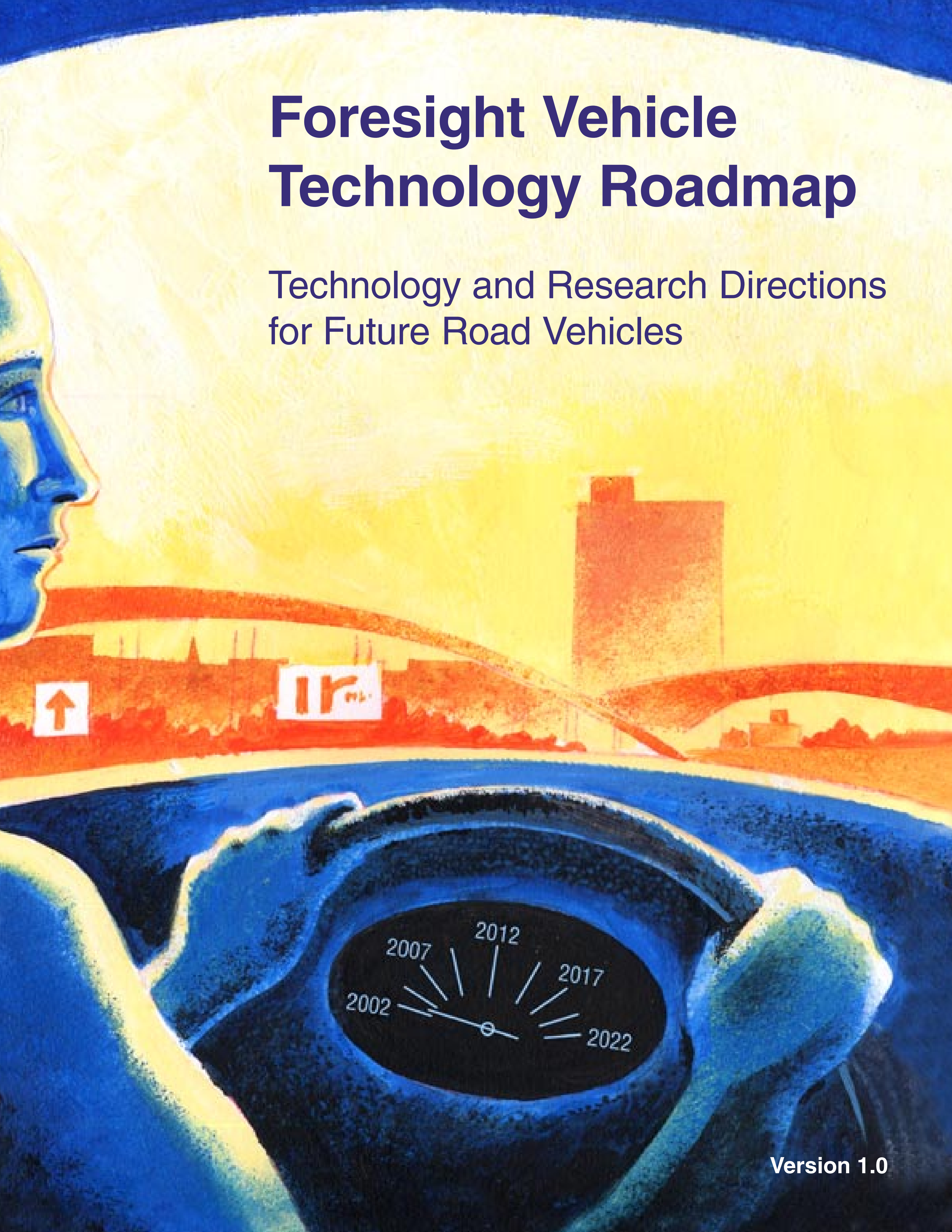
Foresight Vehicle

Foresight Vehicle Technology Roadmap

Technology and Research Directions for Future Road Vehicles



Version 1.0

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Technology and research directions for future road vehicles

Contents

Overview

Foresight Vehicle is a collaboration between industry, academia and Government to identify and demonstrate technologies for sustainable road transport. Future products and technologies must meet social, economic and environmental goals, satisfying market requirements for mobility, safety, performance, cost and desirability, with the objectives of improving the quality of life and wealth creation in the UK.

The Foresight Vehicle technology roadmap has been developed to identify technology and research themes for road transport, aiming to support UK industry in the globally competitive market for transport products and to provide sustainable mobility for UK citizens. The roadmapping process has brought together more than 130 experts from across the road transport sector, from more than 60 organisations. The goal was to use the roadmap structure (Fig. 1) to capture and share the rich set of views about how road vehicle markets, products, systems and technologies will (and could) evolve in the next 20 years.

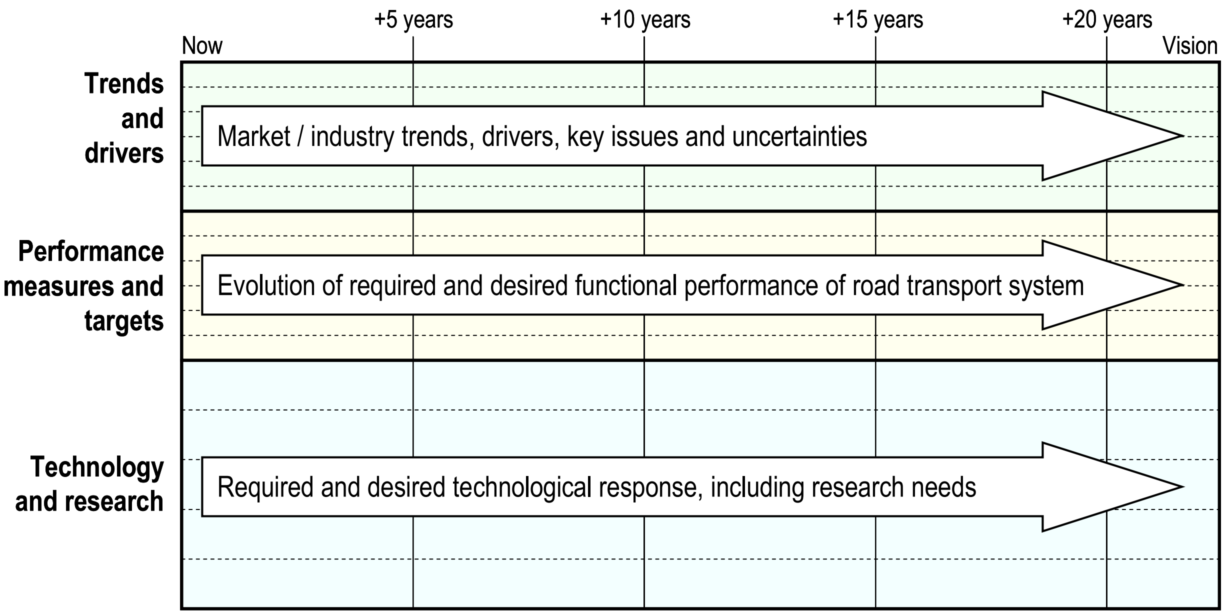


Fig. 1 – Foresight Vehicle technology roadmap architecture

The scope of the Foresight Vehicle technology roadmap is broad, reflecting the complex nature of the road transport system. The roadmap represents a 'rich picture', capturing the knowledge and thinking from a wide range of perspectives within the automotive sector. Owing to the broad scope of the roadmap, the inherent uncertainties associated with the 20-year time frame and the various interests of a diverse set of stakeholders, it is not desirable to overly constrain the research agenda. Rather, the roadmap is used to provide structure, context and broad direction. This structure enables a consistent language and approach to be developed in terms of understanding the relationships between specific technology areas, system performance and industry drivers.

Investment in road vehicle technology and research should be considered in terms of the contribution (impact) that the investment is expected to make towards the primary social, economic and environmental goals:

- *Socially* sustainable road transport system, providing equitable, safe and secure road transport that meets the needs and aspirations of UK society.
- *Economically* sustainable road transport system, supported by a dynamic and successful UK automotive industry.
- *Environmentally* sustainable road transport system, with a low environmental impact in terms of energy consumption, global warming, waste and health.

The Foresight Vehicle programme is currently organised primarily around five technology areas. Each of these has significant potential to deliver high impact technology solutions to meet the above social, economic and environmental goals:

- *Engine and powertrain* technology development, leading to improved thermal and mechanical efficiency, performance, drivability, reliability, durability and speed-to-market, together with reduced emissions and cost.
- *Hybrid, electric and alternatively fuelled vehicle* technology development, leading to new fuel and power systems, such as hydrogen, fuel cells and batteries, which satisfy future social, economic and environmental goals.
- *Software, sensors, electronics and telematics* technology development, leading to improved vehicle performance, control, adaptability, intelligence, mobility and security.
- *Structures and materials* technology development, leading to improved safety, performance and product flexibility, together with reduced cost and environmental impact.
- *Design and manufacturing process* technology development, leading to improved industrial performance, considering the full vehicle life cycle from 'cradle to cradle'.

The Foresight Vehicle technology roadmap (version 1.0) represents a significant first step in terms of capturing, sharing and structuring expert knowledge within the automotive sector, but greater benefits can be obtained if the roadmap can be kept 'alive' on an ongoing basis. It is recommended that the roadmap should be reviewed periodically to refine and update the content and structure, and to enhance the strategic focus.

1. Introduction

The Foresight Vehicle technology roadmap is the result of a collaborative initiative that has brought together more than 130 experts from across the UK road transport sector, from more than 60 organisations. The goal was to use the roadmap structure (Fig. 1) to capture and share the rich set of views about how road vehicle markets, products, systems and technologies might evolve over the next 20 years.

It is important to note at the outset that the roadmap does not represent a prescriptive or linear view, because the future is uncertain and the path forward depends both on the actions that we take and the events that occur over time. For this reason a variety of information is included in the roadmap, including expert opinion, published forecasts, trends and drivers, uncertainties, questions and speculation. It is intended as a resource for thinking about the future, and a framework for supporting collaboration, decision making and action within the road transport sector.

This is Version 1.0 of the roadmap, and it can be refined and improved as we move into the future.

Background to Foresight Vehicle

Foresight Vehicle is a collaboration between industry, academia and Government to identify and demonstrate technologies for sustainable road transport. Future products and technologies must meet social, economic and environmental goals, satisfying market requirements for mobility, safety, performance, cost and desirability, with the objectives of improving the quality of life and wealth creation in the UK.

- *Vision:* "A globally competitive UK industry that meets the aspirations of the customer and society for mobility in the 21st century"
- *Mission:* "To secure the vision by developing, demonstrating and promoting the adoption of technology and by the pursuit of the knowledge to design, manufacture and deliver vehicles to the market throughout the next 20 years"

The initiative has been running for more than five years and has emerged as the flagship UK programme for road transport technology, supported by all the relevant Departments of Government. The associated LINK R&D programme, supported by the Department of Trade and Industry (DTI) and the Engineering and Physical Sciences Research Council (EPSRC), is now worth over £75 million and involves more than 400 organisations.

The Foresight Vehicle technology roadmap has been developed to identify technology and research themes for road transport, aiming to support UK industry in the globally competitive market for transport products and to provide sustainable mobility for UK citizens. This requires an understanding of the market and industry trends and drivers, together with the types of technology, products, services and infrastructure that will be needed in the next 20 years.

Industrial context

The DTI Automotive Innovation and Growth Team (AIGT) has recently published a series of reports[78-82] that provide an assessment of the key issues that will shape the future of the automotive sector, and how the UK can best respond to the competitive challenges which it will face. These reports, which draw on the expertise of the major stakeholders in the sector, focus on four key areas: technology; environment; design, development and manufacture; and distribution, competition and consumer. The findings of this initiative are summarised below, to provide an overview of the industrial context for the Foresight Vehicle technology roadmap.

Over 80% of world car production is accounted for by six major global groups, dominated by the USA and Japan. Consolidation in the commercial vehicle sector has gone even further, with five major groups dominating the global markets for trucks and buses. A similar process has occurred in the component sector, which is increasingly dominated by large multinational firms, which seek to establish a leading position in key technologies. Yet in all parts of the industry some smaller independent companies continue to survive, and indeed thrive, in particular sectors of the market. The retail sector contrasts with this picture, still largely organised along national lines. Retailers are also consolidating, fuelled by increased competitive pressures resulting from new channels to market such as the internet and growth in imports.

The industry is technologically advanced, both in terms of manufacturing processes and in its products. It is characterised by economics of scale and low unit costs, despite the increasing complexity of the fundamental product. Manufacturers are seeking to differentiate their products through technology and branding to restore margins, particularly by applying electronics to vehicles. The proportion of electronics in the average vehicle may well double from the current level of around 20% over the next ten years, particularly in the areas of management systems and telematics. The engine management system alone can be at least 10% of the value of the vehicle. Suppliers are taking an increased responsibility for product development, design and sub-assembly as the manufacturers focus on core capabilities. A key force driving technological change and innovation is environmental legislation. The industry has made major strides in the areas of emissions control and safety, but will face pressures for further development.

The automotive sector has provided a major contribution to the UK economy over the past 20 years, with car production and sales reaching record levels (total UK car production in 2000 was 1,64 million units, expected to rise to 1,87 million by 2004[62]), supported by significant inward investment that has transferred world best practice in manufacturing. UK automotive businesses are leaders in global best practice in many areas of manufacturing, purchasing, product development and logistics, and the skills and knowledge of the industry provide a key source for improvement throughout the whole manufacturing sector in the UK.

There is only one UK-owned volume car manufacturer, MG Rover, although the UK does provide a manufacturing base for 7 of the world's leading volume manufacturers, 9 commercial vehicle production facilities, 17 of the world's top tier one suppliers, and around 20 of the world's leading independent automotive design engineering firms. Turnover of the UK automotive sector as whole is £45bn, contributing approximately 1.5% of GDP and employing some 715,000 people - both directly in vehicle manufacturing and in the supply and distribution chains. About half of added value comes from manufacturing and assembly, which represents about 15% of total UK manufacturing added value. Exports totalled nearly £20bn in 2000, greater than any other manufacturing sector. The industry is highly globalised, with complex supply chains (a total of 65% of UK automotive output is exported, while 75% of UK car registrations are imports). An estimated 7,000 automotive component companies operate in the UK, 90% of which are SMEs. Turnover in the UK components sector in 1999 was £12bn. The UK sector's particular strengths include design engineering, especially advanced technology in motorsport, with 80% of the world market. Motorsport currently has a £5bn turnover (of which more than 50% is export sales), and the sector employs over 40,000 people, of which 25,000 are highly trained engineers in more than 3,000 businesses. The UK is also increasingly becoming a centre for engine production, and has a strong position in 'premium' cars.

The automotive industry suffers from global over-capacity and with manufacturing best practice rapidly diffused around the world, the fight to build and retain market share is relentless and competition fierce. Lean production is not enough, and companies are striving to improve profitability by building desirable brands, through excellence in design, engineering and marketing. Over-capacity in Europe, the current economic downturn and recent financial losses of vehicle manufacturers are resulting in plant closures and other rationalisation programmes. The pressures on suppliers, which are already intense, are likely to increase yet further.

The automotive industry in the UK faces significant challenges, with the majority of vehicle manufacturers, including those with outstanding productivity records, making losses, with low returns on capital. The last few years have seen decisions to close two major assembly plants and threats to the future of several others. There has been a major switch to sourcing vehicles and parts from Western and Eastern Europe, and further afield. It is estimated that UK based assemblers will soon be sourcing well under 50% of their components in the UK. The fact that the headquarters of major vehicle manufacturers are not located in the UK is a disadvantage, in that key decisions about technology, products and manufacturing are made abroad.

Despite more than doubling output in the last 25 years, the UK tends to lag behind major car producing countries in terms of productivity. In 1999 the relative output per hour worked in the motor vehicle manufacturing sector was 11% higher in Germany, 50% higher in the USA, and 100% higher in France[64]. However, this situation is not universal; the two most productive car plants in Europe are located in the UK, as well as the most productive truck plant. Industry is further hampered by a severe shortage of engineering and science skills[77], together with exchange rate volatility, particularly with respect to the US dollar, Euro and Yen. In the context of European industry and markets the recent strength of the pound has resulted in business failures and job losses, together with reduced investment in UK plant, equipment, research, product development and skills. Historically the UK has invested less in research and development (about 80% of the international average), with a bias for quick results reducing the appetite for strategic expenditure.

Future success of the automotive sector in the UK requires action by industry, universities and Government, particularly in terms of encouraging innovation and adoption of best practice. Technological capabilities are becoming increasingly important as a source of competitive advantage, with development and integration of low carbon and fuel cell technologies, together with transport and telematics technologies, identified as areas of particular priority.

Seven key recommendations are made by the AIGT:
1. The Society of Motor Manufacturers and Traders (SMMT) Industry Forum model should be extended to create an Automotive Academy of international standing to provide a comprehensive range of support to greatly enhance process improvement activities right across the industry.
2. DTI and Regional Development Agencies should put arrangements in place to fund Supply Chain Groups extending across the UK.
3. The Foresight Vehicle programme should be refocused with a strong emphasis on the potential for commercial exploitation (within the constraints of the State Aid rules). The objectives of programmes of projects should be more closely defined and, whilst remaining pre-competitive, should demonstrate good prospects of a commercial outcome in a realistic timeframe, perhaps through demonstrator vehicles.
4. The UK should establish two Centres of Automotive Excellence and Development to take forward work on Low Carbon and Fuel Cell technologies, and on Transport Telematics and Technologies for sustainable mobility.
5. A Low Carbon Transport Partnership should be established as suggested by the Powering Future Vehicles Consultation document[43].
6. A pilot mobility services project should be undertaken in London and one other city with the aims of accelerating the adoption of low pollution vehicles and demonstrating new approaches to providing mobility.
7. A Distribution, Competition and Consumer working group should be established to monitor developments in this sector that will result from the recently published proposals from the European Commision on the review of the Block Exemption, in order to maximise the benefits of change and innovation to the UK as a whole.

