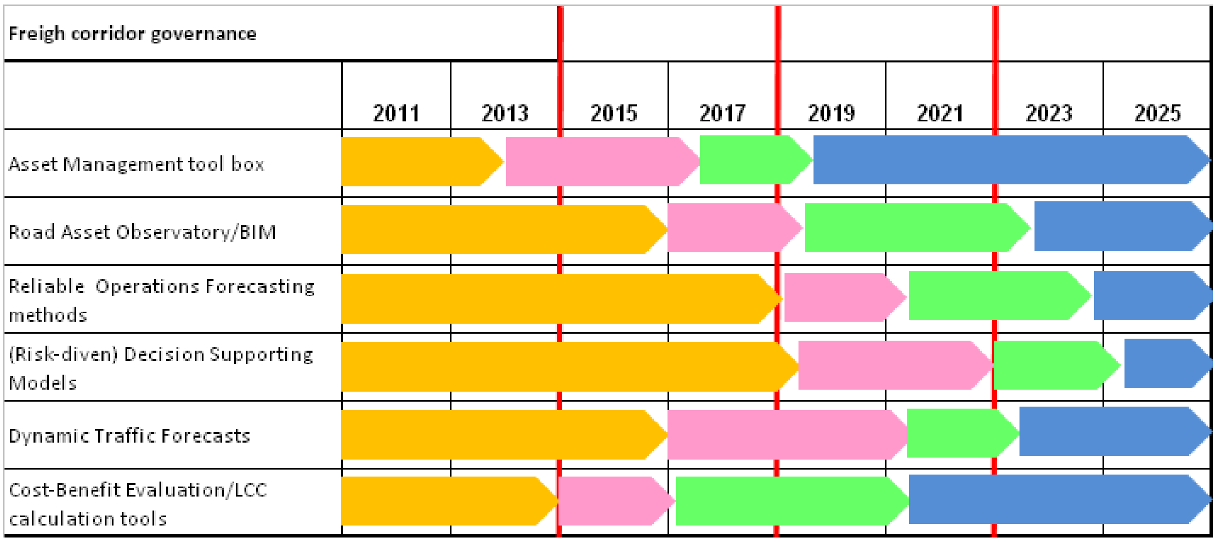

Intelligent logistics systems, Optimising e-freight
2011
2013
2015
2017
2019
2021
2023
2025
Implementation of current ITS and e-freight solutions targeting interoperability & intermodality
Internet based common management platform
e-freight pilots
Synchromodality: ITS solutions for the integration of transport and supply chains
Information community development and system adoption (logistics operators and service providers)
cargo units interacting with the system and self optimizing
Enhanced security of goods. Reduction of stolen and damaged goods
Paper less and electronic flow of information
Full internet e-freight transport


User friendly Design & Construction
2011
2013
2015
2017
2019
2021
2023
2025
Advanced driver villages
Self explaining/forgiving design.

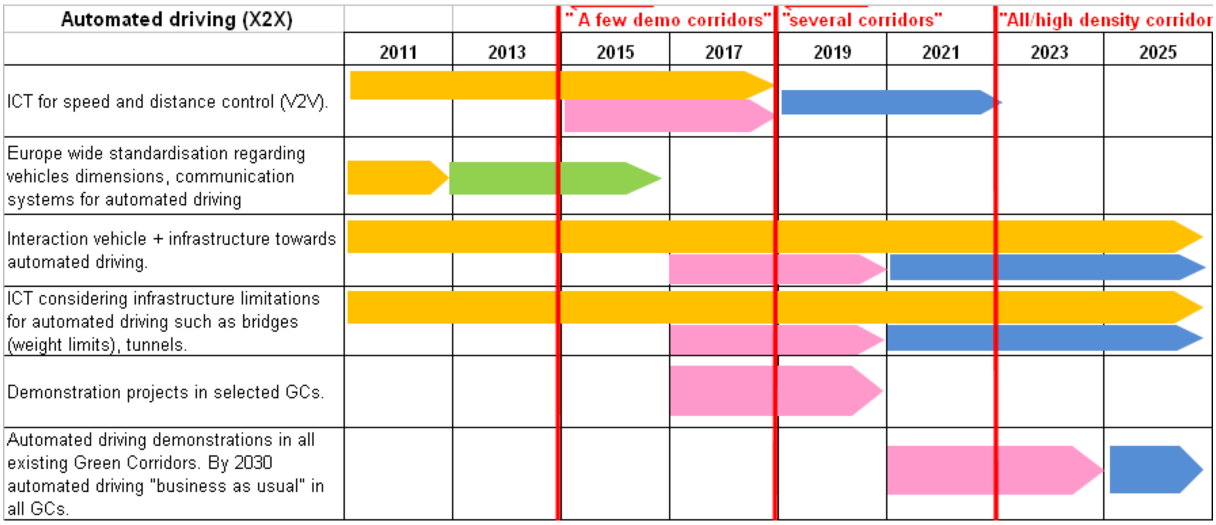

Durable and integrated Pavements, Bridges, Tunnels & Structures
2011
2013
2015
2017
2019
2021
2023
2025
Next generation of durable Overlays and expansion joints
Self Repairing Abilities concepts proven (local)


Advanced Utility, Sensory and Communication Systems
2011
2013
2015
2017
2019
2021
2023
2025
Vehicle Recharging Systems
In-Built & Wireless Sensors and opn standard interfaces
Automated Asset Condition Monitoring and forecasting
Integration of Alternative Energy sources and utility functions


Intelligent Traffic Management strategies
2011
2013
2015
2017
2019
2021
2023
2025
User oriented Multimodal traffic and travel information services
Remote Operation Concepts
Optimisation of Network utilisation
Cooperative systems
Incident and Calamities Management Systems and Processes


Freigh corridor governance
2011
2013
2015
2017
2019
2021
2023
2025
Asset Management tool box
Road Asset Observatory/BIM
Reliable Operations Forecasting methods
(Risk-diven) Decision Supporting Models
Dynamic Traffic Forecasts
Cost-Benefit Evaluation/LCC calculation tools


Communication Infrastructure (X2X)+Sustainable transport
"A few demo corridors"
"several corridors"
"All/high density corridor
2011
2013
2015
2017
2019
2021
2023
2025
Optimisation of real-time route planning and control.
Interoperable, harmonized V2V, V2I communication
Adoption of EU-wide regulations for management of data exchange and storage.
Construction of safe, secure, robust and efficient x2x infrastructure
Interactive transport within corridors (V2I and V2V communication) for high energy efficiency
V2I and V2V avoiding bottlenecks in a GC.
Solutions to prevent access to GC for non-compliant vehicles.
Vehicle status monitoring.
ICT using accurate positioning
Vehicles "fully connected" with other vehicles, infrastructure, road operator and their logistic provider.



References

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- Gary Bridgeman, IRU
- Martin Lamb, TRA
- John Berry, European Commission

<u>European projects of reference:</u>

- EGCI-Capire
- Freight Vision
- CVIS

Reference documents:

eia (2010), U.S Energy Information Administration, International Energy Outlook (2010), Transportation Sector Energy Consumption, http://www.eia.doe.gov/oiaf/ieo/transportation.html

COM(2011) 144, White Paper 2011 'Roadmap to a Single Transport Area - Towards a competitive and resource efficient transport system'

EGCI (2010). *Long Distance Trucks, EGCI Road map v5-11-2010.* http://www.green-cars-initiative.eu/public/documents

EGCI (2010). *Electrification of Road Transports, EGCI Road map v2.0 November 2010.* http://www.green-cars-initiative.eu/public/documents

EGCI (2010). *Logistics and Co-Modality, EGCI Road map v November 2010.* http://www.green-cars-initiative.eu/public/documents

ERTRAC (2010). *A Strategic Research Agenda aiming at a '50% more efficient Road Transport System by 2030.* www.ertrac.org

McKinnon & Piecyk (2010). *Logistics 2050 – Moving Freight by Road in a Very Low Carbon World.*

SIKA, 2008:10, *Potential för överflyttning av person- och godstransporter mellan trafikslag,* *http://www.sika-institute.se/Templates/FileInfo.aspx?filepath=/Doclib/2008/Rapport/sr_2008_10_lowres.pdf*

COM(2009) (279) European Commission communication on "A sustainable future for transport"

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European Roadmap

Towards an Integrated Urban Mobility System

Version June 7, 2011

ERTRAC Working Group on Urban Mobility

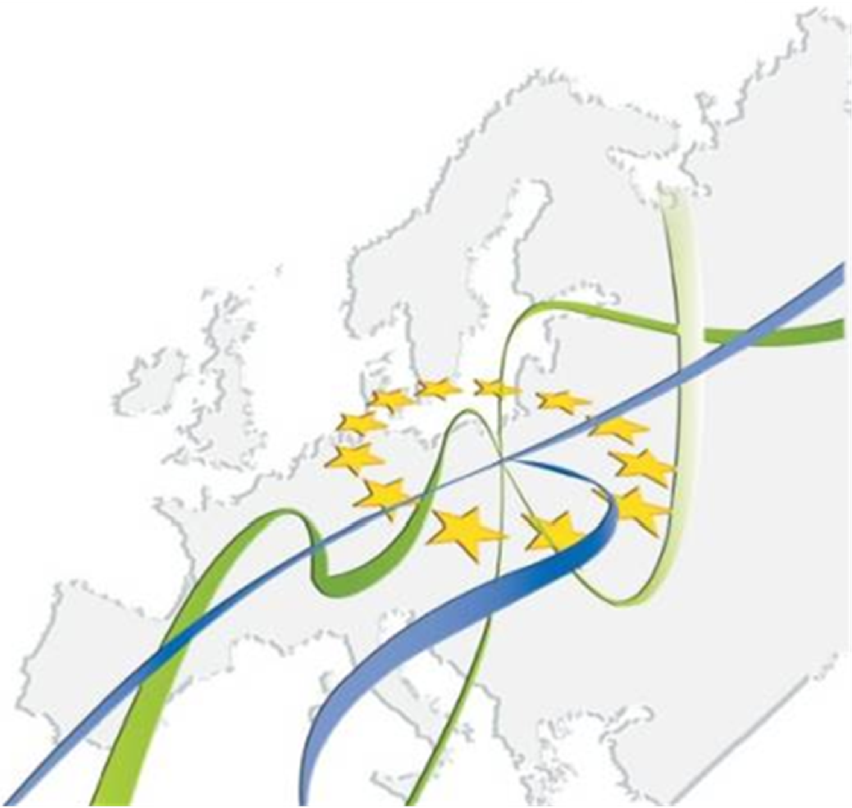


Table of Contents:

1. Executive Summary

Urban mobility should evolve towards enhanced mobility and greater efficiency. For this purpose, all modes of transport should be fully exploited in a complementary way, to offer the most convenient overall journeys for passengers and goods, guaranteeing a high level of accessibility and achieving the highest energy efficiency.

This requires their integration, ensuring that their complementarity is guaranteed through intermodal solutions. It also consists in the integration of the most energy efficient vehicles in the network.

To further integrate the urban mobility network and services, obstacles, real and perceived, related to the transfer of travellers/passengers/drivers from one mode to the other should be reduced to their minimum.

It would involve breaking the barriers between the management systems of the various modes to bring them together as much as required to reach the optimum balance to improve accessibility and the energy efficiency of the system as a whole.

A more integrated urban mobility network also integrates and therefore enables further the use of new mobility services in the urban environment.

The greater integration of public and private modes of transport, of collective and individual modes, will lead to greater room to create incentives and management tools influencing not only vehicles traffic but also the movement of people and goods.

Ultimately, it is an essential component of the future smartcity[1]with the deeper integration of mobility in its urban environment and with the other network industries such as energy.

2. Introduction

a. Background

The ERTRAC scenario 2030 illustrates the need for urban mobility systems to address increasing pressure on the networks and increasing congestion. It also describes the need to improve energy

[1] There is no generally accepted definition of the term smart city. We could understand this as a concept of a city where the underlying IT backbone allow the full connection of the individuals, vehicles, buildings, etc. with their environment, enabling a smarter management of services such as energy (cfsmartgrids), transport, etc.

efficiency to reduce the impact of mobility on the environment and the cost of mobility services for the public authorities, among other things.
Several modes of transport coexist on the urban mobility network, from walking and cycling to light rail, but also various types of vehicles and services for motorized road transport, for passenger travels and freight delivery, including different categories of services (collective and private transport). The scenarios show that this diversity is likely to increase. This creates a growing need for the integration of the various components of the mobility system.

Increasing levels of congestion and mounting pressure on the network (ERTRAC SRA) will challenge the optimization of urban mobility systems in the urban area. This will require further integration between the various modes of transport and services, to allow as smooth as possible transition between modes and networks for efficient intermodal travel and transport solutions. This should be supported by initiatives enabling integrated services.

With the integration between modes of the traffic and travel information, of charging and payment, and a greater physical integration of infrastructures and services, a broader range of tools emerge to manage the urban mobility network. The integration of these different components of the urban mobility system should be complementary.

For this reason, a single roadmap on the research needed to develop the tools required to allow the integration of the system is justified.

b. Scope

This roadmap addresses the whole urban mobility system. It therefore takes into consideration all type of users, all type of vehicles, all types of modes and all type of urban transport infrastructure and services. Public, collective and private transport, motorized and non-motorized (walking, cycling, etc.) trips are considered here.

In the absence of a commonly agreed definition of the urban environment at the European level, one should refer to academic definitions or legal definition in national legislations for a clear identification of the urban borders.[2]

Though there are already of course various modes coexisting on the urban mobility network, they are not supported by a level of integration conducting to the optimum intermodal solutions for the most efficient travel choice and the best transport options. This roadmap focuses on the research required to develop systems and tools that enables the highest level of integration possible.

In this respect the roadmap also covers research on intermodal infrastructure supporting efficient and integrated mobility services for passenger transport.

It therefore addresses a range of topics such as ticketing and charging, network management, traffic and travel information, the interface enabling the integration of information from the various actors involved in urban freight delivery, and the physical integration between modes and networks at interchanges.Those are the key topics to focus on to enable a real integration of the urban mobility system.

The roadmap also takes into consideration the integration of electric vehicles in the urban mobility systems for all the component of the system listed above.

[2]See for instance art. 2-17 of the new Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe

It looks at how these components will integrate the deployment of cooperative mobility, i.e. the integration of the vehicle, the traveler and the goods in the network with ICT.

A system approach

This roadmap does not cover specific technology developments, even though these are enabling the integration of the urban mobility network. It therefore does not include the technology developments required for the electrification of road transport which are covered in the joint ERTRAC-EPOSS-Smartgrid roadmap on this topic.

It will neither cover the technological developments required for the deployment of systems and equipments allowing cooperative mobility.

Finally, the roadmap does not cover technological research related to the development and deployment of communication technologies such as NFC or others. Those will influence significantly the exchange of data supporting the integration of the urban mobility network but their development is outside the scope of this document.

This roadmap therefore preserves various scientific and regulatory options and technological solutions and avoids to choose one above the other when the objective (application) can be achieved in more than one way given the current state of knowledge.

Complementarity between ERTRAC roadmaps

The roadmap addresses the interfaces between the long distance and urban networks. It is therefore coordinated and complementary with the ERTRAC roadmap on ‘Green, safe, and efficient freight corridors’ as the urban delivery of goods is often the end trip of the goods transported on long distance.

The roadmap is also coordinated with the European Bus System of the Future which addresses the integration of the bus system in the urban mobility network.

Most importantly, the research roadmap ‘towards an integrated urban mobility system’ aims at providing a level of integration of the component of the system which will create tools to influence transport and travel behavior and the related markets for mobility services, transport information, etc. It will therefore offer the traveler/driver/user greater choices. It will also allow to send him or her better and more advanced signals and incentives. This means that a more integrated urban mobility network will give a better place to individuals, as it should allow to provide mobility options more tailored to individual needs.

This roadmap is therefore indissociable from ERTRAC research roadmap on the road user behavior.

The research roadmap ‘towards a more integrated urban mobility system’ would allow to reach the objectives of the ERTRAC strategic research agenda to the extent that enhances the level of mobility for passengers and goods through improved accessibility and leads road users to make more energy efficient trips.

This assumes that a greater integration of the system encourages more energy efficient travel behaviour, and a better use of network management tool, also for greater energy efficiency and preserving or improving accessibility.
It therefore presupposed that it will trigger reaction in behaviours from the urban transport users.

The capacity to influence these reactions and their nature is however not sufficiently known. This is the reason why several research topics related to this are identified in another ERTRAC research roadmap on road user behaviour. This roadmap on road user behaviour is complementary with this one. It also addresses several other aspects of the road user behaviours.

The table below identifies the research needs on the transport user behaviour which are of relevance for this roadmap. These research topics are essential to assess how and to what extent the integration of the urban mobility network can contribute to achieve the SRA objectives by influencing travel and transport behaviours. They are detailed and developed further in the ERTRAC research roadmap on the road user behaviour.

Table: Description of the relation between the ERTRAC roadmap on the user behaviour and the roadmap 'towards an integrated urban mobility system.'

Towards an integrated urban mobility system	Road/transport user behaviour
Traffic and travel information	User response to: - intermodal traffic and travel information; - technology used for the provision of information; - environmental information related to trips; - weather information related to trips; - various degree of reliability of information; - road safety risk information; - individual privacy concern and mobility information and services
Integrated charging and payment systems	User response to price signals: - PT fares - Parking fares - Congestion charges - Infrastructure charges - Innovative mobility services prices User response to technologies used for the payment of mobility services Individual privacy concern and integrated payment systems Relative user preference for integrated payments through integrated ticketing or credit card systems
Network management	User response to other network management tools - Access restriction - Speed management - Trip length and time

2.c Benefits to Grand Societal Challenges

The roadmap will aim at enhancing the level of mobility for passengers and goods through improved accessibility and supporting the integration of all modes of transport in the urban mobility network in the most energy efficient way allowing overall more energy efficient trips.

It will also allow a more efficient management of the network, increasing the efficiency of the system, closer to the optimum of energy efficient and accessible mobility system.

It will finally enable more efficient transport services, for instance for urban freight delivery.

As a result, the roadmap will significantly contribute to the targets set in ERTRAC SRA to increase the energy efficiency of the urban mobility networkby 80%.

The improvement of the energy efficiency of the urban mobility network contributes to the decarbonisation objective identified in the ERTRAC scenario. This is part of the effort of the sector to contain and reduce the impact of transport on the climate by reducing CO_2 emissions.

The awareness about CO_2 emissions is growing and would increase in a more integrated urban mobility system. Indeed, this would enable the more systematic provision of information on CO_2 emissions to travellers, and the inclusion of the carbon emissions in the list of parameters used for network management decision support systems.

A more integrated network is also a more climate resilient network as integrated network management tools provide more and better options to adjust to various circumstances.

A greater integration of traffic and travel information, of charging and payment systems, of network management tools and of the infrastructure at interchanges, will also contribute significantly to improve the accessibility on the network. Indeed, if one considers that the accessibility is a composite indicator of the time of travel in the urban environment, the distance travelled and the cost of the trip, a greater integration of the network should impact positively at least one of its components in all cases.

Indirectly, integrated network management tools and traffic and travel information are contributing to better communicate, assess and manage the road safety. For instance they could enable the information about 'safer mobility options' for a given trip. In this respect, they contribute to the road safety objectives of the ERTRAC Strategic Research Agenda.

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'.

Summary of guiding objectives of ERTRAC 'A strategic research agenda aiming at a 50% more efficient road transport system by 2030 (ERTRAC, 2010)

3. Milestones and Roadmaps

The document will detail roadmaps on several topics:

- The integration of urban traffic and travel information;
- The integration of ticketing and charging services for all mobility related charges in urban areas;
- Interchanges for passenger travel and transport;
- Interfaces for a more efficient urban freight delivery;
- Integrating urban mobility management

The integration of urban traffic and travel information

The roadmap will identify the research needed for tools, models and frameworks enabling the integration of traffic and travel information[3]. An integrated urban mobility system should be a system where information on all modes of transport is available to users, transport operators and network managers, and updated as required to make optimal decision.

Various efforts are being undertaken for the integration of the urban traffic and travel information.

Most of those have been listed by the in-Time project which provides a good overview of the State of the Art situation.

The process of implementation of the European ITS directive could greatly influence this roadmap.

Indeed, the directive provides for the development of specifications for actions within identified priority areas, as well as for the development of standards.
The directive appliesITS applications and services in the field of road transport and to their interfaces with other modes of transport.
The priority areas identified within the directive and of relevance here are the following:
— I. Optimal use of road, traffic and travel data,
— II. Continuity of traffic and freight management ITS services,
— IV. Linking the vehicle with the transport infrastructure

Within the priority areas the following priority actions for the development and use of specifications and standards, are of relevance for this roadmap:
(a) the provision of EU-wide multimodal travel information services;
(b) the provision of EU-wide real-time traffic information services;
(c) data and procedures for the provision, where possible, of road safety related minimum universal traffic information free of charge to users.

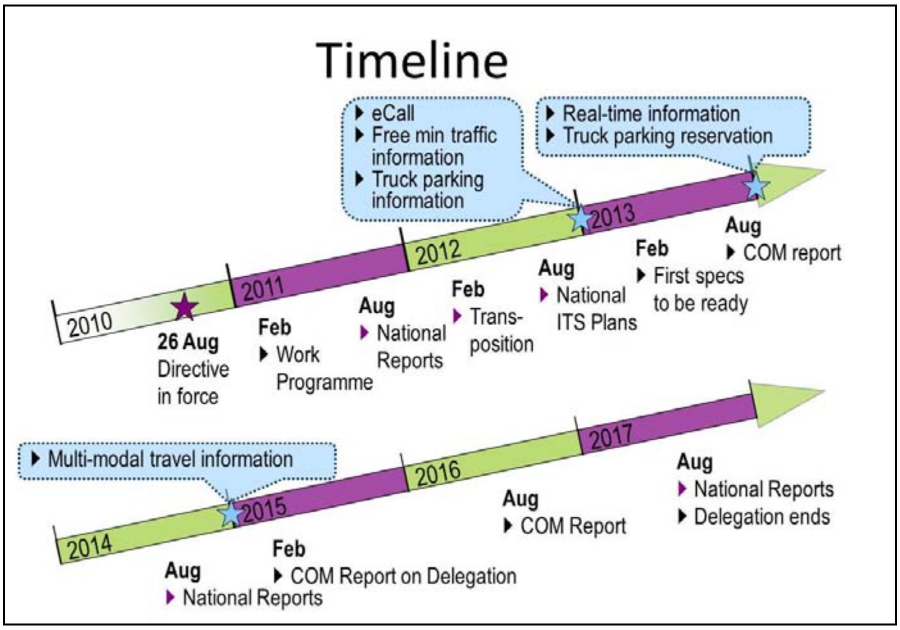
The Commission will first adopt the specifications necessary to ensure the compatibility,interoperability and continuity for the deployment and operational use of ITS for the priority actions.
The Commission will aim at adopting specifications for one or more of the priority actions by 27 February 2013, as illustrated in the graph below.

[3] the ITS directive terminology is the reference for the parts of this roadmap relevant for ITS

Where relevant, and depending on the area covered by the specification, the specification shall include one or more of the following types of provisions:
(a) functional provisions that describe the roles of the various stakeholders and the information flow between them;
(b) technical provisions that provide for the technical means to fulfil the functional provisions;
(c) organisational provisions that describe the procedural obli-
gations of the various stakeholders;
(d) service provisions that describe the various levels of services and their content for ITS applications and services.

The necessary standards to provide for interoperability, compatibility and continuity for the deployment and operational use of ITS shall be developed in the priority areas and for the priority actions.

This roadmap demonstrates the need for these activities to strongly take into account the specificities of the urban environment if they are to cover the urban environment itself.
It also contains several research topics which canbe greatly influenced by the content and the speed at which the specifications and standards will be developed in the framework of the directive.



European Commission, implementation of the ITS directive

For a few years, efforts have been made at integrating travel information, essentially about public transport, for several public transport modes and operators.

Efforts are now also concentrating on the integration of the traffic and travel information and of all relevant mobility information on the urban mobility network.

The first objective of the integration of traffic and travel information is the provision of complete information to the travellers about all his or her mobility options on the urban environment for the trip he or she wants to do or has started. It therefore covers pre-trip as well as on trip information.
Integrated information should include route planning services.

This information must bring together road traffic information, information on walking, cycling, public transport, parking, traffic regulation (including access control),prices and charges for mobility services and infrastructure use if and when applicable.

With the deployment of **electromobility** in the coming years, information of relevance for the use of electric vehicles should also be considered. It would include the location of publicly available charging points, the type of charging points, and services related to electromobility such as for instance electric car sharing vehicles or public electric vehicles.

The provision of integrated information can also be **a tool for the network manage**r to influence travel behaviours, through route planning.

The provision of information therefore includes two components:
- The integration of data on urban transport and mobility;
- Route planning advice, recommendations or incentives

In the later case, and if integrated traffic and travel information is provided by the public authority, it becomes a network management tool.

The requirement regarding **the availability of data**, and the various types of actors likely to use this data to provide information, private or public, local, national or multinational, should be carefully considered for the achievement of this roadmap.

To achieve the accurate provision of integrated urban traffic and travel information, there are a number of pre-requisites which are related to the provision of traffic and travel information beyond the focus of this roadmap. We will therefore not detail these prerequisites which are not specific to urban mobility.
The development of digital maps with updated and accurate transport network attributes, the development of traffic and transport databases or transport data market places, and progresses towards some forms of certification of data quality are all essential to achieve integrated urban traffic and travel information.
They are dealt with at the European and national levels, for instance in the framework of the European directive on ITS.

It should also be stressed that the **governance** supporting data collection and the release of data enabling the provision of integrated traffic and travel information is very important. The cooperation between actors, the role of public authorities,their choice for the release of data to the public and private information providers, ownership of data, and the European and national regulatory framework all condition the terms of the provision of integrated traffic and travel information.

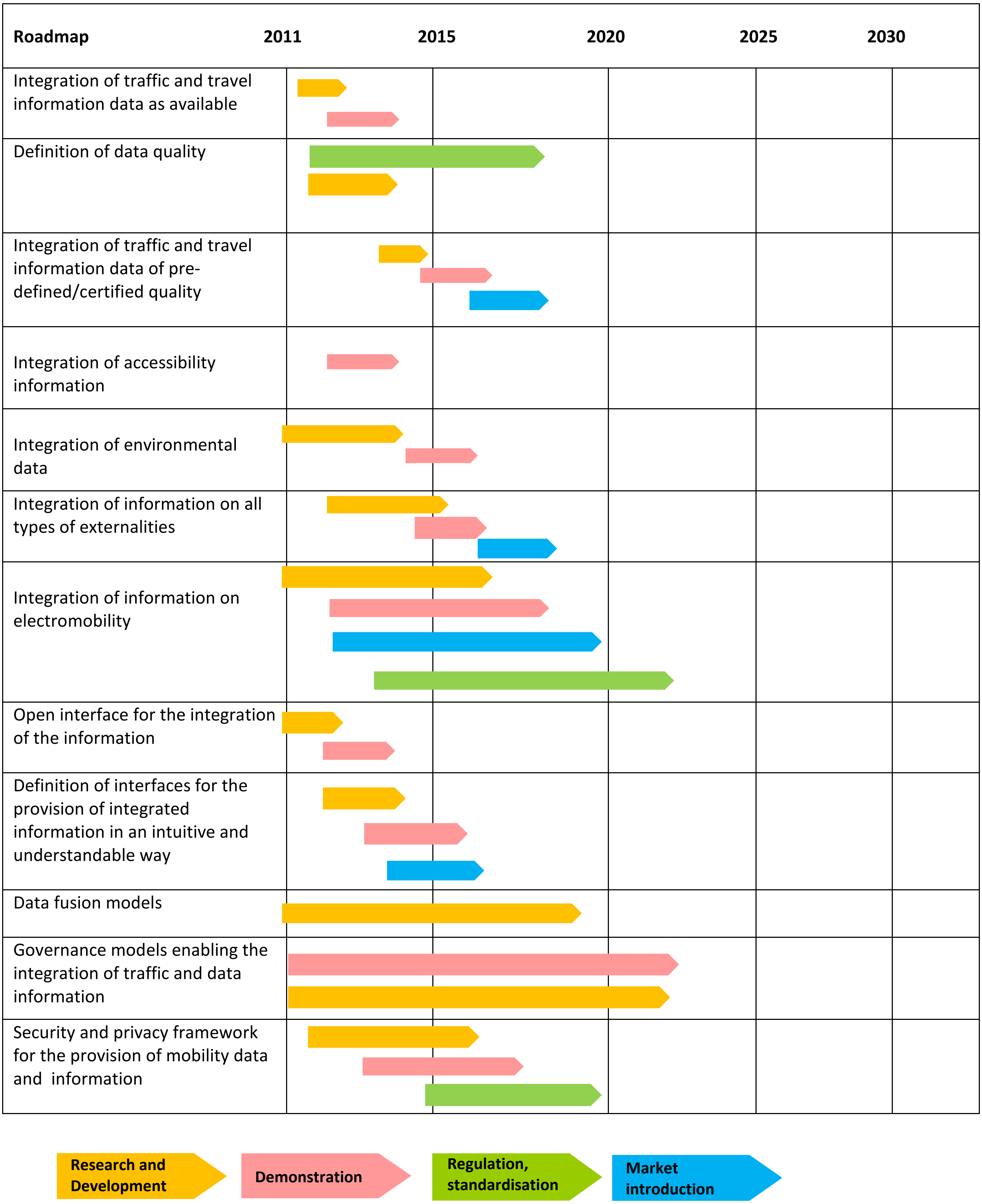
Milestone 2015	Milestones 2020	Milestones 2025
Integration of traffic and travel information and all mobility related information at the urban level, relying on qualified data	Integration of traffic and travel information and all mobility related information, relying on certified quality of data	
	Full integration of externalities with the information: environmental data, risk, etc.	
	Systematic integration of information about all mobility services, including information related to electromobility	
	Integration of information on all urban networks of **all sizes**	

This aspect of the roadmap is obviously strongly related to the roadmap on the road user behaviour.

Indeed, the contribution of the provision of integrated traffic and travel information, depends on the response of the user to the availability of this information. This is very important as the market for transport related information is not yet a mature market and can still evolve significantly.

It should also fulfil the expectations of the transport users who should have access to the information he/she considers of relevance and importance for himself or herself.

The availability of information should be guaranteed to all potential users, without discrimination between users. This requires that the communication infrastructure in the urban environment has the capacity to accommodate the request for information of all users. Bandwith and communication tariffs should therefore for instance not create restriction on the access to information, for certain type of users, such as for instance foreign visitors. This is also essential for the integration of payment and ticketing systems.


Roadmap
2011
2015
2020
2025
2030
Integration of traffic and travel information data as available
Definition of data quality
Integration of traffic and travel information data of pre-defined/certified quality
Integration of accessibility information
Integration of environmental data
Integration of information on all types of externalities
Integration of information on electromobility
Open interface for the integration of the information
Definition of interfaces for the provision of integrated information in an intuitive and understandable way
Data fusion models
Governance models enabling the integration of traffic and data information
Security and privacy framework for the provision of mobility data and information
Research and Development
Demonstration
Regulation, standardisation
Market introduction

The integration of ticketing and charging services for all mobility related charges in the urbanareas

The roadmap identifies research needed for developing systems and models allowing to reach the optimum level of integration for ticketing and payment systems for all mobility related charges.

Mobility related charges can include public transport fares, parking, mobility services such as public bikes, congestion and infrastructure charges, etc. Considering that a key challenge consist in integrating public transport ticketing systems locally and that the number of transactions for public transport is by far the greatest of all payment of mobility services, public transport is driving this integration of ticketing and charging services.

Two parallel streams have to be pursued at the moment. The first one consists in the progressive development of an interoperable fare management system following the recommendations of the EU-IFM project. It should lead to the deployment of a common application for the payment of mobility services across Europe which can be used on various media.

The second stream foresees the integration of the payment of urban mobility services via credit/debit card payment systems used with contactless payment systems.

On the mid-term, these two streams could lead to complementary solutions.

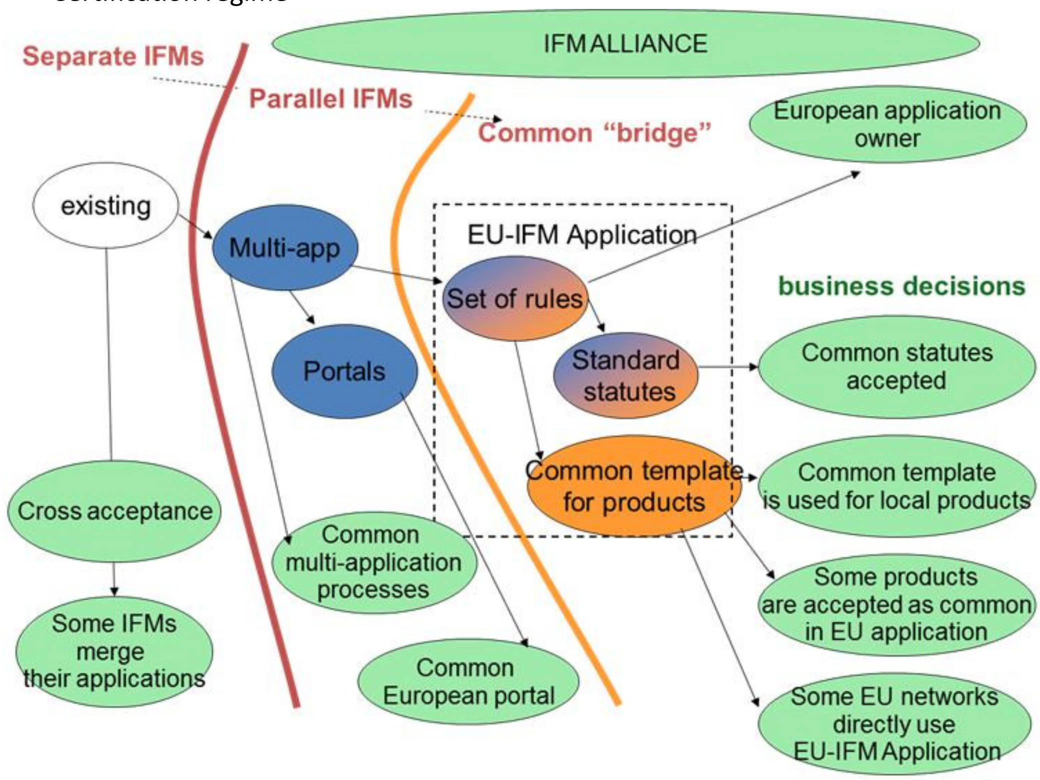
Milestone 2015	Milestones 2020	Milestones 2025
Interoperable common multi-application processes on a single media	Creation of a common application which can be uploaded on several media	
Update of standards for fare collection	Common product template	
	Common fare collection processes	
Integration PT, urban , and urban &LDT, and other mobility services	Integration payment of all mobility services	
integration of the payment of urban mobility services via credit/debit card payment systems used with contact less payment systems		

This figure below illustrates the main principle of the roadmap proposed by the IFM project for the long term development of Interoperable Fare management across the EU.

The implementation of this IFM roadmap requires the following:

- The development of contactless media with an IS0/IEC 14443 Interface that fulfils the requirements of the EU-IFM for Storage Capacity, Performance, and Operating System.
- Development of an Application that can be downloaded by the Internet and/or over-the-air, first by UMTS/GSM

- Secure element is agreed within the media and conditions to use it in a trustful way are defined
- The development of an initial joint EU IFM organisation based on the voluntary participation of each IFM local/regional schemes, which is responsible for EU-Application ownership (which can be third party developed and operated), supply and management of IFM Portal(s), the Security of the IFM, and the Registrar.
- Regional/local products that are available to issue into the EU-Application
- Interoperable EU-Products are defined and available to issue by the customer contract partner which the customer chose
- The system must be designed to ensure the privacy (privacy by 'design system')
- Common security agreement
- Certification regime



Source: IFM project, Roadmap, D. 7.3 Final deliverable

This part of the roadmap covers the integration of the various payment tools but also of the related pricing and charging policies, such as parking, infrastructure charges, public transport fares, ecopass and congestion charges, new mobility services, etc.

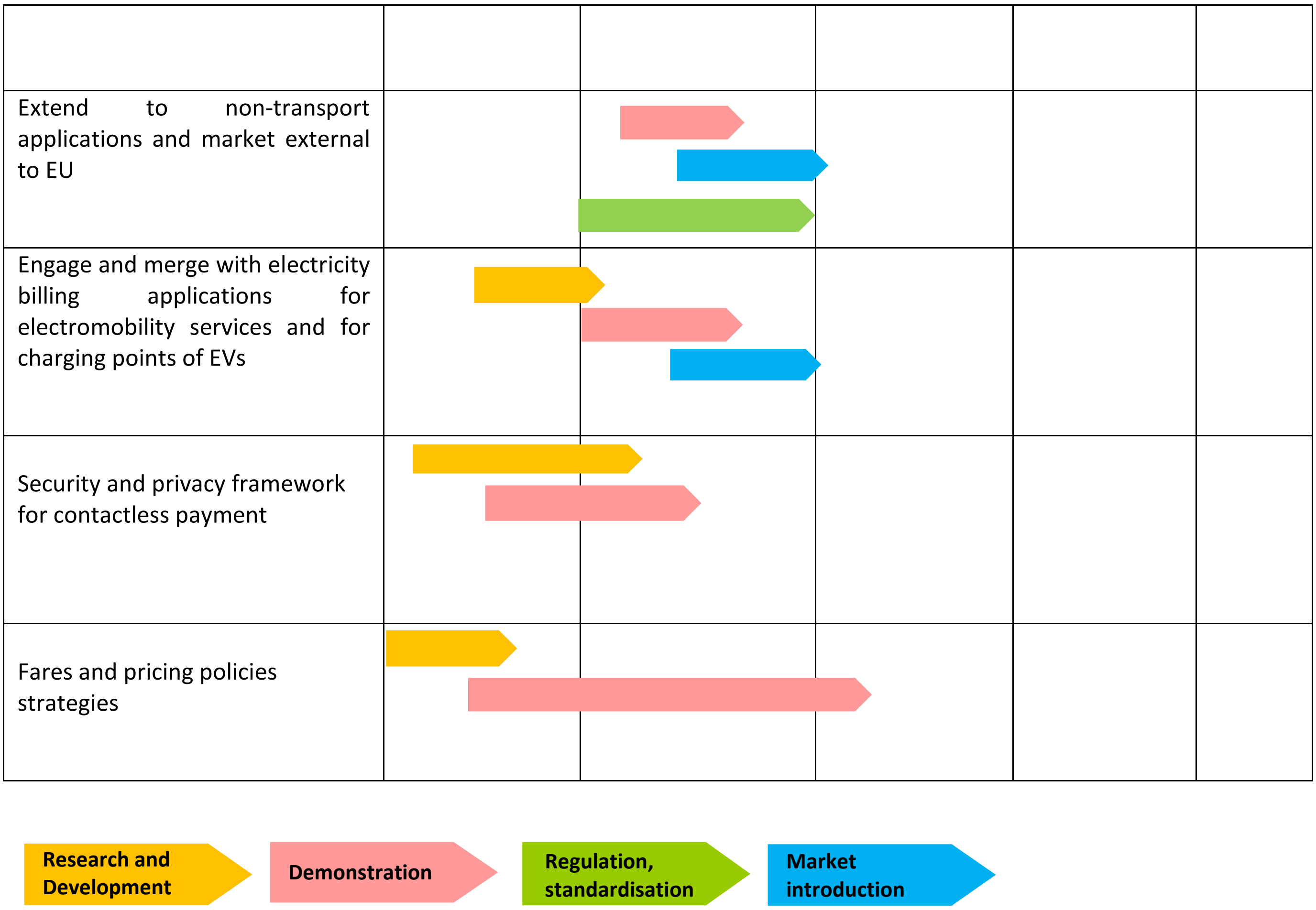
It therefore also covers the research on the definition of pricing and charging of mobility services in the urban environment. Research in this respect cover several issues such as the level of charges, prices and fares, regulatory, financing and business models for mobility services and transport infrastructure from the point of view of the whole urban area.

The definition of these policies, which is strongly related to the analysis of the user 's response to price signals, should consider their impact on the overall societal goal of decarbonisation, greater energy efficiency, and greater accessibility.

A key element in the definition of such a policy is of course the response of users to price signals. This part of the roadmap is therefore closely related to the ERTRAC roadmap on the road user behaviour.

It is also related to the previous part of the roadmap on integrated traffic and travel information as information about charges and fares for mobility services must be a part of an integrating route planninginformation. Indeed, cost of trips should be part of the integrated traffic and travel information at the urban level.

Roadmap	**2011**	**2015**	**2020**	**2025**	**2030**
Establish an EU-IFM Alliance , including funding on the long term					
Create Interoperability for customers through common multi-application processes on a single media in the customer's possession					
Create a Common Portal for customers to remotely load local applications together with the development of an "IFM Brand" to provide assurance and focus					
Update and harmonise current CEN Standards to support EU-IFM					
Create a Pilot operation in a number of Member States in preparation for wider roll-out					
Develop a Common EU-IFM Application and Common Product Templates supporting an extension of the "IFM Brand"					
Develop a commercial and technical framework for the sales and settlement of EU-IFM Products					
Extend functionalities to facilitate inter-modality between road and rail, and support for Demand Management for all transport modes (urban, suburban, regional and inter-urban)					
Engage and merge with existing IFM Systems and other ITS transport modes (including private): e.g. road tolling, bicycle hire, car sharing, public bikes and cars, parking, etc.					



Interchanges for passenger travel and transport

Interchanges allow the physical integration of the various modes and network and the transfer of travellers from one mode to another.

Research should focus at making interchanges enabling as smooth a transition between modes as possible. Their function in the urban mobility network should be enlarged and their role in the urban environment further researched and thought.

Milestone 2015	Milestones 2020	Milestones 2025
Interchanges as the hubs of the urban mobility network facilitating the transition between all modes of transport, offering several transport services	Integrating interchanges in the smartcities	

They should integrate all modes of transport and go beyond the integration of major modes, such as rail public transport and road public transport.

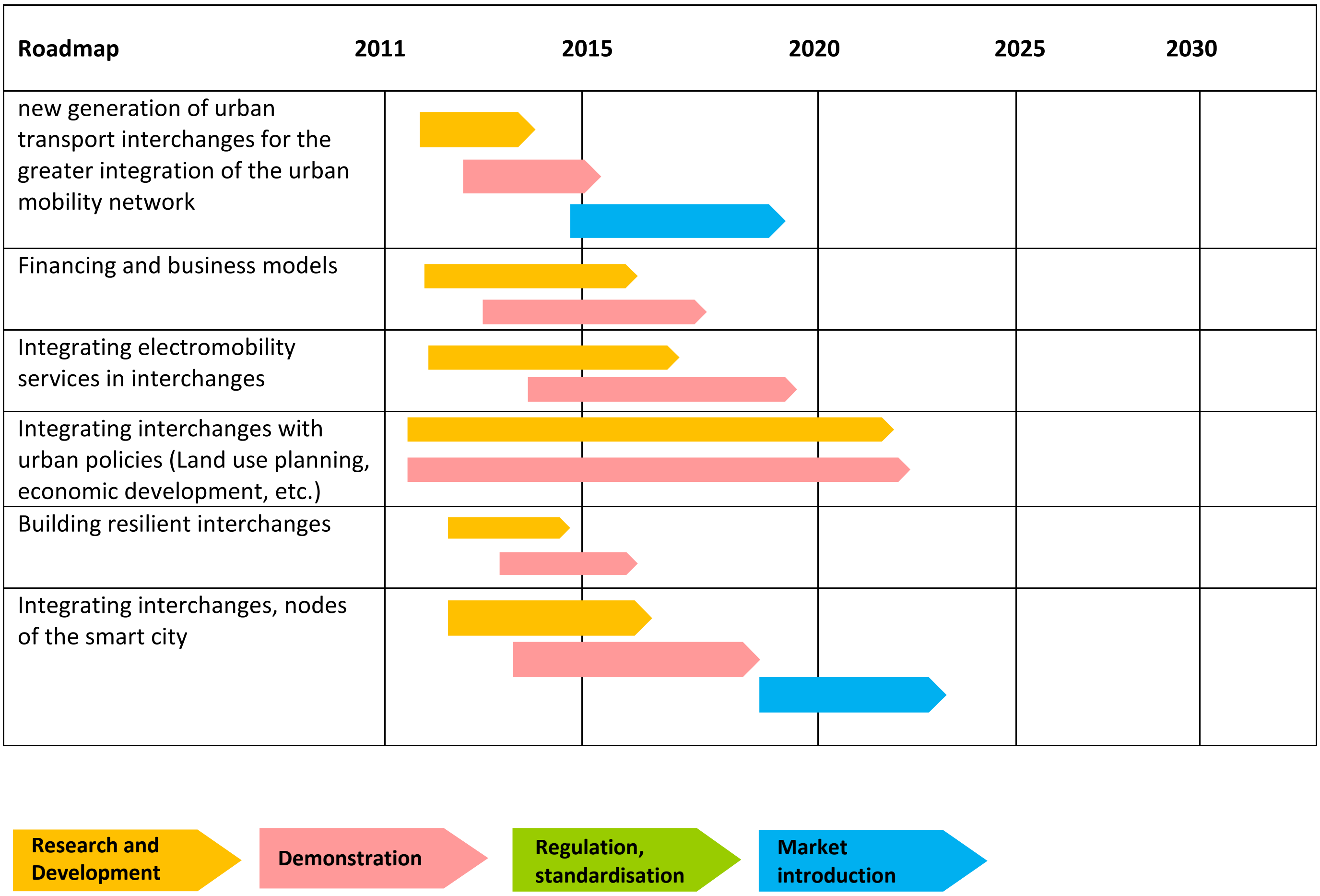
They should foresee the integration of new mobility services, of cycling, of parking, etc. Integration with walking should be an integral part of the interchange design and conception.

Various types of mobility related services should be provided at the interchange, in particular specific traffic and travel information.

Thought as place of urban lives, they should be safe and accessible for all citizens.

Transport interchanges should become the future hubs of the smart cities, integrated not only in the transport network but in their urban environment and the other smart networks, in particular the smart electricity grids. They should themselves, as infrastructure, contribute to the increase of the energy efficiency of the city.

As key component of the transport network and of the urban environment, the planning for interchanges should be coordinated with local land use strategies. The identification of the best location of interchanges for the city and the efficiency of the transport network should be part of the research activity covered by this roadmap.



