# SWEDISH ROADMAP FOR ELECTRIC ROAD SYSTEMS


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## Abstract

Electric Road System (ERS) is a technology concept that has the potential to heavily reduce the fossil fuel dependency in the transport system. ERS is defined by electric 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 road-side rail, overhead-line, and wireless solutions. The basic technologies for power transfer from the road to vehicles in motion have been developed through various research projects across the globe. ERS is now being tested on public roads in Sweden and at least two more are being planned. This paper shows the Swedish roadmap for electric road systems and includes steps like funding, ownership, technology, demonstration and plans for roll out.

**Keywords:** Climate, Heavy duty vehicle, Electric road system, Electrification, Roadmap

## 1. Introduction

Mobility and transportation are key functions in the modern society according to J-P Rodrigue (2017). Each transport operation leave a footprint in terms of uses of finite resources (i.e. fossil energy), emission of greenhouse gases and other local pollutants. The request for, and thus the effects of, transportation grows in the modern society and especially in urban areas (R. Cervero; 2013). At the same time, in a sustainable society all subsystems including transportation must be both functional and sustainable. For passenger transport through road vehicles we have seen a steady increase in global sales of electric vehicles. According to IEA (2017a) over 750 000 electric vehicles were sold during 2016 and the total stock surpassed 2 million electric cars. Also the stock of electric busses is increasing, with a total number of 345 000 busses, with more than 99% of the in China. However, for the heavy duty long haul sector the electrification have not reached the same market penetration.

Heavy goods vehicles travelling by road are responsible for around 25% of the road transport system's energy utilisation, and more or less the same percentage of carbon dioxide emissions. The Riksdag (Swedish Parliament) has made a decision on a climate law which will involve a compulsion to reduce carbon dioxide emissions from the transport sector by at least 70% by 2030, before reaching a zero level in 2045. Similar tendencies present themselves in other parts of the world, and stakeholders involved in the conversion of the transport sector are very much in agreement that electrification has an important part to play.

The forecast increase in freight transport work, in combination with attempts to make the freight transport system fossil-free, presents a monumental challenge. Long-term instruments will be needed in order to drive this changeover. Every transport type will be needed to ensure a sustainable supply of goods. Therefore, every transport type must be permitted to develop both individually and together in cooperative solutions. This will also reinforce reliability and redundancy in the overall transport system.

The publicly funded Swedish road network is almost 15 times as long as the equivalent rail network. Road network capacity is generally good. The road network reaches more or less everywhere in Sweden. Railways and shipping reach only a small percentage of the destinations for freight transport. Rail and maritime transport could stand responsible for the entire transport route for only a minor percentage of transport operations. The road therefore carry approx. 89% of the freight transported within Sweden, and heavy goods vehicles are responsible for 65% of all transport work in Sweden.

These ratios between road and rail transport may only change marginally over the next few decades. The capacity of the rail network is already utilised extensively, and redundancy is limited. Thus, the road network will continue to stand responsible for most of the transport work in the Swedish freight transport system for the foreseeable future. This is precisely why it is extremely important for goods vehicles travelling by road to reduce their energy consumption and environmental impact.

Given the research and knowledge we have at present, it is not apparent that heavy goods vehicles will be capable of carrying the electric power required in order to complete long journeys without sacrificing parts of their carrying capacity. If it is to be possible to run them on electricity for the most part, it is necessary to have another energy storage facility on board, such as fuel cells, or else electricity must be supplied continuously while the vehicle is in motion. There are a number of different technical solutions with regard to how heavy goods vehicles could be powered more or less continuously along their transport routes. Dynamic transfer of power or electric road systems (ERS) need roll out of a new infrastructure. However, the potential is significant as less than 5% of the state owned road network is responsible for more than 50% of the greenhouse gas emissions from heavy goods vehicles.

The objective of this paper is to describe the Swedish national roadmap for electric road systems. This paper is a policy oriented presentation rather than a traditional research paper. However, the policy document identifies several areas where additional research is needed.