The technology roadmap supports the AIGT recommended actions, in terms of providing a framework for:
- Enabling communication, discussion and action within industry collaborations and networks.
- Encouraging technological innovation in road vehicle systems, in the short, medium and long-term. The 20 year horizon provides a 'radar' to ensure that investment in technology and research accounts for the trends and drivers that influence the road transport system in that time frame.
- As well as low carbon, fuel cell and telematics technologies, the roadmap includes detailed consideration of other important areas, including engines, powertrain, software, sensors, structures, materials, design and manufacturing process technologies.

The technology roadmap is based on both expert knowledge drawn from the Foresight Vehicle consortium and a range of published sources (see Appendix D), reflecting both industrial and academic perspectives. A number of these are of particular significance in terms of context:
- The Foresight Vehicle strategic plan[5] and the associated collaborative research programmes.
- The UK ten-year transport plan[30] (see political trends and drivers, Appendix A), together with other Government legislation, white papers and reports.
- Previous and ongoing UK Foresight activities and reports[24] together with other international foresight initiatives.

Aims and scope of roadmap

The overall goal of the technology roadmapping initiative has been to support the aims of the Foresight Vehicle consortium, providing a framework for ongoing investment in UK research partnerships, focused on achieving sustainable wealth creation and quality of life. This requires identification of market and industry trends and drivers that impact future requirements for road transport in the UK, and the associated technology needs and opportunities. The roadmapping process encouraged communication and discussion within a creative workshop environment and the roadmap will provide a framework for continuing this more broadly in the future.

The focus of the technology roadmap is the road transport vehicle of the future, linking current research programmes and technology developments to innovative products and systems. The road vehicle does not exist in isolation, and a systems-level view must be taken to understand the complex interaction between the vehicle and its environment, particularly the infrastructure that must be developed in parallel to vehicles. The scope of the roadmap is broad, reflecting the following elements of the system:

- *Road vehicles:* cars, vans, trucks, buses, emergency and utility vehicles, motorcycles, bicycles, taxis, trams, caravans, trailers and other road vehicle types.
- *Stakeholders:*
  - *Consumers:* owners and users of vehicles, including drivers and passengers of various vehicle types (private, business and professional).
  - *Other road users:* pedestrians, children and cyclists.
  - *Industry:* manufacturers and the associated supply, distribution and service chains, covering the full life cycle of vehicles from design to end-of-life, including both large and small companies.
  - *Research providers:* universities, research and technology organisations, government laboratories and other non-corporate research providers.
  - *Government:* various local, regional and national government departments and agencies that are concerned directly or indirectly with road transport, such as the UK Department for Transport, Highways Agency, Department of Trade and Industry, Department of Health, Department of Education, Home Office, HM Treasury, Engineering and Physical Sciences Research Council and public services.
  - *Other stakeholders:* people living in and visiting the UK, non-governmental organisations and businesses, and stakeholders in other countries with links to the UK.
- *Infrastructure:*
  - *Physical infrastructure:* city / urban, inter-city and rural road systems, motorways, bridges, tunnels, parking, fuel stations, signage, barrier and lighting systems, utilities, earthworks and interfaces with other transport modes.
  - *Information and communications infrastructure:* sensors and cameras, communications, processing and storage systems, utilities, traffic management and control, commercial and public services.
- *Other transport systems:* rail, air and water transport modes, the interfaces between them, and their interoperability (for example, alignment of schedules and through-ticketing).
- *Environment:* external trends and drivers that influence the utilisation and development of the road transport system, including social, economic, environmental, technological, political and infrastructural. The social, economic and environmental trends and drivers are considered to be the primary motivations for change, as these are the three cornerstones of sustainable development. The technological, political and infrastructural trends and drivers can either enable or constrain progress towards the social, economic and environmental goals (see Fig. 3).

Technology roadmapping process

Technology roadmapping is a technique that is used widely in industry to support strategic planning. Roadmaps generally take the form of multi-layered time-based charts, linking technology developments to future product and market requirements. Companies such as Motorola[59] and Philips[60] have used the approach for many years. More recently roadmaps have been used for supporting industry foresight initiatives, such as the Semiconductor Industry Association[58] and Aluminum Industry[9] technology roadmaps in the USA.

Technology roadmapping is a flexible technique, and the roadmap architecture and process for developing the roadmap must generally be customised to meeting the particular aims and context[61]. The process developed for Foresight Vehicle roadmapping is shown in Fig. 2. A series of ten workshops has been used to collect, structure and share information and views, involving more than 130 experts from more than 60 organisations:

a) Planning, to review scope and aims, and to support process design.
b) Exploration of industry and market trends and drivers.
c) Consideration of performance measures and targets for the road transport system.
d) Consultation to solicit views from industry, academia and other organisations.
e) Assessment of technology evolution and research requirements in the five areas of engine and powertrain; hybrid, electric and alternatively fuelled vehicles; software, sensors, electronics and telematics; structures and materials; and design and manufacturing processes.
f) Synthesis and review.

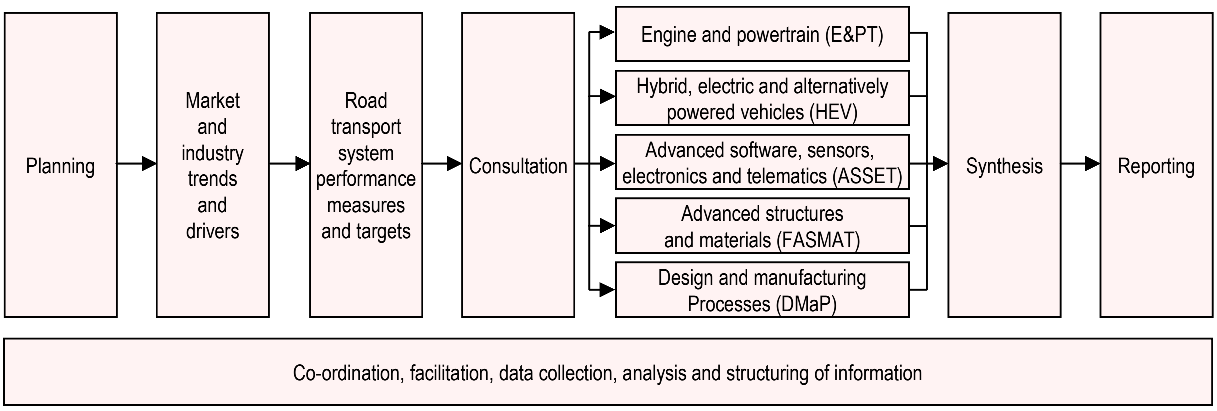


Fig. 2 – Foresight Vehicle technology roadmapping process

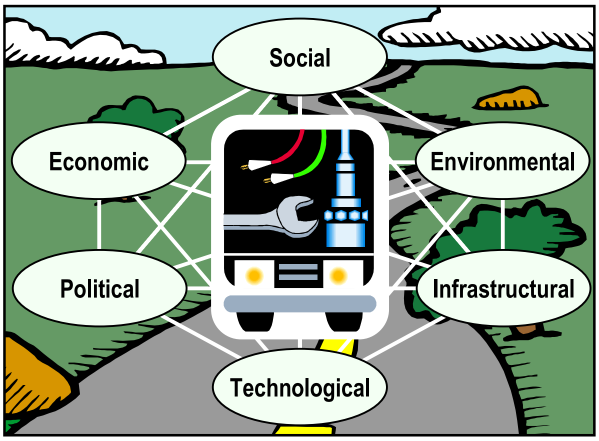
The roadmap architecture is shown in Fig. 1, which is based on a timeframe of 20 years and the following thematic layers:

- *Industry and market trends and drivers,* which define the strategic context in terms of overall goals and requirements, together with enablers and constraints, in terms of the following sub-themes are: society, economy, environment, technology, policy and infrastructure..
- *Road transport system performance measures and targets,* in response to the trends and drivers: society, economy, environment, technology, policy and system.
- *Technology solutions and options* that can enable the performance targets to be achieved: engine and powertrain; hybrid, electric and alternatively fuelled vehicles; software, sensors, electronics and telematics; structures and materials; design and manufacturing processes.

The detailed roadmaps presented in this report (Appendices A to C) result largely from a creative workshop process, and reflect the expert opinion of a wide range of participants involved with the road transport sector. The information does not represent official company or Government policy, but rather individual perspectives. The content of the top two layers (trends & drivers and performance measures & targets) has been supplemented with reference to published sources (Appendix D).

2. Trends and drivers

The aim of the Foresight Vehicle technology roadmap is to relate technology and research requirements to the trends and drivers that define the future needs of road transport in the UK, in the context of the broader integrated system of which it is a part. Six broad themes have been used to structure the information contained in the roadmap, which is focused on the development of a sustainable road transport system:



Society, economy and the environment

Social, economic and environmental drivers reflect the three cornerstones of sustainable development.

The overall goal must be to meet social aspirations while ensuring that the environmental burden of production and consumption is managed. Economic goals are crucial, as wealth enables social and environmental goals to be achieved.

Technology, policy and infrastructure

Technology, policy and infrastructure are different from the above three themes, in that activities here can either enable or constrain progress towards the primary social, economic and environmental goals

Fig. 3 – Trends and drivers that influence road transport system

1. *Social* trends and drivers relate to the social systems we live in, including demographics, life style aspirations and choices, mobility requirements and behaviour, working patterns and desires for health, safety and security.
2. *Economic* trends and drivers relate to the financial systems that affect our lives, including global, national, corporate and personal economic considerations.
3. *Environmental* trends and drivers relate to the physical environment in which we live, including energy production and consumption, waste, emissions and pollution, and the associated health impacts.
4. *Technological* trends and drivers relate to how technology affects the way we live, including development of new fuel and power systems, electronics and control technologies, structures and materials, together with manufacturing and business processes.
5. *Political* trends and drivers relate to the systems that govern us, including policy, regulation and legislation, together with the political processes that lead to them.
6. *Infrastructural* trends and drivers relate to the systems that support road transport, including the physical roads and infrastructure, together with provision of associated services and information, and the interfaces with other modes of transport.

These six themes are not independent, and there are many complex interdependencies between them. For example, the related issues of vehicle fuel efficiency and CO_2 emissions have significant implications for society, economics, the environment, technology, politics and infrastructure.

The detailed roadmap content is shown in Appendix A for each of these themes, summarised in this section.

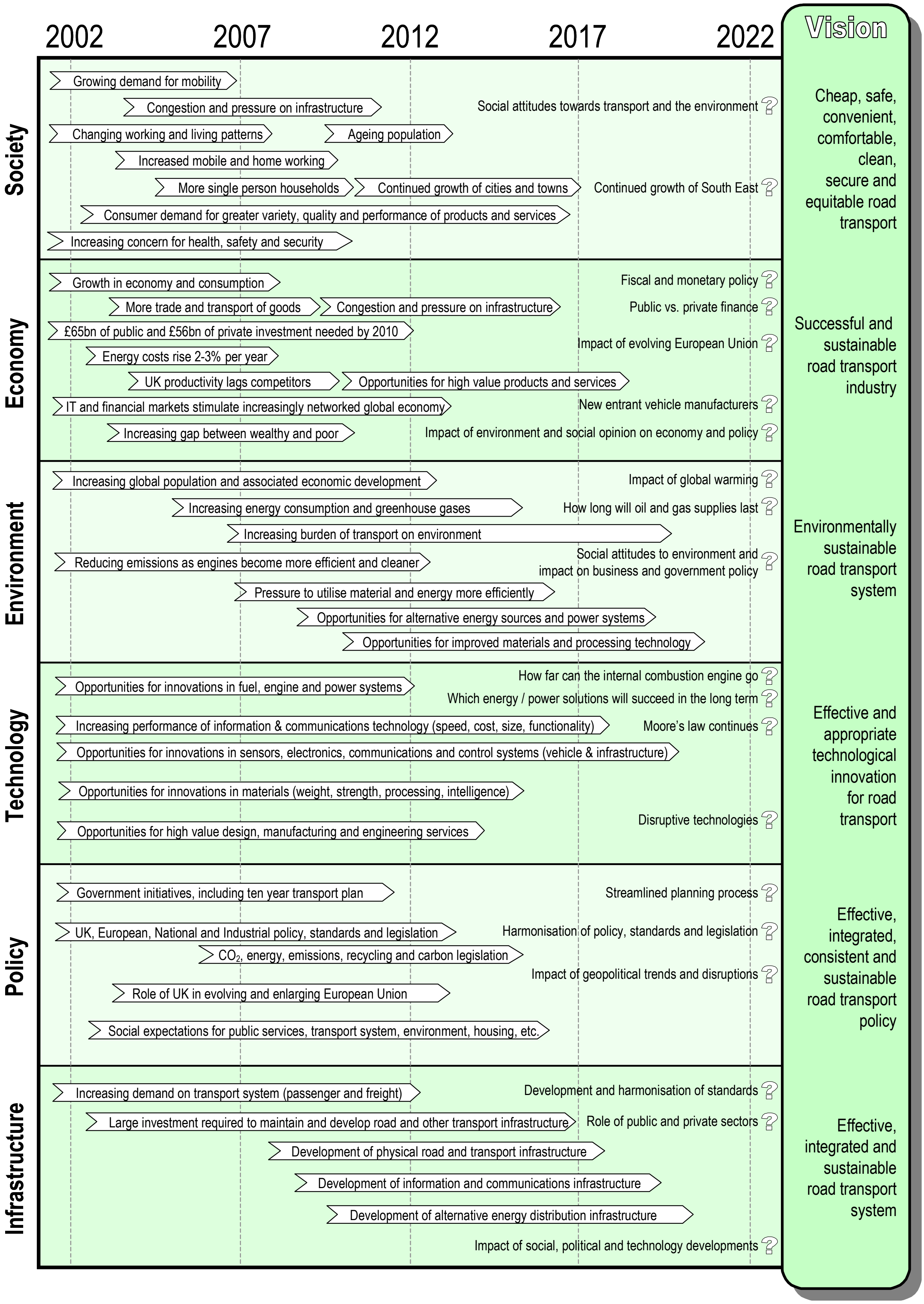


Fig. 4 – Industry and market trends and drivers

Social trends and drivers

Vision	Cheap, safe, convenient, comfortable, clean, secure and equitable road transport

Mobility and congestion

There is a growing demand for mobility (passengers and goods), stimulated by economic growth and development, together with changes in lifestyles and working patterns. The road transport system plays a central role (80% of journeys are by car). With traffic growth of 20-50% anticipated by 2010 for road, rail and air modes, there is a need for massive investment in technology and infrastructure if current congestion trends are to be countered and economic development assured.

Lifestyle and attitudes

The road transport system must satisfy the needs of many parts of society, including drivers, pedestrians, children, parents, employees and emergency services. The role of business and government is to satisfy the needs and aspirations of these groups, economically and with minimal impact on the environment. Living and working patterns are expected to change, with increasing mobile and home working enabled by improved information and communications.

Demographics

There is a need to anticipate and provide for demographic changes, such as an ageing population and growth of industrial and urban areas. The demand for housing is increasing, particularly in the South East, with 20% more houses required by 2020. Approximately a quarter of the population will be of retired age by 2030. Global population growth, combined with economic development, provides commercial opportunities whilst posing a threat to the environment.

Health, safety and security

There are about 3,500 road traffic deaths and 40,000 serious injuries in the UK each year, with a significant social and economic impact (estimated to be 2% of GDP for Europe as a whole). This, combined with the high level of vehicle crime in the UK, has resulted in government and industry efforts to improve passenger and pedestrian safety and security. Social demand for improved health will encourage continuing efforts to reduce emissions and particulates.

Economic trends and drivers

Vision	Successful and sustainable road transport industry

National economics

The transport / automotive sector represent a significant proportion of GDP (transport is estimated to represent 10% of European GDP, with automotive accounting for 5.3% of UK GDP, employing 700,000 and responsible for £20bn annual exports). The annual cost of owning and running vehicles in the UK is £5bn, with an additional investment of £2bn in road construction and £0.5bn in vehicle research and development. In addition, congestion is estimated to cost the UK economy between £15-20bn each year. Significant investment in infrastructure is required over the next 10 years (Government 10-year plan includes funding levels of £65bn from public and £56bn from private sources). Government policy has an important role to play in changing industry and consumer behaviour, with road usage likely to be increasingly taxed in order to tackle congestion and environmental problems.

Freight

Up to 80% of domestic freight is carried by road, although estimates are lower for Europe as a whole (44%). Increasing global production and trade mean that the demand for freight carried by road, air and sea could double in the next 10 years.

Business

The UK has a vehicle manufacturing capacity of more than 1 million vehicles, and an engine manufacturing capacity which will approach 4 million units by 2004. Globalisation and consolidation trends continue, stimulated by financial markets and improvements in information and communications technology. The competitive pressure on volume and labour intensive manufacture will continue, with an increasing focus on services and high-value engineering. Success in global markets will require continual improvement to productivity and product development times for new vehicles, together with the development of new and innovative high value technologies and products.

