European Green Cars Initiative

III. Long Distance Truck

Version November 2010

Content

1. Introduction

The economic development and competitiveness of Europe depends on an effective and efficient transport and logistics system. The mobility of people and the flow of goods to, from and within the Europe must be cost efficient and at the same time safe and environmentally sustainable. Increasing globalisation and competition in most sectors further emphasize the importance of a competitive European transport system. The importance of the European transport system is further emphasized in the European Commissions communication on “A sustainable future for transport” (COM(2009) 279) stating that 7% of European GDP and 5% of employment can be attributed to the transport industry at large.

Despite efforts to decouple GDP growth from freight transport during the last decade, demand for freight transport has increased with 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 the major part of the increase in oil consumption during the last three decades, a trend that is expected to increase. In the EU the environmental footprint of transport corresponds to 23.8% of green house gases and 27.9% of CO2. As the sector is to 97% dependent on fossil fuels, the environmental concerns are well aligned with efforts to improve energy security (COM(2009) 279). Hence, the entire transport sector, and particularly road freight transport by trucks and lorries has been focused as a main policy area where further environmental and overall efficiency improvements are critical for a sustainable future of European transport.

The future of commercial transportation, to ensure sustainability and global acceptance, requires the development of systems that reduce the dependence on oil and minimise the emission of greenhouse gases. Today, the transport sector accounts for 58% of the global oil consumption and approximately 20% of the global, energy-related emissions of green house gases. The whole transport system needs to be restructured and reorganized. Transport emanates from needs of private citizens, business and public organisations to get goods and employees moved from selected geographic locations. 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-modes 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 months to real-time. The transport system as a whole is gradually being more effective but there is an untapped potential for improvement. Furthermore, its sustainability, safety, and reliability must be improved. A

significant amount of these requirements will need new business concepts, and new technologies as well as pan-European standards and regulations developed in public private collaboration.

Examples of new concepts, also found in the ERTRAC Scenario document, is for instance the 'green corridor' concept which could be introduced and used for highly-populated multimodal corridors in Europe by 2030. The criteria for access to these corridors could be related to new vehicle concepts, performance and transport efficiency. In the road part of these corridors, more transport and energy efficient vehicles could possibly be coupled electronically into convoys that are "platooning". Thereby, the throughput of trucks and goods, safety and energy consumption per load unit (volume, weight) could be higher compared to present highways. The trucks and trailers would need to be optimized for the load carried so that the speed can be harmonised. Emissions would fall, and the levels would depend on the increased throughput, reduction of congestion and the fuel efficiency of complete vehicle concepts. On average, the CO2 emissions could be 25 per cent lower in a corridor, compared to the overall average vehicle emissions.

In 2030, tri-modal land hubs could provide fast transhipment of people and goods between rail, inland waterways and road services. Conventional inland terminals, as exist today, will still be operating, serving regional traffic and local distribution. At these sites, fast but cost-effective 'horizontal' transhipment could take place, including the loading and discharge of trains and barges for inland waterways. Small lifting equipment could be used for loading trucks, when needed for short hauls. Dual-container loading facilities could be provided, both 'horizontal', i.e. making use of automatic shuttles rolling on and off the vessels; and 'vertical', using batteries of container cranes in parallel loading several containers at the same time. A standard loading unit (worldwide) would have been agreed and would be used globally, as well as RFID technology (an ICT protocol which can be used for the remote tracking and tracing of freight consignments).

A network of intermodal transfer points of various sizes and degrees of reach would facilitate the seamless transfer of cargo between the backbone of interconnecting multimodal corridors and the regional networks. Automatic locking on container castings and tray castings, in combination with the automatic positioning of the train at the loading floor, would be standard as would enhanced communication technology to enable cargo and pallets to remotely communicate their status, and smart dust providing physical security for loading units. For delivery trucks, this would also enhance road security for cargo and drivers. Transport of goods for delivery to local shops or customers would become autonomous.

The system would be further enhanced by efficient information usage and driver support systems (vehicles will be fully 'connected' and able to communicate with each other as well with the road operator, transport planner, etc.) and by the development of strategically located, advanced hubs for both intermodal transfer and the transfer between urban and non-urban freight transport.

2. General Expectations and Approaches for Road Transport Improvement

All transport modes are needed in seamless coordination due to capacity limitations. 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 figure 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'.

Figure 1. 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 document aims to address primarily emphasis *long distance trucks* whereas aspects relating to *co-modality & logistics* are covered in a separate chapter. Correspondingly a number of cross-cutting issues exist, and are treated in both documents from different perspectives, in particular: green corridors & hubs, city logistics, and intelligent logistics solutions.

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 aimed at addressing this problem by among others increasing capacity through different means

requiring a systems approach involving vehicle and trailer manufacturers, road and ICT infrastructures, logistics operators, etc. Another resource that should be made more effective is the co- and intra-modal hubs. By co-utilisation between different forwarders and speeded up transfer times land resources can be freed. In both cases vehicles, load carriers and switching equipments must be optimised to work in these new physical environments.

In general, full vehicles supporting consolidation of freight loads enable the highest level of transport effectiveness and also fewest number of freight movements thus reducing congestion. However, the need for rapid delivery and short-stock piling times make it sometimes difficult to fill or use 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 to adequately address this issue is required, in addition to focusing attention on business models, service platforms & databases, ICT & protocols, modularised goods carriers & vehicles, etc.

Following this approach has important implications on both vehicles and infrastructures. While respecting the limitations on vehicle size given 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 on the layout and design of vehicles which are optimised for a more specific mission profile and better overall efficiency is required.

