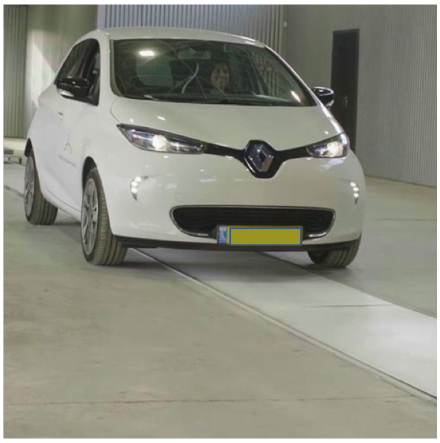
Swedish-German research collaboration
on Electric Road Systems



Overview of ERS concepts and complementary technologies

Editors

Martin G. H. Gustavsson, RISE Research Institutes of Sweden

Florian Hacker, Öko-Institut

Hinrich Helms, Institut für Energie- und Umweltforschung Heidelberg – ifeu

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The research collaboration "CollERS" consists of the core members from the Swedish Research and Innovation Platform for Electric Roads and the two national German research projects Roadmap OH-Lkw and StratON:

- **German research partners**
  - Öko-Institut e.V.
  - Institut für Energie- und Umweltforschung Heidelberg (ifeu)
  - Heilbronn University
- **Swedish research partners**
  - RISE Research Institutes of Sweden
  - Chalmers University of Technology
  - KTH Royal Institute of Technology
  - Swedish National Road and Transport Research Institute (VTI)
  - Swedish Transport Administration
- **Funding agencies**
  - German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)
  - Swedish Transport Administration

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The main contributors to this report are Martin Gustavsson and Conny Börjesson at RISE; Florian Hacker and Sven Kühnel at Öko-Institut; Hinrich Helms, Julius Jöhrens and Julius Rücker at ifeu; and Magnus Lindgren at the Swedish Transport Administration.

The pictures on the front page are courtesy of Region Gävleborg, eRoadArlanda, and Electreon, respectively.

Content

Introduction

Background and national perspectives

The German government's climate protection plan sets a 45 percent reduction in greenhouse gas emissions by 2030 compared to 1990 levels. Zero emissions are to be achieved by 2050. The interim target for the transport sector is to reduce emissions by 40 to 42 percent by 2030 [1].

Compared to the reference year 1990, the German transport sector has not yet been able to reduce its emissions. To achieve the 2030 target, transport would have to reduce its current emissions of 170 million tonnes of carbon dioxide equivalents by 70 million tonnes. Around 40 million tonnes are currently emitted by heavy-duty vehicles (gross vehicle weight > 3.5 tonne).

The Swedish climate goals established by the government and parliament states that by 2045, Sweden will have net zero emissions of greenhouse gases into the atmosphere and should thereafter achieve negative emissions. Emissions from domestic transport, excluding domestic aviation, will be reduced by at least 70 percent by 2030 compared with 2010.

Road traffic in Sweden generates 94 percent of the emissions of greenhouse gases from the domestic transport sector. In 2016, emissions from domestic road transport amounted to 15.8 million tonnes of carbon dioxide equivalents, which is 16.7 percent lower than in the reference year 2010. Among domestic road transports, passenger cars account for the major part of the emissions of greenhouse gases, 65 percent, followed by heavy-duty vehicles representing 21 percent [2].

Scope of report

Electric Road Systems (ERS) is a technology area with immense potential to reduce fossil fuel dependency, reduce greenhouse gas emissions, reduce air pollution as well as reduce noise in urban environments, while increasing energy efficiency in the transport sector.

ERS is defined as a system enabling power transfer from the road to the vehicle while the vehicle is in motion and could be achieved through different power transfer technologies such as rail, overhead line, and wireless solutions. The definition of ERS is technologically open and various solutions are thus covered in this report.

The implementation of ERS at national and international levels is likely to work together with the application of other solutions for cleaner transportation. This report therefore contains descriptions and comparisons of complementary technologies.

There are several ongoing studies and demonstration projects on Electric Road Systems (ERS) in Germany, Sweden and around the world which have the aim to explore different techniques for energy transfer and different use cases. The various ERS technologies have different maturity, and each ERS solution has its own advantages and disadvantages. To ensure a common ground for a collaboration it is fruitful to have an assessment of different ERS concepts, including an overview of international ERS activities.

This report aims to give an overview of ERS concepts and complementary technologies, and is a preliminary a result of the CollERS project.

The purpose of this report is twofold:

- *ensure common ground for collaboration, and*
- *provide a state-of-the-art description for stakeholders and other interested readers.*

Real-world experience

Demonstration projects currently under way will test ERS on public roads and in real-life environments, addressing various legal, political, economic, and efficiency aspects of ERS. Public road tests would provide decision makers and investors with a foundation for further investments that would bring ERS to commercial operation. At the time of writing, there are two ongoing demonstrations on public roads in Sweden, one demonstration on a public road in the USA has been finalized, and the German federal government funds the construction of three future demonstrations on public roads, which will be successively put into operation from 2019 onwards. In addition, the Swedish Transport Administration has issued a pre-commercial procurement in order to gain knowledge from additional demonstrations on public roads.

The following table gives a summary of ongoing and planned activities on public roads:

Name	**Location**	**Solution**	**Start of vehicle operation**	**End**
E16 Electric road	E16 in Region Gävleborg, Sweden	Overhead lines	2016	2020
SCAQMD	Los Angeles County, USA	Overhead lines	2017	2017
eRoadArlanda	Arlanda Airport, Sweden	Rails	2018	2019
ELISA	A 5, Germany	Overhead lines	2019	2022
FESH	A 1, Germany	Overhead lines	2019	2022
eWayBW	B 462, Germany	Overhead lines	2020	2023[1]
Pre-commercial procurement by the Swedish Transport Administration	Not decided	Not decided, rail and wireless solutions are considered	2020 (estimated)	2022 (estimated)

[1] Planned end year for eWayBW, not approved at the time of writing.

Electric Road Systems

Overview of ERS and its subsystems

An Electric Road System (ERS) consist of five different subsystems as illustrated in Figure 1 and described below.

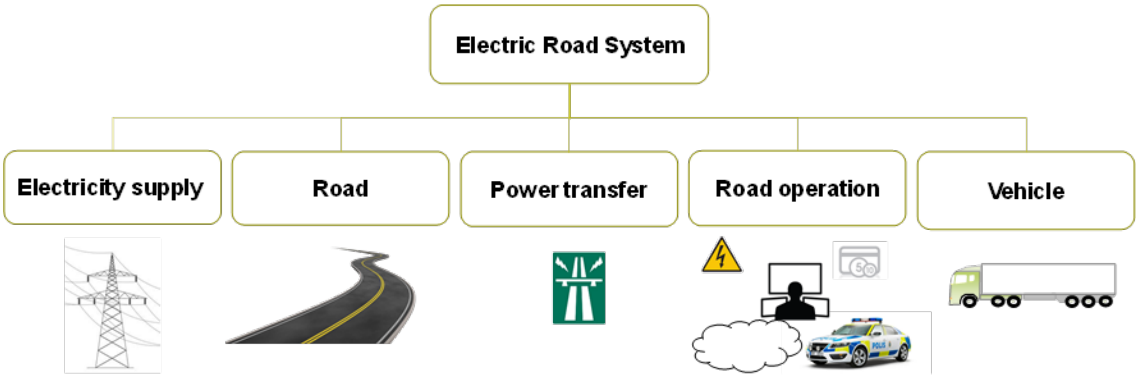


Figure 1: Overall system layout of ERS with five subsystems.

Electricity supply

The electricity supply consists of transmission, distribution and management components. Transmission includes how the electric power flows from the generation sources over long distances. Distribution is how the power flows through a grid to the power transfer subsystem. The management component controls the operation and balance the energy.

Road

The road subsystem consists of pavement, barriers and auxiliary components. The pavement includes the actual structural body and road markings. Barriers includes both safety and noise protection components. Auxiliary components are road signs and other necessary roadside components.