Interface for a more efficient urban freight delivery

Urban freight delivery suffers from the lack of coordination of the actors whereas they share to a large extent the same objective of an efficient system for the delivery of goods in the city.

The main stakeholders (public authorities, freight operators, retailers, infrastructure managers) lack the appropriate framework and tools to exchange information and adjust accordingly their transport plans.

It is therefore necessary to develop an interface allowing the integration of the information of relevance for urban freight delivery and facilitating the exchange of the relevant information between the public actors, in particular the public authorities regulating and managing the road network, and the private actors. This will enable new delivery concepts and services.

Milestone 2015	Milestones 2020	Milestones 2025
Deployment of a an information exchange platform for urban freight delivery stakholders	Integration of eFreight in this platform to extend some of its features to the urban environment	

This interface should include all information related to traffic regulation, parking and access related to urban freight delivery. It could also be used for the management of urban distribution centers and logistics platform, and for the use of electric vehicles for urban freight delivery.

The interface should also enable the other stakeholders to upload non commercially sensitive information for the optimisation of the rules and recommendations for freight delivery.

It would lead to useful route planning recommendations and incentives.

The definition of the information to be exchanged by all parties is a first important step for the definition of the interface.
The platform should then be demonstrated, and progressively become a European reference.

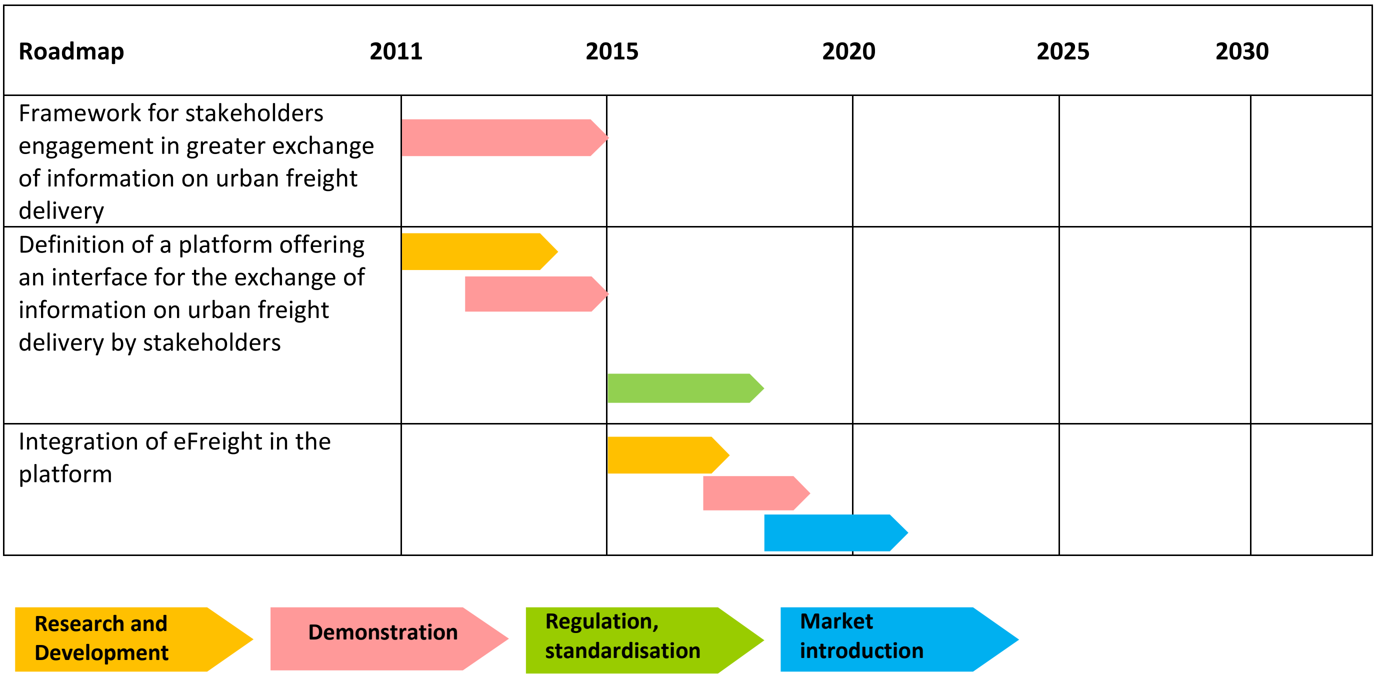
Further work on engaging stakeholders – including users such as freight forwarders, is required to ensure their commitment to the platform and their cooperation in using it.

As it is important that the platform protects the commercial interest of all stakeholders and do not allow the communication of sensitive information affecting commercial operations and competition, it should be a very secured environment.

The deployment of eFreight could create further opportunities for managing urban freight delivery. Several features of eFreight could be extended to the urban environment in a second stage.

The platform could support this and integrate some eFreight components, to allow on the longer term to move towards a greater management of the goods directly in an urban logistic system.

This would raise interesting opportunities for maximising the efficiency of consolidation.



Integrating urban mobility management

The management of the urban mobility network currently involves a broad range of tools. These include public transport management, traffic management, at intersections and through the control center, and the use of various incentives and regulations.

These are the parking policies, traffic regulations, access rules and regulations, and in some cases access charges. Those can be considered as demand management tools.

Network management also include the provision of various mobility choices in the urban environment such as walking and cycling paths, and the support to various types of mobility services such as car sharing or public vehicles.

Traffic and travel information with travel planning and recommendations, on trip and pre-trip, are another type of network management tool. When these are provided by the public authorities, they can be direct tools for network management.

When they are provided by information providers consolidating various types of data, they provide information about the various tools mentioned above.

The segmentation of the various tools, in particular public transport and traffic, prevents to a large extent a real integrated network management in real time.

The increase of the amount of data collected on the network through cooperative systems, mobile phones, and other data sources, increases the potential for network management. The integration of these various tools is important to enable its optimization.

As it would bring together data from private and public transport, and from individual and collective modes of transport, it should allow better knowing and managing the movement of persons and not only of vehicles.

An important number of research activities are required to achieve this objective of an integrated network management.

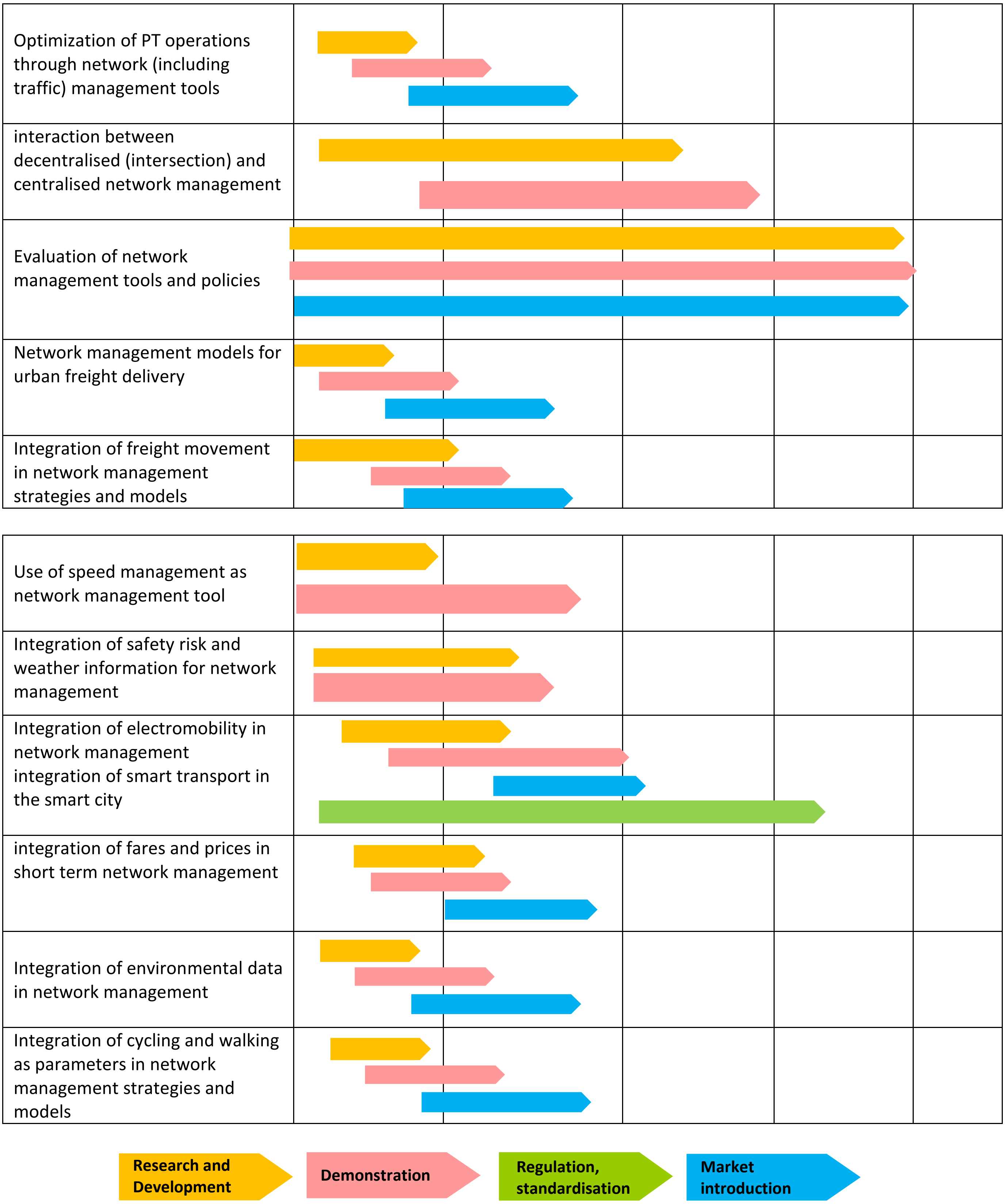
The research needed to provide models, tools, systems and frameworks for integrating the management of the various components of the network, in particular traffic management and public transport, is identified. These tools and models will aim at allowing the optimization of the use of the urban infrastructure, though for instance a better use of the data collected, and the strategic provision of information.

The management of the network should also include and address the management of freight delivery in the urban environment. This should allow for a better consideration for freight movement and gaining efficiency in managing freight traffic (LDVs, etc.) and in enabling innovative freight delivery services.

Milestone 2015	Milestones 2020	Milestones 2025
Integration of network management tools, based on vehicles and individuals data	Integrated network management optimizing individual accessibility and urban mobility network efficiency	

Roadmap	**2011**	**2015**	**2020**	**2025**	**2030**
Network management strategies, integrated with sustainable urban mobility plans					
Governance for the coordination of the network management tools					
Interaction between private cooperative network management initiatives and public network managers					

Algorithms for network management integrating: - New levels of traffic; - Multiplication of data sources (cooperative systems, …);					
Short term forecasting models					
New intelligent decision support systems for network management: - addressing also the identification of the optimum between potentially conflicting objectives - learning cycle for the optimization of DSS - for private operators and for public authorities - real time qualification of traffic situation					
Integration of demand management tools in short term network management					
Interaction between centralized and decentralized information management models, also considering communautary information					
Strategies and models to face serious network disruption, network management for climate resilience					
Evaluation of models efficiency (considering also their potential complexity)					


Optimization of PT operations through network (including traffic) management tools
interaction between decentralised (intersection) and centralised network management
Evaluation of network management tools and policies
Network management models for urban freight delivery
Integration of freight movement in network management strategies and models
Use of speed management as network management tool
Integration of safety risk and weather information for network management
Integration of electromobility in network management
integration of smart transport in the smart city
integration of fares and prices in short term network management
Integration of environmental data in network management
Integration of cycling and walking as parameters in network management strategies and models
Research and Development
Demonstration
Regulation, standardisation
Market introduction

4. References

For the preparation of this roadmap, ERRAC, the European Rail Research Advisory Council has been regularly consulted.

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European projects of reference:

- In-Time
- EU Spirit
- EU-IFM
- Rosatte
- CONDUITS
- HEAVEN

Reference documents:

- The Innovation Union strategy, requesting to take a system approach including deployment aspects in order to deliver innovation: COM(2010) 1161, 'Europe 2020 flagship Initiative - Innovation Union';
- The Green Paper on the next Framework Programme: COM(2011) 48, Green Paper 'From Challenges to Opportunities: Towards a Common Strategic Framework for EU Research and Innovation Funding';
- The Transport White Paper from DG Move setting the "new" 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 from DG Enterprise covering both ICEs and EVs: COM(2010)186, 'A European strategy on clean and energy efficient vehicles';
- The overall Europe 2020 strategy, focusing on sustainability and global competitiveness: COM(2010) 2020, 'Europe 2020 - A strategy for smart, sustainable and inclusive growth';
- DIRECTIVE 2010/40/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport
- Communication from the Commission: Action Plan for the Deployment of Intelligent Transport Systems in Europe [COM(2008)886]

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COUNCIL

European Roadmap

Road User Behaviour and Expectations

Version May 9, 2011

ERTRAC Working Group on Urban Mobility

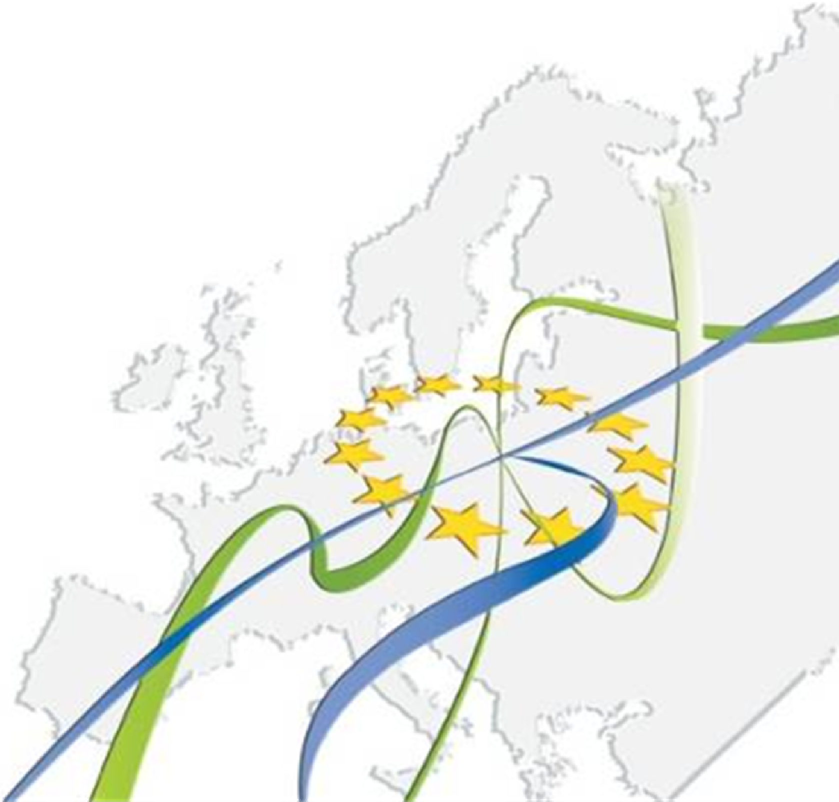


Table of Contents

1. Executive Summary

Road user is not only the direct consumer of entire transport network, but, above all, is the beneficiary (or the victim) of any plan, design, construct and maintain infrastructure in the future, which are determined by transportation decision maker. Therefore, road users need to be kept at the heart of transport policy in order to build a more efficient and safer road network system.

The consideration of road user behaviour and his or her expectations has virtually been the subject of transport planning activities. But, studying user behaviours and expectations has increasing difficulties and challenges because of the more complex travel patterns and social diversity. Therefore there is a need to improve researches on user behaviour. We focus on four research areas in terms of the contexts of SRA 2010: transport reliability, environmental concerns, co-modality and travel demand management vision of the road sector.

Therefore, the primary objective of this roadmap is to provide guidance to analyze road user behaviour in the vision of users' needs, preference and future expectations to build an improved road transport environment for passengers. The aim of this roadmap is to address road sustainable

mobility of long distance, in coordination with other transport modes to achieve optimal co-modality use of road network and its associated facilities.

All this analysis is more and more influenced by new technological developments. In fact, telecommunications technologies have a direct influence on driver behaviour. Besides that, they constitute a powerful tool to achieve a continuous communication among all actors: users, transport infrastructures and operators. Information flows allow to receive real time information on user behaviour and to react instantaneously. These changes open a new scenario of integration for the whole transport system.

2. Introduction

2.1 Background

Efficient, sustainable and safe road transport system is a great challenge for the European society and economy. User behaviour and expectations are the essential factor to build a more acceptable and efficient transport infrastructure and to manage the associated transport services.

This has been already the goal of a number of EU policy papers like the 2001 Transport White Paper and its mid-term review. Again the 2011 new White Paper also refers to the necessity to improve quality, accessibility and reliability of Transport Services.

The Directive 2010 of Intelligent Transport Systems highlights the importance of ITS applications to provide useful information over travelling time and routing alternatives to ensure seamless door-to-door mobility services.

Emissions and energy efficiency are also elements of transport policy which clearly affect user behaviour. The energy and environmental policies have a clear impact on fuel prices, and they produce regulations and limits that reduce the performance for trips using different transport modes.

As a general statement the key idea on this regard is the target of placing citizens at the core of the transport policy and practice. This is why user behaviour and expectations have a great importance when developing the future European transport system.

However, there is still a long way to convert policy into current practice. Therefore the end of this roadmap is to settle the way forward to get a user oriented new transport scenario.

2.2 Scope

The roadmap of road user behaviour and expectations should address key challenges to achieve the objectives set in the SRA 2010 (Strategic Research Agenda, ERTRAC) and propose a process towards their achievement. For this purpose, research needs are identified, in cooperation with elements from the technology roadmaps developed by ERTRAC.

Firstly, the different categories of individual road users and organizational road users specified in this roadmap are:

- Individual road users
  - ✓ Long distance passengers
  - ✓ Travellers for all regional and metropolitan transport means, groups and individuals, motorised and non motorised
  - ✓ Car drivers
  - ✓ Professional drivers for freight and passenger road transport

- Organizational road users
  - ✓ Transport operators and companies for passenger and freight transport
  - ✓ Decision makers
  - ✓ Interchange operators

2.3 Complementarities with other ERTRAC Roadmaps

This roadmap follows a system approach, adopting the point of view of the user. That means that the road infrastructure should be not considered alone, but including also all the equipments and facilities which constitutes the basis for providing high level transport services.

This roadmap has been designed having in mind the content of other roadmaps. ***The Road User Behaviour and Expectations*** roadmap focuses on passenger travel because there is a dedicated roadmap on ***Green, safe and efficient freight corridors.*** It does not deal with accidents either, which are addressed in the ***Safe road transport*** roadmap***.*** The technological side is also avoided in what respects energy, for example eco-driving behaviour, because they are part of the ***Electromobility and Future Transport Energies*** roadmap***.*** On the other hand, vehicles technologies are considered in the ***European Bus System of the Future*** roadmap.

Finally, there are many complementarities with the ***Towards an integrated urban mobility system*** roadmap. To avoid repetitions the *Road User Behaviour and Expectations roadmap* skips actions in the urban environment. However users should perceive a seamless transport chain and as a consequence “last mile” issues are tackled properly as part of the user behaviour. That means that integration between long distance and urban mobility services are also included in this roadmap.

2.4 Integrated system approach: the road system and the user

Although this roadmap in based on the road transport services, it tries to catch up all user needs which are multimodal by nature. Therefore we have to adopt a systemic approach to analyse road users’ behaviour and their expectations about the combination with other modes of transport.

3. Benefits to Grand Societal Challenges

The grand societal challenges addressed by the ERTRAC Agenda are:

1) Decarbonization

2) Reliability

3) Safety

The following figure summarizes the guiding objectives (corresponding to the main areas and indicators) of ERTRAC's "Strategic Research Agenda aiming at a 50% more efficient Road Transport System by 2030".

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'.

Figure 1. Guiding objectives for 2030 (ERTRAC 2010)

This roadmap intends to place the road user in the centre of the RTR (Road Transport Research). Therefore, by principle it addresses all guiding objectives that ERTRAC has stated in its SRA 2010, both on the user side of the road transport system, as well as on maintaining and improving Europe's competitive edge on the global market. None of those objectives is independent of user expectations and behaviour.

4. Research Lines

Through the consultation process there have been identified four longitudinal research areas (reliability, co-modality, environment and energy efficiency, and travel demand management) and two transversal research lines (travel demand estimation and technology responses) to be developed in this roadmap, as shown in Figure 2.

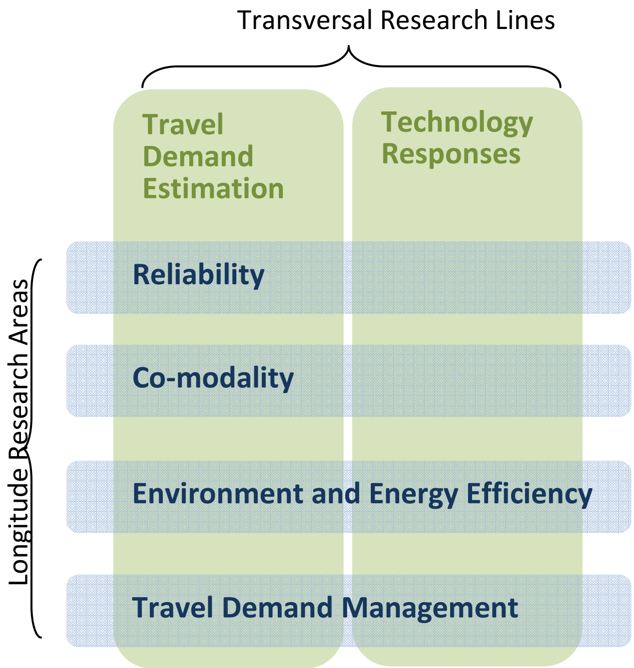


Figure 2. Research framework for The Road User Behaviour and Expectations Roadmap

4.1 A) Longitudinal Research Areas

The longitudinal research areas consider all the key elements and societal needs addressed in the ERTRAC SRA 2010. The explanation and development of research actions are given separately as below.

A1) Reliability

ERTRAC SRA focuses on improving the reliability of transport schedules and metropolitan or interurban accessibility. It aims at reducing congestion and it is strongly linked to economic growth and employment. Consequently, the research about road user behaviour and expectations includes reliability objectives, concentrating on two main fields, transport schedules and metropolitan or interurban accessibility. In this sense, it is needed to evaluate users´ satisfaction for the existing services of transport schedule and accessibility levels to all destinations. This should start by analyzing travellers' needs and expectations in respect to these two fields, through standardized travel demand surveys and case study analysis.

The possible research actions developed in respect of reliability are shown as below:

- studying variables related to transport reliability
- carrying out surveys on users´ satisfaction of transport schedule and territorial accessibility
- analysing the impact of reliability on user behaviour
- analyzing the accessibility for metropolitan areas

A2) Co-modality

The urban sprawl has characterized European cities by the last 20 years; it generates an increasing number of trips between metropolitan areas. In this context, the number of multimodal trips increases because of the longer distance travel. This research area focuses on road users´ behaviour and expectations when they make a multimodal trip (such as car-long distance train, car-airplane, car-metropolitan train or car-long distance bus). Consequently, two main questions could be addressed. In the light of the complexity and breadth of the content on this studied area, two main questions are helped to address the researcher's target:

1) How do road users choose two or more modes to travel? It means that road user behaviour and expectations should be identified and analyzed.
2) What are the barriers and needs of users in a multimodal trip?

One way to study multimodal user behaviour is by realizing travel demand surveys (attitude questionnaire, stated preference or revealed preference) in different European areas.

The results of the surveys analysis would allow developing a comprehensive evaluation of multimodal mobility services, including production systems management. It determines the following research actions:

- Identifying road user expectations and behaviour in respect to the connection with other modes (railway, interurban bus, urban bus, vehicles, bicycle and walking) to realize an integrated mobility and to provide a high quality service
- Analysing the expectations and behaviour of users of intermodal services and multimodal transport. The aim of this analysis should be to identify key variables to influence positively the efficient use of multimodal services.
- Consider separately stakeholders, including operators, and then individual ordinary travellers
- Implementing door to door information and service
- Including the design requirements for achieving a more efficient transport service supply and for fulfilling travelers' needs and expectations.

A3) Environment and Energy Efficiency

A widely use of motor vehicle produces several environmental problems, such as CO_2 emission, pollution and noise, increasing the external costs for all the society.

Using the indicators of decarbonisation made by ERTRAC SRA 2010, several measures could be implemented, including new vehicle technologies application and "Travel Demand Management" policies. The most critical element is to understand users´ behaviour in respect to the environment, influence and convince them to adopt the recommended changes in their behaviour at long term.

The effects between road users and environment are double-sided, one is the effect of road user on the environment; another is the impact of the scheme pricing for internalizing environmental costs on users behaviour.

Consequently, research actions include:

- Calculation of individual footprint
- Energy consumption estimation per person and per trip option
- Social costs estimation including various externalities, including air quality
- Impact of information about environmental and health effects on user behaviour
- Health concerns evaluations: obesity, stroke etc

A4) Travel demand management (TDM)

TDM measures have become a necessary policy approach to restrict the use of vehicles in urban or interurban areas. Some TDM measures are congestion pricing, public transportation infrastructure improvement, bicycle-friendly facilities and environmental oriented developments. Each of these measures affects the performance of road users´ trip. Actually, road users are at the core of all the TDM measures. Only considering attitude, awareness and expectations of road users, the TDM measures can be efficient and acceptable.

This research area consists of two kinds of studies about road users´ behaviour. One is focused on the analysis of the impact of existing TDM policies on road users; another is to address the future (new) TDM polices considering the expectations of road users. In consequence, all of these measures should be included in an efficient design of transport infrastructures and services.

Research actions related with this area are:

- Analysis of users´ attitude, preference and acceptance of road pricing policies (such as parking restriction, congestion pricing).
- Evaluation of past TDM policy actions and criteria for improving their effectiveness
- Users´ expectations definition about public transport services (such as transit, park and ride)

4.2 B) Transversal Research Lines

Two transversal research lines are included in this roadmap: travel demand estimation and technology responses. The first one focuses on the analysis of travel demand in respect of four longitudinal research areas introduced before. The second one studies the specific response to each

advanced technology, such as information & communication technologies and saving energy technologies.

These two research lines have to be crossed with the longitudinal research areas.

B1) Travel demand estimation

It would allow developing an analysis on the characteristics of interurban users´ behaviour and the expectations of different road users groups. Two main subjects are analyzed in this research line: the first one concerns the definition and the estimation of behaviour variables for forecasting the travel demand; the second one includes the re-orientation of expectations, preferences and needs of road user for future travelling. Both subjects aim to understand users´ awareness, motivation and attitude towards different mobility options and address them.

The results of this action will serve to identify the potential and the design of the transport infrastructure or services for road transport users. It will also help decision makers to implement new policies to manage the increased interurban travel demand.

Several research actions are foreseen to achieve proper travel demand estimation:

- Aggregate & disaggregate travel surveys
- Estimation of macro/micro and static/ dynamic demand models
- Analysis of users' sensitivity to different TDM policies and other policies relevant for transport demand
- Identification of the impacts of different categories of road users by their age, travel mode or motive
- Analysis of the characteristics, attitudes and behaviours of road users with respect to road pricing schemes (cost internalization and acceptability)
- Study of user behaviour and its expectations about an integrated transport system. This action should be realized in collaboration with the roadmap of "Towards an integrated Urban Mobility System".

B2) Technology Responses

Technology response is a transversal research line considered in the *Road User behaviour and expectations roadmap*. It mainly analyzes users´ responses to new technologies, including ITS (intelligent transportation system) and new energy sources for vehicles. Particularly, it is oriented to study the responses of road users to the rapid development of information technologies. In consequence, it will be necessary to develop some guidelines for testing how the ITS is able to fulfil expectations and needs of road user and to influence his behaviour.

The technology responses will address issues such as: co-modality, multimodal trip management, long-short distance trips integration, costs internalisation, accessibility, logistic and mobility services.

The research actions proposed to define the reactions to the new technologies are:

- Analysis of needs, expectations and responses of road user, in general
- Estimation of the behaviour of the specific groups of road users

5. Milestones

The objective of the next twenty years is to develop the following three milestones related to the focus of this document that is user behaviour and expectations.

- **Milestone 1: UNDERSTANDING** road user behaviour and expectations (2015):
  The first milestone is oriented to understand the behaviours and expectations of different groups of road users. In consequence the foreseen actions will be:
  1) Collecting the information about drivers´ demand;
  2) Defining the expectations of travellers on different levels of quality of services;
  3) Analysing the attitude and the behaviour of user in respect to transport policies (infrastructures and services).

  The results will serve to identify the potential and the design of infrastructure and services for road transport users. It will also define the way to organize a citizen oriented network of transport services. In this perspective, it is important to define the socio-economic and psycho-social variables like costs and revenue, social responsibility and fairness, for example, determining the road users' behaviour.

- **Milestone 2:** To **INFLUENCE & CONVINCE** road user behaviour and expectations at mid- term (2020):

  Once collected the data about the socio-economic and psycho-social variables influencing the road user behaviour, it is necessary to design the corresponding policy actions to influence the behaviour of road users. In other words, it is hopeful to define the TDM policy measures accompanied by awareness campaigns, marketing and their impact analysis.

  Once obtained the results about road user behaviour and expectations, it is needed to identify
  - Policy actions that influence user behaviour
  - Best practices of management of transport infrastructures and facilities
  - Co-modality and multimodal management
  - Answers to targeted TDM policy actions

- **Milestone 3**: To **CHANGE** road user behaviour at long-term (2030)

  The target of this roadmap is to change user behaviour to achieve the objectives of 50% efficiency improvement by identify and analyze their behaviour and expectations. In this last milestone, the research areas may focus on the long term objectives on changes of behaviour of road users after the implementation of new policies.

The following two tables (Table 1 and 2) summarise the detailed description of the three milestones with respect to the four longitudinal research areas and the two transversal research lines, respectively.

Table 1 – Milestones of longitudinal research areas

	Milestone 1 (2015)	**Milestone 2 (2020)**	**Milestone 3 (2030)**
	Understanding Road Users behaviour and expectations	**Influence & Convince** Road Users behaviour and expectations	**Change** Road Users behaviour and expectations
Reliability	- Collecting DATA on trip characteristics and user preferences	- Adaptation of regulation and transport services to the preferences and characteristics of road users	- Change of transport services and schedules in relationship with the characteristics and preferences of road users
Co-modality	- Obtaining variables characterizing users´ behaviour in respect to co-modality - Analyzing different case studies among European cities	- Make co-modal transport services safer and more convenient to users	- Implementation of smart, seamless and friendly co-modality infrastructure and services.
Environment	- Collecting DATA about the economic and psycho-social attitudes of road users in respect to the environment	- Create incentives for the road users to economize fuel consumption and to reduce CO2 and other emissions	- Zero pollution and environment friendly policies for transport by a change of users behaviour
Travel demand management	- Including Comprehensive DATA about users´ characteristics and preferences - Analysing the impact of TDM measures	- Define acceptable, easy and costless TDM measures	-Travel Demand Regulation to reduce the road congestion

Table 2 – Milestones of transversal research lines

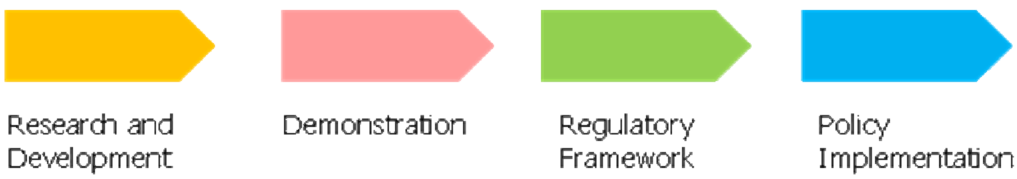
	Milestone 1 (2015)	Milestone 2 (2020)	Milestone 3 (2030)
	Understanding Road Users behaviour and Expectations	**Influencing & Convincing** Road Users behaviour and Expectations	**Changing** Road Users behaviour and Expectations
Travel demand estimation	- Obtaining data about the travel demand of road user	- Estimating and forecasting the travel behaviour of road user	- Use the results of Milestone 1 and 2 to define new transport demand policies to change road user behaviour
Technology Responses	- Defining a common database on users´ preference and needs	- Improving transport technologies innovations among the most popular road transport modes.	- Incorporate new transport technologies to make road modes more friendly and convenient for road users.

6. Roadmap phases and their milestones

Following the definition of milestones, this section defines the roadmap corresponding to the two types of research (longitudinal and transversal) in order to achieve the stated objectives.

The roadmap indicates the main tasks towards a better understanding of road user expectations and behaviour.

The framework document of the roadmap elaborated in the ERTRAC Strategic Research Agenda (2010) defines four steps for the implementation of the actions for each roadmap. The following arrows synthesize these steps that have been use for the action diagram below:



A) Longitudinal Research Areas

A1) Reliability

- Studying variables related to transport reliability including intermodality
- Carrying out surveys on satisfaction of transport schedule and territorial accessibility
- Analysing the impact of reliability on user behaviour
- Analysing accessibility for metropolitan areas

A2) Co-modality

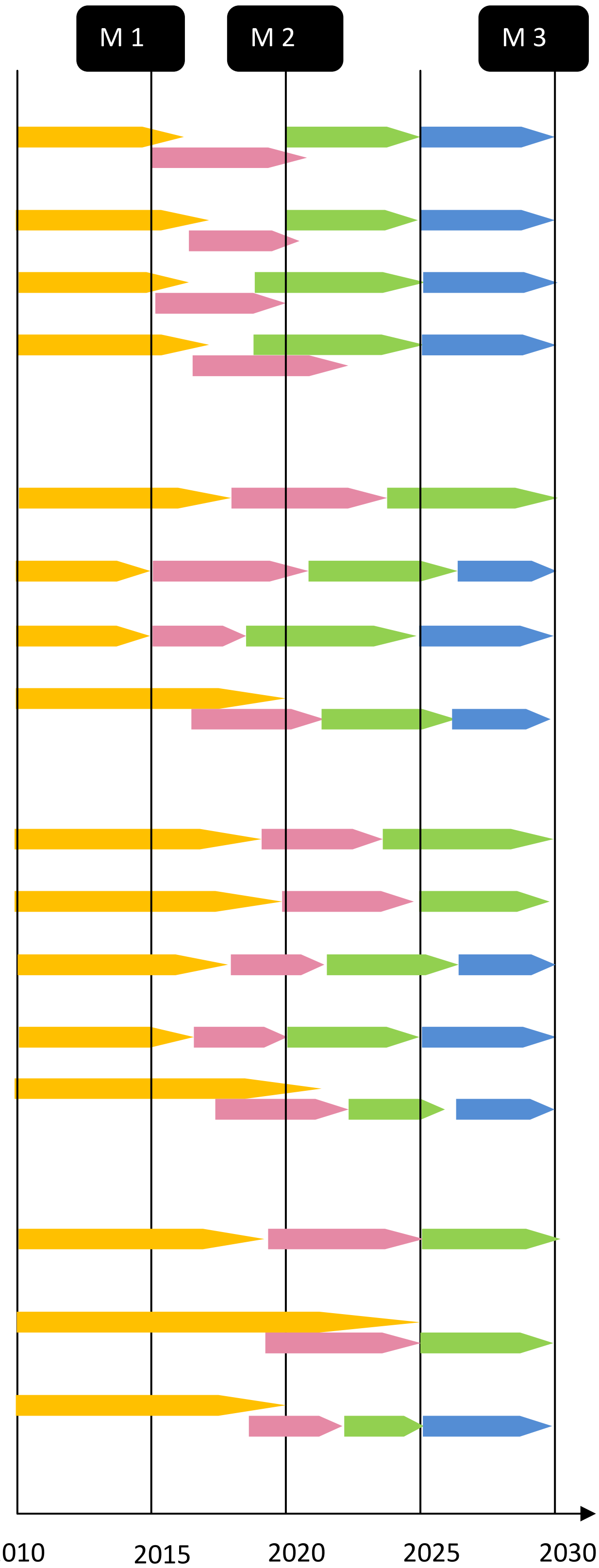
- Identifying road user behaviour and expectations in respect to the connection with other modes
- Analysis of expectations and behaviour of users of intermodal services and multimodal transport
- Implementing door to door information and service
- Making easier, better and friendlier interchanges

A3) Environment

- Calculation of individual carbon footprint
- Energy consumption estimation per person and per trip option
- Impact of information about environment and health effects on user behaviour
- Health concerns evaluation: obesity, stroke etc.
- Social costs estimation including various externalities

A4) Travel Demand Management

- Analysis of users´ attitude, preference and acceptance of road pricing policies
- Evaluation of past TDM policy actions and criteria for improving their effectiveness
- Users´ expectations definition about public and private transport services



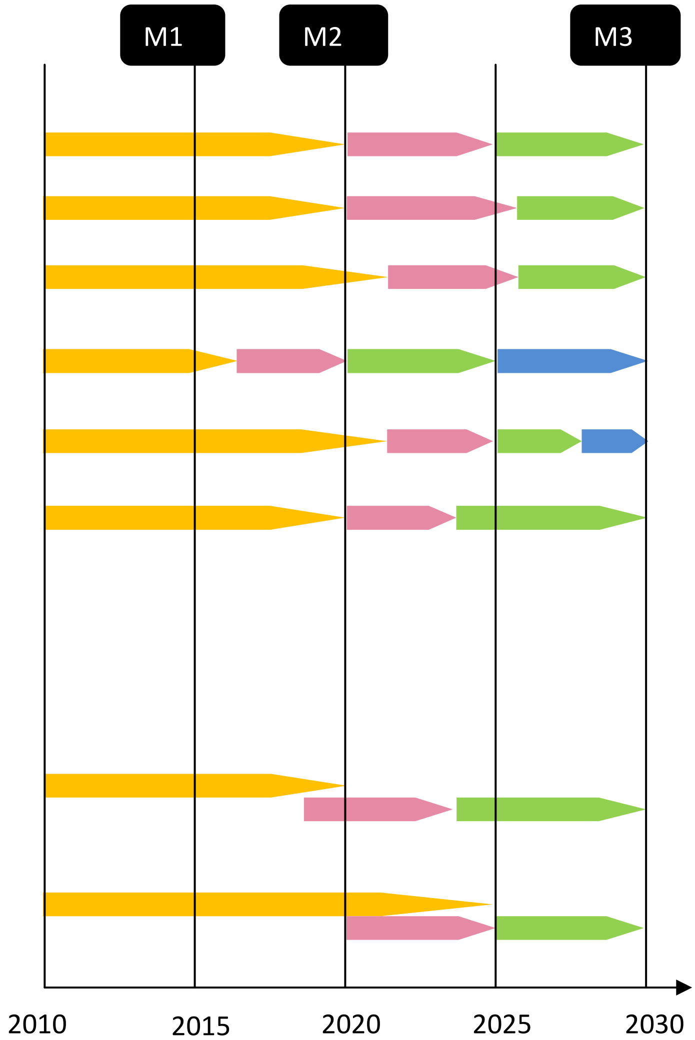
B) Transversal Research Lines

B1) Travel Demand Estimation

- Implement aggregate & disaggregate surveys
- Estimate demand models
- Analyze sensitivity to TDM policies
- Identify impacts of different categories of road users
- Analyze the characteristics and attitudes of road users with respect to road pricing schemes
– Study traveller behaviour and expectations related with future integrated transport system

B2) Technology Response

- Identification of general road user needs, expectations and responses related with new technologies
- Estimation of specific impacts of new technologies on future road users' behaviour



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7. References

- ERTRAC Strategic Research Agenda 2010. Towards a 50% more efficient road transport system by 2030, May 2010
- European Commission COM (2007) 551, Green Paper 'Towards a new culture for urban mobility'.
- European Commission Action Plan on Urban Mobility: SEC(2009) 1211-1212
- Innovation Union strategy COM (2010) 1161, 'Europe 2020 flagship Initiative - Innovation Union'.
- Green Paper on the next Framework Programme: COM (2011) 48, 'From Challenges to Opportunities: Towards a Common Strategic Framework for EU Research and Innovation Funding'.
- Transport White Paper COM (2011) 144, White Paper 2011 'Roadmap to a Single Transport Area - Towards a competitive and resource efficient transport system'.
- Mobility and Transport in FP8. EUCAR position, November 2010
- The strategy for clean vehicles COM (2010)186, 'A European strategy on clean and energy efficient vehicles'.
- Europe 2020 strategy COM (2010) 2020, 'Europe 2020 - A strategy for smart, sustainable and inclusive growth'.
- Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport
- Communication from the Commission: Action Plan for the Deployment of Intelligent Transport systems in Europe [COM(2008)886]

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European Roadmap

European Bus System of the Future

Version June 16, 2011

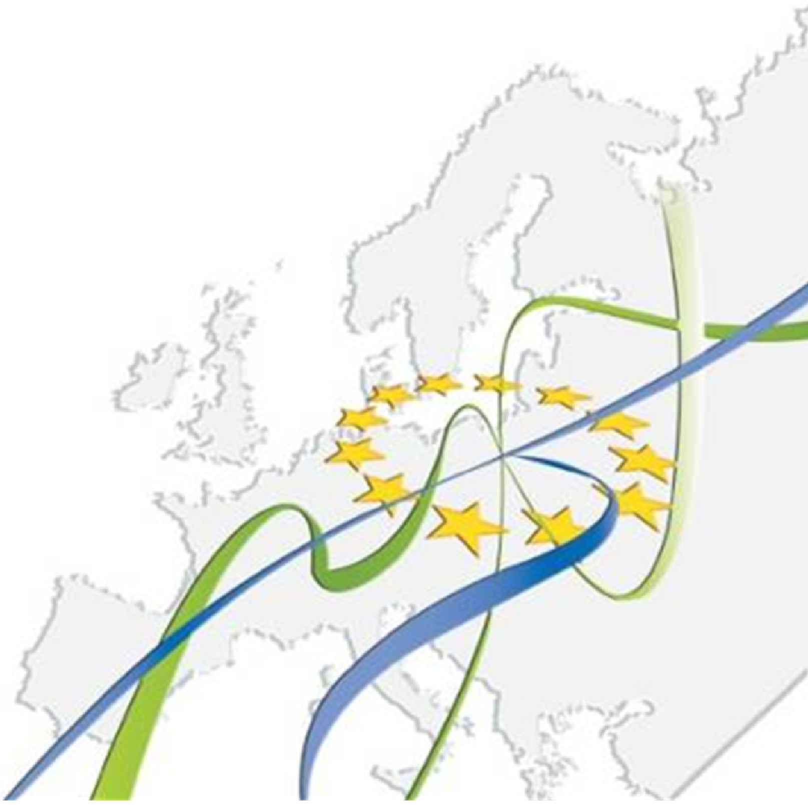

Table of Contents:

1. Executive Summary

The main research objectives for the stakeholders of bus systems such as the industry (manufacturers and suppliers), operators and authorities are identified in line with the UITP global association strategy for the Public Transport sector of doubling PT market share by 2025:

- Reduction of the production costs, increase of the efficiency and the productivity, and increase of competitiveness
- Better effectiveness of investments and operation costs
- More attractiveness of bus systems for existing passengers and for potentially new customers
- Environmental performances and energy alternatives.

2. Introduction

2.1 Background

Today, urban public transport is able to give relevant contribution to some of the EU key issues, such as a more homogeneous European citizens living standards, to achieve a full economic integration, and to reduce the unsustainable sacrifice of human beings that the European society annually pays on its roads to perpetuate its economic model.

On this regard, the bus is a very efficient mode of public transport, as it is cheap, flexible and, in many cases, tailored to the needs of end-customers both in terms of capacity and speed. Buses operate most of the time in mixed traffic. They are therefore in the front line in competing with private motorised transport. In addition, buses have moderate infrastructure costs (mainly depot and workshop but also stops), and are easy to put in service. From an economic, environmental and social point of view, buses still remain the most universal solution for a balanced and sustainable urban development. Today, urban buses have a stake of 60% of the total European public transport in urbanised areas[1].

Urban buses offer clear advantages also in terms of less space needed to answer the mobility needs of citizens. Furthermore, if 69 % of road accidents occur in cities (EU White paper on Transport, 2011), public transport is by far recognized as the safest means of passenger travel amongst ground transportation modes. Travelling by bus in particular is ten times safer than by car.

Although bus systems still remain the most universal solution for balanced and sustainable urban development, from an economic, environmental and social point of view, they have often suffered from a poor public image. The bus is still perceived as less attractive than other modes of transport.

In order to break such perception, EBSF (the European Bus System of the Future) is conceived as a driver to increase the attractiveness and raise the image of the bus systems in urban and suburban areas, by means of introducing new technologies on vehicles and infrastructures in combination with operational best practices.

[1] UITP statistical findings

Through the application of a “system approach”, which looks to vehicle, infrastructure and operation as a whole, EBSF aims at setting up innovative high quality bus operating in the new generation of urban bus networks in Europe.

In these years, the EBSF system has been designed in its basic characteristics and functionalities. In addition, some related key new technologies and operational concepts have been developed, simulated and tested in real urban scenarios. Last but not least, EBSF has set-up the initial frame for the harmonisation and standardization of the solutions developed.

In the research scenario, the European Bus System of the Future (EBSF) can be seen as a tree where European research activities on bus systems grow like branches. In coherence with the global system design performed by EBSF and the common specifications defined in EBSF, these new branches:

- develop specific areas or aspects of the whole EBSF system,
- contribute to enrich the global bus system definition

EBSF is based on the identified requirements for bus systems (for the whole system as such and in detail for each system component vehicle, infrastructure and operation) which were validated by a large number of stakeholders (public transport operators, public transport authorities, bus manufacturers). Stakeholders can access to the latest up-to-date EBSF specifications through a specific repository and traceability tool: this would enable the homogeneous and transparent deployment of the EBSF tree through the whole bus sector (i.e., authorities, operators, manufacturers, suppliers).

Furthermore, it must be underlined that the “EBSF tree” with its system requirement and architecture platform, will emerge as the benchmark for testing innovative solutions or analysing the impact of changes on the requirements or behaviour. For example, it could be used to assess the effect of new enabling technologies (like Galileo, Wireless Mesh communication radio system) on IT applications and guidance solutions; or it could be the basis to analyse new requirements coming from new environmental issues.

2.2 Scope

The EBSF Roadmap is built on the basic key functionalities identified for the Bus Systems. With the aim to improve the attractiveness of the bus service as a means to achieving modal shift without adding constraints to people, the different aspects which improve the attractiveness of the bus service are exploited, like comfort, performances, safety and costs.