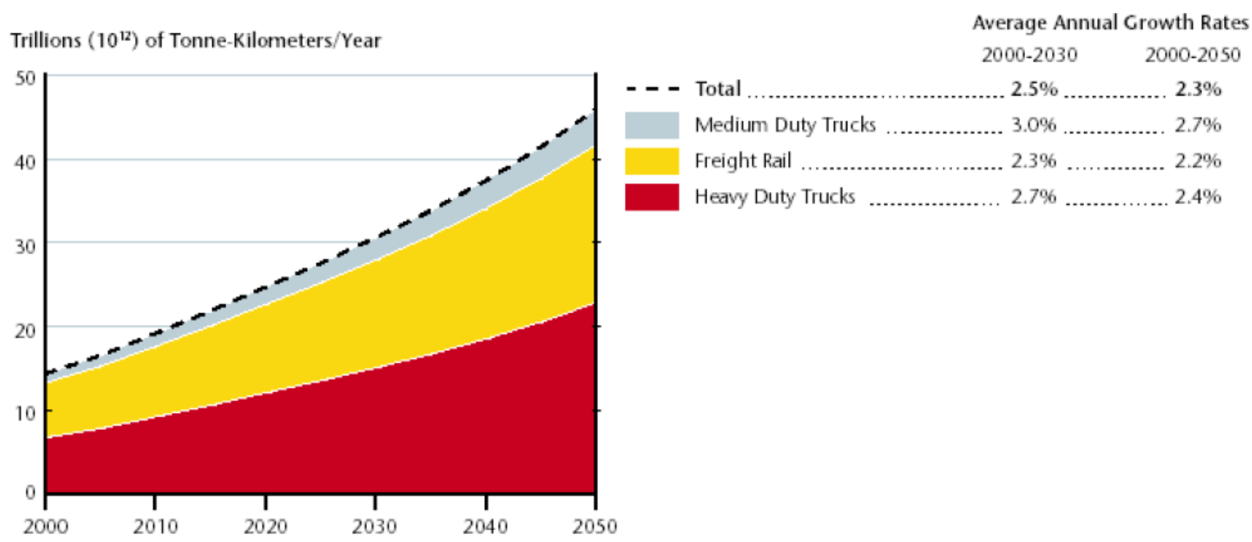
Moreover a significant part of long distance transport using heavy *trucks* is associated with connecting to customers in urban areas. In this context, city logistics issues are a crucial part of the overall picture. Usually hubs at the city periphery are used as switching points for the goods, with concepts based on tailoring of vehicles and goods carriers to facilitate movement within city environments to load and unload at local consolidation centres. An interesting concept to be developed further is this context is the extension of green corridors into the urban environments. In the longer term it should be possible to convert large trucks into smaller vehicles, and vice verse, and to use electric prolusion while moving within the city provided an adequate infrastructure is available (e.g. for battery charging, etc).

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. The limited energy storage capacity and energy transfer speed will require considerable investments in the whole energy supply infrastructure. For *long distance trucks,* a broad approach aiming at developing sustainable trucks which can run on onboard fuels but also have opportunities to attach to available grid sources along the roads are under way. The partial electrification of certain drive train systems will assist in this development. It is important to emphasize, however, that CO2 neutral liquid fuels and combustion engines is the basic energy conversion concept for the foreseeable future.

As indicated in figure 1, of the forecast improvement in the efficiency of long distance freight approximately half must be provided by increased energy efficiency of the vehicle itself. Improved driver support systems and logistics and infrastructure should also contribute significantly to improvements in efficiency. Furthermore significant improvements for long distance trucks is expected in the area of safety, reducing accidents and fatalities.

3. Challenges and Prospects for Long Distance Truck Innovation

In the 2006 mid-term review of the White Paper 2001 of the European Commission, goods transports in Europe are projected to increase with 50% between 2000 and 2020. Regardless of the future scenarios chosen to meet this challenge it is evident that goods transports on European roads will have to absorb the lion’s share of the increasing transport demand.



Source: WBCSD (2004):Mobility 2030: Meeting the challenges to sustainability. Geneva

Figure 2. Predicted transport demand.

Modal shift from road to rail, short sea shipping and inland waterways are of course put forward as a more sustainable alternative but the potential is intensely debated and limited at best, compared to the potential for energy efficiency improvements in the road transport system. Modal shift indications can be found in studies of the UK situation which showed that the road share could decrease with 14% (tonne-km) to 2050. Studies in Sweden have

indicated the potential to move freight from road to rail and sea to around 10% (McKinnon & Piecyk, Logistics 2050, 2010 and SIKA, 2008:10). Efficient use of incentives may stimulate the use of innovative logistics solutions such as e-freight, online load and capacity sharing platforms. Considering the projected increase in transport demand, Europe will probably continue to rely on long distance trucks to maintain a competitive transport system.

A key factor for the transport sector is to be flexible enough to adapt to possible changes in the transport patterns. Logistics will be much more complex and flexible due to new trading partners, due to increasing integration of order & production process with transport and delivery and due to changing transport corridors, e.g. road and rail transport between Asia and Europe.

Road transport accounts for about 75% (EEA (2010) TERM report) of goods transport today, and continues to develop rapidly, not least because of its transport and quality characteristics.

One major challenge in road transport is congestion. It will be addressed in different ways. There is for instance the concept of green corridors which among others aims to improve the safe and clean usage of transport infrastructures. In principle it can be applied in both inter-urban and urban environments. This concept will put a strong demand on the development of more effective vehicles, standardised load carriers and supporting ITS/ICT systems.

The potential for increasing energy efficiency and safety of long distance trucks is structured into three main areas in which timely R&D, demonstrations, production, market introduction and regulatory framework development are pointed out in a roadmap format.

3.1 Vehicle Efficiency

Areas vital to the truck OEM industry to address include 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 also benefits from vehicle optimized aerodynamic design, reduced rolling resistance and internal friction, lighter truck and trailer concept and efficiently designed and controlled auxiliaries.

Areas important for increasing the efficiency of the truck and its operation are e.g. 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.

Vehicle Concepts and Technologies for research:

1. The safe and intelligent truck
2. Matching vehicle to operation
3. Design dimensions for optimised load capacity
4. Aerodynamics
5. Low Rolling Resistance
6. Energy Management & Efficient Auxiliaries
7. Advanced Materials and Design

1. The safe and intelligent truck

To be fully integrated into the transport system vehicles will have to be smart enough to 'sense' their surroundings and navigate through traffic safely and efficiently, while providing their occupants and cargo comfort and convenience. The vehicle will be a 'node on the internet', and will be 'on-line' with other vehicles (v2v), with the transport infrastructure (v2i), and with homes, businesses and other sources (v2x). When on-line, the vehicle will assist the driver by offering automated responses to developing traffic and operational situations, leading to increased efficiency, safety and enhanced quality of service.

2. Matching Vehicle to Operation

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 its operation 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, for example efficient transition between long distance transport and urban delivery. The vehicle needs to be flexible with regard to powertrain capabilities and chassis design and to the freight modules composition, set up

and weight (e.g. flexible tire sizes). The vehicle needs to have upsize/downsize capability optimising payload.

Innovative leasing solutions, that could be offered to transporters, so that vehicles can be leased (short, medium, long-term) and towing units can be switched on a given trip inline with their customers' requirements according to capacity and engine power needs, will be explored.

Increased level of modularisation of freight modules is crucial for freight inter-modality and efficiency. Common standards need to be agreed and implemented for the design, dimensions of freight modules (goods containers) in order to optimize the inter modal 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.

Ensuring smooth, safe and swift transhipment between modes could remove an important bottleneck in intermodal transport chains and obstacle to an increased share for intermodal / combined transport.

3. Design dimensions for optimised load capacity

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, users acceptance, etc.).

According to MacKinnon et al [ref 3], 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 how much 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, safety, traffic generation etc., strategies to

optimize pay load, chassis control (braking, handling, traction) and modular vehicle architecture.

4. Aerodynamics

Aerodynamic drag is an important loss factor for long distance highway freight, and is key target to reduce for optimising the complete vehicle efficiency. Vehicle aerodynamics can be optimised by changing the design with regard to shape, contour and minimised total front area. Reduced aerodynamic drag shows a near linear effect on fuel consumption [2].