## 2. Electric Road Technologies

The transition to a sustainable transport system requires a portfolio of policy measures and accompanying technical and societal solutions. In the white paper from 2011 the European Commission state that innovation will play an important role in the transition to a competitive and resource friendly transport system. The entire chain from research to deployment needs to be assessed in an integrated way. Measures will be needed is all areas such as transport efficient society, energy efficient vehicles and renewable energy including electrification. Both electrification and bioenergy will be important technology pathways for the future transport system. However, according to the IEA technology roadmap on delivering sustainable bioenergy, transportation biofuels accounted for 4% of the road transport energy demand globally in 2016. In Sweden, biofuels reached almost 20% of the fuels sold during the same time. This is the same order of magnitude of bioenergy potential, compared with final energy demand, on a global scale by 2060 according to IEA (2017b). Bioenergy alone will not be able to supply the transport sector with energy, thus bioenergy needs to be combined with electrification in order to reach the long term sustainability goals. Although electrification of road transport has been known for long, dynamic transfer of electricity to road vehicles is an innovative system and need specific policy measures.

The technical solution involving the transmission of electricity to a vehicle moving on a road has existed since 1882, and trolleybus lines have been operating since 1902. In Sweden, trolleybus services were provided in both Stockholm and Gothenburg from 1941 up to the early 1960s. Goods vehicles powered by catenaries were also found in countries such as Germany and the Soviet Union in the first half of the 20th century, up to the 1960s. Sweden had a combined line for trolleybuses and tractor units for freight between Södra Station in Stockholm and Kvarnholmen in Nacka, a distance of around 5 km, between 1941 and 1959. A new trolleybus line was commissioned in Landskrona in 2003. But beyond trolleybusses, the field has largely lain fallow up to the last decade.

In recent years, electric road systems has increased in attention with several activities around the world. There are currently three main focus areas as regards technology for continuous, vehicle-related transmission of power from the infrastructure to electric road vehicles:

- conductive transmission via overhead lines
- conductive transmission via some form of rail or conductor in the road
- inductive transmission, via electromagnetic fields, from the roadbed

All three types have been tested in some form. The technology involving overhead lines has made the most progress. Overhead lines are not suitable for cars as the distance between the roof of the vehicle and the lines will be too great. Electric road systems with overhead lines, for heavy vehicles, have been tested on the Siemens test track, 2 km long, which is situated east of Berlin. Full vehicle integration has taken place in partnership with Scania for tests in Germany and Sweden. Integration in three different heavy duty vehilces, one of which is a Mack, is also taking place in the US.

Testing involving overhead lines on public roads began in Sweden in 2016 and in the US in 2017. The Swedish test is taking place on a 2 km section of the E16 motorway near Sandviken. The American test began in the summer of 2017 on a 1.6 km section of highway near Los Angeles (City of Carson) and ended early 2018. This is being managed by the South Coast Air Quality Management District (SCAQMD).

Elways AB has developed a road-side rail that is recessed in the road surface. This technology has been tested on a test track 400 metres long near Arlanda. Vehicle installation and the technology for switching between segments with rails have not been documented publicly as yet, but this forms part of the project. The second step is to test the electric road system on a public road 2 km long with the vehicle technology fully integrated in a DAF lorry, using E-Traction and a ZF powertrain. The installation was completed late 2017 and test will continue until 2019.

Alstom has carried out tests involving power rails in the road together with AB Volvo on a test track 300 metres long at the Volvo test site in Hällered. Vehicle integration has been carried out as part of a Slide In research project, which is funded by the Swedish Energy Agency.

The Swedish Energy Agency is currently funding a research project, with start 2017, which will demonstrate a solution involving a rail on the road which is based on technology by Elonroad. The biggest difference between this and the solutions by Elways and Alstom is that live parts of the Elonroad technology are significantly shorter and always fully covered by the vehicle.

Bombardier has spent more than five years researching dynamic inductive power transmission as a further development of its Primove commercial static solution. This system has been integrated in a Scania heavy duty truck and tested on a closed test track, 80 metres long, in Mannheim, Germany, as part of the Slide In project.

Commercial company OLEV, a spin-off company at KAIST University in South Korea has invested 50 million dollars in inductive power transmission since 2008. Their solution has been undergoing testing on a public road on the KAIST Daejeon campus since 2012. A bus route with two buses, with a total of 144 metres of installed coils, has been operational in Gumi since 2013.

An EU project headed by Spanish company Endesa, involving an electric bus route in Málaga using an autonomous bus, began in 2016. This route is based on inductive power transmission developed by CIRCE. Eight 80 cm-long 50 kW coils are installed along the road, which is 100 metres long. The autonomous bus is supplied by Gulliver.

The Transport Research Laboratory (TRL) in the United Kingdom has worked on behalf of Highways England to complete a pilot study on dynamic inductive power transmission along a network of major roads in the UK.