Power transfer

The power transfer subsystem is divided into three components: road power transfer, vehicle power transfer and control. The road power transfer component consists of in-road and/or roadside equipment that handles detection of the vehicle and transferring of power from the road. Vehicle power transfer controls safe activation and operation of a power receiver, and measures transferred energy after successful acknowledgment. The control component monitors the energy handover and system operation.

Road operation

The electric road operation subsystem controls the energy management of the overall system, provides user information and handles payment and billing. This subsystem also handles access and lane control of the road based on vehicle identification.

Vehicle

The vehicle subsystem includes the necessary component that converts the power from the power transfer subsystem into either propulsion of the vehicle or to energy storage. A control component provides user information, fleet management and vehicle positioning.

The three main ERS concepts

Currently, there are three main concepts for road electrification: overhead conductive lines, conductive rails in a road surface, or wireless solutions. All these concepts have their advantages and disadvantages and are being developed and marketed by different actors. Below, we examine the state of the art of ERS as well as various projects and developments being undertaken by international ERS actors. The concepts are illustrated in Figure 2.

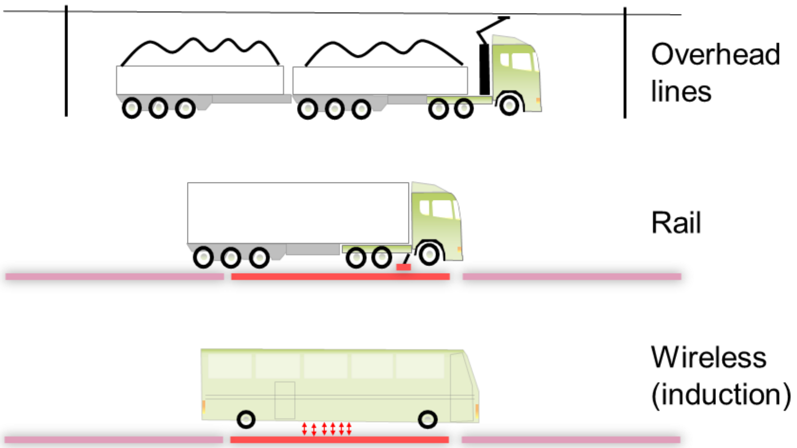


Figure 2: The three main concepts for road electrification and power transfer to moving vehicles.

An overhead line solution uses conductive wire lines (also known as catenaries) above the vehicle to provide the energy. The energy is transferred to the vehicle by means of a power receiver device (sometimes called a pantograph) installed on top of the vehicle, and which follows and detaches automatically from the overhead lines.

A rail solution for conductive energy transfer from roadway to electric vehicles uses conductive rails installed in the road to provide the needed energy. The energy is transferred to the vehicle via a power receiver pick-up arm installed beneath the vehicle, and which follows and detaches automatically from the rail.

A wireless solution uses a magnetic field to provide the energy. Electric current in primary coils installed in the roadway create magnetic fields which induces current in a secondary coil installed beneath the vehicle.

Technologies

Siemens eHighway

Siemens has worked with overhead catenary lines, and its technology named eHighway has been tested on a 2 km closed test track east of Berlin, Germany [3]. Full vehicle integration has been made with heavy trucks from both Scania and Volvo Group. The Siemens solution has been demonstrated since 2016 together with Scania trucks by Region Gävleborg along 2 km of the E16 highway outside Sandviken, Sweden. The eHighway solution has also been demonstrated during 2017 by South Coast Air Quality Management District together with three different trucks along one mile of an urban road in the City of Carson in Los Angeles County, California, USA.

Alstom ERS

Alstom has a service-proven power system for tramways called APS which supplies electricity through a third rail at ground level and eliminates the need for overhead lines (in order to meet new requirements for tramways in urban areas). The APS product is used in many cities for energy transfer during movement and has been used as a foundation when Alstom has developed its ERS system that involves two rails in the road surface level. AB Volvo has developed power receiver pick-up arms for heavy transport vehicles and tests have been made at a Volvo test site in Sweden. The vehicle integration was performed as part of the Slide-in research project [4].

Elonroad

Elonroad is a solution with a rail that consists of short segments in sequence. The rail is intended to be installed on the road surface and rises about 5 cm and has slantwise sides. The power receiver device has at least three contacts. Demonstration along a test track is ongoing in southern Sweden [5].

Elways

The rail solution from the company Elways involves one rail with two trenches where the conductive parts are placed down in the trenches [6]. The rail and a customized power receiver pick-up arm integrated into a medium sized truck have, since 2018, been used for demonstration of electrified shuttle transports along a public road in the vicinity of Arlanda Airport, outside Stockholm, Sweden [7]. The Elways solution has had many years of development and tests in various environmental conditions.

OLEV

The commercial company OLEV, a spin-off of the university KAIST in South Korea, has developed technology for wireless power transfer to buses. Its solution has been tested on a public road inside KAIST's Daejeon campus since 2012. Since 2013, a bus route of 24 km traversed by a few buses has been in operation in Gumi with a total of 144 m of installed coils [8], [9].

Bombardier Primove

Bombardier has been conducting research on dynamic wireless power transfer as an evolution of its Primove commercial static solution. The system has been integrated into a Scania truck and tested in 2013 on an 80 m closed test track in Mannheim, Germany, as part of the Slide-in project [10].

FABRIC

The large EU project FABRIC has built two facilities for demonstrations of dynamic wireless power transfer: a test track outside Torino, Italy, using a Fiat van and power transfer technology developed by SAET group and the university Politecnico di Torino, and the Vedecom test track in Satory, France, using a Renault van and power transfer technology based on a commercially available static wireless solution from Qualcomm. The FABRIC project concluded its demonstration activities at the end of June 2018 [11].

WAVE

A test track for dynamic wireless power transfer has been completed at Utah State University using technology developed by WAVE. A system in the range from 25 kW to 40 kW can be tested using a 20-seat passenger bus [12].

Electreon

In recent years the Israeli company Electreon (previously Electroad) has been known for its ambition to enable large scale adoption of pure electric buses by developing a dynamic wireless electrification system for urban transportation [13].

Others

The technologies described above are the most well-known. But there are more developments and technologies going on around the world and we foresee that more developers and manufacturers will be active in the coming years. For example, Honda R&D in Japan has worked with an ERS lane on the side of the road and performed tests of high power charging at high speeds [14]. In addition, high ambitions from China have been expressed in news media [15], [16].

Applications

The electrification of long-haul freight transportation has been the driving force for ERS and continues to be the focus for several activities. There are however synergies with other applications as also studied using PESTEL analysis in the FABRIC project [17]. Road electrification can be utilized for various kinds of vehicles, even though not all types of ERS technologies are suitable for all kinds of vehicles. Some examples of interesting use cases are listed below and illustrated in Figure 3:

- Transportation of goods with long haul heavy trucks
- Transportation of goods with light trucks
- Public transport with buses
- Municipal service (e.g. health care)
- Maintenance service (e.g. sanitation)
- Personal transports with cars

Figure 3: Examples of applications utilizing road electrification by means of a ground-based solution. Pictures courtesy of Dan Zethraeus.

Configuration of ERS long-haul trucks

Trucks using external electricity supply from Electric Road Systems (ERS) have a power receiver and an electric drive, and can therefore be operated in pure-electric mode on electrified road sections. The hybrid drive with an additional combustion engine, a fuel cell or a battery ensures that the vehicle can also drive beyond the electrified sections. Therefore, a continuous area-wide ERS is not a mandatory requirement for the use of electric trucks in long-distance road haulage. The external power supply enables the electric operation of long-distance trucks over long distances without having to rely on large, costly and heavy batteries and long downtimes for battery charging.

Options for hybrid drives are parallel or serial concepts with conventional combustion cycle engines, LNG engines, fuel cells or traction batteries. Two basic vehicle configurations are currently discussed: parallel hybrid trucks with a conventional combustion engine (ERS-HEV) and purely electric trucks with a traction battery (ERS-BEV), as illustrated in Figure 4. Serial hybrid concepts with a range extender (combustion engine or fuel cell) are also plausible in the future, but will not be examined here in detail.