As a first step towards true optimisation of the aerodynamic design of trucks, it is essential to study and identify best-practices in order to enable standardised methodologies for aerodynamic simulation and analysis to be defined, referring also to other sectors of industry where finely-tuned aerodynamic analysis is critical (aeronautics, performance cars, etc).

Tractor and trailer is the most common configuration in Europe. Only optimising the tractor, or trailer, will not result in any major gain; it is by investigating the whole system a significant impact can be reached. Seeking both increased transport capacity and reduced carbon footprint, aerodynamic solutions have shown a great potential [1]. Robustness for different speeds and conditions combined with adaptive configurations and control of the whole vehicle will have a big impact. Front geometry for optimised cooling, better safety and minimised drag, tractor-trailer air-gap control, coupled with rear end solutions and aerodynamical side-skirts covering wheels have all shown to reduce drag significantly. New aerodynamic solutions should, however, not compromise operational efficiency of cargo handling. Integrated solutions need to be developed.

Platooning or convoying (vehicle-to-vehicle control and communication) could contribute to increased transport efficiency due to reduced aerodynamic drag and reduced contribution to road congestion but must be assessed against safety concerns, dedicated new infrastructure requirements and costs.

5. Low rolling resistance and low friction

Reducing friction, in all parts of the long distance truck, has a direct impact on fuel economy and vehicle lifetime productivity. New roller bearing concepts, along with novel lubricants is necessary. New simulation techniques will guide us how to reduce friction even more. Combining coatings with low viscosity lubricants will substantially reduce hydrodynamic friction losses. The whole powertrain and axles parasitic losses should be decreased. Cost efficiency can be maintained by smartly designing for and using low friction coated bushings to replace lubricated bearings. Lubricants will also be developed and tailored for new driveline concepts.

The use of advanced tires with extreme low rolling resistance will be an important contribution to improved complete vehicle efficiency. Future work should thus include the development of technology prototype tires and wheel units for testing and minimising rolling resistance. Adding improvements in tire-vehicle interaction fuel savings of up to 10%

might be in reach. To reach these goals potential target conflicts (wet/winter performance, mileage, robustness, cost...) will have to be overcome. Different transportation needs could also require different wheel radii for minimising rolling resistance; e.g. volume load benefits of large diameter wheels, whereas maximum laden vehicles benefit from smaller diameter wider wheels. Matching vehicle to mission – configurable or adaptive.

Intelligent solutions such as tyre pressure monitoring systems, or adaptive tyre pressure systems, along with information to the driver on tyre condition (age, mileage, wear, damage, temperature) for example via radio-frequency tags or sensors could further improve tyre performance.

6. Energy management and efficient auxiliaries

Auxiliaries include water pump, oil pump engine fan, air compressor, active steering, A/C compressor, pneumatic system, defroster/heater/air conditioning, waste heat recovery systems. The objective is to optimise and control all these sub-systems, in order to make a balance between mission performance and energy consumption. This can only be done efficiently (in real time) if all units are electrified, and systematically controlled in a complete energy-balancing system. The power supply to the trailer and the control of electrically or hydraulically power outputs are also to be included in the control loop. The vehicle should be able to be self-aware of the current configuration and situation, in order to be efficient and not to overload the operator or driver. All this can only be introduced with a distributed electrical architecture and aiming for as few energy conversions as possible, for better energy efficiency. The path is to go fully electrified with auxiliaries – especially with the advent of electric hybrid powertrains. Higher voltage components (some as "simple" as Bi-Xe head lights) can increase efficiency, and benefit from certain hybrid technology. Other lights, interior and exterior, should also be changed to LED's or other lean alternatives.

Idling can make up for a significant part of the workday for certain vehicles; loading, unloading, or when the driver is sleeping or resting. The cab is a work place and also a resting place, so good insulation (light weight, recyclable, noise insulation, heat and cold resistance will also contribute.

An efficient auxiliary power unit (APU) is vital. Energy storing, and charging, must be solved for highest impact of an electrical system. Fuel-cells alternative could be a solution. Energy management aims at optimising the performance and synergies for cooling performance and optimised control of all electrified auxiliaries.

The actual transport situation, i.e. type of mission, route, traffic situation, possible charging possibilities, etc should be taken into account for a complete energy management system. This includes situation sensing and adaptation. Examples are

- Optimisation of all configurable vehicle parameters depending on the actual mission.
- Energy balancing including efficient electrical power generation, conversion and distribution to different systems
- Energy recovering/scavenging/harvesting
- Optimisation of external energy , e.g. quick energy charging stations

Waste heat recovery systems and APU's can provide a secondary (backup) source of electrical generation for emergency and safety reasons, auxiliary load powering, and generally as an additional source of electrical generation and efficiency to increase idling efficiency.

The local control strategy must be optimised while taking the overall energy management, into account and balancing local and complete energy storage.

Auxiliaries (APU:s) are important when reducing idling energy consumption. Centralised management of all components and sub-systems will play an important role in energy management and control.

7. Advanced materials and Design

A lightweight truck have many advantages like increased payload capacity (increasing energy efficiency) i.e. less fuel consumption (especially for start-stop situations), reduced road wear (per ton transported goods). However, this is a challenge that needs to find an optimum balance between many demands and requirements – safety is not to be neglected; production cost, too. As a HGV is most likely to have a life of several 100 thousands of km, durability is a key element.

For a truck cab, new light weight designs and materials have many possibilities; improving aerodynamics for the hood, if present, roof and air deflectors. The weight reduced cab will also be optimised with regard to manufacturability, structural integration, durability and safety. Lessons and synergies from the passenger car industry are increasing and transferred not only to trucks, but also to busses and other heavy equipment. Similar approaches will be adopted for the chassis and trailer structures.

Being a place of work, the importance of the interior design of the vehicle must not be overlooked. New solutions for thermal, acoustic and vibration comfort must be sought by improving in the design of the cab interior and its sub-systems including the seat, controls and HVAC system, and through the development of multifunctional materials. The use of advanced materials and innovative technologies could also lead to weight reduction in addition to improving the real and perceived comfort which will also lead to improved safety through enhanced driver performance.

In this context, the development of materials as an enabler must not be underestimated. As regards the structure of the vehicle the trend must be to first design "smart" with existing traditional materials, like steel, ultra high strength steels, magnesium, aluminium, etc low weight alloys, and then turn to low cost composites for certain structures (roof, panels, etc) and then using the extreme weight saving properties of carbon fibre reinforced plastics for certain key elements.

The development of nanotechnologies will have a significant impact on future manufacturing and designing of components – the nano era will make possible to tailor material properties for specific applications; high stiffness and high damping in the same

material, for example. Nano reinforced (thermo-) plastic matrices will also make it possible for more rational manufacturing processes.

When considering novel materials, one must maintain a rational view on the benefit, from a Life Cycle Assessment perspective, or cradle-to-cradle analysis. This means that the introduction of new materials, for instance compared to steel, the life of the product must be analysed – from manufacturing, via usage, to recycling and “rebirth”. Key here is to find the most effective solution for increased transport efficiency and lowered energy consumption, both laden and empty.

