ERRAC

ERRAC Roadmap
WP 01 The Greening of Surface Transport

“Towards 2030 – Energy Roadmap for the European Railway sector”

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Deliverable "Towards 2030 – Energy Roadmap for the European Railway sector"

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1. General background, targets, references

Transport plays a vital role within the economy and society: transport systems are of crucial importance for the competitiveness of any nation or regional economy as well as for the mobility of its citizens. However, while they bring significant benefits to society there are also substantial costs. The current growth of the transport sector is far from being sustainable. In Europe it is the only sector with uninterrupted and rapidly growing energy consumption and CO_2 emissions, and is now responsible for around 25% of total EU greenhouse gas emissions. The European Environment Agency (EEA) has estimated that, on current trends, the transport sector’s projected emissions would, by 2050, be more than the total emissions target for all the sectors combined in Europe if an overall reduction target of 60% or more was desired.

There have undoubtedly been some improvements: exhaust emissions such as particulates, acidifying substances and ozone precursors have reduced over the last decades. But as the EEA has pointed out, absolute emissions of CO_2 continue to rise as the gains from the technical improvements in transport continue to be outpaced by increased transport activity. The current transport system is a heavy burden for the environment and the health of citizens, and is moving in the wrong direction[1].

In this context, rail has the capability to play a key role in any sustainable transport system by offering efficient transport with low environmental impact, and these strengths need to be articulated in the political decision-making process. Through the use of mechanisms such as fairer pricing and the internalising of external costs, modal shift to rail, and innovative co-modality concepts become more achievable and offer sustainable solutions for the various challenges in the transport sector.

Seen in the wider picture, when analysing the current situation together with future development and expectations from society, it becomes clear that a number of trends can be identified that influence the transport sector and its sustainability. These trends can be grouped into three essential clusters:

- Changing socio-economic frameworks of societies, e.g. globalization, ageing and urbanisation
- Significant and growing ecological imbalances worldwide, e.g. climate change, scarcity of resources and degradation of biodiversity
- Increased regulation and use of new technologies in the transport sector, e.g. alternative traction concepts and information and communication technologies

Rail already has a strong focus on how to continuously improve its sustainability performance. But of course rail is not the only transport mode working on new solutions to reduce its ‘whole-life’ environmental impact from construction, through to operations and end-of-life. Other modes continue to seek improvements to their environmental

[1] According to TERM 2008, European Environment Agency, Report No. 3/2009

performance[2], and rail manufacturers, infrastructure managers, and operators all have to put strong emphasis on working together and improving performance in order to remain the least polluting major mode of transport. Thus, a long term strategic approach is needed: one that forms an efficient answer to the challenges of the future and that allows a solid base on which to build.
This roadmap is based on a mid and long-term vision and has four target points in time:

- Year 2015
- Year 2020
- Year 2030
- Year 2050

At a first glance this time frame seems to be long. But the railway sector has very long life cycles; today's "new technology" is likely still to be in operation towards year 2050. For typical train sets the time from idea to production, operation until end of life are in the range of 30-50 years. Even though this structure might also change in the decades to come in order to improve rail performance and competitiveness, it is not too early to think, plan and act now for the performance of railways in 2050.

1.1 Background

Energy consumption for passenger and freight transport has exploded together with transport demand in the last decades – worldwide as well as in Europe – putting heavy pressure on fossil fuel resources as well as increasing the emission of industrial greenhouse gases. Railways are very energy efficient compared to other modes of motorised transport mainly due to lower rolling and air resistance combined with a controlled driving pattern.

In order to stay economically competitive and act socially responsible towards the environment, railways must increase their energy efficiency – not the least to enjoy a continued strong political support. Three main reasons for the railway sector to act now are:

1. Rising energy costs

The European railway networks are spending billions of Euros annually on energy and the energy costs have increased significantly over the last few years (more than 10% per year). The continued increase in oil prices to a level of 100 $ per barrel underlines the necessity for improved energy efficiency, also because the electricity prices are highly influenced by the prices on coal, crude oil and gas.

2. Energy security & independency

[2] In 2009, the International Road Transport Union (IRU) adopted a voluntary commitment to reduce specific CO2 emissions by 30% by 2030 using a 2007 baseline, while the International Air Transport Association (IATA) adopted a target of reducing CO2 emissions by 50% by 2050 compared to 2005.

Energy security is getting more important as well. More and more countries want to be independent of foreign energy supplies. Also for the railways, reducing the energy demand will reduce the dependency. In addition, with improved energy efficiency the railways in some cases could be able to accommodate more traffic growth before reaching the technical limits of the railway (electrified or non-electrified) infrastructure (e.g. maximum power feed etc).

3. Climate protection

Climate change has become a strategic cornerstone for the railways. Railways are fortunate to run 80% on electricity in Europe but it is not possible for all industrial electricity consumers to switch to renewable energy sources at once. Therefore improved energy efficiency is vital when the railways want to achieve their individual CO_2 targets.

The energy mix in Europe is highly inhomogeneous as the percentage of nuclear power, energy from fossil fuels and regenerative energies vary very much from country to country.

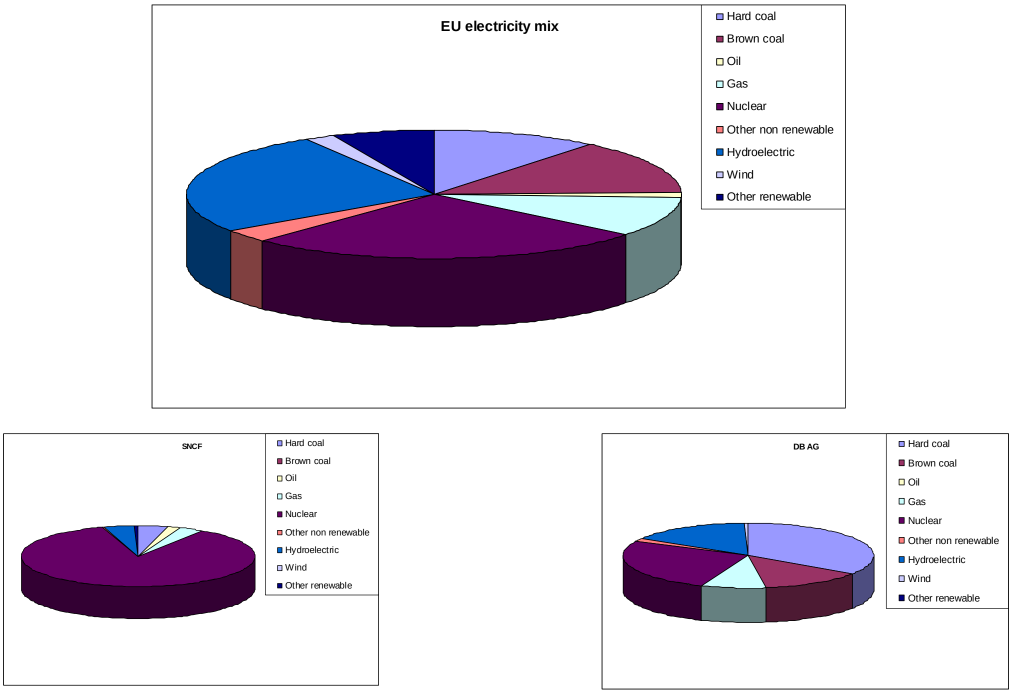


Figure 1 - Pie Charts - Electricity Mix 2005 -2008 - EU/SNCF/DB (Source UIC Statistics)

The sources of energy, the production and the transmission are not part of the ERRAC Energy Roadmap's consideration.