The World Road Association (PIARC) has established a Special Projects fund to enable it to respond outside the usual four-year Technical Committee cycle to emerging issues and priorities identified by its members. In 2018 this Special project was titled “Electric Road Systems (ERS) – a solution for the future?”. TRL was awarded this project and the final report is expected by the end of 2019

Germany’s Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) has issued an invitation to fund the demonstration of electric road systems based on overhead lines. Installation on public roads is expected to begin in 2018. The first of at least three projects has already been procured and will be implemented around Frankfurt in the federal state of Hessen.

The Norwegian Public Roads Administration is funding the Norwegian research organisation SINTEF for implementation of the ELINGO study, which is studying a wireless ERS solution on the E39 coastal road. This project is being coordinated with Swedish research projects.

The extensive EU project FABRIC demonstrated dynamic inductive power transmission on two test tracks in 2016. Inductive technology developed by the SAET Group has been tested on a test track near Turin, Italy, using a Fiat van. The second demonstration has been installed at the Vedecom test track in Satory, France. This power transmission technology is based on the commercially available static charging solution from Qualcomm, and has been installed on a Renault van.

ElectRoad in Israel has a 30-metre inductive transmission test track in Caesarea, Israel. This technology will be tested on 300-400 test track during 2018. The project receives funding from the Israeli government. In 2018 Electroad merge with another company and formed Electreon. If the outcome of tests is good, a section 18 km long between Eilat and Ramon International Airport may undergo development.

## 3. National Roadmap

In October 2017, the Swedish Government commissioned the Swedish Transport Administration to investigate and report the prerequisites for whether electric road systems could be a part of the state road network. The assignment was presented for the Government in November 2017 and below the roadmap is presented in brief. In figure 1 the major activities for the roadmap is shown.


**Figure 1 – Major activites in National roadmap for electric road system in Sweden**

### 3.1 Funding

One significant element when planning the introduction of electric road systems is to devise models with regard to how the facilities required are to be owned, funded and paid for. The government finances and owns most of the road infrastructure, while fuel and power for charging electric vehicles are provided under market conditions. Electric road systems are systems that involve these areas, and whether the government or the market is to own them cannot be assumed.

This paves the way for various funding models, e.g. development of electric road system technology on the road network in a public and private partnership (PPP), with the government as the client and project funding from private stakeholders. The government can then compensate the PPP counterparty with accessibility-based charges or transfer the traffic risk to the PPP counterparty by means of a concession, for example.

Funding and ownership models may also vary depending on which stakeholders and electric road system technologies will be involved. The choice of a funding model is also dependent on the extent to which a decision is made to electrify the road network, and on whether the system applies only to heavy vehicles or to cars as well. A business logic and business model that suits one technology will not necessarily suit another business model. How charges and taxes on both fuel and electricity develop will have a major impact on the business models.

As the forthcoming planning period will probably primarily involve carrying out further demonstrators and pilot projects, and as the electric road system technologies are still undergoing development, it may be relevant to use procurement procedures based on some kind of cooperation between the government as a road owner and stakeholders in the private sector.

Sweden has gained momentum as regards the development of ERS compared with the rest of the world thanks to active research and development work. Continued research, development and demonstration are of the utmost importance, and if it turns out that technologies emerge as early as the next planning period that would be appropriate to implement on a commercial basis, the Swedish Transport Administration will work to support earlier implementation, thereby helping to bring about faster development of the Swedish electric road system market.

### 3.2 Electric road system technologies

There are currently three main focus areas as regards technology for continuous, vehicle-related transmission of power from the infrastructure to electric road vehicles:

- conductive transmission via overhead lines
- conductive transmission via rails or conductors in the road
- inductive transmission via electromagnetic fields from the roadbed

In 2013, The Swedish Transport Administration launched a pre-commercial procurement within the area of electric road system. In total 13 projects were offering their solution, which were evaluated in three different steps. Of the candidates, two remained in the end and was offered a contract. The resulted in the construction of the first electric road, on public roads, for heavy duty trucks in the world. The inauguration was 22 June 2016. The second project, based on a conductive rail in the road surface was inaugurated 11 April 2018.

Several other ERS technologies are under development, and these technologies should also been given the opportunity to be demonstrated on public roads. The Swedish Transport administration launched a second pre-commercial procurement, in February 2018, to gain additional knowledge on further ERS. The purpose of the pre-commercial procurement is to gain knowledge about construction, operation and maintenance of electric road systems.