Consumer	Global population growth, combined with economic development, will provide both commercial opportunities and pressure on political systems and the environment. Increasing affluence, combined with new living and working patterns, will result in demand for improved variety, performance and quality of goods and services. Social disruption caused by an increasing wealth gap may have economic implications.

Environmental trends and drivers

Vision	Environmentally sustainable road transport system
Environmental burden	Increasing road, rail, sea and air transport results in a greater burden on the environment, in terms of greenhouse gas and other emissions, industrial and consumer waste, and depletion of oil and other reserves. Road traffic in the UK is predicted to grow by 19% by 2008, and by 50-160% over the next 20-30 years.
Global warming	Transport is responsible for 22% of UK greenhouse gas emissions, which may increase by 25-50% over the next 10-20 years based on current trends, although government policy aims for a 20% reduction in CO_2 emissions by 2010. The global warming that may be associated with greenhouse gas emissions could result in an average global temperature rise of between 1.5 and 4.5^{o}C by 2050.
Pollution	Pollution causes around 24,000 premature deaths each year in the UK. Continuing legislation, technological developments and progressive replacement of the vehicle fleet by more modern vehicles will reduce vehicle emissions to less than 20% of their 1990 level by 2010, although increasing transport demand and congestion will have a counter effect.
Energy	Fossil fuels supply 98% of transport energy demand, with world oil demand growing at between 1.1 and 2.7% annually. It is predicted that conventional oil supply will peak sometime between 2020 and 2040, after which demand will outstrip supply. The environmental and commercial pressure for alternative energy systems will increase, leading to a number of competing alternatives (for example, bio-fuels, electric motors and batteries, hybrids, hydrogen internal combustion engines and hydrogen fuel cells).
Waste	End-of-life vehicles account for 1.8 million tonnes of waste in the UK each year. The rising cost of landfill, together with European legislation on recycling will have an impact on vehicle design, manufacturing, financing, maintenance and disposal.

Technological trends and drivers

Vision	Effective and appropriate technological innovation for road transport
Energy and power	Currently road transport is heavily dependent on oil as a primary fuel source. However, within the next 20 to 40 years the natural reserves of conventional oil may not be able to keep up with an estimated 100% increase in demand. Activities are concentrating on reducing fuel consumption of conventional vehicles, together with developing alternative energy and power systems, such as hybrids, electric and alternatively fuelled vehicles. Hydrogen and fuel cells are of particular importance, although it is likely to be 15-20 years before such systems become widely available. The large investment in fuel distribution infrastructure required is a significant barrier to widespread adoption for many alternative fuel solutions.
Electronics and control	The performance of electronics and communications technology is rapidly advancing, in terms of processing speed, miniaturisation, cost and functionality, driven by Moore's law (and the International Semiconductor Industry Roadmap). The value of electronics and software in new vehicles will continue to increase, in areas such as control and intelligence, telematics, information and service provision, entertainment and user interfaces. Many of these functions will require parallel development of the infrastructure to enable communications and system-level control. The development and agreement of standards is a key enabler.

Structures and materials

Developments in materials technology can provide a number of economic and environmental benefits, in terms of reduced weight and material consumption, increased strength, reduced energy consumption and increased vehicle performance. New materials technologies of interest include lightweight alloys and polymers, fluids, coatings, biotechnology and nanotechnology.

Processes and systems

Effective manufacturing and management processes and systems are a key competitive factor in the automotive sector, in terms of both efficiency and effectiveness. Of particular importance are processes associated with research, design, new product development, manufacturing and service provision. The UK has particular strengths in design and value-added engineering services, although significant shortages in skilled engineers, scientists and technologists are predicted.

Political trends and drivers

Vision

Effective, integrated, consistent and sustainable road transport policy

Transport

Significant government effort is directed towards transport, stimulated by the economic and social impact of worsening congestion. The UK ten-year transport plan anticipates £64.7bn public and £56.3bn private investment in urban and regional transport infrastructure by 2010. Targets have been set for reductions in congestion; road widening of 380 miles of the strategic road network; 80 trunk road schemes; 100 new bypasses; 130 major road improvement schemes; noise reduction; maintenance of roads, bridges and lighting; improved information, booking and ticketing systems; 40% reduction in deaths / serious injuries; accelerated take-up of cleaner vehicles. Bus, tram and light railway solutions are planned for urban and regional development.

Energy and CO_2

The need to use energy efficiently and reduce pollution, greenhouse gases and waste is reflected in international agreements, European legislation and UK policy. Clear targets are specified for improved fuel efficiency and the total level of CO_2 and other greenhouse gases produced as a by-product.

Waste

End-of-life vehicles account for 1% of Europe's waste, with the UK producing 1.8 million tonnes each year. Reduced availability of landfill sites, together with taxation and European end-of-life legislation may eventually lead to new forms of vehicle design, manufacture and ownership. By 2015 it is expected that 95% of vehicles will be recyclable, with only 5% destined for landfill (currently vehicles have one of the highest recycling rates - more than 75%).

Health and safety

The desire to reduce road deaths and serious injuries is emphasised in the UK ten-year transport plan. Targets of 40% reductions in deaths and serious injuries, and 50% fewer children killed or seriously injured have been set for 2010. This requires improvements to infrastructure and vehicles, enabled by UK, European and Industry agreements and standards and regulations. In addition there are European and UK targets for reductions in emissions, particulates and pollutants.

Political system

UK and European political systems and processes underpin the delivery of an efficient and effective road transport system, which requires a partnership between the private and public sectors. The long-term capital investment associated with infrastructure requires stable and integrated policies, while environmental targets require a willingness to develop and abide by international agreements. Issues of particular importance in Europe include the liberalisation of markets (for example, freight by 2008) and harmonisation of legislation and standards.

Infrastructural trends and drivers

Vision	Effective, integrated and sustainable road transport system
Physical road infrastructure	Significant efforts are needed to ensure that the physical road transport infrastructure is maintained in good condition, and extended to accommodate future demand (which may double by 2020). The UK ten-year plan includes substantial improvements to the urban and regional road transport infrastructure. New road surfaces are being developed to reduce noise and wear, with the long-term possibility of installing equipment to support road trains (vehicle platooning).
Information and communications infrastructure	Rapid improvements in communications bandwidth and computer processing power provide opportunities to improve the overall road transport system performance, in terms of traffic management, reduced congestion, information services, improved safety and security. The development of appropriate technical standards is important, particularly when combined with new vehicle developments.
Energy infrastructure	If alternative energy and power systems are to be developed and deployed widely in vehicles, then appropriate fuel distribution networks will need to be established. It is probable that a number of competing energy and power systems will be developed, starting with LPG and battery / hybrid powered vehicles. However it is likely to be at least 15 years or more before alternative energy sources such as hydrogen and bio-fuels will be widely available.
Integrated transport system	The effectiveness of the overall transport system demands that the links between the road and other transport modes be considered. Inter-modal transport requires synchronisation of timetables, integrated ticketing systems, together with accurate and up-to-date information services for both passenger and freight.

3. Performance measures and targets

The performance of the road transport system needs to improve if the desired social, economic and environmental goals are to be achieved, enabled by technology, policies and infrastructure. Foresight Vehicle is primarily concerned with supporting the development of innovative and appropriate technologies that will lead to improvements in performance of the road transport system. The relationship between technology developments, system performance and trends and drivers is a fundamental aspect of the technology roadmap architecture (Fig. 1).

The performance measures and targets have been themed in a similar way to the trends and drivers:

1. *Social* performance measures and targets relate to mobility and congestion, lifestyle and attitudes, together with health, safety and security.

2. *Economic* performance measures and targets relate to both business and consumer perspectives.

3. *Environmental* performance measures and targets relate to the overall environmental burden of road transport, global warming, pollution, energy and material waste.

4. *Technological* performance measures and targets relate to energy and power, electronics and control, materials and structures, together with the processes and systems that support development of these technologies. This theme is different from the others, in that it directly relates to the five technology areas considered in detail in Section 4.

5. *Political* performance measures and targets relate directly to Governmental policy, regulation, legislation and action in the areas of energy and CO_2, health and safety, and waste management.

6. *System* performance measures and targets relate to the road transport system as a whole, which includes consideration of the infrastructure and the level of system integration. It should be noted that performance measures and targets for the infrastructure itself are not included in this roadmap, as the focus in on road vehicles.

The technology roadmap builds on previous Foresight Vehicle work. The Strategic Plan[5] defines a set of nine visionary ‘Beacons’ that represent integrated aspects of the future system, encompassing technology, product and market concepts, and these are described in detail in Appendix B. The Beacons are related to road transport system performance measures and targets defined in the Strategic Plan, summarised in Fig. 5 and presented in detail in Appendix B, which also includes additional potential measures and issues identified during workshops.

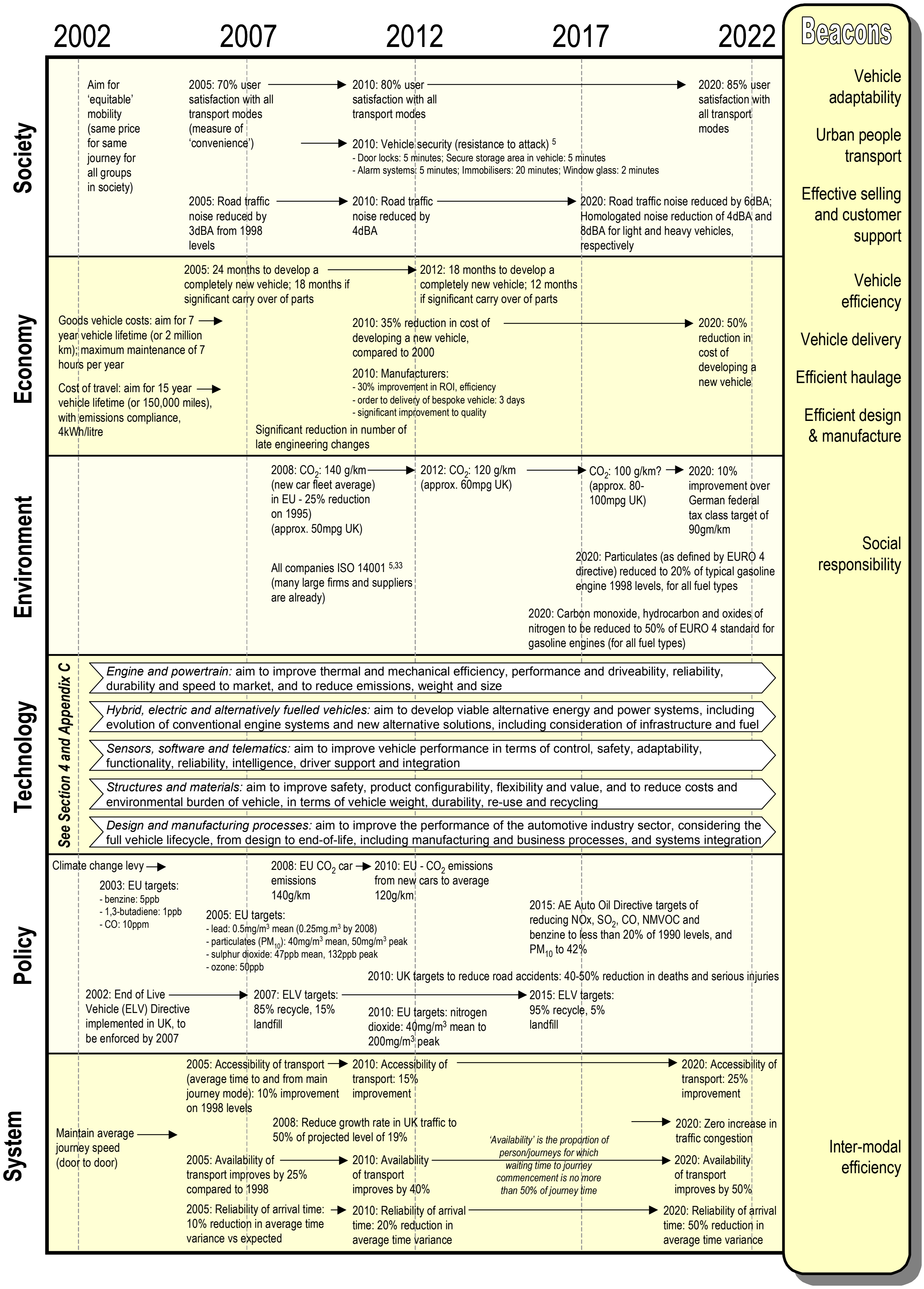


Fig. 5 – Road transport system performance measures and targets

4. Technology

Technology provides the principle means by which the required improvements to the road transport system will be achieved. The broad definition of technology as ‘know-how’ has been adopted, which emphasises that technology concerns the application of knowledge. This includes ‘hard’ technology, which is based on science and engineering principles, as well as ‘soft’ technology, which includes the processes and organisation required to exploit science and engineering know-how effectively.

This section includes a summary of the outputs from five workshops (Appendix C), focusing on the following technological areas, each of which represents a Foresight Vehicle Technology Group (TG). Technology evolution is considered, together with research challenges.

1. Engine and powertrain (E&PT)
    - Thermal and mechanical efficiency
    - Performance and drivability
    - Emissions (pollution and noise)
    - Reliability and durability
    - Speed to market and cost
    - Weight and size
2. Hybrid, electric and alternatively fuelled vehicles (HEV)
    - Hydrogen and fuel cells
    - Hybrid and advanced internal combustion engines
    - Electrics and electronics for energy and drive systems
    - Conventional and alternative fuels
3. Advanced software, sensors, electronics and telematics (ASSET)
    - Shift to software
    - Access and use of vehicles
    - Architectures and reliability
4. Advanced structures and materials (FASMAT)
    - Safety
    - Product configurability / flexibility
    - Economics
    - Environment
5. Design and manufacturing processes (DMaP)
    - Lifecycle
    - Manufacturing
    - Integration

The information contained in this section and Appendix C is based largely on expert opinion (workshops). Many of the resources listed in Appendix D also consider future technology development.

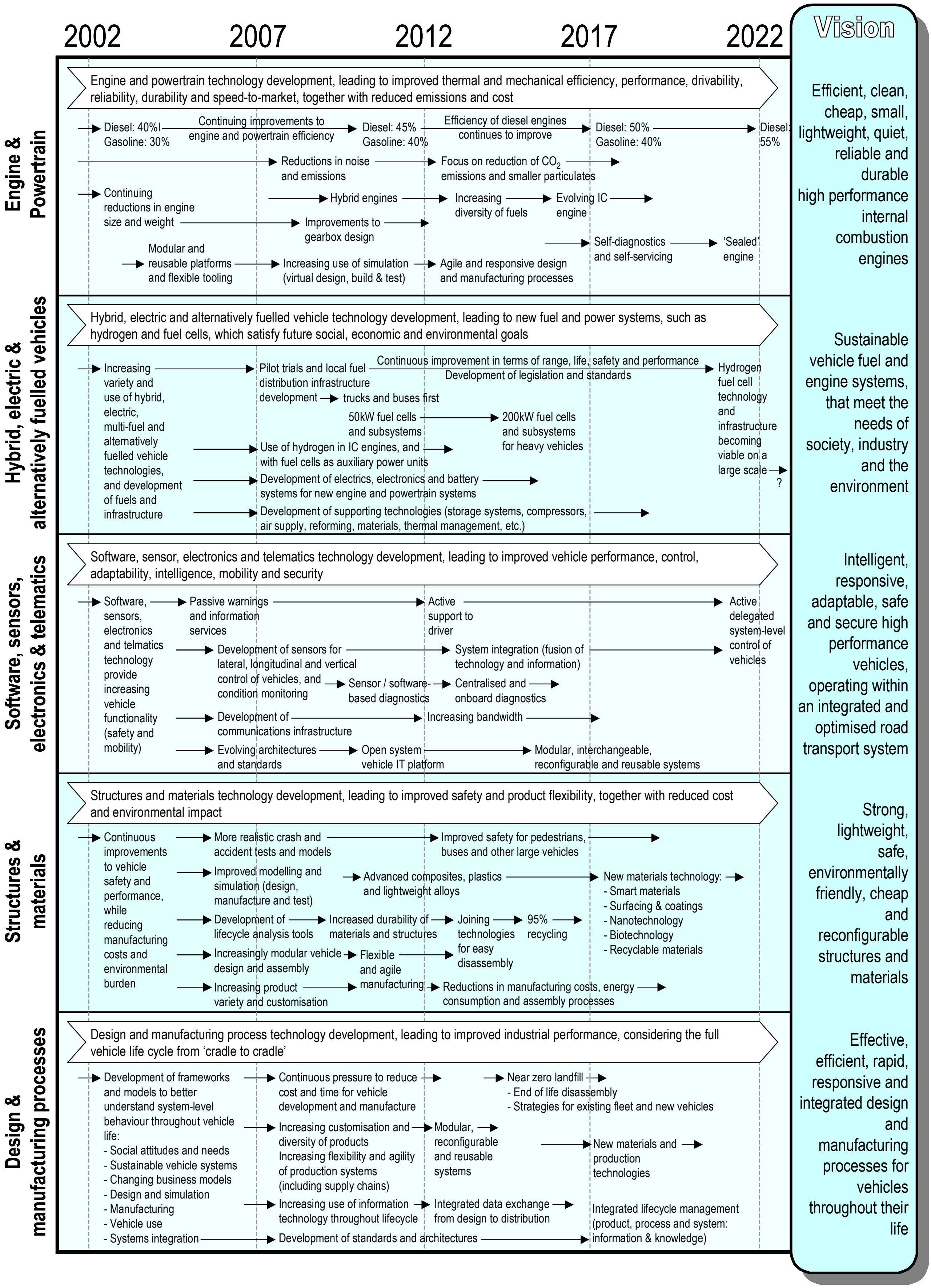


Fig. 6 – Technology evolution

4.1 Engine and Powertrain

Scope

The engine and powertrain (E&PT) technology theme includes the following vehicle functions and systems:

- On-vehicle fuel filling systems and fuel types
- Conversion of energy in fuel to useful mechanical power
- Transmission of power to wheel hub
- Associated and auxiliary systems such as air flows, after treatment, lubrication systems, generators, alternators, climate control.