Furthermore the intention of the Roadmap is examining the management of energy, especially considering energy saving potentials both in rolling stock as well as in the electric railway infrastructure, and by considering the railway system as a whole.

1.1.1 Diesel Propulsion

The European railway network is the densest in the world and features the highest percentage of electrification totalling almost 70%. On the electrified part of the network about 80% of the total transport volume (Passenger + Freight) is hauled. The main lines in Western Europe that have been or will be partly turned into high-speed lines are operated by electric traction exclusively. For lines in rural areas and in the Eastern European countries Diesel traction still plays an important role. Further use of diesel locomotives hauling freight trains avoids time-consuming traction changes at the national borders.

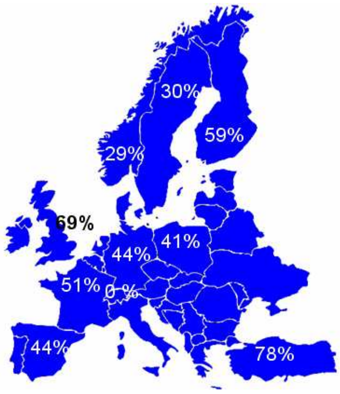
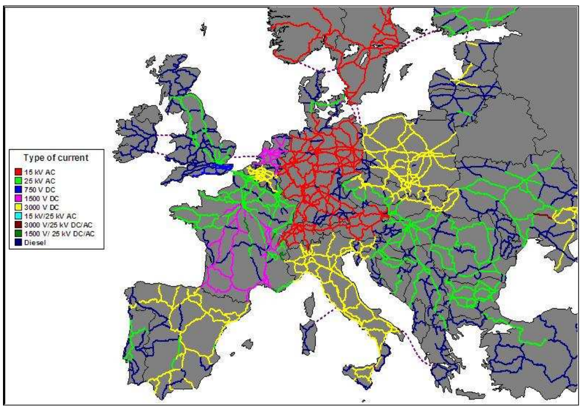


Figure 2 - Non electrified network in Europe

1.1.2 Electric Propulsion

The electric propulsion covers more than 70% of the European Rolling Stock fleet. Locomotive manufacturers and railway operators have introduced several technologies and techniques in order to reduce train losses and/or to increase train speed at lower energy consumption. They also worked together in order to design standardised, interoperable components for the European train and particularly they focused on improving the performance of the running gear, in order to require both less energy and maintenance, on standardising trains' control and monitoring systems and on optimising and standardising the on-board power system, particularly on the interfaces between traction components, high voltage equipment and the pantograph.

1.1.3 Electric Traction Infrastructure



The European electric railway infrastructure is highly inhomogeneous due to historical reasons. European infrastructure managers operate different electric systems of which 2 are alternating current (AC with 25 kV 50Hz, 15 kV 16 2/3 Hz) and 3 different direct current (DC with 750V 1.5 kV and 3 kV). The different electric systems impede the free flow of passengers and goods. Currently cross-European trains (like the European high speed train Thalys) with electric

traction are still an exception to the rule.
Electric supply system is regarded a highly energy efficiency, even though losses have to be taken into account. The main disadvantages of electric traction are the high cost for electrification and the vulnerability of the electric infrastructure, especially the overhead catenary system, due to extreme weather events.

1.2 Targets

- "Moving towards Sustainable Mobility: Rail Sector Strategy 2030 and beyond – Europe –
  - Strategy proposed by CER/UIC to the European railway industry and considered as relevant by WP1
    - Vision 2050 - The European railway sector will seek to supply its customers and society with attractive, carbon free and resource efficient solutions for sustainable mobility and transport. Through responsible business leadership the European railway sector maintains and expands its leading position while continuously improving its sustainability performance.
  - Climate protection
    - By 2030 the European railways will reduce their specific average CO2 emissions from train operation by 50% compared to base year 1990; measured per passenger-km (passenger service) and gross tone-km (freight service).
    - In addition, by 2030 the European railways will not exceed the total CO2 emission level from train operation in absolute terms even with projected traffic growth compared to base year 1990.
    - The European railways will strive towards carbon-free train operation by 2050 and provide society with a climate neutral transport alternative.
  - Energy efficiency
    - By 2030 the European railways will reduce their specific final energy consumption from train operation by 30% compared to the base year 1990; measured per passenger-km (passenger service) and gross tonne-km (freight service).
    - The European railways will strive towards halving their specific final energy consumption from train operation by 2050 compared to the base year 1990; measured per passenger-km (passenger service) and gross tonne-km (freight service).
  - Exhaust emissions: Nitrogen oxides and Particulate Matter (PM10)
    - In addition, by 2030 the European railways will reduce their total exhaust emissions of NOx and PM10 by 40% in absolute terms even with projected traffic growth compared to base year 2005.
    - The European railways will strive towards zero emission of nitrogen oxides (NOx) and particulate matter (PM10) from non-electric trains by 2050.

If going towards a carbon free European transport sector seems necessary, we want to underline that the railways operators do not manage electricity production. So this a goal for the overall Europe, not only for the railway sector.
Nevertheless, we want to express:

- That the use of energy by the European railway sector is efficient (compared to others modes)
- That even for railways, the savings of energy are unavoidable
- That progressing towards a free carbon economy is unavoidable.