The Roadmap enables EBSF to identify and assess the most promising future solutions, technologies (IT and engines etc) and upcoming needs (social, economic and environmental) by offering a platform

for their definition, development and test. Then, the EBSF system definition can evolve according to upcoming needs or advantageous new technologies.
On this purpose, the strong use of open technical standards (current and future) and shared operation practices is an important element to reduce costs, improvement operations and enhance product quality for public transport users.

An important part of the Roadmap deals with the EBSF integration in the future urban mobility scenarios, in order to achieve an efficient use of urban space and contribute to improving the image of the city. A service which is integrated into the city-environment and that gives to people the possibility to reach their destinations without obstacles enables the city to focus on its living and working-functions.
To achieve integration, is necessary the efficient interaction with other private and public modes of transport; such interaction requires coordination and planning, as well as operational aspects on transport devices, interchanges, information, etc.…

The Roadmap exploits research areas for all the bus system stakeholders:

- to provide all kind of passengers with different needs, goals, experiences and expectations with high quality bus services integrated into their operational environment, and combining a set of complementary services and transport organisation concepts for different sizes of cities.
- to offer different Bus System Solutions to decision makers: for this reason, EBSF has to include tools to assess its quality parameters in order to provide the European decision makers with the most appropriate information to make the right implementation choices, to identify the best solutions, to pursue optimization in investments, etc…
- to allow a reduction of the operational costs: all along its implementation, encourages the development/introduction of technologies and practices for operational cost reduction/control, like maintenance costs, with an impact on the subsidizing government or the customers.

The roadmap addresses the smart use of existing and alternative energy resources for all the elements of the bus systems. The smart use of the resources (maximal performance per energy-use) and research and development of alternative and cleaner energy sources are key points for bus and public transport in general, in order to maintain its characteristic of an environmentally-friendly transport mode.

Then the roadmap addresses the adaptation of the bus system to each specific operational and environmental condition: modularity at all levels can balance the highest level of standardization required by the operator and industry and the individualization of the service provided according to users' preference to have environmental benefits.

The topics included in each area of the roadmap have been initially identified in the last two years by the EBSF Project Consortium. Then, with the objective to produce a roadmap complete, robust and supported by the key actors in the bus service domain, a wide consultation process involving more than 100 stakeholders has been done, involving the EBSF User Group, the UITP Bus Committee, the UITP VEI (Vehicle Equipment Industry) Committee and the UITP ITI Committee (for the aspects relative to the ICT).

As results of the above process, the 6 following research areas have been identified.

1. EBSF integration in the urban scenario, including bus-stop/terminal and urban infrastructure aspects, new system functionalities, the contribution of bus system to the evolution of the concept of urban mobility, and the aspects needed to facilitate the introduction of the EBSF concepts.
2. EBSF ICT platform integration, including standardisation aspects, and the development of key pilot applications, in particular relative to interoperable passenger information and evoluted maintenance processes based on remote diagnostic and predictive maintenance.
3. The sustainability of bus system, in terms of energy efficiency, improvement of the environmental performances, and key aspects relative to the electrification of the bus systems.
4. Research on innovative vehicle technologies, oriented to drive modes, accessibility and comfort
5. Modularity through the application of the system approach, and after the allocation and development of the different functionality aspects to vehicle, infrastructure and operation.
6. The mobility challenges of an ageing society, as majority of European countries are facing an increase of the average population age, and therefore it is important to make public transport more attractive and especially usable by elderly people.

3. Benefits to Grand Societal Challenges

The following figure summarizes the guiding objectives (corresponding to the main areas and indicators) of ERTRAC's "Strategic Research Agenda aiming at a 50% more efficient Road Transport System by 2030".

With reference to it, the grand societal challenges addressed by the ERTRAC Agenda for 2030 and objective of the EBSF Roadmap are:

1) Decarbonization: energy efficiency for urban passengers
2) Reliability: urban accessibility
3) Safety: accidents with fatalities and severe injuries

By considering the system approach on the optimization of interaction of bus vehicles, bus infrastructure and bus operation, the EBSF roadmap will help to increase the performance and efficiency of bus systems (the "green evolution" of the whole bus system) as well as make them more attractive for customers. This will result in an increase of passengers using such bus services and the overall public transport system with a modal shift that is the most efficient strategy towards decarbonisation.

As mentioned in the EU White Paper on Transport (2011), "in addition to lowering greenhouse gas emissions, soft modes of transport (walking, cycling and public transport) bring major benefits in terms of better health, lower air pollution and noise emissions, less need for road space and lower energy use" (point 61). Thus "personal mobility would also be enhanced by greater quality and availability of public transport. This would also reduce accidents, noise and improve air quality" (point 122).

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'.

Figure 2. Guiding objectives for 2030 (ERTRAC 2010)

As a result, the EBSF Roadmap will significantly contribute to the targets set in ERTRAC SRA to increase the energy efficiency of the urban mobility network by 80%, to improve current levels of accessibility as well as to reduce fatalities and severe injuries in road accidents by 60%.

4. Milestones and Roadmaps

This section details the roadmaps of several topics on innovation and research for bus systems. In general such topics can be developed in the framework of large research and demonstration projects capitalising to a maximum extend the already available knowledge developed for the European Bus System of the Future (EBSF) by the ongoing activities, and more mature results could include or drive harmonisation, standardisation and legislation.

The roadmaps are drafted indicating the main phases to achieve the objective, considering research & development, demonstration as well as the establishment of regulatory frameworks and market introduction. The colours associated explanation of the arrows used in the roadmaps is given below:

a. EBSF integration in the urban scenario

The “Bus System” perspective should be prioritised in order to manage efficiently interfaces with infrastructure, traffic and all users’ needs. Combining a “system” approach which links end-users, vehicles, infrastructure and operations together with a high service quality is a daily challenge for operators and manufacturers. The “bus system” integration refers also to the coherence and complementary of its own characteristics with other modes of transports and its ability to adapt to the different typology and transport infrastructures of the cities.

Bus-Stop and Bus Terminal (co-modal and intermodal)

- New generation of bus-stop and bus terminal with: scalable design; architecture to facilitate passenger flow. It includes also the design of bus sections in the interchanges stations and the needed accompanying measures (like regulations and guidelines for Natural Gas buses in underground interchanges).
- Provision of integrated (PT and not-PT) information in bus stops and terminals.
- Integration of stops and terminal in the whole city planning as key for seamless mobility.

  Development of new service and business models (like private sector participation) for infrastructure, bus-stops and terminals funding and exploitation, aiming to economically profitable integration of bus stations/stops into the urban environment (for mixed used of transport and urban functions).

Urban infrastructure for bus systems

- Improvement of average bus commercial speeds via technical solutions (optimisation of traffic light control for enhanced crossroads performance; wear-resistant material for bus lanes -especially if guided-, rutting –orniérage-, etc…), development of a suitable regulatory framework (for example to provide BHLS the same priority that the tram has, by suggesting at CEN level a work item on bus priority for testing and studying the conditions for giving to the bus the priority that the tram have in reference to the Vienna convention on Road Signs and Signals – 1968) and improvement of the interfaces between operators and authorities.
- Improvement of special users’ accessibility to urban public transport infrastructure (digitalisation / special adaptation to guide special needs’ passenger…).

Contribution of Bus systems to Urban mobility concepts evolution

- Market and sociological studies (such as evolution in trends of needs and expectations), to ensure the understanding of mobility needs of citizens, to accompany technological developments and consequently the evolution of the bus system.
- Bus mobility concepts as contribution to smartcity mobility mix, done by individual traffic and public transport
- Development of intermodal transport concept and strategy (which include also bicycles and e-bikes) to maximize the efficiency of the urban transport system using a wide range of measures, including congestion pricing, public transport improvement, promoting non-motorised transport systems and policy tools for mobility management.

EBSF System functionalities

- Design of EBSF external interfaces (with “outside PT world” and “other services of PT network”) as contribution to mobility management. Outside PT world is considered as the set of entities which interact or can influence the bus service and does not belong to the PT domain. For example: urban utilities, police, meteo information provider.
- EBSF specification management tool, available to PT stakeholders for tendering processes to set the requirements for the suppliers accordingly with the EBSF results and prescriptions, and featuring content updates to accommodate results of further EBSF R&D activities
- EBSF assessment tool available to PT actors for assessing options of changes in specific areas (for example accessibility) by choosing the most suitable KPI from the EBSF KPI Database, evaluating them according to the indicated methodologies, and eventually creating composite quality factors defined on purpose. In particular, creation of test environments where users with special needs (not only physically or mentally-challenged users but also elderly and children) may assess and validate innovative solutions for transit facilities and vehicles, in order to elaborate safety, security, comfort, accessibility specifications and establish common design criteria at EU level. In particular are identified:
  - common indicators for bus safety assessment, in particular for sharing results among BHLS. In fact, even if buses are the safest mode of transport, BHLS are increasing with higher speed and specific lanes, so that there is now a need to be able to measure the effects of these trends, in order to maintain the same quality and safety level.
  - enlarged indicators for quality assessment in contract between operator/authority: for example standard deviation indicators, geographical presentations… This could also require to improve, in case, afterwards the EU standard on service quality (EN 13816).
- Define of EBSF Safety Management Systems (SMS) in line with the EBSF requirements and functionalities. They are composed by processes and tools specifications for assessing “changes” in the system from the point of view of safety of the system itself. The implementation of the most modern practices and tools for safety management allow every evolution related to bus transport to be subject to safety assessments.

EBSF introduction

- Analysis of Bus Service models in Europe and identification of an optimal theoretical service model for EBSF
  - Pilot case of bus services developed according to EBSF recommendations, in order to demonstrate the understanding of the mobility needs of citizens.
- Implementation strategies for advanced BRT systems
- International cooperation also with extra-EU actors for:
  - raising the awareness of the EBSF (by improving the bus system image, promoting its sustainable character)
  - cross-feeding between experiences in innovative bus-services (with South America, US, Asia)
  - transferring of applicable concepts to developing countries (like Africa)
- Identify appropriate governance and (new) financing instruments, in order to ensure a more rapid deployment of research results (in cooperation with EIB and national bank authorities) and coverage of start-up costs necessary for enlarging offer of public transport, with an effective co-operation between the European funding agencies (EIB), and local, regional and national governments and bank authorities (e.g. similar programs like the trans-national funding program ERA-NET Plus "electromobility").
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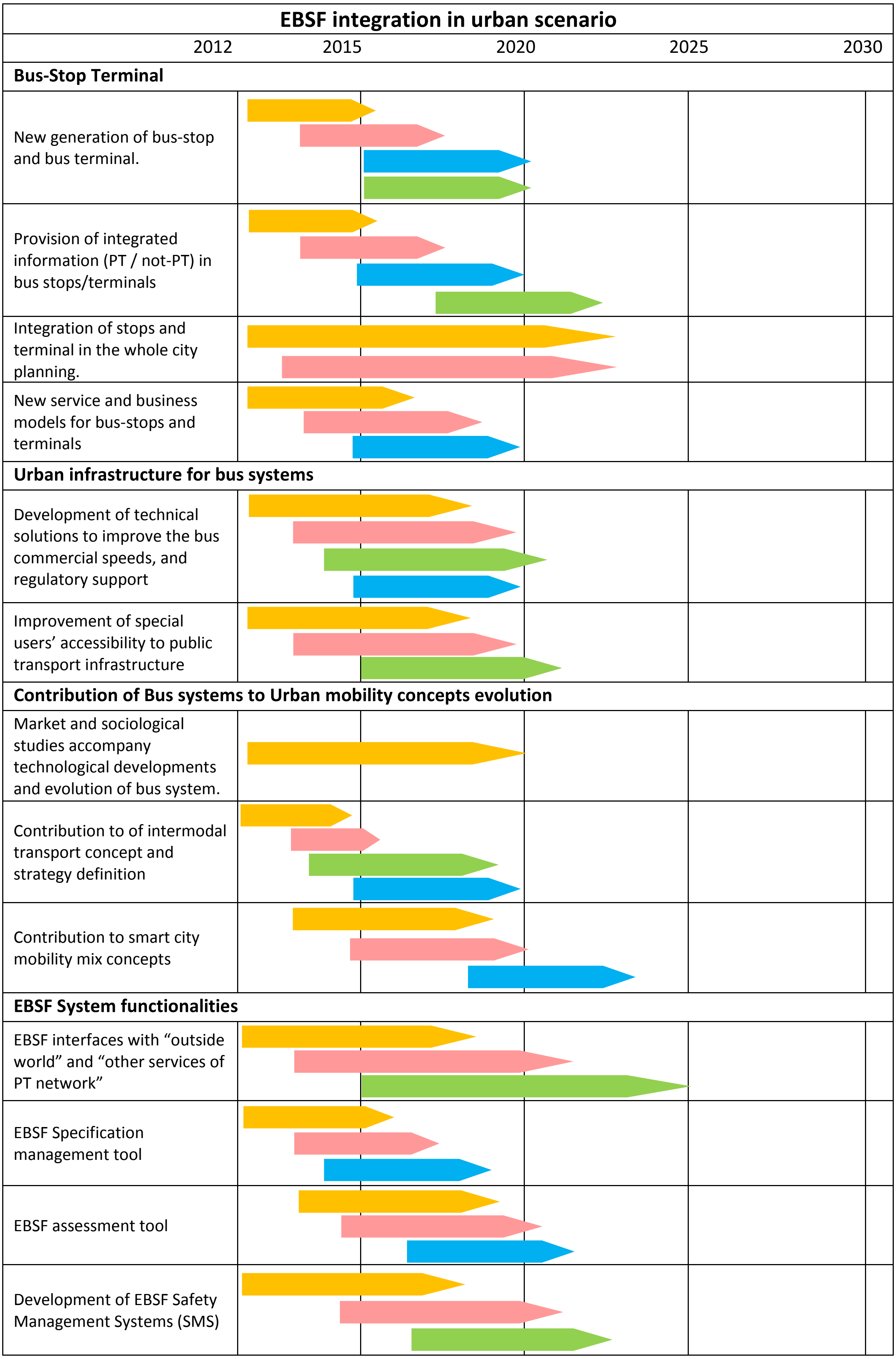
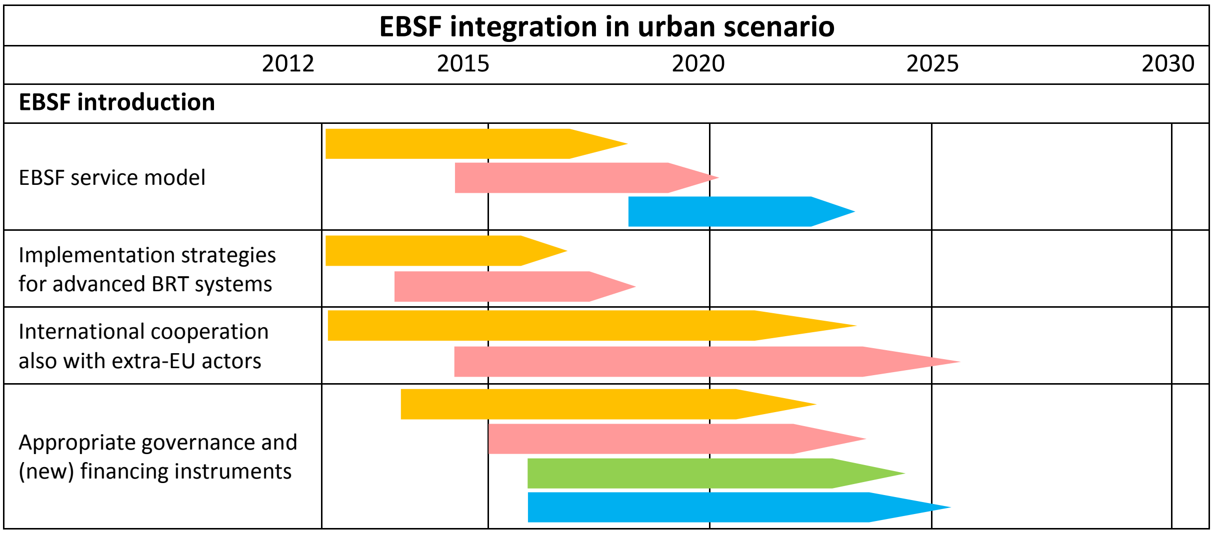

EBSF integration in urban scenario
2012
2015
2020
2025
2030
Bus-Stop Terminal
New generation of bus-stop and bus terminal.
Provision of integrated information (PT / not-PT) in bus stops/terminals
Integration of stops and terminal in the whole city planning.
New service and business models for bus-stops and terminals
Urban infrastructure for bus systems
Development of technical solutions to improve the bus commercial speeds, and regulatory support
Improvement of special users' accessibility to public transport infrastructure
Contribution of Bus systems to Urban mobility concepts evolution
Market and sociological studies accompany technological developments and evolution of bus system.
Contribution to of intermodal transport concept and strategy definition
Contribution to smart city mobility mix concepts
EBSF System functionalities
EBSF interfaces with "outside world" and "other services of PT network"
EBSF Specification management tool
EBSF assessment tool
Development of EBSF Safety Management Systems (SMS)



b. EBSF ICT platform integration

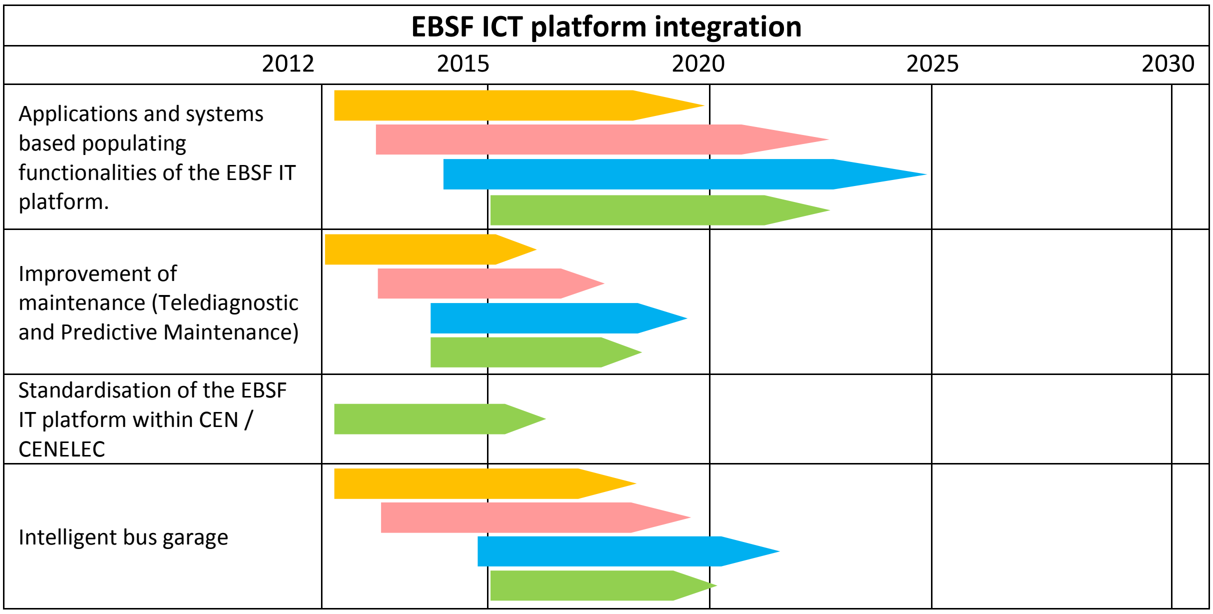
Standardization and harmonization of information system and open architecture are the logical answer to efficient bus system integration.

In general, individual mobility can be achieved only by guaranteeing that clear and complete information are provided to the passenger all along his journey, and independently by the combination of means of transport he use: the PT-user requests complete (i.e. relative to all the means composing the urban mobility scenario), permanent, available and updated information to move from A to B and to remain informed about possible changes all along the trip. For this reason, interoperability between the systems that contribute to the set of information required by the passenger has to be ensured, to provide timely and complete information to the passenger during the entire trip, from the planning stage to efficient door-to-door navigation.

For operators, harmonization of information system through an open architecture is the priority to improve quality of the service provided to the citizens, by enabling efficient maintenance procedures that are based on remote diagnostic to the on-board systems, and prediction of failures by applying sophisticated algorithms.

- Development and test of pilot applications and systems based on the IT platform for communication between vehicle, stations/stops and “back office” developed in EBSF, taking advantage by new enabling technologies (Galileo, Multi-channel gateway using wireless mesh communication network), and targeted to the specific stakeholders needs (i.e. fleet management systems, operations control, integrated ticketing, passenger counting for PT operators, multimodal travel information for passenger/infotainment, traffic data for public authorities, law infringement for police, system performance for industry)
- Improvement of maintenance processes through: the mature implementation of remote diagnostic; and the development of algorithms, implementation of software and systems integration for predictive maintenance of key vehicle equipments.
- Follow-up of the already started standardisation activities for the EBSF IT platform and its IP based communication protocol.

- Development of concepts, requirements and technologies of an "intelligent bus garage", with programmable multi-function utilities for fleets with large variety of vehicles. This activity is based on the EBSF back-office specification and design and includes pilot.



c. Sustainable bus system

A sustainable Bus System is fundamental to achieve the strategic objectives. Sustainability of bus system can be reached via smart use of the energy all along the Bus System (of which the electrification offer an important contribution), and the improvement of the environmental performances.

C1. Energy Efficiency of Bus Systems

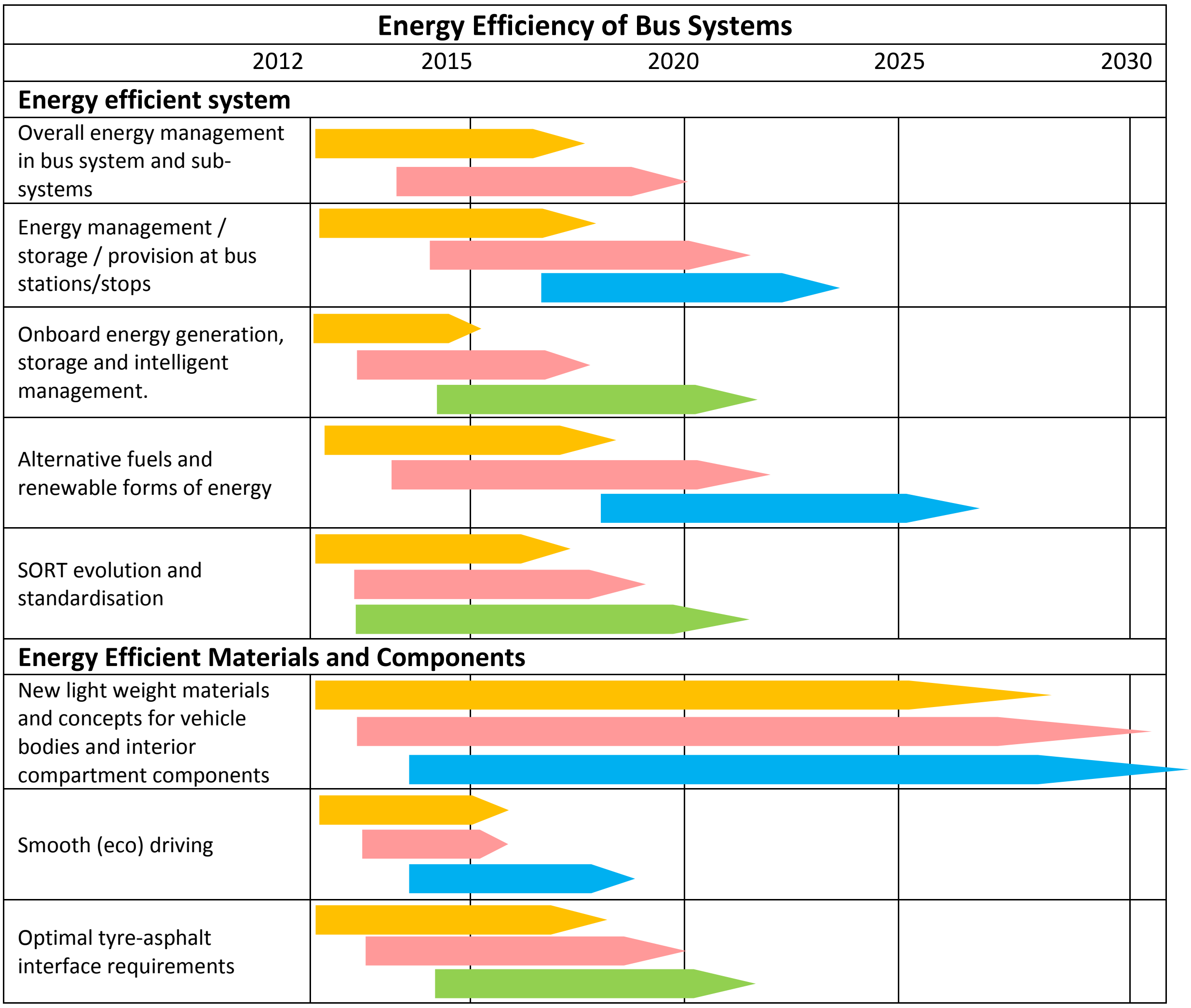
The Bus Systems of the Future shall facilitate and promote the smart use of existing and alternative energy resources: the smart use of the resources (maximal performance per energy use) and research and development of alternative and cleaner energy sources are key points for EBSF and public transport in general, in order to maintain its sustainability and its characteristic of an environmentally-friendly transport mode. To pursue that, it is necessary to focus researches:

Energy efficient system

- Overall energy management solutions for bus systems taking into account vehicle, infrastructure and operation, like efficient bus lanes and traffic control measures.
- Energy management at bus stations/stops (via photovoltaic decentralised energy supply), in combination with “plug-in”/docking solutions to rapidly charge energy into electric buses, energy storage (in batteries)
- Onboard energy generation, storage and intelligent management, including recuperation of maximum breaking energy for hybrid vehicles, new HVAC, auxiliary components and total energy management for electric buses.
- Further developments of alternative fuels and renewable forms of energy with a particular attention to hybrid and electric solutions (see C3)
- SORT evolution and standardisation at European level

Energy Efficient Materials and Components

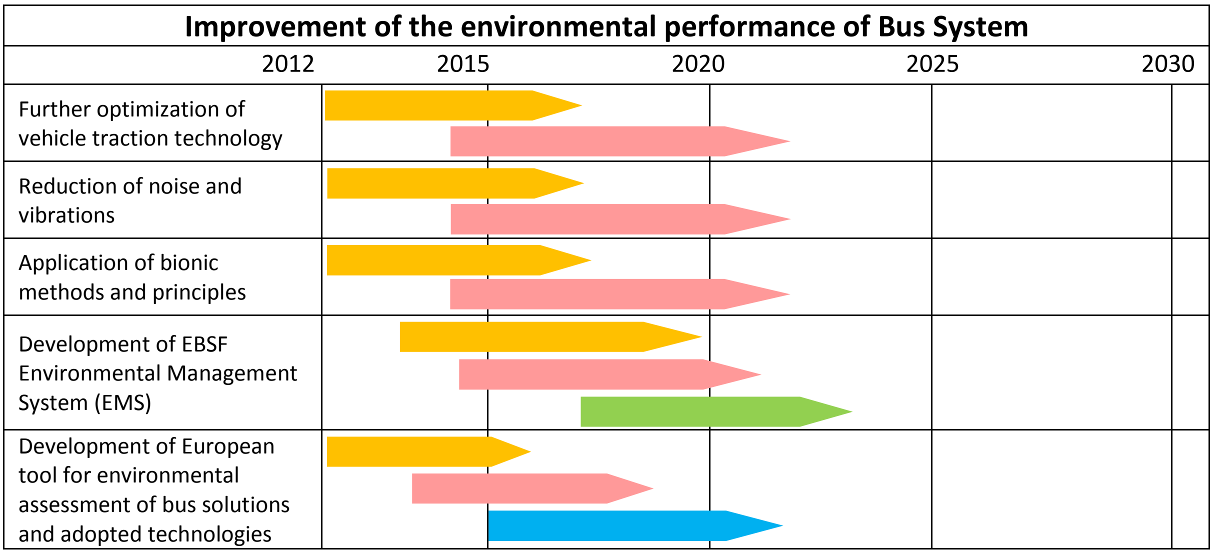
- Development and application of new light weight materials and concepts for the production of vehicle bodies and interior compartment components
- Research in smooth (eco) driving, optimal tyre-asphalt interface requirements



C2. Improvement of the environmental performance of Bus System

In the light of further demands from European legislation (EURO VI), the need to introduce low GHG emission technologies research for further improvements is necessary in the following areas:

- Further optimization of vehicle traction technology including innovative gear control systems
- Reduction (in particular active reduction) of noise and vibrations
- Application of bionic methods and principles like: adoption of specific materials, weight optimisation concepts
- Development of EBSF Environmental Management System (EMS) in line with the EBSF requirements and the functionalities (see also a). They are composed by processes and tools for assessing “changes” in the system from the point of view of environmental impact on the system itself.
- Development of a European tool for the environmental assessment of bus solutions and adopted technologies, and which take into account the complete life-cycle of the vehicle, but also the energy source methods.



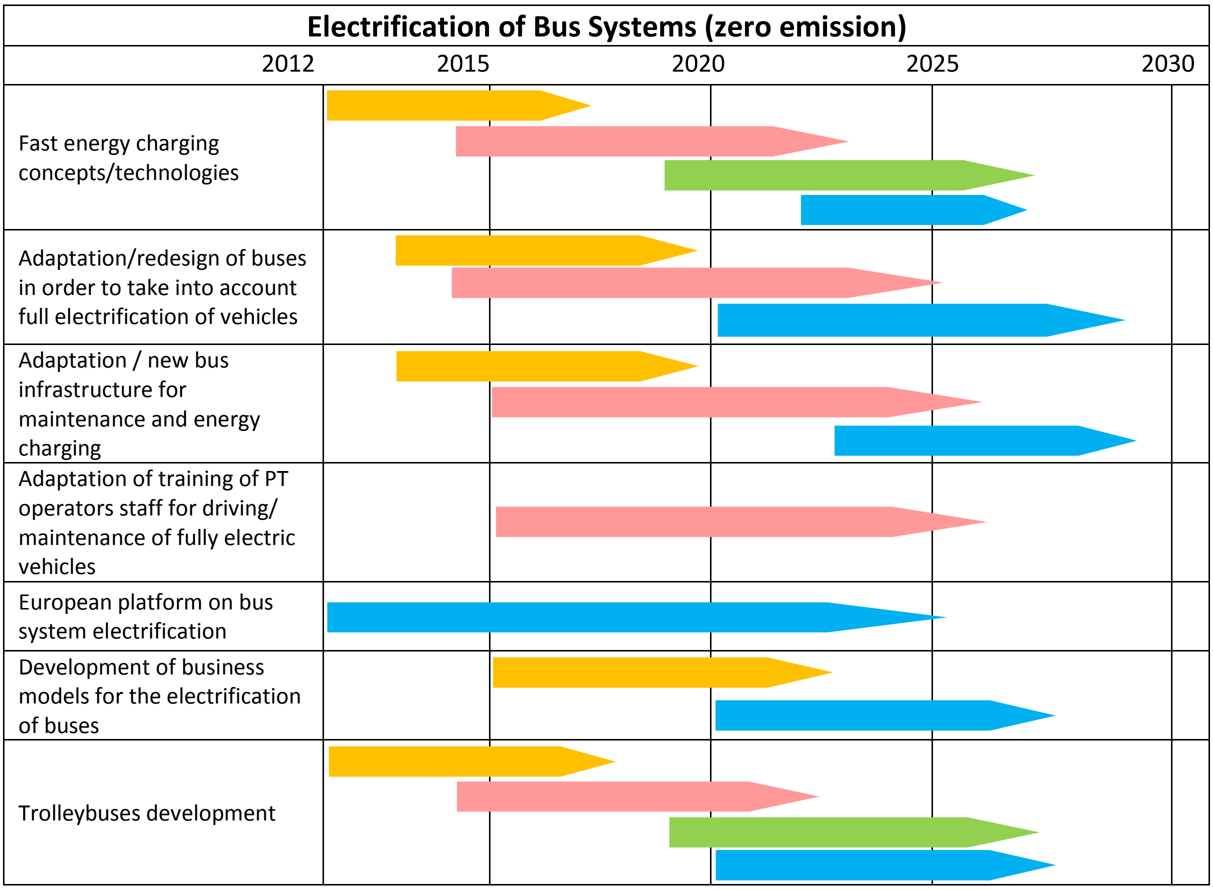
C3. Electrification of Bus System (zero emission)

Electrification of buses contributes to the achievement of the two previous action areas for sustainability; the complexity and potential of the topic requires a specific area of action. Bus fleets are ideal for electrification as buses are normally 10 to 18 h/day in operation and energy charging infrastructure can be installed in a very cost-efficient way in existing bus depots or at dedicated bus stops. Second generation hybrid buses are a first step in the direction of fully electric buses. The trolleybus technology potentialities have to be taken into account in research priorities.

Further research is especially needed in the field of:

- Fast energy charging concepts/technologies ("plug-in"/docking systems/inductive power transfer, high performance batteries/batteries swapping, supercapacitors) during service operation (in contrary to cars which stand still 90% of the day) with high reliability in order to maintain a high availability of buses. For instance, fast recharging available at the terminus (taking just two to three minutes) or at a station (during a normal stop) by recharging the vehicle's on-board supercapacitor storages
- Adaptation/redesign of buses in order to take into account full electrification of vehicles including development of necessary batteries for urban bus operations and optimization of recharging interfaces.
- Adaptation of existing infrastructure for maintenance and design of new infrastructure for energy charging at depots/major bus stops/terminals (including optimization of recharging interfaces)
- Adaptation of staff training of public transport operators for driving/maintenance of fully electric vehicles.
- Common European platform (composed by operators and producers) for exchanges, feedbacks and investigations: by pooling know-how on best practices, this platform could certainly provide a powerful tool for generating economies of scale and also provide the basis for a decision-making tool. Initial activities would be investigations aiming to identify: which type of traffic is suitable for which type of electro mobility; how electro mobility will change the operation from economical and environmental point of view; strategies for development of electrification bus system solutions at European scale.
- Development of business models for the electrification of buses eventually embedded in more comprehensive business models for public transport systems, and exploring funding and incentives schemes.

- Trolleybuses: breaking energy recuperation and feedback in the grid or combination with energy storage systems; relative energy management; contact-less concepts/technologies for down-town and historical city center crossings.



d. Research on innovative vehicle technologies

Oriented to drive modes

- Automatic drive modes and systems
- Design of specific Bus Driver assistance systems like distance control, night view, bird view camera systems, and so on...
- Advanced collision guard systems for bus drivers and pedestrians

Oriented to accessibility

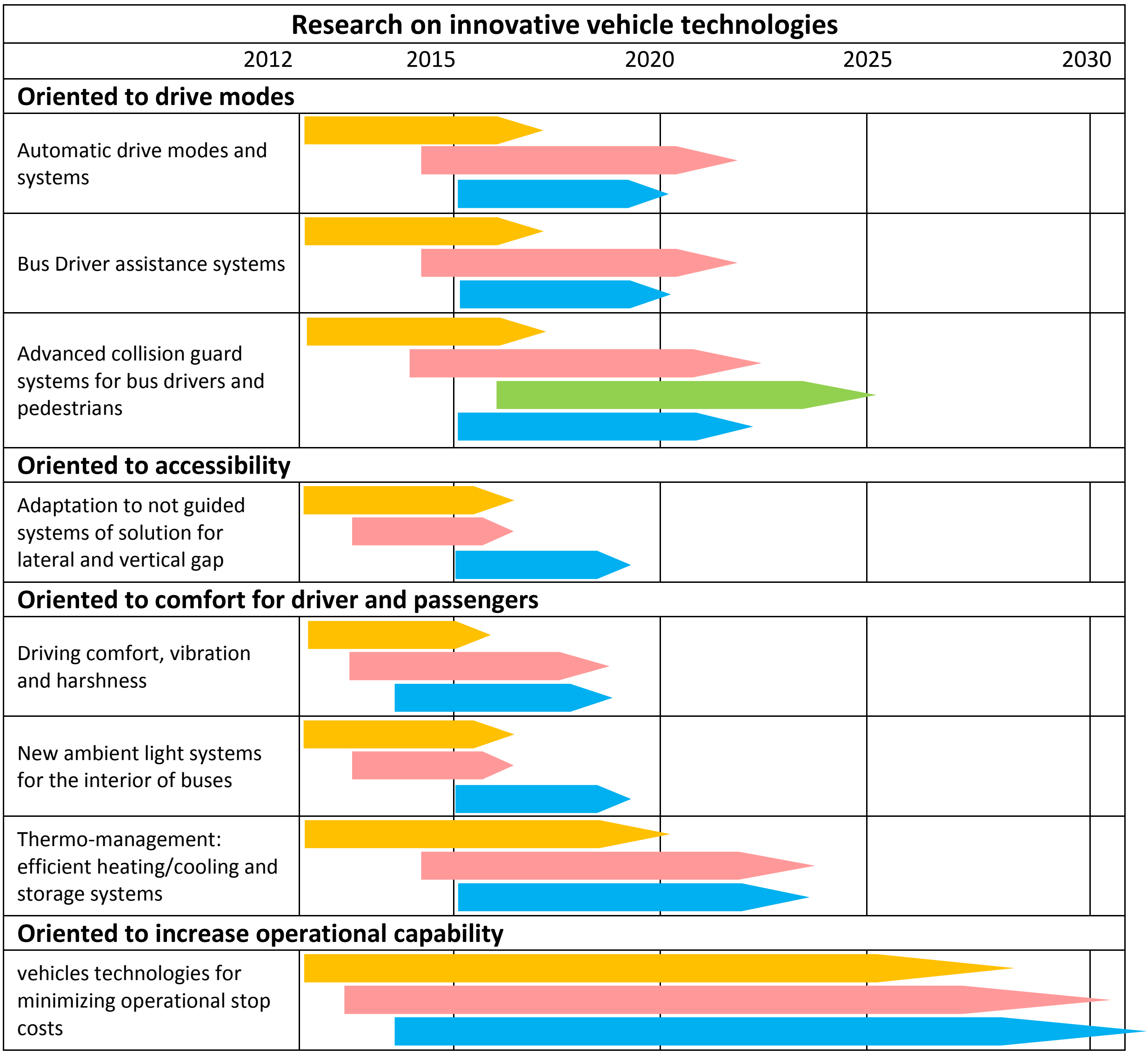
- Adaptation to not guided systems of the solutions to reduce lateral and vertical gap between bus and dock to improve accessibility especially for reduced mobility people

Oriented to comfort for driver and passengers

- Driving comfort, vibration (coming from vehicle and/or infrastructure) and harshness
- New ambient light systems for the interior of buses
- Thermo-management: efficient heating/cooling and storage systems

Oriented to increase operational capability

- Innovative vehicles technologies for minimizing operational stop costs (for example constructive solution of glued bus glasses) due to vandalism effects and collisions


Research on innovative vehicle technologies
2012
2015
2020
2025
2030
Oriented to drive modes
Automatic drive modes and systems
Bus Driver assistance systems
Advanced collision guard systems for bus drivers and pedestrians
Oriented to accessibility
Adaptation to not guided systems of solution for lateral and vertical gap
Oriented to comfort for driver and passengers
Driving comfort, vibration and harshness
New ambient light systems for the interior of buses
Thermo-management: efficient heating/cooling and storage systems
Oriented to increase operational capability
vehicles technologies for minimizing operational stop costs

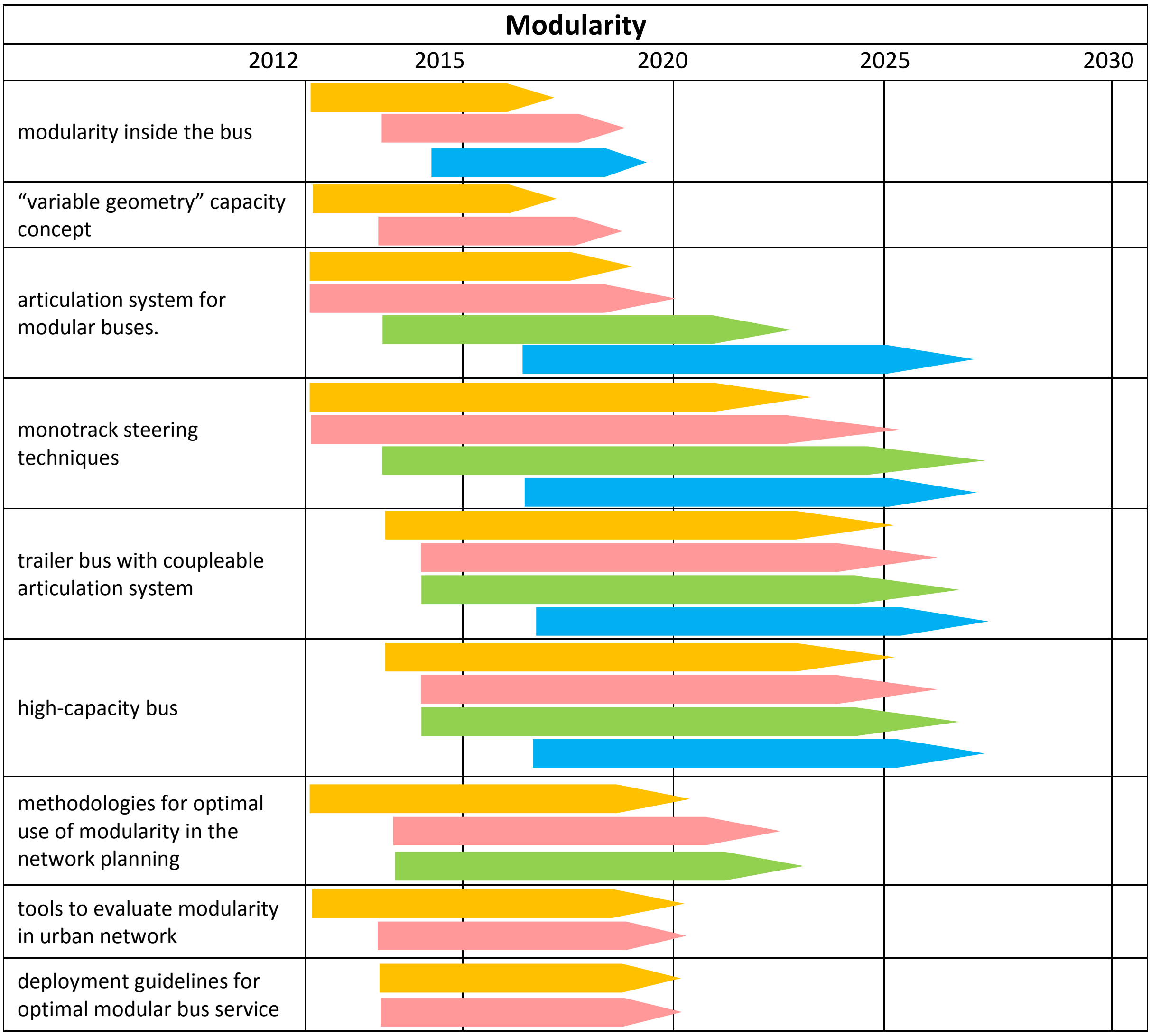
e. Modularity

Modularity can bring an important contribution to the attractiveness of the bus system, through the optimization of the capacity, consumption (and emissions), frequency during different hours according to the demand. It also provides benefits to operators' economy thanks to the increase of the capacity and the dilution of driving costs during peak hours.

For this reason, it is today considered a priority for research for both operators and industries: the first have started identifying the potential benefits, the latter is reaching maturity in the research and development.

The concept of modularity is achieved by applying the system approach, then allocating and developing the different functionality aspects at vehicle, infrastructure and operation level:

- Flexibility of the bus interior layout, for a rapid conversion from maxi capacity to maxi seating
- Develop "variable geometry" bus capacity concept for addressing "peak/off-peak" compatibility.
- Advanced development of articulation system for modular buses aiming to fast and safe plug / un-plug of bus modules.
- Advanced development of monotrack steering techniques and relative prototype. Review of impacted regulations about bus length, and regulatory framework about steering-by-wire
- Development of a bus with trailer by using a coupleable articulation system
- Development of high-capacity bus with a length of 30m+ (to fill the capacity cap between buses and trams)
- Definition of methodologies for making the optimal use of modularity in the network planning, contributing to make easy the identifications of potential benefits,
- Design of tools to identify and evaluate the introduction of modularity in the urban network through Key Performance Indicators specifically identified
- Definition of an optimal deployment plan for the operators, based on the two points above, which will include modularity in the city in the most profitable way.


Modularity
2012
2015
2020
2025
2030
modularity inside the bus
"variable geometry" capacity concept
articulation system for modular buses.
monotrack steering techniques
trailer bus with coupleable articulation system
high-capacity bus
methodologies for optimal use of modularity in the network planning
tools to evaluate modularity in urban network
deployment guidelines for optimal modular bus service

f. Meeting the mobility challenges of an ageing society

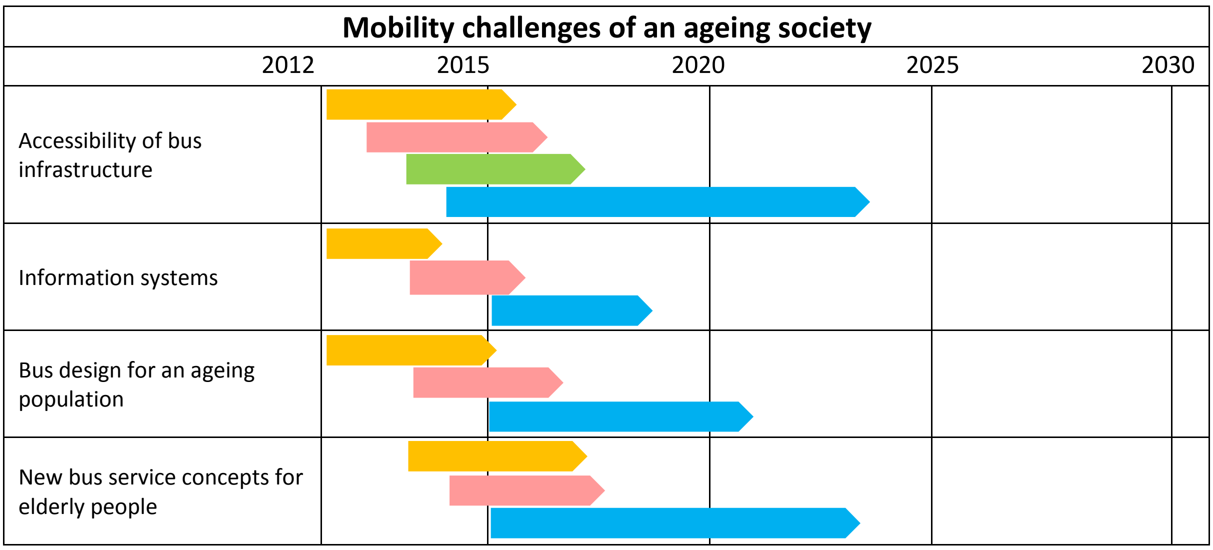
The majority of European countries face average population age increase and the challenges of a shrinking population. It is wrong to assume that elderly people will automatically be “naturally born” customers of public transport. Investigations into mobility behaviour in the US showed that people who grew up using a car will also tend to drive a car as pensioners. Apart from providing service to the public bus operators will be more and more forced to attract elderly people as necessary costumers.