Market and industry trends and drivers that are particularly relevant to this technology theme include:

Social	Demand for greater vehicle adaptability (configurability, upgradeability and modularity) and vehicle performance (to meet different consumer needs and driving styles), and reduced vehicle noise.
Economic	Competitive pressure to reduce development and manufacturing cycle times and costs, and to improve responsiveness, agility, flexibility, durability, efficiency and quality, in order to achieve greater profitability and return on capital.
Environmental	Requirement for improved fuel efficiency and to reduce engine weight and emissions of CO_2 and other greenhouse gases (during manufacture and use of vehicles), noxious and hazardous emissions such as particulates, carbon monoxide, nitrogen oxides, sulphur dioxide, lead, benzene and ozone.
Technological	Competition to develop innovative solutions in the areas of engine and powertrain solutions for new fuel types, including hybrid and fuel tolerant IC engines, new engine materials and lubricants, together with electronics, sensors and software (for both engine management and design & manufacture).
Political	UK Government, European and international policy, regulation and legislation concerning transport, energy, CO_2 and other emissions, health & safety and waste management.
Infrastructural	The need to develop new engine solutions in parallel to developments in fuel and energy infrastructure.

Development of engine and powertrain technologies, together with associated research challenges, have been explored in an expert workshop that identified and considered the following themes, summarised below and detailed in Appendix C:

- Thermal and mechanical efficiency
- Performance and drivability
- Emissions (pollution and noise)
- Reliability and durability
- Speed to market and cost
- Weight and size

Note that there is some overlap with Section 4.2 (hybrid, electric and alternatively fuelled vehicles).

Technology directions

Thermal and mechanical efficiency

The efficiency with which the engine and powertrain can convert the energy stored in fuel to useful mechanical power is crucial for reducing fuel consumption, the cost of vehicle operation and emissions (CO_2 in particular). The average efficiency of current petroleum and diesel engines is modest (30-40%), with the driving profile for urban environments presenting a barrier to significant improvement. Technological improvements to engine systems could lead to an increase in efficiency of about 10% within 20 years. In parallel to improvements in current powertrain systems, it is anticipated that new fuel and engine solutions will appear on the market (compressed natural gas, electricity, hydrogen, etc.). Particular challenges to overcome include the need for new infrastructure, social acceptance, cost and the migration from current systems. In this regard hybrid solutions, and vehicles that are tolerant to more than one fuel type are crucial.

< 10 years

- 5% increase in efficiency
- Improving energy / heat recovery
- Increasing use of hybrid power systems
- Improving energy storage systems (batteries, gas)
- Smarter cooling / lubrication systems
- Camless on 50% vehicles
- 170 bar maximum cylinder pressure for heavy duty vehicles
- Increasing transmission efficiency
- Integrated engine / transmission control
- Compressed natural gas trucks and buses

10 – 20 years

- Further 5% increase in efficiency
- Integrated systems
- Feedback control of combustion injection process
- Flexible engine cycles
- Improved sensors
- Materials for higher temperature combustion
- Continuing development of fuel
- Increasing use of renewable fuels and H_2
- Combustion tolerates alternative renewable fuel blends
- Thermal insulation

> 20 years

- Efficiency (diesel) peaks at 65%
- Maximum cylinder pressure for heavy duty vehicles reaches 250-300 bar

Performance and drivability

Vehicle and engine manufacturers must meet consumer demand for improved vehicle performance and drivability characteristics, while simultaneously reducing fuel consumption and emissions. This can be achieved by a combination of weight and size reduction, combined with improvements to primary engine and auxiliary system technology (airflow management, transmission and gearbox, traction control, sensors and control systems, fast warm-up, etc.).

< 10 years

- Compact light gearboxes with more ratios
- Auto–shift manual on 50% of vehicles
- Hybrid enables driveable downsizing
- Standard response feel pool car
- Electric water & oil pumping

10 – 20 years

- 20% efficient continuously variable transmission
- Downsizing and octane-boosting
- Technology ready for safe convoy driving

> 20 years

Emissions (pollution and noise)

While CO_2 is a primary by-product of the combustion process, other health-damaging emissions, such as particulates, noxious gases and noise can be reduced substantially. Significant progress towards emissions reduction is expected in the next decade, stimulated by legislation and technical advances. It is likely that the focus will shift towards reducing emission of small particulates (< PM 1) and CO_2.

< 10 years

- Less use of compressed natural gas (CNG) in the short term
- Increasing use of PM traps
- Continuing focus on ‘next worst pollutant’
- Optimised after-treatment
- Self diagnosis
- Reducing cold start pollution
- Reducing noise from heavy vehicles and auxiliary systems (e.g. cooling fan)
- Urea widely available as emissions-reducing agent

10 – 20 years

- Emissions control for PM size (< PM 1)
- Cleaner air quality achieved, and focus shifts to CO_2
- New breakthrough NOx after-treatment (biotech / nanotech)
- Control interface to telematics & GPS
- Sealed engine
- Lubricant reduced wear
- Full homogeneous charge compression ignition
- CNG making a comeback

> 20 years

Reliability and durability

Significant advances in engine and powertrain reliability and durability has been achieved in the past two decades, and it is anticipated that this trend will continue. The ultimate goal is to achieve ‘self-diagnosing’ and ‘sealed’ engines, which would have significant benefits in terms of longer engine life, together with reduced pollution (from lubricants), maintenance, cost and material consumption.

< 10 years
- Oil quality sensors
- Combustion solutions for lower cylinder pressures
- Lubrication quality management systems for near-zero disposal
- Structural solutions for high cylinder pressure & drive torque
- Intelligent condition monitoring and ageing compensation
- Service intervals increase to 30,000 miles

10 – 20 years
- Failsafe onboard diagnostics
- Fault-tolerant and ‘self-servicing’ systems
- ‘Sealed for life’ lubrication and sensor technology
- Dry lubricants and coatings

> 20 years
- ‘Zero faults for life’

Speed to market and cost

The engine and powertrain represents a significant proportion of vehicle cost (approximately one third of vehicle cost and increasing). Improvements in vehicle design and manufacturing processes have a significant role to play in reducing costs and time-to-market, and hence improving competitiveness of vehicle manufacturers. Key areas for improvement include the development of more sophisticated simulation and integrated computer aided design solutions, combined with more flexible manufacturing systems and tooling.

< 10 years
- Increasing modularisation and development of common platforms
- Simulation of flexible manufacturing and tooling
- Virtual engine and powertrain simulation and calibration
- Reliable life prediction for non-ferrous alloys
- Lower cost power electronics

10 – 20 years
- Low cost high pressure fuel injection
- Increasing use of knowledge-base design
- Self-calibrating systems
- Lower cost batteries
- Faster technology rollout
- Low cost gaseous fuel storage
- New fuel cell technology developments

> 20 years
- Rapid time to market (e.g. one year)

Weight and size

The engine and powertrain represent a significant proportion of total vehicle weight. Reducing weight and size provides benefits in terms of vehicle efficiency, performance and design flexibility. Weight and size reductions will be achieved by advances in materials (non-ferrous), improvements in engine design and management systems.

< 10 years
- Increasing specific power output
- New liner-less bore technologies for shorter engines
- Non-ferrous gears
- Downsizing and good drivability
- Composite engine and transmission structures (including ‘plastic’)
- Integrated ancillaries

10 – 20 years
- Systems control to avoid peak loads
- Plastic ‘gears’
- Compound gear paths (shorter gearbox)
- Ancillaries moved off engine
- Lighter crank and rod materials
- Thermal management for high power density

> 20 years
- ‘Weight and size never compromise the vehicle’

Other potential areas of technology development include:
- More standardisation
- Human interface and response
- ‘Smart’ car (responsive to driver needs)
- Noise reduction (wheel / infrastructure)
- Software, sensors, electronics and telematics
- Gas turbine engines
- Compound engines (turbo)
- Smart lubrication and cooling systems
- Adaptive engine control in operational use
- Vehicle condition & usage information back to asset owner / dealer / manufacturer (telematics)
- Modularisation of major powertrain components (outsourcing)
- Self-diagnosis and rectification
- Reducing design and fabrication re-work
- Improved recycling technology for engine fluids
- Improved oil life (‘re-energised’ oil)
- New engine types and configurations

Research challenges

- *Improve combustion process,* to reduce CO_2 emissions and noise, and to improve tolerance to diversification of fuel types. Challenges include improving knowledge of combustion processes, in order to achieve low emissions and good cycle efficiency. Example technologies include in-cylinder sensing, adaptive calibration, model-based control, camless valve operation, variable compression, alternative cycles and improved fuel systems.
- *Optimise powertrain systems,* to reduce CO_2 emissions and improve environmental performance. Challenges include optimising powertrain performance for a wide range of operating conditions whilst maintaining acceptable vehicle performance and driveability. Example technologies include heat recovery systems, hybrid systems, novel transmissions, downsizing, compounding, energy storage systems, intelligent control and smart ancillary systems.
- *Improve emissions control,* in response to legislative targets, social demand, and to reduce the environmental burden associated with vehicles. Challenges include reducing cold-start emissions (HC, NOx, ultra-fine particulates), reduction of pressure loss, and the development of robust, small, and low cost systems. Example technologies include novel after-treatment systems and configurations, HC traps, biotechnology and catalysts (with reducing dependence on precious metals).
- *Downsizing of powertrain system while increasing power density,* to reduce weight, material usage, cost and space requirements, and to increase efficiency. Challenges include ensuring mechanical and thermal integrity, development of new materials and lightweight structures, improving durability and fluid flows (air and coolant), integration of engine and transmission, and development of efficient auxiliaries. Example technologies include turbo- and super-charging, composite structures (including plastics, metals and ceramics), thin-wall structures, novel thermal and mechanical solutions, intelligent ancillaries and transmissions, lightweight gears and novel reciprocating part solutions.
- *Virtual design,* to increase speed to market, reduce technology and product development risks, reduce design and manufacturing costs, and to optimise integrated systems. Challenges include development of robust simulation, correlations and validation, development and application of knowledge bases, faster rollout of designs and products, and holistic tracking of attributes. Example technologies include simulation (of functional attributes, manufacture and tooling), knowledge-based design, virtual and self-calibration, integration of research and virtual engineering with marketing and business planning, and modularisation.
- *'Zero' servicing,* to increase consumer convenience and to reduce costs (especially for trucks and buses) and environmental impact (disposal of used fluids). Challenges include improved tribology, condition monitoring, fault tolerance and self-diagnosis and repair. Example technologies include sensors, age-compensation control, onboard diagnostic systems, telematics, failure modelling and prediction, advanced lubricants, additives and filtration, coatings, bearing materials, design concepts, inhibition of corrosion and cracking, and advanced sealing / fastening systems.

4.2 Hybrid, Electric and Alternatively Fuelled Vehicles

Scope

The hybrid, electric and alternatively fuelled vehicle (HEV) technology theme includes the following vehicle systems and functions:

- Application of new and alternative vehicle fuel types, such as hydrogen, liquified petroleum gas, compressed natural gas, liquefied natural gas, bio-diesel, and bio-ethanol / methanol
- Conversion of energy in alternative fuels to useful mechanical power
- Electrical motors for vehicle propulsion, storage systems, hybrids and fuel cells for converting fuels directly to electrical energy

Market and industry trends and drivers that are particularly relevant to this technology theme include:

Social	Growth of cities and increasing urban population density, together with a demand for quieter and less polluting vehicles.
Economic	Increasing demand for energy is likely to eventually overtake supply of conventional oil, leading to increased cost and regulation of supply and use. Established fuel and engine systems, which are continually improving, represent barriers to entry for alternative solutions, with competitive pressure to improve performance and reduce cost.
Environmental	Global warming, with a requirement to reduce fuel consumption and emissions of CO_2 and other harmful substances during manufacture and use of vehicles, combined with increasing pressure on conventional oil supplies.
Technological	Competition to develop innovative solutions in the areas of new fuel and power systems, such as hydrogen and fuel cells, together with hybrid and fuel tolerant IC engines.
Political	UK Government, European and international policy, regulation and legislation concerning transport, energy, CO_2 and other emissions, health & safety and waste management.
Infrastructural	New engine solutions need to be developed in parallel to the establishment of associated fuel and energy infrastructure.

Development of hybrid, electric and alternatively fuelled vehicle technologies, together with associated research challenges, have been explored in an expert workshop that identified and considered the following themes, summarised below and detailed in Appendix C:

- Hydrogen and fuel cells
- Hybrid and advanced internal combustion engines
- Electrics and electronics for energy and drive systems
- Conventional and alternative fuels

Note that there is some overlap between the first two themes, and also with Section 4.1 (engine and powertrain).

Technology directions

Hydrogen and fuel cells

New fuel and engine solutions are required if international, European and UK targets for reducing CO_2 emissions are to be met, and as a response to longer term challenges posed by potential global warming and depletion of hydrocarbon energy resources. Fuel cells are one of the most promising technologies, with hydrogen as a particularly attractive fuel in terms of reducing vehicle emissions. However, the transition to widespread adoption of such solutions will require significant barriers to be overcome, especially in terms of costly infrastructure development. It is likely to be at least 10-20 years before such alternative fuels become widely used, although pilot applications will emerge in the shorter term, supported by developments in local infrastructure. Hybrid and bi-fuel engine systems provide a potential migration path towards the adoption of new solutions such as hydrogen and fuel cells.

< 10 years

- Mainstream introduction of mild hybrid vehicle technology and 42V electrical systems
- Rapid start-up hydrogen IC, fuel cell and hybrid vehicles
- Cryogenic, high pressure and efficient chemical storage of H_2 (with reduced vehicle range)
- Onboard reforming of H_2
- Fuel cell vehicle pilots (vans, buses and cars)
- Safety of H_2 (vehicle and infrastructure)
- Fuel cell auxiliary power units for reliable pre-heating and cooling
- Robust evaluation of H_2 infrastructure requirement and production technology (including cradle-to-grave CO_2 inventories)
- Distributed generation of H_2 at local level
- Low noise compressors
- H_2 fuel cell – internal combustion engine hybrids
- New legislation and regulations for gas powered vehicles
- Support technologies and systems for fuel cells (air supply, control electronics, thermal)
- Economic bio-fuels gasification production of H_2
- Evaluation of fuel cell options (e.g. H_2, methanol and naphtha)
- 50kW fuel cells and subsystems

10 – 20 years

- Extension of hybrid vehicle technology mainstream use to full hybrids with HEV mode (parallel / series)
- H_2 supply infrastructure emerges
- Industrial scale H_2 production technology starts to emerge with focus on cradle-to-grave CO_2 inventory
- H_2 storage systems with equivalent vehicle range
- Urban fuel cell hybrid buses and delivery vehicles
- Vehicle design for fuel cell hybrids (electric drives, modular design, crash worthiness, lightweight materials)
- 200kW fuel cell and subsystems for heavy vehicles (buses and trucks)
- 'Switchable' H_2 vehicle tanks at refilling stations
- Volume manufacturing plant for fuel cell vehicles in UK
- Recycling / re-use of fuel cell materials
- Fuel cell fuels options clearly evaluated and direction established
- Solid oxide / ceramic fuel cells for heavy vehicles
- Fuel cells for long distance coach and freight vehicles

> 20 years

- Next generation fuel cell systems (20kW/litre)
- Significant (>5%) uptake of fuel cell passenger cars

Hybrid and advanced IC engines

The internal combustion (IC) engine has been evolving for many decades, and will be the primary means of converting energy to useful mechanical power in vehicles for some time to come. Hybrid and advanced IC engines have a crucial role to play in terms of enabling migration to the widespread use of alternative fuels such as CNG, LPG, LNG and bio-diesel. The use of hydrogen fuel in IC engines is of particular importance in developing a hydrogen fuel infrastructure, as dual fuel petrol/hydrogen in an interim period can simplify the fuel introduction process. The onboard hydrogen can also facilitate the development of fuel cell auxiliary power units to provide an onboard electricity source.