Coupled to mass optimisation are the noise and vibration issues – higher speeds more aerodynamic noise, lower speeds with more acceleration – higher engine and transmission noise. Tyre-road interaction also plays an important role for speeds over 50 km/h. Noise from auxiliary systems should also be examined and reduced, as well as noise lifting equipment, reversing signals and door slamming which are relevant for urban (nighttime) deliveries. Smart solutions should reduce weight and noise, without compromising safety or productivity. Nano-material reinforced composites have shown potentials in this direction – also making possible tailoring properties like damping and stiffness. Tyre noise is a challenge, as friction, noise, rolling resistance could all pose conflicting demands on the material. The nano technology will also here be of importance.

[1] Long Distance Trucks, Strategy paper, L-G Rosengren et al, Volvo Group Version 3.2, 2009-11-27

[2] An optimised transport concept for tractor-semitrailer combination, ATZ 0212008 Vol 10, M Colombano, L Consano, Iveco SpA, 2008

[3] Logistics 2050 – Moving Freight by Road in a Very Low Carbon World, McKinnon & Piecyk, 2010

3.2 Driveline Efficiency

The driveline with its energy conversion and transmission of power is crucial in obtaining a fuel efficient vehicle. A systematic search for energy efficiency savings based on driveline topologies control approaches as well as new sub-systems, components and technologies is the main road forward. The opportunities in an increased usage of bio-mass based fuels, assisting the move into a sustainable transport sector, need to be explored further. Full electrification of long distance trucks seems unlikely, at least for a foreseeable future relying on an on-board battery, due to limited storage/range and long charging times of batteries. However a portion of the driveline has to be electrified or hydraulic solutions may be used e.g. to save and re-utilize brake energy. In the long term technologies for continuous/discontinuous transfer of electricity from the infrastructure to the vehicle needs to be explored.

In addition to high reliability, which is a prerequisite in the engineering of long distance truck, a powerful driving force today is the customer requirement for increasingly fuel-efficient vehicles to reduce operational cost. Historically, heavy-duty diesel engines have had a history of continuous improvement of fuel efficiency which, however, has been offset on limited occasions by the introduction of stricter emission regulations. After the introduction of tighter emission levels, continued improvement through research and development has allowed the positive trend in fuel efficiency to resume. The need for research and development is thus even more important to the future achievement of practical and cost-effective sustainable transport concepts.

As a long term goal it is envisioned that improvements in the powertrain area can contribute to a decrease of fuel consumption by 20%. Since diesel-powered commercial vehicles already have very high efficiency, this level of reduction in fuel consumption is not an easy task. It requires considerable technical advances and an integrated approach to reach the desired result. For long-haul trucks, a possible road forward is to combine highly efficient engines, advanced transmissions, mild hybridisation, and the use of (sustainable, second-generation) bio-fuels. Optimized as an integrated system, these technologies are expected to give a considerable reduction in fuel consumption and, thereby, in the emission of greenhouse gases.

New Generation drivetrains

1. Future Powertrain concepts & complete system integration
2. Advanced Combustion and Aftertreatment
3. Waste Heat Recovery
4. Advanced Powertrain Control
5. Alternative and multi-fuel capabilities
6. Friction
7. Hybrid Powertrain
8. Innovative high efficiency energy conversion

1. Future Powertrain Concepts and System Integration

While electrification of the powertrain is envisioned to have an increased importance for passenger car vehicles within the next decade, powertrains for heavy-duty long-haul trucks are expected to be based on internal combustion engines for the foreseeable future. However, technology development that enables recovery of both brake and heat energy will be needed. Hybridization, including brake recovery, is anticipated to play a major role for heavy-duty engines with the degree of hybridization depending on the development of among others battery technology. In other cases hydraulic systems can be used which do not depend on battery technology and can also recover brake energy. For certain applications in

urban environment, which is not in focus here, i.e. service and delivery vehicles, full hybridization and/or electrical vehicles, might be expected in the future.

Engine downsizing has a significant potential to further reduce fuel consumption especially in combination with integration of hybrid systems for boosting the power for acceleration and starting of heavy duty trucks on a hill. This approach also opens for a reduced emission potential, due to reduced transient behaviour period of the truck engine.

The general development to increase transport efficiency may alter the vehicle size and weight which affect the torque and power needed from the powertrain. The powertrain system needs to be right sized and optimized according to the application. Further developments of major subsystems such as the turbo charging system, thermal management for the aftertreatment system and the SCR system will be key enablers for flexible powertrains.

Bio-fuel blendings influence fuel quality and developments are needed to adapt the combustion and the aftertreatment system. The increase of other fuels such as natural gas or bio-gas makes it necessary to develop high performance dual fuel engines.

The above mentioned factors do all affect the requirements put on the complete powertrain system for long-haul applications. It will thus be necessary to analyse and substantiate these trends to find optimal future engine sizes. Different levels of hybridization will also affect the sizing and the constraints put on the engine.

2. Advanced Combustion and Aftertreatment

The main form of energy conversion for long-haul powertrain solutions will be internal combustion of hydrocarbon fuels for the foreseeable future. The Diesel process is very efficient and emissions are expected to reach sustainable levels with the EU6 legislation. However, the combustion process and in particular the Diesel engine and aftertreatment system as a whole can still be improved to obtain more favourable fuel efficiency. Important research needs cover:

- Efficient combustion and clean combustion
- Advanced injection strategies
- Advanced closed loop control
- Combustion modes with high thermal efficiency (eg. PPC combustion)
- Reduced thermal losses
- Highly efficient and integrated EATS system
- Advanced SCR systems (e.g. new catalytic materials)
- Advanced DPF systems

3. Waste Heat Recovery

Although improvements in the combustion and aftertreatment system will lead to lower exhaust temperatures a substantial amount of energy is still contained in the exhaust. An efficient recovery of this exhaust energy is of crucial importance to reach a substantial improvement of fuel economy. A further development of Rankine waste heat recovery systems and in particular the associated components are of high importance. Future research should also include investigation of more advanced waste heat recovery systems based on Rankine cycles or other advanced technologies. The integration of waste heat recovery systems with different degrees of hybridization is also crucial.

- Rankine Cycles (organic/non-organic)
- Advanced system and heat exchanger design
- Development of expander systems
- Cooling system and integration on vehicle
- Thermo-electric WHR
- Advanced solutions

4. Advanced Control

A complete integration of the entire driveline will be a crucial factor in achieving a major improvement in fuel efficiency. The full benefit of this integration will be available only if advanced control is employed.

Advanced control is a key enabler for integration of the entire driveline providing means for high efficiency low emission combustion and a co-optimization of the combustion and aftertreatment system. Important research needs are closed loop control (cycle-to-cycle, in-cycle) technologies and the development of advanced and reliable sensors. To ensure optimal operation for various fuel blends in terms of emissions and fuel consumptions sensor and advanced control technology will be of crucial importance.