Therefore it is important to make public transport more attractive and especially usable for elderly people. Some features of state-of-the-art buses and bus stops, including information systems, do not meet the requirements of elderly people, e.g. accessibility of bus stops, visibility and audibility of information, arrangement of seats, areas for wheel chairs and walking aids or bus entrance areas.

Most if not all elderly people’s requirements do also facilitate the mobility of people with other mobility handicaps. However, some of the elderly people’s requirements directly interfere with other people’s comfort demands, e.g. sound volume of information, number and arrangement of seats. It is therefore indispensible to find an optimal compromise between the requirements of the different user categories.

Four major research and development areas can be identified

- Accessibility of bus infrastructure including information and guiding systems (distance to bus stops, barrier-free access, visibility of information and guiding signs)
- Information systems at bus stops and inside the bus (e.g. visibility, varying sound volumes of information in different areas within the bus, comprehensibility of information)
- Design of the bus interior incl. entrance areas (e.g. arrangement of seat, areas for walking aids, hand rails, passenger department illumination, colouring and colour contrasts etc.)
- New bus service concepts for elderly people (e.g. flexible bus routes on demand during off-peak traffic)



6. Recommendations

A large consultation of the EBSF Roadmap has been performed within several committees and groups. Such consultation has produced, in addition to specific contributions, the main priorities within the presented topics of the EBSF Roadmap . Here below the main priorities are indicated.

EBSF ICT platform integration. The need for a standardised platform for data communication between vehicle and infrastructure elements is the main priority, due to its positive impact on all the bus service stakeholders, allowing the interoperability of solutions and systems, the development of innovative applications for passengers and fostering the introduction of improved maintenance processes. It is recommended that relevant institutional actors support such standardisation process.

Decarbonisation, electrification, energy efficiency and environmental-friendly bus-system. Such research topics require to be developed with a strong system approach, facing all the aspects that contribute to the objective, not only specifically to vehicle developments or infrastructure. In addition, they require the strong involvement of all the actors of the bus service value chain. For such a reason, it is recommended a long-term perspective with a single dedicated funding programme at European level with a relevant budget to develop European bus system research and incentive and/or co-finance the renovation of fleets. Then, **modularity** (with its impact on operational costs), **innovative vehicle technologies** (in particular oriented to the comfort of passengers and drivers) are identified as priotity, together with operational and technical solutions for increasing **bus average commercial speed**.

Then, priority have been identified for all the aspects relative to the **bus stops, interchange hubs, bus infrastructure components** and **urban infrastructure.**

Finally, it is worth to highlight that in order to improve the attractiveness of the bus-system, promotion of bus services and demonstration of the associated benefits plays an important role, through specific awareness campaign or large pilots.

As stated in section 2, the EBSF “tree” enable the capitalisation and inter-link of all EU R&D related efforts and fields in relation to the bus systems.

7. References

Documentation

- EBSF Project material
- Transport White Paper from DG Move setting the "new" EU transport policy: COM(2011) 144, White Paper 2011 'Roadmap to a Single Transport Area - Towards a competitive and resource efficient transport system'
- UITP PTx2 Strategy

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Consulted groups:

- EBSF Project Partners (all the Consortium partners)
- EBSF User Group (all the members)
- UITP Bus Committee (all the Committee members)
- UITP VEI Committee (all the Committee members)

- UITP EU Committee (some members for some topics)
- UITP ITI Committee (chairman and some members for some topics)
- COST action TU603 “Buses with a high level of service” (all members)
- ERTRAC working group, boards and committees

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ROAD
TRANSPORT
RESEARCH
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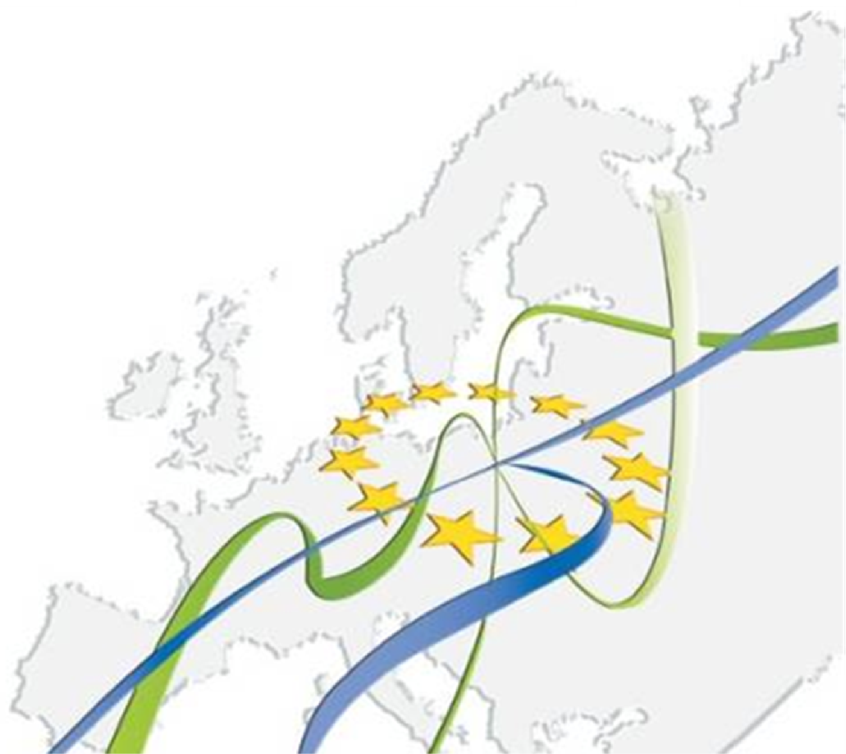
COUNCIL

European Roadmap
Climate Resilient Road Transport

Version May 20, 2011



- A reliable transport system is essential to the functioning European society
- The financial external cost of network interruption from extreme weather events is significant
- Climate change will increase the severity and frequency of extreme weather events and thereby lower the reliability of the transport system
- Given the long life cycle time of infrastructure, action is needed urgently
- The following headline actions are proposed:
  - Assess climate change models
  - Identify vulnerabilities on the key European transport networks
  - Establish future service levels
  - Identify technologies for climate change adaption
  - Identify key high risk points on the network
- The R&D funding for to achieve a European Climate Change resilient transport networks will be relatively low, but will increase significantly once Full Scale Field Operation Tests are under construction

Table of Contents:

Terms used[1]

Mitigation means taking action to tackle the causes of climate change, that is reducing concentrations of greenhouse gases in the atmosphere.

Adaptation means taking action to deal with the consequences of a changing climate, resulting from increased levels of greenhouse gases. This document will concentrate almost entirely on adaptation.

[1] Adapting to climate change – UK Climate Projections 2009. UK Department for Environment, Food and Rural Affairs - www.defra.gov.uk/environment/climate/documents/interim2/climate-uk-projections.pdf

Executive Summary

An efficient and reliable transport system is essential for the society, for the transport of goods, for employment and for leisure. Currently, Europe's transport systems struggle to cope with extreme weather events, and climate change is predicted to increase the frequency and severity of certain weather events. Additionally, traffic prognoses show that freight volume transported on roads will increase by approx. 70% until 2030 (prognosis for German motorways).

The entire transport infrastructure (road, rail, sea and inland waters) will be significantly impacted by climate change, affecting the way Europe's transportation sector plan, design, construct and maintain infrastructure in the future.

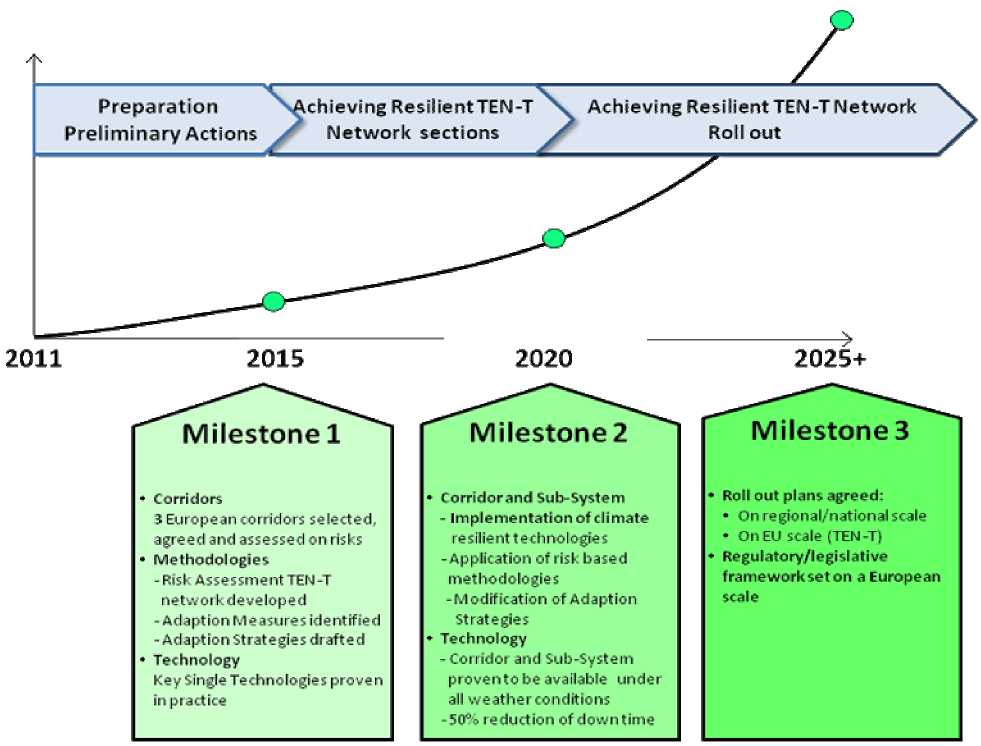
On the basis that there will be significant impact from climate change, and considering that all eventualities cannot be catered for, this roadmap aims to determine how road transport infrastructure shall adapt to the inevitable changes.

Facing this situation road authorities need to be supported with appropriate strategies to ensure reliability, availability, maintainability and safety (RAMS approach) of road infrastructure.

Whilst there are many initiatives that will look to mitigate the effects of climate change through the adoption of low carbon technology, some impacts are inevitable, and this roadmap sets out the steps required to maintain, and ideally improve the resilience of the three key transport networks (road, rail and inland waterways) to extreme weather events, and specifically the key TEN-T European transport networks. The key guiding objective to which the milestones will relate is as follows:

A climate resilient transport network will ensure that key corridors will be available to the user in all weather conditions.

The following figure outlines the key steps and timescales that have been proposed.



The 'headline' tasks proposed are:

- Selection of 3 European corridors
- Identification and modelling of climate change effects.
- Risk based vulnerability assessment for TEN-T Network.
- Adaption Technology identification, proving, integration and roll out.
- Development of adaptation strategies and their implementation for existing infrastructure.

Extreme weather events currently cause significant disruption to transport networks and Climate Change may amplify this. As such the potential impacts of Climate Change cut across many of the other roadmaps including; Sustainable Long Distance Freight Transport, Urban Mobility and Road Transport Safet

1. Introduction

There is widespread scientific consensus that climate change due to human activities is real, and that regardless of the international response, some effects are inevitable. Notwithstanding the uncertainties, significant warming is predicted (greater in northern Europe in the winter, and greater in southern and central Europe in summer), mean annual precipitation is forecast to increase in the North and decrease in the South, whilst flooding events and droughts will become more common. Coastal regions will be at greater risk of flooding from increased storm events and sea level rise.

Safe and efficient transport systems are essential in the functioning of business and society; the disruption caused by extreme weather events such as snow, flooding or heat are evident. This will have implications for all travel modes.

The consequence of increasing weather extremities due to climate change could be a related loss of network availability and subsequent reduction of transport reliability and accessibility to urban and economic areas, as well as increased accident frequency and severity. Climate change can also manifest itself by gradual changes in climate parameters. Unlike extreme weather events, gradual changes can go unnoticed but still have effect on the durability and functioning of road infrastructure, like steady increases in temperature, sunshine (UV exposure), seawater-level and changing groundwater-levels.

The economic costs of current extreme weather events are significant, even for relatively limited losses of availability, as the recent examples below show[2]:

- The Belgian road haulage association, FEBETRA calculated that the 5 days during which some 30,000 trucks were blocked in Belgium cost the sector and the economy some 99 million Euros.
- The French road haulage association FNTR calculated that winter conditions in France in December 2010 cost a loss in turnover of about 150 million.

2. Scope and Approach

Climate change is real and impacts all aspects of road transport. Currently, the transport network struggles with extreme weather events, and these are likely to increase in frequency and severity. Additionally, traffic prognoses show that freight volume transported on roads will increase by approx. 70% until 2030 (prognosis for German motorways).

On the basis that there will be significant impact from climate change, and considering that all eventualities cannot be catered for, this roadmap aims to determine how road transport infrastructure shall adapt to the inevitable changes. This will affect design, construction, maintenance and operation of new and existing road infrastructure.

Facing this situation road authorities need to be supported with appropriate strategies to ensure reliability, availability, maintainability and safety (RAMS approach) of road infrastructure.

This roadmap aims to support road authorities using a stepwise approach. The first step consists of an analysis of regional climate projections. On the basis of this projections road relevance scenarios are to be developed. Using these scenarios holistic vulnerability analyses can be conducted.

[2] Written communication from Marc Billiet, Head EU Goods Transport, International Road Transport Union (IRU). January 21st 2011.

Finally, risk based approach and economic assessments can be used for the identification of sustainable adaption measures.

3. Transport System Vulnerability to Climate Change

Some uncertainty exists about the potential impacts that climate change may cause, not least because of uncertainty as to the international response in reducing greenhouse gas emissions (mitigation). Nonetheless, it is generally accepted that there has been an impact on climate patterns, and this will continue to a greater or lesser extent. The purpose of this roadmap is not to go into scientific details of climate change, but to examine what potential impacts there might be, what impact that might have on the transport infrastructure, and what adaptation measures might be required. The predicted impacts and resulting vulnerabilities are considered below.

Potential temperature and rainfall patterns across Europe are presented below, showing a general increase in temperature across Europe, but particularly in the far south Mediterranean areas, in Eastern and the far north of Europe and in mountainous regions. This generally corresponds with a decrease in precipitation in southern Europe and an increase in northern Europe, although this is unlikely to be uniform. The United Kingdom and northern France show virtually no change, however it is possible that the summers will be drier, whilst winters will be wetter.

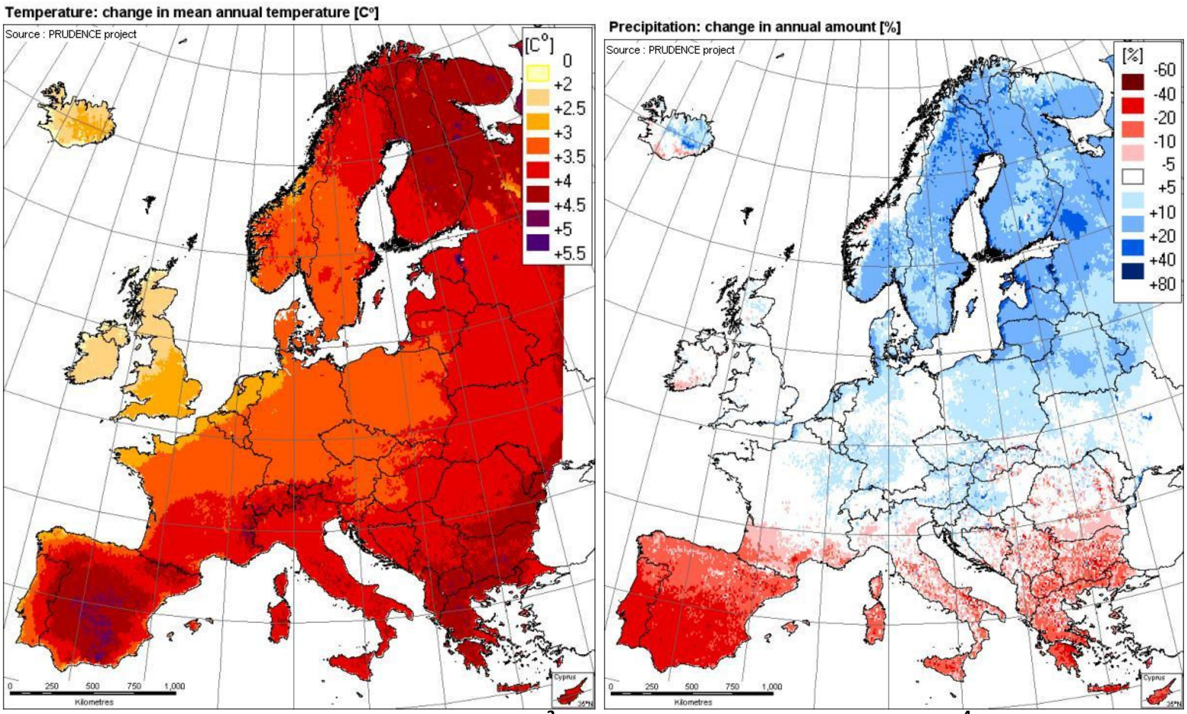


Figure 1 Change in mean annual temperature[3] (left) and mean annual precipitation[4] by the end of this century (taken from http://peseta.jrc.ec.europa.eu/docs/ClimateModel.html)

[3] Absolute change in mean annual temperature between control period 1961-1990 and 2071-2100, under the IPCC SRES scenario A2. Data from EC-funded project Prudence (HadCM3 global circulation model, and HIRHAM regional climate model in 12km resolution), map elaboration by EC JRC/IES. [3]

[4] Relative change in mean annual precipitation between control period 1961-1990 and 2071-2100, under the IPCC SRES scenario A2. Data from EC-funded project Prudence (HadCM3 global circulation model, and HIRHAM regional climate model in 12km resolution), map elaboration by EC JRC/IES.

As the climate changes, extreme weather events like heat waves, droughts heavy rain and snow, storms and floods are becoming more frequent, more intense and longer lasting. Vulnerability to climate change varies widely across regions:

- Generally, it is rainfall that would cause changes in groundwater levels. This can cause problems for relatively low lying countries with islands and extensive coastlines. For example, changes in groundwater levels have been reported to have an impact in Denmark, causing 'blue spots' where sea level change will affect land drainage causing groundwater to reach the surface temporarily or permanently, causing road closures[5].
- In Europe the Mediterranean area is becoming drier, making it even more vulnerable to drought and wildfires.
- Northern Europe, meanwhile, is getting significantly wetter, and winter floods could become common.
- Europe's far north, the Arctic and Outermost regions (due to increased global warming).
- the Alps (due to rapid melting of snow and ice)

4. The European Ten-T Network

In considering strategies to deal with the impacts of climate change on the European transport network, it is likely that a staged approach will be implemented. There are key road, rail, inland waterways, ports and airports across European Member States whose continued efficient function is vital to maintain European economic competitiveness. It is these transnational assets that will require the immediate focus, followed by national, regional and local transport networks.

The Ten-T European network represents the key trans-national assets of road, rail and inland waterway / ports. In addition to these, key airport terminals such as London Heathrow, Paris Charles de Gaulle, Frankfurt and Schiphol could be added. The continent has significant coverage of roads, and similar network of rail links, although a smaller network of high speed links. The inland waterway network is largely concentrated around northern and central Europe, with key seaports in northern France, Belgium, the Netherlands and Germany, with many of these representing modal hubs. For example, from Europe's largest port of Rotterdam, goods can be transported by road, train or inland waterway. The protection of these assets against possible effects of climate change is imperative.

5. Transport Service Levels

In recognising that climate change will have various impacts in various regions of Europe, and that there is a critical network of transport modes that require protection, an obvious starting point would seem to be to determine, firstly, the key infrastructure assets that might be at significant risk, and to agree service levels for various tiers of infrastructure.

For example, for the Tier 1, Ten-T networks that are key European transport corridors, it might be required that they operate at 99.99% availability, whereas local roads might be assigned a lower availability level based on the cost-benefit of keeping operational. The point at which the service levels are set will have a significant bearing on the required adaptation measures.

The transport system in Europe is made up of the road, rail and inland waterway systems. As the dominant sector in terms of passenger and freight movements across Europe, the road sector is one which offers the greatest flexibility in terms of re-routing opportunities. In order to determine the

[5] Kristiansen, J R: 2010. Rising groundwater levels can cause permanent flooding of roads. Transport Research Arena Europe. Brussels.

roadmap and the milestones, the first step is to determine what is envisaged by a climate resilient road; i.e. once a target is defined, the steps to achieve that target can be identified.

It will not be possible to make a road, or transport system totally resilient to climatic events, and certainly not at an acceptable economic cost. The ultimate milestone (with a realistic target for 2050) would be that:

In 2050 a blocked route will not affect the capacity / performance of the network'

In the 2025 to 2030 timeframe the following specific targets are considered appropriate:

- Only the core network (TEN-T) can be made resilient
- Service levels should be set, specifically with a target for a reduction in downtime of 50%; this will cover all aspects of downtime, and not just that related to weather events.
- Several corridors will be resilient, with downtime reduced by 50%.
- For reconstruction and new building the roads should be designed to be resilient, and vulnerabilities should be accounted for and/or avoided. This requires 'Intelligent Road Design'.
- There is a challenge in competence and skills shortage currently which should be addressed.
- Maintenance and management cost effects and long term (life cycle) effects should be accounted for.

The proposed target for 2025 is shown below, and the milestones presented in this document will be geared towards this target.

In 2025 a climate resilient transport network as a whole will ensure that key routes are available to the user in all expected weather and climate conditions.

Effectively this means the network service might be limited for an acceptable period of time, but the transport routes that are key to the European economy and society may not be blocked. Selection of key routes will be subject to a cost-benefit evaluation over the corridors/routes involved.

6. Research and Innovation Themes

The current transport system cannot grow with demand and so there is a balance to be made in ensuring that the future transport system is accessible, can satisfy the requirements for sustainable economic prosperity, and yet which will be resilient to climatic impacts. This requires a holistic solution which will cover development and implementation of technologies and methodologies, management and adaption strategies as well as specification and introduction of technical regulations.

The research and innovation activities focus on a broad range of themes. The key fields are highlighted below:

Development and implementation of methodologies

1. Development of a tool for risk-based methodologies assessing vulnerabilities of the road network. Analysis of vulnerability of road network and detection of potential affected road network elements inclusive making out climate effect vulnerability maps.
2. Estimation of economic costs of adaption measures and development of risk based procedures to consider the cost of disruption due to extreme weather events versus the cost of adaption

Development and application of technologies

1. Resilient drainage systems, soil strengthening and rock stabilization techniques, and early warning systems
2. Resilient asphalt and concrete pavements (mixture and pavement design, paving technologies) and methods of increasing skid resistance.
3. Resilient, long life and low maintenance new bridges and adaption measures for increasing resilience of existing bridges including foundations, pre-emptive protection systems for tunnel structures against flooding and solutions for conservation of groundwater reserve during tunnel construction and operation.
4. Rapid and automated inspection and survey methods as well as sustainable maintenance measures and techniques.

Development and introduction of management and adaption strategies

1. Models to predict weather events, congestion, other relevant factors and real time management systems to provide early warning of trigger events and instigate intelligent re-routing and modal shift. Development of guidelines to cope with restricted flow during extreme weather events.
2. Development and implementation of adaption strategies, measures and techniques for new and existing road network infrastructure.

7. Roadmaps and Milestones

The roadmap will provide proven solutions that are ready to implement by the National, regional and local infrastructure authorities. The generic build up is from single technology trials from around 2013 towards full systems proving on a network scale around 2020. From 2020 the roadmap will be concerned with supporting and facilitating the roll-out activities by the authorities. It is in this stage that the Climate Change Resilient Transport will be implemented.

Milestones are proposed for 2015, 2020 and 2025 for short, medium and longer term implementation respectively, and are outlined in Figure 2, below.

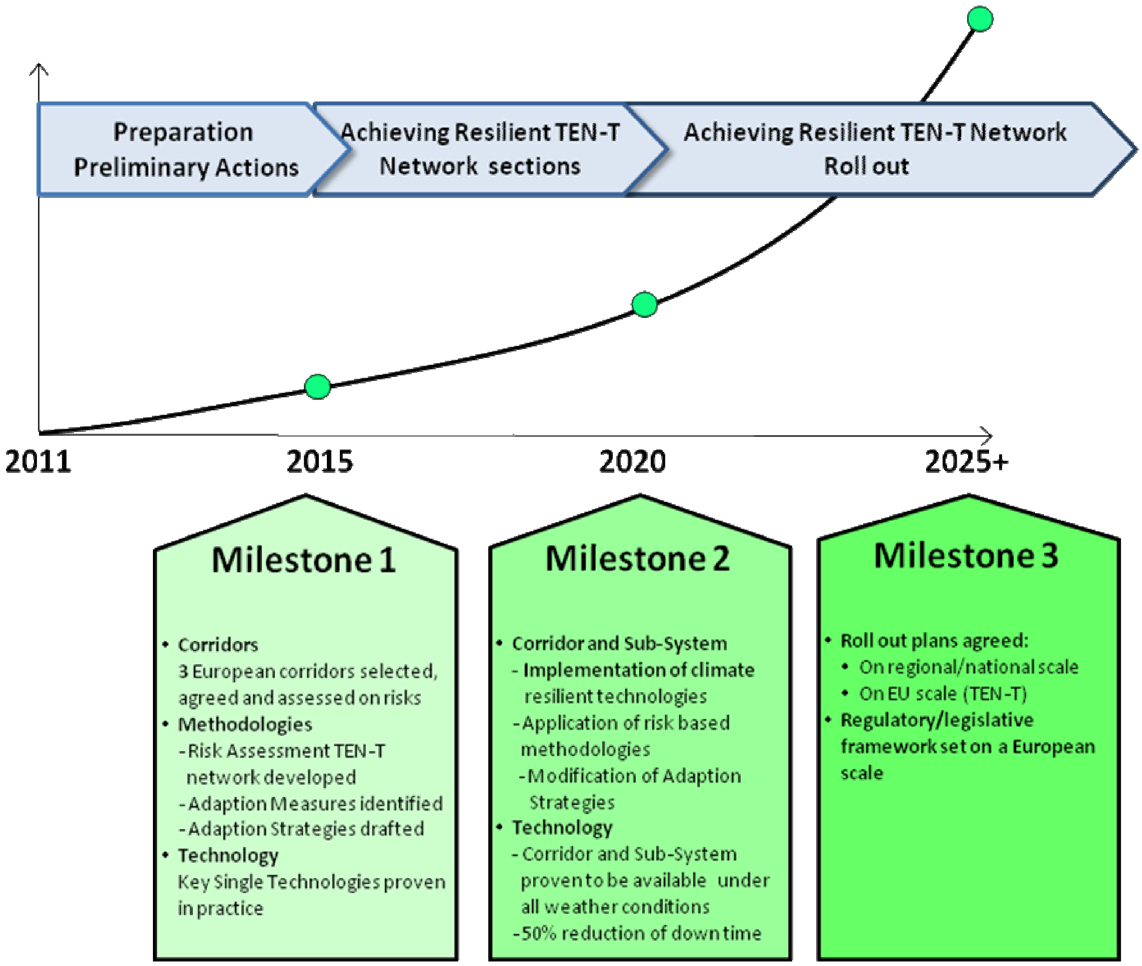


Figure 2: Outline Milestones for Climate Change Resilient Transport

Milestone 1: Preparation and preliminary actions (2015)

The main topics of Milestone 1 are the selection of 3 TEN-T Pilot Corridors, collection of background information and implementation of a unified database on transport related climate change effects/scenarios and the application of single technologies on selected infrastructure elements.

Corridor selection

- Selection of 3 TEN-T Pilot Corridors.
- Preliminary assessment of weaknesses based on currently available methodologies (RIMAROCC, SWAMP and already available national tools).
- Encourage road authorities to carry out pilot projects for eliminating identified weaknesses.

Methodologies

- Review, analyze and assess existing regional climate projections regarding European Transport needs.
- Further development of the regional climate projections (where necessary).
- Fusion on regional climate projections with the aim to gain a unified knowledge data base specific for European Transport (TEN-T).
- Development of risk based methodologies for assessing the vulnerabilities of transport infrastructure.
- Identification of adaption measures with regard to the possible vulnerabilities.
- Development of adaption strategies and their implementation for existing infrastructure.

Technology proving

- Optimization of identified adaption measures and further development to enable deployment.
- Selection of infrastructure elements for pilot applications.
- Single technology proving of selected adaption measures/technology.
- Validation of technologies based on the results of pilot projects.

Milestone 2: Achieving resilient sections of the TEN-T network (2020)

By 2015, validated information on adaption technologies available can be provided. Unified information on regional climate change effects as well as scenarios relevant for transport infrastructures will be available. Validated methodologies for the identification of vulnerabilities will have been proven. Key elements are:

Corridor and Sub-System Proving

- 3 TEN-T Pilot Corridors and sub-systems like city rings and transport interfaces to implement climate resilient technologies.
- Agreement on common specifications for identified routes.
- Application of risk based methodologies for assessing the vulnerabilities of the 3 selected corridors/sub-systems (identification of hot spots; modification of adaption strategies).

Technology proving

- Ongoing research on additional potential technical solutions.
- Real time traffic management systems that monitor traffic and environmental conditions and provide an early warning of trigger events.

- Improved weather and traffic prediction models.

- Enabled technology on a systems level (i.e. integrated over materials and components, management strategies and policy and governing principles).
- Feed forward to optimise supply chain. The business case would state the % reduction in down time.
- Methodologies for Cost-Benefit analyses; evaluation on sub-system level.
- Allied to the technical tasks should be the development of new nation level management and governance processes.

Milestone 3: Achieving resilient TEN-T network (2025)

It is expected that all technical solutions have been tested and validated on sub-system level; cost-benefit analyses have been carried out. Key task of milestone 3 is implementation of all technologies on system level (3 TEN-T Pilot Corridors).

By 2025 all technologies for resilience should have been proven on a European scale, incl. sub-systems identified by 2020. At this stage, there will be a requirement to take best practice from the three routes, to learn and improve and to continue to deploy solutions more widely across the TEN-T network. At this stage, technologies, operational strategies and governing principles will be fully integrated.

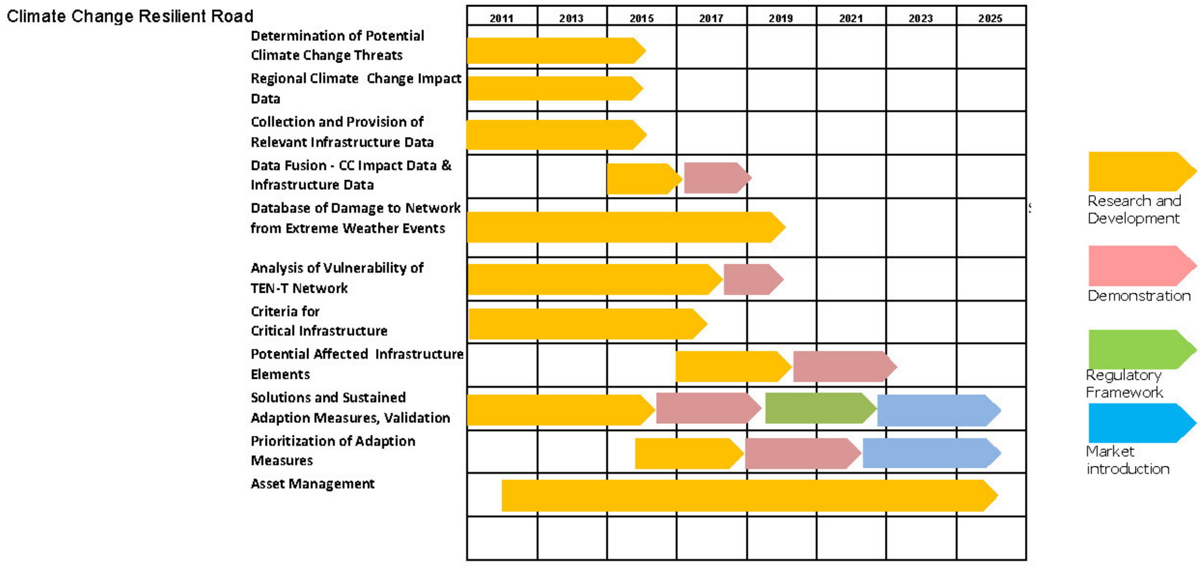
Underpinning this will be the development of Governance and Management Systems with an overview at a European Union level; these will be based on risk-based asset and accessibility management. Allied to this will be Transport and Asset Management strategies, at a European level with affiliates in Member States.

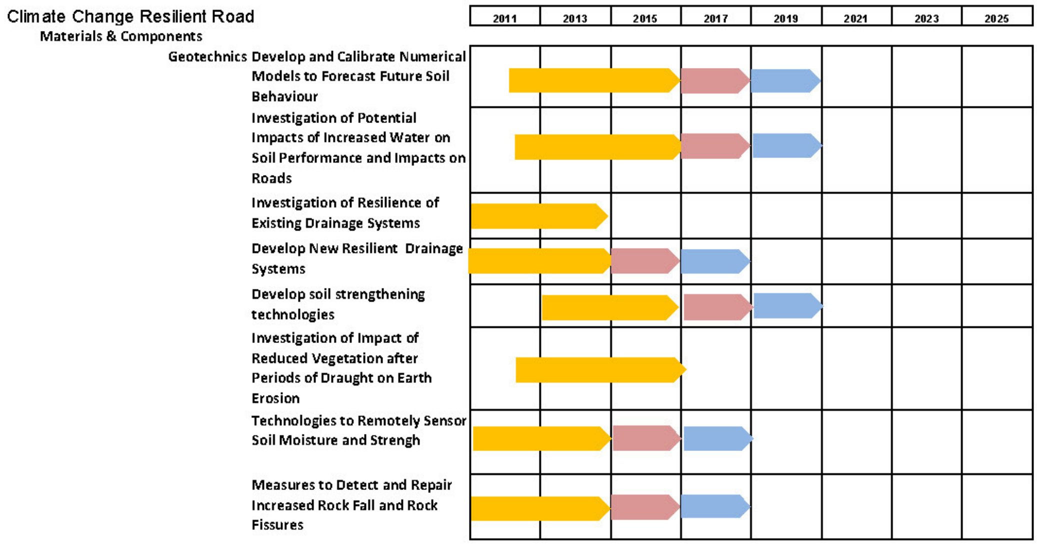
Roll out: 2025 and beyond

Following milestone 3 all methodologies and technologies for resilience can be handed over to European Road owners/operators for direct implementation.

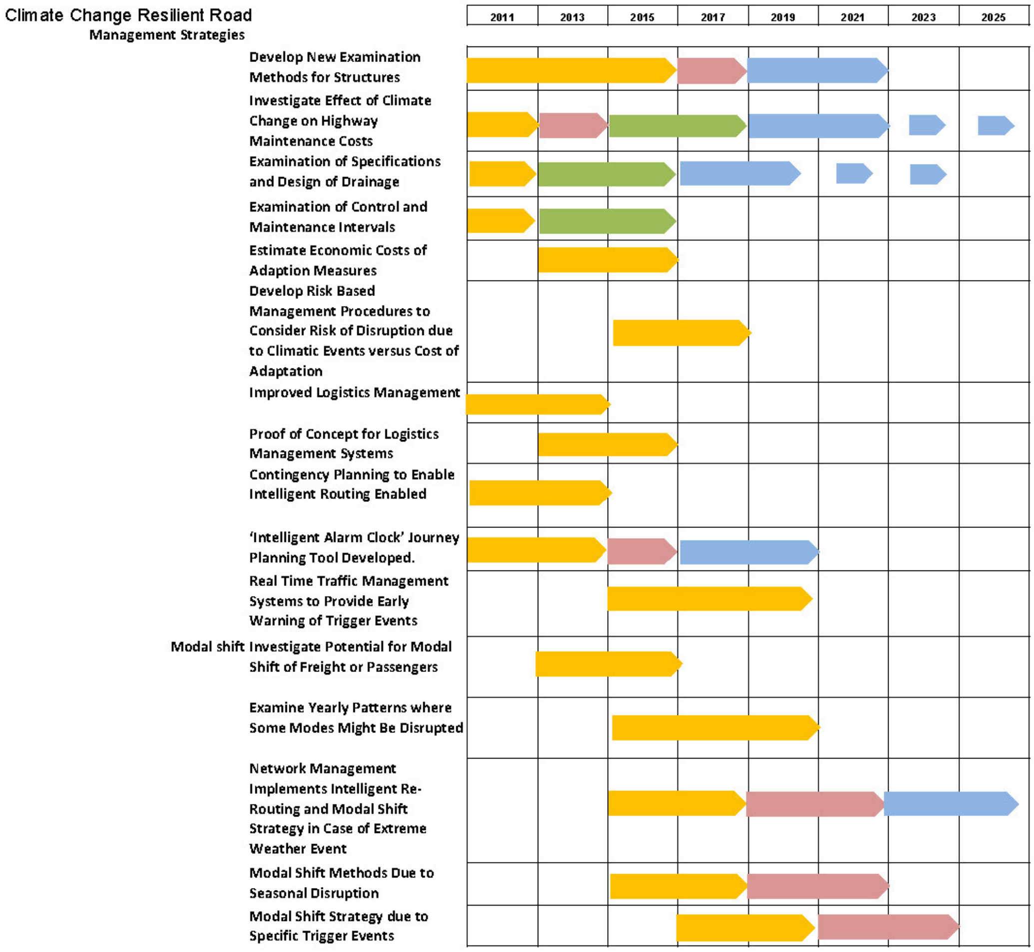
8. Proposed Research Topics

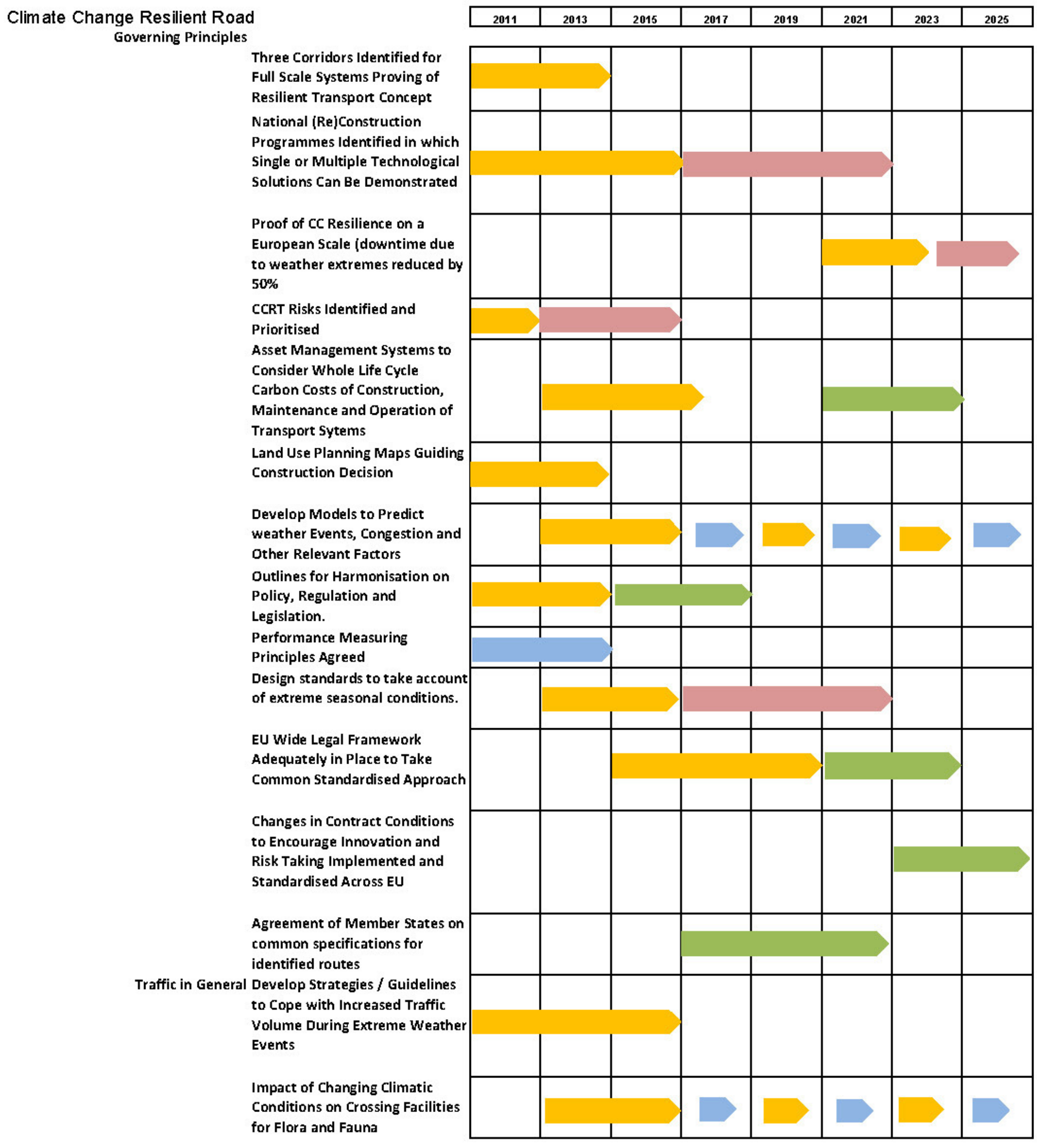
Presented below are more detailed proposed research topics that could potentially be developed into work packages, and an indicated timeline.






Climate Change Resilient Road
Roadways and Structures
2011
2013
2015
2017
2019
2021
2023
2025
Asphalt Roads
Investigation of Developement of Plastic Deformations Caused by Increased Temprature
Develop Resilient Asphalt Roads
Adaption of Bound and Unbound Layers
Improve Drainage on Aspahlt Roads (Surface and Sub-Surface)
Concrete Roads
Investigate Impact of Increased Heat on Concrete Fixings
Develop Resilient Concrete Roads (Modified Construction)
Improve Drainage on Concrete Roads (Surface and Sub-Surface)
Increased Surface Reflection Behaviour (Shortwaved Albedo)
Develop Manufacturing Process under Changing Climate Conditions
Design
Adaption of Input Variables
Maintenance
Develop Sustainable Measures
Adaption Maintenance Stategies
Bridges and Tunnels
General Aspects
Investigate Impacts of Climate Change on Bridge and Tunnel Loading
Develop Data Fusion Tools to Identify Endangered Bridges and Engineering Constructions
Specific Research Needs
Development of Reinforcement Measures for Bridge Foundations
Development of Pre-Emptive Protection Systems for Tunnel Structures Against Flooding
Solution Concepts for Conservation of Ground Water Reserve During the Construction and Operation of Road Tunnels
Decision Support Software for Low Carbon Construction and Maintenance Solutions
Production of Long Life and Easy to Maintence Structures


Climate Change Resilient Road
Management Strategies
2011
2013
2015
2017
2019
2021
2023
2025
Develop New Examination Methods for Structures
Investigate Effect of Climate Change on Highway Maintenance Costs
Examination of Specifications and Design of Drainage
Examination of Control and Maintenance Intervals
Estimate Economic Costs of Adaption Measures
Develop Risk Based Management Procedures to Consider Risk of Disruption due to Climatic Events versus Cost of Adaptation
Improved Logistics Management
Proof of Concept for Logistics Management Systems
Contingency Planning to Enable Intelligent Routing Enabled
'Intelligent Alarm Clock' Journey Planning Tool Developed.
Real Time Traffic Management Systems to Provide Early Warning of Trigger Events
Modal shift
Investigate Potential for Modal Shift of Freight or Passengers
Examine Yearly Patterns where Some Modes Might Be Disrupted
Network Management Implements Intelligent Re-Routing and Modal Shift Strategy in Case of Extreme Weather Event
Modal Shift Methods Due to Seasonal Disruption
Modal Shift Strategy due to Specific Trigger Events


Climate Change Resilient Road
Governing Principles
2011
2013
2015
2017
2019
2021
2023
2025
Three Corridors Identified for Full Scale Systems Proving of Resilient Transport Concept
National (Re)Construction Programmes Identified in which Single or Multiple Technological Solutions Can Be Demonstrated
Proof of CC Resilience on a European Scale (downtime due to weather extremes reduced by 50%
CCRT Risks Identified and Prioritised
Asset Management Systems to Consider Whole Life Cycle Carbon Costs of Construction, Maintenance and Operation of Transport Sytems
Land Use Planning Maps Guiding Construction Decision
Develop Models to Predict weather Events, Congestion and Other Relevant Factors
Outlines for Harmonisation on Policy, Regulation and Legislation.
Performance Measuring Principles Agreed
Design standards to take account of extreme seasonal conditions.
EU Wide Legal Framework Adequately in Place to Take Common Standardised Approach
Changes in Contract Conditions to Encourage Innovation and Risk Taking Implemented and Standardised Across EU
Agreement of Member States on common specifications for identified routes
Traffic in General
Develop Strategies / Guidelines to Cope with Increased Traffic Volume During Extreme Weather Events
Impact of Changing Climatic Conditions on Crossing Facilities for Flora and Fauna

9. Links to other roadmaps

Extreme weather events currently cause significant disruption to transport networks and Climate Change may amplify this. As such the potential impacts of Climate Change cut across many of the other roadmaps including; Sustainable Long Distance Freight Transport, Urban Mobility and Road Transport Safety.

Future long distance transport requires highly available infrastructure (green corridors). This will require roads to be designed to meet demands for longer and heavier vehicles, which will exert significantly higher loading. Additionally, infrastructure for green corridors have to fully take into account more frequent, intense and longer lasting weather events and their impact on planning, design and operation. The recommended research in this roadmap will help ensure that these requirements are met.

