FINE 1

D3.3 Future Railway System

Due date of deliverable: 31/08/2018

Actual submission date: 08/10/2019

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Reviewed: Y

Document status		
Revision	Date	Description
0.1	02/08/2018	First draft
0.2	31/10/2018	Integration of contributions from FINE1-Partners
0.3	29/11/2018	Integration of contributions from TDs and further FINE1-Partners, amendment of future SPD
0.4	11/12/2018	Last FINE1 internal review, sent to the TMT for review
1.0	19/12/2018	First edition
2.0	19/12/2018	Final version after TMT approval
2.1	24/04/2019	After project review on April 3rd: Amendment of chapter 7 “Long-term vision”
2.2	08/10/2019	Final version after quality check

Project funded from the European Union’s Horizon 2020 research and innovation programme – Shift2Rail		
Dissemination Level		
PU	Public	x
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

Start date of project: 01/09/2016 Duration: 38 months

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EXECUTIVE SUMMARY

In the first part of the delivery the energy strategies of different stakeholders are described. The European Commission, European states and railway undertaking have ambitious targets for the reduction of greenhouse gases and energy efficiency.

The technologies developed in Shift2Rail will change will contribute to these targets by increasing the energy efficiency and reducing the energy usage and CO_2 impact. The main technologies are:

- New traction technologies contribute to a reduction of energy losses and weight (SiC-converters, medium frequency transformers and permanent magnet motors)
- Lighter running gears and carbody shells reduce weight and energy usage
- HVAC-systems with natural gases reduce the climatic impact and energy consumption
- Connected driver assistant systems (DAS) and automatic train operation (ATO) lead to an energy-optimised driving and prevents unnecessary stops
- Energy supply substations with electronic converters reduce the losses along 50Hz overhead lines (only applicable for some countries and lines)
- Diesel engines in shunting locos and regional trains can be substituted by battery drives, at least for small and medium distances. This will reduce the energy usage and the CO_2 emission

Further reductions of energy usage and CO_2 impact require additional developments not yet covered by Shift2Rail. Examples are

- Fuel cell drives
- Energy supply from renewable energy sources
- Improved rolling stock energy management

In order to push the additional technologies, research activities within subsequent research projects are required (e.g. Shift2Rail II)

In the last chapter of the deliverable a possible long-term vision of the future railway system with respect to energy is drawn that covers all technologies mentioned above. But for reaching the energy saving targets, these new technologies have to be implemented. This requires special activities from different stakeholders.

ABBREVIATIONS AND ACRONYMS

Acronym	Definition
ATO	Automatic Train Operation
CO_2	Carbon Dioxide
DAS	Driver Assistant System
EMU	Electrical Multiple Unit
EU	European Union
HVAC	Device for “Heating, Ventilation, Air conditioning and Cooling”
IP	Innovation Program within Shift2Rail
JU	Joint Undertaking (organisation within Shift2Rail)
KPI	Key Performance Indicator
MAAP	Multi Annual Working Plan of Shift2Rail
SiC	Silicon Carbide
SPD	System Platform Demonstrator
S2R	EU-project Shift2Rail
TD	Technical Demonstrator

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1. INTRODUCTION

The European Commission, European states, Railway Undertaking and industry have ambitious targets for the reduction of greenhouse gases and improvement of energy efficiency. The railway sector can contribute in five ways:

- Increasing **energy efficiency** of trains and reducing losses on the infrastructure side, maintenance facilities and railway stations
- Increasing energy efficient **behaviours**: eco-driving, parked trains switch off
- Increasing the degree of **capacity utilisation** of passenger and freight trains
- Increasing usage of **renewable energy** resources
- Increasing the percentage of railway traffic (**modal split**) by improving the performance and attractiveness of railway transport in relation to other means of transport

Several Technical Demonstrators (TD) carried out within the S2R Innovation Programs (IP1 – IP5) contribute to the first and second point, since they have an impact on energy efficiency and usage. Implementing these innovations will change the railway technology in the future. Within FINE1 Task 3.3 "Future railway system" the future railway technology with respect to energy is described.

Other TDs contribute to the other points. But this effect on energy usage is not covered by FINE1.

Within **chapter 2** of this document the energy strategy of the different stakeholders is described.

Within **chapter 3** the state-of-the-art and future technology of all energy-relevant modules of the railway system is listed. The future technology covers all energy-relevant Technical Demonstrators (TD) of Shift2Rail.

Based on the module technology the future technology of the railway system with respect to energy is described in **chapter 4**.

Some future technologies will have an impact on all traffic segments / SPDs, some only for certain SPDs. This is covered by **chapter 5**.

In **chapter 6** the impact on the railway technology of further technology developments outside of Shift2Rail is described. Last not least subsequent research activities are suggested that contribute to further energy savings and reduction of CO_2-impact.