### 3.3 Planning and utilisation

It is thought that electric road systems will be able to assist with both long-term climate targets and transport policy targets. This primarily involves the consideration target, specifically the limiting of climate impact with which electric road systems will assist by making it possible for vehicles to become independent of fossil crude oil. There may also be positive contributions to the general generation target in that electric vehicles do not generate exhaust emissions. In the longer term, electric road systems may also help to achieve the function target by ensuring that the transport system has plenty of access to energy that is sustainable in the long term. Depending on how costs and instruments develop, electric road systems may also help to increase commercial competitiveness due to the fact that new systems and solutions will be developed in Sweden and result in lower transport costs. Initial assessments show the carbon dioxide emissions from heavy goods vehicles may be reduced by more than 200,000 tonnes for relatively busy sections 250-300 km long if 70% of these heavy duty vehicles use the electric road system. This traffic flow is essentially equivalent to the traffic flow of heavy vehicles on the Stockholm-Malmö-Gothenburg route, a distance of 1,365 km. The benefits may increase if cars use the electric road system as well.

There needs to be further analysis of which roads are appropriate for electrification and which group of road users is to use the electric road system. The first sections of electric road systems will probably be linked with areas with a stable transport requirement over time, probably with shuttle service elements. This work must take place in partnership with regional stakeholders and intended users and suppliers of the electric road system.

Different electric road system technologies will need varying adaptation to the landscape and natural and cultural environments. It is thought that ground-based technologies will have less impact, while technologies involving overhead lines will have a clearer impact on the urban environment and landscapes from a road user perspective and with regard to residential and outdoor recreation considerations.

The Swedish Transport Administration or the stakeholder responsible for the construction and operation of infrastructure must be compliant with the legal requirements specified in the Environmental Code and the Historic Environment Act, for instance, when adapting the infrastructure. The Roads Act and the Railway Construction Act also specify a general requirement indicating “that attempts must be made to achieve an aesthetic design” and that “the urban environment and landscapes, and natural and cultural assets, will be taken into account”. This is also applicable to the design, instruction and operation of infrastructure for electric road systems.

### 3.4 Standards and regulations

Making a switch towards a more transport-efficient society in which electric road systems are assumed in the long term to become part of the government road network in Sweden is dependent on a coherent legal framework. This involves a framework which underpins parallel development lines such as automation, sharing economy, digitisation, electrification, etc. and which emphasises the importance of efficiency and the impact of regulations in community planning.

An initial analysis has identified a number of areas where legal aspects need to be reviewed: access to land for the construction of necessary infrastructure, funding for construction and operation of necessary infrastructure, instruction and operation of necessary infrastructure and distribution of power to the electric road system network. The Swedish government, via the Swedish Transport Administration, has what is known as right of way for the existing public road network. It is unclear as to whether land outside the road area can be earmarked for components of the electric road system. If the electric road system infrastructure is to be owned by a stakeholder other than the Swedish Transport Administration, right of way cannot be applied directly. However, it is possible for the Swedish Transport Administration to grant a permit for construction of facilities within road areas.

A similar situation occurs in respect of power grids and power distribution. Permits, or what are known as grid concessions, are generally required for all high-voltage lines. Any legal entity running grid operations must not trade in electricity at the same time. This means that the stakeholder that owns the power grid is prevented from selling power for vehicles via its grid. However, there are options for constructing internal grids as an alternative to grids requiring concessions. For electric road systems, an internal grid would need to be constructed within the road area and used to provide the owner's own system with power, at least in part. Whether transmission to vehicles on public roads can be considered to constitute transmission to the owner's own system is unclear.

### 3.5 Power supply

It must be possible to provide either low-voltage power (cf. trams, approx. 1000 volts) or high-voltage power (cf. trains, approx. 16,000 volts) to vehicles. The low-voltage option involves lower vehicle costs but higher infrastructure costs. The opposite is true for the high-voltage option. The electric road systems currently being developed are all of low-voltage type. Both AC and DC voltage systems are being tested. The Swedish Transport Administration is of the opinion that low-voltage systems will be tested over the next five years.