Concrete vehicle configurations are discussed below. Especially due to the highly dynamic state of the development of battery electric trucks and numerous product announcements by vehicle manufacturers in recent years, an early equipping of ERS-HEV with larger batteries seems conceivable (see battery descriptions below).

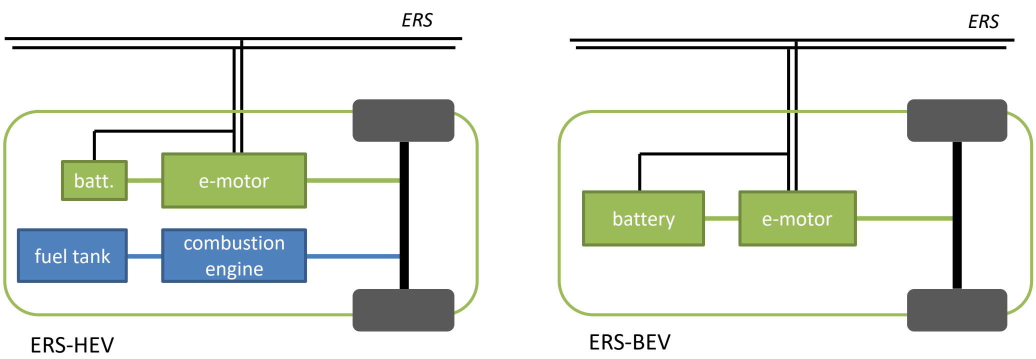


Figure 4: Schematic structure of the drive of an ERS-HEV and ERS-BEV.

Hybrid-electric ERS truck concept (ERS-HEV)

The ERS-HEV concept assumes that the full drive power equivalent to that of a diesel truck is always available (with and without contact to the ERS) [18]. The vehicle therefore has a fully-fledged diesel and electric drive train. This means that even longer inclines in the ERS network can be fully covered electrically.

The buffer battery has a relatively low capacity compared to ERS-BEV. Hybrid vehicles with batteries up to 20 kWh have been tested by a manufacturer in order to be able to cover distances up to about 10 km electrically without direct contact to the ERS. Recent product announcements (at the IAA Commercial Vehicles 2018 event) for conventional HEV (without ERS) have batteries of up to 85 kWh. An early integration of larger batteries into ERS-HEV therefore seems to be possible. Accordingly, the electrical range outside the ERS would increase considerably (over 40 km). Beyond the electrical range, the diesel engine is used to drive the truck.

Battery-electric ERS truck concept (ERS-BEV)

The battery-electric ERS truck concept is based on a purely electric drive train consisting of an electric motor, a traction battery, a power receiver device and power electronics. Outside the electrified roads ERS-BEV have a limited range and operational flexibility that depend highly on the on-board battery capacity: the battery size is modular and can be adapted to the user's requirements (in particular electrical range and payload). However, it must be noted that payload losses increase with increasing battery capacity. In the following section, ERS-BEV variants with a relatively small battery electric range of 100 km (ERS-BEV 100) and a significantly larger battery electric range of 250 km (ERS-BEV 250) are illustrated. The required battery capacity amounts to about 175 kWh (ERS-BEV 100) and 400 kWh (ERS-BEV 250), respectively, when considering the electricity consumption of the vehicles and a feasible depth of discharge for the batteries.

Advantages and disadvantages of different ERS vehicle configurations

The following table summarizes the most important characteristics of the ERS vehicle configurations discussed above. Other vehicle configurations are also tested by truck manufacturers, especially within the range shown.

Column heading	**ERS-HEV**	**ERS-BEV 100**	**ERS-BEV 250**
Engine power	2 × 350 kW	350 kW	350 kW
Electric range beyond the ERS	≤ 10 km	100 km	250 km
Battery capacity	≤ 20 kWh	175 kWh	400 kWh
Battery weight	≤ 240 kg	≈ 800 kg	≈ 1 800 kg

Data based on Kühnel, Hacker and Görz [18].

The advantages and disadvantages of the vehicle configurations under consideration are strongly dependent on the ERS infrastructure design, including network coverage (see discussion in the following section). The following overview compares the basic strengths and weaknesses of the two vehicle configurations, which are independent of the infrastructure.

Parameter	**ERS-HEV**	**ERS-BEV**
Purchase costs	(+) small battery	(–) large battery
Operating costs	(–) lower electric driving	(+) full electric driving
Local emissions	(–) exhaust emissions during conventional mode	(+) no exhaust emissions due to full electric driving
Greenhouse gas emissions	(–) emissions during use of fossil fuels	(+) only upstream emissions of electricity production[2]
Flexibility	(+) no range limitation	(–) range limited by battery capacity
Payload	(+) no relevant restriction	(–) possible reduction due to battery weight

(+) means favourable, (–) means unfavourable

[2] Increasing advantage with growing share of renewable energies in electricity generation.

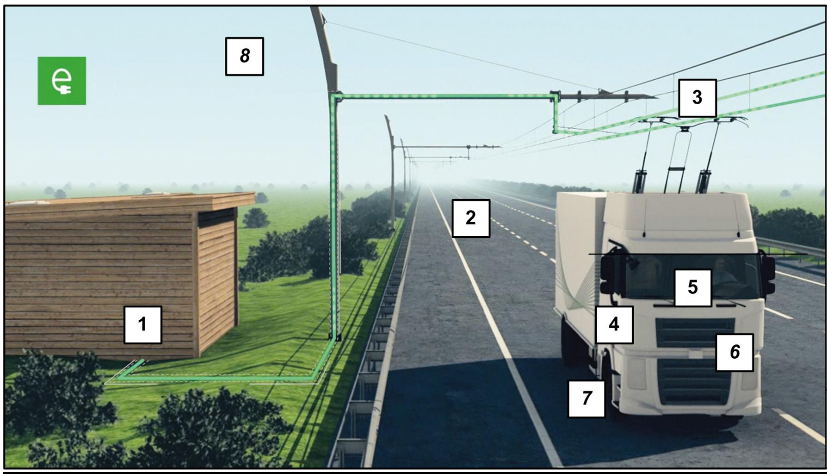
Configuration of ERS infrastructure

The design of the ERS infrastructure determines the advantages of the vehicle configuration under consideration during operation. The possibilities of infrastructure design are at the same time determined by other external factors that are discussed in more detail below.

In principle, the ERS infrastructure is discussed here independently of the selected system (overhead line, rail or wireless). Where necessary, this is explicitly mentioned. Detailed considerations are made using the example of the overhead line system that is illustrated in Figure 5.

The ERS infrastructure consists of the following main components:

- Connection to the medium-voltage power grid
- Substations
- Power supply infrastructure along the road (overhead lines, rail or wireless)



#	interface
1	substation to overhead contact line (i. e. power supply to transfer)
2	contact line to road (power transfer to driveway)
3	contact line to panto-graph (power transfer to vehicle pick-up)
4	pantograph to electric drive (vehicle pick-up to hybrid base vehicle)
5	pantograph to driver/ truck cabin (vehicle pick-up to operation)
6	*vehicle to hybrid drive*
7	*vehicle to road*
8	*vehicle to OCC*

Figure 5: Technical overview using the example of overhead line ERS.

Influencing factors on the system design

The external requirements for the ERS infrastructure (approval procedure, social acceptance etc.) are expected to be lower than the requirements for the vehicles (cost pressure, flexibility of use, vehicle availability etc.). Since the technical restrictions are also considered to be lower than the restrictions the battery imposes on vehicles, the ERS infrastructure as a whole is likely to be made more flexible and adapted more easily to the needs of the vehicles than vice versa. It can therefore be assumed that the infrastructure design will be oriented towards the technical and economic optimization of vehicle operation. At the same time, however, possible restrictions on infrastructure development must also be considered. The goal is to develop a user-friendly and cost-optimized overall system.

