

Electric avenues

In ten years we could be charging our electric cars simply by driving down the motorway. **Kristina Smith** reports on how the UK is looking to lead the world in the implementation of this technology

On 11 August the government announced that it was to commission trials of wireless power transfer technology which could charge electric and hybrid vehicles as they drive over a road. The trials, which would be carried out off-road, are due to begin later this year and last for around 18 months; on-road trials could follow.

The announcement follows the publication of a feasibility study produced by TRL, a UK transport research body, with input from a range of partners in academia and industry. Highways England (formerly the Highways Agency), which commissioned the study, accelerated its programme so that it took place in seven months rather than 13 as originally planned.

Though other countries have done more to develop the technology, Highways England's resolve to push forward with its plans for 'electric highways' could catapult the UK into the lead in terms of implementation. The UK's approach differs from other programmes, as it aims to get going now with what is already developed, rather than invest in more R&D. Says Denis Naberezhnykh, head of ultra-low emission vehicles at TRL: "In the UK we are saying there is already quite a lot of technology out there. How close to market is the technology and how feasible would it be to us in five years' time for use in UK highways?"

One of the biggest potential benefits of introducing dynamic charging on our motorways could be that it speeds up the adoption of electric and hybrid vehicles. Motorists won't worry about running out of charge, and batteries can potentially come down in size. "The challenge is that any electric vehicle driving on a motorway uses a disproportionately high amount of electricity," says Naberezhnykh. "They are OK for shorter trips and city driving, but the charge burns very fast on the motorway." However, as TRL points out in its feasibility study, this is a chicken and egg situation: by providing dynamic charging, you encourage people to buy electric vehicles, but in order to make the business case for providing dynamic charging, there have to be enough people using it, and paying for it.

A greater proportion of electric vehicles would mean better air quality, particularly in cities where traffic congestion is an issue, and a reduction in carbon emissions. Considering a scenario where 30% of light vehicles were using dynamic charging, and 75% of heavy vehicles, TRL calculated that there would be a reduction in emissions local to a stretch of motorway of 35% for nitric oxide and nitrogen dioxide (NOx) and 40% for particulate matter.

There are still a number of challenges, such as the cost and method of installation in the road, ongoing maintenance impacts for roads and the efficiency of power transfer. There is also a

big question mark about interoperability: whether the same dynamic charging device could service both a car and an HGV. A car or light van would be likely to require between 20kW and 40kW, whereas trucks and coaches would need between 100kW and 180kW. TRL's projections have assumed that one system could service both but notes that, at this moment, the technology doesn't exist.

One of TRL's recommendations in its feasibility study report is that attention should be turned first to commercial vehicles and in particular HGVs in order to have the biggest impact. "The reason why dynamic wireless power transfer is so interesting is that it potentially allows electrification of HGVs which is not possible at the moment because they require too much energy," says Naberezhnykh. "If you had a battery-operated electric truck at the moment, you would not have any room for the goods because the battery would be so big."

Some vehicle manufacturers have been looking at catenary systems for HGVs, similar to those used for electrified railways. However, TRL did not consider this option in any detail.

How it works

Electric vehicles have made a promising debut in the UK. According to nextgreencar.com there were 37,000 plug-in cars and 2,600 vans registered by June 2015. There has been a surge in ownership over the past 12 months, with electric cars

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now accounting for 1% of the total new-car market in the UK. Currently, most electric vehicles are charged simply by plugging them in, either at home or at charge points, of which there are now 8,700. Whether dynamic charging becomes a reality or not, Highways England has said it still intends to install charge points every 20 miles on the motorway network over the medium term. But how would 'electric avenues' work?

The technology to charge wirelessly through induction while vehicles are stationary already exists and is in operation in several locations around the world. This uses the same principal as an electric toothbrush: a primary coil – under the road – creates a



Vision of the near future? The UK's launch of trials has sparked interest around the world

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magnetic field when a current runs through it which induces a current in the secondary coil – attached to the vehicle. In the UK, there are already some 'live' uses of stationary wireless power transfer. In Milton Keynes a fleet of eight buses uses two charging pads, with charging at the end of the route taking between five and 15 minutes. And the European ZeEUS project (Zero Emission Urban Bus Systems) will see wireless power transfer systems installed in both Glasgow and London.