Future urban mobility will aim for significantly improved integration of freight delivery requirements in urban planning. The demand for delivery of goods and services will increase, and the urban road infrastructure has to meet these challenges. Additionally, the predicted more frequent, more intense and longer lasting weather events, especially heat waves, can have a significant impact on the urban microclimate. The design of new, and the upgrading of existing urban road infrastructure, including the use of ITS applications will have to take account of both the climate predictions and freight requirements.

The roadmap “Climate Resilient Road Transport” will also support the need for safety and security in road transport and provide the necessary level of protection, and will contribute to ERTRAC’s ambitious target of reducing by 60% fatalities and severe injuries by 2030 (baseline 2010).

EUROPEAN
ROAD
TRANSPORT
RESEARCH
ADVISORY
COUNCIL

European Roadmap

Safe Road Transport

Version June 28, 2011

**ERTRAC Working Group on
Road Transport Safety and Security**

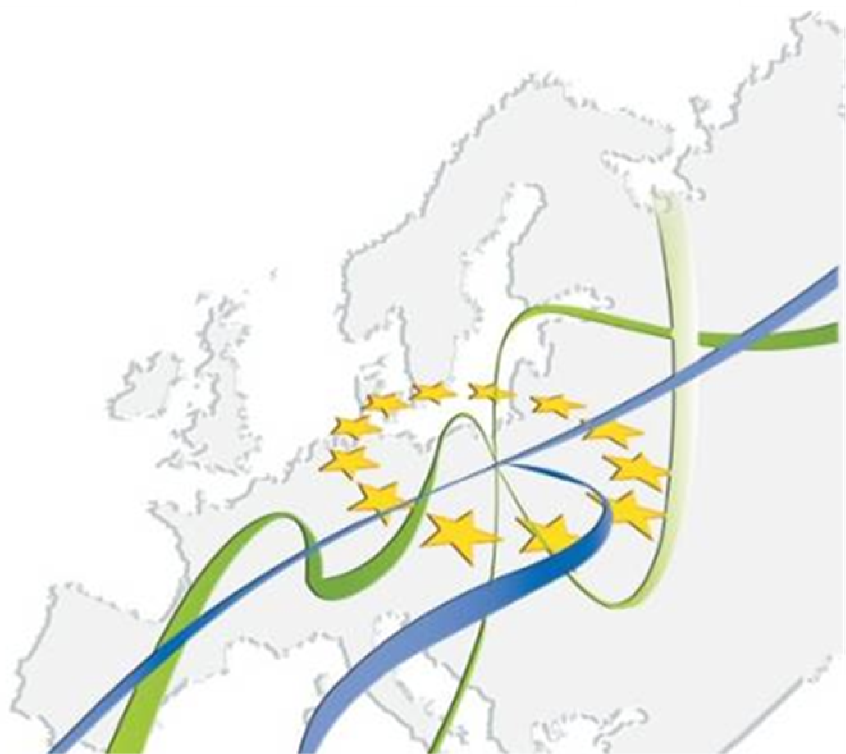


Table of contents:

1. Executive Summary

Strong efforts have been spent by the European Commission and all Member states in the last ten years to reduce the impact of road transport in term of fatalities and injuries. The overall objective to halve the number of fatalities between 2001 and 2010 has not completely reached but significant improvements have been made. However the final target is to reduce to (almost) zero fatalities and severe injuries, at the level of a "reasonable" risk, similar to other safer transport means like rail or air transport.

As a further step towards the "zero fatalities " objective, ERTRAC has defined an ambitious target: to reduce by 60% fatalities and severe injuries by year 2030 (baseline 2010).

To reach that safety level different approaches have to be followed, compared with the previous 10 years: continuing in research on passive and active safety and enforcement of traffic rules, strong effort in preventive safety, both at vehicle and infrastructure level, education and continuous training of drivers, strong enforcement of driving under alcohol or drug effects and protection of vulnerable road users.

Furthermore integrated and cooperative safety could provide the needed level of "protection and perception" to ensure to drive always with enough margin to be able to properly react to any sudden problem, like vehicle failure or static obstacles in the road.

2. Introduction

Background

As stated in the ERTRAC Strategic Research Agenda the societal need for safety and security in road transport is on reducing fatalities and severe injuries, as well as reducing the amount of freight cargo lost due to theft and damage. The policy of reducing fatalities is a long-standing objective which reflects the ongoing efforts of the European Commission, the Member States and industry in reducing fatalities on the roads towards zero in the long term. However, ERTRAC has extended the reach of this indicator so that it now also includes the reduction of severe injuries. Considering the trend in urbanisation and in new concepts of vehicle (lightweight, full electric, etc.) vulnerable road user protection will be an important issue.

Scope

This roadmap will cover all actions related the improvement of road safety on the vehicle, on the infrastructure, promoting a better driver behaviour, and the organization of the transport system. All different types of safety (cooperative-preventive-active, passive and after crash) will be considered, within an integrated approach.

Security in freight transport will be considered, promoting solutions that will not put in risk the professional driver of the vehicle.

The roadmap will cover actions that will improve the deployment of the solutions, since benefits will be possible only with a large penetration of solutions in the overall vehicle fleet. However specific policy (like incentives, taxes, etc.) to increase the deployment of solutions will not be considered. In some specific aspects, like prevention of driving under the effect of alcohol or drug, the roadmap will promote technology development to help the introduction of specific policy for the enforcement.

3. Benefits to Grand Societal Challenges

Clearly the main benefits will be on the safety target, this roadmap will be responsible to have the main impact (almost all) on the objective to reduce by 60% fatalities and severe injuries. But the reduction of accidents will have important benefits on the traffic reliability, since accidents are one of the main causes of traffic abnormalities and then congestions. Clearly the reduction of 60% of accidents with fatalities and severe injuries will have an impact on the reduction of abnormalities due to traffic accidents.

Since congestion will produce also a big increase of fuel consumption due to the very low speed followed by the vehicles (and the continuous acceleration and deceleration) a certain impact also in traffic decarbonisation is expected.

Cooperative systems will allow also a better management of the (remaining) accidents, fast intervention of emergency help, fast information to the incoming traffic to find alternative routes.

4. Research areas

It is generally recognised that human error are responsible of the large majority (more than 90%) of the road accidents. The strategies were directed mainly at improving road users' behaviour, mostly through education, information and enforcement strategies. But it is clear that several of the driver mistake cannot be recovered simply with the education (for example distraction, drowsiness, illness, etc.) and a more comprehensive approaches which included interventions for vehicles, roads and medical care is needed. This is clear in the Haddon Matrix, shown in Table below.

PHASE - FACTORS	Human	Vehicle	Infrastructure
Prevention - Mitigation	Improved pedestrian and 2-wheeler active safety systems for accident avoidance Naturalistic Driving Studies Road user modelling and simulation Driver inattention and impairment Driver Coaching Human-Machine interaction	Vehicle dynamics monitoring and control Driver support for collision avoidance monitoring and support Automated systems	Intelligent traffic systems for VRU safe mobility management Real time road status monitoring Towards zero maintenance roads Self-explaining roads Conception and design for elderly, vulnerable and users with specific needs Automated road

Crash	Biomechanical models and injury prediction	Safety systems for the protection of (motor)cyclists in collisions with motor vehicles. Crash compatibility and improved crash-worthiness of light and/or new vehicle concepts Advanced passenger protection systems including elderly/more fragile people	Forgiving infrastructure
Post Crash	Road accident monitoring and investigation	Automatic crash notification systems Protection of rescue personal and first responders against risks caused by energy storage systems	Advanced Incident and Traffic management

Table 1. Haddon matrix Accident Phases- Factors

The roadmap will consider the following main research areas.

- ***Safety of vulnerable road users***
- ***Safety of new vehicles***
- ***Advanced driver support***
- ***Traffic Safety Analysis***
- ***Safe infrastructure***
- ***Cooperative systems***
- ***Secure road transportation***

4.1 Safety of vulnerable road users

Vulnerable Road Users (or VRU) are defined in this document as those participants in traffic that are not protected by any mechanical system: pedestrians, motorcyclists, bicyclists, and users of mopeds. This includes road users with impairment, e.g. using a mobility aid, or children playing on the road. Car occupants, even when this refers to impaired people, senior people or children do not belong to the category of VRU according to this definition. Their specific needs are included in the roadmap referring to new vehicle developments (Safety of New Vehicles).

Although the total number of fatalities and severe injuries due to traffic accidents is decreasing, e.g. as a result of the introduction of passive and active safety systems, the number of VRU that are killed and wounded in traffic tends to decrease in a much slower pace . Measures to decrease the number of VRU casualties in traffic are dedicated to influence driver and road users to show more safe behaviour, to make infrastructure more forgiving and intuitive in order to decrease the number of accidents and accident severity, and to make motor vehicles more safe e.g. by means of driver warning systems or full autonomous safety systems as to reduce the impact of accidents on injury levels of vulnerable road users. Influencing road user behaviour is outside the scope of this roadmap, except for advanced driver assistance systems which are integrated in vehicles and used in a timeframe prior to the crash at a moment that the driver is fully in control of the situation. Autonomous systems have to take over from the driver at the time that any response from the driver is too late to avoid a potential collision, or when the driver is no longer capable to deal with the information flow regarding a potential critical situation. Intelligent systems are required that not only give information to the driver on the possible collision risk in the continuously changing environment of the vehicle, but also estimate the driver state in order to judge whether the driver is still capable to cope with the ever increasing amount of information to use this information to avoid critical situations.

The following topics are considered to be of main importance in the reduction of the number of fatalities and severe injuries among vulnerable road users in traffic:

1. Intelligent traffic systems for VRU safe mobility management
2. Improved pedestrian and 2-wheeler active safety systems for accident avoidance
3. Safety systems for the protection of (motor)cyclists in collisions with motor vehicles.
4. Safety systems for the protection of single-vehicle motorcyclist accidents.
5. Technology development to mitigate the consequences of secondary impacts after a VRU-to-vehicle collision.

Impact assessment of systems to improve the safety of vulnerable road users is dealt with in a separate roadmap (Traffic Safety analysis).

4.1.1 Intelligent traffic systems for VRU safe mobility management

Especially at inner city black spots where the density of cars and vulnerable road users is high with consequentially many possible hazardous interactions, an automated guiding system for safe VRU mobility could be put into place. Such a system would have to lead to increased awareness of drivers for VRU behaviour, combined with traffic guidance for vulnerable road users and cars depending on the detected traffic flows. A combination of in-vehicle systems (active safety systems), roadside systems (e.g. camera's overlooking a crossing and identifying road users and their future paths), car-to-infrastructure and infrastructure-to-car communication, and an intelligent traffic management system should result in increased driver awareness (e.g. by sending information on pedestrians crossing the street outside the view of the driver), improved awareness for vulnerable road users on the presence of vehicles potentially crossing their path, and guidance by automated traffic guidance systems (e.g. automatically adapting their timed switch and/or the vehicle speed for optimized mobility of cars and VRU).

4.1.2 Improved pedestrian and 2-wheeler detection systems for accident avoidance

Current developments in pedestrian and 2-wheeler detection systems aim at in vehicle sensors, such as a combination of camera's, radars, contact sensors and other sensor types, as these are desperately needed to avoid accidents with VRU. Developments are required to reduce the cost of these sensor systems, to make sensors smarter as to be able to identify the type of road user, and to reduce the number of false positives. There is a major concern about the growing thickness of the A-pillars for car structural resistance and the blind spots generated by the same. Reducing the weight of structural materials might even increase the problem.

In order to have sensors to provide information that add to the drivers view, the information streaming towards the driver becomes important, especially in inner cities with high numbers of road users, including VRU. When a warning is given to the driver, does the driver have the possibility to digest this information, and is he/she capable of acting accordingly? Accident avoidance systems therefore also require an estimation of driver behaviour (capabilities), and driver state, to predict delayed reactions due to fatigue or increasing age. Using this information, the trigger for autonomous action by the car could be adapted.

Apart from in-vehicle sensors, detection could be enhanced by providing pedestrians and 2-wheelers with some sort of transmitter, whose signal is easily picked up by in-car or road side systems. This could especially be used in the protection of young children, that have little notion on the dangers of traffic or for bikers approaching a heavy vehicle with important areas falling under blind spots.

The regulatory framework is very essential for a successful market introduction of accident avoidance systems, especially in the case of autonomous actions of in-car systems. Current legislation has not yet an answer to upcoming questions on responsibility for autonomous acting vehicles. Besides the developments of such systems, the regulatory frameworks well as test procedures for such systems need to be installed.

4.1.3 Safety systems for the protection of (motor)cyclists in collisions with motor vehicles

Systems are developed for collision avoidance. If in unfortunate cases, a collision is unavoidable, then there is still time left to mitigate the impact of the collision. This could be by systems on the car that decrease the impact, by a combination of car deceleration and safety measures to reduce the severity of the contact between car and VRU. Other possibilities are protective garments for the vulnerable road user that become active when an imminent collision is detected. An active bicycle helmet or collar is a simple example of such a system. For motorcyclists such systems could be part of the motorcycle, or of the protective garment, to be activated only if and when needed. A good prediction of what will happen during the accident scenario is crucial to determine the best combination of protective measures and consequently the algorithms to deploy the protection. Moreover, systems should be very easy to handle, and should fit comfortably under all weather conditions.

Enhanced concepts for motorcycling helmets to protect the rider from neck torsion will add to motorcyclist safety.

4.1.4 Safety systems for the protection of single-vehicle motorcyclist accidents

Due to the high speed reachable and the weight of the vehicle, single-vehicle accidents involving PTWs (Powered Two-Wheelers) can be fatal or lead to very severe injuries. Since in the case of a single-vehicle accident no opposing vehicle is present to absorb part of the impact and thus mitigate the collision, measures to reduce the mortality and the level of injury should be implemented on the motorcycle, in the protective garments or in the infrastructure. These systems, similar to developments for cars could follow the strategy of driver warning, collision avoidance, and collision mitigation, the latter with automatically activated protective systems.

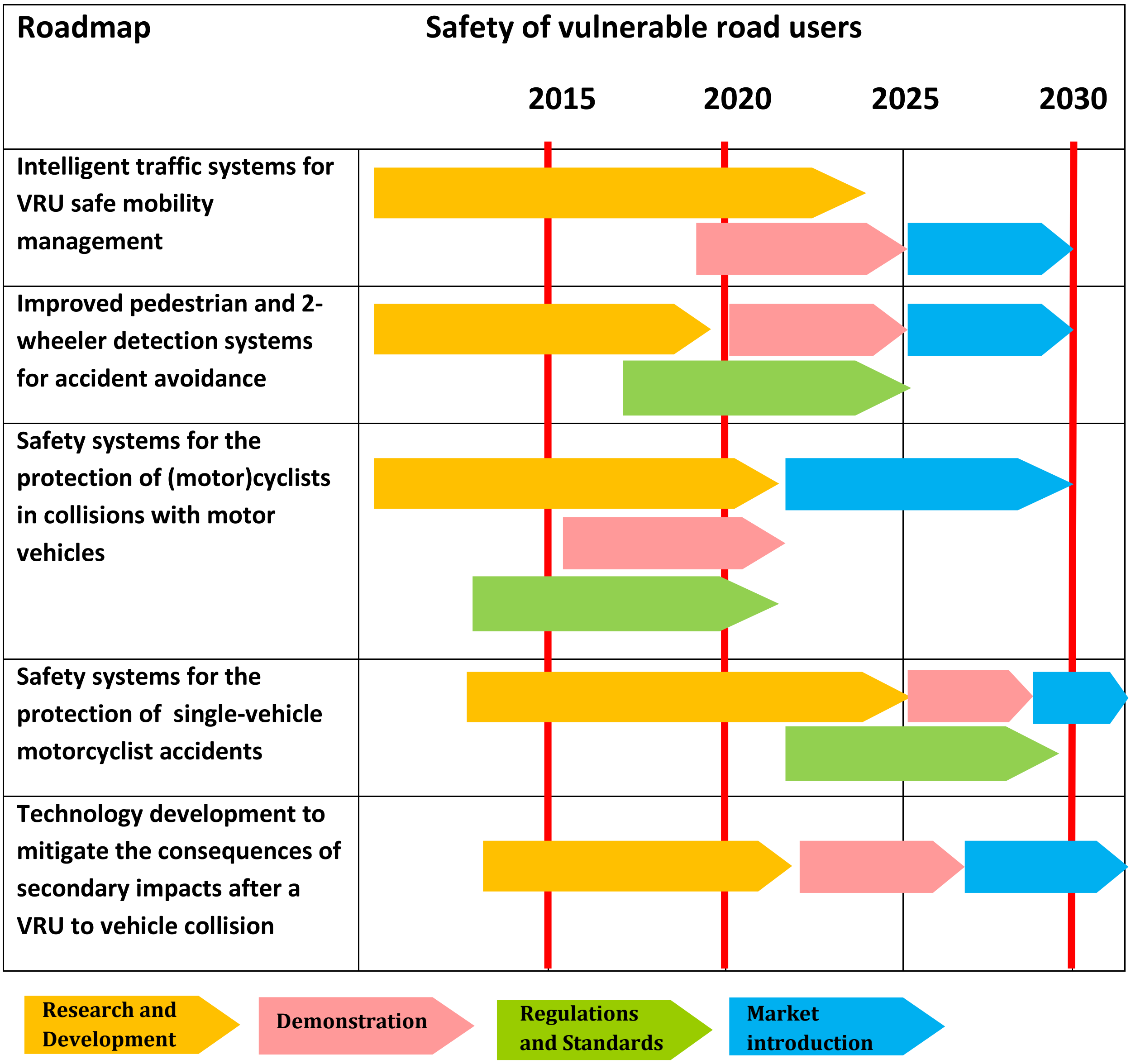
Systems like ESC for PTWs, advanced protective clothing and helmets, wearable air-bags; forgiving infrastructure design and "soft" road furniture should be considered for innovative development.

4.1.5 Technology development to mitigate the consequences of secondary impacts after a VRU to vehicle collision

In most accident scenarios for the collision of a passenger car and a pedestrian, the head will make contact with the bonnet close to the windshield, the windshield, or the vehicle’s A-pillars. Depending on the flexibility of the structure, the deceleration pulse of this primary contact is so high that a fatal injury might result. For this reason various protective measures are currently studied reducing the risk of fatal and severe injuries due to primary impacts.

Only very limited data is available on the secondary impact, i.e. the impact that the VRU faces when bouncing off the vehicle and hitting the road or other equipment. The severity of this contact might be as high as or even higher than that of the primary impact. Consequently

measures should be developed to prevent or soften secondary impact, e.g. retaining systems to avoid secondary impact or forgiving infrastructure/road furniture design.



4.2 Safety of new vehicles

Current state-of-the-art vehicles show a very high level of active (e.g. Electronic Stability Control) and passive safety. Euro NCAP rating is often at the highest level of five stars. However, improvements are still possible and needed considering the introduction of new, smaller and lighter vehicles, and of electric vehicles. These vehicles will have new specific needs, in particular

for passive safety, but will also offer new opportunities with the availability of high electric power on the vehicle and the possibility to control the traction torque at each wheel.

In particular, electric vehicles are more flexible in their architecture compared with conventional vehicles. This aspect, together with the requirement to reduce costs and weights, will probably produce vehicles very different from the current solutions. Research is also needed to better understand the biomechanics of the vehicle occupants during crashes to enable new solutions for the passive safety of these new vehicles, solutions that will guarantee adequate levels of protection without negative impact on vehicle performance (weights and then range).

Topics for research:

1. Biomechanical models and injury prediction
2. Crash compatibility and improved crashworthiness of light and/or new vehicle concepts
3. Solutions for low acoustic perception of FEVs (Full Electric Vehicles)
4. Advanced passenger protection systems including elderly/more fragile people
5. Integrated safety concepts (hydrogen vehicles, fire…)

4.2.1 Biomechanical models and injury prediction

With the convergence of active and passive safety, human-like reactions, as they would occur in the pre-crash respectively low-g phase, will play a more and more important role in the development and fine-tuning of safety systems. This should be supported by research on active human models for all kinds of road users. The bio-fidelity and injury prediction capability of these numerical representations of the human body and in particular their ability to reproduce muscular activity need further improvements. Research in biomechanics will be the basis of such advances. So far most of the knowledge in biomechanics has been focused on so-called structural effects caused by various types of impacts. However, there is an urgent need to get a better understanding about functional effects, e.g. injuries to the nervous system frequently causing long lasting or disabling injuries. This knowledge will be a prerequisite for the definition of refined injury criteria and reference values.

4.2.2 Crash compatibility and improved crashworthiness of light and/or new vehicle concepts

$C0_2$ emission regulations, global anti-pollution policies, management of resources and economical development call for cars with reduced size and weight, which are ecologically friendly (emissions, material recycling, manufacturing processes), affordable and still safe. Current requirements for crashworthiness, however, set limits to the trend of “downsizing” and to the weight savings which can be achieved. On the other hand, there are classes of extra-low mass vehicles (L5e and L7e) which are largely unregulated in terms of vehicle safety. Research should therefore aim at establishing the scientific basis for harmonizing these requirements and for giving greater room to weight savings without compromising the high level of safety which even small cars offer today.

An important route to realise substantial weight reductions is the application of lightweight and particularly of composite materials in the vehicle structure. Apart from high material and processing costs, the lack of numerical crash simulation tools with truly predictive capability still constitutes a major barrier to the introduction of these materials in the virtual development processes of the motor vehicle industry. Research should bridge this gap by developing numerical tools which offer the capability to predict also the failure and the post-failure behaviour of composite materials under impact loading at high levels of confidence and which can be integrated seamlessly in the existing industrial development processes.

Apart from the general trend of downsizing, the electrification of drive trains in particular causes new challenges with regard to crashworthiness and, at the same time, offers new chances to improve the crash safety of vehicles. The bulky and heavy battery packs which vehicles will have to be equipped with in the coming years in order to offer a significant purely electric operating range might not only form a safety risk on their own when being damaged, but will also have a major influence on the full vehicle's crash deformation behaviour and on the resulting deceleration patterns. High voltage lines and hydrogen tanks for energy storage in fuel cell electric vehicles will introduce new risks which have to be tackled, too. On the other hand, new package concepts enabled by the replacement of mechanical shafts by electric power transmission and the introduction of wheel-hub motors in particular will facilitate radically new designs of crash structures and finally enable rethinking the vehicle architecture as a whole. In combination with the application of new materials, this will be the basis for major advances in the lightweight design of electric vehicles allowing for the extension of purely electric operating ranges. Research activities should cover the whole range from basic risk analyses to the development of design guidelines and test procedures which allow for a holistic safety assessment of electrified vehicles while limiting the risks immanent in the tests themselves.

Not only electric vehicles might be based on totally new architectures in the future though. Special attention is currently paid to two-seater concepts with in-line seat arrangements, for example. Such vehicles could be equipped with the full range of drive train technologies available, but will in any case show different impact kinematics than conventional passenger cars. Research should therefore explore routes to guarantee the crashworthiness of such vehicle structures in terms of energy-absorption mechanisms, deceleration patterns and survival spaces. Moreover, the adaptation of restraint systems to the requirements of such new vehicles concepts should be addressed.

Last but not least, the interaction of different types of vehicles in terms of crash compatibility should be a topic of future research, as this issue will become even more important with the trend of downsizing and the introduction of a growing number of extra-low mass vehicles. According to current safety paradigms, smaller vehicles have to be designed with stiffer structures, modifying the energy absorption characteristics and requiring more aggressive restraint systems. In addition, the introduction of new vehicle architectures might also result in issues of geometric compatibility with other vehicle types (override / underride effects etc.). Based on an in-depth analysis on what are the optimal safety features a small car should provide compared to those of a larger vehicle and making full use of the results of former projects in this field, research should be targeted towards the amendment of safety requirements for the

different types of vehicles available. This might also necessitate the modification of test and assessment methods in order to better reflect the requirements of crash compatibility.

4.2.3 Solutions for low acoustic perception of FEVs

Novel acoustic characteristics of fully electric vehicles (FEVs) do not provide the same recognizable impressions regarding interior and exterior noise as conventional vehicles - particularly at low speeds. This means a perceptible sound has to be developed in order to avoid additional risks for vulnerable road users and maintain public acceptance. Significant progress towards regulations for exterior noise characteristics of quiet road vehicles has already started in the USA, Japan and Europe. However, there is still a substantial need for further research in this area of psycho-acoustic characteristics for artificial noise measures, increased driver awareness as well as novel smart system approaches to maintain the advantages of FEVs regarding the reduction of urban noise pollution. Thus the NVH-behaviour of new vehicle concepts (in particular FEVs) is an interdisciplinary research domain, also involving innovative materials and production methods. In this context also infrastructure measures could be developed in combination with in-vehicle measures. As an example, one could imagine smart systems in pedestrian paths, especially at crossroads, which generate sound and vibration to vulnerable road users. In-vehicle measures as wells as infrastructure measures should be integrated with the help of innovative HMI solutions in order to generate an automated acoustic system environment for the safety of new vehicles.

Thus there are important challenges in the next two decades which demand holistic R&D approaches. In the first stage an initial research and demonstration phase has to be initiated. The major aims of this first phase are:

- Sound (and vibration) functionality and generation devices are developed at a prototype and/or pre-series-production level (mainly in-vehicle measures)
- Sensing strategies and HMI-integration (Human Machine Interaction) for acoustic solutions are developed (in-vehicle but also infrastructure measures)
- Demonstration / field testing (mainly vehicle level but also infrastructure measures)

This refers to a small scale application of technical systems and methods regarding effective solutions for the low acoustic perception of FEVs. First R&D projects on these aspects are running or currently being started.

In the second stage, the validation and integration of these acoustic solutions for a preventive vulnerable road user protection is a major aim. As a major future aim, a holistic automated acoustic system environment for collision avoidance, mainly in terms of vulnerable road user protection, has to be established. This involves economically advantageous and validated applications at large scale.

4.2.4 Advanced passenger protection systems including elderly/more fragile people

Already more and more systems are penetrating the market where passenger protection systems are electrically driven instead of mechanically driven, this trend will continue in the future due to the availability of a higher voltage battery also in conventional vehicles. The availability of even higher electric power in electric or hybrid vehicles opens possibilities to redefine passive safety

systems altogether. Not only restraint systems can be redefined to more dynamically and less aggressively (taking into account the different statures of occupants) respond to dangerous situations, but also the supply of power can be used to trigger crash mitigation systems like dynamic changes to the structure of the vehicle. A strategy should be developed how the demands of different actuators should be handled by such a power system. Also, questions of energy management arise in the event of a crash: actors need to be generally redefined. Do the protection systems have sufficient power and may there be a demand for power supply after the crash? How will this power supply be secured without endangering the occupants or first responders? These questions have to be answered to (re)define the passenger protection systems in the overall safety concept.

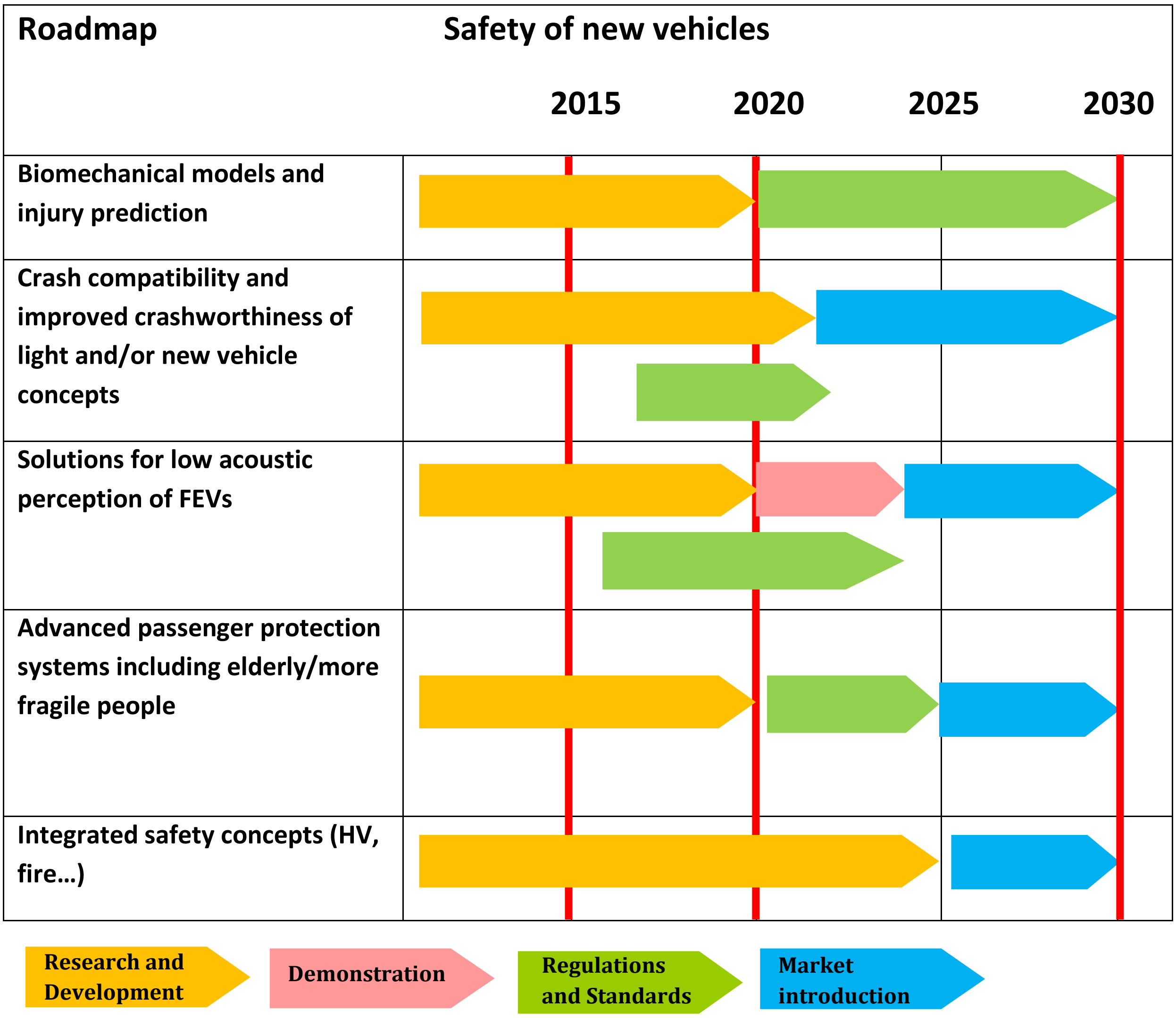
4.2.5 Integrated safety concepts (HV, fire…)

Vehicles with an alternative propulsion system, like battery operated vehicles and hydrogen and fuel cells driven vehicles, put higher demands on traditional safety systems. The use of these new energy storage systems in combination with the changed characteristics of the vehicle asks for an integrated safety approach encompassing primary, secondary and tertiary safety systems. These systems should be directed at the energy storage system itself (battery or hydrogen tank), the vehicle as a whole and the environment of the vehicle. Additional safety challenges as discussed in the following paragraph should be compensated by improved primary and secondary safety systems. Since these vehicles will be introduced first in urban environments also specific safety systems directed at the protection of vulnerable road users should be considered.

Also post-crash, the alternative powertrain components (battery, hydrogen storage, high voltage lines) pose new challenges for rescue teams. Emergency personnel must be able to identify the specific type of vehicle it is dealing with and secure the scene so rescue work can begin. They also need to know when to call for trained personnel equipped with proper protective gear for assistance. First arriving emergency responders should be protected as well as the occupants of the vehicles and bystanders at the scene.

For the electric vehicle the so-called electronic crush zone is even more important not least due to the different architectural designs (2-seaters, in-line etc). Therefore, further research on reliable sensing is a must. The reliability of the sensing systems has to be increased in order to be able to use the signals for the deployment of collision mitigation systems.

Research activities should be aimed at a holistic approach looking at prevention, avoidance, protection, rescue and care. Firstly a profound analysis is needed of the specific safety requirements of the different new vehicle concepts (battery, hydrogen). Primary safety systems should be redefined in order to focus these systems on urban environments and vulnerable road users. Safe vehicle dynamics is a further area that needs extensive research for the different new vehicle concepts, including 2- and 3-wheelers. For the secondary safety systems, pre-triggered occupant protection systems need to be elaborated, adapted actuator concepts which take into account the diversified crash behaviour. Furthermore, improvement of tertiary safety systems is needed taking into account fire, leakages of chemical materials and high voltage.


Roadmap
Safety of new vehicles
2015
2020
2025
2030
Biomechanical models and injury prediction
Crash compatibility and improved crashworthiness of light and/or new vehicle concepts
Solutions for low acoustic perception of FEVs
Advanced passenger protection systems including elderly/more fragile people
Integrated safety concepts (HV, fire…)
Research and Development
Demonstration
Regulations and Standards
Market introduction

4.3 Advanced driver support systems

In-depth accident analysis and naturalistic driving studies have consistently demonstrated that the great majority of road accidents involve some form of driver error, in particular related to inattention. The key purpose of advanced driver support systems is to prevent such errors or mitigate their consequences by providing drivers with information or warnings on potential hazards, or even intervening by automatic steering and/or braking. In addition, some functions partly automate the driving control task. Also, enhanced logging capabilities have enabled driver coaching functions that provide drivers with performance feedback, during or after the trip, with the general purpose to obtain long-term behavioural change. Today, several advanced driver support systems have entered the market but the penetration rate is still relatively low.

To accelerate deployment, it will be of key importance to reduce development costs. This will require an increased level of integration both on the sensor and on the actuator/HMI side. Future technological developments will include improved perception capabilities, also utilising short-range communication enabled by cooperative system technologies. This will also enable a higher level of automated driving, which will require new regulatory frameworks. Increased integration of the suspension, braking, steering and propulsion systems will enable new forms of vehicle dynamics support functions. There are also key challenges for the design of the human-machine interface to manage the rapid growth of functions interacting with the driver, minimise distraction and ensure a high level of acceptance and adoption of new functions.

The following main research topics have been identified:

1. Vehicle dynamics monitoring and control
2. Driver support for collision avoidance
3. Driver inattention and impairment monitoring and support
4. Automated systems
5. Driver Coaching
6. Human-Machine Interaction

4.3.1 Vehicle dynamics monitoring and control

A key future trend in this area is increased chassis integration, that is, integration of the suspension, braking, steering and propulsion systems to provide safer functionality by combined management of these systems. Thus, future active safety systems will be able to directly act on the vehicle dynamics.

Road transports of tomorrow, especially heavy goods vehicles, face challenges in increasing their transport efficiency and reducing their environmental footprint. One viable future option is to design longer modular transport systems than agreed in Directive 96/53 EC within long haul and regional distribution. Research is needed on how these vehicle combinations should be managed

in safety critical situations and how safe corridors can be detected and evaluated to choose an optimal driving path for high speed situations as well as low speed including reversing. To secure the right level of control with energy and cost efficient systems an integrated approach of propulsion, braking and steering is needed.

Coordination of legislation and development of common standards is also needed to facilitate the development of integrated chassis systems.

4.3.2 Driver support for collision avoidance

Today, several types of collision warning systems exist on the market, primarily in premium segment vehicles. Recently, vehicle manufacturers took the next step to further enhance safety by introducing systems like Automatic Emergency Braking which autonomously takes control over the brakes when necessary to mitigate rear-end collisions. In the near future, active safety will be increasingly deployed in lower-cost segments. To achieve this, research needs to be directed at systems with multiple functions, with high accuracy / reliability, and reduced cost. Deployment in heavy goods vehicles and buses will be accelerated by 2013/2015 legal requirements on mandatory CMbB and LDW systems.

On the sensor side, accuracy and reliability will be further enhanced, in particular regarding the detection of vulnerable road users (as addressed in more detail in section 4.1). Moreover, in the near future, short-range communication technologies (V2V, V2I) will function as additional sensors. In combination with digital maps and e-Horizon, this will substantially enhance the robustness and predictive capacity of today's collision warning systems, thus minimizing false warnings and enabling automatic intervention across a wider range of scenarios. Enhanced predictive capabilities is also essential for systems supporting green driving, so synergies between those two application areas may be exploited.

The development of integrated information, warning and intervention (IWI) strategies for multiple functions is another key challenge. Yet another future trend will be proactive information (e.g., based on digital maps, traffic information and/or V2V, V2I communication) supporting drivers' anticipation of potentially critical events, thus enabling more "foresighted" driving. Finally, there will be a trend towards increased integration of active and passive safety functions where, for example, collision prediction is used to optimise protection systems prior to impact.

4.3.3 Driver inattention and impairment monitoring and support

Driver inattention and impairment monitoring systems have started to appear on the market. These systems analyse different information on driving behaviour (lane keeping, steering and braking patterns, etc), and/or information from a interior cameras, to mitigate inattention (e.g., eyes off road) or physiological impairment (e.g., alcohol intoxication or drowsiness). In the case of alcohol, solutions that will disable the possibility to use the vehicle are foreseen. This may even include stopping a vehicle in motion, which requires a high level of accuracy and reliability.

Of key importance will also be to reduce the intrusiveness of some technologies (e.g., alco-locks), and to increase the real-world detection accuracy and reliability of others (e.g., distraction and drowsiness mitigation). Future inattention and impairment detection systems will combine signals from multiple (driver-, environment- and vehicle) sensors. Moreover, inattention and

impairment monitoring systems will integrated into the general onboard perception platform and used for enabling a wide range of functions including inattention warning, driver coaching (see below) as well as driver state-adaptive collision avoidance.

Driver state monitoring will also be important for ensuring that the driver is in the loop during mode transitions in semi-automated driving.

4.3.4 Automated systems

From a technological perspective, fully automated driving is a reality today. However, the deployment of fully automated road vehicles will require more precise, reliable and extended environment perception and situation understanding. Here, positioning and qualified map data and short-range communication (V2V and V2I) will be of key importance. It may be foreseen that, within the time-frame of the present roadmap, full automation will be limited to specific contexts (e.g., platooning or dedicated lanes) where the driver will maintain the overall responsibility for safe driving, although in a monitoring role. A key issue here is thus the development of automation strategies, e.g., for handling transitions between automatic and manual control modes. As discussed in Section 4.5, the infrastructure design will also play a key role in enabling automated driving and a systems perspective needs to be adopted.

Finally, legal and regulatory frameworks for automated driving need to be developed in order to enable large scale deployment.

4.3.5 Driver Coaching

The general idea behind driver coaching is to improve driving performance by means of feedback. This may involve improvements in safety as well as driving efficiency, and performance feedback may range from immediate feedback provided while driving to post-trip reports summarising performance over a longer time period (e.g., a drive, a week or a month).

Driver coaching may be based on relatively cheap aftermarket video data recorders or more advanced onboard logging and communication systems which are also used for other purposes (such as vehicle uptime monitoring, vehicle optimisation and accident/incident analysis). These systems log inappropriate behaviours (e.g., hard braking, speed violations, close following, drowsiness/distraction episodes) and this information may then be used by a fleet manager to coach the driver towards safer and/or more efficient driving behaviour, using different forms of incentives. For private drivers, the information may be linked to incentives such as reduced fuel consumption or insurance premiums.

As the required logging technologies are relatively mature today, the main challenge for future development of driver coaching concerns the implementation and deployment strategies. A critical issue is incentive schemes sufficient to motivate long-term behavioural change. For commercial fleets, it may be foreseen that driver coaching will to an increasing degree form part of general safety management strategies, and be combined with other measures, such as driver education and training. Technologically, driver coaching system will merge with other driver support systems. For private driving, new business models will emerge involving incentives, possibly linked to insurance and dynamic pricing (e.g., pay-as-you-drive). Another potential application, of increasing importance due to current European demographic trends, is the coaching of elderly drivers.

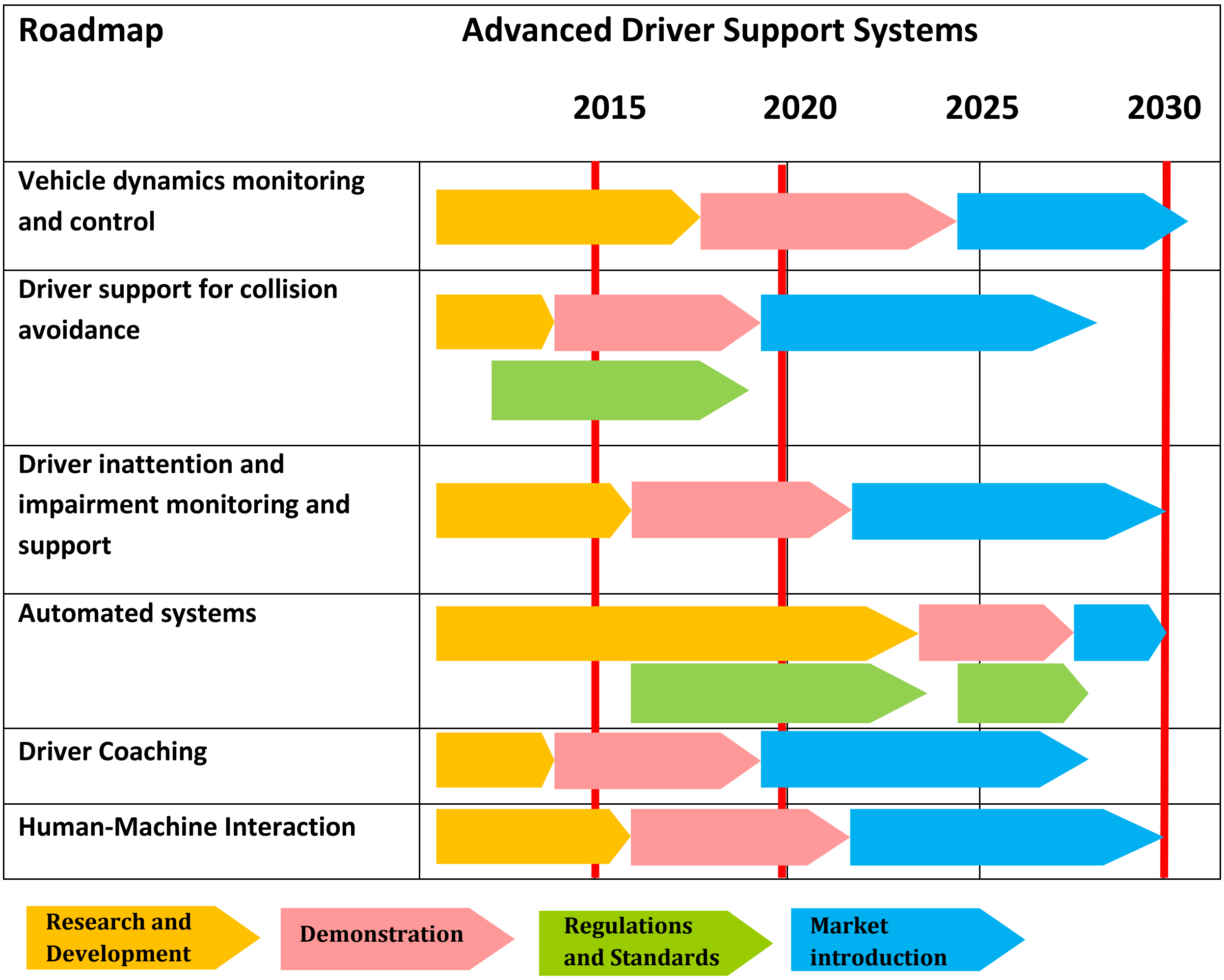
Finally, as the level of automation increases, so will the requirement for driver coaching. Future systems may thus focus more on drivers' monitoring, as opposed to operational driving, performance.

4.3.6 Human-Machine Interaction

Drivers experience advanced driver support functions through the human-machine interface. Hence, the Human-Machine Interaction (HMI) design critically determines the level of user acceptance and adoption and is thus key factor for successful deployment.

A general future challenge for automotive HMI design is to handle the rapid growth of functions interacting with the driver. In addition to factory-fitted and aftermarket functions, this will soon include cooperative system functions as well as downloadable third-party applications. Today, driver support systems are still, to a large extent, interacting with the driver independently of one another, but this situation will quickly become infeasible as the number of functions increases. Thus, there is a need for more holistic approaches to automotive HMI design.

In-vehicle HMI technologies will develop towards increasingly intuitive and distraction-free driver support systems, involving in particular more advanced speech-based interfaces, based on natural speech understanding, which minimise the need to take the eyes off the road. A key concern today is the great distraction potential of consumer electronics systems not designed for use while driving. To some extent, integration of third-party applications into the vehicle HMI is already available in modern premium vehicles. This development is expected to continue towards increasingly seamless integration solutions. This may also involve more advanced methods for workload management, including, for example, dynamic scheduling and lock-out of information. A key step for enabling this development is new business models involving vehicle OEMs, consumer electronics OEMs and application developers. Due to the ageing of the European population, a further important topic concerns the potential to adapt the in-vehicle HMI to better suit elderly drivers.


Roadmap
Advanced Driver Support Systems
2015
2020
2025
2030
Vehicle dynamics monitoring and control
Driver support for collision avoidance
Driver inattention and impairment monitoring and support
Automated systems
Driver Coaching
Human-Machine Interaction
Research and Development
Demonstration
Regulations and Standards
Market introduction

4.4 Traffic Safety Analysis

There are explicit visions in many countries that aim at reducing the number of fatalities and serious injuries in traffic to zero within a few decades. To achieve this, a combination of increased knowledge and improved technology is required. The main source to obtain the knowledge required is field data. Awareness of the value of field data to make the right priorities, understand the underlying mechanisms of accidents and injuries, and to evaluate the safety potential of new system, has gradually increased over the years and is today a natural part of the development process of safety on roads.

In recent years, new technologies have opened new possibilities for understanding the causes of accidents. Data logs from the vehicle, the driver, and the surrounding environment, where data is collected continuously during normal driving, will greatly improve understanding of accident causation, but also implicate major challenges in the development of methods for collection, storage, and analysis of data.

Crashes are rare events and therefore are not always practical to measure due to (1) small sample sizes and (2) lack of details regarding crash failure mechanisms and especially the driver crash avoidance behaviour. Therefore surrogate (crash-substitute) measures of safety are required. A surrogate measure is (a) based on an observable non-crash event that is physically related in a predictable and reliable way to crashes, and (b) uses a method that converts the non-crash events into a corresponding crash frequency and/or severity. Many methods (such as those outlined below) use surrogates as a way of improving efficiency of analysis.

Road User Modelling and Simulation of traffic may be expected to become an increasingly important tool in the traffic safety analysis on several levels, from large scale traffic simulations to case analyses of accident and injury causation. Development of knowledge and method in the area of Impact Assessment, where estimations can be done how a certain safety intervention affects road safety, will be essential to have the possibility to measure the effect of action taken and also for cost benefit estimations.