The design of an ERS system ought to consider the following factors:

- Interactions between infrastructure and vehicle configurations
- Restrictions (technical, legal, social acceptance)
- Degree of electrification (continuous versus partial electrification)
- Costs of infrastructure versus cost of vehicles
- Number of ERS compatible vehicles (market ramp-up)

Interactions between infrastructure and vehicles

Different vehicle concepts impose different demands on infrastructure. ERS-HEV mostly draw their electric traction energy from the ERS, but also have an additional need to recharge their batteries. With increasing battery sizes for ERS-HEV, and also for ERS-BEV, comes a demand for higher power output since the vehicles have an increasing need to recharge their batteries while using the ERS.

An increasing number of vehicles (in the context of a market ramp-up) also increases the power requirements on the ERS infrastructure. Performance peaks must be taken into account – for example simultaneous acceleration in high-congestion areas, especially on an incline.

Restrictions

There are places where electrification is technically impossible or would involve a great deal of additional technical and economic effort given the space required by ERS alongside, in or above the road. These places include, for example, viaducts, tunnels and sections with restricted clearance heights, side spaces, or restrictions of the road surface (e.g. reinforced concrete road surface on bridges). In Germany, approximately 6 percent of the highway network is classified as non-electrifiable according to first estimations. This proportion could still increase if further sections of the highway should turn out to be non-electrifiable for other reasons, for example within the framework of the approval procedure, lack of acceptance by stakeholders like neighbours due to environmental concerns. In Germany this is estimated to be approximately 10 percent of the highway network [18]. An approval procedure has not yet been completed for longer distances.

In view of the existing basic pollution caused by conventional vehicles on the road, the potential positive effect of ERS vehicles on the emission side could result in a high social acceptance. Nevertheless, the visual influence from the ERS infrastructure (especially overhead lines) on the surrounding cultural landscape must be considered. Also, safety issues due to exposed rail solutions and magnetic fields from inductive solutions need to be handled. The ongoing and planned ERS test tracks on public roads offer the opportunity to gain empirically sound knowledge about the social acceptance of ERS.

Degree of electrification

Excluding certain sections of the road from electrification as part of a technical and economic optimization of the ERS system should also be considered. Arguments in favour of partial electrification are the above-mentioned restrictions on infrastructure development, the lack of necessity on downhill slopes, the technical possibility of bridging these sections in diesel or battery mode, and lower infrastructure investment cost. To keep the performance of the overall system constant in case of a partial electrification, a proportionally higher energy content must be transmitted on the electrified sections in contrast to a continuous electrification with no gaps along the road.

A lower degree of electrification leads to savings on infrastructure components, such as masts, wiring or conductor rails. This results in lower material and space requirements and reduced “optical impairment”, that in turn leads to cost savings and might increase acceptance. In addition, complicated sections of the route can also be omitted, which might simplify the approval procedures. On the other hand, a lower degree of electrification imposes higher requirements on the vehicles and the performance of the electrified sections.

In order to ensure the same proportion of electric driving, vehicles in a partial electrification system must have batteries large enough to bridge the non-electrified sections and cope with the higher number of charging cycles. In the electrified sections, the infrastructure must have a higher power output with the same number of vehicles, since not only the driving energy but also the energy for recharging the batteries must be transferred within these sections.

However, larger batteries lead to higher vehicle costs as well as a higher vehicle weight and associated payload. In contrast, ERS-HEV with smaller batteries would have a shorter driving distance on electricity outside the electrified sections and might thus lose ecological and economic advantages.

As explained above, considering sections that are not technically feasible for electrification or can only be electrified at great expense, an upper limit of 90 percent electrification appears reasonable. At a very high degree of electrification almost no restrictions to the performance of the vehicles are expected and a high level of supply robustness can be guaranteed. In this case a maximum proportion of the total mileage of electric driving can be achieved regardless of the battery size.

With the same number of vehicles, the requirement for power output per electrified kilometre is reduced compared to a partial electrification. The performance limits of the infrastructure will only be reached with a higher number of vehicles.

Technical options for increasing performance are the installation of additional substations, and reinforcement lines in the case of an overhead line system. With a partial electrification, the gaps can also be closed. In addition, the voltage level can be raised to further increase the performance of the system. An adaptation on the vehicle side would be necessary in this case.

Infrastructure costs

The ERS infrastructure costs consist of the supply line from the feed-in point to the respective substation, the substation itself and the actual energy supply infrastructure along the road. Further costs can be incurred with passive protective equipment and structural adaptations to the road. The main differences in the costs of the ERS systems under consideration are related to the energy supply infrastructure along the road, i.e. either masts and overhead lines or longitudinal cabling, switching devices and conductor rails, or longitudinal cabling and induction loops.

So far, only estimates for different system designs are available for all ERS systems [18], [19], [20]. In addition to fundamental uncertainties, which can be justified by the early technological stage, considerable cost differences can occur depending on the assumed performance of the system and the distance to the medium-voltage grid. Cost ranges of 1.7 to 4.1 million € per kilometre are given for the overhead line system, accounting for the different framework conditions [19]. The cost rate refers to equipping one kilometre of road with overhead line infrastructure in both directions of travel and includes all costs starting from the connection to the medium-voltage grid. The construction of a comparable network based on a rail technology or an inductive system is currently estimated to be in the same order of magnitude [20].

Savings due to partial electrification are not proportional, because the same total amount of energy per distance must be transferred to the vehicles. It is not possible to save the corresponding components and subsystems, as their costs correlate with the installed capacity. These include, above all, the substations including their connection to the medium-voltage grid. Significant savings are only possible for components and expenditures that scale directly with the length of the electrified line. Lower costs are also to be expected for planning and approval than in the case of largely universal electrification. The cost reduction is difficult to quantify and always depends on the specific route (topography, distance to the medium-voltage network, frequency of complicated sections).

Advantages and disadvantages of different ERS concepts

In recent years there have been several studies and demonstrations of solutions for road electrification, and each one presents its own advantages and disadvantages. Although product development has not yet been completed for any solution, it is our opinion that advantages and disadvantages, for future deployed and operational ERS technologies, can be anticipated from today's perspective and based on the current state of knowledge.

In general, the overhead line concept is currently the most mature technology and system prototype demonstrations have occurred in an operational environment. But there is not yet any completed product system that has been proven through successful mission operations from end-to-end with high-traffic intensity. In the case of future deployed overhead line systems that are used in a successful operation, we anticipate the following advantages:

- no impact on the roadway surface and interior,
- no dependency on roadway quality,
- medium to high power,

and the following disadvantages:

- negative impact on the visual impression of the road,
- allocates space over and alongside the road,
- large and heavy power receiver devices on the vehicles,
- not applicable for all kinds of vehicles.

A few proposed rail solutions have been validated on test tracks and there is, at the moment, one ongoing demonstration in an operational environment. In case of future deployed rail systems that are used in a successful operation, we anticipate the following advantages:

- can be used by various kinds of vehicles,
- technology suitable for charging of different vehicles with various power needs,
- minor visual impact.

and the following disadvantages:

- impact on road structure,
- exposed rail in the roadway surface (more or less easy to access),
- need for maintenance due to dirt, snow and ice,
- exposed power receiver device in rough environment underneath the vehicle.

The wireless solutions are technically advanced and appealing from a user perspective, but they also present the least mature technologies. More studies and research are needed. In case of future deployed wireless systems that are used in a successful operation, we anticipate the following advantages:

- not visible for outside viewers,
- no add-on technology with moveable parts,
- the power receiver is not subject to mechanical wear,

and the following disadvantages:

- impact on road structure,
- medium to low lateral tolerance,
- generates magnetic field,
- low to medium power transfer.

The above reasoning about advantages and disadvantages of deployed operational systems assumes that compliance with regulatory requirements, e.g. on functional safety and maintenance, can be achieved.