1.3 Megatrends

Higher level

- The focus on environmental issue will continue to grow (less emissions, less noise and vibrations, less use of dangerous or scarce materials, recycling of materials, climate change approach.)
- The climate change will continue
- The energy cost will increase
- Cars and heavy goods vehicle will progressively become smarter and cleaner
- Power regeneration, energy supply progress

Lower level

- The competition for public funds will increase, public funds will not be sufficient for all needs. Loss making entities will face increasing difficulties.
- Knowledge will increase and the distribution will be faster worldwide
- Limitations of the infrastructure
- Higher integration of different transport modes to respond to a comprehensive mobility demand by users

1.4 Indicators

- CO_2 emissions
- Specific CO_2 emissions (emissions per passenger-km or tonne-km)
- Consumption of energy
- Consumption of primary energy (diesel)
- Consumption of electricity
- Specific primary energy consumption (per pkm or tkm)
- Global efficiency of the energy consumption

2. Targets and Goals of Research

Climate protection

- By 2030 the European railways will reduce their specific average CO_2 emissions from train operation[3] by 50% compared to base year 1990; measured per passenger-km (passenger service) and gross tonne-km (freight service).
- In addition, by 2030 the European railways will not exceed the total CO_2 emission level from train operation in absolute terms even with projected traffic growth compared to base year 1990.
- The European railways will strive towards carbon-free train operation by 2050 and provide society with a climate neutral transport alternative.[4].

Energy efficiency

- By 2030 the European railways will reduce their specific final energy consumption from train operation[5] by 30% compared to the base year 1990; measured per passenger-km (passenger service) and gross tonne-km (freight service).
- The European railways will strive towards halving their specific final energy consumption from train operation by 2050 compared to the base year 1990; measured per passenger-km (passenger service) and gross tonne-km (freight service).

Exhaust emissions: Nitrogen oxides and Particulate Matter (PM_{10})

- In addition, by 2030 the European railways will reduce their total exhaust emissions of NO_x and PM_{10} by 40% in absolute terms even with projected traffic growth compared to base year 2005.
- The European railways will strive towards zero emission of nitrogen oxides (NO_x) and particulate matter (PM_{10}) from non-electric trains by 2050.

[3] 'CO_2 emissions from train operation' is defined by indicator 3 in the UIC leaflet 330, UIC 2008
[4] Any moves towards a totally carbon-free rail sector ultimately depends on necessary changes in the electricity supply industry, which is outside of the direct control of the rail sector.
[5] 'Specific final energy consumption from train operation' is defined by indicator 1.1 in the UIC leaflet 330, UIC 2008

3. Past projects and results and recent development

3.1. Diesel Propulsion

GREEN - GREEn heavy duty ENgine **(FP 6)**

GREEN was a research project which was funded by the EC within the scope of the 6th Framework Programme. One of the major objectives within GREEN was, as far as the rail part is concerned, the development of an internal combustion process which meets the stage IIIB regulation. Therefore, various combustion technologies from on-highway applications were analysed and their adaptation to heavy duty engines was evaluated. It was shown that the EGR has the potential to reduce the emissions of nitrogen oxides so that the stage IIIB regulation is met and the emissions of particulates are reduced by a diesel particulate filter (DPF). The results of the GREEN project provide important input to the CleanER-D project.

CleanER-D – Clean European Rail-Diesel (FP 7)

CleanER-D is a partly European Commission funded project that aims to develop, improve and integrate emissions reduction technologies for diesel locomotives and rail vehicles.
Its target is to achieve emission levels below the limits established by the new European Directive 2004/26/ EC and to evaluate innovative and hybrid solutions for the best possible contribution to reductions in CO_2 emissions.

3.2. Electric Propulsion

Railenergy (FP 6)

The overall objective of the FP 6 project "Railenergy" is to cut the energy consumption in the railway system thus contributing to the reduction of life cycle costs of railway operation and the CO_2 emissions. The project target is to achieve a 6% reduction of the specific energy consumption of the rail system by 2020
This will be done by addressing the energy efficiency of the integrated railway system and to investigate and validate solutions ranging from the introduction of innovative traction technologies, components and layouts to the development of rolling stock, operation and infrastructure management strategies.

In Railenergy has been estimated to reach 2.5% of reduction of specific energy consumption can be achieved by the energy efficiency improvement of the electric propulsion drive and on board energy distribution system.

Process, Power, People (UIC/ATOC project)

This project, subtitled energy efficiency for railway managers, had been a UIC best practice projects gathering all information about ongoing energy efficiency measure for European railway operators and outlines how this can be implemented using existing management systems.

Energy Billing (UIC project)

More and more traction units in Europe are equipped with metering systems collecting data regarding energy consumption and the positions of the traction units. To avoid different metering systems being installed according to national specifications it is necessary for cross-border traffic to standardize the exchange of data. In this light the Energy Billing Project was set up in October 2005 in order to ensure an exact billing of energy consumption for interoperable cross-border rail traffic in Europe.
Together with the standardization of the metering equipment by CENELEC the results of the Energy Billing project will enable rail operators to pay the energy bill according to the actual energy consumption only.

3.3. Hybrid Traction

Rolling stock on-board energy storage solutions

A way to improve the energy efficiency of the trains is to install on-board energy storage solutions that, in case the recovered energy is not able to be used at the moment it is generated for other equipment (in the same train or in other trains connected to the same catenary), they can store the energy for a latter use.

Nowadays, there already exist many innovative solutions from different suppliers based most of them in energy storages like fly-wheels, batteries or supercapacitors. With the current state of the art technology trains may achieve very significant reductions of the consumed energy in certain applications. Meanwhile this solution has the drawback to load the traction units with big and heavy equipment according to performance required.

However, we may expect – driving by the so-called "electro-mobility" of cars - a big evolution on such technologies in the following years to improve the energy and power volume and weight specific densities that will allow manufacturers to design more compact and lighter energy storage solutions with higher energy and power capacities at lower costs (initial and LCC). This evolution will allow train manufactures to integrate energy storage solutions with higher capacities that will make the trains more energy efficient.
However, on-board energy storage solutions will always have an additional functionality that in some cases could be the reason to choose this technology: the ability to run the train temporarily without overhead or underground lines.

3.4. Hydrogen Propulsion

HyRail (FP 6)

HyRAIL made an assessment of the state of the art of technologies available and R&D activities and projects on hydrogen and fuel cell, drawing possible scenarios of transport system and energy supply related to railways. Gaps and technological innovations were identified and proposal put forward to solve fragmentation and to remove bottlenecks. HyRAIL provided a "vision" and drew a position paper for its implementation in European Railways for the medium long term. Particular attention was paid to identify user's needs and industrial suppliers, especially for SME, as well as cost and benefits, energetic and environmental issues were taken into account.

3.5. Electric Traction Infrastructure

Optimization of components and operation of infrastructure auxiliaries systems are controlled nowadays individually per equipment without transport system energy optimization leading to waste of energy by lack of control. This can be included in a real time optimization and energy control system from operation control centres.

Railenergy (FP 6)

The railway electric traction system (from external feeding points to the train current collector, track side) constitutes a critical part of the global energy system. The energy saving potential related to the distribution system could be realized by reducing transmission losses, recovering energy, optimizing the process or potentially upgrading and renewing the infrastructure. Railenergy looked at both the existing systems (no modification to the train feeding voltage) and innovative systems (with adoption of new architectures including modification of the train feeding voltage).