A full integration of waste heat recovery systems and different levels of hybridization will be subject to developments in advanced control.

5. Alternative and multi-fuel capabilities

Future long-haul powertrain systems will have to be tolerant to blends of Diesel and bio-fuels complying with upcoming legislation. The development of fuel quality tolerant combustion and aftertreatment systems will be key issues. Advanced control and sensor technology will be a major enabler to reach these goals. One of the most important development needs in the utilization of alternative fuels is to maintain and in the best of cases exceed the energy conversion efficiency possible with traditional fossil diesel combustion. This is especially important for non-diesel fuels, were other combustion processes, such as HCCI or flame propagation needs to be applied. The engine efficiency is highly dependant of the injection tuning which in turn is dependant on the fuel quality, and especially the oxygen content when bio fuels are used. Therefore a cycle to cycle closed loop

optimization for the fuel currently combusted important. The utilization of sensor systems which enables direct or indirect measurement of fuel or combustion quality may then be the enabling component/system to realize high bio fuel flexibility. These type of sensors systems are also important to adjust the aftertreatment conditioning parameters to maintain durability and total system efficiency.

It is also envisioned that multi-fuel capabilities will become more important. The availability of natural or bio-gas might increase on certain markets. Further research on multi-fuel systems including advanced combustion modes and improved aftertreatment solutions should be the focus.

6. Friction

Measures to lower engine friction have a potential to give major efficiency gains. Future research should focus on new technologies, materials, oils and bearings.

7. Hybrid Powertrain

Future long-haul powertrains will include a certain degree of hybridization. Battery cost and weight will probably be a limiting factor for the foreseeable future. Upcoming research should include cost-efficient and advanced start/stop capabilities and brake energy recovery. Smart energy management and advanced systems for hotel mode are also crucial topics.

In certain applications hydraulic systems can be used for hybrid concepts. This has the advantage to be independent from battery development, hydraulic components are rugged, reliable and do not need basic research efforts.

However, to reach a substantial improvement in fuel efficiency the use of at least mild hybrid systems will be critical. A full integration of the powertrain with the hybrid system including WHR, aftertreatment and controls is paramount.

Several steps of energy efficiency and cost reduction actions may be applied for an engine dedicated to be operated in combination with a full hybrid power train. 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. The requirements for engine transient operation will be reduced significantly which opens up for engine simplifications and efficiency improvement. This is also valid for the aftertreatment solution. Special attention need to be taken of how to start and stop the engine an in an efficient, silent and durable way. The engine system needs to deliver high efficiency in the defined hybrid driving modes which may differ considerably depending on the type of hybrid application, i.e. the degree of parallel or serial type of set up.

It is unlikely that full electric long haul vehicles will be a reality if not the targets in the electrification road map on the energy storage systems is widely surpassed. An alternative solution to be investigated may be a system which transmits energy to long distance vehicles during travel.

8. Innovative high efficiency energy conversion

To reach a drastic and long term reduction in CO2 for long haul applications work on novel break-through technologies is essential. These technologies should go beyond the current limitations and boundaries of today's state-of-the-art. They should either stretch the thermal efficiency limits, use new energy conversion principles or new combinations of those technologies. New solutions in this area could be an enabler for an essential further step in CO2 reduction beyond the technology development mentioned above. Further research actions within the area of efficient drivelines for long haul should thus without a doubt include activities of a long term nature. For these breakthrough technologies to be developed and deployed, R&D should begin in the near term.

3.3 Driver Efficiency

The drivers' driving behaviour has great impact on the quantity of emissions as a function of the fuel consumption. Therefore, the drivers' driving behaviour is a critical factor that has great impact on the emissions. By combining cooperative systems using vehicle-infrastructure communication, there are potential of fuel saving by 20% [1].

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 supporting drivers and fleet managers to improve fuel efficiency. The DCS on market today are based on technologies that register information from the vehicles. Information can be displayed directly to the driver while driving to support fuel efficient driving or can be configured as post-trip reports. With this information fleet managers can take measures to improve fuel efficiency in the fleet, e.g. by supporting the drivers to improve their eco-driving.

The next generation of Driver Coaching Systems is believed to have a potential of fuel saving by 20% and will be characterized by a systems perspective combining cooperative systems using vehicle-infrastructure communication. Further research is however needed in the area of driver compliance and automated DCS reducing the impact of individual compliance, if the full potential of DCS is to be reached.

[1] Proposal to FP7, ICT Programme, Objective ICT-2009.6.1, ICT for Clean and Efficient mobility

4. Milestones

- Milestone 1: Optimized Truck, 2015
- Milestone 2: Tailored Truck, 2020
- Milestone 3: Sustainable Truck, 2025

	Milestone 1: 2015 **Market 2018-2020**	**Milestone 2: 2020** **Market 2023-2025**	**Milestone 3: 2025** **Market 2028-2030**
Target (include fuels)	+15% tonkm/kwh, 10% biofuel share +20% tonkm/gCO2	+30% tonkm/kwh, 15% biofuel share +45% tonkm/gCO2	+40% tonkm/kwh, 25% biofuel share +60% tonkm/gCO2
Vehicle concept	**Optimized Truck** *Cross links to green corridors, hubs, etc*	**Tailored Truck** *Cross links to freight bundling, city logistics, etc*	**Sustainable Truck** *Cross links to electrification, biofuels, etc*
Main elements	Vehicle dedicated for green corridors, load & capacity sharing logistics platforms, advanced combustion & aftertreatment, driver ECO support, elctrification auxiliaries, Low rolling resistance tyres & TPMS, advanced safety equipment (LDWS, AEBS),	Tailored truck, modular design, advanced wheel units, ultralight structures, hybrid powertrain, energy optimised down sized/right sized powertrain	Convertible vehicles, adaptive aerodynamics, load factor and weight control, grid charging

	Milestone 1: 2015 Optimized Truck	Milestone 2: 2020 Tailored Truck	Milestone 3: 2025 Sustainable Truck
Vehicle Efficiency			
Safe and Intelligent Truck	Robust communication, sensors and data fusion	e-horizon based vehicle control. E freight enabled vehicle	Semi self-operated vehicle
Matching vehicle to operation	Optimized vehicle parameters for efficient transport operation. More flexible vehicle leasing concepts.	Vehicle fully adapted to its operation and freight. Modularity. Inter-modal efficiency	Vehicle that can convert between long and short distance
Design dimensions for optimised load capacity	Vehicle optimized for green corridors	Vehicle optimised for all infrastructure	Efficient transformable truck. Load factor and weight control
Aerodynamics	Aerodynamically efficient complete vehicle (tractor and trailer) 7% drag reduction	Improved aerodynamics, more flexible directives, new vehicle combinations 13% drag reduction	Adaptable exterior geometry, suspension, air gap and speed control, 20% drag reduction
Low Rolling Resistance	New tyre materials and tread patterns. Optimal use of super single and other wheel combinations. Individual wheel control, 10% rolling resistance reduction, TMPS	Optimised wheel units, material composition and adaptive tyre pressure. New low friction nano materials. Wheel hub units. 15% parasitic loss reduction. Intelligent tyre management and communication to driver (RFID).	Advanced wheel multi-functional control. Monitoring and control of all parasitic rolling losses on vehicle. 20% reduction friction losses