The maturity of different technologies in terms of technology readiness levels (TRL) was discussed in 2016 by Sundelin, Gustavsson and Tongur [21], but the development of ERS technologies is fast and there is thus a need for recurring maturity evaluations. The possibility of utilizing rail technologies for automatic charging of cars, that are stationary or moving slowly over short distances, has been discussed by Gustavsson, Börjesson, Eriksson and Josefsson [22].

Complementary drive systems and fuels

Several options for heavy duty trucks are under consideration, besides ERS, in order to achieve future fossil free transports. These options could either be independent of- or integrated with future ERS (as part of the ERS vehicles). The discussed drive systems are in general either based on combustion engines using conventional fossil diesel fuel, biomass-based fuels and so-called electrofuels, methane gas (e.g. liquefied natural gas, LNG); or on-board storage of either electricity (in batteries) or hydrogen (for conversion into electricity via a fuel cell).

In general, fuels based on biomass have challenges with high costs and limited renewable feedstock availability. Sufficient power from renewable electricity generation is a general challenge for electrofuels, batteries and hydrogen.

A brief technical overview of drive systems and fuel options is given below. Afterward these drive systems and ERS are compared along economic, environmental and operational criteria.

Overview of drive systems and their fuels

Diesel drive system fuels

The diesel engine is by far the most common drive system used in heavy commercial vehicles today and therefore provides a reference for the evaluation of alternative drive concepts. The major strength of the diesel drive system is the high energy storage density of the diesel fuel, which means that the payload is only slightly affected by the on-board storage of the energy carrier. Despite the moderate efficiency of the diesel drive system compared to a fully electric one, diesel trucks can cover ranges of more than thousand kilometres. In addition, there is also an established and comprehensive refuelling infrastructure, which means that the refuelling process does not impose restrictions on logistical freedom. The weaknesses of the diesel drive system are found primarily in relation to its environmental characteristics (greenhouse gas, pollutants[3] and noise in urban areas[4]) and its limited potential for further development while retaining its cost competitiveness and freedom to operate.

The primary fuel for diesel trucks today is **fossil diesel**, but the diesel engine can use a number of **renewable diesel fuels** without major modifications. The most common renewable alternatives today are Fatty Acid Methyl Esters (FAME) called **biodiesel** and hydrotreated vegetable oils known as **HVO**. These fuels can either be blended or used neat. Depending on the production process and evaluation method biodiesel and HVO can lead to significant reductions in greenhouse gas emissions. However, the availability of both fuels is limited as they are based on vegetable oils and waste streams.

[3] Air pollutant emissions of diesel trucks have significantly decreased with the Euro VI standard and the use of exhaust aftertreatment i.e. diesel particulate filter (DPF) and selective catalytic reduction (SCR). However, the aftertreatment remains a challenge in respect to lower performance in real world operation (low temperatures) and bears the risk of malfunction or manipulation by vehicle owners.

[4] Noise at low speeds is dominated by the engine, whereas noise at higher speeds is dominated by the tire/road interaction that is fairly the same for all drive systems.

Methanol is another option which has been explored and tested in different vehicle applications in recent years. Methanol is primarily used in Otto engines and often blended in small proportions in gasoline, but can also be used in diesel engines and theoretically in fuel cells. In addition to reduced greenhouse gas emissions when produced from renewable resources, methanol has potential for improvement of regulated exhaust emissions. Methanol can be produced from a wide range of renewable and fossil feedstocks such as any type of biomass, fossil methane gas or coal. The process is relatively simple and established for other applications. Obstacles for methanol use are lack of infrastructure for distribution, low energy density compared to diesel fuel, and public acceptance since methanol is toxic and therefore needs to be handled carefully[5].

Also, **dimethyl ether (DME)** can in principal be used in diesel engines but the fuel injection system and tank need to be modified. Therefore, DME cannot be blended with traditional diesel fuel and a separate filling infrastructure is needed. DME is a gaseous fuel that could be distributed in liquid state under 5 bars pressure. No soot formation during combustion is an advantage and also makes it easier to reduce NO_x. The process to produce DME from renewable resources is rather straight forward and almost identical to that of methanol since the DME process is just adding one step by dehydration of methanol. The main obstacles are lack of infrastructure for fuel distribution and limited availability of vehicles[6].

Electrofuels (also known as e-fuels) produced from electricity and CO_2 by a Power-to-Liquid (PtL)/Power-to-Gas (PtG) process are increasingly under discussion. The primary energy source is electricity which is used for production of hydrogen (electrolysis) that is used together with CO_2 in further processing into any carbonaceous fuels. This option makes (renewable) electricity available for existing diesel and gasoline drive technologies with their established supply infrastructure. However, the production of electrofuels is comparatively less efficient than the direct use of electricity as high amounts of electricity is required. On the other hand, electrofuels in principal offer potential for balancing the power system and store energy over longer times and are often discussed in this respect. Nevertheless, electrofuels would result in a significantly higher power demand compared to direct use of electricity.

Liquefied natural gas and biogas

In recent years, gas drive systems have also emerged as an alternative to diesel technology worldwide. **Liquefied natural gas (LNG)** is produced by liquefying fossil methane gas, and **liquefied bio gas (LBG)** is produced using methane gas from renewable sources. In contrast to biodiesel, any degrees of admixture of fossil and renewable methane can be used (up to 100 percent) without requiring any modification of the vehicle. While compressed natural gas (CNG) and compressed bio gas (CBG) is often used in passenger cars and light commercial vehicles, LNG and LBG

[5] Professional users, e.g. in the marine sector, can rely on spill free systems and adequate handling procedures.
[6] Vehicle producers working on DME fuelled trucks are primarily Volvo Trucks, Ford and Isuzu and some Chinese actors.

are suitable for use in long-haul heavy-duty vehicles due to their greater energy density.

In general, LNG and LBG can be used in both diesel and Otto engines. However, Otto engines running on fossil LNG offer only minor (if any) savings in greenhouse gas emissions compared to diesel engines running on fossil diesel fuel due to lower fuel efficiency. Diesel engines running on LNG have an energy efficiency that is similar to diesel engines running on conventional diesel fuel. When comparing fossil LNG and fossil diesel, LNG generates approximately 20 percent less tailpipe greenhouse gas emissions due to the lower carbon content of methane.

LNG and CNG are identified as fuels of interest for the European transport sector [23], and vehicles are available on the market. However, LNG and CNG are still fossil fuels, require a complex fuel station technology[7], bear the risk of methane slip, and fuel stations are not available today in considerable numbers.

Hydrogen and fuel cells

A **fuel cell** drive system is an electric drive system where the energy source is **hydrogen** gas (H_2) that, together with oxygen from the air, is converted to water and electricity within a fuel cell. A battery is generally required to reduce the effect of power changes. The generation of electricity in the fuel cell does not cause direct greenhouse gas or pollutant emissions, but the production and preparation of hydrogen as a fuel are energy-intensive processes. Fuel cell trucks only exist in very limited numbers today.

Hydrogen can be produced by electrolysis from water using electricity or by steam-reforming from fossil or renewable methane gas. The used energy for hydrogen production is crucial for the climate impact, and the lowest greenhouse gas emissions are only assured if the hydrogen is produced by electrolysis using renewable electricity. The energy efficiency of hydrogen production by electrolysis and end-use in fuel cells is lower than for pure electric drive systems but not as low as for the electrofuel option.

Hydrogen must be either stored in high pressure tanks or liquefied because of the low volumetric energy density, and thus requires a complex fuel station infrastructure. Some fuel stations for cars and busses are available in the EU, but there is not yet any fuel station network suitable for heavy duty trucks.

Battery electric drive systems

Application of **pure battery electric** drive systems for road freight transport have previously been focused on light and medium weight commercial vehicles due to the low energy density and the high power-to-weight ratio of battery storage. In the case of inner-city delivery services, the benefits of the electric drive (such as the high energy efficiency and brake energy recuperation) outweigh the disadvantages associated with the additional weight of the battery. In the case of regional transports, the vehicles cover a short daily mileage giving that a limited range is not much of a restriction.