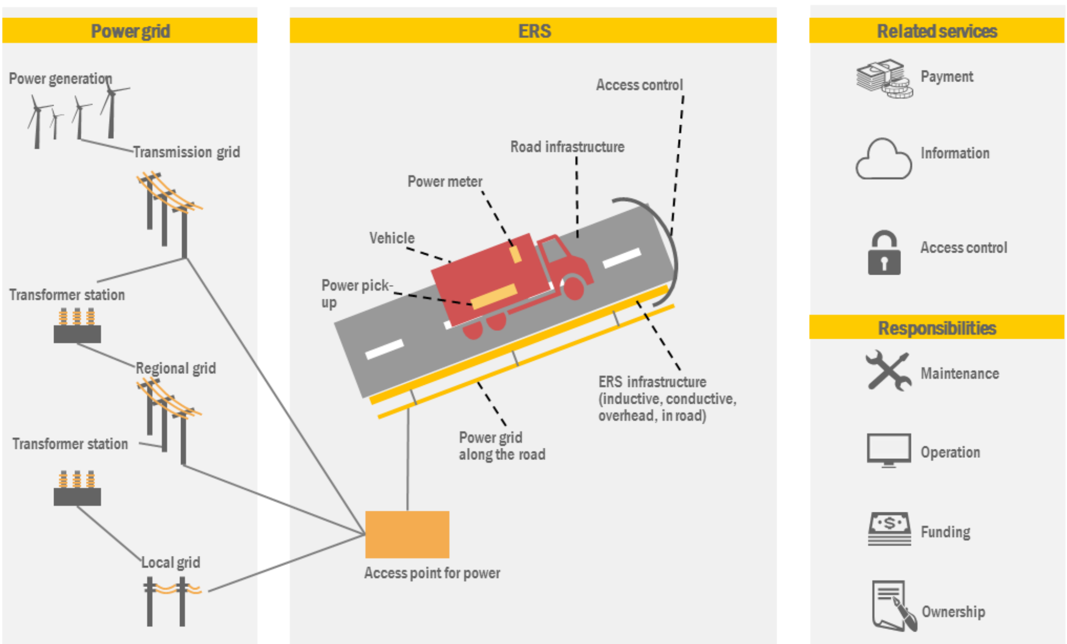


**Figure 2 – Principal layout of the electric road system and adjecent system and services**

Current from the public power distribution grid will need to be transformed in batches in order to power vehicles. A principal layout of the system is shown in figure 2. The power transformation takes place over three stages:

- A high-voltage grid parallel to the road, in or near to the road area, will probably need to be constructed as there is normally no existing grid for connection points to a sufficient extent.
- Transformer stations, which convert high voltage into low voltage, need to be constructed every two or three km along the road.
- Low-voltage grids for final distribution to vehicles need to be constructed in accordance with the design of the technology in question.

The identity of the proprietor of the electric road system needs to be investigated. However, it is important for the Swedish Transport Administration, in its role as the road owner, to have access to the electric road system facilities for the purposes of operation and maintenance of the road infrastructure.

## 4. Conclusions

In order for electric road systems to be a part of the future transport system, they have to be included in the national infrastructure plan, irrespectively of who the owner is and who is funding the project. The current national infrastructure plan runs from 2018 to 2029, and is revised every fourth year. For electric road system to be part of national infrastructure plan sufficient information about electric road systems need to be acquired before 2022, se figure 3. The main steps are:

- Market and funding,
- Promote, contribute to and pave the way for a broadened market and greater competition between the transmission systems by raising more systems to a higher level of maturity,
- Prepare and implement a major electric road system pilot, and
- Create a long-term plan for the construction and development of electric road systems

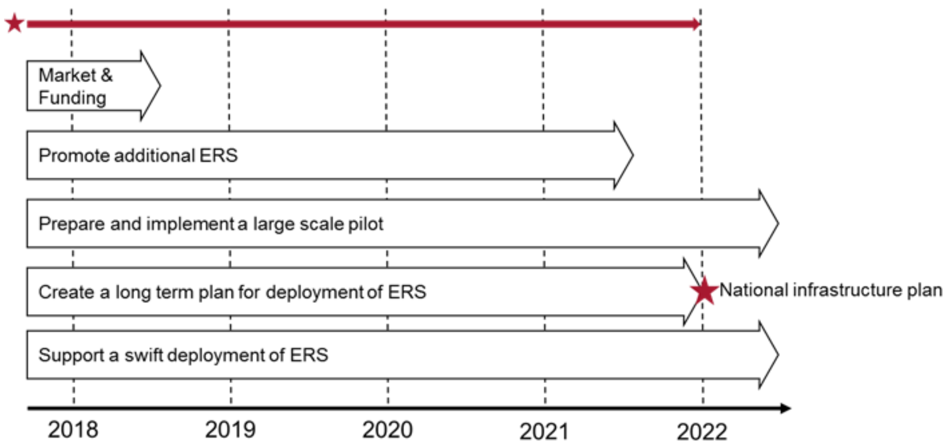


**Figure 3 – Main step and time plan for National roadmap**

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