Within **chapter 7** the results are summarized.

2. ENERGY STRATEGY

The implementation of energy innovations requires a strategy and implementation plan of all stakeholders, especially:

- European Commission

  (European energy strategy, targets for reduction of energy usage, CO_2-impact and renewable energy, energy labelling, defining research programs)

- Governments
  (State energy strategy, targets for reduction of energy usage, CO_2-impact and renewable energy, tender for regional traffic incl. alternative drives)

- Railway Undertakings

  (Company energy strategy, energy requirements for purchase of vehicles, energy-optimised operation)

- Infrastructure Managers

  (Renewable energy production, reversible and electronic substations, electric charging points for battery drives, gas or hydrogen supply, intelligent traffic management systems)

- Industry (vehicle integrators and component suppliers)
  (Development and application of energy-efficient technologies)

2.1 European Commission

EU energy strategy [4]

Target for 2030:

- a 40% cut in greenhouse gas emissions compared to 1990 levels
- at least a 27% share of renewable energy consumption
- indicative target for an improvement in energy efficiency at EU level of at least 27% (compared to projections)

Target for 2050:

- The EU has set itself a long-term goal of reducing greenhouse gas emissions by 80-95%, when compared to 1990 levels

But up to now there are no concrete targets and time lines for CO2-reduction within the transport sector known (Rail, road, air and water). The only target is a required CO2-reduction of cars per company (CO2-impact per km). For trucks it is just under discussion these days.

Implementation in research programs

Within the Shift2Rail JU a Multi-annual action plan (MAAP) is developed that contains the Shift2Rail vision [3]. There 12 capabilities are defined. Capability 5 “Optimum energy use” covers the energy strategy.

> *Railways maintain their position as the most environmentally friendly mode of transport by decreasing energy consumption. This is achieved together with lowered operating costs through the use of an intelligent energy management system. The introduction of new technologies and methods as supporting tools enable reduced and optimised demand-led energy use and energy efficiency.*

A. *Alternative propulsion concepts such as **fuel cells** are introduced. Hybrid powertrains allow running over non-electrified track sections. Discontinuous electrification at stations and on branch lines dramatically reduces the capital costs of extending electrification.*

B. *Automated Train Operations (**ATO**) improves energy efficiency.*

C. *Optimised on-board and line-side **energy storage** and charging technologies (e.g. dynamic wireless power transfer) allow the railway to redistribute energy throughout the system according to supply and demand.*

D. *A high proportion of energy is recovered through **regenerative braking**, and small-scale energy generation and harvesting technologies feed energy efficient trackside systems.*

E. *A fully integrated system approach to intelligent energy supply maximises **renewable energy generatio**n and the use of **smart grids**, including those outside the railway system, through links with the wider energy supply sector.*

2.2 Governments

The governments of the European states have to implement the European targets with respect to energy saving and efficiency within their own means.

A very efficient means for implementation the goal is to formulate it in the call for tenders for national funded traffic (mainly regional). For freight and high-speed passenger traffic, there are no special governmental requirements for energy efficiency and usage known.

Germany

In Germany, there are already several calls for tender for regional traffic that pretend alternative drives (battery or fuel cells) for non-electrified lines. Further, hydrogen and battery train projects are funded by the National Innovation Program for Hydrogen and Fuel Cell Technology (NIP).

In 2017, the “Bundesministerium für Verkehr und digitale Infrastruktur” [5] has defined a “Masterplan Güterverkehr” that contains mainly measures for increasing the modal split of rail freight. But it also includes measures for increasing the energy efficiency and reduction of CO_2 impact like:

- Electrification of lines
- Hybrid locomotives
- Driver assistant systems
- Innovative freight wagons

The implementation of the masterplan will be funded by means of the “Bundesprogramm Schienengüterverkehr”. Further, the electrification is pushed by the “Sonderprogramm Elektrifizierung” and electrification projects within the “Bundesverkehrswegeplan” [6].

France [7]

In France, the administrative region asks for alternative solutions of diesel-electric locomotives.

In June 2018, a parliamentary mission on greening rail rolling stock in France was launched. This mission focuses on alternative solutions to Diesel. The goal is to stay on the cutting edge of technological innovation to ensure environmental transition. Today, two technology families are mature enough to provide low-cost electromobility without the need for electrification of small lines and the replacement of diesel engines: electrochemical battery technologies, and fuel cell technologies (hydrogen).

Spain

The Spanish Ministry of Development launched in April 2018 a three years plan for 2018-2020 period that pursues fostering Spanish companies worldwide leadership within the smart and sustainable mobility markets. Said Plan for Transport and Infrastructures will focus on four main dimensions named: digitalization, internet of the future, intermodal passenger transport and energy transition; for which it will be granted with EUR 76 million funds to be used by the group of public-owned companies devoted to the different transportation modes: road, rail, maritime and air.

