

THE FOREVER OPEN ROAD – DEFINING THE NEXT GENERATION ROAD

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ABSTRACT

The world's road network has taken thousands of years to develop. The 'generations' of road have, however, been few; emerging from the track to the paved road, then the smooth road and onto the continuous road (motorway). The Forever Open Road programme aims to create the next generation of road; one which is adaptable, automated, and resilient. It will demonstrate how to build and maintain roads where new technology can be easily accommodated and that are resilient to climate change. It will take the best of existing and future technologies, fill the gaps to produce a solution suitable for all types of road, whether urban, rural or motorway.

The Forever Open Road concept forms the flagship research programme of the Forum of European Highway Research Laboratories. Technology trials that support the concept are already underway, and planned research will lead to large-scale demonstration projects showing how the next generation road will work. This Paper describes the Forever Open Road concept and its programme of research. It calls for future research funding to deliver a comprehensive strategy that creates a next generation of road that can be adopted across Europe, rather than continue with the current 'hit-or-miss' approach to research.

1. INTRODUCTION

The world's road network has developed over thousands of years; emerging from the track to the paved road, then to the smooth road (enabling modern vehicles to travel at high speed), and on to the continuous road (the motorway). The last two of these 'generations' being developed over the past 100 years or so. A new generation of road will, however, need to be developed if we are to meet the challenges now faced by Europe's highway networks. These challenges include the changing climate and more extreme weather events, greater traffic volumes and demand for minimal disruption to road users. At the same time, developments in Intelligent Transport Systems, vehicle design, mobile and wireless communications and sensor technologies continue apace. In recognising the challenges and embracing the opportunities, the Forever Open Road programme aims to redefine how roads are designed, constructed, operated and maintained in the future. Whilst acknowledging the significant advances that have been made in highway research, these have largely been incremental improvements in various engineering disciplines and based upon a rather 'hit-or-miss' approach to identifying research needs. The Forever Open Road adopts a holistic approach that covers all aspects and aims, through a more comprehensive strategy for future research, to achieve 'revolution, not evolution'.

The Forever Open Road will be suitable for new or existing roads, whether urban or interurban. It will be constructed from pre-fabricated elements, built and maintained using sustainable materials. It will have adaptable capacity provision (lanes, hard shoulder & central reserve), and built-in services and communication systems. It will measure its own condition, harvest energy and clean and repair itself. It will communicate with vehicles and will allow for automated driving. The concept will take the best of existing and future technologies, fill in the gaps, and produce a solution that can be adopted across Europe.

The concept of the Forever Open Road is built on three elements: the Adaptable Road, the Automated Road and the Resilient Road. The Adaptable Element is the overriding requirement, as it will enable future transport needs to be accommodated without structural change or retro-fitting of technologies. For example, on motorways, extra lanes or a second deck could be added, the central reservation could be moved in response to traffic demand, and damaged sections could be removed, then sent away for repair.

The Automated Element will include a pavement that will monitor its own condition, and enable cooperative vehicle-infrastructure systems to be introduced, where speed and lane guidance systems could be controlled automatically.

The Resilient Road will be resilient to, and mitigate the effects of, a range of environmental factors. The road will be quiet, will be built from low carbon materials, rainwater will be collected to prevent flooding, solar energy will be captured to power lighting, signage or even the electric vehicles themselves. It is envisaged that through appropriate design the road could be carbon neutral or even carbon negative. Within each of the three elements, there will be requirements to develop all aspects of Road Network Management, such as materials & components, asset management strategies, governing principles and common standards.

The Forever Open Road has been developed as the flagship programme of the Forum of European Highway Research Laboratories (FEHRL). Originally conceived and developed by six 'founder' organisations; comprising TRL (UK), BASt (Germany), RWS (the Netherlands), IFFSTAR (France), DRI (Denmark) and AIT (Austria), it is now opening out to the entire FEHRL community, as well as external stakeholders, such as consultants, contractors, materials and vehicle manufacturers and communications and IT specialists.

2. THE NEED FOR THE FOREVER OPEN ROAD

Roads are indispensable to modern society. The economic importance may be illustrated by the fact that 80% of freight in the EEA 30 region of Europe is carried by road [1]. Billions of Euros are spent each year on the design, construction, operation and maintenance of roads in Europe with the sole objective of keeping Europe 'on the move' and ensuring that the European Economy remains both sustainable and able to grow; especially given that over the coming two decades, the growth in road traffic will be about 50% [2].

The provision and operation of our road networks and of the traffic that uses them comes, however, at a cost to society; including environmental impacts and financial investment. For example, about 25% of total CO₂ emissions in the EC27 region were from transport [3]. The common understanding is that under the 'business as usual' scenario road transport will be the only sector for which the CO₂-emission will increase in absolute terms. Furthermore, road fatalities in the EU were 34,500 in 2009 [4], not counting deaths that could in part be attributed to air pollution or the many more severe injuries [5]. Also,

the cost of congestion amounts to tens of billions of Euros and has increasingly become a major concern within most European and national transport and economic policies.

Against this background, it is clear that efforts to simultaneously meet societal challenges for decarbonisation, journey time reliability, energy reduction and safety, will require new ways of building, operating and maintaining our road infrastructure within the overall European transport system. Indeed, this is supported within ERTRAC's Strategic Research Agenda 2010 [2], where it is acknowledged that infrastructure plays a key role in achieving 6 of the 7 guiding objectives it pursues, but also that integration with the other components of the Road Transport System is crucial in maximizing the efficiency improvement of the system as a whole.