Energy Management & Efficient Auxiliaries	All major auxiliaries electrified. Cooling system optimised and integrated	Optimised integrated auxiliary systems regarding energy efficiency. Situation sensing and adaption. Efficiency up >20%	E-horizon data for optimal overall control and performance. All electrical systems integrated and energy optimised
Advanced Materials and Design	Systematic re-design and material optimisation. Both traditional and novel composites. 5-10% weight reduction	Novel materials optimally used through multi-disciplinary optimisation. Multi-functional materials. Lower weight and better performance	Significant weight reduction, integrated design of components in optimal material. Nano materials with multi-functional properties enabling >20% weight reduction
Driveline efficiency			
Future Powertrain Concepts & complete system integration	Mild hybrid low speed narrow band engine with brake energy recovery. Transmission system with predictive gear ratio management and advanced turbo system	Distributed powertrains for tailored truck applications. Engine downsizing with exhaust heat energy recovery. High peak cylinder pressure and variable valve actuation	Advanced hybrid concept with range extender
Advanced Combustion and Aftertreatment	Advanced injection with closed loop functionality	Non-precious metal catalytic materials and particulate matter sensors	Advanced combustion modes (*eg.* PPC) combined with advanced combustion cycles
Waste Heat Recovery	Development of optimized heat recovery cycles such as rankine	Advanced heat recovery systems	Highly efficient thermoelectric systems

Advanced Control	Closed loop control cycle-to-cycle	Closed loop in-cycle control and advanced and reliable sensors. Electronic-horizon	Auto-calibration engine control and durability predictive control
Alternative and multi-fuel capabilities	Fuel sensor and bio diesel tolerant engine	Multi fuel combustion	Multi mode combustion
Friction	New low friction coatings	Optimized low friction concepts utilizing nano structured surfaces and lubricants	
Hybrid Powertrain	Mild hybrid concept	Full hybrid concepts combining cost efficient energy storage solutions. Advanced systems for hotel mode. Advanced design of power electronics.	Novel concepts based on continuous or intermittently transferred electricity from grid
Innovative high efficiency energy conversion	Understanding of ultimate boundaries in combustion with ultrahigh efficiency	Concepts based on research to stretch thermal efficiency limits.	New highly efficient energy conversion principle
Driver efficiency			
Driver support systems	Eco support, Next generation ADAS, improved route planning.	Automated Ecodriving Cooperative safety systems	Semi automated driving.
Freight handling	E freight, paperless transport, internet load & capacity sharing platforms.	Load factor monitoring and weight control	Automated carrier operation and loading

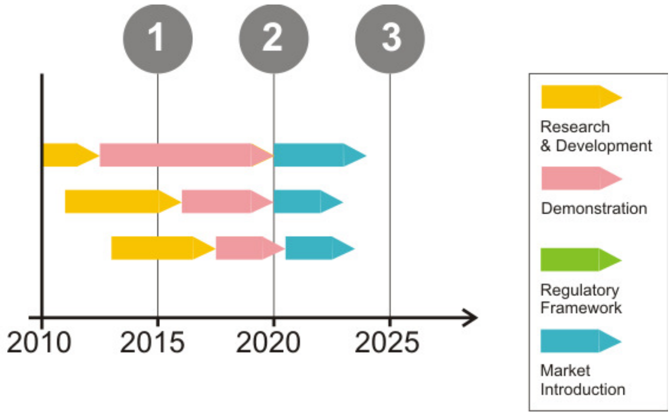
5. Roadmaps

The Safe and Intelligent Truck

Intelligent Transport System (ITS)

Driver Support Systems

Cargo and Driver Security Systems



Matching Vehicle to Operation

Vehicle Adaptation Strategies

Develop Flexibility in Vehicle Powertrain Capabilities

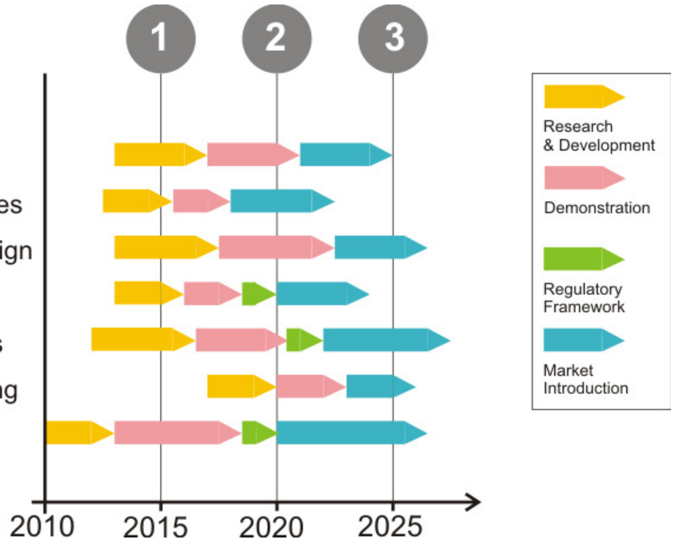
Develop Built-in Flexibility in Chassis+Vehicle Design