Among the 70 initiatives defined by an open innovation process that takes into account the totality of main transport stakeholders, five strategic lines regarding energy efficiency and sustainability has been established: renewable energy sources, decarbonisation, new infrastructures, autonomous vehicle and education, communication and entrepreneurship. More specifically, these lines have become energy-centred projects such as:

- Fostering of energy generation, storage and distribution means for consideration of renewable energy sources, utilization of train's regenerated energy and onboard energy storage systems. This EUR 1,4 million project is being leaded by Adif, the railway infrastructure administrator, together with Renfe, the Spanish railway operator.

- Deployment of new traction methods such as LNG (Liquefied natural gas), which is currently under an on-track viability test, or hydrogen; through a EUR 2 million project sponsored by Renfe.
- Analysis of mixed transport services for goods combining maritime and rail transport. This project with an allocation of EUR 1 is also leaded by Renfe.
- An Adif EUR 0,7 million initiative for the monitoring of emissions due to passenger and freight transportation in order to define best transport routes according to the lowest environmental impact.

Switzerland [8]

Switzerland has set a target for energy usage reduction for all kind of traffic by 50% until 2050.

Sweden

Overall, the Swedish government has outlined following short-term and long-term targets for the whole society connected to greenhouse gases, emissions and energy efficiency:

Overall national goals- short term:

- Greenhouse gases decrease by 17% in 2020 compared with 2005
- The share of renewable energy will increase by 4% by 2020
- Increase in energy efficiency by 2020, expressed as reduced energy intensity by 20% compared with 2008

Overall national goals- long term:

- Domestic transport, by 2030, emissions must be at least 70% lower than in 2010
- Sweden should not have any greenhouse gas emissions by 2045

2.3 Railway Undertakings and Infrastructure Managers

Most railway undertakings, infrastructure managers and railway organisations have environmental strategies with the main goal of reduction of energy usage and CO_2-impact. Some energy solutions (e.g. hybrid drives) need infrastructure developments such as partial electrification of lines and hydrogen or gas supply at the depot.

UIC & CER

UIC (the Worldwide Railway Organization) and CER (the Voice of European Railways) have defined an environmental strategy with the following objectives:

		1990	2005	2020	2030	2050
CO2	Specific emissions (pkm & tkm)	Baseline		-40%	-50%	
	Total CO2 emissions	Baseline			-30%	
	CO2-free train operation					-100%
Energy	Specific energy consumption (pkm & tkm)	Baseline			-30%	-50%
Exhaust emissions	Total PM & Nox emissions		Baseline		-40%	
	Zero emissions of PM & NOx					-100%

UIC collects regularly data from railways involved in the ESRS (Environment Strategy Reporting System) project to monitor the progress towards the targets.

Deutsche Bahn

The Deutsche Bahn has formulated a long-term environmental strategy with the following targets [9]:

- Reduction of specific CO_2e-emission by at least 50% until 2030 (in relation to 2006) over all traffic modes
- Zero CO_2 emission in 2050 for the railway traffic in Germany
- 80% renewable energies until 2030 for the electric railway traffic in Germany

SNCF

SNCF emits less than 1% of all transport-generated emissions in France. 66% of these emissions are due to the traction including direct emission (diesel locomotives) and indirect emission (electric locomotives). By consequence, SNCF has taken on commitment [7]:

- Cut CO_2 emission by 25 % in 2025 compare to 2014 emissions
- Increase the overall energetic performance (energy consumption reduction) about 20% in 2025. The traction part (diesel and electric) has to decrease its consumption by 20% between 2014 and 2025. Buildings and train stations have also the same commitment.

A road map toward a responsible use of energy has been defined:

- Measure, control and pilot energy consumption
- Reduce consumption: energy efficient technologies and behaviours
- Get rid of fossil energy: hybridisation, biofuel, biogas, H2, frugal electrification
- Secure energy costs: energy market, taxes...
- Produce and consume renewable energy
- Make clean mobility attractive

Trafikverket

In general, Trafikverket have embraced EU Commissions papers "Transport White Book, 2011" and "A European Strategy for Low-Emission Mobility, July 2016". However, for domestic traffic, more stringent targets are imposed regarding emissions and greenhouse gases. To a large extent, the goals are based on the short-term and long-term targets decided by the goverment and the new climate act that recently entered into force in Sweden.

2.4 Industry

Best practices are being applied by the need to comply with the growing efficiency demands that comes from operators. With every new product, rolling stock manufacturers and supply chain companies are achieving reductions in the train most relevant systems and therefore, in the overall energy efficiency behaviour of the system.

Siemens

Siemens takes great efforts to lower the energy consumption of their rail vehicles due to lower weight, improved aerodynamics, increased efficiency of propulsion components and driver assistance system. The outcome of these efforts is a significant reduction in energy consumption up to 30%.