For example, the energy-efficiency of the vehicle in operation is significantly determined by the design of the road, such as the rolling resistance of the surface, and management of traffic flow, the provision of effective driver information e.g. on traffic situation or on services required, mobility planning, and efficient maintenance and reconstruction.

In addition, the influence of road infrastructure on the environmental quality is significant (noise, air quality, natural habitat, resources). In fact over the last decades it has been a major driving force for many large scale research programmes, such as the Dutch IPG (Innovatieprogramma Geluid) and IPL (Innovatieprogramma Luchtkwaliteit) programmes for noise and air quality respectively, and the EUCAR programme for vehicles. The existing generation of road will not cope with these challenges, and a new generation road will therefore need to be developed – the Forever Open Road.

3. BENEFITS OF THE FOREVER OPEN ROAD

The development of a next generation roads implies innovative ways of designing, building, operating and maintaining our road infrastructure as an essential element of the overall European transport system. The development of the technologies concerned is costly and time consuming, budgets are under pressure and the time schedule for achieving Europe's strategic ambitions is aggressive. However, the long-term benefits to the European economy, environment and society from the development of such a next generation road; one that is cost effective will be substantial (see Figure 1).

ADAPTABLE	AUTOMATED	RESILIENT
<p><i>The Adaptable Road will provide a quick and cost effective method of designing, constructing and maintaining roads.</i></p>	<p><i>The automated road will integrate road side intelligence with ICT applications in the vehicle, the services and the operator.</i></p>	<p><i>The resilient road will provide consistent availability under the effects of climate change (weather extremities).</i></p>
<ul style="list-style-type: none"> • Reduced maintenance / renewal requirements; • Improved transport integration, adapting with light rail, guided bus, cycling and walking; • Adaptable to future transport trends and technologies; • Reduced maintenance costs / lower whole life costs; • Low / neutral / carbon negative construction and operation; • Reduced road user and road worker accidents; • Reduced construction site hazards; • Reduced noise. 	<ul style="list-style-type: none"> • Reduced congestion / improved journey time reliability; • Improved transport integration; • Continuous monitoring of the asset condition to inform asset management strategies and optimize maintenance; • Improved safety for users; • Improved air quality management; • Effective road charging and tolling of vehicles; • Cost effective use of spin-off technologies. 	<ul style="list-style-type: none"> • Adaptable to Climate Change Impacts, such as flooding, heat and cold; • Reduced energy use through in situ energy generation; • Emission capture and mitigation.

Figure 1 - Key Benefits of the Forever Open Road

3.1. Economic benefits

Most important are the benefits that come from reduced congestion and associated improvement of travel time reliability at a lesser cost. In addition, the FOR concept will help realise developments in enhanced mobility and logistics as it aims to coordinate and integrate with comparable development programmes for vehicles, services and energy and resources supply. At the same time, FOR will encourage Pan-European engagement and collaboration, and stimulate research across the member states bringing cost savings and benefits for all. These benefits will reinforce the European economy to be highly competitive on the global market.

3.2. Societal benefits

Society will profit from FOR as it will help reduce fatalities and severe injuries from road traffic e.g. by providing better design principles (self-explaining and forgiving roads). The programme also will target construction site safety e.g. by automating and robotizing activities that are dangerous to construction workers. Furthermore the concept will enhance social inclusion within the European societies by supporting the development of a seamlessly integrated transport system for passengers and goods.

3.3. Environmental Benefits

Next to economic benefits, reduced congestion will benefit the environment as well, both at local (pollutants) and the global (GHG) scale. The liveability in the vicinity of the road networks will improve by further advancements in noise abatement e.g. by innovations to pavement systems such as Helmholtz Resonators. By providing advanced traffic management technology, road operations will be able to dynamically manage traffic demand e.g. by segregating flows on basis of their environmental class (electric versus combustion engines). Furthermore, FOR will aim to preserve and even improve natural habitats in the vicinity of the road network, congruent with respective policies such as NATURA 2000.

4. THE FOREVER OPEN ROAD APPROACH

The Forever Open Road concept aims to develop methods and systems that will perform across Europe's varied transport network; integrating with existing road provision and adapting to differing environments, whether urban or rural. The concept would apply to the maintenance and renewal of existing roads as well as to new road construction, and will be able to provide for, and meet targets relating to Europe's:

- highest levels of traffic intensities;
- needs for accessibility and reliability;
- aims for reducing level of fatalities and severe injuries from road accidents;
- reduction in greenhouse gas and noise emissions; and
- demand for security in freight transport.

This programme will develop and demonstrate the viability, benefits and practicability of the three main elements:

4.1. The Adaptable Road

The Adaptable Road will provide a quick and cost effective method of constructing and maintaining roads. This will involve a re-think of how roads are built, including the use of

prefabricated, upgradeable pavement structures with long-life characteristics that are capable of incorporating removable and changeable infrastructure services and accommodating new forms of powered vehicles and guidance systems. The adaptable element will be the key to making the concept work, supporting the automated and resilient elements.