Optimize Modularity for Freight Modules

Optimized Loading and Load Control Technologies

Automated Operation+Freight Module (De)Coupling

Develop Inter Modal Optimized Vehicle

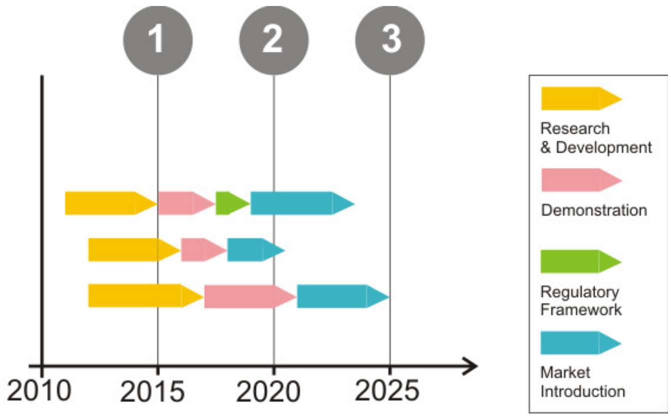


Design Dimensions for Optimized Load Capacity

Optimized Road Vehicle Mass and Dimensions

Optimized Chassis Control

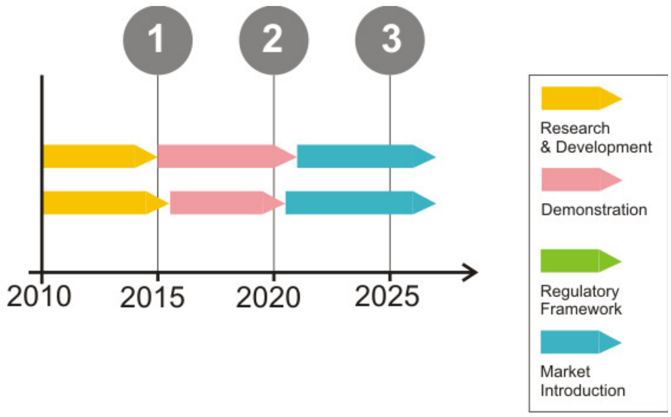
Develop Modules Vehicle Architecture



Driver Efficiency

Develop Driver Support Systems

Freight Handling



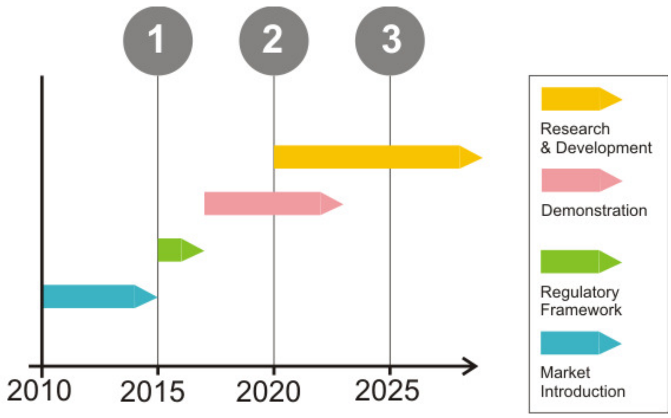
Aerodynamics

Adaptive Aerodynamics

Vehicle Controlled Aerodynamics

Vehicle Max. Dimensions?

Complete Vehicle Aerodynamics

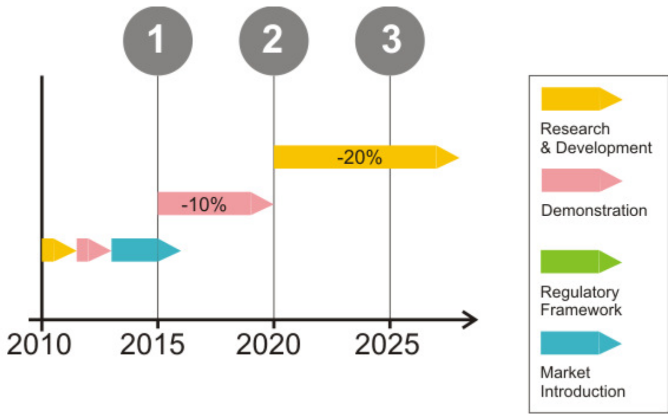


Low Rolling Resistance

Wheel Hub Motors for Adaptive Control

Optimized Wheel Units for Low Rolling Resistance

Low Rolling Resistance Tyres

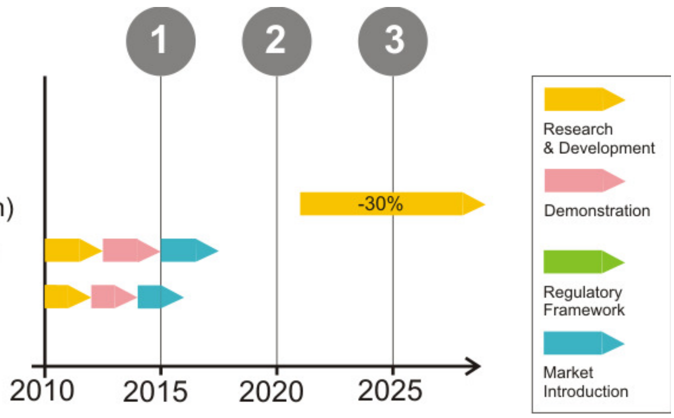


Energy Management & Efficient Auxiliaries

Situation Sensing, Forward Looking (incl. eHorizon)