SOTRELE

The project "Système d'Optimisation Temps Réel de puissance et Energie éLEctrique"(SOTRELE) aims at defining and developing a energy management system of data acquisition and processing able:

- to reduce energy consumption by optimisation of power and energy requirements per vehicle , group of vehicles , for operating zones and stabling areas;
- to limit in real time the maximum electric power for traction and infrastructure auxiliaries;
- to acquire in real time of energy flows and quality independently of electricity provider;
- to comply with infrastructure equipment capabilities ref TSI and EN standards.

4. Priority areas

4.1. System View

The European railway system is largely electrified and the electric propulsion is highly efficiently used by the railway mode; the figures are well known.

There is a shared and increased knowledge about the sources of wasted energy. The development of energy metering systems (due to the development of energy bills adapted to the real consumption of energy by the consumers, Railway Undertakings, Stations, etc.) confirms that there are ways for a more efficient use of energy.
"A better knowledge will lead to a far more efficient use of energy".

We consider that the higher and more efficient savings of energy will be ensured by considering the consumption of energy in the overall railway system, and also considering all the interactions between the different sub-systems. The better efficiency will be reached by managing the different parts of the railway system and their interactions between all of them.
➲ We highly recommend to fully considering the overall system.

Electric propulsion (highly efficiently use in the railway system)
The evolution to manage the electrified system as a smart grid networks (many sources / many consumption locations) is unavoidable.
We have shared the following statements to consider for the energy management:

- The electricity regenerated during railway operations should be store in the railway system or recovered to the public grid, depending from technical and economic assessment
- Storing energy will be part of the management of peak demands (higher prices of the electricity)
- Storing energy can be of interest when the price of electricity is low
- The management of electricity will be more and more dependant to the electricity price contract, given the general high interdependence of the railway electricity grid with the public grid.

The Re-use of kinetic energy

- ADIF (Spain) ➲ High speed trains equipped with regenerative braking = 76 GWh (2006) are returned back to the public grid
- Trenitalia (Italy) ➲ 300 GWh/year are lost during the braking phases

We have shared the following statements that are developed below:

- There is high potentials of savings during missions with many stops and braking phases (urban missions)
- In some cases, up to 30 % of the energy used could be saved and stored

- The storage of energy (diesel mode / electric mode) has to be considered
  ⇨ in the rolling stock
  ⇨ in the infrastructure
- The management of energy is highly dependant on economic parameters (especially electricity contracts) and on technologies available
- The hybridisation of the energy (management of various sources of energy and various locations of consumption) will increase in the railway sector.

Recovering of intermittent energies like photovoltaic or wind energy is a field of intense activity, and presents many similarities with recovering the braking energy of the rolling stock. The misbalanced situation between the intermittent energy offer and the demand often calls for an energy storage system to provide the requested flexibility. Such system can be located onboard as well as on the trackside, providing new opportunities for efficient Railways operation modes, both in avoiding energy losses & optimizing energy flows. The higher the penetration of such intermittent energy sources will be, the more the impact of the ESS in allowing those new modes without global network negative impact.

An evolution is already at work in the Railways system, showing a global reduction of the average energy consumption, especially on open networks. This increases the differential to the cost of energy during peak periods loads, typically very directional in big cities, with more passengers toward the centre and more empty rolling stock back, making it difficult to transfer the energy to interchange traffic. Other solutions than transferring to the external grid through the infrastructure appear promising to increase the global energy efficiency.

Energy management onboard the rolling stock is already implemented in all current vehicles for auxiliaries, in order to provide safety & comfort to passengers in case of loss of the primary energy source, whatever electrical or from fossil fuels. This is typically a battery containing a limited energy amount to be available for duration of 1h30 to 5 hours. It doesn't allow recovering the kinetic energy on the point of view of both power (typical braking time being 15 to 30s to recover the maximal kinetic energy portion) and energy (high cadencies requested for acceleration / deceleration means for a battery using a partial amount of the nominal energy considered for auxiliaries, in order to maintain an acceptable life duration). This is where a hybrid vehicle, as vehicle able to recover the kinetic energy, comprises an onboard rechargeable energy storage system (RESS), placed between the power source (often a diesel engine prime mover or an electric transformer) and the traction transmission system connected to the wheels. Surplus energy from the power source, or energy derived from regenerative braking, charges the storage system.

Similar considerations, on other sectors like automotive, led for mass production vehicles to an evolution of the storage of energy on board (example: Daimler Mercedes-Benz S-class S400 Blue-hybrid car) toward higher power Li-ion technology batteries designed for such high cycles request, and could be considered for potential technology transfer, requesting adaptations specially for the higher scale factor architecture, safety and expected life duration. Other technologies for onboard storage systems, such as flywheel or double layer capacitors, have also been under testing (alone or combined to batteries), especially for light rail vehicles.

Those base technologies applied to railways system would open the door to local autonomy or outage mitigation, optimum use of renewable intermittent energy sources, peak shaving (at certain time of the day or above certain power levels). If considered onboard, the global amount of available energy will allow to increase the safety & comfort functions in case of

emergency situation through increased auxiliary support (e.g. keeping HVAC until intervention in case of catenaries loss), or even allow an increased overall efficiency through the use of local electrically stored braking energy directly for onboard auxiliary electrical system, while travelling or at stop points).
Combined with the existing infrastructure (which is very specific as compared to other transportation modes), voltage support as well as participation in the power regulation market could be envisaged as well, with also potential technology transfer from centralized energy systems or grid stabilization solutions, which have been developed to a scale even bigger than for the railways system. Infrastructure limitations could be mitigated to optimize system deployment. As a global, management of those aggregated resources (both on rolling stock & infrastructure) will be possible given the starting integration of smart metering and predictability possible thanks to energy storage, in order to adapt to the demand in real time.
Implementation in the existing rolling stock and infrastructure in terms of retrofitting or in term of new systems will request demonstrated operation before it can start to be deployed, as a complement to already closed or still running funded projects dedicated to identify optimum operation modes.

4.2. System View Roadmap – from vision to action

Sector	Vision & Need	Type of activity[6]	Time Horizon[7]	Priority[8]
Railway System	**Monitoring Systems** *Provision of detailed information about energy consumption in the railway system (by service type)*	R	2020	☆☆
Railway System	**Re-use of kinetic energy** *Improvement of technologies with basic systems being available* *Link to smart grids* *Reliability to be proven*	R	2020	☆☆☆
Railway System	**Smart Grids[9] and the multiplication of energy sources** *Development of techniques based on an economical potential*	R & D	2030 Continuous research efforts required	☆☆☆

[6] CSA = Coordination Support Activity / R = Research / D = Development
[7] Technical Maturity
[8] 1 ☆ = Low Priority / 2 ☆ = Medium Priority / 3 ☆ = High Priority
[9] Intelligent distribution and storage of energy within the railway system (comprising rolling stock, infrastructure, real estate etc.) with a potential interface to the public grid and the ability of timely balancing the energy flow

	assessment			

4.3. Rolling Stock

Modern electric traction systems are already quite efficient equipment. For example traction converters for DC catenaries may have efficiencies around 98% resulting in global efficiencies in the whole traction chain around 80-85%.