Key aspects of this element will include:

- Developing new forms of road construction, such as prefabrication with integrated service provision to reduce costs;
- Providing for enable fast and effective maintenance to reduce delays;
- Using robotised methods of on-road maintenance and traffic control to improve safety;
- Self repairing and self cleaning roadsto reduce costs and environmental impact;
- Developing flexible drainage systems to cope with storms;
- Using harvested solar energy to moderate road temperature and reduce the need for winter maintenance, and to power roadside lighting and signs, and potentially even the vehicles themselves;
- Cost-effective, low energy integrated lighting systems;
- Low noise and low spray pavements.
- Building and maintaining using low carbon and low energy materials and processes.

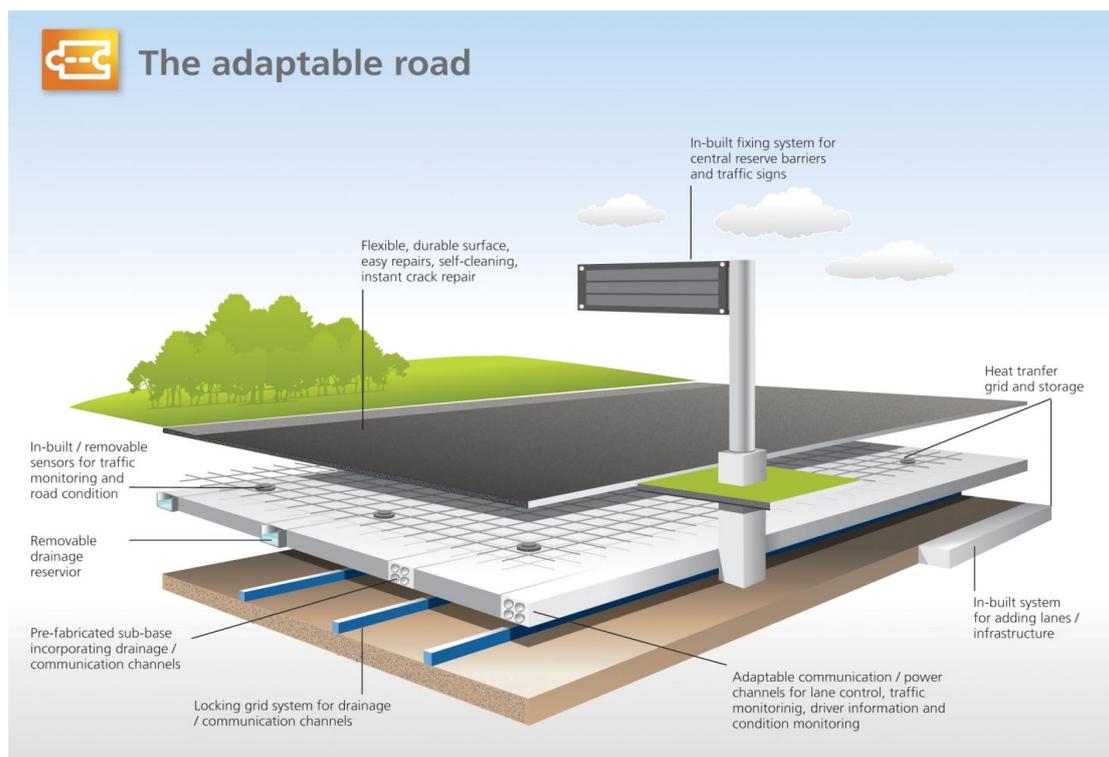


Figure 2 - The Adaptable Road

4.2. The Automated Road

The Automated Road will integrate road side intelligence with ICT applications in the vehicle, the services and the operator. The sensory and communications technology involved will enable the deployment of advanced (e.g. dynamic) guidance and management systems tailored to respond to in situ requirements, in effect improving reliability and efficiency of the network management.

Key aspects of this element will include:

- Comprehensive, interoperable communications system linking driver, vehicle, road and operator;
- Integrated sensors and systems to measure and monitor road condition and performance;
- Enabling future vehicle to highway guidance, speed control and direction guidance;
- In-road vehicle guidance using to change lane usage and manage traffic;
- Powering vehicles from the highway and harvesting solar energy;
- Monitoring traffic and road conditions as well as vehicle performance to improve reliability and efficiency;
- Incident monitoring and automated response systems to reduce delays;
- Providing for effective road charging and tolling to improve effectiveness.