Further work deals with vehicles using energy storage systems and hydrogen technology using fuel cells due to the goals of CO2-reduction and elimination of diesel-engined vehicles. The crosslinking of vehicles allows optimized energy consumption concerning instantaneous power.

Alstom

The company mission is to accompany the customers’ transition towards sustainable transport systems. In line with our aim to facilitate a global transition to a low-carbon transport system, Alstom has pioneered several sustainable mobility solutions. The hydrogen powered train is a perfect illustration of an environmentally-friendly mean of transport. This is the combination of different innovative elements: clean energy conversion, flexible energy storage in batteries, and smart management of traction power.

CAF

CAF takes great efforts to lower the energy consumption of their rail vehicles due to reduce vehicle weight, improved aerodynamics, increased efficiency of propulsion components, optimise the energy management within the complete vehicle by combination of driver assistance system, heat management and intelligent auxiliary systems management. The outcome of these efforts concludes on significant energy consumption reduction expectation. The reduction could vary from 15 to 30% depending on SPD.

New alternative energy propulsion sources are also studied for CO2-reduction, as supercapacitors and batteries, fuel cells and optimised hybrid strategy among different energy sources.

Further work dealing with bi-mode vehicles for different catenary types and catenary and catenary free mixed zones are also studied. This will result in applying the most efficient propulsion system depending on the specific driving zone.

Talgo

Talgo is committed to reducing industry's energy footprint and its environmental impact understanding their products a a complex system, what influences in the way designing, manufacturing and maintenance are carried out through all the rolling stock life cycle. Thereby a certified Environment Management System has been implemented in line with the standard UNE EN ISO 14001:2004.

As Talgo is convinced that the future of the global economy will be defined by limiting carbon emissions, the company observes an overall energy consumption reduction plan by taking a firm, environmentally-sustainable approach leveraging its technological principles based on manufacturing the lightest vehicles in the market with a low number of axles layout, in combination with independently rotating and self-guiding wheels' running gears. Thus, Talgo's HST family has the best power-to-weight ratio, lower CO2 emissions, better sliding and lower energy consumption.

3. MODULE TECHNOLOGY

All energy-relevant innovations carried out within Shift2Rail Technical Demonstrators are analysed with respect to the impact on the future railway technology with respect to energy. Some future technologies mentioned are already applied for some applications or other industry branches. But they are mentioned because they are further developed within Shift2Rail or they are applied for more applications.

The work is based on Delivery D3.2 “Sub-level KPIs” [2], where all energy-relevant TDs are listed. It covers passenger trains, freight train, infrastructure and operation.

3.1 Passenger Trains

Within this chapter the state-of-the-art and future technology for passenger trains is described for the following train modules:

- Traction (transformer, converter, motor, gearbox and energy control)
- Running gear
- Car body
- Heating, ventilation, air conditioning and cooling (HVAC)
- Train control system

Within Table 1 the state-of-the-art and future technology is described for these modules and components. Further, the related TDs and their energy impact are listed.

Table 1: Technology of passenger train modules and components

Module/ Component	State-of-the-art technology	Future technology	TD	Energy impact of TD
Transformer	Conventional transformer	Medium frequency transformer	1.1 Traction	Higher efficiency, lower weight
Converter	IGBT	Silicon carbide	1.1 Traction	Higher efficiency, lower weight
Motor	Asynchronous motor	Permanent magnet synchronous motor	1.1 Traction	Higher efficiency
Gear box	With gear box	No gear box	1.1 Traction	Reduced energy losses and lower weight
Carbody	Carbody with steel or aluminium	Composite carbody shell with fibre reinforced plastic	1.3 Carbody	Reduced weight
Running gear	Conventional running gear	Lightweight running gear with new materials and improved steering (less curve resistance)	1.4 Running gear	Reduced weight
HVAC	Constant speed scroll compressor and condenser fan with fixed speed	Digital scroll compressor and high-pressure controlled condenser fan	1.1 Traction	Reduced energy consumption during driving and parking
	HVAC with synthetic gases and conventional heating	HVAC with natural gas and heat pump for heating	1.8 HVAC	Reduced energy consumption for heating
Train control system	Manual train driving	First automation step: Train driver drives energy-optimized by means of Driver Assistant Systems (DAS)	2.2 ATO	Energy reduction due to optimized driving style
		Second automation step: Automatic energy-optimized train driving		

3.2 Freight Trains

Within Table 2 the state-of-the-art and future technology for freight train assets is described.