In order to achieve the goals we seek, a further development of databases and methods for data analysis is an obvious prerequisite. Data from the Investigation of Accidents and from Naturalistic Driving Studies must be combined to provide optimal value. Further development of methods and tools for analysis and simulation must be given high priority.

In the future, accident analyses will be cost-efficient and use integrated data sources. The future analysis system includes data from accident (and injury) investigations, naturalistic driving studies, data from cheap after-market data recorders, and event data recorders. This integrated future dataset will significantly improve explanatory power and cost-efficiency.

Topics for research:

1. Road accident monitoring and investigation
2. Naturalistic Driving Studies
3. Road user modelling and simulation

4. Impact assessment and cost benefit

4.4.1 Road accident monitoring and investigation

Road accident research in terms of accident investigations has been an important and fundamental input to traffic safety analysis for decades. During previous and ongoing research throughout the world standardisation and harmonisation of the methodologies for accident investigations has been developed, e.g. in the FP7 project DaCoTA. With the harmonised methodologies in place the accident investigation system can be implemented to allow researchers to gain access to real-world data across Europe. Important issues for the future are to understand how the decreased number of fatalities affects the injury outcome including the long term consequences. The aim is to make the investigations more cost-effective by e.g. developing methods for merging incident and accident data from naturalistic driving studies (NDS) with other data sources and make use of information from site based as well as vehicle based monitoring (such as Event Data Recorder data) in the investigations. With these methods the road user behaviour can be approached in several ways. However the accident data always need to be linked to injury data for usage in impact assessment and cost benefit analyses.

Data from hospital or insurance sources could be compared to accident data to know precisely the causes of accidents and consolidate accident statistics.

Another important issue is to find statistical methods how to generalise in-depth data from streamlined investigation locations in a few European countries to the whole European road accident situation. Methods for using reconstructions of accidents for risk modelling and to predict accident outcome needs to be developed and confirmed with real-world data.

4.4.2 Naturalistic Driving Studies

Safety countermeasures can best be developed if causes and contributing factors for accidents are well-understood. In Naturalistic Driving Studies (NDS) various recording devices (typically of video and vehicle kinematics data) capture objective, detailed recordings of the events preceding real accidents and safety critical events. These detailed recordings enable risk analyses of many driver-, vehicle- and environmental characteristics that have not previously been possible. The need for in-depth pre-crash knowledge combined with the need for a statistically large enough sample of accidents for analysis is best satisfied by studies with high-fidelity continuous data recordings and larger studies with low-cost event data recorders (with video).

Since accidents are rare events, research on surrogate safety measures (crash-substitute measures) such as near-crashes or incidents is greatly needed. The link between lower severity crash-relevant events and accidents needs to be determined and validated. If this relationship between crashes and surrogates is well-understood, these surrogate measures become tools to speed up countermeasure development, deployment and evaluation.

An integrated approach where Naturalistic Driving Studies are used to collect data simultaneously for safety, efficiency, mobility and environment research and evaluation purposes should be encouraged. Understanding driver behaviour and driving patterns is also essential for solving environmental issues in the Transport area. NDS data, in combination with in-depth knowledge of driver, vehicle, and road and infrastructure features, will enable the development and statistical validation of countermeasures.

4.4.3 Road user modelling and simulation

Computer simulation of traffic may be expected to become an increasingly important tool in traffic safety analysis, from simulation of entire infrastructure networks over a long time, to specific near-crash scenarios involving one or a few road users during a few seconds. Large-scale traffic simulations do exist today, but further research is needed in order to make these fully useful in the study of safety effects of e.g. Cooperative systems and future infrastructure solutions. One specific need in this context is improved surrogate safety measures for the analysis of simulation output. For near-crash simulation, the main need is high-fidelity models of road user behaviour in near-crash situations. Regardless of simulation time scale, models are needed of behaviour in relation to active safety systems (both immediate reactions and longer-term behavioural adaptations), and modelling should also be expanded beyond the current focus on passenger car drivers, to include all types of road users. Further, scientifically sound conceptual models of road user behaviour are needed, on which to base the quantitative models. The diversity of users have to be integrated in the models (age, driving experience, health status, ….). In all of the above, inter-individual variance is a crucial factor to consider.

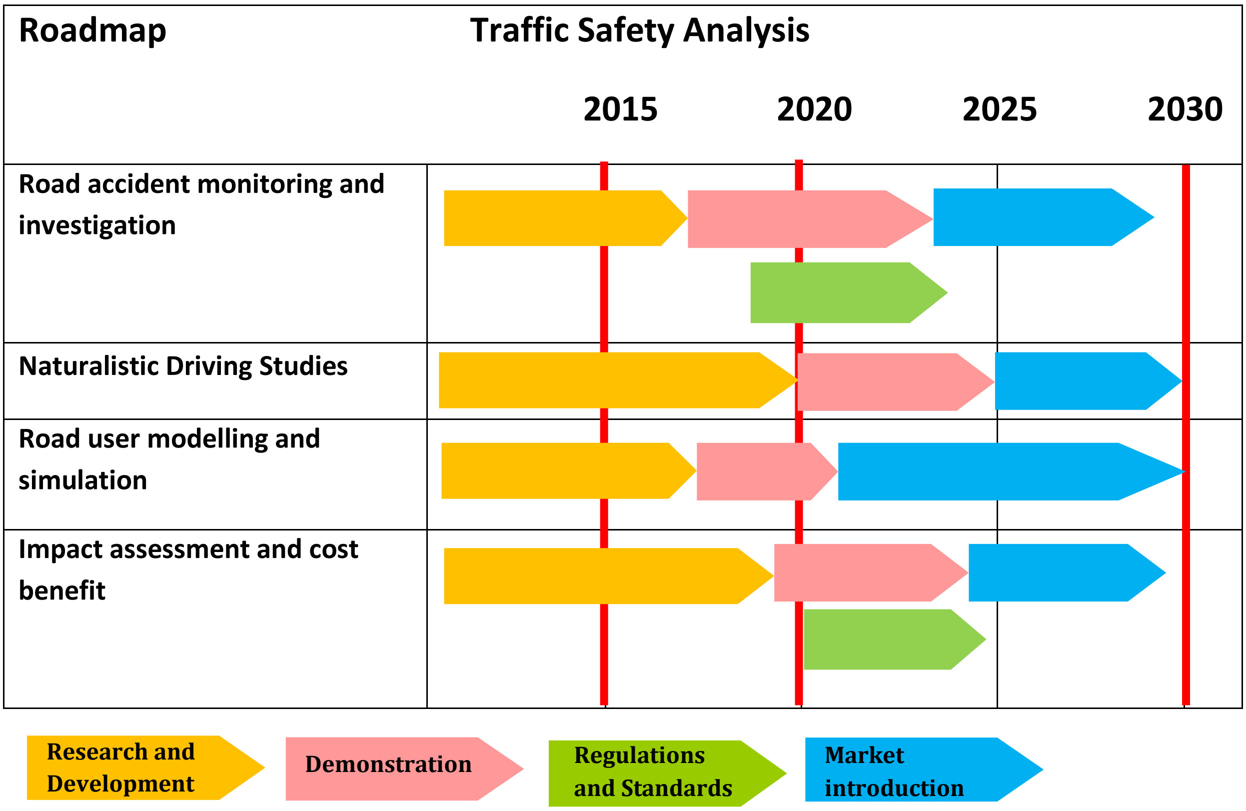
4.4.4 Impact assessment and cost benefit

The goal of safety impact assessment is to estimate the effect of certain safety intervention on road safety. While the most straightforward approach is simply to compare the situation before and after the intervention was introduced (e.g. in terms crash frequency or crash severity), it is of great value to be able to predict prior to introduction what the safety impact will be. This involves the development of risk models which define the mathematical/statistical relation between a safety intervention and its impact to a specific road safety measure. One approach is to relate parameters in statistical accident databases (e.g., speed limit, road surface condition) directly to crash risk or crash severity. Increasing the precision of such models requires improved quality of accident data and the development of new mathematical models, also taking into account regional differences as well as influence over time.

Field Operational Tests (FOTs) potentially yield a more detailed understanding of how a safety system influences behaviour/performance. However, since real crashes are rarely captured in FOTs, the effects of a system in critical situations ("crash relevant events") needs to be extrapolated to its effects on actual crash risk and crash severity. In order to bridge this gap, FOTs and statistical accident data may be combined. This may be further aided by simulation of pre-crash and crash scenarios, based on advanced biomechanical and behavioural models. A complementary approach is to use traffic-level simulations which integrate all aspects in traffic safety (vehicle, infrastructure, driver behaviour and traffic) on a systems level. This will be particularly important for assessing the benefits of system-level interventions such as traffic management and the introduction of cooperative systems. In the future, it may be foreseen that simulation will partly replace large-scale FOTs as the basis for impact assessment. Here, it is important that the behaviour diversity relating to geographical and cultural differences is taken into account.

In order to finally bridge the gap between incidents and accidents, large amounts of detailed data on real crashes as well as incidents are needed. Naturalistic driving data has a great potential to provide this information, which can then be used to develop detailed models that map from microscopic changes in driver behaviour (e.g. eyes-off-road time) to crash risk. As mentioned above, this type of data may be collected at a relatively low cost, through cheap aftermarket data recorders.

A further step is to relate the cost of a safety intervention to the financial benefit of the reduced impact. Today, such calculations focus mainly on societal costs of fatalities and injuries. However, long-term consequences of injuries need to be better accounted for and calculation methods need to be harmonized between countries. Moreover, secondary costs related, for example, to congestion, material damage, vehicle uptime, should also be taken into account. Sufficiently precise calculation methods may also be used as the basis for creating new business models for safety systems involving multiple stakeholders (e.g., drivers, OEMs, authorities, insurance companies, etc,), and thus help accelerating market deployment.



4.5 Safe infrastructure

Road infrastructures have an important role in traffic safety, accident reduction and accident impact mitigation. Further, society is not accepting an unsafe transport system and therefore constantly improvement of road quality and strengthening of inherent infrastructure safety aspects is of political interest. In this context the status of the road network is an important performance criterion and aids in determining road infrastructure's safety level. Research is needed to precisely define the "safety rank" of the road network considering all safety aspects and developing cost-effective solutions to improve the safety performance of the existing road network. As a consequence, critical road sections are identified and available resources and budgets are distributed to improve the road network.

Road monitoring and maintenance are important parts in providing a reliable and safe infrastructure. However, these tasks require alignment with the societal needs for mobility and sustainability. Research and development on real-time road status monitoring and on evolving towards zero maintenance roads is needed to avoid disruption of traffic.

Road infrastructure can help the driver by either explaining a proper use (adapted speed profile) or by mitigating consequences of erroneous behaviour. These concepts are called self explaining roads and forgiving roads. Research is needed to evaluate and understand both concepts with the aim of cost-effective and targeted deployment. An integrated approach of both is needed to streamline results as effects might have opposing impact.

Vulnerable road users, elderly people and people with specific needs are important groups in road safety due to accident severity. Further, the societal challenge of ageing society requires preparing the road transport system for future needs. Current roads and road design do not consider these groups particularly. The challenge is to adapt the current system to the specific needs and increase the level of protection. Research is needed on how to achieve this adaptation in a cost efficient way.

A long-term objective in road transport research (beyond 2025) is to gain a certain level of automation in the transportation system. Assuming that all security and liability issues are solved the automated road will support efforts in traffic safety to achieve vision zero. Coordinated research efforts with ITS related topics (see cooperative systems) are needed towards better integration of the infrastructure, infrastructure related databases, traffic management centres and control centres. Better incident management is one research item which requires coordination of all involved stakeholders. Future ITS solution shall support this process. Economic benefits from such improved systems are among others reduced congestion and reduced risk of secondary accidents.

Topics for research:

1. Real time road status monitoring
2. Towards zero maintenance roads
3. Self-explaining roads
4. Forgiving infrastructure

5. Advanced Incident and Traffic management
6. Conception and design for elderly, vulnerable and users with specific needs
7. Automated road

4.5.1 Real time road status monitoring

The road status and the road condition are significant in the interrelation of accidents and infrastructure. Currently, road sections with higher risks (accident blackspots) are identified by accident statistics. The challenge is to identify dangerous sections beyond accident blackspots related to the road status. In this context it is important to have continuous information (road data, traffic condition, weather information, visibility etc.) both in spatial terms and time wise. Research is needed to develop techniques for in-situ monitoring (sensors and communication) and condition monitoring under traffic speed conditions to avoid disruption. Specifically on the secondary road network where funds are limited and monitoring on a regular basis is not feasible, concepts need to be developed to increase information quality. Probe vehicle concepts making use of extended floating car data communicated in a cooperative system might be a reasonable and cost efficient approach. Road safety on secondary roads is even more relevant as accident statistics show a considerable higher accident risk compared to urban roads or motorways.

4.5.2 Towards zero maintenance roads

Construction and maintenance works on roads (highways and motorways) reduce the level of service. Besides the associated higher chance of congestion, construction areas exhibit a higher accident risk (especially rear end collision, side impact and accidents with oncoming traffic). It is therefore a reasonable objective for road transport safety to reduce downtime due to construction and increase the level of service. Research includes concepts to increase durability and reduce maintenance interventions and costs by advanced asset management approaches. The challenge is to unify expectations in lifecycle cost reduction by at the same time increasing availability, quality and reliability of the road infrastructure network. This and traffic safety concepts especially in road construction areas will aid in reducing accident risks. Safety road workers and concepts to reduce the risk of accidents involving road workers are of specific interest.

4.5.3 Self-explaining roads

Self-explaining road design aims at preventing drivers from errors while driving [...]. It is an important tool to adapt user behaviour to road safety level. The road design and landscape stimulate the drivers to choose the proper speed and safe driver behaviour. These concepts support calming of road traffic and reducing road user mistakes.

One of the major challenges is to develop the concept for each kind of network (secondary road, motorway, etc.) and to provide helpful rules to design or rebuild the roads.

Self-explaining road design needs consolidation with forgiving roads principles to evaluate effects on traffic safety in and integrated approach. This is necessary as effects might be contradicting.

4.5.4 Forgiving Infrastructure

Forgiving roads mitigate consequences of accidents. The first priority of forgiving roadsides is to reduce the consequences of an accident caused by driving errors, vehicle malfunctions or poor roadway conditions. The main objective of forgiving infrastructure is to bring errant vehicles back

onto the lane to reduce injury or fatal run-off-accidents. If the vehicle still hits a roadside element, the second priority is to reduce the severity of the crash. In other words, the roadside should forgive the driver or vehicle erroneous driving by reducing the severity of run-off-road accidents. The challenge is unifying considerations to preserve the landscape with risk reduction efforts due to roadside obstacles. Consequently, self-explaining road and forgiving road concepts require consolidation. Research is needed to evaluate risk reduction effects in a unified concept as separated consideration might yield controversial results.

4.5.5 Advanced incident and traffic management

Traffic safety and congestion are influencing each other bidirectionally. And both challenges have a major economical impact. For cost-effective solutions it is necessary to manage European roads in a sustainable way and improving the use of the existing road network. The challenge is to support road authorities by identifying cost-effective solutions and assessing the impact of ITS in traffic management. One of the first research priorities is related to a better incident management including all stakeholders. Incidents often resulting in congestion need a comprehensive management system. This will increase the level of safety and reduce secondary costs (congestion and secondary accidents). Research is needed to obtain valid and good quality data to anticipate incident. Concepts like extended floating car data should be integrated. Further incident management should accelerate post accident rescue and lifesaving. Especially in the transition phase for new vehicle based safety technologies (e.g. eCall, cooperative systems) it is important to properly prepare the infrastructure (infracall). Research is needed on how and where the infrastructure can support non-equipped vehicles in a proper and cost-efficient way.

4.5.6 Conception and design for elderly, vulnerable and users with specific needs

Of specific interest is the protection of VRU, elderly people or people with specific needs. In this context safe infrastructure design, construction and technologies play a significant role. Ageing society makes it even more important to act soon on reviewing and preparing the road infrastructure for the needs of elderly people. The future in road transport safety will strongly depend on how elder and vulnerable road users as well as their needs are better integrated in the systems safety considerations. Research and development specifically considering the needs of this user group and improving protection for VRU or prevention of VRU accidents is required. Further research is needed to review current regulatory framework and design guidelines to identify gaps and suggestions for improvement.

4.5.7 Automated road

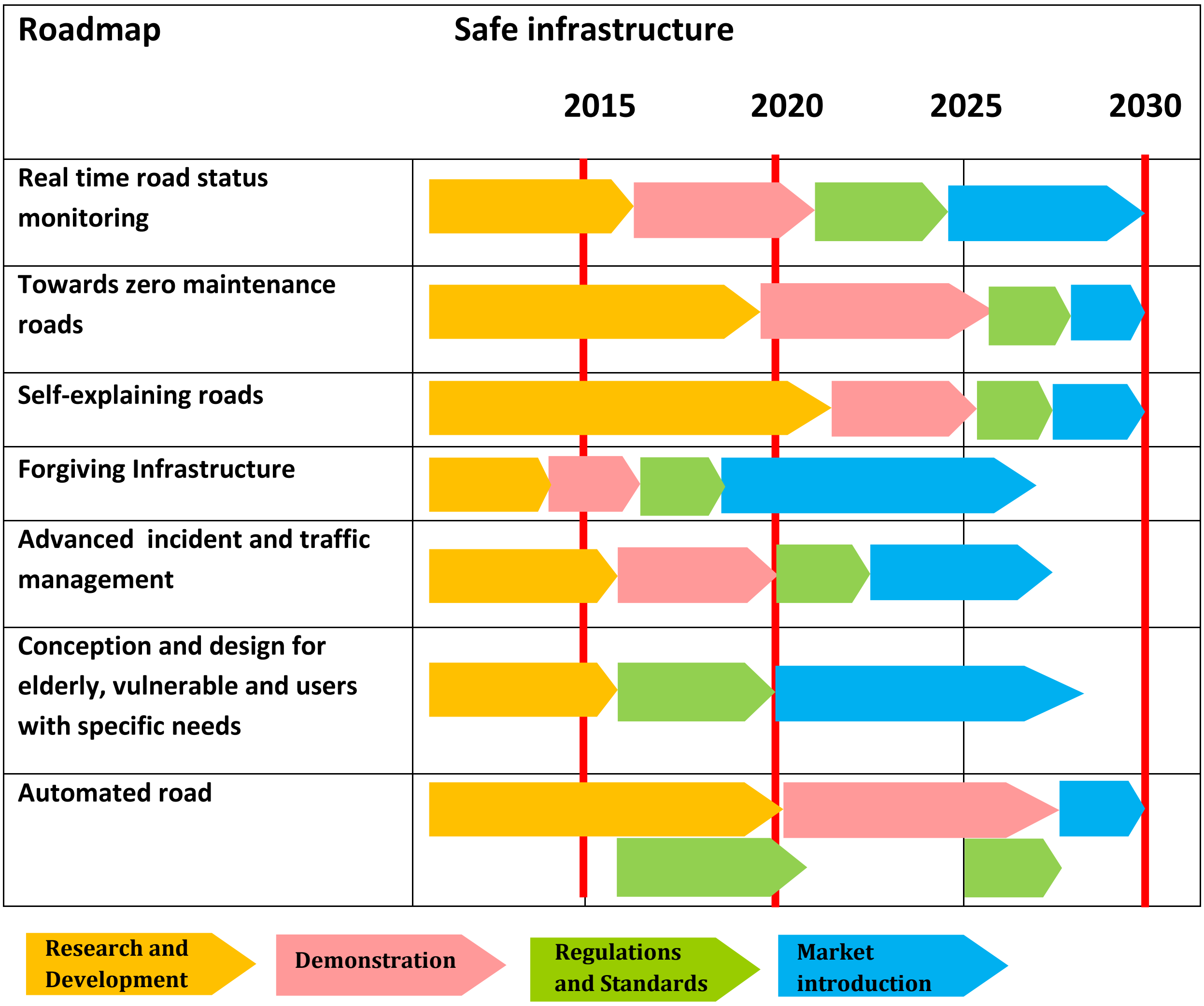
A certain level of automation of the road transport system will aid in increasing the level of service, the level of safety and energy efficiency. This includes concepts of platooning in freight transportation (demonstrated in the EC SARTRE and Citymobil projects) and advanced control functionality through cooperative systems. By 2025 the developments towards automation of the road transport system progress to a certain level (including considerations on liability and legal framework) where infrastructure needs to be prepared for that step change.

The Automated Road will integrate road side intelligence with ICT applications in the vehicle, the services and the operator. The sensory and communications technology involved will enable the deployment of advanced (e.g. dynamic) guidance and management systems tailored to respond to in situ requirements, in effect improving reliability and efficiency of the network management.

It is therefore inevitable to connect infrastructure, databases, traffic control centres in the development process. Virtual or physical separation of traffic is required to proceed with automation of road transport. Demonstration projects need to elaborate this system orientated approach towards automated driving.

Another challenge due to the complexity and sensitivity of automated driving is more fundamental: accurate positioning to allow fail-safe lateral and longitudinal vehicle control. The research steps will concentrate on on-site sensor systems monitoring and control algorithms. A systems approach is needed combining vehicle, infrastructure and driver to develop roads towards automation.

Comprehensive, interoperable communications system linking driver, vehicle, road and operator is required. This enables future vehicle to highway guidance, speed control and direction guidance and in-road vehicle guidance using to change lane usage and traffic management.



4.6 Cooperative systems for road safety and security

It should be emphasized that the concept of cooperative systems is very broad. The common view today is that it covers modern and innovative use of Information and Communication Technologies as a basis for functions and applications that facilitate and improve the quality of the mobility for people and goods in general terms.

This chapter will only cover needed research and development aspect to facilitate cooperative system like communication technologies and the closely connected standardization. These are prerequisite and enablers for a broad implementation of co-operative systems. It is worth mentioning that the communication technologies will not only support road transport safety and security issues which this road map deal with, but also other challenges like environmental issues and transport efficiency. The communication technologies are fundamental to all applications and will be used for a broad variety of them.

This chapter emphasise as well the necessity of Field Operational Test as an important step to validate the technologies, models and developments on the way to large scale implementation and deployment.

Road safety is expected to gain from the cooperation between vehicles (V2V) and between vehicles and infrastructure (V2I) and it is clearly the approach that allows moving close to the final target of “zero accidents”. There are still several aspects to cover in research: standardisation, cost-effective hardware and software solution for communication between vehicles and with the infrastructure, precise relative localization and proper management of non equipped vehicles and road users. Due to cooperative systems and the connection between vehicles and to the infrastructure, advanced safety support functions are possible. The applications supporting drivers range from warning systems for low friction surface, congestion warning and intelligent speed adaptation. Research is needed to bring forward support applications with impact on road safety based on the previous project results considering the standardised communication routines. Subsequent to the research and development of algorithms and applications large field operational tests are required to assess safety impacts, user acceptance, cost benefit and driver behaviour in order to correctly design all components and the entire system.

Another research question is to what extent and how are Powered Two Wheelers (PTW) other Vulnerable Road Users (VRU) integrated in cooperative systems given their above average involvement in severe crashes. Risk compensation by drivers may undo the advantages of cooperative systems if drivers too heavily rely on a system that leaves the most vulnerable road users uncovered.

Topics for research:

1. Communication protocols, standards, …
2. Safety of co-operative systems
3. Security of co-operative systems
4. Field Operational Test (FOT)

4.6.1 Communication protocols, standards, …

Ongoing standardisation work in different bodies (ETSI, CEN) provides a sound basis for communication between vehicles and from vehicles to the infrastructure and reverse. This work is related to communication standards and the services.

The previous EC-funded R&D projects have been the major contributors to European standardisation in the ITS area.

The main focus of the standardization activity carried on by each of the main organizations is different. Each is developing separate sets of standards, tailored to their specific focus:

- ISO mainly focuses on multiple media management
- IEEE focuses on lower layers (802.11) and a "simplified" architecture for just 5.9GHz communications
- ETSI focus is currently mainly car-to-car multi-hopping and geo-networking
- CEN is focusing on standards for messaging, protocols, architecture etc. for cooperative mobility applications.

In general, proliferation of incompatible ITS standards is very inefficient and works against the conditions for actual deployment of cooperative ITS solutions. Such fragmentation can lead to increased cost and deployment delays and, most importantly, can increase the risk of compromising the achievement of safety and efficiency benefits.

Unfortunately, since no real interoperability has been actually guaranteed in current specification work, large overlaps and a substantial amount of duplicated effort has developed. In addition, the standardisation groups have not been taking advantage from a collective cooperation

Based on the previous considerations, during the last year, the shared awareness that global cooperation and vision is ultimately needed has been increasingly developing among all the different actors, such as:

- Standard Development Organizations (SDOs)
- ITS-related government entities (DoTs)
- ITS R&D projects

This cooperation has eventually started to happen among the SDOs in the form of official liaisons and cross member participation to the different committees and ETSI TC ITS is particularly active in this harmonization activity that needs continuous backing and support.

The results of the activity performed in the frame of the main EU R&D projects are now being effectively transferred into the standardization process in the ETSI TC ITS and CEN TC 278 domains and the overall scenario seems now adequate to achieve a stable set of standards able to support the market take up of the cooperative ITS solutions. This direct link between research project and standardisation should be intensified. However, the rigorous approach of the standardisation experts

might be needed at one point to create a structured approach leading to conformance testing and certification procedure.

4.6.2 Safety of co-operative systems

Quite a few of the applications based on cooperative system technologies require a high degree of overall system safety, assuring a minimum of systems breakdown of a type that jeopardize the traffic safety. Such applications can be found dealing with cooperation between vehicles e.g. Cooperative forward collision warning as described in ETSI TR 102638 V1.1.1 (2009-06). This and many similar applications require use of well validated models standards and technologies to be able to provide a failsafe system. The system on each node must have a supervisory application that is permanently running in parallel and is checking the relevance of the input data and calculated results which in the end generates a signal to an actuator affecting in the case of Cooperative forward collision warning the speed regulator and or the brake. This fail safe functionality is already implemented among the OEMs when it comes to other ADAS systems e.g. lane keeping assist, but is important to mention in practical terms and in this context. When it comes to co-operative systems the failsafe issue is of a much higher dignity than in autonomous ADAS and needs special focus in research and development agendas.

In developing systems towards autonomous driving as a tool for e.g. platooning the importance of safety issues in communication, in standards etc for cooperative systems will be even higher.

As the communication safety issues related to cooperative systems are very broad due to the variety of applications and their different demand, it is not meaningful to point out any specific subject. Instead the important horizontal issues relevant for all applications are:

- Fail safe communication link
- Validated standards
- Validate communication link in a big variety of traffic composition, density etc.
- Field Operational Tests to consolidate and validate the communication functionality

To get national, regional and local road authorities as well as commercial road operators involved there must be convincing evidence from large scale FOTs. Secondly to get cross-border functionality there is a need for cooperation between road operators and road authorities or between organizations that represents them to a common agreement on how to proceed.

4.6.3 Security of co-operative systems

Security of the cooperative systems deals with designing and ensuring a communication system that is resistant against cyber attacks, false messages etc. Privacy is also connected to security and a system has to ensure a certain level of security for user acceptance. A challenge for future research is to improve the security level without any negative impact on the efficiency or lowering capacity of the system.

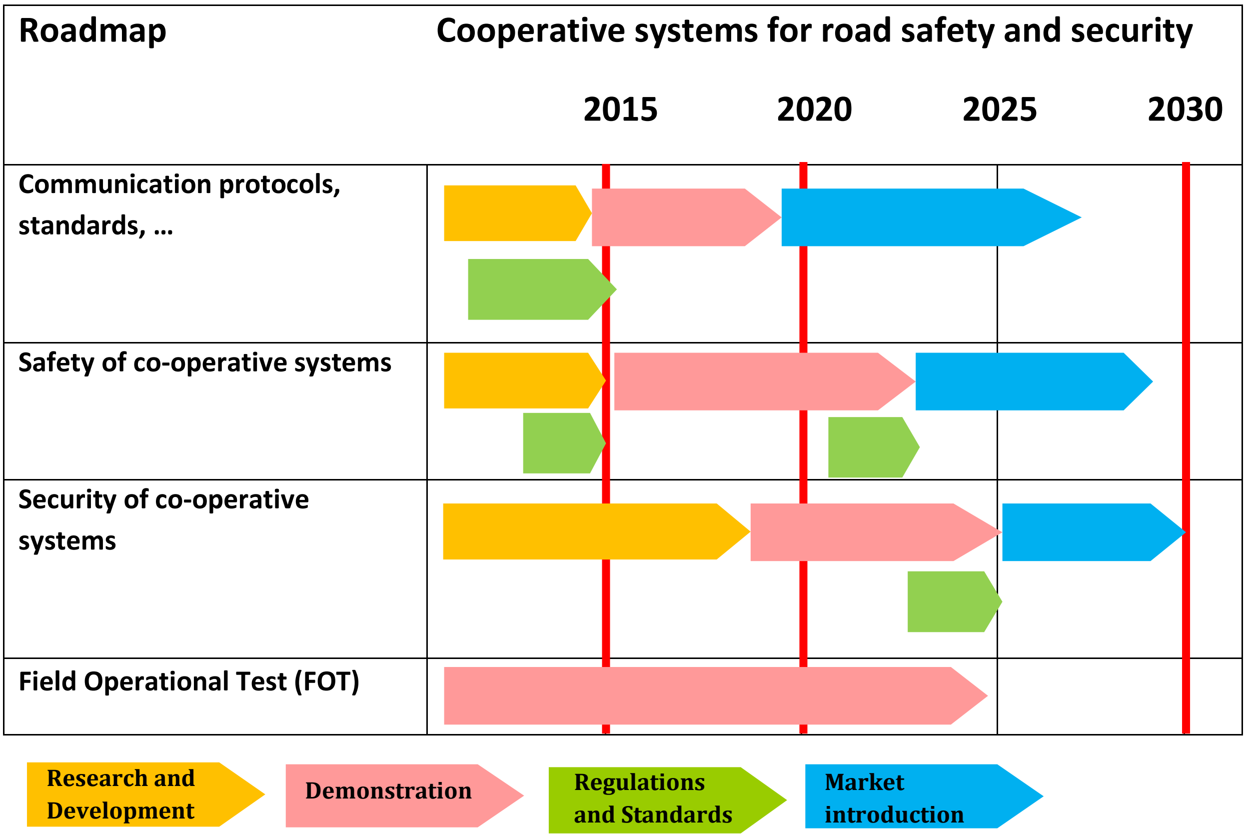
The security of co-operative systems has been well addressed in the deliverable D31 European Communication Architecture from COM eSafety support action.

4.6.4 Field Operational Test (FOT)

Field Operational Test is an important tool to validate models and calculations made to estimate the functionality and impact of applications based on cooperative systems. Validation is needed of

simulation models for communication and other models that have been developed for cooperative systems. Those models have been validated in research projects containing a small number of vehicles. Large scale Field Operation Tests are now needed to validate the models in a greater context to ensure the functionality. Another reason is to convince road operators and politicians, local and regional officials responsible for the public road network. Therefore the FOTs need to have a critical mass of vehicles/users to give relevant answers. Other objectives in FOTs are related to impact assessment specifically any the safety impact, the user acceptance and the cost/benefit of the tested systems. This is necessary to develop adequate business models and support large scale deployment. So the FOTs have many objectives where proving and consolidate the communication functionality is one.

There is an ongoing discussion among the infrastructure stakeholders if the impact of a cooperative system (especially V2I) is of such magnitude justify the implementation costs. It is important to remember that investments in cooperative systems compete with many other traditional measures where the cost/benefit is well known. The existing recommendations concerning V2I implementation priorities from different stakeholder groups currently lack this information. Those recommendations are not yet based on impact assessments performed during/within large scale Field Operational Test.



4.7 Secure road transportation

Economic growth is always accompanied with an increasing amount of freight and passenger transport which challenges the infrastructure and vehicles not only to keep pace with the increasing traffic volume but also to ensure security standards being met. Major challenges in the area of stolen or lost goods, vehicle theft, driver security, data security as well as protection against manipulation shall be addressed.

A study published by the European Parliament in 2007 has shown economic losses due lost or stolen goods in the European Union to amount of 8,2 Billion Euro annually . According to TAPA (Transported Asset Protection Association) this number is only a fracture of the economic damage as it doesn't account all costs the industry suffers (e.g. replacement goods, re-shipping etc). A report from EUROPOL, published in 2009, also states various modus operandi like curtain slashing, jump up thefts, load diversion, use of fraudulent documents as well as use of gas or explosives to incapacitate the driver. Therefore countermeasure solutions shall be developed and promoted to reduce the amount of lost, stolen or damaged goods to ensure free trade and economical competitiveness. These measures will also help reducing illegal freight transport (drugs, weapons, etc.) or illegal boarder crossing in freight compartments.

There is also a continuous challenge to prevent vehicles from being stolen or broken-up. Technological improvements over the last decades have increased the complexity to manipulate anti-theft systems. This leads to the situation that criminals are better organized and use more sophisticated methods to disable remote access or immobilization systems. Trafficking with stolen vehicles has become to a regular field for economic activity of criminal organisations and is often accompanied with other criminality. Novel systems will have to be developed to hinder, discourage and prosecute thieves as well as increase the recovery rate of stolen vehicles and goods.

Along with the emergence of vehicle telematic (ITS), cooperative traffic, co-modality and particularly vehicle tracking systems, data security questions will need to be solved to ensure user acceptance and avoid data misuse.

The following research topics for new generation road transport security systems need to be addressed:

1. Secure road transport facilities
2. Tamper-proof identification and access systems
3. Advanced alarm and tracking systems for vehicles and goods
4. Cooperative systems to increase security level in the freight transportation
5. Data security in road transport systems

4.7.1 Secure road transport facilities

Freight distribution centres, park&ride areas and resting places for trucks will need to be equipped with secure and intelligent surveillance, alarm and access systems. The deployment of systems that use or combine optical technologies (camera, infrared) will prevent attacks to parked trucks and may be operated manually or (semi-) automatically. Solutions in connection with future ITS systems allowing truck drivers to identify and reserve free and secure parking places, where incoming and

outgoing traffic is monitored, are highly desired and will need to be integrated in traffic management centres.

4.7.2 Tamper-proof identification and access systems

Secure and reliable identification and authentication is the baseline for every security system and their design is always a balance between the level of security and available time. Requirements for short identification times always suffer cut-backs in security and vice versa. Therefore developments in the area of identification technologies (e.g. RFID, smart labelling, etc.) require continuous effort as new technology always open benefits in efficiency and/or comfort. For access- or immobilization systems, new technology will allow reliable protection against vehicle theft or malice intrusion. It will allow reliable, novel ICT connectivity functions like smart phone or handheld interfaces. Hidden or secret identification systems will help to detect fraudulent documentation (e.g. spare parts from stolen vehicles, waybills) but will require pan-European (or even worldwide) harmonization of databases and methods. Access systems to freight distribution areas or roads that are dedicated to specific vehicles, will need to have sufficient protection against trespassing along with efficient usability. Supply chains and freight delivery with seamless cargo monitoring (incl. on-board) down to continuous single parcel identification will allow significant reduction in stolen or lost goods and improves correct sender/receiver identification. The profitable and comprehensive implementation of such systems will require continuous improvement of current identification technology as well as new approaches.

4.7.3 Advanced alarm and tracking systems for vehicles and goods

Advanced localization and tracking systems will enjoy growing popularity for fleet and freight management as they help to increase not only efficiency but also security. Following an incident where a vehicle or a piece of good has been stolen these systems may be embedded in a powerful emergency chain of alarm systems and containment measures that avoid trafficking with stolen vehicles and goods and will increase the chance to identify offenders. The first step of this emergency chain are reliable and tamper-proof alarm systems that detect malice intrusion (or intrusion attempts) in vehicles, cargo compartments or containers using various types of sensing technologies (e.g. infrared, ultrasonic, microwave, vibration, narcotic gas detectors, etc.). Key features of these systems are a close-to-zero false alarm ratio and an effective alarm scenario that should include automatic emergency message to police or law enforcement agencies. To protect the driver from violence or threat the system will need to have arming/disarming mechanisms that do not require his action or involvement. In a second step systems that localize stolen goods or vehicles will allow continuous persecution. To prevent the systems from manipulation or re-moving they need to be securely mounted or hidden. The systems shall be able to work also in a degraded mode with redundant power supply, communication channels and alternative localization techniques (jammed or no GPS/Galileo). As a third and last step systems shall be able to stop a vehicle to prevent continuation of unauthorized movement. This needs to be done without endanger other road users and avoiding dangerous situations (e.g. blocked vehicles on railway crossings or in tunnels). The systems will enjoy quick market penetration when economic benefits are offered (lower insurance rate or taxes).

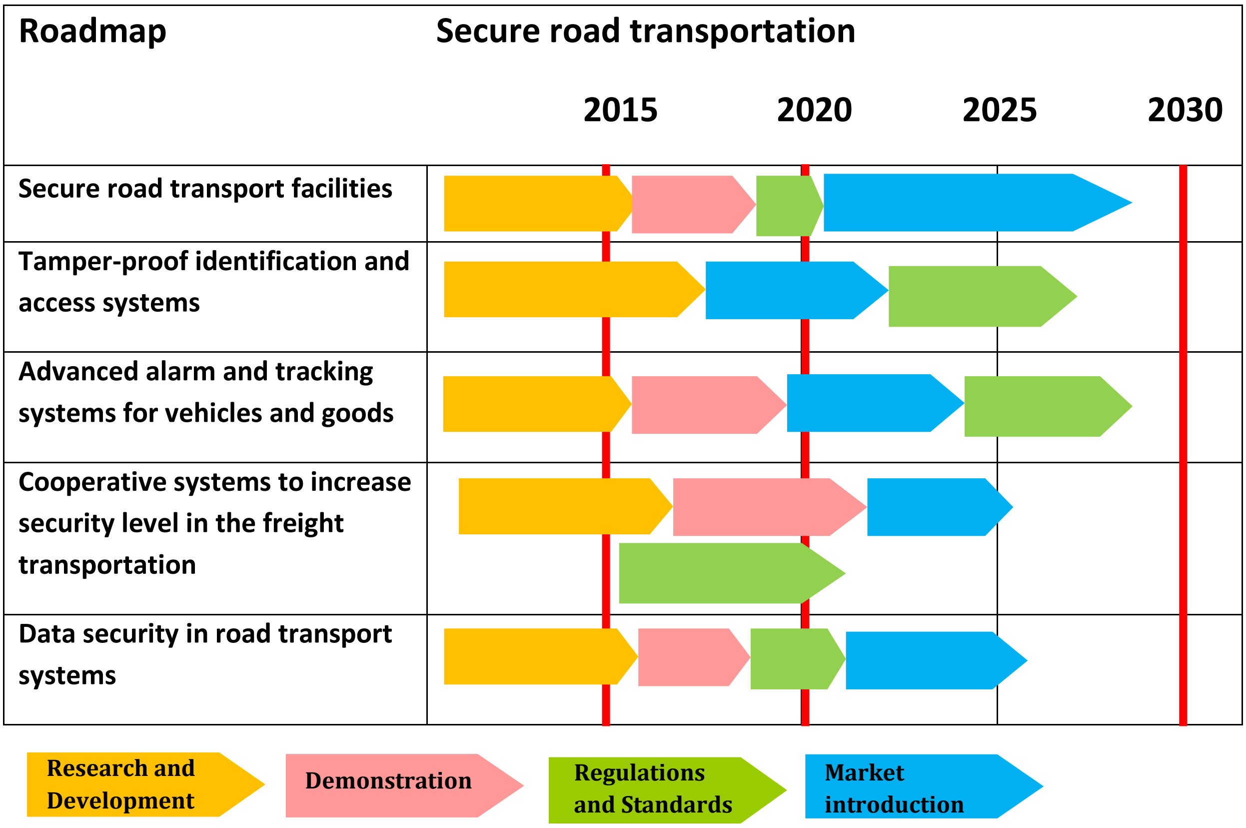
4.7.4 Cooperative systems to increase security level in the freight transportation

Future ITS Solutions and cooperative systems aid in protecting people and goods in road transportation. This is very relevant for dangerous or sensitive goods but also for freight transport in

general. Innovative technologies and functionality for tracking/tracing of vehicles and goods shall be integrated. Satellite based positioning (GPS, Galileo) in combination with V2X and ITS is a key element to enable redundancy of systems. Within a cooperative system, other vehicles and drivers may be warned after a reported theft. Dangerous and sensitive goods transports will be the first ones equipped with these applications. Demonstration activities are needed to show full vehicle and infrastructure based tracking/tracing with cooperative systems. Integration of road infrastructure based sensors for tracking, speed and weight monitoring, tolling, etc. is required. Another aspect is the security of drivers. In this context systems are necessary to authenticate information given to driver about unscheduled route changes (prevention of ambush attacks after route deviation) making use of cooperative systems. The network of goods (integrated smart sensor networks or RFID tags) allows creating ubiquitous awareness for goods and connecting them in the cooperative systems. This aids in immediately identifying any unauthorized position change or any physical or environmental (temperature, humidity, etc.) damage of the freight. Demonstration activities should incorporate pan-European activities towards harmonization of identification systems, tracking systems and (electronic) freight letters. Large demonstration activities or field operational trials with cooperative systems (see cooperative systems roadmap) shall include services for security of people and goods as well as protected data storage and transmission (see data security).

4.7.5 Data security in road transport systems

Along with the deployment of new systems in the area of vehicle tracking/tracing, cooperative systems or any other ITS the users' data privacy needs to be protected at any time. Unauthorized use of data, protection against manipulation or attack will not only cause short time danger (e.g. hacker or terrorist attack) but may also cause users to be hesitant using novel systems. The commercial success of systems like automatic road tolling or parking fee collection, access to restricted areas or entry to roads dedicated to special vehicles will depend on the user's trust in the protection of his privacy and security. Thus it will be inevitable to establish appropriate standards with pan-European (or worldwide) acceptance that define storage, handling, transfer and protection of personalized data.


Roadmap
Secure road transportation
2015
2020
2025
2030
Secure road transport facilities
Tamper-proof identification and access systems
Advanced alarm and tracking systems for vehicles and goods
Cooperative systems to increase security level in the freight transportation
Data security in road transport systems
Research and Development
Demonstration
Regulations and Standards
Market introduction

5. Milestones

5.1 Milestone 2015 : Safe Green Transport

Expected benefits – 20% of accidents

- 30% freight lost

Safety of low emission vehicles
Improvement of driver assistance systems (all scenarios)
Vulnerable road user protection
Secure parking

5.2 Milestone 2020 : Full integrated safe road transport

Expected benefits – 30% of accidents

- 30% freight lost

Enhanced driver assistance systems (control)
Cooperative systems - Support
Safe infrastructure
Secure Transport
Road User Behaviour improvement
Preventive Vulnerable road user protection

5.3 Milestone 2030 : Towards Near Zero accident Road Transport

Expected benefits – 30% of accidents

- 30% freight lost

Automated system for collision avoidance
Cooperative systems – Control
Cooperative - Vulnerable road user protection
Full support for road user safe behaviour
Dedicated road infrastructure

Safety of vulnerable road users			
	2015 - Safe Green Transport	**2020 - Full integrated safe road transport**	**2030 - Towards Near Zero Accident**
Intelligent traffic systems for VRU safe mobility management	Systems for VRU guidance, driver awareness and VRU awareness.	Selection of demonstration sites. Installed in-vehicle systems, infrastructural detection and identification systems and smart management systems. Demonstration in well-known black spots.	Market introduction and impact analysis.
Improved VRU active safety systems for accident avoidance	Smart systems for VRU detection to achieve: • increased VRU detection • lower system cost • increased reliability • smart use of driver workload estimation. Autonomous accident avoidance system based on smart sensors.	Demonstration of most promising systems in inner cities. Definition of test protocols and adequate testing systems for VRU active safety systems. Harmonized protocols included in a regulatory framework.	Show effects of VRU active safety systems.
Safety systems for the protection of (motor)cyclists in collisions with motor vehicles.	Active and passive systems to decrease the collision impact between VRU and motor vehicle, both on-vehicle and protective garments. Demonstration of in vehicle measures.	Demonstration of protective garments. Market introduction of most effective systems. Regulatory framework for autonomous actions of in-vehicle systems.	
Safety systems for single-vehicle motor-cyclist accidents		Protective measures in single-vehicle motorcyclist accidents: both motorcycle measures, garment integrated systems and forgiving infrastructure.	Demonstrated reduction in casualties for single-vehicle accidents.
Mitigation of secondary impact	Definition of criteria for evaluation of secondary ground impact i.e. accident kinematics, injury parameters, scenarios, influence of	Development of adequate counteractive measures. Demonstration of most promising safety measures.	Market introduction and definition of test procedures.

	vehicle geometry and speed.	Analysis of potential for autonomous braking systems regarding secondary ground impact.	
Safety of New Vehicles			
	2015 - Safe Green Transport	**2020 - Full integrated safe road transport**	**2030 - Towards Near Zero Accident**
Biomechanical models and injury prediction	Injury criteria for neurological deficits incl. injury criteria for elderly and other VRUs. Worldwide harmonized more biofidelic crash dummies for frontal and side impacts. Human body models for safety assessment with biofidelic kinematics and realistic injury predictions for integrated safety	Human body models suitable for multiple events. Harmonized human body models as a basis for a worldwide accepted virtual safety assessment methodology. Intro-duction of virtual safety assessment methodology for primary and secondary safety in global regulations and consumer testing	
Crash compatibility and improved crashworthiness of light and/or new vehicle concepts	Harmonised safety requirements for downsized and extra-low mass vehicles. Design guidelines for crashworthiness of electric vehicles and specific test procedures. Crashworthy structures for two-seaters with in-line seats. Restraint systems adapted to the requirements of lightweight vehicle concepts.	Predictive numerical simulation tools for composite materials under impact loading incl. the post-failure behaviour. Require-ments for crash com-patibility and related test procedures har-monised worldwide.	
Solutions for low acoustic perception of FEVs	Sound functionality and generation devices. Sensing strategies and HMI integration for	Validated, integrated acoustic solutions for preventive vulnerable road user protection	Holistic automated acoustic system environment for collision avoidance, mainly in

	acoustic solutions. Demonstration / field testing		terms of vulnerable road user protection
Advanced Driver Support Systems			
	2015 - Safe Green Transport	**2020 - Full integrated safe road transport**	**2030 - Towards Near Zero Accident**
Vehicle Dynamics Monitoring and Control	First generation integrated chassis.	Driver assistance systems acting on the integrated chassis, including long vehicle combinations for heavy goods vehicles.	Distributed energy storage and propulsion (on vehicle combinations for heavy goods vehicles)
Driver Support for Collision Avoidance	Wide-scale deployment of active safety systems in all vehicle models and types	Enhanced perception platform, integrating onboard sensing, V2X, e-Horizon and driver monitoring; Integrated IWI strategies	Automatic intervention in a wide range of critical scenarios
Driver Impairment Monitoring and Support	Wide scale deployment of alcohol-locks and drowsiness mitigation systems	Integration of driver inattention and impairment monitoring into the general perception platform	Driver monitoring supporting semi-automated driving
Automated systems	Wide scale deployment of basic semi-automated functions (ACC Stop&Go with automatic Go, full longitudinal support and limited lateral support)	Advanced semi-automated functions (e.g. full longitudinal and full lateral support in optimal conditions)	First fully automated functions (e.g., platooning in dedicated areas)
Driver coaching	Stand-alone Driver Coaching systems widely deployed	Driver Coaching integrated with other driver support systems and part of general safety management programs	Driver Coaching for automated driving

Human-machine Interaction	Integrated HMI solutions minimising driver distraction, including centralised-workload management functionality	Seamless integration of third-party applications	Adaptive HMI solutions tailored for specific user groups (e.g., elderly drivers)
Traffic Safety Analysis			
	2015 - Safe Green Transport	**2020 - Full integrated safe road transport**	**2030 - Towards Near Zero Accident**
Road accident monitoring and investigation	2015 Implemented accident investigation infrastructure for harmonised European in-depth data which feeds the traffic safety analysis research.	Understand the shift in injury patterns due to implementation of future safety countermeasures. Methods for cost-efficient data collection and analysis merging different types of field data.	Integrated analysis from field data including event data recorders, Naturalistic Driving studies, accident and injury data fully available for impact assessment and cost benefit analyses
Naturalistic driving studies	first results from established Naturalistic Driving database across EU	The relationship between accidents and surrogate (crash-substitute) measures is validated. Non-crash events are predictably and reliably related to crashes.	Integrated approach between accident/Naturalistic driving and simulators
Road user modelling and simulation	Off-the-shelf high-fidelity simulation models of driver behaviour in selected accident scenarios; Large scale traffic simulation validated for safety assessments	General off-the-shelf high-fidelity models of road user behaviour in all major accident scenarios, including all types of road users	Integrated, general modelling and simulation of road user behaviour on large and small time and space scales
Impact Assessment and Cost benefit analysis	Validated European impact assessment methods based on	Simulation-based impact assessment tools linked to continuous	More advanced, and precise, cost/benefit analysis methods for

	combination of accident statistics and, FOT data and simulation	collection of naturalistic data	road safety (based on the previously developed impact assessment methods)
Safe infrastructure			
	2015 - Safe Green Transport	**2020 - Full integrated safe road transport**	**2030 - Towards Near Zero Accident**
Real time road status monitoring	System specification for real-time road status monitoring	Demonstrator of a monitoring system finished	Standardisation and market introduction
Self-explaining roads		Self explaining roads and forgiving road consolidated and demonstrated	Integration of self explaining and forgiving design and construction in the standards, guidelines and regulation finished
Forgiving Infrastructure		Self explaining roads and forgiving road consolidated and demonstrated	Integration of self explaining and forgiving design and construction in the standards, guidelines and regulation finished
Towards zero maintenance roads		Large scale Demonstration projects	Starting Market Introduction and Implementation
Conception and design for elderly, vulnerable and users with specific needs	New concepts for road design developed considering VRU and elderly people or people with specific needs	Large scale testing	Standardization, Guidelines and regulations adapted to consider needs of VRU, elderly people and people with specific needs
Automated road		Specifications, prototype and system definitions finished	Large-scale Demonstrator of an automated road system

Cooperative Systems			
	2015 - Safe Green Transport	**2020 - Full integrated safe road transport**	**2030 - Towards Near Zero Accident**
Consolidation of communication standards	Communication standards covering most layers of the communication stack is available.	Verification made on communication standards supporting secure semi-autonomous driving	Verification made on communication standards supporting secure full autonomous driving
Large field operational tests on cooperative systems support functions.	Cooperative systems support functions. Impact assessment and functional verification completed.	Cooperative systems used for support integrated functions. Impact assessment and functional verification completed.	Cooperative systems used for Semi automated systems Impact assessment and functional verification completed.