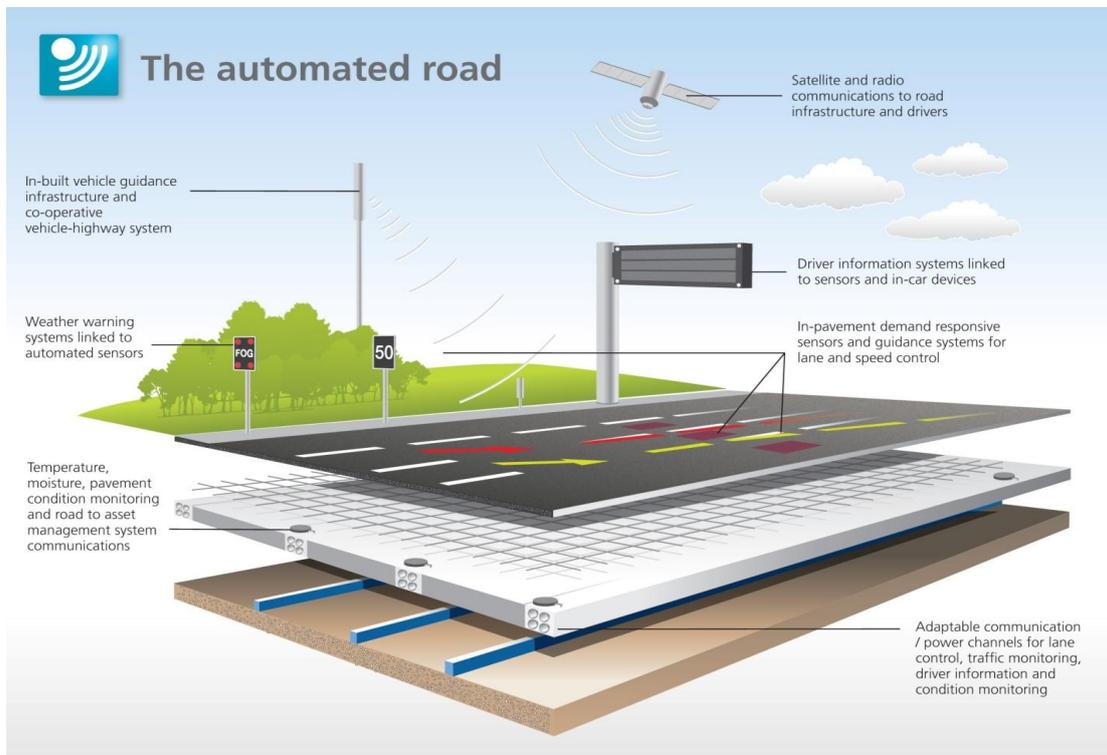


Figure 3 - The Automated Road

4.3. The Resilient Road

The Resilient Road should be resilient to extremities of weather, such as temperature and rainfall, and also mitigate the negative aspects of road construction and operation, such air and noise pollution. Key aspects of this element will include:

- Integrating the road with its environment to make effective use of water, energy and planting;
- Means of dealing with extreme weather conditions, e.g. storms, wind, heat and cold.

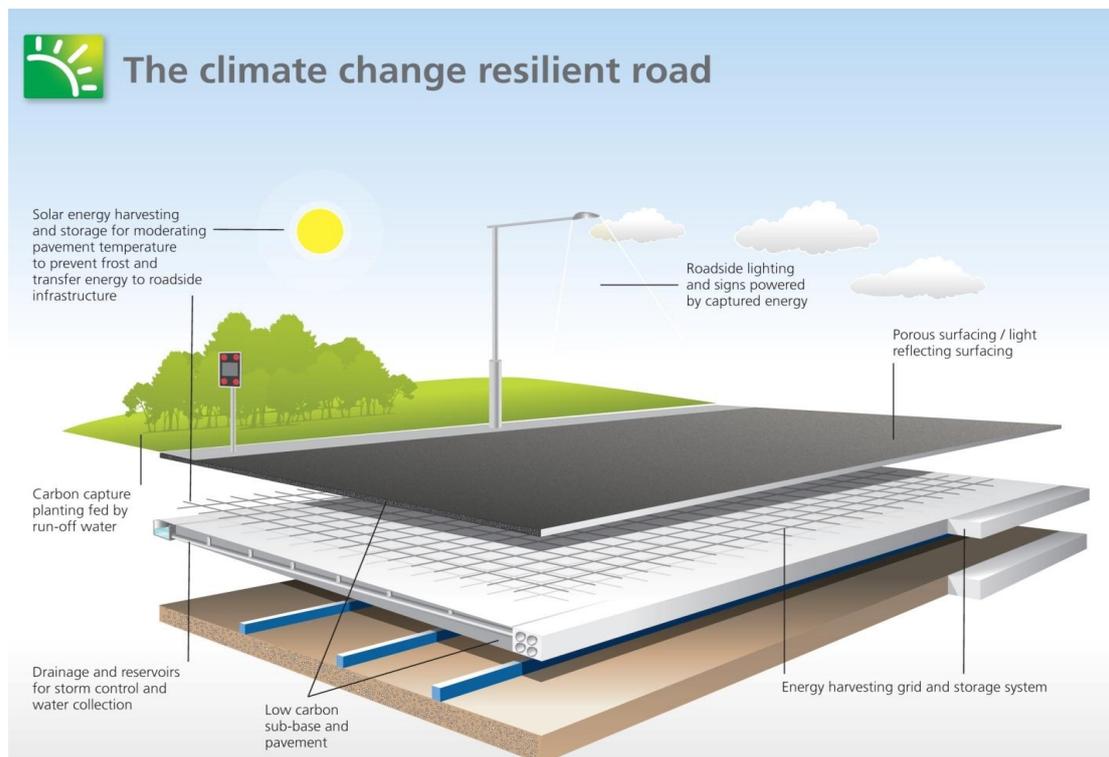


Figure 4 - The Resilient Road

4.4. Timeline

The Forever Open Road is already an active programme. It will be delivered in four phases. In Phase 1, the concept of the Forever Open Road, was crystallized and agreed in November 2009; and in Phase 2, the Research and Development Plan, was delivered in October 2010.

Phase 3 is underway, and will involve the development of roadmaps for the each of the three elements, along with ongoing Technology Trials. From 2013 onwards, Phase 4 will develop full scale system demonstrations. The rest of this Paper primarily covers our work on Phase 3.

5. TECHNICAL APPROACH

Whilst the technical approach of the programme is ambitious and challenges many of the preconceptions of highway design and construction, there is no desire to repeat research, with the aim being to take the best of what we have today, and the best of what's to come.