Control+Optimization of Complete Energy System

Electrification of Major Components

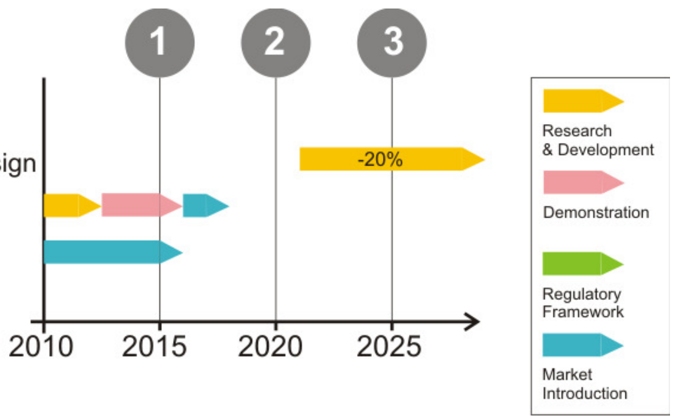


Advanced Materials & Design

Multi-functional Nano Materials, Multi-Material Design

Optimized Structures+Novel Materials incl. LCA

Designing for Low Weight

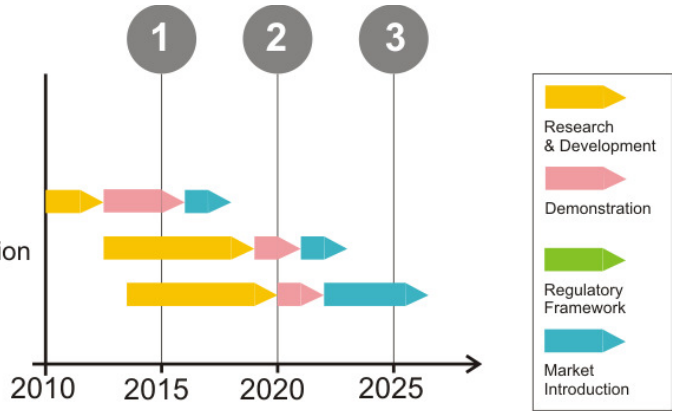


Future Powertrain Concepts and System Integration

Engine Resizing / Speeding

Distributed Powertrains for Tailored Truck Application

Advanced Electrified Powertrain Concepts with Range Extender

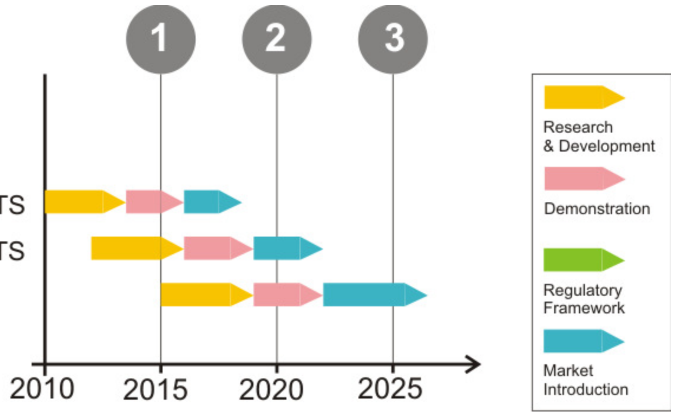


Advanced Combustion and Aftertreatment

Advanced Injection,Turbo Charging,Integrated EATS

Novel Combustion Modes with Highly Efficient EATS

Non-Precious Metal Catalytic Systems

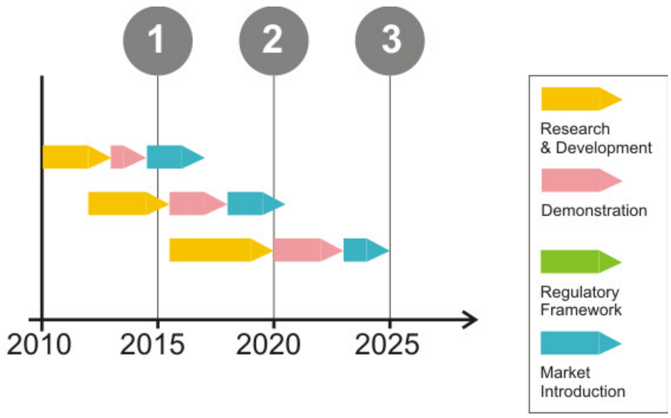


Waste Heat Recovery

Rankine Systems

Advanced Heat Recovery Technologies

Highly Efficient Thermoelectric Systems

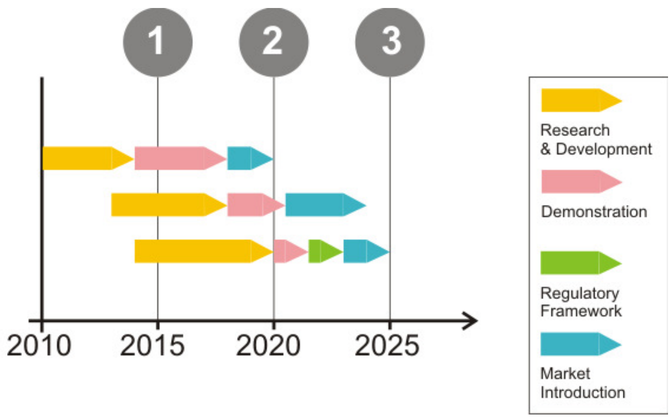


Advanced Control

Closed Loop Control (Cycle to Cycle, In Cycle)

Predictive Control (incl. Full Electronic Horizon)

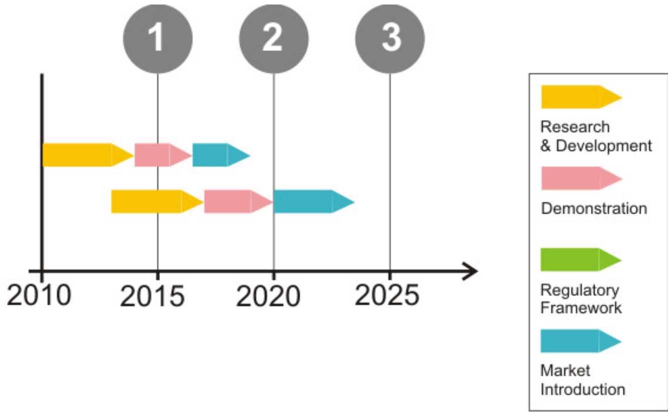
Adaptive Control and Auto Calibration



Friction

New Low-Friction Coatings

Optimized Low-Friction Concepts
Utilizing Nano Structured Surfaces and Lubricants



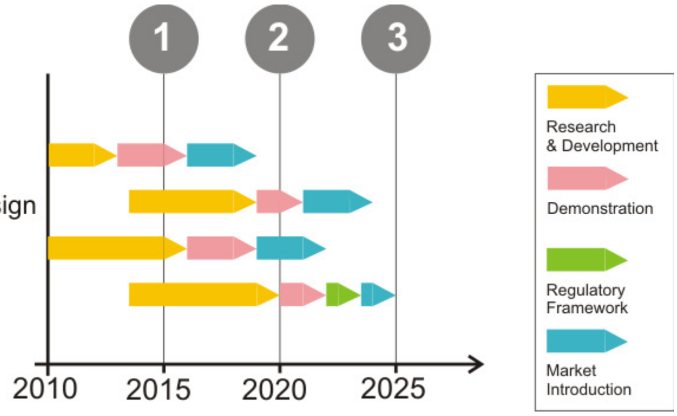
Hybrid Powertrain

Mild Hybrid Concept

Full Hybrid Concepts w Cost Efficient, Robust Design

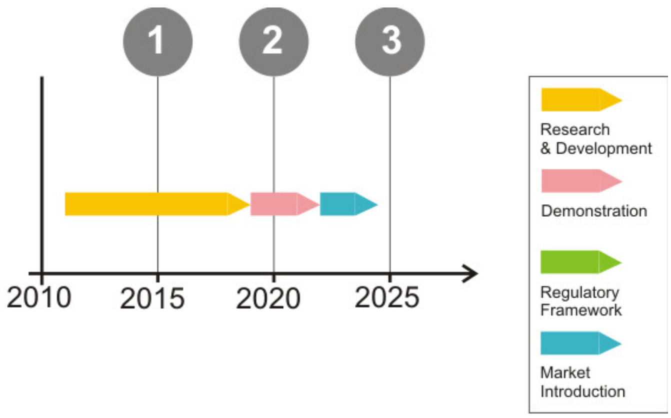
Advanced Systems for Hotel Mode

Novel Concepts Based on Continuous or
Intermittently Transferred Electricity from the Grid



Innovative High Efficiency Energy Conversion

New Energy Conversion Principle



6. Recommendations

A further breakdown on how to address research needs in various FP7/FP8 work programs will be delivered after consultation.

6.1 Preliminary themes 2012

Efficient trucks for long distance transport

- **Complete vehicle energy management**
    - Complete vehicle energy management
    - Optimized power management and distribution
    - Electrification of auxiliaries
    - Cab insulation
- **Vehicle technologies for long distance transport**
    - Advanced vehicle aerodynamics
    - Extreme Low Rolling Resistance Tires
- **Driver efficiency for long distance transport**
    - Driver support (Eco driving / Driver coaching)
    - Efficient work environment (Handling / Cab interior / Alertness)

6.2 Preliminary themes 2013

Optimized trucks for green road freight corridors

- **Configurable and tailored trucks**
    - Optimized trucks for transport mission
    - Configurable truck-carrier and vehicle concepts
    - Energy tailored Driveline, rightsizing

- **Vehicle technologies for long distance transport**
    - Green corridor traffic safety (active safety systems and Platooning)
    - Green corridor cargo and driver security
- **Efficient drivelines for long distance transport**
    - Alternatives and multi-fuels capabilities

6.3 Preliminary themes 2014

- **Complete vehicle system integration**
    - Total truck – trailer architecture
    - Advanced materials
    - Distributed driveline including high level of hybridization
- **Efficient drivelines for long distance transport**
    - Innovative high efficiency energy conversion
    - Friction