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[7] The fuel tank for LNG must be cooled, and special cryogenic fuel pumps and dispensers are needed.

Most truck manufacturers are involved in the development or production of pure battery electric trucks in the light and medium weight segments, and applications for heavy duty trucks have been considered to be inconvenient. However, the American electric car manufacturer Tesla Motor announced in 2017 a traction unit with a range of up to 800 km designed for a 40 tonne semi-trailer truck (Tesla Semi) to be available on the market from 2019 and onwards.

Stationary recharging of very large batteries for long-haul heavy-duty trucks requires very high charging powers in order to keep charging times sufficiently short. Nationwide networks of such charging facilities are not available today.

Characteristic	**Diesel**	**LNG & LBG**	**Fuel cell**	**Pure battery electric**	**ERS**[8]
Engine and fuels	Diesel engine and fossil diesel, biodiesel, methanol, DME or electrofuels	Otto engine (mostly, diesel engine is possible) and fossil or renewable methane	Electric motor and electricity from fuel cell using hydrogen	Electric motor and electricity stored in battery	Electric motor and direct electricity from grid
Storage	Conventional fuel tank	Cryogenic tank (3 to 10 bar, at -160 °C)	Pressurized tank (700 bar)	Large battery	Small battery
Fuelling/charging point	Conventional filling station	LNG filling station	Hydrogen filling station	Charging station	Electric Road System
Power density	36 MJ/l (fossil diesel)	21 MJ/l	4.6 MJ/l (700 bar)	100 Wh/kg battery	Not Applicable
Achievable range	> 1 000 km	> 1 000 km	> 800 km (today)	< 400 km (today)	Depends on infrastructure
Efficiency tank-to-wheel	≈ 40 %	≈ 40 %	≈ 45 %	≈ 85 %	≈ 85 %
Main challenges	Consumption, pollutant emissions, feed stock availability	Consumption, pollutant emissions, infrastructure, reduced range	Costs, infrastructure, reduced range	Costs, infrastructure, power grid, reduced range	Costs, infrastructure
Pollutant emissions	High, but decreasing with EURO VI	Depending on technology	No local vehicle emissions	No local vehicle emissions	No local vehicle emissions

[8] ERS is in this comparison a pure electric drive system, ERS-vehicles in operation outside an electrified road need to be complemented with other drive systems.

Comparison of complementary drive systems

The following analysis is designed to evaluate ERS for trucks in comparison to other alternative operational concepts. It follows three strategic assessment criteria:

- Economy
- Environment, energy and resources
- Operational and organisational aspects

Comparison of economy

In terms of economic viability, diesel trucks are currently the benchmark and have dominated the development of the logistics industry and its cost structures. A global sales market has ensured high quantities of relatively few diesel engine variants. Nevertheless, the market is exposed to uncertainty due to fluctuating oil prices and future emissions legislation, and the possibility to counter this uncertainty with engine innovations is limited.

Common challenges associated with alternatives to fossil diesel are getting fuel production started, lack of distribution infrastructure, and availability of vehicles since the current policy framework creates uncertainty among investors.

Biodiesel and electrofuels can be used in conventional diesel engines, without or with minor modifications, however the fuel cost in comparison with fossil diesel is higher. Current assessments of total cost of ownership (TCO) for vehicles using electrofuels in a time frame from 2020 to 2030 are considerable higher than TCO for fossil diesel vehicles (see Figure 6). DME is also a viable alternative for diesel engines since there are only minor modifications to the vehicles such as fuel injection equipment and on-board tanks. In economic terms DME is one of the most cost-effective ways to produce fuels from renewable energy resources and at large scales DME vehicles are estimated to be cost neutral to standard diesel vehicles.

Gas drive systems are another viable alternative to diesel drive systems for heavy commercial vehicles. The procurement costs for gas drive vehicles is high in comparison with diesel vehicles. However, TCO in a time frame between 2020 and 2030 are frequently assessed to be even lower than TCO for fossil diesel vehicles due to lower operational costs (see Figure 6).

The prevalence of hydrogen filling stations and cost reductions for fuel cells, hydrogen and hydrogen tanks will ultimately decide whether the fuel cell system can be competitive and prevail over the other drive systems on the market. Current assessments of TCO in a time frame from 2020 to 2030 are significantly higher than TCO for fossil diesel vehicles (see Figure 6).

Pure battery electric drive systems for long driving ranges and heavy loads have high vehicle procurement costs, and may also reduce the possible goods weight. Although the electric drive train should have a longer service life than a conventional drive system, there is insufficient data on the development of the battery life cycle when used for heavy road freight transport. Current assessments in a time frame between 2020 and 2030, place TCO for battery trucks slightly higher than TCO for fossil diesel trucks (see Figure 6). The development, however, is very dynamic and further potentials for cost reduction exist.

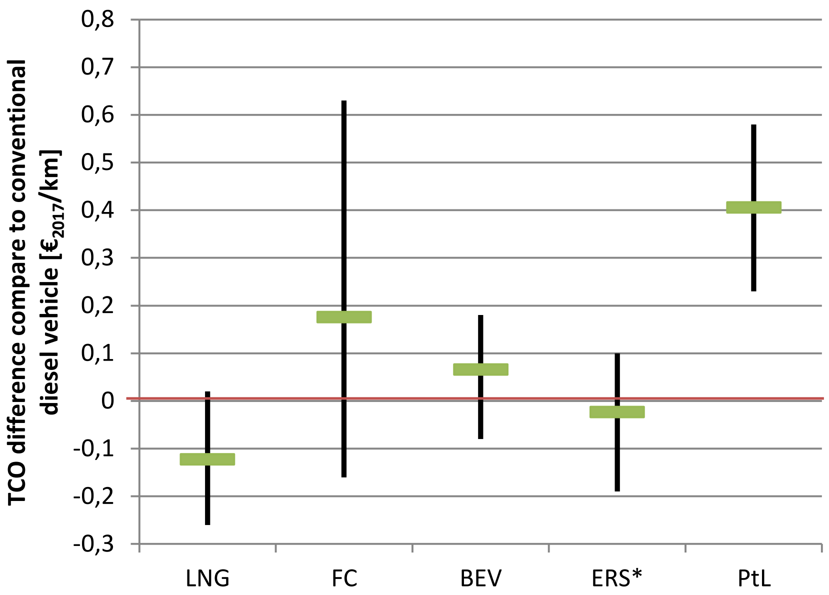

Figure 6: Differences in total cost of ownership (TCO) for different complementary drive systems and fuels compared to a fossil diesel vehicle 2020–2030 (*ERS with overhead lines). PtL means Power-to-Liquids i.e. electrofuels. The green horizontal bars show averages and the black vertical bars shows intervals between different studies compiled by Plötz et al. [24].

ERS vehicles have the same operational cost benefits as pure battery electric vehicles without the disadvantage of costly large battery storage. A rise in crude oil prices and the low volatility of the electricity price compared to the diesel price would create a relatively secure long-term planning horizon for electric drive systems. The main challenges are lack of ERS infrastructure and missing real-world experience. In the longer term, operating cost benefits could be used to partially finance the infrastructure, but the transition period remains a challenge and potentially needs public intervention. Current assessments of TCO in a time frame between 2020 to 2030 are slightly lower than TCO for fossil diesel vehicles (see Figure 6).

There are risks related to financing the market introduction phase. Innovative business models and financing strategies might be required in order to reduce the uncertainties regarding deployment of infrastructure and vehicles especially in the initial phase.

Comparison of environment, energy and resources

The energy efficiency of modern diesel engines – and thereby reduction of fuel consumption and greenhouse gas emissions – will eventually approach its physical limits. The pollutant emissions from diesel engines can however be further reduced with a certain degree of technical effort. Additional reductions of greenhouse gas emissions from the engine can only be achieved through decarbonisation of the upstream fuel supply chain, which in turn can lead to resource problems if not managed in a sustainable manner.