A number of tasks and sub-tasks were identified during Phase 2 that were considered to potentially contribute to important aspects of the Forever Open Road. Information was collected on technologies that currently exist (whether they are widely used or not, or whether they require improvement or not), items that might become commercially available in 2 to 5 years, mature technologies in other sectors that could be transferred to the Forever Open Road, and longer term technologies that would not be commercially available or viable within 5 years. The rationale to this approach was that by identifying existing, future and missing technologies, it will be possible to determine the implementation, research and development tasks. The pyramid in Figure 5, outlines this approach.

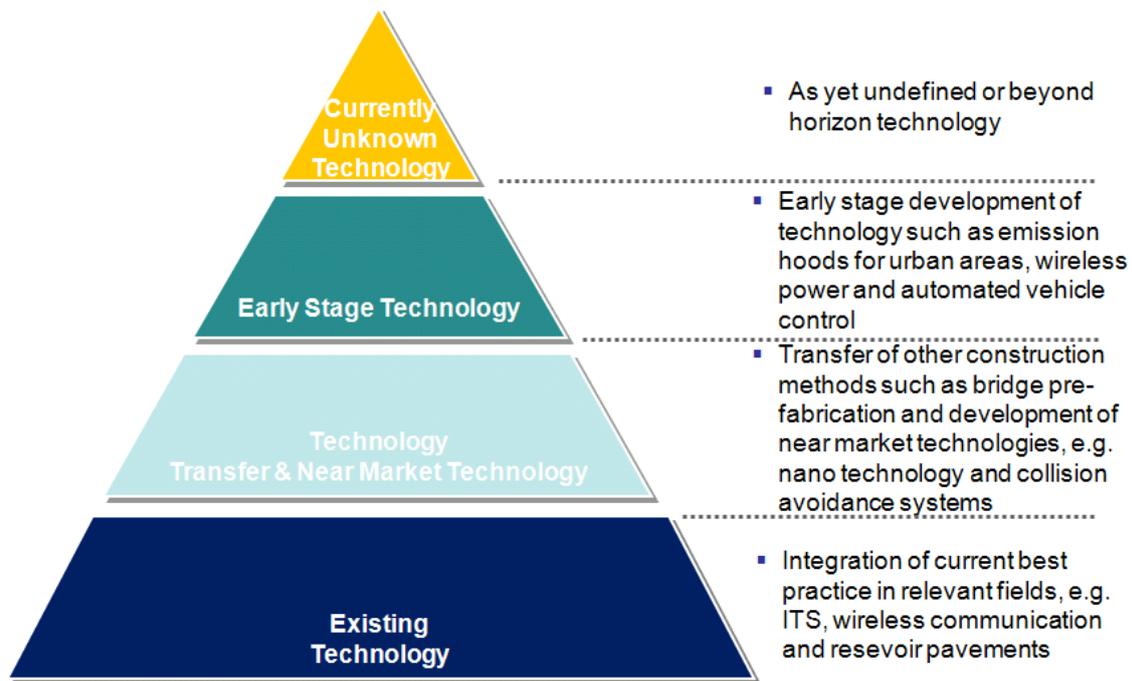


Figure 5 - Technology Stages and Relation to Forever Open Road

For most of the technologies identified, the pyramid represents accurately the technology status, i.e. there is a considerable amount of technology already available, and a considerable amount to come in the short term. There are only a few areas of the research programme for which there is a requirement for very long term research, or where the technology is unknown.

6. EXAMPLES OF INNOVATIVE RESEARCH

The technology identification process identified that in Europe, the USA and Asia there are many truly innovative technologies that were at the demonstration stage that fulfilled many of the requirements of the Forever Open Road programme, and which could potentially be developed or adapted for rapid deployment. Some examples are presented below.

6.1. Modieslab

Modieslab is a prefabricated road slab manufactured from concrete elements, constructed from two different open layers of concrete on a further supporting layer of concrete, designed to be anchored to piled foundations. The slabs can be constructed with channels for utilities connections, and the open concrete surface has been designed to have low noise characteristics and low rolling resistance. Water run-off channels are designed to allow rainwater to be quickly discharged, and it is claimed, have road surface self cleaning properties. The concept was originally introduced to the innovation programme 'Roads of the Future' established by the Netherlands Public Works and Water Management department. Since this time, three trials have taken place, most recently a 100 metre test lane on the A12 motorway near Utrecht, involving a full-scale motorway set up under intensive traffic conditions. Test results have demonstrated shape retention, noise reduction and fast run-off of rainwater.



Figure 6 - Modieslab section being put into place

6.2. Road on a roll - Rollpave

The Rollpave concept has also been developed from the Dutch 'Road to the Future' Innovation programme, and is a prefabricated asphalt mat, approximately 30 mm thick, that is laid on top of an existing pavement with sufficient structural strength to carry the design traffic. The design allows for repairs to be carried out 50% faster than conventional methods, whilst providing a low noise surface course, comparable to a 2-layer porous asphalt; this is reported to give noise reductions of circa 6 dBA from conventional dense asphalt layers.



Figure 7 - Rollpave Test Section

6.3. Solar Roadways

The Solar Roadways project is being developed by Solar Roadways in Idaho, USA. The premise behind the concept is that if the roads, parking lots and other impervious surfaces

such as driveways in the lower 48 states in the USA were covered with solar panels it would generate three times the energy requirements of the USA [6].