We have shared the following statements that are developed below:

- each train today is an energy consumer, but will as well act as a source of energy in the future
- the scientific and technological development of the storing systems (batteries, supercaps, flywheels) will be mainly guided by the development carried out by the automotive industry
- We will have to face the RAMS characteristics of these new storing systems that should be managed in a collaborative way by the railway stakeholders.
- Train power supply concepts
  - Separation or common management of the auxiliaries from the propulsion ➲ that depends on the mission
  - Alternative sources of energy for auxiliaries
- Diesel and exhaust emissions
  - How going towards carbon neutrality?
  - Increase efficiency, decrease the max power / downsizing of the diesel motors
  - Replace diesel by bio-fuels of 2^{nd}, 3^{rd} or 4^{th} generation
- Lightweight rolling stock
- Improving the aerodynamics of the rolling stock ➲ some margins (few %) to progress

More compact, lighter, and more efficient equipment

Some efficiency improvements will be achieved by the use of better control strategies, more efficient traction motors (e.g. synchronous traction motors with higher efficiencies than traditional asynchronous traction motors), and so on, but in general terms we do not expect significant improvements in the following years regarding the efficiency of such equipment.

Some efficiency improvements may come from:

- <u>New energy efficient control strategies</u>. Control strategies to optimize the consumption of the energy in every situation (reduction of motor flux, etc.).

- Permanent magnet synchronous traction motors. They have in general higher efficiencies than asynchronous traction motors but may require liquid cooling.
- Total thermal management (Reuse of cooling and heating). Normally each equipment that requires cooling or heating incorporates its own cooling or heating mechanism. The consumption of energy from the auxiliary supply is quite relevant. We may expect reductions of the consumption of the energy by a more coordinated train level management of cooling and heating.
- Superconducting transformers. One of the less efficient equipments in a AC traction system is the transformer. Transformers based on superconductors may have a much higher efficiency. Nevertheless, they require a complicated cooling solution (cryogenic cooling) and the energy efficient improvement in the total traction chain is not so high.
- Electronic transformers. The “electronic transformer” aims to replace the classical low frequency transformer by power electronics and medium frequency transformers. The medium frequency transformers are more compact, lighter and more efficient a traditional low frequency transformers. The main problem is that due to the voltage limitations of current power semiconductors the “electronic transformer” needs a lot of serial connected power modules to be able to connect directly to the AC catenary. Even if more efficient, the cost of the power and control electronics makes the cost of the system very high and the reliability of the system much lower than solutions based on traditional low frequency transformers.

Other improvements toward reduction of consumption of electric energy will come from the design of more compact and lighter equipment.
The opportunities to reduce volume and weight on traction system equipment and also improve the efficiency of such equipment are:

- Medium frequency transformers based on nanocristaline cores. Comparing classical low frequency transformers with new medium frequency transformers based on nanocristaline cores we may expect considerable reductions of volume and reductions of 4 times or more the weigh of the transformers in some applications.

- Power electronics based on wide bandgap semiconductors. The current power electronics for traction converters is based on IGBTs (Insulated Gate Bipolar Transistor) made with Silicon (Si) material. They have maximum switching frequencies of around 1-2 kilohertzs, maximum operating temperatures of 125-150 ºC, and maximum voltage operation of a few kilovolts (the higher 6k5V). We may expect some evolution on the state of the art Si-based IGBTs by slightly increasing the maximum switching frequencies and operating temperatures, but the major improvements may come from the generation of new power semiconductors based on wide bandgap materials. Nowadays, the most promising wide bandgap materials are Silicon Carbide (SiC) and Gallium Nitride (GaN). These power semiconductors based on wide bandgap materials may achieve much higher switching frequencies (even more than 10 times the current

maximum switching frequencies), be able to work at much higher operating temperatures (even higher than 300 ºC), and work also with much higher voltages. Based on these new semiconductors the industry will be able to design more compact and energy efficient power electronic equipment with higher switching frequencies resulting in lower losses in the traction motors. Also as these new semiconductors will be able to work at higher voltages we may expect relevant progress on the application of “electronic transformers”.
- Cancellation of on-board braking resistors when the line receptivity is settled >99% by infrastructure equipments.

Auxiliary elements cover a wide range of functions within railway vehicles. By definition the system covers elements of propulsion and electrical equipment, comfort systems, bogies and running gears to ensure the reliable utilization and safety operation of railway equipment.

Comfort systems:
The most energy intensive elements of modern railway vehicles are comfort systems like air conditioning, heating and ventilation. For Metro vehicles it can be up to 30 - 50% of overall energy consumption.
Therefore different technologies to enhance the energy efficiency of parked and moving trains were carried out within funded R&D projects. The saving potentials of current technologies compared to conventional HVAC systems depend on climatic and operational circumstances.
The technologies are available from simple measures such as: [Haller et al, 2008]
- demand-controlled fresh air supply;
- intelligent, optimised air conditioning control;
- demand-controlled set point adjustment;
- Up to very complex room comfort management systems used in building technologies.

Additionally, regular maintenance and control of the specified parameters can help to bring about a significant reduction in energy consumption. E.g. reduction of comfort level temperature

Lighting:
Furthermore electrical subsystems like lighting systems can be optimized by using high efficient LED lights. LED lighting concepts are currently used in household application and will be also applied for passenger compartments in trains.

HVAC:
New HVAC concepts such as optimised thermal insulation for car bodies and/or duct systems, active insulation, e. g. use of exhaust air heat for heating car body surfaces, exhaust air heat recovery, load-dependent cooling system and heat pump can reduce the energy consumption by more than 20%.

Full recovery of braking energy
The electric traction systems have the ability to recover the braking energy from the train and to return this energy back to the catenary. In AC catenaries the railway electrical net is

connected directly to the general AC electrical net so the catenaries are able to absorb all the regenerated energy. However, in DC supply systems the unidirectional flow of current inside the substations prevents total recovery of energy except that can be exchanged between trains.