< 10 years

- Commercial mainstream introduction of mild hybrid vehicles
- Integration of hybrid vehicle systems with the rest of vehicle (supervisory control, charge storage devices, aftertreatment, downsizing)
- Liquid H_2 bi-fuel IC hybrid engines
- First commercial introduction of H_2 IC vehicles
- Development of IC engine technology (lighter, smaller)
- Development of advanced powertrains better optimised to alternative fuels (dual or flexible fuel)
- CNG engines for buses and trucks
- Photovoltaic production of H_2

10 – 20 years

- Mainstream adoption of full hybrids (parallel / series) with ultra efficient downsized IC engines designed specifically to suit hybrid applications
- Zero tax on H_2 replaced by progressive 'well to wheel' carbon tax (zero tax for renewables)?
- Advanced powertrains suited to alternative fuels
- Downsized IC engine and hydraulic hybrid (bus / coach)
- Liquid H_2 onboard storage (2 week storage target)
- HCCI combustion H_2 IC engine
- Expansion of liquid H_2 infrastructure
- 1% of new vehicles with H_2 fuel cell by 2015
- Emissions control of vehicle interlinked to

> 20 years

- 50% of vehicle fleet running on H_2
- Diesel and gasoline from renewable sources

- Local development of liquid H_2 infrastructure
- Fleets of buses and trucks with H_2 IC engines by 2010
- Emergence of low emission homogeneously charged compression ignition (HCCI) combustion of gasoline and diesel
- Feedback combustion control for multi-fuel compatibility

telematics

- H_2 only IC engine with increased compression ratio and cryogenic injection
- Exhaust heat recovery from IC engine
- New battery technology (low cost, high power density, long life)
- Reversible fuel cell energy storage

Electrics and electronics for energy and drive systems

Fuel cells and other new energy and drive systems will require parallel development of the electric and electronic systems for energy storage, engine management and control, power generation, conversion and transmission. Advances in software, sensors and electronics provide significant opportunities for supporting the integration of systems to provide increased functionality and performance.

< 10 years

- Optimisation of electric motors for hybrid drives
- Hybrid IC vehicles wit dual voltage electrical architectures (42V/14V)
- Advances in lead acid batteries (increased power, longer life, lower cost)
- Advances in nickel metal hydride and lithium battery technology (safety and cost)
- Continuous variable transmission (clutchless)
- Improved vehicle journey models
- Fully integrated power converter and electric drive
- AC power distribution systems
- Advanced supervisory control systems providing advantages of system integration
- All electric (regenerative) braking, idle stop/start and torque assist modes for mild hybrids

10 – 20 years

- Ultra high speed low cost generators
- Hybrid IC vehicles with single voltage electrical architectures
- High density energy storage systems
- New energy storage systems (hydraulics, flywheels)
- Zero emission vehicle (ZEV) mode for full hybrids
- Low maintenance engines
- Higher temperature silicon
- Low cost multiplex systems
- Low cost, low range RF controllers
- Light weight affordable wheel motors
- High voltage systems
- Super magnets
- Superconductors
- Neural networks

> 20 years

- Low cost superconductor-based energy storage
- Fuel cell cost at \$3,000/vehicle

Conventional and alternative fuels

It is likely that in the next 20-50 years global demand for energy will begin to outstrip conventional supply as crude oil reserves are depleted, leading to sharply increasing fuel prices and new taxation regimes. Alternative energy sources will become economic, stimulating innovation in new fuel, engine and infrastructure technology. The need to reduce CO_2 emissions will provide a significant stimulus to improve engine efficiency and to shift to low- or neutral-carbon fuels such as hydrogen and bio-diesel (the draft EU Directive 92/81/EEC[105] aims for a minimum of 20% biofuels sales by 2020). A major challenge is the need to develop new fuels, vehicle systems and infrastructure in parallel, and it is likely that a variety of competing solutions will emerge over the next 20 years.

< 10 years

- Standards development for liquid petroleum gas (LPG), natural gas (NG) and advanced ‘gas to liquid’ fuels
- Flexi-fuel vehicles
- Improvements to ultra low sulphur diesel, with progressive reductions to <10ppm
- Safety issues for new and alternative fuels
- Relative advantage of LPG and NG fuel diminishes as conventional IC and alternative fuel technology advances
- 5% bio-diesel by 2010
- Hydrogen fuel cells and hybrids

10 – 20 years

- Advanced ‘gas to liquid’ fuels suitable for reforming (in the longer term petrol will not be suitable)
- Advanced bio-fuel and H_2 production technologies (low CO_2 method for H_2 production)
- Commercial fuel cells for light vehicles
- Need for rare earth metals / catalysts (supply & disposal)
- Naphtha for distribution in existing infrastructure with onboard or local reforming
- Methanol introduction

> 20 years

- Availability of UK bio-diesel limited to 10% (due to availability of arable land and competition with food production)
- IC engine still used for heavy goods vehicles in 2050 (LPG)
- Significant use of renewable H_2

Other areas of technology development may include:

- Improved / oxygenated fuels
- Bulk handling of power electronics
- Low cost power switching
- Shielding for electromagnetic fields (low frequency)
- Integration of vehicle and infrastructure
- Models for supporting socio-economic-environmental analysis of transport and technology (private and public)
- H_2 production at home (from tap water and electricity)
- Servicing and maintenance of new energy systems
- Supply chain issues for HEV technologies

Research challenges

- *Hybrid electric applications,* where an electric motor is used as part of the propulsion system, to support the combustion engine or to operate separately for specific, limited driving situations. The application of the electric drive can be implemented in many ways and there is a research need for improved models (simulations) of the drive system and the driving modes, in order to determine the optimum system layout and machinery sizes for particular applications. This will lessen the expense of building and operating prototype vehicles. Support systems and components that need to be researched and developed for these applications include:
  - *Power Battery.* To support the combustion engine, especially in acceleration mode or when the electric drive is operated alone, the battery needs to be able to deliver high 'instantaneous' power with minimum weight and cost. It also has to be able to deliver a large number of power cycles for a good lifetime durability. Challenges include cell engineering, energy management systems, low cost materials and design for manufacture. Desirable goals (for cars) would be storage systems with the following performance levels: 30kW, 3kWh, 40kg, $450.
  - *Electric Motor and Power Electric Inverter.* The key feature of the motor is the ability to deliver high power for successive acceleration demands with high efficiency and to handle the necessary cooling requirements. In many hybrid applications the motor will need to be closely integrated within the combustion engine or transmission system. Providing the electrical drive to the motor, the power electric inverter has similar demands for high power and cooling. A key element is the research and development of high power, low cost power switching devices so that, ideally, the same cooling system as that used for the combustion engine can be used. Desirable goals are 50kW for cars and 150kW for commercial vehicles, at a cost of less than $1,000. Challenges include high operating voltages and device specifications, new materials (for example SiC), high temperature capacitors, thermal design and management, and cost reduction. Advances in the aerospace sector may be useful if they can be transferred to automotive.
  - *Combustion Engine, Exhaust Aftertreatrment and Transmission.* In order to make maximum benefit of the hybrid system for performance, fuel economy and exhaust emission the 'conventional' power train has to be optimised – in particular to design the system for its role without the need to meet high power acceleration demands. In a similar vein the transmission system can be optimised for fewer gear changes and to link the gear changing with the electric drive for automated operation. This area of research can also include 'alternative' combustion engine systems such as external combustion and gas turbine. Challenges include suitability for hybrid duty cycles (stop / start), compatible combustion systems (conventional, bio- and CNG / H_2 fuels), product engineering for customer acceptance (reliability and performance), and how to improve efficiency. Example technologies include downsizing and low weight, advanced combustion / feedback control, heat recovery and gaseous fuel handling.
  - *Electronic Control of Power Train.* The combustion engine and the electric motor are very different in their capabilities and operational uses and yet they need to perform together in harmony for optimum efficiency and driving performance. There is therefore the need for a whole vehicle drive system electronic control. To optimise efficiency (engine and congestion), ensure smooth and stable performance, improve ease of use, safety, security and law enforcement, and to reduce emissions. Challenges include multiple system modelling integration, network design / architecture (control), low cost high power CPV's, better use of communication links, and improved system compatibility. Example technologies include system control / diagnostics, adaptive and intelligent vehicle management systems.

- *Battery electric applications,* where the mileage range of battery powered vehicles will always tend to be a limitation, not least because of the time to recharge from electrical power outlets. It is expected, therefore, that these vehicles will meet 'niche' markets for short range and specific fleet / delivery / public transport applications. Support systems and components that need to be researched and developed for this application are similar to hybrid electric, with the principal exception of the battery:

- *High energy battery.* In contrast to the power battery for hybrid applications (above), this application needs to concentrate on high energy to maximise range per charge in addition to meeting the full acceleration power demand. The lifetime demand on the battery in this case is for a fewer number of deeper battery charge/discharge cycles. Similar requirements for battery management are required. Desirable goals would be 50kW, 30kWh, 100kg, $3,000. Challenges include battery solutions for high energy density and low weight, 'stage of charge' management to prolong life, onboard diagnostics and recycling / disposal. Example technologies include advanced batteries, alternative storage devices (such as hydraulic and flywheel systems), new developments in bio- and nano-technology, and advanced control systems.

• *Fuel cell applications,* which depend on the following four areas of technology research: the fuel cell and its associated support systems, the hydrogen fuel delivery system (onboard or off-board), the electric motor propulsion drive, and a high power battery to provide fast start up and high acceleration demands. The latter two have been discussed above for battery electric and hybrid electric applications, illustrating the need to consider all of these technologies as inter-related.

- *Fuel Cell Stack & Support Systems.* Next generation automotive fuel cells, to reduce cost, volume and weight (to increase kW/litre performance), to enhance fuel cell life and reduce maintenance. Challenges include new materials development (plates and membranes), manufacturing, design optimisation (stack and sub-systems), thermal and water management. A desirable goal would be a fuel cell with 20,000 hour zero maintenance. The support systems include low power and low noise compressors and pumps for the operation of air, hydrogen and temperature control systems.
- *Hydrogen Fuel.* This can be generated on board via a reformer from other fuels (CNG, methanol, etc.) or provided externally and stored on board as hydrogen. Research is required for the route to the hydrogen economy (liquid hydrogen / bio-fuel internal combustion), to minimise CO_2 emissions, maintain mobility, performance and cost, minimise investment by vehicle manufacturers, provide a migration strategy, facilitate introduction of fuel cells (later), provide energy security for the UK and to support the development of renewable energy sources. Challenges include high efficiency liquid H_2 plant, low cost liquid H_2 filling equipment and onboard cryogenic storage, and maximisation of UK renewable H_2 generation, planning for distribution of hydrogen. Example technologies include cryogenic fuel injection, improved mono-fuel combustion efficiency, NOx elimination and leak detection. Associated with this work concerns fuel standards, to ensure defined and consistent fuel supply, quality and safety. Challenges include accommodation of fuels from various sources and meeting public safety concerns. Example technologies include refuelling systems and equipment.

• *Alternative fuels for conventional vehicles,* including the use of gaseous fuels produced from fossil fuel sources or biomass and the use of hydrogen; the latter can be seen as also providing a 'fast track' route to the hydrogen fuel issue for fuel cell vehicles.

- *Pathways to sustainable mobility,* to develop sustainable transport solutions and ensure security of fuel supply. Challenges include the development of solutions (scenarios) for economically and environmentally justifiable transition / migration paths. Example technological solutions would support the avoidance of onboard reforming and short-term infrastructure and expensive systems that do not contribute in the long term.
- *Variable production routes for renewable transport fuels.* Challenges include efficient production technologies, cost reduction, improved access to viable and sustainable resources, and increased energy efficiency. There is also a safety case, for performance of H_2 / fuel cell vehicles in crash and/or fire, to ensure public acceptance of the technology. Challenges include improved understanding of mechanisms (modelling and experiment), performance of cryogenic containers and behaviour of punctured gas cylinders.

4.3 Software, Sensors, Electronics and Telematics

Scope

The software, sensors, electronics and telematics (ASSET) technology theme includes the following vehicle functions and systems:

- Onboard systems for road travel, vehicle and driver assistance, including electronics and sensors, information / communications and control, and high voltage electrics to support future engine systems.
- Interfaces with the road traffic specific infrastructure.

Market and industry trends and drivers that are particularly relevant to this technology theme include:

Social	Demands for greater mobility (and the associated congestion), together with changing patterns of working and vehicle ownership, and concern about safety and security, in terms of reducing accidents and theft of vehicles and contents.
Economic	Increasing economic impact of congestion and demand for increasing levels of services, product functionality and flexibility, together with competitive pressure to reduce development and manufacturing cycle times and costs, and to improve responsiveness, agility, flexibility, durability, efficiency and quality, in order to achieve greater profitability and return on capital.
Environmental	Requirement to reduce fuel consumption and emissions of CO_2 and other harmful substances, during manufacture and use of vehicles.
Technological	Rapidly increasing performance of information technology (electronics, communications and computing systems), combined with competition to develop innovative solutions in the areas of software, sensors and telematics to improve vehicle performance, functionality, safety, security, control, information and other services, together with overall performance of the road transport system.
Political	UK Government, European and international policy, regulation and legislation concerning transport, congestion, energy, CO_2 and other emissions, health & safety and waste management.
Infrastructural	The need to develop new engine solutions in parallel to developments in the infrastructure, particularly in terms of traffic management control systems and information service provision (telematics).

Development of software, sensor, electronics and telematics technologies, together with associated research challenges, have been explored in an expert workshop that identified and considered the following themes, summarised below and detailed in Appendix C:

- Shift to software
- Access and use of vehicles
- Architecture and reliability

Technology directions

Shift to software

The general trend towards increasing use of software, electronics and communications technology will have a major impact on vehicle design, manufacture and use. Major technical areas where this will apply include vehicle control (lateral, longitudinal and vertical), vehicle adaptability, system integration and intelligence. Over the next 20 years it is expected that these technologies will provide increasing support to the driver, initially in terms of improved warning information systems, to increasingly automated (and semi-automated) control systems. Technology and systems developed will need to be safe, with high redundancy and integrity. Systems integration is a key requirement if these goals are to be achieved.

< 10 years
- Adaptive cruise control
- Ultrasonic parking
- Long range radar
- Standards development
- Active suspension
- Vertical motion sensors
- Driver / condition monitoring
- Wireless networks
- Inertia navigation
- Video image processing
- 360^{o} sensing systems
- 5.8 GHz infrastructure
- Driver 'DNA'
- Online mapping
- 63 GHz & 3G GSM communications

10 – 20 years
- Open system vehicle IT platforms
- Galileo satellite system (GSP)
- Electronic maps
- Ad hoc vehicle networking
- Reduction in road degradation
- Driving ability monitoring
- Vehicle motion control
- Dynamic network management
- Wearable technology
- Lane keeping systems
- Adaptive cruise control (roadside pedestrian detection, video, radar)
- X-wire systems (redundancy, control algorithms, actuators, sensors)
- 'Plug and play'

> 20 years
- 4&5G GSM communications
- Vehicle 'AI'
- Applications on demand
- Sensor enabled vehicles
- Lane merge support
- Automated highway systems
- 110 GHz radar?
- Vehicle adaptability (affective design)
- Adaptability for changing driver behaviour
- Full authority vehicle

Access and use of vehicles

Software, sensors, electronics and telematics technology will lead to significant 'access-related' benefits, in terms of improving safety, reduction of congestion and crime, increasing mobility, accessibility and vehicle adaptability. Key themes include driver interaction with vehicle, crime reduction, safety, enabling and controlling vehicle access and vehicle interaction with infrastructure.

< 10 years
- Adaptive cruise control
- Biometric systems
- Auto emergency alert
- Stop & go
- Multi-modal information
- Data collection and transmission (vehicle usage)
- Controlled access to clear zones and for freight (e.g. height)
- Legality / access rights
- Identification of driver
- Characterisation of driver (setting up vehicle)
- Identification / characterisation of passenger

10 – 20 years
- Electronic licence / insurance
- Standardised definition of system requirements (delivery of x-by-wire)
- Controlled access to infrastructure
- Advisory system for economical driving (environmental)
- Interaction of traffic information
- Advanced biometric systems
- Intelligent speed adaptation
- Vehicle fingerprinting
- Vehicle prioritisation
- Sensing of road and environment
- Urban and rural drive assistant
- 'Fit to drive' detection
- Dynamic route guidance
- Remote anti-theft (vehicle control)
- Vehicle-to-vehicle communication
- Tuned vehicle performance

> 20 years
- Automated highway control driving

Architecture and reliability

The benefits described above require development of appropriate system architectures, with an emphasis on safety and reliability. The long-term vision is to develop vehicle systems that are 'worry-free' (tolerant, self-diagnosing and repairing), and which can adapt to particular user requirements. Areas that will require focused efforts include sensors, self-diagnostic systems, artificial intelligence, maintenance, standards, simulation, and design for disassembly and interchangeablility.