Biodiesel and electrofuels could in principal be used to decarbonise diesel vehicles with no significant changes in fuel consumption and pollutant emissions. The consideration of overall greenhouse emissions must include the entire life-cycle from feed-stock/electricity generation to end-use. Even though biofuels can offer a significant reduction in greenhouse gas emissions, depending on the feedstock, challenges remain in respect to feedstock availability and/or (indirect) land use changes among others. Electrofuels produced from renewable electricity even would allow for decarbonisation of road transport, but overall energy efficiency is considerably lower compared to direct use of renewable electricity.

DME can also decarbonise diesel vehicles and the DME engine has roughly the same energy efficiency as a standard diesel engine. In addition, DME can help to reduce pollutant emissions mainly due to the absence of soot and relative ease of reducing nitrogen oxides (NO_x) emissions. DME can be produced from both renewable and fossil feed-stock. It is possible with a considerable sustainable supply of biodiesel and DME even though it will be limited [25].

Gas drive systems can help to reduce pollutant emissions, the climate impact varies with different feed-stocks. Currently, the greenhouse gas emissions from trucks using fossil gas is nearly the same as that of trucks using fossil diesel fuel (see Figure 7). This can be attributed to high energy losses involved in the liquefaction of fossil gas (LNG), the complex storage, and the lower energy efficiency of today’s gas engines. In order to achieve a sufficient contribution towards decarbonisation of road freight transport using gas drive systems, it is necessary to use gas from renewable and sustainable sources. For synthetic methane, as for electrofuels, the energy-intensive production must also be considered.

Pure battery electric drive systems are very energy efficient and pollutant emission free. The contribution towards decarbonisation depends on the electricity generation, and battery trucks facilitate a major reduction of greenhouse gas emissions in long-haul transport if operated with renewable electricity. However, energy and resource consumption of battery production has to be taken into account in a lifecycle perspective regarding the large battery packs required for long driving ranges. Well-to-wheel greenhouse gas emissions with the current EU28 electricity mix are only about 15 percent lower than for diesel fuel (see Figure 7). Further improvements, however, can be expected with progressing decarbonisation of the European electricity market. Direct use of electricity offers the most energy efficient use of renewable electricity. In comparison, use of electricity via electrofuels is a far less energy efficient pathway.

Fuel cell vehicles also have the general benefit of being pollutant emission free. The contribution towards decarbonisation depends on the climate impact of the electricity generated for hydrogen production. There are significant energy losses associated with the production of hydrogen and reconversion to electricity in the fuel cell: the overall efficiency is about 50 percent lower than for battery electric drive systems. However, production of hydrogen can be seen as beneficial in some cases when there is an electricity surplus and for processes where hydrogen is a secondary product. Energy and resource consumption for fuel cell must thus be taken into account in a lifecycle perspective. Furthermore, the implementation of fuel cell drive systems is determined by the availability of precious metals such as platinum required for catalysis.

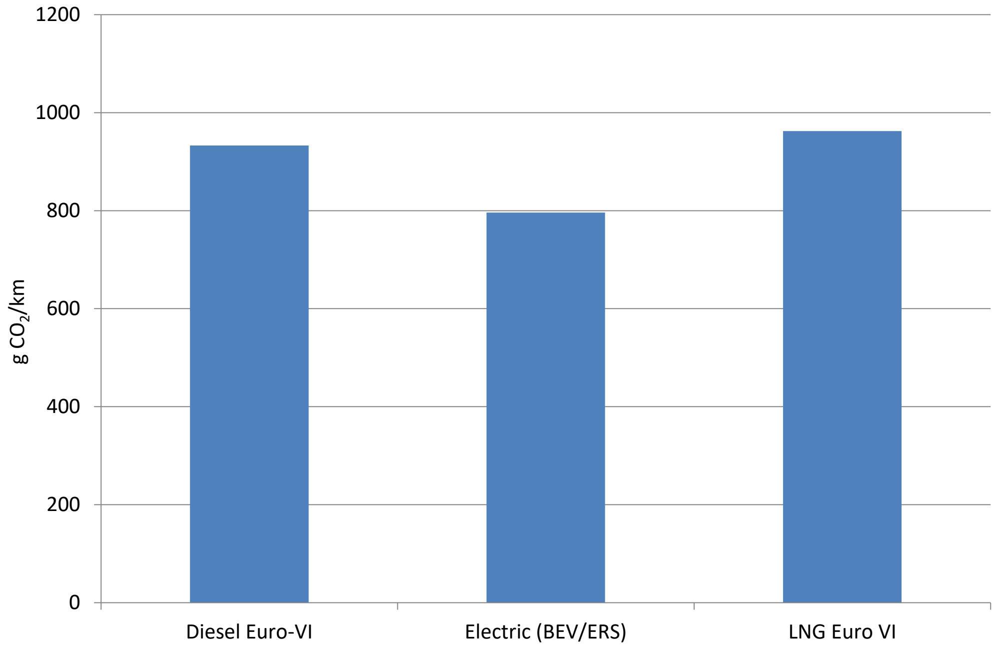

Figure 7: Comparison of well-to-wheel greenhouse gas emissions of 40 tonne trucks with average load EU28 electricity mix is used for BEV and ERS trucks. Source: https://www.ecotransit.org/.

ERS drive system are at least as energy efficient as pure battery drive systems due to the direct feed electric energy from the infrastructure. The systems are pollutant emission free and facilitate a major reduction of greenhouse gas emissions if operated with renewable electricity. However, the power requirements placed on the higher-level distribution network by the ERS must be taken into account. In order to operate an ERS truck outside the ERS infrastructure, a complementary drive system such as battery electric, fuel cell or combustion engine has to be added to the vehicle. This means that the resulting vehicle inherits the environmental, energy and resource properties of the added drive system.

However, with a relatively small battery pack it is possible to reduce the required degree of electrification of the road (i.e. proportion of electrified sections, see the section "Degree of electrification") and simultaneously facilitate zero emission driving to and from the ERS infrastructure.

Comparison of operational and organisational aspects

Diesel drive systems are the most familiar of the discussed systems and thus a benchmark for a comparison. The service network is excellent, and drivers know the technology. The second-hand market for vehicles is fully developed and the operator has a clear business case for the complete vehicle lifecycle. Biodiesel and electrofuels can, with zero or minor modifications, be used for the diesel drive systems and maintain benefits such as familiarity and flexibility of the technology. However, fuel availability is scarce, and the distribution networks need to be developed. In addition, there is a low operational risk due to access restrictions for diesel vehicles, e.g. in city centres, and this risk is increasing with challenges and debate related to air quality.

DME vehicle costs are judged to be neutral compared to standard diesel vehicles. The main challenges are availability of fuel and the second-hand market vehicle value as with all new alternative drive systems. The energy content of DME is roughly half of diesel so the tanks needs to be double size to get the same range as standard diesel vehicles. In the short term, new drive systems such as vehicles using DME is suitable for captive fleets as a start and can grow from there as infrastructure develops. In the medium to long term, DME can be applied to almost any type of transport case.

There are cost beneficial business cases for gas drive systems using methane in various forms, and there is a world-wide availability of methane. However, the operational range using compressed methane (fossil CNG and renewable CBG) is too short for long-haul road freight transportation. Vehicles using liquefied methane (e.g. fossil LNG) have long operational range, but are associated with high acquisition and maintenance costs, lack of experience regarding residual values, and an inadequate fuel infrastructure.

Pure battery electric drive systems have so far been prevented from being used in long haul road freight transportation due to lack of vehicles with adequate driving range and fast-charging infrastructure for commercial vehicles. However, if these obstacles can be overcome, battery electric trucks can become an interesting alternative for transportation operators due to flexibility and low operational cost. The limitations of battery technology must be considered for heavy duty applications, at least in the medium term.

Fuel cell drive systems have so far not been applied in commercial long-haul road freight transportation, but the technology is in development for heavy duty vehicles and could offer some advantages such as low maintenance costs. Vehicles and hydrogen fuel infrastructure need to be deployed in parallel in order to be accepted by the transportation actors. Even though a fuel cell drive system uses an efficient electric motor, the energy efficiency is low in a well-to-wheel perspective. Currently there are barely any mandatory specifications and conflicting signals from industry regarding fuel cell drive systems.