The next step is dynamic charging: using the same principle of induction to charge vehicles while they are moving. The power transferred from road to vehicle could either be directed straight to the vehicle's motor, could go to the car's battery, or both. Several institutions around the world have ongoing research programmes related to dynamic charging, as do vehicle manufacturers and specialist firms. As part of the feasibility study, TRL reviewed 17 wireless power transfer systems, eight of which had the potential to be used in a dynamic system as well. TRL is also working with European partners from academia and industry on a project called "FABRIC", under whose banner several dynamic wireless power transfer trials are planned.

Not such a new idea

Engineers and researchers have been looking for ways to power vehicles from the roads for well over 100 years – pretty much since 'horsepower' stopped implying the physical presence of

horses. The first patent for such a vehicle was granted in 1894. The oil crisis of the 1970s provided a strong motivation to revisit the concept. Lawrence Berkeley National Laboratory built and tested a prototype electric bus in 1976 and there were subsequent US programmes including Partners for Advanced Transit and Highways (PATH), which the University of California, Berkeley began in the 1990s. In New Zealand, a team of researchers at Auckland University has been working since 1990 on inductive power transfer systems. Auckland's technology has been commercialised by Qualcomm through its Halo technology, one of the systems also now being adapted for dynamic use.

Bombardier in Germany has been developing its Primove system where on-board energy storage systems can be charged by induction. In August it announced the launch of four buses in Berlin which are charged at their end stops using this technology. Ground-powered trams have been running since 2004 in Bordeaux, France, although the dominant system used here, Alstom APS (Aesthetic Power Supply), uses conduction rather than induction to transfer power.

In the last six years, it's probably fair to say that Korea has taken the lead in developing dynamic charging, spurred on by generous state funding. Having demonstrated its first On-Line Electric Vehicle (OLEV) in 2009, Korea Advanced Institute of Science and Technology (KAIST) is now on version number five. According to Professor Chun T Rim of KAIST, the third-generation version of

OLEV has been deployed in five locations in Korea: in the Seoul Grand Park, on two of KAIST's campuses, at Yeosu Expo in 2012, in Gumi City in 2013 and, this year, in the newly created Sedjun City. "Gumi City was the first time that it was commercialised," says Rim. According to KAIST, between 5% and 15% of the route needs to be electrified for such a solution.

KAIST is now looking at that issue of interoperability: big vehicles versus littler ones. "We are developing another dynamic charging system that is compatible with stationary charging systems as well," says Rim. "It will be a dual-use charging system that's mainly used for dynamic charging of buses but can also be used by passenger cars. I understand that car companies are also developing that kind of system."

In the US, though government funding is not being directed in earnest towards the technology, several universities are pushing ahead to work with industrial partners to develop both static and dynamic wireless power transfer. Utah State University has just moved into its newly-constructed Electric Vehicle and Roadway research facility. The track is a way of bringing together many related research fields and projects from the university including dynamic charging, electric vehicles, and construction implications and costs. "The new facility is important because it will allow us to take the various components of research and pull them together to demonstrate them in application," said Regan Zane, director of the facility. "It will also allow us to uncover and resolve challenges in system integration."

Utah's research targets tough technical problems including efficiency of the power transfer, weight of the components, and cost of the components in both the vehicle and in the roadway. It plans to set up a centre with industrial partners in the next three or four months to develop future research. Utah had already developed a static inductive wireless power transfer system, which is now available commercially through a company called WAVE which came out of the university. Now researchers will be looking to modify that system so that it can be trialled on the track next year. "Essentially it's based on technology we had on the bench last year or the year before," says Zane. "We're excited to be able to put that together. It's a big step."