Diesel application:
Transportation Sector is highly dependent upon fossil fuels and therefore it is clear that a diverse energy strategy is required for both energy security & competitive reasons. However, there is no single silver bullet technology. Successful Energy & Advanced Propulsion Strategies must be tightly integrated in order to guarantee a competitive and sustainable rail industry.
The application of new diesel engine technologies currently in research and development could lower fuel consumption. These developments based on knowledge gained on heavy duty truck engines due to their shorter life cycles, higher demand, and need to comply with more stringent emission standards. As these technologies mature, they may be adopted by the railroad industry to reduce operating costs and meet emission regulations. For this reason, future improvements to rail vehicle engines will be the result of technologies currently being researched or deployed in the trucking industry, and previously in the automotive industry.
Amongst the technologies included to achieve such improvement are: reduced internal friction, increased peak cylinder pressure, improved fuel injection, use of turbochargers and turbo-compounding, and improved thermal management. Of course, new technical and operational measures will have to be implemented to reduce diesel exhaust emissions and improve the environmental performance.

Rail industry will have to invest in diesel engine improvements, hybrids, other power sources and overall vehicle performance improvements in order to have competitive advantages in the future. However, when it comes to diesel engine improvements and other possible power sources and because of the market volume and the possibility to achieve economies of scale is much greater in the automotive and truck industry, rail will have to monitor and consider these other industry developments in order to get advantages of its technology developments, adapt them to the particularities of rail vehicles and make rail even more sustainable.

4.4. EE Rolling Stock Roadmap – from vision to action

Sector	Vision & Need	Type of activity[10]	Time Horizon[11]	Priority[12]
Rolling Stock	**Lighter Trains** *Assessment of the technology transfer potentials from the*	CSA	2015	☆☆☆

[10] CSA = Coordination Support Activity / R = Research / D = Development
[11] Technical Maturity
[12] 1 ☆ = Low Priority / 2 ☆ = Medium Priority / 3 ☆ = High Priority

	aeronautic and automotive sector to the railway sector			
Rolling Stock	**Lighter Trains** *Weight reduction for the suburban and urban passenger services* *In due consideration of standardisation and regulation issues (e.g. crashworthiness)* *Design methodologies to be re-evaluated*	R & D	2020	☆☆☆
Rolling Stock	**Hybrid Traction** *Multiple power sources for traction in due consideration of RAMS*[13] *aspects for diesel applications* *Development of prototypes* *Energy Storage on-board Technologies to be carried out* *Engine stop at station*	Concluding research (R) activities required followed by (D)	2020 - 2030	☆☆☆
Rolling Stock	**EE Auxiliaries** *Optimisation and development of intelligent management of auxiliaries (e.g. powering auxiliaries with kinetic energy)*	R	2020	☆☆
Rolling Stock	**Next generation of power semi-conductor** *Improvement of efficiency, weight, volume among others* *Standardisation (Common expressed request by the railway sector to the semi-conductor industry)*	R	2020 - 2030	☆☆

[13] RAMS = Reliability, Availability, Maintenance, Safety

4.5. Infrastructure

We have considered that the main goal for infrastructure is to decrease the losses in the system (especially in the DC systems)

- DC electrification Losses = 15 to 20 %
- AC electrification Losses ca 3 to 5 %
- Mainly losses in the catenary system

Technology evolutions of the electrification toward a smart grid

An optimised use of the energy for the electric infrastructure can be done by developing smart grid networks where the energy is not recovered in the public grid but it is stored and use according to the electrified infrastructure demand. This concept enlarge the idea to save the braking energy up to the definition of smart grid able to fulfil the energy demand including peak demand of energy by storing and managing through the smart grid the requested energy for both AC or DC electrified railway infrastructure. The energy can be stored in the smart grid storage equipment not only by regenerative braking energy but also by acquiring the night energy of the public grid. The energy stored in the smart grid can be managed to be used for both peak demand and public grid blackout conditions.

Minimising the losses in the electric railway infrastructure

The losses in the electrified infrastructure are mainly due to the line losses, especially in the low voltage DC electrification system. The line losses can be minimised by adopting one or more of the following technological solutions:

- section wise catenary systems;
- voltage increase of the electric lines (catenary and/or return feeder) in order to optimise the current distribution and minimise the energy consumption.

Energy saving in the electric DC infrastructure

Reuse of the braking energy through energy storage systems on the DC electric supply

In DC railway systems the new generation fleet of rolling stock is equipped with two types of braking systems: mechanical unit and electrical unit. The electrical braking unit is able to reverse the energy flow during the vehicle deceleration (kinetic energy reduction) and the related energy may be dissipated in braking resistors or regenerated to the energy supply system.

As a consequence there is a potential of recovering a significant amount of energy, till now dissipated in the on board rheostats: in a reference study provided by Trenitalia, in the Italian DC railway network electric traction consumes roughly 4300 GWh/y.

Approximately 50% of such energy is used by vehicles with electric braking: 40% of such part goes in braking losses: the part related to electrical braking is approximately 35%. Such energy can be stored on the trackside by means of storage equipment such as supercaps, flywheels or batteries.

Saving braking energy through reversible Electrical Substations in DC electric supply

The existing DC ESS consists of DC uncontrolled rectifiers connected to the utility grid by means of transformer groups. This solution does not allow the total energy recovery due to the unidirectional current flow.
To provide the almost total energy recovery to the upstream grid as well as the opportunity of the conversion group to operate in the four quadrants a new structure of the AC/DC static converter must be designed including new power electronic devices (voltage controlled rectifier and inverter)
The target of such system is to regenerate up to 99% of recoverable braking energy therefore to master harmonics by active filtering, to control output voltage and output loads for power balance between substations.

Improvement of the DC transmission and distribution losses

The losses in the electric railway infrastructure can be higher than 5% of total power when the network is overloaded or has to face to increasing traffic. Railways should investigate how to minimize the losses in the electric railway infrastructure:

- .Although the target system recommended by the European Specification of Interoperability Energy is the 25kV system, conversion of DC lines in AC lines which offers a greater voltage is expensive for existing networks .So intrinsic improvements of DC supply systems should be done for the future
- The main levers of optimizing the losses in the existing systems are:
    - Increasing of cross section of conductors,
    - Improving the conductivity of the material: hybrid 3rd rail, conductivity of the contact wire
    - Reducing the no-load losses ,
    - Improving efficiencies of equipments,
    - Using a 2X Un DC power supply system,
- Balance between investment costs and life cycle costs for return on investment should be taken into consideration.

Energy optimization of auxiliaries infrastructure equipments:
This depends on the configuration of the railway network. On that chapter should be taken into account:

- Passenger stations energy consumption: Lighting, air conditioning, escalators, lifts…
- Control of operation according to peak and off-peak hours,
- Tunnel and air ventilation in line: Minimizing losses from rolling stock will prevent excessive temperature in tunnel and minimize air intake from outside,
- Depot: Minimizing consumptions of trains in depot (Preheating, preconditioning, cold chain for catering) will reduce energy consumption in depot
- Heating of shunting devices in line: Optimisation and control,

Control and optimization of energy consumption of infrastructure auxiliaries can be done at the control centre level by a real time energy management system which takes into account the global power consumption of the system, the market price of electricity, and manage the load shedding in relation with operation constraints.