Table 2: Freight train technology

Component	State-of-the-art technology	Future technology	TD	Energy impact
Freight wagon	Heavy waggons and with poor aerodynamics	Waggon with reduced weight and improved aerodynamics	5.3 Waggon	Higher efficiency, lower weight
Main line locomotive	Diesel locomotive for last mile (Shunting or main line)	Electric mainline locomotive with Li-Ion battery for last mile	5.4 Propulsion	Lower energy consumption
Shunting locomotive	Diesel shunting locomotive	Hybrid shunting locomotive with small diesel engine and Li-Ion traction batteries	5.4 Propulsion	Lower energy consumption
Train control system	Manual train driving	First automation step: Train driver drives energy-optimized by means of Driver Assistant Systems (DAS) Second automation step: Automatic driverless energy-optimized train driving	5.1 Digitalisation	Energy reduction due to optimized driving style

3.3 Infrastructure

Within 3 the state-of-the-art and future technology for the infrastructure for energy supply is described.

Table 3: Infrastructure technology

Component	State-of-the-art technology	Future technology	TD	Energy impact
Substation	Substation with 16.7 or 50 Hz transformer Single side fed power supply for 50Hz overhead lines switches for separation of overhead line sections	Substation with converters Double fed power supply for 50Hz overhead lines with increased substation distance and no switches for separation of overhead line sections	TD 3.9 Smart Power Supply	For 50Hz overhead line: • Reduced energy losses of the catenary due to double instead of single feeding For 16.7Hz overhead line: • No impact, since double feeding is state-of-the-art

4. FUTURE RAILWAY TECHNOLOGY (FIRST SCENARIO)

Within this chapter the future railway technology concerning energy is described. It considers the realisation of all energy-relevant S2R innovations. The result defines the first future scenario. It is also the basis for the calculation of the energy- and KPI-improvements within Shift2Rail. Since it requires the renewal the energy-relevant components of the railway system, it takes 5 – 30 years until the total benefit is achieved.

The future technology is described for all modules where S2R innovations are carried out. The relevant TD is mentioned in brackets. It is described for passenger trains, freight trains, infrastructure and operation.

4.1 Passenger Trains

Medium frequency Transformer (TD1.1)

For the transformation of energy from the 15 or 25kV grid to lower voltages of the traction system transformers are required. Especially for 16,7 Hz the transformers are very heavy and have a large volume. The future lies in medium frequency transformers. They have a lower weight and less energy loss, but require an additional converter between the pantograph and the transformer. The main benefit is achieved for 16,7 Hz supply systems.

Silicon carbide converter (TD1.1)

State-of-the-art trains are equipped with IGBT converters. In the future they will be replaced by silicon carbide converters, that allow a higher switching frequency and cause lower losses within the propulsion system. Due to the higher switching frequency the harmonics of the input and output currents are reduced. This leads to lower harmonic losses of the motor, inductor and transformer. Further silicon carbide converters have a lower weight that further reduces the energy usage. The new converters can be applied for new or refurbished trains.

Distributed drive system (TD1.1)

Due to lighter and smaller traction components the traction system of future passenger trains can easier be integrated into the coaches (electrical multiple units, EMU). Hence the traction system can even be integrated in double-deck coaches without the loss of too many seats. For passenger traffic locomotives are not required anymore. This reduces the train weight and energy usage and increases the seating capacity per train. In addition, recuperation of brake energy can be increased due to avoidance of dynamic brake force limits currently valid for locomotives.

Synchronous Motor (TD1.1)

Induction motors may be replaced by synchronous motors with permanent magnets. They have a higher energy efficiency, but they require a separate converter for each motor. Permanent magnet synchronous motors may be directly connected to the wheels, hence no gearbox is required. This reduces the vehicle weight and energy usage. The disadvantage is that the motor weight and volume is increased due to the lower rotating speed. Within Shift2Rail only the application for one type of a high-speed train is developed. But the synchronous motor can be applied for regional, urban and freight trains as well. This technology can only be applied for new trains.

Battery powered drives (TD1.1)

In the future diesel trains will be substituted by hybrid drives powered by a diesel and batteries. This reduces the energy consumption, CO_2-impact and noise. If the non-electrified part of the line is comparatively short (less than 20 – 40km) electrical trains with pantographs and batteries will be the solution for zero CO_2-impact. But it requires charging stations or partly overhead lines for charging the batteries. As the battery technology is improved these trains can be used for larger non-electrified lines. Battery drives can be applied for new trains or by retrofitting of existing trains.

Carbody shell (TD1,3)

For the carbody shell or parts of it fibre reinforced plastic may be used instead of aluminium or steal. This reduces the weight and consequently the energy usage of the train but may increase the costs.

Running gear (TD1.4)

Innovations consider new materials and concepts that result in lower boogie weight of and consequently in a reduction of energy usage of the train.