The rationale for incorporating the technology into the road itself, rather than on the verge, for example, is that there would be a cost involved in constructing the asphalt surface, which can be discounted from the cost of the more expensive solar panels. Moreover, the solar road would potentially bring other benefits such as integrated LEDs which could provide lane marking, and heating elements to prevent winter snow and ice build up. Theoretically, the generation of electricity from the road panels would over time cover the construction cost, whilst if deployed widely, would provide a decentralised electricity grid system.

Solar Roadways were awarded \$100,000 from the US Federal Highway Administration to make a prototype panel, which was constructed in 2010. The concept involves a multi layered, prefabricated panel that would have a transparent surface layer of glass as a surface course underlain by solar panels with embedded LED lighting. Beneath this is an electronics layer containing a microprocessor that controls the lighting, heating, communications and monitoring, and finally a base plate layer that distributes power and data signals.

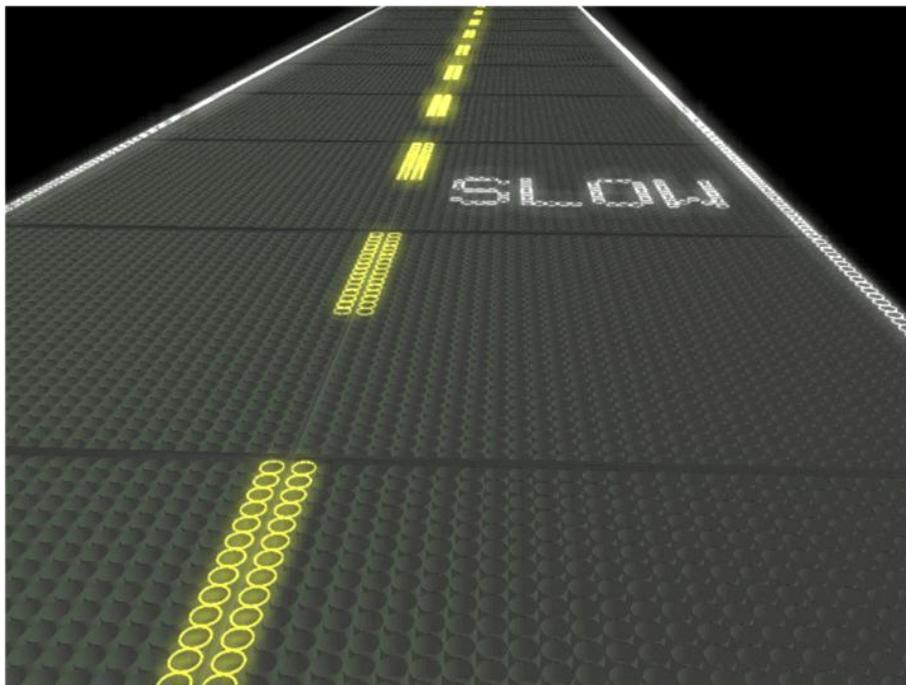


Figure 8 - Illustration of Solar Roadways Panel and LED lighting

6.4. Inductive Charging

The Korean Advanced Institute for Science and Technology (KAIST) has instigated the on-line electric vehicle (OLEV) programme where electric vehicles pick up power from cables buried underground via a non-contact magnetic charging method, with a 13 cm airgap between the road and the bottom of the vehicle. This removes a significant obstacle currently experienced by electric vehicles in that the batteries have only a limited range, and are heavy. By providing such a system, the range of an electric vehicle would be almost unlimited, and it would require only a limited battery supply for local journeys. Currently, trials are underway in South Korea using 'golf buggy' sized vehicles, shown in

The team at KAIST has developed a roadmap for research and development that will lead to the commercialisation of the technology. This will involve the development of practical prototype technology in 2011, and standard prototype technology in 2012, with introduction to market from 2013 [8].

7. OUTPUTS

The Forever Open Road programme has delivered a comprehensive Research and Development Plan. The development of roadmaps for the delivery of the research for each Element is underway and will be complete in October 2011. The key elements in delivering the vision, however, will be to demonstrate that the concept can be built and maintained. In order to achieve this, a series of Technology Trials has been implemented, with more to be added.

The Technology Trials have so far been limited to single technologies, but the Research and Development Plan has identified potential work packages that are considered important in developing the vision of the programme, the specific details of which are being developed in the roadmaps. As the work packages develop it is intended that multiple technologies will be developed and incorporated and tested at a sub-system level. The eventual aim will be to have a series of Demonstration Projects that exhibit the concept at a full system scale. The steps are outlined in Figure 9, and explained in further detail below.