Secure Road Transportation			
	2015 - Safe Green Transport	**2020 - Full integrated safe road transport**	**2030 - Towards Near Zero Accident**
Secure road transport facilities	Integration of secure parking areas in large ITS FOTs	Proven concepts in market (<10% of all areas) with ongoing legislation activities	50% of all areas protected with advanced systems
Tamper-proof vehicle access and immobilization	Concepts for secure novel ICT vehicle connectivity and ITS integration available	Ongoing market introduction with 20% of novel vehicles equipped with ICT connectivity	Close-to-zero possibility to illegally unlock and start a novel vehicle with ICT connectivity
Seamless on-board cargo monitoring	Demonstration of concepts for on-board identification of individual parcels	Deployment in supply-chains for high value and sensitive goods (<10 % of all freight transport)	50% of all parcels are continuously monitored 65% reduction of stolen or lost goods compared to 2010
Advanced alarm and tracking systems	Integration of advanced alarm/tracking systems in ITS FOTs	All new vehicles with optional tracking systems available, pan-European service available, promotion by insurances	>65% of all new vehicles equipped with alarm and tracking systems. >80% of all freight transport protected with tracking systems.

Cooperative systems to increase security level in freight transportation	“Network of goods” inclusion in large ITS FOTs	>50% of dangerous or sensitive good transports are integrated in ITS	65% reduction of stolen, lost or damaged goods compared to 2010
Data Security in road transport systems		Pan-European standards for ITS data security established	

6. References

1. Strategic Research Agenda ICT for Mobility – RTD Working Group of the eSafety Forum
2. Mobility and Transport in FP8. EUCAR position, November 2010
3. EARPA Position Paper: FURTHER ADVANCES IN AUTOMOTIVE SAFETY IMPORTANCE FOR EUROPEAN ROAD TRANSPORT RESEARCH. 9th November 2009
4. EUROPOL, Cargo Theft Report, The Hague 2009
5. The Innovation Union strategy, requesting to take a system approach including deployment aspects in order to deliver innovation: COM(2010) 1161, 'Europe 2020 flagship Initiative - Innovation Union'.
6. The Green Paper on the next Framework Programme: COM(2011) 48, Green Paper 'From Challenges to Opportunities: Towards a Common Strategic Framework for EU Research and Innovation Funding'.
7. The Transport White Paper from DG Move setting the "new" EU transport policy: COM(2011) 144, White Paper 2011 'Roadmap to a Single Transport Area - Towards a competitive and resource efficient transport system'.
8. The strategy for clean vehicles from DG Enterprise covering both ICEs and EVs: COM(2010)186, 'A European strategy on clean and energy efficient vehicles'.
9. The overall Europe 2020 strategy, focusing on sustainability and global competitiveness: COM(2010) 2020, 'Europe 2020 - A strategy for smart, sustainable and inclusive growth'.
10. COM(2010) 389, "Towards a European road safety area - policy orientations on road safety 2011-2020".

7. Glossary

CEN	**- European Committee for Standardization**
CMbB	**- Collision Mitigation by Braking**
ERTRAC	**- European Road Transport Research Advisory Council**
ESC	**- Electronic Stability Control**
ETSI	**- European Telecommunication Standards Institute**
EuroNCAP	**- European New Car Assessment Programme**
FEV	**- Full Electric Vehicle**
FOT	**- Field Operational tests**
HMI	**- Human Machine Interaction**
HV	**- Hydrogen Vehicle**
ICT	**- Information and Communication Technologies**
IWI	**- Information, Warning, Intervention**
LDW	**- Lane Departure Warning**
NDS	**- Natural Driving Studies**
NVH	**- Noise, Vibration and Harshness**
PTW	**- Powered Two Wheeler**
RFID	**- Radio Frequency Identification**
V2I	**- Vehicle to Infrastructure communication**
V2V	**- Vehicle to Vehicle communication**
V2X	**- Vehicle to infrastructure/vehicles communication**
VRU	**- Vulnerable Road User**

8. Contributions

Organisation	Family name	First Name
EUCAR / Centro Ricerche Fiat	Burzio	Gianfranco
CLEPA / Delphi	Schaffitz	Stephan
CLEPA / Delphi	Ghosh	Lali
EUCAR / Volvo	Rilbe	Magnus
EUCAR / Volvo	Engstrom	Johan
EUCAR	Godwin	Simon
CLEPA / Bosch	Mayr	Kerstin
CLEPA / Bosch	Buter	Catharina
EARPA / TNO	Versmissen	Ton
EARPA / TNO	op den Camp	Olaf
EARPA / IKA	Urban	Peter
EARPA / Ricardo	Robinson	Tom
EARPA / LMS	Donders	Stijn
EARPA / SAFER	Nilsson-Ehle	Anna
EARPA / Hexagon Studio	Aslan	Alper
FEHRL / AIT	Deix	Stefan
FIA / ANWB	Botman	Wil
ERTICO	Flament	Maxime
FEHRL / LCPC	Gallenne	Marie Line
FEHRL LCPC	Goyat	Yann
ECTRI	van Vliet	Pieter
Univ. of Florence	La Torre	Francesca
MS / Sweden	Hallstrom	Bengt
MS / Spain / Move2Future	Prat	Jaume
MS / Spain / Move2Future	Montesi	Alan
MS / UK	Funnell	Cliff
MS / Greece	Iliou	Nikos
DG MOVE	Marolda	Cristina
DG INFSO	Kopman	Helen

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European Roadmap

European Technology and Production Concept for Electric Vehicles

Version May 2011

ERTRAC Working Group Global Competitiveness

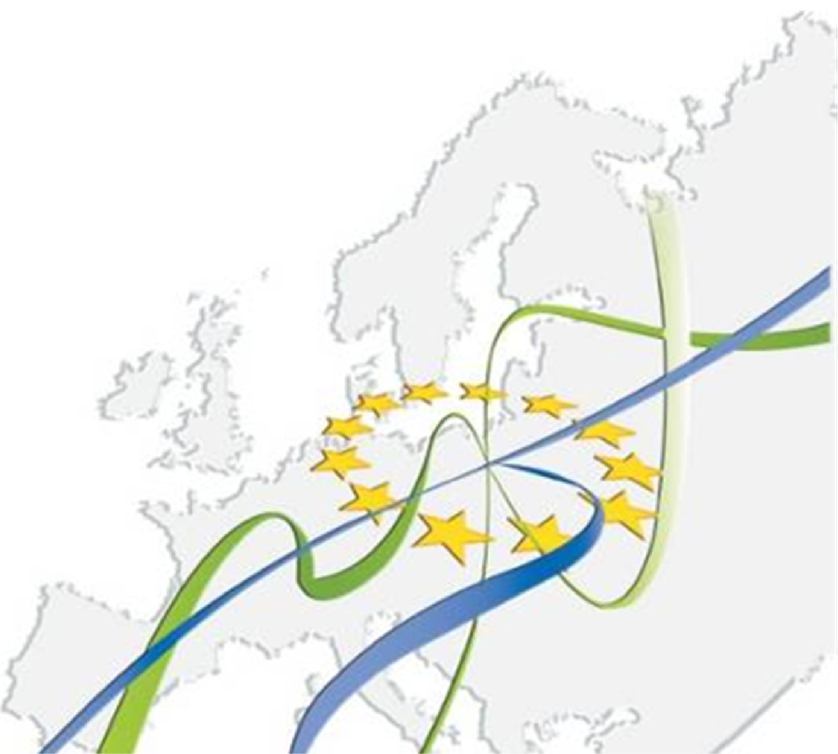
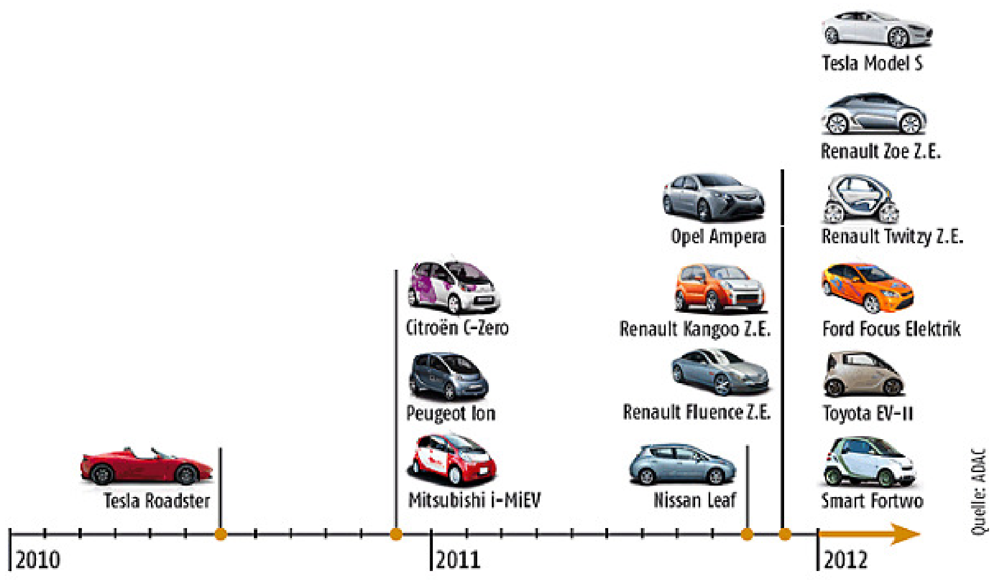


Table of Contents

Abstract

The objective of the roadmap on a "**European Technology and Production Concept for Electric Vehicles**" (**ETPC-4-EVs**) is to support the development and implementation of all those global processes, methods and technologies that allow to produce hybrid and fully electric vehicles affordable for and thereby attractive to the customer.

As shown in the figure below, electric vehicles are just starting to enter the market win increasing numbers of models and there are many problems unresolved, so far that might pose a bottleneck to significant market penetration: **first and maintenance cost of the vehicle**, electric charging infrastructure, communication and service infrastructure.



Market entry of new models until 2012

The ETPC-4-EVs roadmap places its focus on the first cost of future "**Plug-in Hybrid Electric Vehicles**" (**PHEVs**) and fully "**Electric Vehicles**" (**EVs**) and in here particularly on those ***novel technologies*** that are primarily responsible for the costs of the product, which is the ***production***, ***supply chain logistics*** and the related ***business processes*** as well as the ***social infrastructure*** necessary for successful enterprises. In a networked world with changing market volumes and volatile economic conditions the global aspect is of particular importance and was selected as a "file rouge" item throughout all considerations. In consequence, detailed content of work was compiled and edited for the 5 domains:

- **"Out of the Box Design" (defines future technology requirements)**
- **Global Production Processes**
- **Global Supply Chain Management & Logistics for EVs**
- **Global Business Processes**
- **Global Education and Qualification**

A set of consistent recommendations concludes the current state of the roadmap with highlighting that a pilot project needs to get started as soon as possible and definitely before 2013 in order to deliver tangible results that can support the industry in due time before the 1st 2020 milestone is reached (taking a 4 years project duration and 2 years project preparation into account).

1. Rationale

Next to the three most obvious "Societal Needs"

- **decarbonization of Road Transport**
- **the reliability of all products, as well as their**
- **safety & security in use**

the **competitiveness** of all products developed and manufactured by European companies on the global market place is of same importance. With regard to the emerging electrification of road transport, it is particularly the area of hybrid and fully electric vehicles where the most immediate needs regarding Research, Development and Demonstration initiative emerge.

This roadmap supports the vision of Electric and Plug-in Hybrid (EV/PHEV) Vehicles achieving the widespread adoption by 2050. Crucial for the mass deployment of EVs and PHEVs that guarantee the continued mobility of persons and goods at minimum energy investment and emissions is the affordability of the vehicles in first price and use. Starting from the technical requirements for future EVs and PHEVs this roadmap sets strategic goals and identifies the steps that need to be taken to

accomplish these goals. This roadmap also outlines the roles and collaboration opportunities for different stakeholders and shows how regulatory and governmental influence can support the overall achievement of the vision. The ETPC-4-EVs roadmap places its focus on the electrification efforts of the automotive sector and does not address pure production aspects, such as factory equipment, tools and robots or general manufacturing processes.

The strategic goals for supporting the widespread adoption and use of EVs and PHEVs worldwide by 2050 cover the development of the respective global market in relation to the economic development and the ecologic constraints. The technology-specific goals include the following:

- The **“Out-of-the-Box”** EV/PHEV Technology scout for the 2020 scenario (3rd EV Generation) and beyond to define the generic scope of products needed for the manufacturing of affordable EVs and PHEVs

- A bottom-up approach to cost-optimized **global production processes** needed to identify the least cost and least environmental impact approaches to global manufacturing of EVs/PHEVs and their systems and components

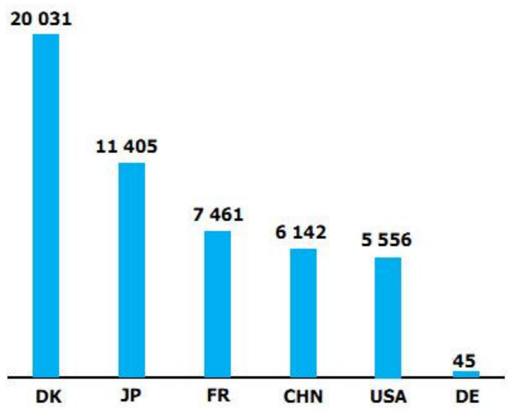
- A **global Automotive Supply Chain Model**, which takes the specific customer and industry characteristics into account with a particular Research, Development and Demonstration (RD&D) initiative to accelerate the market entry of EVs with cost-effective instruments for both consumers and industry even at volatile market conditions

- The **framework of Global Business Processes** to consequently investigate the consumer needs and behaviours, develop coordinated strategies to include the European industry in the global market introduction of EVs, engage in international policy efforts to secure the availability of natural resources, examine and establish a robust material and commodity strategy

- A global **education and qualification initiative** to enhance the corporate identity throughout the whole workforce of global European companies and to maintain European companies and staff in the global labour market regardless if the market for EVs should take-off outside Europe.

Obviously, the development and implementation of the necessary charging and service infrastructure is of similar importance as is the development of an effective and affordable technology for the electric motor car of the future. These items comprising electricity demand and supply features, communication, charging and management problems need to be tackled outside this roadmap. However it is important to recognize that the development and provision of costworthy vehicles cannot become a success when treated as a singular approach that is disconnected from progress in the field of infrastructure and services. After all, the user of a PHEV or EV will have to bear compound of cost for mobility including first and maintenance costs for the vehicle itself plus the costs for use/electricity and infrastructure.

Regarding market entry and penetration it is also worth mentioning the incoherent global level of incentives which are currently granted:



Maximum incentive per vehicle in [€] Status: May 2011

There is high expectation that further engagement in international collaboration schemes will support the spread of European technologies and processes, world-wide and thereby contribute to keep the European automotive industry and its workforce on the global competitive edge. There are a number of key areas for information sharing and collaboration:

- Research and Technology as well as Demonstration Programs
- Codes and Standards
- Vehicle Testing Facilities
- Setting of Market Development Targets, such as Vehicle Sales
- Alignment of Infrastructure, Charging and Vehicle Systems, as appropriate
- Policy Development and Experience in Implementing Different Approaches.

2. Electric Vehicles and Europe's Global Competitiveness

The most recent economic downturn left the global economy in uncertainty and imbalanced growth in a world split in blocks struggling for resources and trying to master political, religious and environmental threats. The automotive industry managed to survive this economic crisis but suffered deep financial losses and was saved via lay-offs, short-time labour and scrappage schemes before returning after 3 years only to near-boom growth – of which nobody can foretell on how long this will last. The global economy and particularly the automotive markets are no longer predictable beyond a few weeks or months:

- governments, may cap the number of new registrations,
- slow economic recovery in important car markets may restrain the sales,
- conflicts, as seen in the Arabic world and/or the consequence of disasters may lead to soaring oil prices.

In this environment the automotive industry is setting out for the electrification of road transport with huge investment in vehicle technologies and at the same time developing solutions regarding the global production in order to make these new PHEVs and EVs affordable.

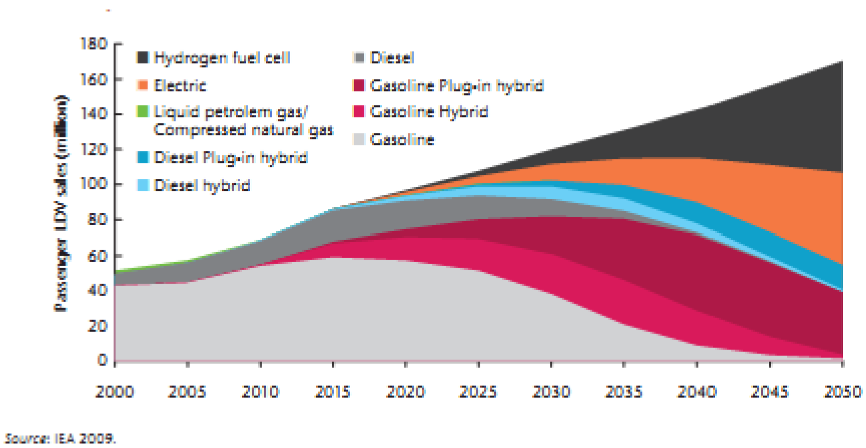


Figure 1: Co-existence of vehicle propulsion types

A key factor to the economic success of electric drive is the achievement a widespread adoption and use of EVs and PHEVs by 2050. The International Energy Agency estimates that by 2020 global sales of EVs and PHEVs (combined) should achieve at least 5 million per year.

In consequence the automotive industry has to master the enormous challenge during the next decades of handling the co-existence of ICE-powered vehicles, hybrids, PHEVs, as well as EVs and still remain profitable to shoulder the respective development costs (see Fig. 1).

Whereas the vehicle related part regarding the "Electrification of Road Transport" is convincingly outlined in the respective roadmap by the European Technology Platforms ***ERTRAC***, ***EPOSS*** and ***SMARTGRID,*** it is the purpose of this roadmap to complement the "big picture" perception of electrification of road transport by addressing the "affordability" of PHEVs and EVs. In addition, this roadmap identifies the role for different stakeholders and describes how they can cooperate to reach common objectives.

„Electric Drive Vehicles are unlikely to succeed without strong efforts in making vehicles affordable and ensuring that the adequate recharging infrastructure is in place – next to resolving vehicle related challenges".

The ETPC-4-EVs Roadmap places its focus on the "**Research, Development and Demonstration"** (**R,D&D**) requirements in the areas of future design options, related production and Supply Chain Management needs, the inclusion of most relevant business processes, as well as the social implication and looks beyond the 2nd generation of electric powertrains in intervals up to 2020, 2025 and 2030.

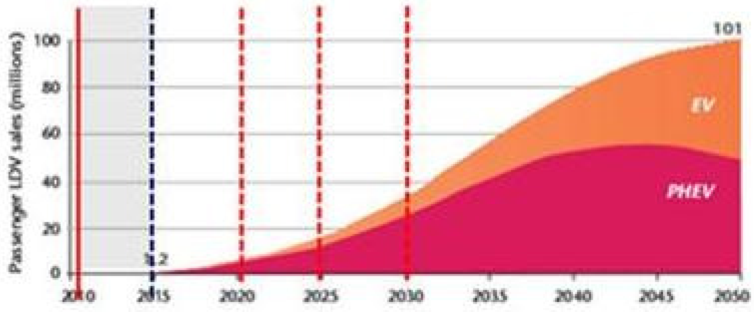


Figure 2: R,D&D Target Time Periods

In 2010 approximately 60 million cars were sold globally with 64.5 million sales predicted for 2011. Important to register, however, that the shares per region shift considerably. According to the prediction of VDA in Germany, China's global market share will rise from 10% in 2008 to 19% in 2011, meaning that one out of five new cars will be sold in China, soon. At the same time, Western Europe and the USA will loose 3% each, while emerging markets, such as Brazil, India or Russia are continuously growing. This assessment is supported by the most recent survey of the International Monetary Fund for 2020, where economic market capacities are clearly shifting to Asia and Africa.

Figure 3: Economic Market Capacity Prediction for 2020

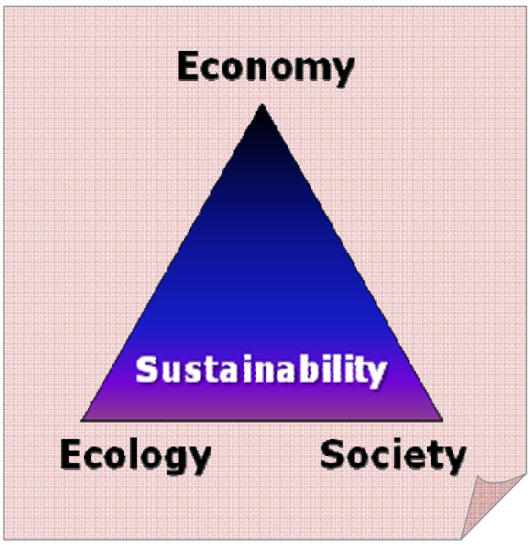
In all these diverse and dynamic regions European manufacturers have increased their capacities in the recent years and they are still busy to explore new sites by following their markets. Experience with currency swaps, political constraints or proximity to customers have supported this move.

3. Sustainability in Global EV Production

For the automotive industry, Sustainable Production of Electric Vehicles means delivering on our global priorities: producing profitable in full consideration of all economic constraints, energy efficiency and social responsibility in global competition. And it means doing all of this while minimizing the impact on the environment, using the earth's limited resources responsibly, relying on renewable sources of energy and fulfilling the industry's fundamental role in moving world economies forward.

To deliver on our global priorities, we need to make sure that vehicles and technology remain affordable, and that a partnership of industries, governments and consumers is in place to advance Sustainable Mobility together.

The sustainability triangle represents the balance between the economic challenges inherent in global production processes of EVs, the ecologic awareness to protect the earth's resources and atmosphere in manufacturing and operating global supply networks, as well as mastering the human development and social implications in operating global workforces effectively.



The European automotive industry is highly innovative and aware of the economic requirements, but in order to remain on the leading edge and to extend their shares in the global market place of the future, they need to incorporate new economic prediction and reaction elements to support the respective operational infrastructure. Most important, however, is the real time inclusion of crucial economic factors, which have essential influence on the production process of EVs, their systems and components, as well as the services (e.g. sourcing, logistics, maintenance, retrofit, etc.), and the recycling after the product's end of life.

In context of a significant improvement of market predictability the impacts of market mechanisms need to be better understood. The capability to measure the improvement by balancing competition amongst market players against possible horizontal inner-industry or cross-industry cooperation is of strong influence in order to correctly assess future shared capacities for all market players.

The ***economic wing*** of sustainable EV production holds the following challenges:

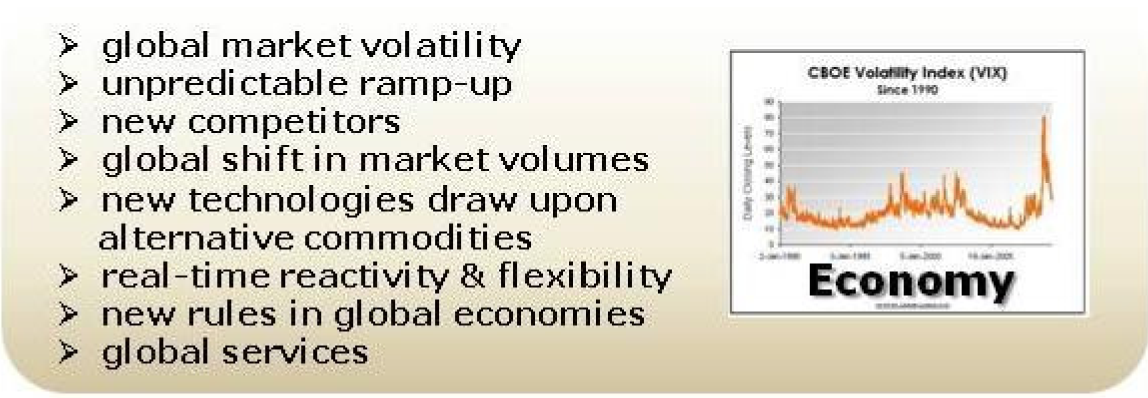


Figure 4: Economic Challenges

The ***ecologic corner*** of the sustainability triangle is characterized by the needs for global EV eco-production models, addressing an optimized utilization of energy streams, the reduction of environmental impact and the improvement of resource efficiency. This model of an advanced green manufacturing is complemented by the development of an integrated preventive environmental strategy to process and produce EV components and systems by full inclusion of the aspects of conservation of resources and energy by design aiming at eliminating emissions and waste by point source treatment and recycling. Specific threats and concerns affect the emissions in production and supply chain logistics, the careful use of resources and the energy investment in EV production.

The environmental awareness in production systems regarding factory equipment, tooling, robots etc. is exhaustively covered by the ***EFFRA*** (Factories of the Future) Strategic Multi-Annual Roadmap. Since future electric vehicles designed to purpose will source and produce their components globally particular attention will be assigned to a highly reactive and robust eco-friendly supply grid.

Buoyant economies outside Europe with strong economic growth attract the automotive industry to produce closer to the customer at lower costs and avoiding high import taxes. Most recent ***employment*** surveys in Europe indicate that these companies are no longer mere labour cost refugees since employment in the sector were on the rise or at least constant. Important to note, however, is the impact on the European employment structure, which shows a shift from factory workers towards technicians and engineers. Taking the IMF assessment into account it is obvious that tools and mechanisms need to be developed to allow the highly qualified but relatively small European work force to participate in a effectively in the global labour market. In this context education and skills of staffs will be of ever growing influence for which expressive indicators have been established by the United Nations' Human Development Index. Traditionally, a job produced output – nowadays, it is a ticket to learn, a job is a defining feature and rewarding aspect to life and represents therefore an equal element of the sustainability triangle.

4. Building Blocks and Timeline for Implementation

4.1 Substantial Approach

Although few serious technical hurdles seem to prevent the market introduction of PHEVs and EVs battery technology accompanied by ultra light weight solutions are integral parts of these vehicles that still need to be significantly improved. In parallel to the pure technical and engineering challenges to

- increase the battery storage,
- robustness and durability and
- design and build EVs and PHEVs with ultra-light weight materials to purpose

there is another critical challenge, which is reaching an economy of scale in global production and logistics in volatile markets and constrained business scenarios.

To date there is no market volume for PHEVs and particularly for EVs that would allow the establishment of high volume production processes. The automotive industry draws much of its profitability from high production volumes and small margins. Since the roll-out and market penetration of electric propulsion is extremely difficult to predict industry is careful in investing into the development and set-up of mass-production facilities, since these require the presence of the “Economies of Scale”, which is shown for batteries in Fig. 5, where the effect of mass production is related to a cost reduction of 35%.

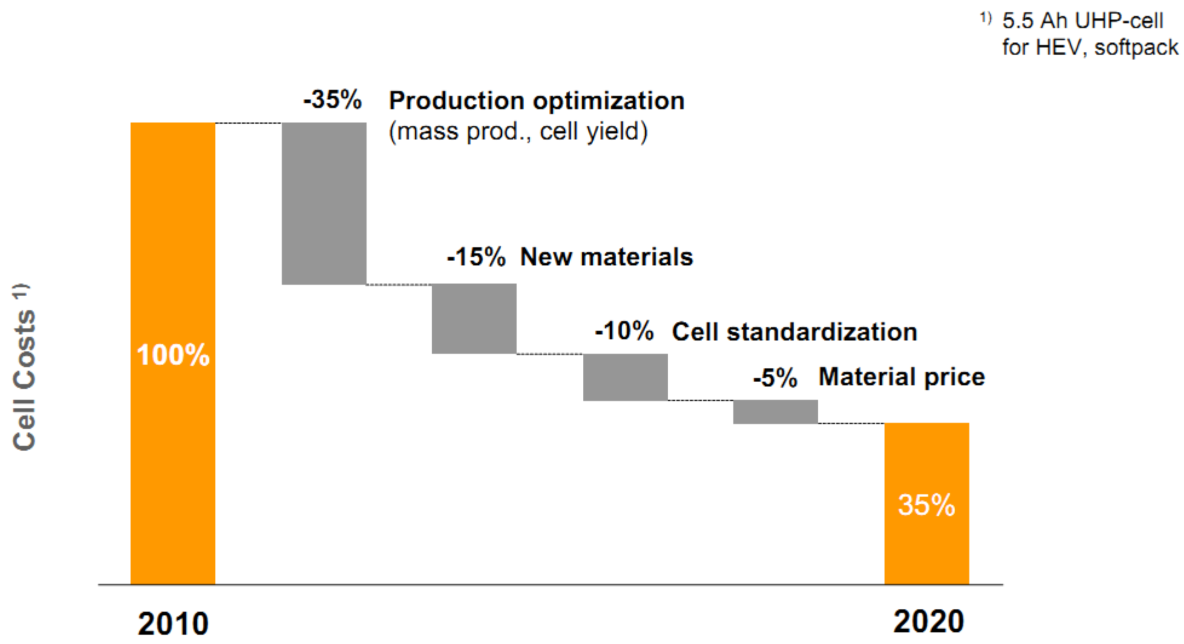


Figure 5: Cost Reduction of Battery Cells by high volume production

“Economies of Scale” describe the reduction in cost per unit resulting from increased production, realized through operational efficiencies. “Economies of Scale” can be accomplished because as production increases, the cost of producing each additional unit falls, as shown in Table 1:.

PHEVs	EVs
Economies of scale: • Mass production levels needed to achieve economies of scale may be lower than those needed for EVs, for example if the same model is already mass-marketed as a non-PHEV hybrid; however, high-volume battery production (across models) will be needed.	Economies of scale • Mass production level of 50 000 to 100 000 vehicles per year, per model will be needed to achieve reasonable scale economies; possibly higher for batteries (though similar batteries will likely serve more than one model).

Table 1: Economies of Scale for PHEVs and EVs

From the industry’s point of view a profitable ramp-up scenario is of utmost importance, since this only can guarantee an early return of the investment into the new PHEV and EV technologies. This is of particular importance to the automotive sector, which is characterized by relatively short product cycles and low

margins. Therefore, vehicle model types and sales growth rates will play a crucial role in customer acceptance and market penetration.

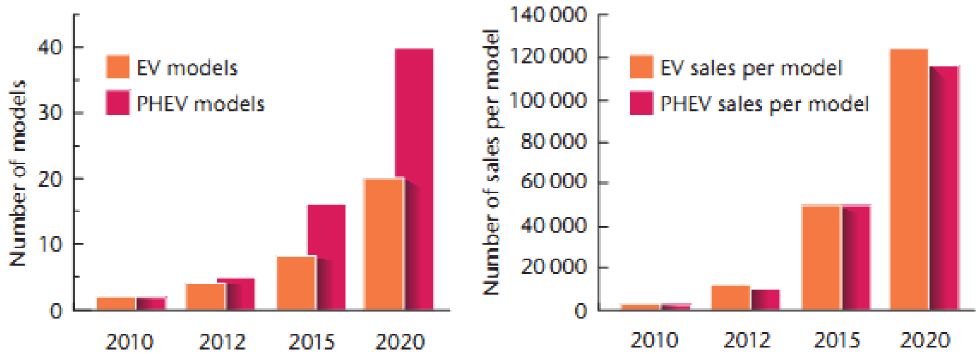
It is assumed that a steady number of new models will be introduced over the next ten years, with eventual targeted sales for each model of 100 000 units per year. However, it is also expected that this sales rate will take time to achieve. During 2010 to 2015, it is assumed that new EV and PHEV models will be introduced at low production volumes as manufacturers gain experience and test out new designs. Early adopter consumers are expected to play a key role in sales, and sales per model are expected to be fairly low, as most consumers will wait to see how the technologies and market develop. As a result, it is assumed that from 2015 to 2020, the existing number of models and sales per model will increase fairly dramatically as companies move toward full commercialization.

	2012	2015	2020	2025	2030	2040	2050
PHEV	0.05	0.7	4.7	12.0	24.6	54.8	49.1
EV	0.03	0.5	2.5	4.4	9.3	25.1	52.2

Source: IEA 2009.

Table 2: PHEVs and EVs Deployment Targets [million units]

In order to achieve the deployment targets in Table 2, a variety of EV and PHEV models with increasing levels of production is needed. Figure 6 demonstrates a possible ramp-up in both the number of models offered and the annual sales per model. This scenario achieves 50 000 units of production per model for both EVs and PHEVs by 2015, and 100 000 by 2020. This rate of increase in production will be extremely challenging over the short time frame considered (about ten years).



Source: IEA projections.

Figure 6: EV/PHEV Number of Models Offered and Sales per Model Through 2020

However, the number of new models for EVs and PHEVs in Figure 6 easily fits within the total number of new or replacement models expected to be offered by manufacturers around the world over this time span (likely to be hundreds of new models worldwide) and typical vehicle production levels per model. A bigger question is whether consumer demand will be strong enough to support such a rapid increase in EV and PHEV sales.

It is essential to note that the sales per model must rise rapidly to reach scale economies, but the number of model introduced must also rise rapidly.

On a regional basis, Figure 7 offers a plausible distribution of EV/PHEV sales by region, consistent with this roadmap's global target of achieving an annual sale of approximately 50 million EVs and PHEVs by 2050. Regional targets reflect the expected availability of early-adopter consumers and the likelihood that governments will aggressively promote EV/PHEV programs. EV and PHEV sales by region are also based on assumed leadership by OECD countries, with China following a similar aggressive path. Sales in other regions are assumed to follow with a market share lag of five to ten years.

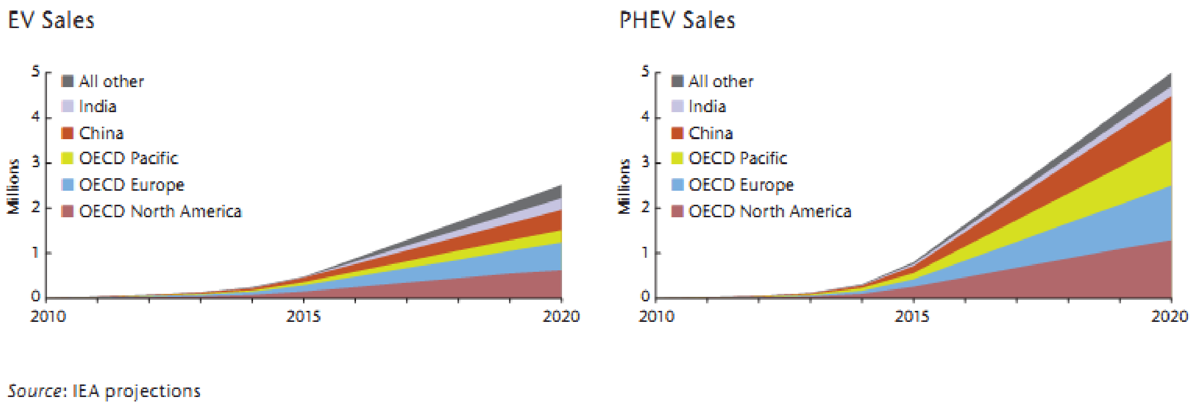


Figure 7: Expected EV/PHEV Total Sales by Region through 2020

Although the ramp-up in EV/PHEV sales is extremely ambitious, a review of recently announced targets by governments around the world suggests that all of the announced targets combined add up to an even more ambitious ramp-up through 2020, particularly for Europe. A key question is whether manufacturers will be able to deliver the vehicles (and battery manufacturers the batteries) in the quantities and timeframe needed. To achieve even the 2050 sales targets, a great deal of planning and co-ordination will be needed over the next five to ten years. Whether the currently announced near-term targets can all be achieved, with ongoing increases thereafter, is a question that deserves careful consideration and suggests the need for increased coordination between countries. Since the user will play the crucial role in this respect it is important to consider the influence the "Total Cost of Ownership" that will be imposed on her/him:

Total cost of ownership (TCO)

Customers buy cars for a wide variety of reasons, including purchase price, new vs. second-hand, depreciation rate, styling, performance and handling, brand preference and social image. Calculating the TCO of the power-trains is therefore important because it describes the costs associated over their entire lifetime – on top of which individual customer criteria are applied. TCO includes:

- ***Purchase price:*** the sum of all costs to deliver the assembled vehicle to the customer for a specific power-train and segment

- ***Running costs:***
  – Maintenance costs in parts and servicing specific to each vehicle type and power-train combination
  – Fuel costs based on the vehicle fuel economy and mileage, including all costs to deliver the fuel at the pump/charge point and capital repayment charges on investments made for fuel production, distribution and retail; or for EVs/PHEVs, for charging infrastructure.

TCO Equation:

TCO = Purchase Price	**+**	**Running costs**
- Parts Costs		- Maintenance Costs
- Supply Costs		- Fuel & Infrastructure Costs
- Assembly Costs		
- SG & A[1]		
- Margin		

All projected cost reductions for EV components are based on proprietary data and include:

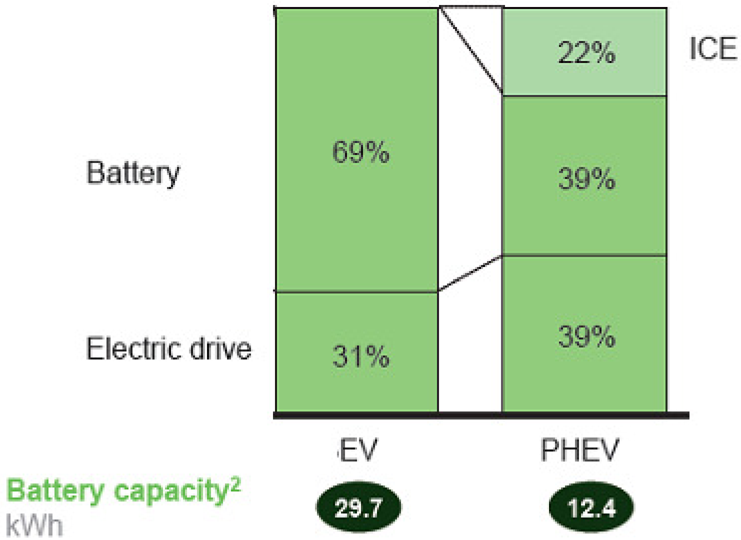
- Improvements in production engineering: operations such as electrode cutting, forming, stacking and contacting of the collectors will gradually grow more efficient through the introduction of advanced laser technologies and a shift from “batch to continuous” production modes. The automation and rationalization of quality testing along the production line will also generate efficiency gains

- Economies of scale from larger production plants (3 million BEVs in the EU by 2020).

EVs and PHEVs are complementary technologies as they share many similar electrical drive-train components, i.e. battery and electric driven as well as components, sub-systems and systems. Investments in EVs therefore also benefit PHEVs and vice versa.

[1] Selling, General and Administrative Expenses. Income statement item which combines salaries, commissions, and travel expenses for executives and salespeople, advertising costs, and payroll expenses

By 2020, the purchase price of EVs is expected to be still several thousand €s more than that of ICEs, but reasonable public incentives on vehicle, fuel and an attractive customer value proposition could be sufficient to bridge this cost gap. The purchase price of PHEVs is lower than EVs. The purchase prices of electric vehicles may vary widely according to market conditions and car manufacturers who may either be further advanced in achieving cost reductions and/or choose to limit the premium. They also depend on branding strategies, with a whole range of purchase prices within any car segment – from lowest cost to premium vehicles.



[2] Different types of batteries for each powertrain depending on their driving pattern

Figure 8: Relative Total Powertrain Costs of EVs and PHEVs

As outlined in the "European Electrification of Transport Roadmap" mass production of EVs is expected to be reached by 2020 with the 3rd Generation EVs while the 2nd Generation is predicted to enter the market by 2016, already. Obviously, the development of a realistic roadmap on global PHEV and EV production processes requires the placement of focus on the 3rd generation EV technologies and beyond that are needed for the new models. For this purpose, the "**Out-of-the-Box Design**" initiative is introduced, which aims at identifying innovative, discontinuous and radical technologies and concepts for electric road transport of the future.

4.1.1 Out-of-the-Box Design

The purpose of "Out-of-the-Box Design" is to complement the typical mainstream forecast with the identification of generic, more innovative and far-sighted design ideas of PHEVs and EVs in order to provide a perception of the global production and supply chain requirements beyond 2020. Hence, this roadmap element is supposed to give recommendations regarding possible technology features to be considered in mass production and global sourcing processes and by taking the specific customer, market and product characteristics of the sector into account.

An integrated Research, Development and Deployment scheme in the area of Global Competitiveness for EVs and PHEVs requires to look towards the longer term and more radical solutions for EVs and PHEVs alike and to extract the generic preconditions regarding the related components sub-systems and systems and their production, supply chain logistics and business framework. In order to avoid competitive frictions within the industry due to proximity to current developments but still to provide a significant technology forecast a team of stakeholders will gather in a string of workshops to examine more innovative and far-sighted ideas that:

> **"This activity is built around the desire to anticipate a more generic, innovative and far sighted approach than typical of mainstream, evolutionary research".**

- are forward-looking rather than immediate in application;
- have specific technology challenges;
- offer a prospect of significant requirements to the global production system and supply chain management;
- offer the prospect of substantial impacts and benefits.

Given the fact that the market introduction of electro-mobility is strongly dependent on global economic and ecologic change it is important to indicate three factors that drive this change:

- ***the demands of the market***,
- ***new technology***, and
- ***the changes in the economic/ecologic circumstances of the automotive system***.

The basic ideas and perceptions will be screened by assessors against a set of weighted criteria, which in turn will be used to condense and sequence the findings and to connect related subjects.

4.1.2 Global Automotive PHEV & EV Production

There are four major columns available for industry that have the potential to fundamentally increase the affordability:

- Optimizing production by enabling dramatic increases in scale and automation
- Materials Improvement
- Design Standardization
- Sourcing

Obviously, global automotive companies will continue to operate according to the economic, ecologic and social constraints when it comes to the introduction of PHEVs and EVs. There will remain the compelling challenges directly resulting from competition and cooperation, local autonomy and global behavior, design and emergence, planning and reactivity, uncertainty and plethora of information. The resulting issues associate a model based on responsive and cooperative manufacturing:

- Responsiveness expresses a generic attitude in production engineering, a continuous quest for solutions that work in reality even under changing conditions. Responsiveness is a repeated effort of mapping projections of the future (i.e., plans) to actual developments and actions in the real world. Responsiveness implies ongoing interaction with the execution environment and requires that the environment can be at least partially observed. This calls for the identification of objects, as well as the monitoring of their behaviour, whether in the real or the virtual world. The innovative use of sensor and active identification technologies enables so-called context-aware manufacturing and lays the foundations for the smart factory thereby leading to responsiveness.