HVAC with improved technology (TD1.1)

State-of-the-art systems for heating, ventilation, air conditioning and cooling (HVAC) use compressors and condenser fans with constant speed. Future HVACs can be equipped with digital Scroll compressors and speed regulated condenser fans (EC technology). These new technologies reduce the energy consumption of the HVAC during driving and parking. Further they reduce the noise in parking mode.

HVAC with natural gases (TD1.8)

Future systems for heating, ventilation, air conditioning and cooling (HVAC) use natural gases like air or CO_2. Compared to state-of-the-art HVACs with artificial gases they have a highly reduced climatic impact. Further, a heat pump can be integrated to reduce the energy usage for heating. This technology can be applied for new trains or during the refurbishing of existing trains.

4.2 Freight Trains

Freight wagon (TD5.3)

The freight wagon for the extended market will have better aerodynamics and lower weight. That reduces the energy usage

Battery powered last mile drive (TD5.4)

Since the core freight network is electrified, electrical freight locomotives are used for more than 90% of the rail freight traffic. But for many small terminals the “last mile” to the terminal is not electrified. This requires the provision of diesel locomotives for the last mile and requires time and staff for locomotive change. Even large terminals require diesel traction within the terminal, since within the loading area of the terminals overhead lines are not possible. Future main line locomotives will be equipped with batteries for the traction power for the last mile. The effect on energy usage is low, but the transport process time is reduced

Battery powered Shunting locomotives (TD5.4)

Diesel shunting locomotives will be replaced by hybrid shunting locomotives with a diesel engine and batteries. This reduces the energy consumption, CO_2-impact and noise. This technology can be applied for new locomotives or during the refurbishing of existing ones.

As the battery-technology improves hybrid shunting locos might be substituted by total electrical locomotives with pantographs and batteries. But this requires overhead lines for part of the shunting area.

4.3 Infrastructure

Converter substations (TD3.9)

Today 50Hz overhead lines are supplied via 1-phase transformer from the national 50Hz grid. Adjacent substations are supplied from different phases. Between adjacent substations section phase separation switches are required. Vehicles can only be supplied from one side which leads to higher overhead line losses and shorter substation distance compared with a two-side fed system.

Future 50Hz substations can be equipped with a converter. This allows a double-side feeding of the vehicles from two adjacent substations, since the frequency and phase of adjacent substations can be aligned. This reduces overhead line losses and opens the opportunity to increase the substation distance. But on the other hand, additional energy losses are created within the substation. Up to now, it is not known whether the energy usage is reduced or increased. A further benefit of this technology is that there is no interruption of the traction force when a phase separation switch is passed.

4.4 Operation

Connected DAS (TD 5.1)

As a first automation step the train driver is assisted by a Driver Assistant System (DAS) that assists energy-optimized driving. The DAS of the future (Connected DAS) also uses real time data of the actual traffic situation, e.g. delays of a preceding train. Since data of the overall traffic management system are used, unnecessary stops can be minimised. This reduces the energy usage.

ATO (TD2.2, TD5.1)

As a second automation step trains will run automatically according to an energy-optimised driving style not depending on the individual driving style of the train driver. Therefor the energy usage is further reduced.

5. FUTURE SPD

In the energy base line [1] the System Platform Demonstrators (SPD) / traffic segments are described with respect to energy. Most S2R-innovations are demonstrated for certain traffic segments. But they can be applied to other segments as well. Tables 4 and 5 shows for which traffic segment the innovations are carried out (dark grey and No of TD) and for which alternative traffic segments they can be applied in the future (bright grey).

Table 4: Application of S2R-innovations of IP1 for SPDs

<table>
<tr><th rowspan="3">SPD/ Main Service Category</th><th rowspan="3">Sub Service Category</th><th colspan="6">S2R Innovations with respect to energy</th></tr>
<tr><th colspan="6">IP1</th></tr>
<tr><th>Electronic trans-former</th><th>SiC-con-verter</th><th>Synchro-nous motor</th><th>Carbody shell</th><th>Running gear</th><th>HVAC</th></tr>
<tr><td rowspan="3">SPD 1 High Speed</td><td>High Speed 300</td><td></td><td></td><td>TD1.1</td><td>TD1.3</td><td rowspan="8">TD1.4</td><td></td></tr>
<tr><td>High Speed 250</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Intercity</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">SPD 2 Regional</td><td>Regional 160</td><td>TD1.1</td><td>TD1.1</td><td></td><td></td><td>TD1.8</td></tr>
<tr><td>Regional 140</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">SPD 3 Urban</td><td>Suburban</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Metro</td><td></td><td>TD1.1</td><td></td><td>TD1.3</td><td></td></tr>
<tr><td>Tram</td><td></td><td>TD1.1</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">SPD 4 Freight</td><td>Freight Mainline</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Freight Shunting</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 5: Application of S2R-innovations of IP2, 3 and 5 for SPDs