Use of alternative sources: wind, solar energy
The energy demand for the electrified infrastructure and the railway operation should be produced for a large percentage on alternative energy sources or low carbon footprint sources. The energy production for electrified infrastructure can be obtained by alternative sources such wind, solar sources and stored by using storage equipment connected to dedicated smart grids.

4.6. EE Infrastructure Roadmap – from vision to action

Sector	Vision & Need	Type of activity[14]	Time Horizon[15]	Priority[16]
Infrastructure	**Sector Smart Grids[17]** *Development of techniques based on an economical potential assessment*	R	2030	☆☆☆
Infrastructure	**Advanced Traction Energy Supply** *Assessment of existing catenary materials and components – Potential analysis for optimisation*	CSA	2015	☆☆☆
Infrastructure	**Advanced Traction Energy Supply** *Increase of line voltage in order to decrease the losses* *New catenary materials*	R	2015 - 2020	☆☆☆
Infrastructure	**Infrastructure Sections without catenary** *Railway lines without catenary operated with particular adapted rolling stock (traction energy supply by pantograph and energy storage on board)*	R	2050	☆☆
Infrastructure	**Feeding kinetic energy back to the public grid**	R	2020	☆

[14] CSA = Coordination Support Activity / R = Research / D = Development
[15] Technical Maturity
[16] 1 ☆ = Low Priority / 2 ☆ = Medium Priority / 3 ☆ = High Priority
[17] Intelligent distribution and storage of energy within the railway system (comprising rolling stock, infrastructure, real estate etc.) with a potential interface to the public grid and the ability of timely balancing the energy flow

	Political approach and economic assessment			
Infrastructure	**Energy Storage in the infrastructure**	D	2020	☆

4.7. Railway operations

Management of operations / traffic flow management

The European railway infrastructure was mainly built in the 19th century based on the parameters and the engineering experience of those days. On the one hand progress has been made (e.g. high speed lines and rural rail systems on separate networks among others) but on the other hand with the constant increase of passenger and freight traffic on the existing track the network reaches its capacity limit(s). Various bottlenecks limit the amount of trains to run fluently on the network and hardly allow more trains to operate. These bottlenecks force trains to stop and accelerate frequently and limit the potentials of energy efficient driving.

The European Commission, the national administration and European Railways including the railway undertakings and infrastructure manager intend to transport more passengers and freight on track and change the modal shift in favour for the rail system(s). Different approaches exist to smoothen the traffic flow like traffic flow management, longer trains, double stack wagons or removing bottlenecks by adding a third track (which is not always possible especially in densely populated urban areas). Traffic Flow Management is given the highest potential to allow a smooth traffic flow including energy efficient driving with an increase of rail capacities in parallel. By applying energy consumption oriented traffic management systems they support the energy consumption reductions which are achieved by today's state-of-the-art driver assistance systems which help to reduce the energy consumption of a single train.

Automatic Driving

Automatic train operation (ATO) ensures partial or complete automatic train piloting and driverless functions. Many modern systems are linked with Automatic Train Control (ATC) where normal signaller operations such as route setting and train regulation are carried out by the system. The ATO and ATC systems will work together to maintain a train within a defined tolerance of its timetable. The combined system will marginally adjust operating parameters such as the ratio of power to coast when moving and station dwell time, in order to bring a train back to the timetable slot defined for it.

4.8. EE Railways Operations Roadmap – from vision to action

Sector	Vision & Need	Type of activity[18]	Time Horizon[19]	Priority[20]
Operation	**Standardised EE Driving** *TecRec "EE Driving" (Stand-alone system) and TecRec "Drivers Desk"*	R	2015	☆☆
Operation	**Traffic Flow Management** *Holistic Approach towards traffic "fluidification"* *Specification of interfaces/ communication between IM and RU* *Real time traffic optimisation*	R	2020	☆☆☆
Operation	**Parked Trains Management** *Specification and Recommendations*	R	2015	☆☆☆

[18] CSA = Coordination Support Activity / R = Research / D = Development
[19] Technical Maturity
[20] 1 ☆ = Low Priority / 2 ☆ = Medium Priority / 3 ☆ = High Priority

4.9. Hydrogen and fuel cell

The application of the fuel cell in the European railway market is not foreseen before 2050 The main problem remaining is to solve is the production and the storing of hydrogen, in conjunction with the decrease of the operating cost of the technology.

It could be a solution for insulated and stationary installations in the infrastructure or as auxiliary power units onboard, but these applications are so far not clearly visible.

RAMS characteristics will be a key point for applications in the railway domains.

Application scenario	FC technology	FC system configuration	
Short/Mid term Shunting locomotives Tram-Trains	**PAFC** pros: already commercialized cons: low efficiency **PEMFC** pros: high efficiency, suitable for transportation cons: lifetime, cost, water management	**Pure fuel cell or hybrid fuel cell**	
Long term Long distance train	Introduction of high temperature **SOFC** pros: fuel flexibility cons: thermal stresses, size	**Mostly hybrid power trains**	

4.10. Innovative Propulsion Roadmap – from vision to action

Sector	Vision & Need	Type of activity[21]	Time Horizon[22]	Priority[23]
Innovative Propulsion	**Innovative Propulsion** *Implementation of hydrogen fuel cell in due consideration of RAMS[24]/LCC[25] incl. the aspect of hydrogen production and storage*	D	2050	☆

[21] CSA = Coordination Support Activity / R = Research / D = Development
[22] Technical Maturity
[23] 1 ☆ = Low Priority / 2 ☆ = Medium Priority / 3 ☆ = High Priority
[24] RAMS = Reliability, Availability, Maintenance, Safety
[25] Life Cycle Costs

5. ERRAC Roadmap the Greening of Surface Transport – Roadmap Overview

Sector	Vision & Need	Type of activity[26]	Time Horizon[27]	Priority[28]
Railway System	**Monitoring Systems** *Provision of detailed information about energy consumption in the railway system (by service type)*	R	2020	☆☆
Railway System	**Re-use of kinetic energy** *Improvement of technologies with basic systems being available* *Link to smart grids* *Reliability to be proven*	R	2020	☆☆☆
Railway System	**Smart Grids[29] and the multiplication of energy sources** *Development of techniques based on an economical potential assessment*	R & D	2030 Continuous research efforts required	☆☆☆

[26] CSA = Coordination Support Activity / R = Research / D = Development
[27] Technical Maturity
[28] 1 ☆ = Low Priority / 2 ☆ = Medium Priority / 3 ☆ = High Priority
[29] Intelligent distribution and storage of energy within the railway system (comprising rolling stock, infrastructure, real estate etc.) with a potential interface to the public grid and the ability of timely balancing the energy flow