- Where system components interact with each other in a production network, there is a special opportunity to tackle various forms of incertitude (which can be broadly classified as uncertainty, risk, ambiguity and ignorance). This is called cooperation, an interactive relationship that makes possible to harness knowledge of other system components or to make use of their actions in the service of joint interests. Cooperation is the alignment of various, eventually even disparate goals in the hope of some mutual benefit.

Key Issues:

- **Elaboration of crucial influence factors to balance the global PHEV & EV production footprint**
- **Combining product features, production equipment & its properties and economic & ecologic constraints with dynamic market requirements**
- **Establishment of self-learning real-time monitoring and reaction tools**

4.1.3 Global Automotive Supply Chain Management & Logistics for EVs

The shift from ICE powered motor cars towards PHEVs and EVs will boost the inclusion of electric components and systems, which will trigger new inter-industrial collaboration schemes and require radically new concepts for joint planning and controlling global production and supply networks. Beyond the challenge of becoming profitable even at a very low-volume production of EVs, it is obvious that the step towards the electrification of the powertrain requires the increased inclusion of other key-industries, such as the semiconductor branch and the consideration of commodity (e.g. carbon fibres, etc.) and material (e.g. Copper, Lithium etc.) suppliers.

The configuration of a highly flexible and reactive automotive/semi-conductor supply organism in global context will be crucial to success even in ramp-up and small series production phases. Both the automobile and the semi-conductor industries operate at multiple locations around the world and the critical mass of a site is of higher influence on competitiveness than the critical mass of a product. Therefore, a business model is called for that dynamically integrates company economics in a volatile global economic environment, also in consideration of local resources, such as commodities, energy, labour, etc. Such global governance model actively influences the capacity capabilities and related services according to economic constraints and will enable European companies to offer their customers a broader variety of choice of affordable products and an extended range of services.

Rapidly changing economies demand dynamically adaptive supply networks that operate on standardized data-models, formats & interfaces allowing integrated scalable planning and execution. For the successful supply of automotive systems and components for future EVs on a global market place where the largest economic growth is most likely to take place outside Europe, the establishment of the respective standards is paramount for the European Automobile industry and its workforce. These standards should be open to all participants and address pan-industrial supply chains, network collaboration schemes and international supply characteristics.

Key Issues:

- **Collaborative planning and real-time management of highly distributed macro/micro production networks**
- **Workflow-based decision making for global site management:**
  - **Resource optimization**
  - **Global Capacity planning & balancing**
  - **Production planning within a highly reactive global supply network**
- **Development of characteristic data-Platforms for real-time decision support, planning and recovery systems**

The establishment of such an integrated macro system combines customer needs and business opportunities across different global market segments and is concurrently interrelated with global economic change. This model of a macro-system takes the technological progress and customer needs into account, as well as product design and customer satisfaction, and includes the overall economic/ecologic market drivers in context of trading and commercial aspects. The elements of fast response and flexibility are the key attributes of the system.

4.1.4 Global Business Processes

In a mid- to long-term perspective the electrification of road transport via PHEVs and EVs will become a key factor to the competitiveness of the European Automotive industry on the global market place. In this context, it is obvious that the conventional “hard” Research and Technology Development of the engineering domain needs to be complemented with “soft” Economic and Business Process Research by including the aspects of globalization, energy and climate challenge, as well as the availability of materials and commodities. Hence the prime objective of the necessary global business processes is to keep the products of the industry affordable to an ever growing number of customers world-wide and with regard to PHEV & EV technology, which has considerable potential to reframe the industry.

The automotive industry is a leading EU export sector with a net trade contribution of almost € 30 billion.
Leading in high-quality products, the industry sells and produces vehicles in all major world markets.

The European automotive industry partnership is highly innovative, but in order to remain on the leading edge and to extend their shares in the global market place of the future, they need to incorporate new economic prediction and reaction elements to support the respective operational infrastructure. Most important, however, is the real time inclusion of crucial economic factors, which have essential influence on the production process of EVs, their systems and components, as well as the services (e.g. sourcing, logistics, maintenance, retrofit, etc.), and the recycling after the product’s end of life. In context of a significant improvement of market predictability the impacts of market mechanisms need to be better understood. It is important to measure the improvement by balancing competition amongst market players against possible horizontal inner-industry or cross-industry cooperation in order to correctly assess future shared capacities for all market players.

The automotive sectors’ own R&D investment of €32.8 billion in 2008 (without suppliers) ranks 1st, in front of the pharmaceutical sector with €19.8 billion and the telecommunications equipment sector with €12 billion.

Beyond the foreseeable requirements of future automotive supply chains, such as:

- **production close to end-markets,**
- **Global Value Chain (GVC) governance regarding rising product complexity, which demands effective adaptability/flexibility concepts,**
- **new forms of GVC collaboration with work shifting to the supply base and a small number of hugely powerful large companies,**

new mechanisms of collaboration need to be developed and implemented that are able to cope with “Joker Events”.

During the past decade numerous “Joker Events” hit the societies globally, and left their deep impact on the economies and industries due to their inter-relation of networked economies:

- **9/11 (2001),**
- **Tsunami in the Indian Ocean (2004),**
- **Hurricane Katrina (2005),**
- **Economic downturn in consequence of the banking crisis (2008),**
- **China steps-up efforts to influence the global commodity market (2009),**
- **Ash cloud of the Icelandic volcano Eyjafjallajökull (2010),**
- **Blow-out of the oil platform Deepwater Horizon (2010),**
- **Uproar in the Middle East (2011),**
- **Fukushima (2011)**

It is undisputed that number of events over longer time periods doesn’t increase. However it is the severity of impact of these disasters (events related to climate change are currently still controversial among experts) that demands a radically new approach: in globally networked economies and densely populates areas consecutive disasters affect the technical infrastructure, the crisis management and lastly the industrial structures and effectiveness. Future global business processes have to incorporate that mega-events are increasingly becoming an evolutionary principle.

Future global business processes have to incorporate that mega-events are increasingly becoming an evolutionary principle.

Current commodity markets continue to be influenced by contemporary problems: metal sheets for instance are made of iron which in turn is still overly exposed to market volatility, speculation and deficits in global recycling strategies: an unexpected upbeat of manufacturing data from emerging and developing economies alike may fuel a bounce in industrial metals price and helps commodities rally to new peaks. European governments establish national commodity strategies – some in isolation - others support the “**Raw Materials Initiative – Meeting our Critical Needs for Growth and Jobs in Europe**” of the European Commission. These activities are of cross-cutting nature and apply to all industries regardless their specific needs regarding future commodities and their dependency on rare materials for future developments, as shown in Fig. 9.

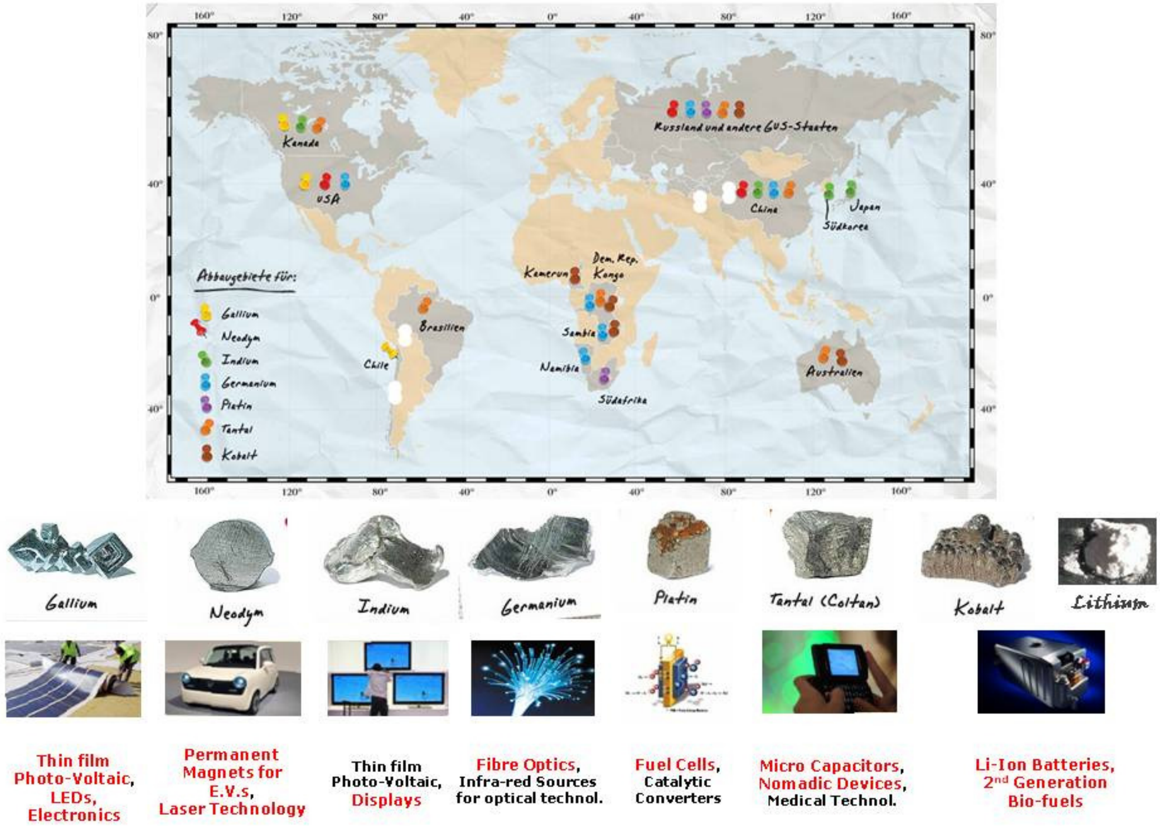


Figure 9: PHEVs & EVs Commodities and their Global Origin

Price volatility in raw materials affects the profitability and competitiveness of many European companies. It is highly unlikely that traditional approaches, including strategic sourcing and volume aggregation, can be relied upon to bring it under control. However an integrated approach to global commodity and rare materials management that utilizes multiple tactics needs to be developed that makes the difference. Commodity and rare materials strategies for the automotive industry on European scale, based on informed insight, will help organizations to manage price volatility and availability with a new level of effectiveness. A novel approach on the buying side and/or the selling side is required that renders European automotive enterprises substantial improvement. Applying integrated commodity and rare material management to procurement and sales can help provide the momentum to make volatility a key differentiator in global competition: positioning it to gain a competitive edge, satisfy crucial stakeholders and thrive in the global market place.

4.1.5 Global Education and Qualification

Triggered by the electrification of road transport in combination with the effects of globalization the market for future powertrain components is expected to more than double by 2030 with an annual growth rate of ~ b€ 460 and creating 420.000 jobs world-wide. This global growth in electro-mobility creates economic growth in Europe, as well, with an expected increase of market volume by factor 2 up to b€ 170 and the need for 110.000 additional jobs for experts in chemical and electric/electronic engineering. In turn, this buoyant market volume causes extensive shifts in the value chain: OEMs and suppliers will have to cope with volatile portfolios of high uncertainty in consequence of spatial and temporal differences in market take-up. Therefore, the automotive industry needs to maintain all technology options ranging from the “Internal Combustion Engine”, via all variants of Hybrids to the “Fully Electric Vehicle” and concurrently develop an effective global “Materials & Commodity Management”, as well as building new “**MeChemTronic**” competence among its staff.

PHEVs & EVs create growth and employment in Europe: 110.000 Jobs until 2020

The technical progress towards electrification brings about an enormous challenge in the development of the respective competences in the global staffs of all members of the supply network: the competence profile of the automotive industry workers advances from pure mechanical skills to ***me***chanic, ***chem***istry and elec***tronic*** expertise – the “**Me-Chem-Tronics**”. According to detailed screening of the component groups in the value chain, there is high expectation that the share of staff dealing with mechanical tasks is going to shrink from 80% today down to 60% by 2030. By 2030, the remaining 40% of personnel will be covered by electronic an chemical specialists. The prediction for Europe foresees the need for 110.000 new job opportunities in the disciplines of chemistry, plastic engineering, micro-electronics and software/ICT. This enormous can be achieved, only, in close and early collaboration of industry and education.

Tackling electro-mobility in global production concepts needs to remind that the trade-off between education, opportunity and global labour is at risk in a global knowledge-driven economy, as the opportunity to exploit the talents of all, at least in the developed world, is now a realistic goal. Enduring social inequalities in the competition for a livelihood and an intensification of ‘positional’ conflict must be avoided, particularly when the global spread of work associates such developments and ‘opportunities’ are becoming harder to cash in. The
opportunity-cost is increasing because the pay-off depends on getting ahead in the competition for tough-entry jobs.

4.2 Criteria

There are many determinants driving productivity and competitiveness. Understanding the factors behind this process has occupied the minds of economists, ranging from Adam Smith's focus on specialization and the division of labour to neo-classical economists' emphasis on investment in physical capital and infrastructure, and, more recently to interest in other mechanisms such as education and training, technological progress, macro-economic stability, good governance, firm sophistication, and market efficiency, among others. While all of these ideas are likely to be important, they are not mutually exclusive – two or more of them can be true at the same time.

With respect to the objectives of the current roadmap for the "**European Technology and Production Concept for Electric Vehicles**", it is obvious that the issues of relevance need to be focused on a:

- substantial technology related core – defining the ***basic requirements***,
- commercial and strategic framework – outlining the ***efficiency enhancers***,
- workforce inclusion – inter-relating ***innovation*** with societal aspects (see Fig. 10).

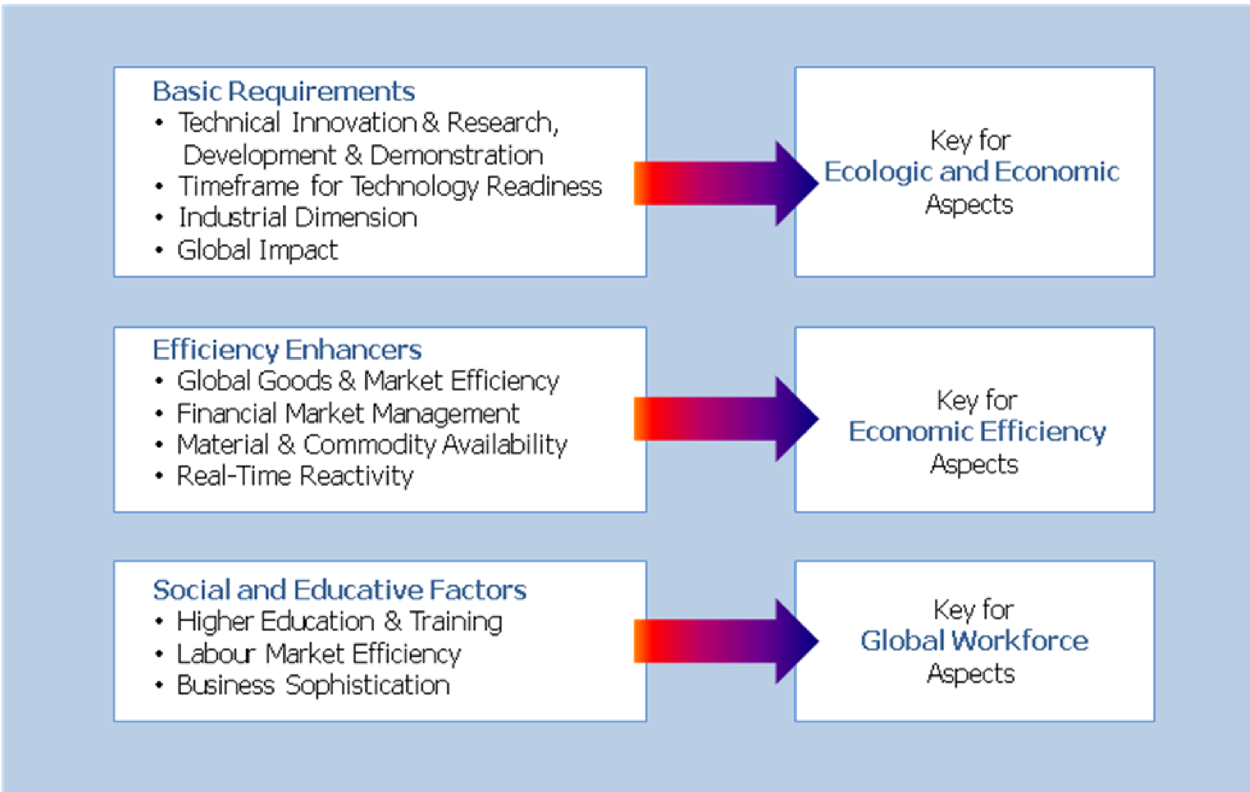


Figure 10: Requirement, Efficiency and Innovation Driven Key Factors

All items proposed to be included into the 5 RTD avenues of ETPC-4-EVs roadmap were submit to a set of **Selection Criteria** according to the matrix above.

In more detail these criteria include as basic requirements:

- the **technical and scientific ambition**, e.g. no issues that are already addressed elsewhere or that are incremental improvement rather than fully fledged development or that are lacking a demonstration and roll-out scheme

- the **time horizon for implementation**, e.g. 2020 (near-term), 2025 (mid-term), 2030 (long-term); as a rule of thumb: project preparation: 1 year; project proposal development, submission, evaluation, negotiation: 1 year; project duration: 3 – 4 years

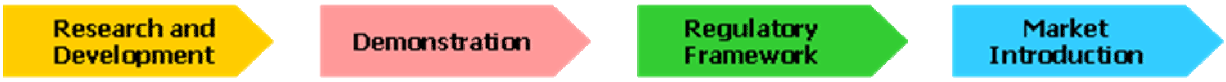
- the **industrial dimension**, e.g. sufficient combination of technical aspects and economic/business prospects, as well as inter-industry partnership (e.g. full supply chain plus research/business partners)

- the **global perspective**; e.g. specific automotive industry aspects need to be included in global context.

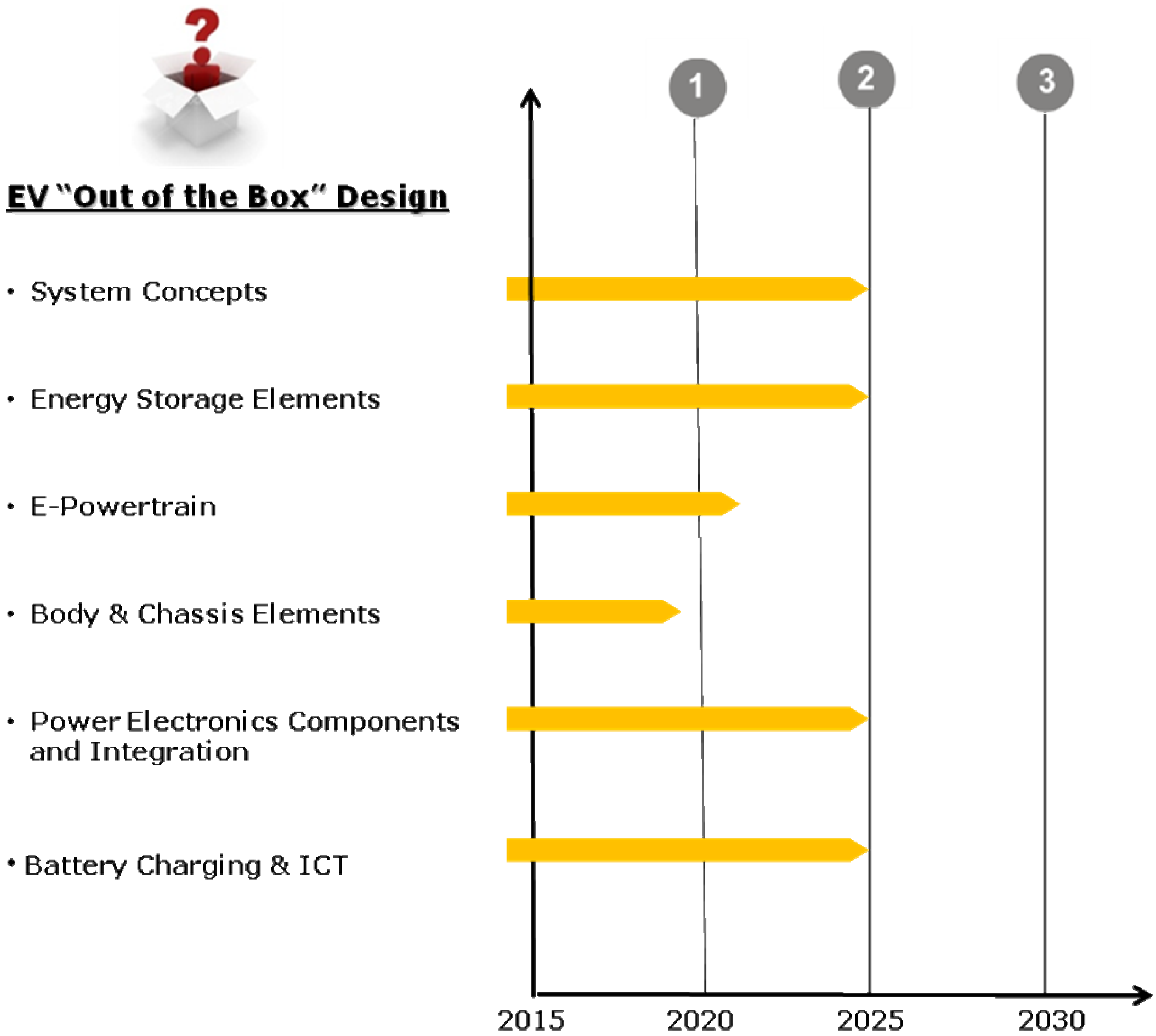
In parallel, similar criteria were defined for the efficiency enhancers, as well as for the social and educative factors. This process has not been exhaustive and will be continued repeatedly in order to refine the content of the roadmap and update it as appropriate.

5. Roadmaps

With regard to the EU Commission's fresh approach to industrial policy and the respective new orientation of the next Framework Program, all items identified for future research, development and demonstration, which will increase the competitiveness of the European automotive industry, are assigned to the following areas:

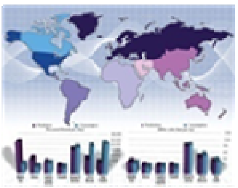


5.1: The Incubator*

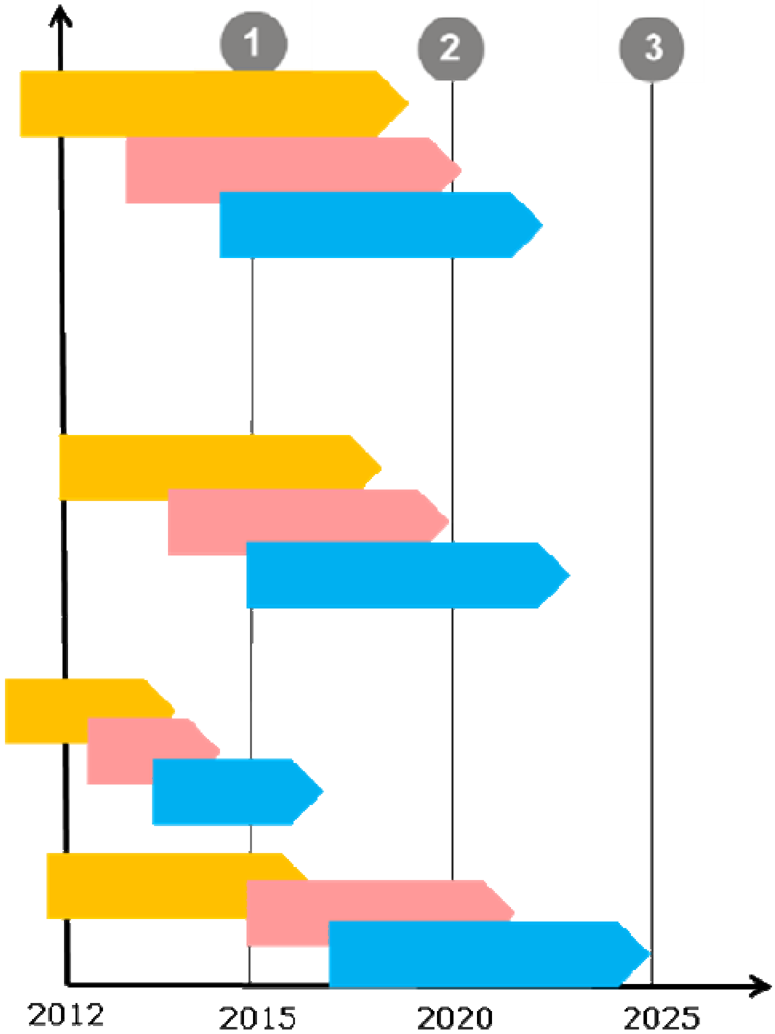


* Since it is the purpose of the "Out of the Box Design for Electric Vehicles in their environment" to collect ideas about the future vehicle technology needs and to stimulate novel ideas, no development, demonstration let alone market introduction will be supported.

5.2: Global Automotive PHEV & EV Production

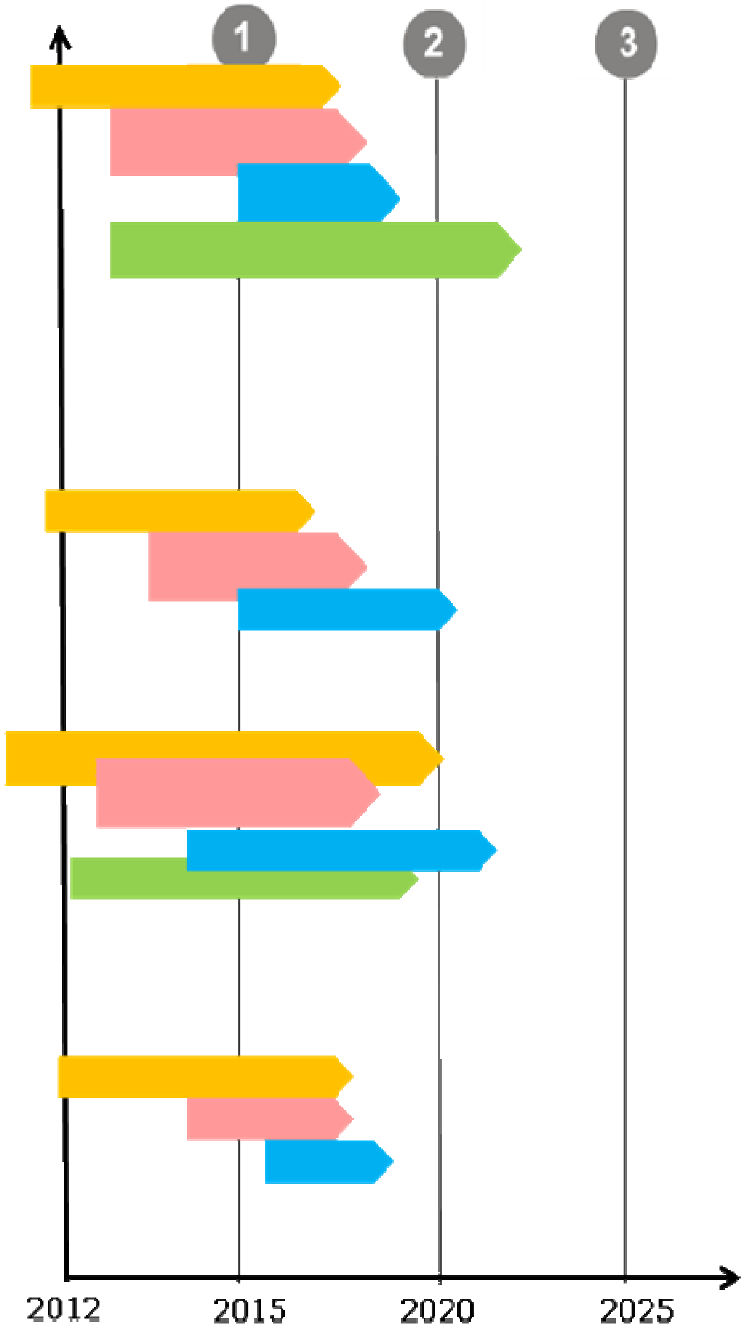


- The EV Factory"
  - variability, modularization & fexibility in EV production for HVs, PHEV,s and EVs
  - handling of high-voltage components in production, assembly & repair
  - production forecast system for EV-components
  - novel joining concepts in EV production
  - new high volume production concepts for high quality E-Motors and batteries
  - affordability in EV manufacturing (batteries, power electronics, quality control)
  - step-change in variants; "brand+system=EV2.0" collaborative planning & responsiveness
  - global ICT production concepts
- The Just-in-Place EV Factory"
  - rapid factory adaptation & novel global location in decentralized EV sites
  - global micro-factory management
  - real-time shop-floor control systems & product planning in global EV component production
  - sequencing on plant, grid & industry level
- Industrial Interdependence
  - synchronizing the highly volatile EV sector and the longer term driver semi conductor industry
  - cross industry resource planning and control
- Eco-Modelling & Impact Assessment
  - Emission & energy aware production of EVs
  - sustainability driven EV production & decision support system
  - global CO2 production footprint in EV manufacturing
  - assessment tools for designing CO2 neutral EV production plants



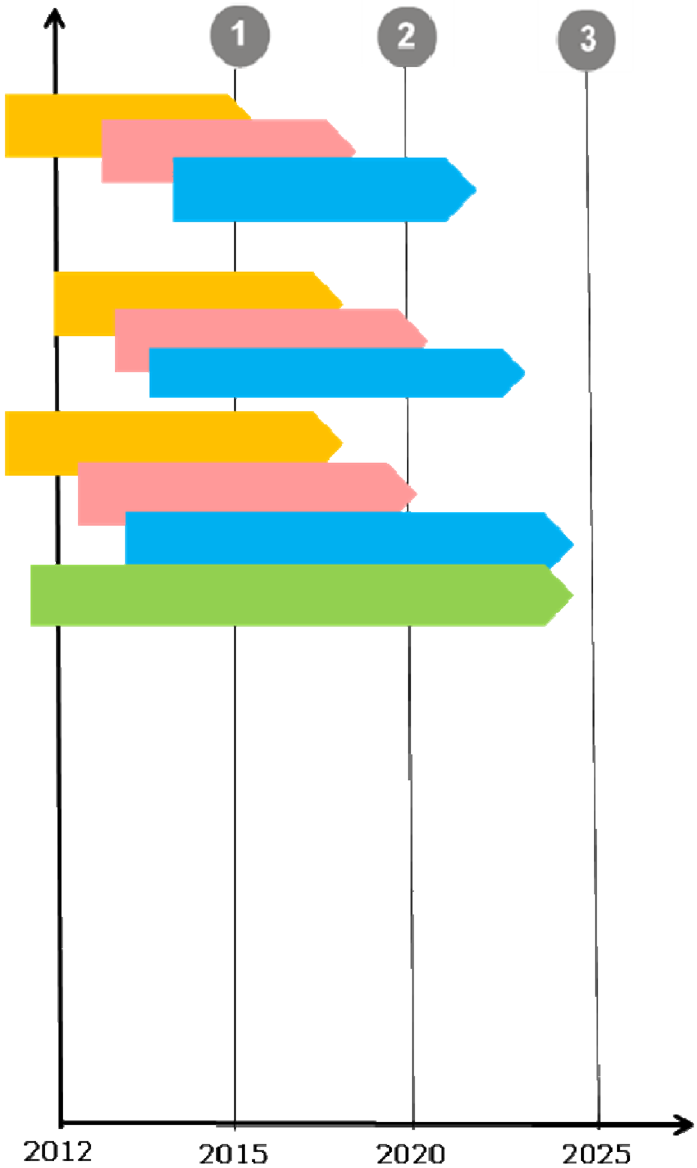
5.3: Global Supply Chain Management & Logistics for EVs

- **"Connecting Decentralized global Production Grids"**
  - global responsiveness by decentralized/downsized sites
  - automated SC & planning transparency
  - Trust/Security & Partners awareness
  - Real-time (RT) demand planning & RT Supply Chain adaptation
  - Business processes & communication security
  - the global FEV battery/chassis/powertrain Supply Chain
  - Ontology mapping/merging
  - Business models facilitation cooperation
- **Systems Network beyond nodes**
  - Supply Chain Re-design (e.g. micro production sites)
  - Adaptive logistics for flexible plant in global parts production
  - new ways of FEV-SC cost-benefit sharing
  - Self-organization
  - Production as service type models
- **Global Dynamic Supply Loops**
  - Advanced IT Systems for global application
  - open exchange interfaces to incorporate SMEs
  - intra-network capacity communication
  - "Optimized Transport Flow" under various biz conditions
  - Global Forecast Inclusion for FEV supply
  - Competence management to balance local & global suppliers to FEV production
  - Material & Commodity Supply Chain
  - Overall connectedness and computing, tracking and tracing
  - Advanced, robust local planning
- **Energy/Emission optimized global logistics approach**
  - Tools to determine the specific CO2 Footprint for FEV logistics
  - FEV supply network simulation instruments
  - green logistics 4 FEVs
  - 2030 Packaging



5.4: Global Business Processes

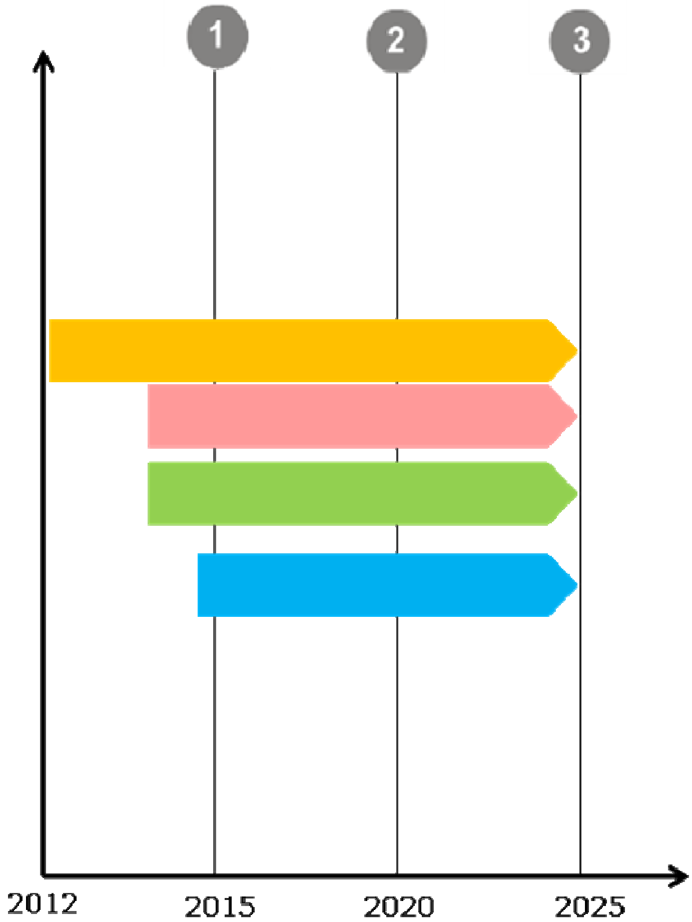
- **Process & Equipment IT**
  - Internet/Cloud of EV Things
  - technical standards for FEVs and their impact on global production & maintenance
- **Global Market Monitor**
  - business scenarios and real-time reactivity tools
  - intra-industry collaboration models for economy dependent business scenarios (segmented, constrained, stagnation)
- **Global Commodity Management**
  - new forms of collaboration: industry sourcing tools vs. Commodity trading instruments
  - increasing the efficient use of raw materials
  - enhancing materials and materials replacement strategies
  - generic mechanisms of cooperation based on reputation
  - eco-labeling, "green and lean" logistics
  - complete life-cycle compatible business models (new LCA approach for EVs)
  - EV "cradle-2-cradle"initiative on raw/rare materials (new concept on sourcing, processing, waste, recycling, reuse)
  - pollution dependent sourcing
  - establishment of a real-time materials & commodity data base
  - recycling and reverse logistics under hard capacity constraints
  - Integrated EV Commodity Management
    - balancing the buying & selling side
    - tools that cope with price volatility as a constant
    - inclusion of "Commodity Futures" (Materials, Energy, Plastics..), "Complex Financial (Swaps, Options, Collars,..), "Strategic Actions" (Capacity Expansion, Back Integration, change in Production Mix, Product Redesign, Strategic Sourcing)
    - Terms of measuring/quantifying the advantage



5.5: Global Education & Qualification

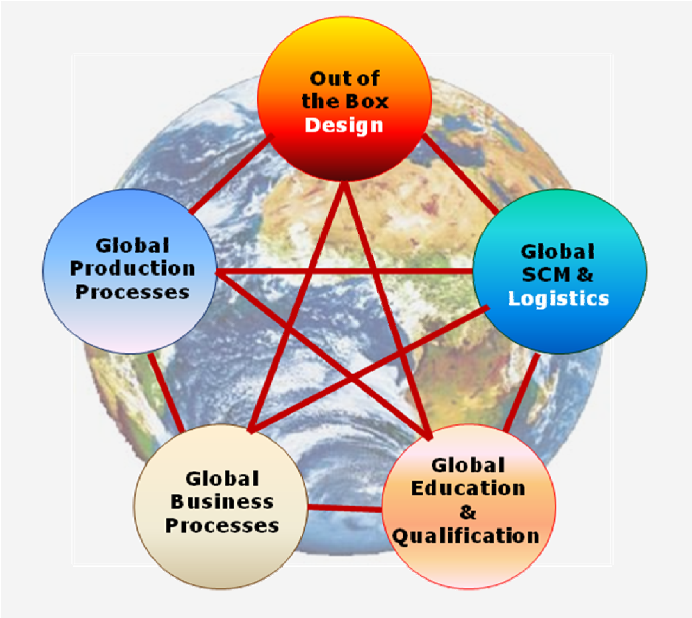
Global Staff & Expertise

- "COMPEDIA" the wiki for global competence rating
- Global labour standards & their implication on industry
- Collaborative Learning
- Awareness of new skills demands: Prepare in advance competences related to R&D, production and market related workforce, maintenance and repair
- How can the automotive sector become attractive to talented young engineers



5.6: Milestones

It is important to register that none of the 5 major domains is of self-standing character and all are inter-related with the "Out-of-the-Box Design" making an intelligent guess on all future technologies of relevance and the respective production, SCM and business process domains, as well as the social part, following suit.



	Milestones 2020	Milestones 2025	Milestones 2030
Out of the Box Design	Updated short list of EV concepts and related technologies	Global component tool kit	
Global PHEV & EV Production	Global production concepts for 2[dn] Gen EVs operational	Roll-out of global production concepts for 3[rd] Gen EVs	
Global SCM & Logistics for EVs	Demonstration of advanced collaboration schemes on global scale; Implementation of tools to assess the CO_2 Footprint	Implementation of concentric global collaboration, planning and real-time event management	
Global Business Processes	New IT processes implemented; Harmonization of engineering and Business IT accomplished; 1[st] Tools for PHEV/EV Commodity Management in service	Implementation of real-time materials data base; Next Generation Commodity Management instruments tested and implemented	
Global Staff & Expertise	MeChemTronic Engineers education & Training implemented, Global Competence & Social Standard Wiki adopted	Establishment of novel educational degrees	

6. Recommendations

Tackling the affordability is crucial for advancing from niche products of PHEVs and particularly EVs towards a sufficient market penetration of electric vehicles. Since the affordability is directly related with reaching the respective economies of scale and high volume production a roadmap on the Technology and Production Concept for Electric Vehicles is of high value for the European automotive industry partnership. Specific features of the automobile sector regarding the products, the customers, the industrial network and the challenge of the novel technologies justify a separate approach to secure and enhance the global competitiveness within the framework of ERTRAC and its related Green Cars Initiative. The roadmap on the "***European Technology and Production Concept for Electric Vehicles***" will collaborate closely with all other ERTRAC roadmaps and is also ready to cooperate, as appropriate, with other related Technology Platforms and their PPPs, e.g. the "European Factory of the Future Association" (EFFRA).

ERTRAC's Global Competitiveness Working Group (GC-WG) has addressed its needs for RD&D in various submissions against the ERTRAC Steering Committee. The principles that the industry recommends are:

1. That competitive performance in global markets should be the primary reason for investing in RD&D – especially for the European industry that needs to secure market shares in other parts of the world.

2. That Community funding should also recognize the dimensions of the industry and the ways it takes part in the global market, directly with prime products and indirectly through the supply of systems and components for hybrid and fully electric vehicles.

3. Funding should be applied to programs that as near to market as the conventions of international trade and the collaborative ability of European firms permit.

4. That funds should only be applied to submissions of high quality which hold out the prospect of tangible gains from the work. The industry strongly confirms its own commitment to the criteria of technical excellence and high quality in any submission intended to attract Community funding.

5. That a pilot RD&D initiative is launched within the current Framework Programme in order to allow achieving the objectives of affordable PHEVs and EVs already during the market ramp-up phase securing the profitability of European companies in global competition.

7. References

1 Schumpeter 1942; Solow 1956; and Swan 1956

2 Technology Roadmap, Electric and plug-in hybrid electric vehicles, IAE, 2009

3 European Roadmap, Electrification of Road Transport, ERTRAC, EPOS, SMARTGRIDS, 2009

4 European Factories of the Future PPP, Strategic Multi-annual Roadmap, Brussels, 2010

5 United Nations Development Program, Human Development Report Office, Oxford 2004

6 A portfolio of power-trains for Europe: a fact-based analysis, McKinsey & Company 2010

7 La Civilization du Risque, Patrick Lagadec (1981)

8 The Raw Materials Initiative – Meeting our Critical Needs for Growth and Jobs in Europe; Commission Staff Working Document, Brussels SEC (2008), 2008

9 Commodity Management: Profiting from Volatility Deloitte, 2006

10 The Global Competitiveness Report 2009 – 2010, World Economic Forum, 2010

11 Supply Chain Decarbonization, World Economic Forum, 2009

12 brand eins – Die Problemlöser: Schwerpunkt Logistik; Heft 03, März 2010

13 Human Development Report 2009; United Nations Development Programme 2009

14 Zukunft der Mobilität; Szenarien für das Jahr 2030; ifmo, 2010

15 EU Sectoral Competitiveness Indicators; European Commission, DG ENTR, 2005

16 Elektroautos schaffen Jobs Wachstum und Jobs in Europa; McKinsey&Company, 2011

17 Communication from the Commission to the EU Parliament, the EU Council, the EU Social Committee and the Committee of the Regions: An integrated industrial policy for the globalization era putting competitiveness and sustainability at centre stage Brussels, COM (2010) 614

18 Global Manufacturing Competitiveness Index, Deloitte Touche Tomatsu, June 2010

19 Paving the way for electric vehicles: a trajectory for a 50% cost reduction by 2020, PRTM Management Consultants, Brussels 2010

20 The Raw Materials Initiative – Meeting our critical needs for growth and jobs in Europe, Commission Staff Working Document, Brussels, 2008

21 European Industry in a changing world – updated sectoral overview 2009, Brussels SEC (1111 final)

22 Roadmap to a Single Transport Area - Towards a competitive and resource efficient transport system; White Paper 2011, Brussels COM(2011) 144

23 White Paper: European transport policy for 2010: time to decide; Brussels, DG MOVE (2011)

Note:

This report is considered a living document that will be periodically reviewed, updated, and made available to the community through the websites of the involved European Technology Platforms, e.g. for ERTRAC at www.ertrac.org.

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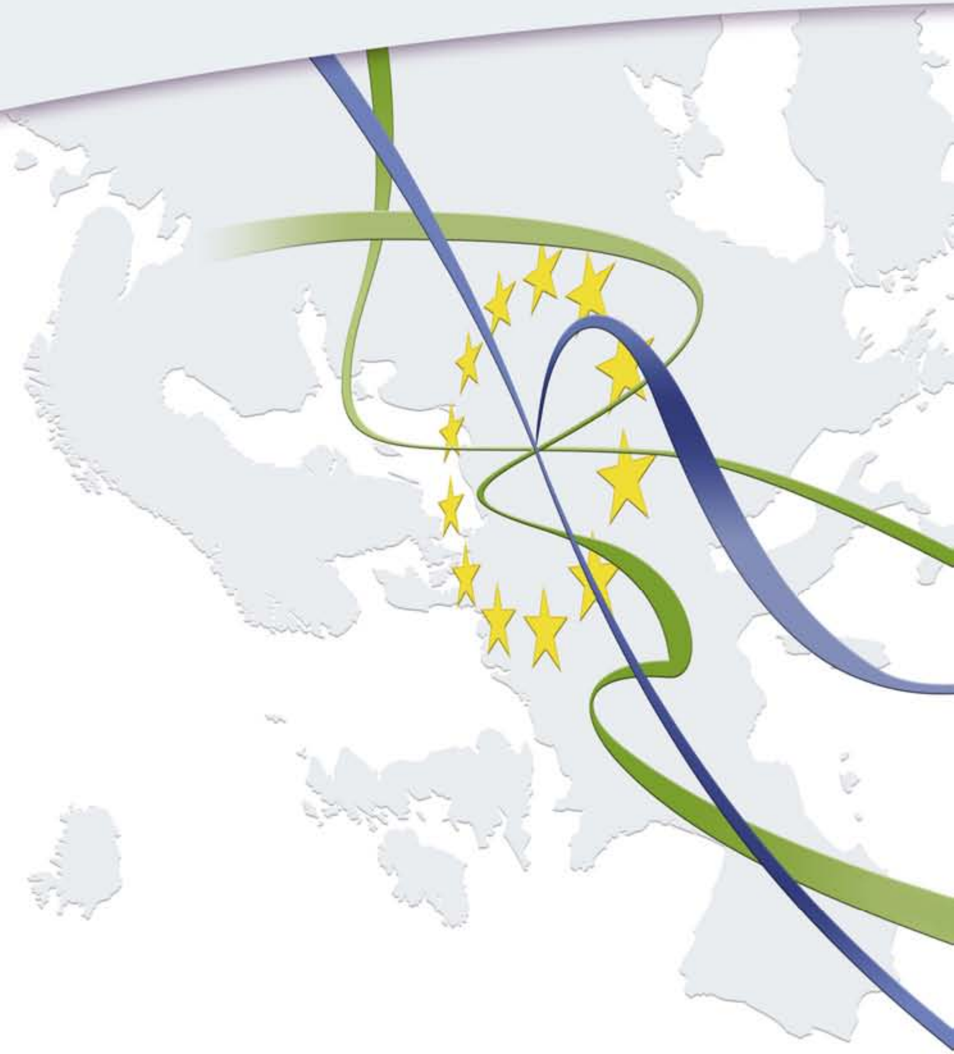

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