<table>
<tr><th rowspan="3">SPD/ Main Service Category</th><th rowspan="3">Sub Service Category</th><th colspan="7">S2R Innovations with respect to energy</th></tr>
<tr><th>IP2</th><th>IP3</th><th colspan="5">IP5</th></tr>
<tr><th>ATO</th><th>Converter substation</th><th>Innovative Freight wagon</th><th>Last mile drive</th><th>Hybrid shunting loco</th><th>DAS</th><th>ATO</th></tr>
<tr><td rowspan="3">SPD 1 High Speed</td><td>High Speed 300</td><td rowspan="6">TD2.2</td><td rowspan="6">TD3.10</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>High Speed 250</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Intercity</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">SPD 2 Regional</td><td>Regional 160</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Regional 140</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">SPD 3 Urban</td><td>Suburban</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Metro</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tram</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">SPD 4 Freight</td><td>Freight Mainline</td><td>TD2.2</td><td>TD3.10</td><td>TD5.3</td><td>TD5.4</td><td></td><td>TD5.1</td><td>TD5.1</td></tr>
<tr><td>Freight Shunting</td><td></td><td></td><td></td><td></td><td>TD5.4</td><td></td><td></td></tr>
</table>

6. FURTHER TECHNOLOGY DEVELOPMENTS (SECOND SCENARIO)

Within this chapter further technological developments with respect to energy, carried out outside of Shift2Rail are described. The number of further developments is very few, since most areas are covered by Shift2Rail. The sum of S2R-innovations and further developments defines the second future scenario. The developments aim on further increase in energy efficiency and reduction of CO_2-impact, both goals of the energy strategies of the stakeholders.

6.1 RUNNING DEVELOPMENTS

Fuel cell drives

The range of battery-powered trains is presently limited to 20 – 40km. For longer non-electrified lines fuel cells might be used in addition to the batteries to supply the energy. The fuel cells use hydrogen as an energy source. But up to now the overall efficiency of fuel cell trains including the hydrogen production by electrolysers is lower than electrical or full battery powered trains [10]. Fuel cell trains reduce the CO_2-impact, noise and pollution. Fuel cell trains might be a solution for long non-electrified lines in order to fulfil the climatic targets for these applications

Switching off traction units [11]

Today all traction units (Converter, gearbox and motor) are in operation when the train is running. Switching off some traction units during cruising and all units during coasting reduces the losses of converter and motor. But it might cause mechanical damages of the gear box. Alternatively the load can be uneven split between the traction units.

Super capacitors

Super capacitors may be used as a short-term energy storage system in addition to batteries to cover power peaks (acceleration and braking) and to increase the live span of batteries.

6.2 SUGGESTED DEVELOPMENTS

Energy supply from renewable energy sources

In order to fulfil the climatic targets, the future railway energy demand has to rely on renewable energy sources like wind and sun. This requires the building of wind and solar power plants that feed the energy into the railway energy grid. Further it requires storage systems and a smart energy control for stabilising the energy supply system, since the energy source as well as the energy consumers vary a lot. Electrolysers for hydrogen production can also be used to stabilise the grid.

Energy management including auxiliary vehicle energy consumers

Today auxiliary energy consumers, e.g. HVAC-system are controlled independently of the status of main drive (acceleration, casting, braking). Hence the input converter of the vehicle must be dimensioned for the power of the main drive and the auxiliary consumers. This is even worth for battery powered trains. In the future, an energy management system should adopt the HVAC-system to the status of the main drive: During acceleration the HVAC-system should consume less energy and during braking more. This requires controlled HVAC-systems. The benefit are lower energy losses and a smaller dimensioning of the input transformer and converter.

Parking energy supply

In general, during night-time parking electrical passenger trains auxiliary consumers (e.g. control system and HVAC) are fed from the overhead line. This causes energy losses within the input transformer during the whole night. If the pantograph is dropped during parking and automatically raised in the morning, the losses can be reduced. Further this reduced the parking noise during the night. This procedure requires an adoption of the energy management system and may affect the homologation.

Lithium Ion batteries for auxiliary systems

Today for auxiliary power lead or NiCd-batteries are used. In the future they will be replaced by Lithium Ion batteries or further improved battery technology. This reduced weight and energy usage.

Liquid natural gases and biofuel

Combustion engines powered with liquid natural gas (LNG, French GNL gaz naturel liquéfié) or compressed natural gas (CNG) may be an alternative to diesel engines. This reduces the pollution and the climatic impact if the natural gas is locally produced. Further alternatives are GTL (gas to liquid), BTL (biomass to liquid), B100 or “Power to gas” that is produced from excessive electrical energy, e.g. from wind power plants. On the other side biofuel like B100 is ecologically controversial since it is partly produced from palm oil.