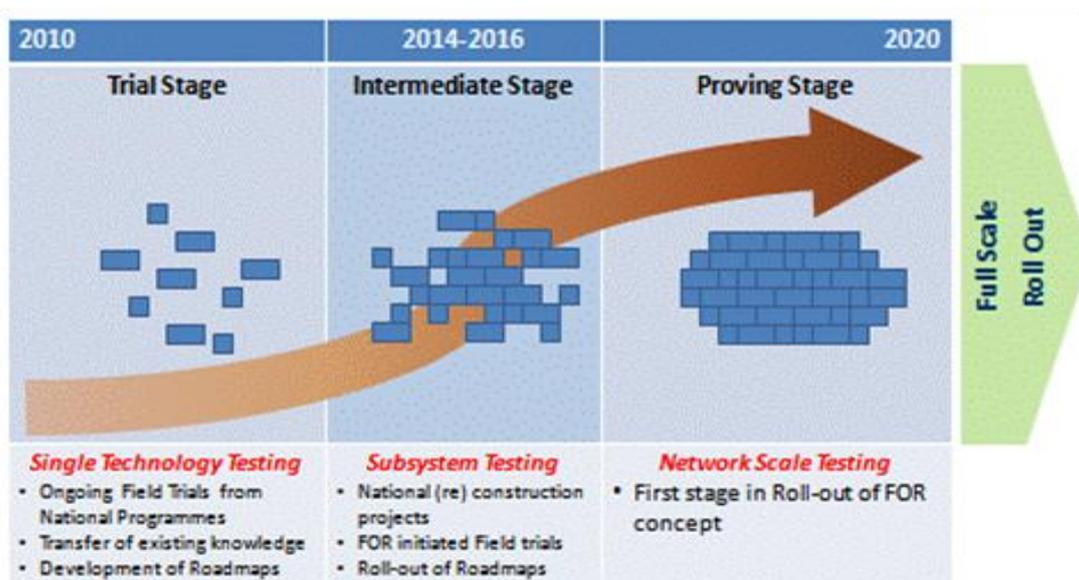


Figure 9 - Outline of Forever Open Road Proving Stages

7.1. Technology Trials

Examples of Technology Trials that are underway are as follows:

7.1.1 Floor Heating on Bridge Decks

This project is aimed at using geothermal energy to prevent the need for winter maintenance. Generally the asphalt surfacing on bridge decks - especially on steel bridges - is exposed to a higher risk of icing compared to asphalt pavements. In these cases, using geothermal energy to heat the asphalt surfacing on the bridge deck can possibly prevent the need for winter maintenance and contribute to increased road safety.

A new concrete bridge has been constructed in the North of Germany. This new bridge has been equipped with underfloor heating, with heating tubes placed approximately 10 cm over the bridge deck and shortly after overlaid with a layer of asphalt. Ground-water with a temperature of around 12°C will be piped through the tubes with the objective of warming the asphalt surfacing during the winter. In addition, this heating system can be also used in summer for cooling the asphalt layer in order to reduce or avoid rutting.



Figure 10 - Laying of bridge deck heating pipes (Germany)

7.1.2 *Removable Urban Pavements*

The aim of this project is to guarantee easy access to service networks embedded under road pavements or footpaths. It is based on the concept of a modular concrete pavement structure, placed on a base course, made of a controlled low strength material, enabling the structure slabs to be easily removed and the base course easily excavated to give access to the service networks. The base course and pavement structure can easily be rebuilt, reusing the initial slabs. Two field trial demonstrators have recently been built, in Nantes and near Rouen city.



Figure 11 - Laying of Removable Pavement (France)

7.1.3 *Induction Healing of Porous Asphalt*

Ravelling is a common and inevitable phenomenon in older porous asphalt pavements. It is caused by ageing processes in the bitumen binder, which becomes brittle and less apt to bind the aggregates. As a consequence over time the aggregate comes loose from the

surface. At a certain point in this progressive process, the road needs resurfacing, resulting in delays for road users. Any extension to the time period between resurfacing would be welcomed.

In order to increase the life span of porous asphalt, Rijkswaterstaat is undertaking a technical trial with a new ZOAB (porous asphalt) mixture in which steel fibres are mixed in the bitumen binder. This allows an in situ rejuvenating heat treatment of the road surface by means of induction. In recent tests with the Roll Pave concept (speeding up resurfacing by application of prefabricated porous asphalt surfaces) the induction technique was already demonstrated on the associated adhesive. Now the technology is tested on the (prepared) binder itself.

By passing a large scale induction plate over the road surface, the steel fibres are heated as well as the bitumen in which they are mixed, the latter should regain their original suppleness and the life span of the road will be prolonged. The trial is carried out in collaboration with TNO and Technical University of Delft.

7.1.4 *Noise Reducing Thin Layers*

In 2009, the Danish government initiated a new six year noise research program that is mainly conducted by the Danish Road Institute/Road Directorate. This project has the objective to demonstrate the effect of the noise reducing thin layers currently on the market in Denmark. In August 2010 a test section with six different pavements was constructed on a rural highway. A detailed measurement program has been established including yearly noise measurements and visual inspections. It is planned to follow the test sections for at least a five year period. The test sections will also be used as a new calibration site for noise measurement equipment used in relation to the Noise Reducing Wearing Course System.



Figure 12 - Construction of Noise Reducing Thin Layers (Denmark)

7.2. Work Package Identification

The Research and Development Plan has identified a number of areas of research that are considered important, and which may be developed into work packages as the programme develops. Given the potential scale of the Demonstration Projects, that will develop from them, they are unlikely to be funded from National Programmes as has happened so far, and there will be a requirement for pan-European funding. Whilst some of these suggested work packages, e.g. prefabricated pavements, have been investigated

to some extent already, in the Systems Proving Phase, they will be deployed on a larger scale.