Sector	Vision & Need	Type of activity[30]	Time Horizon[31]	Priority[32]
Rolling Stock	**Lighter Trains** *Assessment of the technology transfer potentials from the aeronautic and automotive sector to the railway sector*	CSA	2015	☆☆☆
Rolling Stock	**Lighter Trains** *Weight reduction for the suburban and urban passenger services* *In due consideration of standardisation and regulation issues (e.g. crashworthiness)* *Design methodologies to be re-evaluated*	R & D	2020	☆☆☆
Rolling Stock	**Hybrid Traction** *Multiple power sources for traction in due consideration of RAMS[33] aspects for diesel applications* *Development of prototypes* *Energy Storage on-board Technologies to be carried out* *Engine stop at station*	Concluding research (R) activities required followed by (D)	2020 - 2030	☆☆☆
Rolling Stock	**EE Auxiliaries** *Optimisation and development of intelligent management of auxiliaries (e.g. powering auxiliaries with kinetic energy)*	R	2020	☆☆
Rolling Stock	**Next generation of power semi-conductor** *Improvement of efficiency, weight, volume among others* *Standardisation (Common*	R	2020 - 2030	☆☆

[30] CSA = Coordination Support Activity / R = Research / D = Development
[31] Technical Maturity
[32] 1 ☆ = Low Priority / 2 ☆ = Medium Priority / 3 ☆ = High Priority
[33] RAMS = Reliability, Availability, Maintenance, Safety

	expressed request by the railway sector to the semi-conductor industry)			

Sector	Vision & Need	Type of activity[34]	Time Horizon[35]	Priority[36]
Infrastructure	**Sector Smart Grids[37]** *Development of techniques based on an economical potential assessment*	R	2030	☆☆☆
Infrastructure	**Advanced Traction Energy Supply** *Assessment of existing catenary materials and components – Potential analysis for optimisation*	CSA	2015	☆☆☆
Infrastructure	**Advanced Traction Energy Supply** *Increase of line voltage in order to decrease the losses* *New catenary materials*	R	2015 - 2020	☆☆☆
Infrastructure	**Infrastructure Sections without catenary** *Railway lines without catenary operated with particular adapted rolling stock (traction energy supply by pantograph and energy storage on board)*	R	2050	☆☆
Infrastructure	**Feeding kinetic energy back to the public grid** *Political approach and economic assessment*	R	2020	☆
Infrastructure	**Energy Storage in the infrastructure**	D	2020	☆

[34] CSA = Coordination Support Activity / R = Research / D = Development
[35] Technical Maturity
[36] 1 ☆ = Low Priority / 2 ☆ = Medium Priority / 3 ☆ = High Priority
37 Intelligent distribution and storage of energy within the railway system (comprising rolling stock, infrastructure, real estate etc.) with a potential interface to the public grid and the ability of timely balancing the energy flow

Sector	Vision & Need	Type of activity[38]	Time Horizon[39]	Priority[40]
Operation	**Standardised EE Driving** *TecRec "EE Driving" (Stand-alone system) and TecRec "Drivers Desk"*	R	2015	☆☆
Operation	**Traffic Flow Management** *Holistic Approach towards traffic "fluidification" Specification of interfaces/ communication between IM and RU Real time traffic optimisation*	R	2020	☆☆☆
Operation	**Parked Trains Management** *Specification and Recommendations*	R	2015	☆☆☆

[38] CSA = Coordination Support Activity / R = Research / D = Development
[39] Technical Maturity
[40] 1 ☆ = Low Priority / 2 ☆ = Medium Priority / 3 ☆ = High Priority

Sector	Vision & Need	Type of activity[41]	Time Horizon[42]	Priority[43]
Innovative Propulsion	**Innovative Propulsion** *Implementation of hydrogen fuel cell in due consideration of RAMS[44]/LCC[45] incl. the aspect of hydrogen production and storage*	D	2050	☆

[41] CSA = Coordination Support Activity / R = Research / D = Development
[42] Technical Maturity
[43] 1 ☆ = Low Priority / 2 ☆ = Medium Priority / 3 ☆ = High Priority
[44] RAMS = Reliability, Availability, Maintenance, Safety
[45] Life Cycle Costs

6. ERRAC Roadmap the Greening of Surface Transport – Graphical Overview

Energy Roadmap

	2010	2015	2020	2030	2050	
Energy Roadmap			**Lighter Trains** * Weight reduction for the suburban and urban passenger services * Design methodologies to be re-evaluated * In due consideration of standardisation and regulation issues (e.g. crashworthiness) **Hybrid Traction** → * Multiple power sources for traction in due consideration of RAMS aspects for diesel applications * Development of prototypes Energy Storage on-board technologies to be carried out * Engine stop at stations	**Smart Grids and the multiplication of energy sources** * Development of techniques based on an economical potential * Improvement of efficiency, weight, volume among others * Standardisation (common expressed request by the railway sector to the semi-conductor industry)		Research Dev
			Energy Storage in the infrastructure		**Innovative propulsion** * Implementation of hydrogen fuel cell in due consideration of RAMS/LCC incl. the aspect of hydrogen production & storage	Development
		Standardize EE Driving * TecRec "EE Driving" (Stand-alone system and TecRec "Drivers Desk" **Parked Trains Management** * Specifications and recommendations **Advanced Traction Energy Supply** → * Increase of line voltage to decrease the losses * New caternary materials	**Monitoring System** * Provision of detailed informa-tion about energy consumption in the railway system (by service type) **Re-use of kinetic energy** * Improvement of technologies with basic systems being available * Reliability to be proven * Link to smart grids **EE Auxiliaries** * Optimisation and development of intelligent management of auxiliaries (e.g. powering auxiliaries with kinetic energy) **Feeding kinetic energy back to the public grid** * Political approach and economic assessment **Traffic Flow Management** * Holistic Approach towards traffic "fluidification" * Specification of interfaces/ communication between IM & RU * Rail time traffic optimisation **Next generation of power semi-conductor** → * Improvement of efficiency, weight, volume among others * Standardisation (common expressed request by the railway sector to the semi-conductor industry)	**Sector Smart Grids** * Development of techniques based on an economical potential assessment	**Infrastructure Sections without catenary** * Railway lines without caternary operated with particular adapted Rolling Stock (traction energy supply by pantograph and energy energy storage on board	Research
		Lighter Trains *Assessment of the technology transfer potentials from the aeronautic & automotive sector to the railway sector **Advanced Traction Energy Supply** * Assessment of existing catenary materials & components Potential analysis for optimisation				Coord Supp Act

2010 2015 2020 2030 2050

Coding:

→ work continues in the next time period

Sectors
- Railway system (black)
- Rolling Stock (purple)
- Infrastructure (green)
- Operation (brown)
- Innovative Propulsion (orange)