Interval / partial / frugal electrification with battery train

The cost of electrification could be strongly reduced with the electrification of only the cheapest zones, avoiding huge works due to tunnels, bridges, etc. An electric train with battery could operate such lines. Developments are required to maintain reliability, as automatized lift up and down of pantograph.

6.3 Impact on Future SPDs

The running and suggested developments also have an impact on several SPSs. Tables 6 and 7 show for which traffic segment the developments can be applied.

Table 6: Application of running developments for SPDs

SPD/ Main Service Category	Sub Service Category	Running technology developments		
		Fuel cell drives	Switching-off traction units	Super capacitors
SPD 1 High Speed	High Speed 300			
	High Speed 250			
	Intercity			
SPD 2 Regional	Regional 160			
	Regional 140			
SPD 3 Urban	Suburban			
	Metro			
	Tram			
SPD 4 Freight	Freight Mainline			
	Freight Shunting			

Table 7: Application of suggested developments for SPDs

SPD/ Main Service Category	Sub Service Category	Suggested technology developments					
		Re-newable energy	Energy manage-ment	Parking energy supply	Li-Ion-batteries for auxiliary consumers	Liquid natural gas	Interval electri-fication
SPD 1 High Speed	High Speed 300						
	High Speed 250						
	Intercity						
SPD 2 Regional	Regional 160						
	Regional 140						
SPD 3 Urban	Suburban						
	Metro						
	Tram						
SPD 4 Freight	Freight Mainline						
	Freight Shunting						

6.4 Required Research

In order to push the new suggested technologies the following research activities and demonstrators should be covered by subsequent research projects:

- Rail energy supply from renewable sources
- On-site hydrogen production from renewable sources
- Bi-mode Regional and Intercity trains with pantograph and batteries
- Regional, Intercity and Freight trains with fuel cell drives
- Retrofitting of Diesel trains for electrical drive with batteries and fuel cells
- Regional, Intercity and Freight diesel trains supplied by liquid gas or biofuel
- Improving vehicle energy management including parking energy supply
- Application of permanent magnet synchronous motors for regional, urban and freight trains as well as for high-speed trains with boogies (instead of single wheel drives)

7. Long-Term Vision

To reduce the energy consumption and to fulfil the European target of a CO_2-free rail transport, the long-term railway system with respect to energy may be characterised as follows:

Concerning Rolling stock:

- New purchased trains are equipped with an energy-saving traction system with SiC-converters, electronic transformers and probably synchronous motors without gear boxes
- All passenger trains have a distributed drive system (no locos) to reduce the mass and energy consumption
- For heating and air conditioning HVAC-systems with natural gases and heat pumps are used to reduce energy consumption and the climatic impact
- All mass-reducing means are applied for new trains like light-weight bogies and carbody
- All trains are equipped with a connected driver assistant system (DAS) that contributes to energy-saving driving. More and more trains run automatically so the optimum driving style is guaranteed
- New purchased and retrofitted electrical battery trains (BEMU) running on regional lines with short non-electrified sections (< 30 – 50 km)
- New purchased and retrofitted hydrogen trains (HMU) running on regional lines with long non-electrified sections (> 30 – 50 km)
- Electrical freight locomotives are equipped with a battery drive for the last mile from the electrical line to the terminal
- Shunting locomotives in marshalling yards are equipped with a fuel cell or battery traction system

Concerning infrastructure:

- Electrical energy supply by means of renewable sources (Solar, wind)
- Electrification of further railway lines with medium traffic (at least 2 trains per hour)
- Electrical charging points or short overhead lines at turning points of battery trains
- Short overhead lines for intermediate stations incl. acceleration range for intermediate battery charging
- Hydrogen refilling stations for HMUs with local hydrogen production sites from renewable energies, others use electrical surplus power in order to stabilise the electrical grid

Up to now there is no preferred solution for freight trains running partly on non-electrified lines. Fuel cell drives may be a solution but require a large volume and additional mass that leads to a separate tender being not economical.

8. CONCLUSION

The European Commission, European states and railway undertaking have ambitious targets for the reduction of greenhouse gases and energy efficiency. The technologies developed in Shift2Rail will change the railway technology of the future and will increase the energy efficiency, reduce the energy usage and CO_2 impact.

Further reductions of energy usage and CO_2 impact require additional developments not yet covered by Shift2Rail. Examples are

- Fuel cell drives
- Energy supply from renewable energy sources
- Improved rolling stock energy management

In order to push the additional technologies, research activities and demonstrators within subsequent research projects are required (e.g. Shift2Rail II)

For reaching the energy saving targets, these new technologies have to be implemented. This requires special activities from different stakeholders, e.g.

- Tenders for regional traffic with requirements for alternative drives and eco-friendly HVAC-systems
- Financing the digitalisation of the railway system to allow automatic driving (ATO)
- Investment in power supply from renewable energy sources

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