- Flexible Durable Pavements
- Prefabricated Pavements
- Low Carbon Construction and Operation
- Integration of Renewable Energy into the Road
- Storm Resistant Pavements
- Adaptive and Intelligent Roadside Lighting and Signs
- Porous, Light Reflecting Surfaces
- In-built Sensor Systems
- Traffic Speed Maintenance
- Weather Protection and Warning Systems
- Communication Network
- Self-Monitoring Road

7.3. Demonstration Projects

Whereas the Technology Trials are generally looking at one technical improvement or new technology, the Sub-System and Systems Proving Phases of the programme will look to integrate several technologies from the three Elements in a series of Demonstration Projects. The realisation of such demonstrators will largely form the output of this phase of the programme.

The design, construction and location of the Demonstration Projects will result from miscellaneous criteria, including an assessment of the degree of maturity and robustness of available technologies tested during the Technology Trials. It is also likely that a Demonstrator might be constructed to address specific road contexts for which there exists a strong motivation for innovation from road users, residents and road operators.

7.4. Deliverables

In addition to the Technology Trial and Demonstration Project results, the Forever Open Road will deliver the following:

- A sound knowledge transfer programme through a proactively managed database. This will ensure that the results of the various trials, as well as other relevant research will be available to the wider research community.
- Proposals for Common European Standards for the Forever Open Road design, in order that it can be deployed across region, regardless of country or region.
- Evidence that a next generation of road (the Forever Open Road) can form the future of Europe's road construction and maintenance programme.

8. NEXT STEPS

8.1. The Forever Open Road Programme

As more projects are proposed for inclusion in the project portfolio and additional demonstration trials proposed, it will be necessary to establish procedures for scientific and technical review. Therefore a Technical Advisory Board will be established to develop procedures for technical review, to identify FEHRL and external experience required and to advise on ongoing research requirements.

In addition to the Technical Advisory Board, a Stakeholder Group has already been established, drawn together from industry and trade bodies that are likely to have an input into the future development, construction and operation of sub-system trials, full scale trials and eventual deployment of the Forever Open Road. This group includes representatives from contractors, vehicle manufacturers and road operators.

Through the management structures within FEHRL for the programme, the Technical Advisory Board and the Stakeholder Group, the key aims of the programme will be maintained, funding identified and the development of the Work Packages and Demonstration Trials will begin in earnest.

Figure 13 below, details the timetable of the Forever Open Road programme and an outline of the actions planned for the coming years.

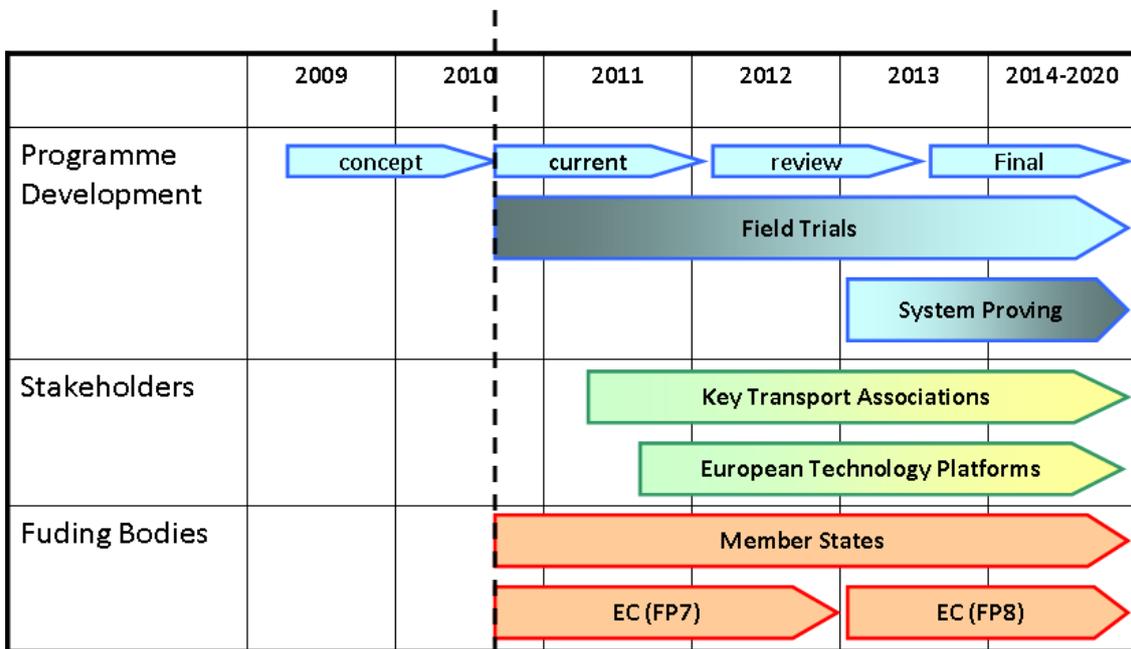


Figure 13 - Forever Open Road Timetable

9. CONCLUSIONS

Started as a concept in 2009, the Forever Open Road programme has now been scoped and developed into a detailed programme of work with ongoing Technology Trials that have been identified by FEHRL Members as illustrative of the Forever Open Road concept. Full scale Research and Demonstration Projects will follow. It is recognised that, by its very nature, the delivery of the programme will be challenging - however, the rewards to society will be substantial.

The Forever Open Road will provide a comprehensive strategy for the development of the next generation road – a concept that can be adopted across Europe for building and maintaining our future road network. It is critical, therefore, to ensure that future research funding and support is aimed at programmes such as this, rather than continue with the current approach to research, where incremental improvements are made in many disparate areas, which at best has little strategic oversight, and at worst, the improvements in one area can be detrimental to another.

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