< 10 years
- Intuitive and undemanding interfaces
- Sensors with common architectures,

10 – 20 years
- Self-diagnostic systems
- Predictive / preventative maintenance

> 20 years
- 'Worry free' vehicles
- Self-repairing systems

for diagnostics
– Sensor-based diagnostics
– Adaptive systems
– Improved simulation for faster development
– Systems for central garage-based diagnostics
– Systems for on-board diagnostics (signal analysis)

– Flexible control systems for manufacturing
– Reconfigurable systems
– Artificial intelligence
– Standards
– Fault tolerant systems
– Design for disassembly
– Interchangeability (component upgrade)

– Cheap sensors (pressure, temperature, strain, flow)
– 'Tailor made morphing' vehicle

Other areas of technology development may include:

– 'Affected' design, linking vehicle handling dynamics to driver / passenger requirements (adaptability)
– Driver identification and condition monitoring
– Illegal access identification
– 'Plug and play' vehicles (self-managing / self-diagnostic)
– Radio frequency (RF) vehicle identification
– Automatic signalling to emergency vehicles
– Open standards and architectures

– 'Black box' systems (data logging)
– Management systems for mixed (realistic) traffic conditions
– Improved near / medium distance sensing
– Component identification / authentication
– Software design for reliability, integration, re-use and safety
– Standards for integration and interoperability

– Reliable control hardware, software and algorithms
– Cost engineering to ensure affordability
– Engine and traffic management (vehicle control) to improve fuel efficiency
– High voltage systems
– Life extension and recycling
– Data collection (vehicle usage)
– Improved simulation to reduce vehicle development time (tuning vehicle dynamics)

Research challenges

- *Vehicle adaptability,* to better meet the various needs of future drivers and passengers and to improve the design and manufacturing processes for more sustainable road vehicles, in terms of modularity, upgradeability and functionality. Example technologies include sensors and diagnostic systems, driver and vehicle condition monitoring, 'plug and play' and 'on-demand' applications.
- *System integration,* to enable the various software, sensors, electronics and telematics technologies to work together to improve overall vehicle performance. Example technologies include architectures and interoperability standards and protocols, fusion of sensors, communication and information, control and automation systems, drive-by-x systems, safety and reliability of critical systems.
- *Vehicle usage and access,* to improve traffic flow and vehicle security, in terms of driver identification and monitoring, vehicle access control and reliability of journey time. Example technologies include biometrics, probe vehicle technology, 'black-box' data logging systems, journey time modelling, vehicle fingerprinting and driver feedback systems (for example, to encourage economic driving).
- *Architectures,* to enable safe and reliable operation of integrated vehicle systems. Example technologies include system fault diagnosis (including human factors), reliability engineering, actuator development, sensor architectures and standards, cost modelling and operating systems.
- *Co-operative vehicle and infrastructure supported applications,* to ensure that system level benefits are attained from developments of autonomous vehicle systems, highway networks and infrastructure management, facilitated by continuing development of sensors and sensor integration, data processing and mobile communications. Such research may realise benefits for all stakeholders by improving safety and network efficiency, better information delivery, driver assistance and comfort, together with other social, economic and environmental benefits. As well as technological development, the legal, institutional and policy issues of such systems need to be understood and resolved.

4.4 Structures and Materials

Scope

The structures and materials (FASMAT) technology theme includes the following vehicle systems and functions:

- Supporting structure (body), which is an integral part of many other systems and features of the vehicle, such as style, glazing, heating and airflow systems.
- Structural components, including suspension, hard and soft trim.

Market and industry trends and drivers that are particularly relevant to this technology theme include:

Social	Demands for improved safety, greater vehicle configurability and reduced fuel consumption.
Economic	Competitive pressure to reduce development and manufacturing cycle times and costs, and to improve responsiveness, agility, flexibility, durability, efficiency and quality, in order to achieve greater profitability and return on capital.
Environmental	Requirement to reduce material waste, energy consumption and emissions of CO_2 and other harmful substances, during manufacture and use of vehicles.
Technological	Developments in new materials, such as composites, polymers, lightweight alloys, smart materials, and associated design and processing methods, together with competition to develop innovative structures and materials to improve vehicle performance in terms of weight, stiffness, safety, responsiveness, fuel efficiency, configurability and environmental impact.
Political	UK Government, European and international policy, regulation and legislation concerning transport, energy, CO_2, safety and waste management.
Infrastructural	Developments in infrastructure that affect safety (telematics and physical infrastructure).

Development of structures and materials technologies, together with associated research challenges, have been explored in an expert workshop that identified and considered the following themes, summarised below and detailed in Appendix C:

- Safety
- Product configurability / flexibility
- Economics
- Environment

Technology directions

Safety

The UK government is committed to reducing deaths and serious injuries from road traffic accidents by between 40 and 50% over the next ten years. Increasing safety needs to be achieved in parallel to the introduction of new materials and structural solutions to reduce vehicle weight, together with new engine configurations and fuel types (such as hydrogen and liquefied or compressed gas). Developments in materials and structures intended to improve safety under collision and accident conditions need to be considered in conjunction with measures that can be taken to reduce the likelihood and severity of accidents, such as advanced software, sensors, electronics and telematics (see ASSET technology theme) and improvements to infrastructure, such as traffic calming and segregation of traffic types (by weight and speed). A combination of passive and active safety systems are required, taking into account forecasts of future mobility requirements and vehicles types.

< 10 years

- Incremental change to current systems
- Legacy vehicles
- More realistic crash & accident tests
- Improved modelling and simulation
- Paving materials (lane highlighting)
- Materials and structures for small lightweight vehicles (motorcycles, urban vehicles)
- Reflective materials
- Ultra stiff occupant cells
- Materials and structures for improved pedestrian safety

10 – 20 years

- New mobility solutions and technologies
- Side impact protection
- Improved safety for buses and other large vehicles (passengers, pedestrians, cars)
- Electro rheological materials
- Smart crash materials (high energy absorption, responsive)
- Crash barriers to meet all road user needs
- Smart crash performance (high and low speed performance tailored to suit crash type)

> 20 years

Product configurability / flexibility

A growing demand for greater product variety is anticipated, to meet future consumer requirements in terms of lifestyles and demographics. The trend towards greater configurability and flexibility will be reflected in the use of vehicles, to meet a greater variety of different needs in service, and in the design and manufacture of vehicles. Industry will need to continually reduce development times and costs, while at the same time increasing agility and responsiveness to consumer needs. Increasingly modular architectures will enable vehicles to be reconfigured more easily, throughout the life cycle, including design, production, service and end of life.

< 10 years

- Increasing platform, product and material mix
- New joining technologies
- Just-in-time processes
- Modular assembly
- 'Pick & mix' equipment interiors
- Space frames to enable low weight and / or low investment products
- Design, validation and simulation / prediction techniques
- Coating technologies
- Recycling systems (material identification and separation)
- Improved material durability (corrosion and fatigue resistance)
- Lightweight hang-on parts
- Easy and low cost repairs

10 – 20 years

- Main chassis / structure common with varied body
- High strength formable lightweight materials
- One chassis with 'snap on' body module
- 'Pick & mix' modules
- Low cost flexible tooling and processes
- Low cost dimension / profile changes
- Increasing configuration at dealer
- Vehicle structural concepts and materials to suit new power / engine options
- 'Turn on / off' joining techniques
- External design by customer

> 20 years

Economics

Structural systems and materials form a significant proportion of vehicle weight and cost, in terms of raw materials, production, use and disposal / recycling. Advances in materials technology, and the associated design and manufacturing processes, also provide significant potential for enhancing vehicle performance and adding value. The economics associated with structures and materials need to be considered in terms of the full vehicle lifecycle: design, manufacture (including the tradeoffs between volume and cost of production), use and recycling.

< 10 years

- Properties and processing of advanced materials and composites, including design constraints of these new materials
- Improved road surface materials (in terms of interaction with tyres and vehicle: friction, rolling resistance, grip, noise)
- Identification and separation of materials for recycling
- Energy used in recovering materials for recycling
- Flexible manufacturing
- Affordable low volume manufacture
- Alternatives to glass for security, safety and vision
- Pre-coated & lightweight materials
- Energy absorption for lightweight materials and structures
- Low cost tooling for low volumes
- Easy to repair / replace
- Reduction in cost of bodywork repairs
- 'No tooling' manufacture processes
- 'Mutual recognition' of European / North American safety regulations / specifications

10 – 20 years

- Plastic structural parts
- Reconfigurable tooling
- Durability of materials
- Self-coloured panels
- Fast curing composites
- Moulded body, reducing assembly
- Technology transfer from motorsports (but at reduced cost)
- Low cost carbon fibre composites
- Nano-composites
- Recyclable composites
- Partial standardisation of safety regulations (e.g. side impact)

> 20 years

- Processes for using lighter materials (e.g. titanium), compatible with conventional production methods
- Standardisation of safety regulations (particularly for crash)
- Smart materials (e.g. polytronics)

Environment

The contribution that materials and associated production processes can make to the environmental goals of reducing energy use, emissions of greenhouse gases and other pollutants need to be understood, to meet government and European targets and legislation, together with the increasing social and consumer pressure for more environmentally friendly transport. The full vehicle lifecycle needs to be considered, including design, materials production, manufacturing processing, use and recycling. Health and safety issues are also important, both in terms of manufacture and use (air quality).

< 10 years

- Technologies to enable economic achievement of 85% recycling target by 2007
- Natural fibre reinforcements
- Lifecycle analysis tools capable of, for example, confirming value of renewable materials in vehicle structures
- Non gassing plastic and rubber components
- Improved air quality in cars
- Low temperature processing of internal mouldings
- Self-extinguishing / non-flammable / non-toxic materials for vehicle interior
- Elimination of secondary processing
- Radiation curing of polymers

10 – 20 years

- Technologies to enable economic achievement of 95% recycling target by 2015
- Affordable sustainable materials
- VOC / solvent free production
- Lightweight low cost structural materials
- Elimination of hazardous materials in vehicle assembly and recycling
- ‘Decomposition on demand’
- Materials for comfort
- ‘Delight’ materials (tactile)

> 20 years

- Economically viable 100% recycling / re-use
- Easy-to-disassemble glues / sealants / coatings
- 50% reduction in body weight
- Environmentally neutral manufacturing

Other areas of technology development may include:

- Multi-modal technologies
- Crash ‘compatibility’ (for different vehicle types and road structures) - more vehicle-to-vehicle testing
- Non-impact systems (e.g. telematics)
- Materials with higher stiffness / weight ratios
- Natural (sustainable) materials
- Improved damage resistance
- Design for manufacturing and disassembly
- Design simulation to reduce development time and costs (reduced testing, materials properties databases, manufacture and use)
- Nanoparticles for optimisation of materials properties (including design rules)
- Impact of reduced vehicle ownership (e.g. leasing)
- Modular body construction
- Standardisation (or techniques for coping with lack of standardisation)
- Electro-magnetic field shielding
- Repair of exotic materials
- External air bags
- Dynamic reconfigurability of vehicles in use (body and interior)
- Freight: lightweight materials and structures; axle loading; low volume production; crime / vandalism reduction
- New fuel types, engines and configurations (implications for materials and structures)
- Improved materials testing (including environmental)
- Behaviour of hybrid materials
- Smart / intelligent materials
- Materials identification (‘genetic’ code)
- Nil paint vehicles
- Economics of manufacturing investment for low volume / light weight products
- Flexible manufacturing and reconfigurable tooling

Research challenges

- *Design techniques for modelling crash with new materials, processes and architectures,* to enable 100% virtual vehicle design, including new materials and processes. Challenges include developing and characterising materials models for crash and related materials performance, linking process to performance modelling, and developing a clear understanding of lifecycle performance needs.
- *Smart materials for pedestrian safety,* to respond to the growing emphasis on reducing pedestrian and other road user injuries. Challenges include the design and development of passive / active materials, together with the associated control systems. Example technologies include electro rheological materials, controlled fracture materials, ‘airbag’ systems and gel technology.
- *Exploitation of ‘crash-free’ environment,* to provide desirable and sustainable vehicles, assuming that crashes can be eliminated by telematics and other smart systems, to meet all user needs (such as comfort and performance) without the burden of passive safety. Challenges include the need to fundamentally review current design rules and methods, expansion of materials options, and the development of architectures to maximise ride performance, payload, refinement, etc. Example technologies include large-scale integrated modelling, integrated fuel tanks and configurable / modular designs.
- *Vehicle reconfigurability (‘mix and match’),* to create more distinctive niche products and to enable vehicle configuration (internal and external) during product life. Challenges include

ensuring structural integrity, joining and 'unjoining', and quantifying the customer need for such systems. Example technologies include high strength 'floor systems' activated and deactivated adhesive systems and new supply chain models.

- *Design for the customer,* to meet consumer needs and desires in terms of individuality, affordability, lifestyle and demographic changes (interior and exterior). Challenges include increasing the range of vehicles types and specifications, modular / flexible production and assembly, enhancing body and interior functionality, and low investment processes. Example technologies include modularity (design and manufacturing), interchangeable panels, product diversification, reconfigurable moulding and shape memory fluids.
- *Reduced lifecycle costs and environmental impact,* to reduce cost of ownership, and to meet consumer demands and legislative targets for more sustainable manufacturing and transport. Challenges include optimising structural performance using new materials and structures (weight, stiffness and energy absorption), total lifecycle cost modelling, cost reduction and life extension. Example technologies include high strength / formable / non-corroding aluminium and low cost reconfigurable platforms.
- *Optimising composite structure design,* to enable lightweight structures (lower fuel consumption, running costs and emissions), improved structural performance (safety, noise and vibration) and manufacturing cost and investment reduction. Challenges include improved design and process guidance, material characterisation and reduction of processing costs. Example technologies include improved resin processing and composites from new resin systems that can be cured more quickly without autoclaves.
- *Long life pre-finished materials,* to eliminate post-processing (paint), maximise vehicle residual value, reduce costs and improve environmental performance. Challenges include increasing the structural durability of vehicles, improved joining techniques (without detriment to material properties) and retaining finish through the manufacturing process. Example technologies include pre-painted steel, gel-coated fibreglass, improved adhesion / edge performance of paint and in-mould / tool painting.
- *Low cost composite structures,* to reduce weight, improve crash-worthiness, reduce manufacturing and operating costs and increase vehicle life. Challenges include reducing material and processing costs, matching performance / properties of steel and maximising design performance. Example technologies include press moulding of co-mingled thermoplastics and perform / sheet resin (PSR).
- *Development of intelligent energy absorbing materials,* to increase pedestrian and occupant safety and to improve vehicle-to-vehicle crash compatibility. Challenges include the ability to react to external signals and direct contact, manufacture, control and durability during vehicle life, and low cost, multi-vehicle application. Example technologies include systems for controlling crash performance of body structures dependent on crash intensity, reducing head impact (occupant and pedestrian) and knee bolsters.
- *Lightweight hybrid material body structures,* to meet fuel economy and emission targets and to reduce capital investment costs. Challenges include forming and joining, cosmetic surfaces, economically viable materials and processes, sealing of joints, low volume application and design tools. An example technology is multi-material sandwich structures.
- *New road / car interface technologies,* to reduce pollution and noise, improve fuel economy and safety, and to lower wear and impact damage. Challenges include improved tyre and road performance, understanding the interface between tyre and road, and cost reduction.

4.5 Design and Manufacturing Processes

Scope

The design and manufacturing processes (DMaP) technology theme is broad, covering the full life cycle of road vehicles, with strong links to the other technology themes:

- Design, engineering, prototyping, manufacturing, assembly, use and recycling / regeneration
- Other business processes, including supply chain management, marketing, logistics, distribution and retail

Market and industry trends and drivers that are particularly relevant to this technology theme include:

Social	Demands for greater mobility and changing patterns of working and living, together with demographic changes.
Economic	Competitive pressure to reduce development and manufacturing cycle times and costs, and to improve responsiveness, agility, flexibility, durability, efficiency and quality, in order to achieve greater profitability and return on capital, together with changes to industry structure (consolidation, globalisation, supply chain, etc.).
Environmental	Requirement to reduce energy consumption, material waste and emissions of CO_2 and other harmful substances, during manufacture and use of vehicles.
Technological	Competition to develop innovative solutions in the areas of vehicle design and manufacture, considering all aspects of the vehicle life cycle.
Political	UK Government, European and international policy, regulation and legislation concerning transport, energy, CO_2, safety and waste management.

Development of design and manufacturing process technologies, together with associated research challenges, have been explored in an expert workshop that identified and considered the following themes, summarised below and detailed in Appendix C:

- Lifecycle
- Manufacturing
- Integration

Technology directions

Lifecycle

The development of sustainable road transport, in terms of meeting social, economic and environmental needs, requires consideration of the full life cycle of vehicles, including design, production, distribution, use and end-of-life (re-use, recycling and disposal). Substantial reductions in total system material and energy consumption are required, together with reduced pollution and waste, whilst at the same time increasing economic performance in a globally competitive market. There are substantial challenges involved with migrating to more sustainable modes of vehicle production and use, which will require social, economic, environmental, technological, political and infrastructural change. A range of actions will result in moderate progress towards these goals, based on evolution of existing technology and approaches. However, in the longer term there is a requirement for improved understanding of the scale and type of change required, at a system level, and the associated implications for technology, industry and society.

< 10 years
- Supply for demand (reduce stock)
- Increased use of information technology (throughout lifecycle)
- Simulation technologies for customer education and market research
- Trend towards ‘full service contracts’

10 – 20 years
- Near zero landfill: strategies for existing fleet and new vehicles
- End of life disassembly: materials separation and fluid handling
- Energy recovery
- Increasing customisation and diversity of

> 20 years
- Substantial (50%) reduction in energy consumption and emissions

- Increase in recycling and re-use
- Improved understanding and measurement of energy, material and pollution in production and use
- Development of scenarios and strategies for sustainable vehicle systems (personal and commercial)
- Improved understanding of social attitudes and needs
- No or low paint systems

products, flexibility and agility of production systems
- New materials and production technologies
- Changing business models (production and ownership)

Manufacturing

Improved manufacturing systems are crucial for achieving the social, economic and environmental goals described above, in terms of reducing energy and material consumption, reducing emissions, and increasing efficiency and competitiveness. Aspects that require attention include component-level manufacture and assembly, system-level manufacture and organisation, management of manufacturing systems, together with commercial and market considerations. Trends towards greater vehicle variety and customisation, together with increasing rates of innovation and technology development, will demand greater flexibility and agility from manufacturing systems whilst simultaneously improving economic and environmental performance.