Oak Ridge National Laboratory (ORNL) in Tennessee also has a number of research projects related to dynamic wireless charging. These include working with industry to move from static to dynamic charging, safety issues, the impact on the grid and creating standards. PT Jones, the advanced vehicle systems program manager at ORNL, also oversees the International Energy Agency's

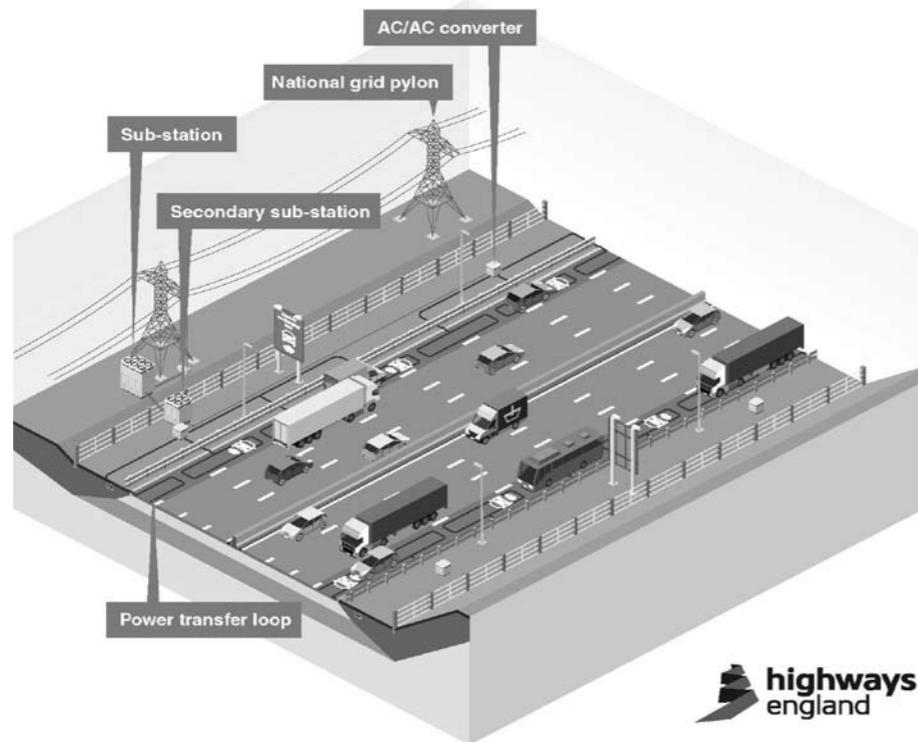
Task 26, Wireless Power Transfer for Electric Vehicles. "The purpose of the task group is to make sure that there is alignment between the codes and standards being produced in the US, Europe, Asia. We don't want to have a situation where components produced in one part of the world are incompatible with systems elsewhere," says Jones.

Jones believes that parts of Europe, and possibly Asia, will be using dynamic charging before the US. "Early deployments will come in communities outside the US that will see the benefits more quickly than us," he says. "It comes down to a transportation formula that goes beyond fuel savings. You have to have a municipality or an industry that's interested in localised emission reduction. Right now, with the low cost of certain types of liquid fuels, it becomes more difficult for municipalities in the US."

Cost, cost, cost

The biggest challenge with dynamic charging is reducing costs, says Chun T Rim. The primary coil itself has to be tough enough to endure almost constant mechanical shocks and big variations in temperature. Rim says that KAIST has managed to reduce the deployment cost of dynamic charging to US\$400,000 per km, which he compares to a figure of US\$1m per km which was achieved in the 1990s on the PATH programme.

In the UK, TRL's report contains an analysis of total cost, based on a scenario where the proportion of vehicles that can be dynamically charged increased from 10% to 30% for light vehicles, and from 5% to 75% for heavy vehicles. According to TRL, the net present value of construction and operating costs, per km, would be £17m, of which infrastructure costs account for 30% and electricity 70%. But the report also states: "There would



A possible configuration of a dynamic power transfer lane

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be a reduction of around £14m in central government revenue, because of the 'loss' of fuel duty and VAT from reduced fuel consumption. This is significantly greater than the capital costs of the fixed infrastructure."

Some efficiencies could be gained by incorporating other technologies into the dynamic charging installation, such as the MIDAS road loops for detecting traffic movement. TRL also suggests that load sensors, to help with asset management, and technology to support autonomous vehicles might also be included.

In terms of purely technical challenges, Rim believes these are becoming less of an issue. "At KAIST we have proved that there is a technically viable solution," he says. Naberezhnykh agrees with this view: "The technical difficulties are the easiest to overcome: power levels, efficiencies, air gaps, how systems are installed in road. That's now becoming clearer so we then can present the boundaries to the system developers."