An ERS truck will probably utilize an electric drive system combined with a power receiver as well as a battery, fuel cell or combustion engine for operation outside the ERS infrastructure. The resulting vehicle cost is likely to be higher than that of a conventional diesel drive vehicle in the near future (an ERS truck without fuel cell or combustion engine might get a lower cost). One of the decisive factors will be whether a higher vehicle cost can be balanced by a lower operating cost. An ERS infrastructure enabling a high share of electric drive will be beneficial for fleet operators with ERS vehicles. There is a discussion about standardization in view of the international integration of freight transport flows. Also, several legal questions still must be clarified before ERS can be introduced commercially.

Conclusions

The national climate protection targets in Sweden and Germany require a significant reduction of transport-related greenhouse gas emissions in the near future. Heavy commercial vehicles account for more than 20 percent of these emissions in both countries.

Electric Road Systems (ERS) is a technology area that is currently being tested in several pilot projects in both countries. The technology offers the possibility of using (renewable) electricity in long-distance truck transport. This can reduce dependence on fossil fuels, avoid greenhouse gas and air pollutant emissions, and increase energy efficiency in the transport sector. There are currently three main concepts for road electrification: overhead lines, conductive rails in a road surface, and wireless solutions. In Germany the focus of development and testing is currently on overhead line systems, while in Sweden the whole range of possible solutions is considered. Both for the design of the infrastructure and the vehicle configuration, different variants are possible which can be adapted to the respective conditions and can take further technological advances (e.g. in battery development) into account. The three conceivable energy supply systems are all still in the development phase, and the various solutions have different levels of maturity. Robust assessments of system-specific strengths and weaknesses, and credible validations of infrastructure costs estimates need further studies and advanced demonstrations in operational environments.

In addition to ERS, other technology options are available in principle for decarbonizing long-distance trucks, even if most of them have not yet reached full market maturity. Battery electric and fuel cell trucks are discussed as alternative drive systems. Battery electric trucks in particular are attracting increasing attention as a result of the advances in energy storage technology. A further option is a continued use of the combustion engine in combination with renewable fuels such as biomass-based fuels and electrofuels. In a comparison of technologies, the direct use of electricity by means of batteries or ERS is characterised by the greatest energy efficiency and likely the lowest overall costs. Fuel cell vehicles, on the other hand, have significantly lower energy efficiency and higher overall costs. The use of renewable fuels in internal combustion engine trucks is characterised by the highest total energy requirement. Under the requirement of climate neutrality, depending on the type of fuel, there are restrictions with regard to the available quantities (e.g. biodiesel from residues) or costs (e.g. electrofuels).

In view of the different requirements to be met by trucks in freight transport depending on the application, different types and combinations of technologies are also conceivable in the future. The combination of ERS and battery-powered trucks, offers numerous synergies, for example use of charging infrastructure and economies of scale due to identical vehicle components.

All alternative drive systems require the development of additional energy supply infrastructure and they are also associated with higher vehicle costs, at least during the introductory phase. Vehicle costs are reduced primarily through economies of scale in production and infrastructure costs are reduced by an increased utilization rate. Thereby a significant cost reduction will only be achieved by an increase in market penetration of the corresponding drive system. The resulting chicken-and-egg causality dilemma between the expansion of the infrastructure and the number of users is inherent in all alternative drive systems and can only be overcome by finding application scenarios with a simultaneously high utilization rate of vehicles and infrastructure.

The central challenge of ERS is the swing-in phase. The first core network will be characterized by high costs, which are offset by a small number of vehicles. In the long term, however, the infrastructure costs will only represent a fraction of the total costs. Appropriate incentives or state subsidies are therefore recommended to bridge the initial phase and enable a functional system in the future. Nonetheless, the swing-in is not a specific characteristic of ERS but rather a characteristic of every new infrastructure network, as hydrogen, LNG or recharging stations.

This report provides an overview of the current state of technology and conceivable configurations of the ERS. In subsequent stages of the CollERS project, a possible German-Swedish ERS corridor will be used to concretize possible design variants and the spectrum will be further differentiated on the basis of different applications.

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Annex: Research projects contributing to CollERS

Research and Innovation (R&I) Platform for Electric Roads

The objective of the Research and Innovation (R&I) Platform for Electric Roads is to enhance Swedish and Nordic research and innovation in this field. This is done by developing a joint knowledge base through collaboration with research institutes, universities, public authorities, regions, and industries.

The result from the project is expected to create clarity concerning the socioeconomic conditions, benefits, and other effects associated with electric roads. The project activities cover investigations of benefits from the perspectives of various actors, implementation strategies, operation and maintenance standards, proposed regulations, success criteria for high acceptance among people and society, as well as development of international collaborative activities.

RISE Viktoria coordinates the project and works together with the research partners Chalmers University of Technology, KTH Royal Institute of Technology, Lund University, the Norwegian Institute of Transport Economics (TØI), and the Swedish National Road and Transport Research Institute (VTI); with the industry partners Fortum, Profu, Scania, Vattenfall, and Volvo Group; as well as with the deployment proposals managed by Airport City Stockholm, Region Gävleborg, and Region Kalmar.

The project has knowledge transfer with the ongoing ERS demonstrations on public roads in Sweden, and a reference group of about twenty parties have an important advisor role.

The project commenced in the autumn of 2016 and will continue until December 2019. The results are disseminated through publications, information meetings, seminars, and an annual international conference. The project has received financial support from the Swedish Program for Strategic Vehicle Research and Innovation (FFI) and the Swedish Transport Administration.

StratON

The StratON project – Assessment and introduction strategies for overhead catenary heavy duty vehicles – analyses the potential of an electrification of heavy commercial vehicles by means of overhead catenary, grid-bound energy supply (OC-HDV). In addition, the project further evaluates alternative propulsion and energy supply systems, such as hydrogen fuel cell vehicles.

The StratON project analyses for the OC-HDV system the overall costs, emissions reductions potentials, and technical and legal feasibility and takes into account various expansion varieties. Originating in the in-depth analysis of the OC-HDV system, potential market introduction scenarios will be developed.

Exchanges with experts and the project advisory board at national and international levels support the technology assessment and development of market introduction

strategies.

The StratON project can provide important findings concerning obstacles and suitable business models for overhead catenary heavy-duty vehicles, thereby offering an important foundation for a possible market launch.

The StratON project is a joint initiative of three partners, Oeko-Institut e.V., Fraunhofer-Institut for Industrial Engineering IAO and Heilbronn University, as well as a cooperation with Intraplan Consult GmbH. The research project is funded by the German Federal Ministry for The Environment, Nature Conservation and Nuclear Safety.

Roadmap OH-Lkw

Exploration of possible introduction strategies of electrically driven heavy commercial vehicles and their energy supply by means of ERS. Coordinated by ifeu.

First a **feasibility analysis of ERS** will identify, describe and evaluate advantageous applications for ERS technology, considering possible operating concepts (e.g. hybrid-electric vehicles, shuttle operation on fixed routes) and the cost difference to conventional drives (total cost of ownership). Geographically specific application profiles will be derived on the basis of data from a traffic model and logistic data.

As a second step a **market introduction strategy for ERS** will be developed and the implications for the expansion of infrastructure be analysed with a focus on the first phase of market launch until about 2030. This includes the identification of cost-effective development strategies based on developments in battery costs, energy prices and traffic volumes, characterization of the strategies in respect to environmental impacts and resource consumption and investigation of the impact on the energy system on the basis of electricity market and distribution network models.

Finally, a **roadmapping** will be undertaken. For logistically, economically and environmentally promising introduction strategies, concrete steps for implementation are to be investigated. The main questions are: Which business models have the potential for market uptake and which stakeholders could be involved? Which policy elements are decisive for implementation? What are the interactions with possible introduction of other alternative drives? The results of the three work packages are to be consolidated into a roadmap.