< 10 years
- Modular construction
- Design for disassembly
- Rapid joining and disassembly technology
- Partnerships for capital intensive plant and process development
- Low capital / cost manufacturing
- Optimisation of global, regional and local supply chain
- In-house disposal systems
- Electronic data exchange
- Increasing primary stock yield (metals)
- Reconfigurable jigs
- Design tolerance management
- Virtual assembly training
- Education and training in new manufacturing technologies

10 – 20 years
- Flexible mixed model assembly lines (including supply chain implications)
- Integrated data exchange (from design to distribution)
- Rapid prototype manufacture
- Reconfigurable assembly systems
- No paint shop vehicles
- New vehicle architectures
- Increasing configuration by dealers
- Reconfiguration tools (low capital cost, rapid part introduction, lower energy)
- New materials (light weight, low cost tooling, efficient & rapid configuration)
- Electronic systems integration
- Cost effective mass production of advanced composites
- Virtual design for manufacturing plant design and redesign

> 20 years
- Modular vehicles (with local reconfiguration)
- Reconfigurable manufacturing, enabling rapid model changeover
- Process energy reduction
- Total automated manufacture
- Shared production processes
- Small production runs (output geared to demand)

Integration

Systems integration is crucial if significant improvements to overall life cycle performance of road vehicles are to be achieved. This includes consideration of how the various vehicle sub-systems operate together, how the vehicle is designed, manufactured and operated, and how the information and knowledge that enables these systems to function can be combined more effectively and efficiently. The challenge will be to increase the level of integration in the design, manufacture, operation and re-use of vehicle systems in parallel to rapidly advancing technology and increasing complexity (engine systems, materials, electronics, software and communications), with increasing demand for more flexibility, agility and customisation. Standards, open systems architectures and metrics will need to be established, while at the same time ensuring that creativity and innovation are not compromised. Greater co-operation and collaborative knowledge sharing will be required, without compromising competitive advantage.

< 10 years
- Requirements mediation systems
- Improved information flows
- Increasing involvement of suppliers
- Increasing onboard monitoring
- Automated diagnostics, data mining and preventative maintenance
- Product and process metrics
- Increasing use of x-by-wire
- Open systems architectures
- Standards for system integration
- Collaborative knowledge sharing
- Information security

10 – 20 years
- Increasing vehicle customisation and adaptability
- System models to understand tradeoffs and cost implications
- Incremental vs. radical innovations
- Information and knowledge sharing (supply chain, consultants, etc.)
- Seamless and minimum design cycle
- Managing information overload
- Systems integration architecture
- Integration of information and communications technology in design
- System-level optimisation
- Robotic maintenance

> 20 years
- Economic to produce low vehicle volumes (<1000)
- Artificial intelligence
- Integration of technical and commercial disciplines
- Flexible procurement of expertise for flexible design and production
- Integrated transport systems

Other areas of technology development may include:

- Shift to service (reduced car ownership)
- Reduced vehicle size
- Increasing software and electronics
- Human-machine interface (in vehicle and manufacturing)
- Dispersed and multidisciplinary working
- Increasing automation
- Opportunities for cross-sector learning
- Design for rapid manufacturing ramp-up

Research challenges

- *Near zero landfill,* for both current fleet and future vehicles, to comply with legislative targets and demands for greater social responsibility, reduce costs and to develop additional revenue streams from recycled materials. Challenges include the development of recycling technologies, establishing economically viable recycling systems with sufficient volumes of similar materials, and the identification of applications for re-use or energy conversion. System scenarios need to be developed to understand how these goals can be achieved.
- *Customer informed design,* to ensure that the diverse needs of customers can be met at an affordable price. The primary challenge is how to understand customer needs better (especially future and unarticulated needs) and associated requirements in terms of cost.
- *Routes to sustainable manufacture,* to reduce energy and material consumption, and to reduce emissions of pollution. Challenges include lack of knowledge and appropriate metrics for existing manufacturing systems (including supply chain) and the lack of effective strategies and methods for migrating to more sustainable production systems.
- *Low investment manufacture,* to improve flexibility. Challenges include how to improve reconfigurability, accommodate late design changes, reduce tooling costs and eliminate the need for the paint shop. Example technologies include rapid direct tooling, high speed hard machining and prepainted sheet.
- *Electronic data exchange for design, analysis, manufacture, test and field,* to improve quality, competitiveness and customer response. Challenges include standardisation, cost reduction and the necessary change in culture required for implementation of such systems. Example technologies include virtual reality and transfer of approaches from other industry sectors (aerospace and defence).
- *Short delivery car,* enabling late vehicle configuration by dealers. Challenges include how to enable assembly near market, changes to the supply chain, data exchange, modular vehicle architectures and inventory management.
- *System integration (product, process, information and knowledge),* to reduce lifecycle costs, improve quality, increase product variety, improve knowledge re-use and reduce time to market. Challenges include information security and protection of intellectual property, lack of appropriate metrics and analysis tools, migration and legacy issues, and effectiveness of cross boundary / collaborative teams. Example technologies include standards and protocols, safety and security systems, automated diagnostics, electronic and software design integration.

5. Summary

The overall goal of the technology roadmapping initiative has been to support the aims of the Foresight Vehicle consortium, providing a framework for ongoing investment in UK research partnerships, focused on achieving sustainable wealth creation and quality of life. The technology roadmap supports the recommended actions of the UK Automotive Innovation and Growth Team (AIGT)[78], in terms of providing a framework for:

- Encouraging technological innovation in road vehicle systems, in the short, medium and long-term. The 20 year horizon provides a 'radar' to ensure that investment in technology and research accounts for the trends and drivers that influence the road transport system in that time frame.
- Enabling communication, discussion and action within industry collaborations and networks.
- Mapping future innovation paths for a number of key technology areas, including:
  - Engine and powertrain
  - Hybrid, electric and alternatively fuelled vehicles
  - Software, sensors, electronics and telematics
  - Structures and materials
  - Design and manufacturing processes

The scope of the Foresight Vehicle technology roadmap is broad, reflecting the complex nature of the road transport system and the changing environment in which it operates. The roadmap represents a 'rich picture', capturing knowledge and thinking from a wide range of perspectives, bringing together more than 130 experts from across the automotive sector, representing more than 60 organisations. Market and industry trends and drivers have been considered, with a 20 year time horizon, together with performance measures and targets for the road transport system and the technologies and associated research that can deliver the required benefits.

Owing to the broad scope of the roadmap, the inherent uncertainties associated with the 20 year time frame and the various interests of a diverse set of stakeholders, it is not desirable to overly constrain the research agenda. Rather, the roadmap is used to provide structure, context and broad direction. This structure enables a consistent language and approach to be developed in terms of understanding the relationships between specific technology areas, system performance and industry drivers.

Investment in road vehicle technology and research should be considered in terms of the contribution (impact) that the investment is expected to make towards the primary social, economic and environmental goals:

Social goals

Mobility	Reduce congestion and journey time, and improve the reliability of journey time (reducing variance), including public and private transport (accessibility and availability).
Equitability	Improve access to road transport for all social groups (inclusion), in terms of demographics and cost.
Safety and security	Reduce accidents, injuries and crime.
Satisfaction	Ensure that road transport meets the increasingly diverse needs of society (lifestyle and attitudes) and improve travel comfort and convenience.

Economic goals

Manufacturing	Reduce costs of vehicle manufacture and increase speed of production, responsiveness, agility and quality of manufacturing systems (to increase value added).
Development	Reduce costs and time associated with vehicle development and improve design processes (including life cycle considerations).
Cost	Reduce total cost of vehicle ownership and use, including congestion, maintenance and disposal (public and private transport).
Freight	Ensure efficient delivery of freight across the UK.

Environmental goals

Energy	Conserve non-renewable sources of energy, develop alternative energy sources and systems, improve efficiency and waste energy re-use, reduce unnecessary travel and improve distribution systems.
Global warming	Reduce CO_2 and other greenhouse gas emissions associated with road transport.
Health	Monitor and reduce emissions hazardous to health (such as particulates, NOx, benzene, carbon monoxide, sulphur dioxide and ozone, together with noise), during vehicle manufacture, use and disposal / recycling.
Waste	Reduce the amount of material used in manufacture and use of vehicles, increase material recycling and re-use, extend vehicle durability and life, miniaturise, increase functionality (services, software & electronics) and waste recovery.

Foresight Vehicle is currently organised primarily around five technology areas. Each of these has significant potential to deliver high impact technology solutions to meet the above social, economic and environmental goals:

Engine and powertrain technology (E&PT)

Thermal and mechanical efficiency	The efficiency with which the engine and powertrain can convert the energy stored in fuel to useful mechanical power is crucial for reducing fuel consumption, the cost of vehicle operation and emissions (in particular CO_2).
Performance and drivability	Vehicle and engine manufacturers must meet consumer demand for improved vehicle performance and drivability characteristics, while simultaneously reducing fuel consumption and emissions.
Emissions	While CO_2 is a primary by-product of the combustion process (for hydrocarbon fuels), other health-damaging emissions, such as particulates, noxious gases and noise can be reduced substantially.
Reliability and durability	Significant advances in engine and powertrain reliability and durability have been achieved in the past two decades, and it is anticipated that this trend will continue, with the ultimate goal of achieving a ‘self-diagnosing’ and ‘sealed’ engine.
Speed to market and cost	The engine and powertrain represents a significant and increasing proportion of vehicle cost, and improvements in vehicle design and manufacturing processes have a significant role to play in reducing cost and time-to-market, and hence improving competitiveness of vehicle manufacturers.

Weight and size	The engine and powertrain represent a significant proportion of total vehicle weight, and reductions here will provide benefits in term of vehicle efficiency, performance, safety and design flexibility.

Hybrid, electric and alternatively fuelled vehicles (HEV)

Hydrogen and fuel cells	New fuel and engine solutions are required if CO_2 emissions are to be reduced and conventional oil reserves are to be preserved. The fuel cell is one of the most promising technologies, and hydrogen a particularly attractive fuel in terms of reducing vehicle emissions.
Hybrid and advanced internal combustion engines	It is likely to be at least 15-20 years before alternative fuel and engine solutions become widely available, and so improvements to the internal combustion engine have an important role to play. In particular, development of hybrid and multi-fuel engines will enable the IC engine to evolve towards a point where alternative fuel and engine systems are more widely available.
Electrics and electronics for energy and drive systems	Fuel cells and other new energy and drive systems will require parallel development of the electric and electronic systems for energy storage, engine management, power generation, conversion and transmission. Advances in software, sensors and electronics provide significant opportunities for supporting the integration of systems to provide increased functionality and performance.
Conventional and alternative fuels	It is likely that in the next 20-50 years global demand for energy will outstrip conventional supply as crude oil reserves are depleted. Alternative energy sources will become economic, stimulating innovation in new fuel, engine and infrastructure technology. A major challenge is the need to develop new fuels, vehicle systems and infrastructure in parallel, and it is likely that a variety of competing solutions will emerge over the next 20 years.

Advanced software, sensors, electronics and telematics (ASSET)

Shift to software	The general trend towards increasing use of software, electronics and communications technology will have a major impact on vehicle design, manufacture and use. Major technical areas where this will apply include vehicle control, adaptability and intelligence, with systems integration being of particular importance.
Access and use of vehicles	Software, sensors, electronics and telematics technology will lead to significant mobility benefits, in terms of improved safety, reductions in congestion and crime, increasing access to mobility and greater vehicle adaptability.
Architecture and reliability	The benefits that can be derived from software, sensor, electronics and telematics technology require development of appropriate systems architectures and standards, with an emphasis on safety and reliability. The long term vision is of a robust, tolerant and self-diagnosing and repairing system that is also responsive to user requirements.

Advanced structures and materials (FASMAT)

Safety	Developments in materials and structures, intended to improve safety under collision and accident conditions, need to be considered in conjunction with measures that can be taken to reduce the likelihood and severity of accidents (such as sensors, telematics and infrastructure). Increased safety needs to be achieved in parallel to the introduction of new materials and structural solutions to reduce weight, together with new engine configurations and fuel types.

Product configurability / flexibility	A growing demand for greater product variety is anticipated, to meet future consumer requirements in terms of lifestyles and demographics. Vehicles need to be re-configured more easily, throughout the life cycle, including design, production, service and end-of-life.
Economics	Structural systems and materials form a significant proportion of vehicle weight and cost, in terms of raw materials, production, use and disposal / recycling. Advances in materials technology, and the associated design and manufacturing processes, also provide significant potential for enhancing vehicle performance and adding value.
Environment	Improvements to materials and associated production processes can make a significant contribution to the environmental goals of reducing energy use, emissions of greenhouse gases and other pollutants, including consideration of the full vehicle life cycle.

Design and manufacturing processes (DMaP)

Lifecycle	The development of sustainable road transport, in terms of meeting social, economic and environmental needs, requires consideration of the full vehicle life cycle, including design, production, distribution, use and end-of-life (re-use, recycling and disposal). Substantial reductions in total system material and energy consumption are required, together with reduced pollution and waste, whilst at the same time increasing economic performance in a globally competitive market.
Manufacturing	Improved manufacturing systems, particularly in terms of flexibility and agility, are crucial for achieving the social, economic and environmental goals described above, in terms of reducing energy and material consumption, reducing emissions and increasing efficiency and competitiveness.
Integration	Systems integration is crucial if significant improvements to overall life cycle performance of road vehicles are to be achieved. This includes consideration of how the various vehicle sub-systems operate together, how the vehicle is designed, manufactured and operated, and how the information and knowledge that enables these systems to function can be combined more effectively.

The Foresight Vehicle technology roadmap (version 1.0) represents a significant first step in terms of capturing, sharing and structuring expert knowledge within the automotive sector, but greater benefits can be obtained if the roadmap can be kept ‘alive’ on an ongoing basis. It is recommended that the roadmap should be reviewed periodically to refine and update the content and structure, and to enhance the strategic focus.

Appendix A

Trends and drivers

This Appendix contains detailed information relating to market and industry trends and drivers, summarised in Section 2. The information in these roadmaps was collected initially by workshop and then supplemented by reference to published information (Appendix D).

Six detailed roadmaps are included:

- *Social* factors relate to the social systems we live in, including demographics, life style aspirations and choices, mobility requirements and behaviour, working patterns, desires for health, safety and security.
- *Economic* factors relate to the financial systems that affect our lives, including global, national, corporate and personal economic considerations.
- *Environmental* factors relate to the physical environment in which we live, including energy production and consumption, waste, emissions and pollution, and the associated health impacts.
- *Technological* factors relate to how technology affects the way we live, including development of new fuel and power systems, electronics and control technologies, structures and materials, together with manufacturing and business processes.
- *Political* factors relate to the systems that govern us, including policy, regulation and legislation, together with the political processes that lead to them.
- *Infrastructural* factors relate to the systems that support road transport, including the physical roads and infrastructure, together with provision of associated services and information, and the interfaces with other modes of transport.

Also included is a table of prioritised market requirements for future road transport, from the Foresight Vehicle Strategic Plan[5].