Building them

Three methods of constructing roads containing the dynamic charging systems were identified by TRL: using trenches, digging up and reinstating the whole lane and prefabrication of a whole lane. The costs for these vary between £1.7m and £5.5m per km, according to TRL, with the cost of connecting to the grid coming on top of that, estimated at between £350,000 and £425,000 for a 1km stretch.

Of all the three options, complete reinstatement looks the most likely. The two in-lane longitudinal joints caused by trenches would cause maintenance issues according to Highways England and prefabrication – such as the Dutch system called Modieslab which is referenced in the report – is likely to be too expensive.

“ We are looking at techniques that would allow us to pour the roadway over the box ”

Regan Zane, Utah State University

At Utah University, researchers are considering pre-fabricating the transmitting coil in a 'box' surrounded by supporting material. "We are looking at techniques that would allow us to pour the roadway over the box," says Zane. "The big challenge is that it would require the ability to have variable separation between transmitting and receiving coils because as we resurface the roadway, the distance changes."

One problem often cited with dynamic charging is the lower levels of efficiency achieved with the power transfer. This is due to a number of reasons including the fact that a vehicle may not be perfectly aligned and because a length of coil may be activated, but not all of it is below the vehicle. "This is a real issue for dynamic charging systems," confirms Rim. "You have a very long primary coil which means you get 3% to 5% additional power loss compared to stationary charging systems." Rim says that whereas stationary wireless power transfer can achieve over 90% efficiency, dynamic is at around 85% efficiency.

Another important consideration is the impact on power networks. TRL is working with Western Power Distribution in Milton Keynes to try and understand what this would be. "We are looking at how distribution providers would cope with providing power if we had a fleet of buses," says Naberezhnykh.

"These systems are very high power. That's the reason why they work."

TRL's study found that dynamic charging systems were likely to impose high peaks and variations in power demand, depending on traffic conditions. It also concluded that different configurations for the dynamic charging pads had an impact on power demands. In Utah, Zane sees the possible introduction of dynamic charging as an opportunity for power companies. "Although we haven't gone into this in fine-grained detail, the numbers have shown that utilities could absorb the load in general," he says. "For more continuous power transfer, we see that has an averaging effect and an opportunity for the utility to have a predictable load, as we can predict what traffic patterns will be."

He adds: "It's a growth opportunity, probably one of the biggest opportunities they have seen in many decades."

Is it really viable?

The biggest question of all is how to assess the economic viability of dynamic charging. "There are so many stakeholders involved in an infrastructure scheme like this," says Naberezhnykh. "And those investing in the roads are not the people operating the vehicles."

In order to calculate costs, TRL's feasibility study assumes that the section of motorway under consideration is part of a wider network which is of sufficient size for economies of scale to apply, and which can support the take-up rates applied. It doesn't make an attempt to quantify how much of the road network would need to be electrified to achieve a particular penetration; back to the chicken and the egg again.

The UK government's announcement has caused interest around the world, particularly in relation to the figure of £500m 'already being committed' over the next five years that was referenced in the press release. However, it's not clear how many different projects and programmes are wrapped up into that figure. "The UK's announcement and the investment that they are making over the next few years becomes a real reference point for us," says Jones in Tennessee. The general consensus among the various experts, however, is that electric motorways are probably a good deal longer than five years away. Most saw the likeliest early deployments to be in urban situations for public transport: buses, light rail, possibly taxis and fleet vehicles. "In ten years we could see significant acceptance in fleet vehicles," says Zane. "There could also be public transport or private options in places including airports, ports of entry, parks, situations where there are controlled roads."

"It's a good solution for routine buses or trains but for passenger cars, they need to be able to go everywhere. There's no single solution. In 30 years' time, we will still need the internal combustion engine for rural areas," says Rim.

So in the future, we will be using a variety of means to charge our vehicles – which may be hybrid with smaller batteries. And the mix will vary depending on whether we are urban or rural dwellers. "Whether static or dynamic wireless power transfer succeeds or not, it's not a replacement for plug-in charging, unless a vehicle is extremely highly utilised and never stops for long," says Naberezhnykh. "For vehicles that are going to be stationary for periods of four hours, plug-in charging will always make sense because it will always be simpler and cheaper."

"It's about creating a flexible charging infrastructure that's fit for purpose. From what we have seen so far it seems that systems based solely on plug-in charging does not quite do that. A combination of ways to charge is much more attractive." □