Market / industry trends and drivers — Social

2002 | 2007 | 2012 | 2017 | 2022 | Vision

2002
- 80-85% of journeys by car [39,40,103]
- 75% of all journeys are under 5 miles and 45% are less than 2 miles [31]
- Nearly one third of UK households do not have a car (13 million people) [31]
- Many different stakeholder groups, with different needs from transport system →
- UK car-centric culture
- 1999: UK 'leads' world in vehicle theft (twice global average at 2.5%); cost of vehicle-related crime £6bn [46,47]
- 2000: 3,500 road traffic deaths and 40,000 serious injuries in UK, at an estimated cost of £13.3bn (40,000 deaths and 1.7 million injuries in EU, representing a cost of 2% of GDP) [8,37,39,40] →
- Growth in personal mobility (70% of drivers use car for leisure day trips every week or month; 50% expect to be making more by 2020) [42] →
- Journey times increasing (70% longer by 2016 in peak travel periods) [67] →
- Vehicles sold increasingly as 'lifestyle' choices ?
- Increasing female vehicle purchase / ownership (women are more likely to describe their cars as 'stylish', 'sporty' or 'fun') [42]
- People and jobs have moved out of the city and town centres [103]
- Balance between global, national and local solutions ?
- Increasing proportion of women in paid employment (9.9 million in 1984 to 12.2 million in 1999) [73] →
- More than half of drivers exceed speed limits on motorways, dual carriageways and residential roads [66]
- More residential traffic calming schemes and pedestrianisation of town centres →
- Demand to reduce deaths and injuries on roads →
- Between 8 and 20% of car-owning households experience vehicle-related crime each year, depending on region [41]
- Increasing concern about crime, security and safety →

2007
- Individual 'time budget' for travel remains constant ? →
- Increasing complexity of lives ? →
- Trend towards career 'downsizing' for improved lifestyle ?
- Increasing leisure time [39,40]
- Increasing mobile working
- Shift in social attitudes to speeding
- 2010: Passenger numbers through UK airports increase by 50% [30] →
- 2010: 20-50% increase in European road passenger and haulage traffic [13,80]
- 2010: 10% increase in bus passenger journeys [30]
- 2010: 50% increase in rail passenger miles [30]
- 2010: 25% of UK workforce teleworking at least two days per week [57]
- Younger generation more IT-literate
- 2007: working at home becoming common (currently more than 66% of European organisations with more than 500 employees already practice teleworking) [28,39,40]

2012
- 2015: 150% increase in international air traffic; 100% increase in domestic, compared to 1995 [1]
- 2012: Bicycle journeys double [31]
- Frustration with congestion and public transport continues ? (journey time no longer predictable)
- Legal issues and frameworks ?
- Shift from car ownership to car access ?
- Increased use of car pools ?
- 2015: 400 million people live in megacities of more than 10 million inhabitants [57]
- Continued growth of cities and towns, mainly in South East →

2017
- New working / living patterns
- Social attitudes towards road transport and the environment?
- 2016: 4 million (25%) increase in housing (80% single-person), increasing demand for travel [1,67]
- 2016: 25% increase in number of UK households, 80% of growth due to single person households; 1.3% rural land use predicted to change to urban land use [39,40] →

2022
- 2031: 57% increase in UK road traffic, compared to 1996 [80,103] →
- 2031: 40% increase in bus / coach vehicle miles, compared to 1996 [1] →
- 2022: 70% increase in journey times in many UK cities 1996 [80]
- 2030: population in the UK is forecast to increase by 3.3%, to 61 million [1,39,40,67], after which it will decline to 57 million by 2050 [73] →
- 2030: 22- 27% of UK population over retirement age, compared to 19% in 1998; pension costs rise from 4.5-5.5% of GDP [1,25,39,40] →
- 2021: Households in South-east forecast to grow by 19% on 2001 levels [41]

Vision
Cheap, safe, reliable, clean convenient, comfortable transport for all

Key: Mobility & congestion | Lifestyle & attitudes | Demographics | Health, safety & security

Market / industry trends and drivers — Economic

2002 | 2007 | 2012 | 2017 | 2022 | Vision

2002
- Road accounts for 44% of goods transport in EU [48]
- Transport sector represents 10% of EU GDP, with automotive 5.3% of UK GDP (employing 700,000 people; £20bn exports) [37,43]
- Current costs [22]:
  - Owning & running vehicles: £5bn
  - Road construction: £2bn
  - Vehicle R&D: £0.5bn
  - Transport problem research: £0.006bn
- 2000: Development time for mass produced cars: Europe 46 months, compared to 36 and 42 months in Japan and USA [2] →
- 15% of average household income spent on travel [39,40]
- 80% of domestic freight travels by road [39,40]
- 30% of HGV capacity on roads not utilised [49]
- Diesel share of Europe market hits 50% ?
- UK joins Euro ?
- Congestion costs UK economy £15-20bn per year; £2bn for London (across EU cost of congestion represents 0.5% of GDP, expected to double by 2010) [22,37,39,40,48] →
- 2006: 30% of UK workforce employed in distribution & transport sector [65]
- 2000-2010: £65bn public and £56bn private investment needed for 10 year UK Transport Plan (75% increase on 1990-2000) [30] →
- Energy costs rise 2-3% per year →
- Emission-based taxation ? →
- EU Framework VI research funding for transport [37]
- UK Fiscal policy ? →
- Public Private Partnership ?
- 2005: 36% of suppliers act as systems integrators, compared to 14% in 1995 [11]
- Trend towards 24-7 economy →
- Strategies, decisions, and actions of major (non-UK) companies in automotive sector ?
- Globalisation trend continues, stimulated by IT & financial markets [40] (markets / engineering / sourcing / mergers / acquisitions) [50] →
- Customers prepared to pay 10% more for hybrid vehicle ?
- Increasing demand for diversity of goods →

2007
- Air traffic in the EU has increased by 7.4% a year on average since 1980; expected to double every 10-15 years [37,40] →
- Congestion charging (expanding from 2003) - needed on 10% of road network to stop congestion getting worse [103] →
- Services emerging as dominant differentiator [50]
- Continuing decline of UK manufacturing base ?
- 2007: Development time for mass produced cars: Europe 35 months, compared to 26 and 30 months in Japan and USA [2]
- 2008: 10% of UK shopping electronic [37]
- 2010: 20-80% increase in European road freight traffic, compared to 1990 [13,37,48]
- 2010: 80-100% increase in rail freight; EU target of 35% freight by rail; Government target to expand rail to accommodate 50% more passengers [30,37,40]
- 2011: 100% increase in seaborne world trade, growing at 4% per year [1,40]
- 2010: increasing demand for mobility in EU (38% increase goods transportation, 24% increase passenger transportation) [37]
- Vehicle tax based on cradle-to-grave environmental index?
- Competition vs. co-operation ? →
- New entrant vehicle manufacturers ? (e.g. Sony); New competition (service / software) [50]
- 2010: 15% increase in commuting to central London [30]
- Continuing consolidation of vehicle manufacturers ?
- 2010: 20% reduction in average cost of motoring [30]

2012
- Heavy goods vehicles increasing in weight (laden) ?
- Reducing cost of vehicle development and manufacture →
- 2015: China GDP overtakes EU [57]
- Role of insurance industry ?
- Different finance models (e.g. leasing) ?
- Cost of cars remains more or less constant [103] →
- Increasing wealth, but wealth 'gap' also increasing ? Increasing social exclusion ? →

2017
- Synthesised liquid carbon fuels become economic to produce →
- Trend towards 'build to order' and mass customisation, supported by modular product and technology architecture
- Sustain / increase public and private investment in R&D ?

2022
- 2031: Increases in road freight vehicle miles (compared to 1996) [1,39,40]: →
  - 124-169% increase in HGV;
  - 100% increase in LGV
- 2050: Freight demand triples in USA, compared to 1990 [4] →
- Alternative fuels in widespread use ? (vehicles and infrastructure)
- 2020: Aim to increase EU rail passenger traffic from 6 to 10% of total, and goods traffic from 8 to 16% [37]
- 2025-2050: World car ownership increases from 1.5 to 3.5 billion [2,15] →

Vision
Prosperous nation and sustainable economy

Key: Freight | National economics | Business | Consumer

See Section 1 (industrial context)

Market / industry trends and drivers — Environmental

2002 | 2007 | 2012 | 2017 | 2022 | Vision

- 1997: Vehicle mileage doubles, compared to 1980 [22]
- UK CO_2 emissions increasing by 26% by 2020 [38]
- Transport responsible for 25% of UK CO_2 and 22 % of greenhouse gas emissions (transport sector responsible for 28% of EU CO_2 emissions, increasing by 50% by 2010 if trends continue) [30,39,40,43,48]
- 24,000 premature deaths from pollution in UK [39,40]
- 1.8 million tonnes of end-of-life vehicles per year in UK (total of 9 million tonnes in Europe, representing 1% of Europe's waste) [51]
- Air traffic growth 4.5% per year in UK [40]
- Environmental burden of vehicle manufacture and disposal, vs. use ?
- 2008: 19% growth in UK road traffic [5]
- Attitudes to environment in USA ?
- Despite improvements to engine efficiency, CO_2 emissions will continue to rise due to increases in traffic [80]
- Heavy duty transportation is responsible for 25% of CO air pollution, 54% of NOx, 33% of VOCs, 47% of PM and 70% of Sox (USA) [55]
- Low sulphur fuel across EU? (<30ppm) [35]
- 2010: 20-50% increase in European road passenger traffic [13]
- 2010: CO_2 emissions reduced to only 2% increase, due to improvements in vehicle and train fuel efficiency [30]
- 2010: 50% increase in CO_2 emissions from road traffic in EU, based on current trends [37]
- 2010: UK Government target for 20% reduction in CO_2 emissions [43]
- 2010: Emissions of the most noxious air pollutants from road traffic reduced by 50% due to improvements in vehicle technology, but set to rise again due to traffic growth [30]
- Attitudes towards environment vs. cost ?
- 2020: World passenger miles double on 1990 levels, and double again by 2050 [4]
- 2021-31: Road traffic increases by between 50-160% [31,38,39,40]
- 2025-2050: World population increases from 8 to 10 billion [2]
- 2020: World carbon emissions up 60% on 2000 levels; 160% by 2050 [4]
- 2050: Average global temperature rises by 1.5-4.5°C [27]
- Fossil fuels account for 90% of commercial energy demand (98% of transport demand) [40,55] → 2000-2020: World oil demand grows at between 1.1 and 2.7% [15] → 2020-2040: Conventional oil supply peaks at 28-55 billion barrels/year; 50% of world's oil reserve depleted (by 2050 oil 'gap' exceeds 50bby) [4,15,17,20,27,40]
- 2004: PNGV target of three times 1994 fuel economy (production-ready prototype) [9] → *2002: PNGV superseded by FreedomCar Program (see technology trends & drivers)* → PNGV long-term target: 80mpg [14]
- 2035: World oil reserves depleted [13]
- 2060: World gas reserves depleted [13]
- Energy use increasing by 2-3% per year
- Increasing variety of fuel types
- 2010: UK Government target for 10% of electricity to come from renewable sources [43]
- 10-20% of typical vehicles energy consumption associated with production and disposal [80]
- What will the energy economy look like in 2020 ?
- 2004: US Office of Heavy Vehicle Technology target of 10mpg (at 65mph) for Class 7-8 truck; thermal efficiency of 55% by 2006 [55]
- 2004: 80% recycling of wrought aluminium in automobiles [9]
- Landfill no longer an option
- 2025: Japanese automotive Foresight targets: 50km/l fuel consumption; 90% reduction in exhaust emissions; nearly 100% vehicle recycling; 50% less noise; 50% reduction in accidents and deaths [2]

Vision: Clean, healthy, safe, secure environment. Zero emission vehicles

Key: Environmental burden | Global warming | Pollution | Energy | Waste

Market / industry trends and drivers — Technological

2002 | 2007 | 2012 | 2017 | 2022 | Vision

- Cost of computer storage reduces by factor of 10 every 5-10 years [24]
- Vehicle design should be driven by 'market pull' (customer need), not 'technology push' (what could be done)
- UK strong in design engineering, engine production, and world leader in advanced motorsport technology (80% of market) [44]
- Increasing shortage of skilled engineers, scientists and technologists, hampering technology and economic development [77]
- 2002-2007: Hybrid and battery-electric vehicle mass market introduction [15]
- 2003-2009: Alternative fuel technology available: Bio-ethanol, bio-diesel, natural gas [15]
- Systems integration increasingly important
- Sensor technology costs falling
- 2003-6: 10GHz chip [57]
- Proportion of electronics in the average vehicle may well double from the current level of around 20% by 2010 [44]
- 2005: 1 billion Bluetooth devices worldwide [57]
- 3G communications [38]
  - DAB / Bluetooth
  - navigation
  - mobile office
  - dynamic traffic information
- Increased use of CCTV
- 2005: All new cars fitted with GPS [24]
- 2005: Liquid crystal display applications double [24]
- Miniaturisation of many products and components [50]
- Use of aluminium rises as cost falls to three times that of steel [9] (other light-weight materials ? magnesium ? joining technology ?)
- Diesel technology improves (power, efficiency, emissions)
- 2007-2012: Fuel cell system vehicle mass market introduction [15,43]
- 2007-2013: Hydrogen, methane hydrates [15]
- Drive-by-wire
- 2008: EU Galileo satellite navigation system online [37] 2020? [38]
- 2007: Electronic money widespread [24]
- 2008: New technology from outside automotive sector? [19]
- Recycling of polymers ?
- Cost of carbon space frames falls significantly (volume production of composites ?)
- 2010: US FreedomCar targets [84]:
  - Fuel cell: efficiency 60% hydrogen, 45% reformer; power 325W/kg, 220W/L; cost \$45/kW (\$30/kW by 2015)
  - Hydrogen fuel / storage infrastructure: efficiency 70% well to pump; energy 2kW-h/kg, 1.1 kW-h/l; cost \$5/kW-h, \$1.25/gal
  - Electric propulsion: power > 55kW 18s, 30kW continuous; cost \$12/kW peak; life 15 years
  - Engine powertrain system: efficiency 45% peak; cost \$30/kW; life 15 years
  - Materials: 50% less weight
- 2017: Solar energy in widespread use [28]
- 2010: Market for alternative drive-train systems small (<5%), but growing and important for niche markets [34]
- Diversity of internal combustion engine technologies continues to grow [34]
- High density storage of H_2
- Reforming of current fuel to form H_2
- Biotechnology - energy
- 2009: 1 billion transistor chip [57] → 2013: 10 billion transistor chip [57] → 2018: 100 billion transistor chip [57]
- 2010: 1 terabit memory chip [24]
- 2010-2020: 4G high bandwidth communications [24,38]
- Increasing use of hybrid IC/electric engines [103] → 2030: Fuel cells exceed IC engines [103] → 2050: Hydrogen is the dominant fuel, probably powering fuel cells, or IC engines [103]
- 2012: Widespread use of network personalised services [24]
- 2010: Telematics market worth \$10 billion worldwide [56]
- 2010: Mobile radio market doubles [24]
- 2015: Intelligent materials with sensors, storage and effectors [57]
- Moore's law continues ?
- Crime reduction technology widely available
- Automated driving in designated lanes [38]
- 2008-2015: New technology: [3,19,24,38,43]
  - wearable computers / voice activation
  - 'infotainment' systems
  - communications / navigation
  - advanced sensors / biometrics
  - control systems (traffic & in-car)
  - driver control / active safety systems
  - smart car systems
  - condition monitoring / maintenance
  - capture waste heat in engines
  - fuel cell and other engine technologies / batteries
  - fluids, coatings
  - lightweight materials / composites
- Will technology be accepted ? (safety, cost)
- High capital mass production vs. low capital batch production ?
- Disruptive technologies ?
- How far can the internal combustion engine go ?
- 2020: Room temperature superconductivity [57]
- Biotechnology - materials

Vision: Effective and appropriate technological innovation. Automated highways?

Key: Energy & power | Electronics & control | Materials | Processes & systems

Market / industry trends and drivers — Political

2002 | 2007 | 2012 | 2017 | 2022 | Vision

Vision: Integrated, consistent transport policy

2000-2005: Delivery of UK DTLR Transport Direct, providing intermodal transport information and booking services [53] → Delivery of UK 10 year transport plan [30] → Where next ?

- £64.7bn public investment
- £56.3bn private investment

(Rail: £49bn; strategic roads: £16.2bn; London: £17.9bn; local transport: £28.3bn)

- £58.6bn public resource/revenue
- Total spending: £179.7bn (75% increase in real terms over past 10 years)

Strategy requires new approach based on integrated transport, public and private partnership, and new projects

Roads:
- Reduction in congestion
- Widening of 360 miles of strategic network
- 80 major trunk road schemes
- 100 new bypasses
- 130 other major local road improvement schemes
- Completion of Highway Agency Targeted Programme of Improvements
- HGV lanes on congested strategic routes
- 60% of trunk road network given lower noise surfaces
- Elimination of maintenance backlog for roads, bridges & lighting
- Smarter management of trunk road network
- Improved information, booking & ticketing systems
- 40% reduction in the number of people killed / seriously injured
- Accelerated take-up of cleaner vehicles to reduce pollution & CO_2 emissions

Rail:
- 50% increase in passenger miles
- 80% increase in rail freight
- Installation of new train safety systems
- Improvements in service quality
- Modernisation of trains and infrastructure
- Improvements to West & East Coast main lines
- High speed Channel Tunnel Rail Link
- Improved commuter services
- Improved integration with other transport modes

London:
- Improved capacity and quality of service on Underground
- Improved capacity and quality of bus services
- New tram / guided bus systems
- Improved rail and road connections

Locally across England:
- New rapid transit lines in cities, doubling light rail use
- New bus systems - 10% increase in passenger journeys
- More park and ride schemes; safer cycling & walking routes
- Support for rural communities, elderly and disabled people

UK energy policy review

UK DTI Automotive Innovation and Growth Team (AIGT) initiative to establish a vision for a future automotive industry in Britain [3,43,44]

Enlargement of European Community, leading to significant increase in size of Union car fleet [48] →

Carbon trading ? →

2010: EU target of 12% energy from renewable sources (in 1997 renewables accounted for 0.5% of UK consumption) [40]

What will follow on from Kyoto ?

European safety agreements (ACEA)

UK air quality strategy

Shift in focus from emissions to CO_2 ? →

Global emissions legislation harmonised

Legislation:
- Freedom of information
- Data protection
- Human rights

UK election

European Parliament legislates for opening up rail freight market completely by 2008 [48]

→ Standardisation and harmonisation of legislation and systems in Europe ?

China joins WTO

Need for partnerships between government, local authorities, police, voluntary groups, manufactures, etc. →

NGO and electorate pressure for environmental change →

Streamlined planning process ?

Improved deployment of policy ?

USA environmental, domestic and foreign policy ?

European and UK legislation ?

Globalisation vs. localisation ?

→ Government policy ?

Key: Transport | Energy & CO_2 | Health & safety | Political system

Market / industry trends and drivers — Infrastructural

2002 | 2007 | 2012 | 2017 | 2022 | Vision

Vision: Fully integrated transport system

Britain's roads and bridges are in their worst condition since formal monitoring began in 1977 [41]

Birmingham north relief road (toll)

Quality of infrastructure - standardisation

Efforts to reduce wear on roads →

2010: 60% of trunk road network given lower-noise surfaces [30,43] →

New high technology road surfaces developed
- road train control
- noise reduction

Increasing pressure and restrictions on land use [34]

High density car parking

Highways Agency Quieten Roads Programme →

Infrastructure-vehicle interface increasingly important (integrated system) →

Roads continue to be dominant means for travel and transport [34]

The average European city devotes 25-33% of its surface area to car parking and road space, compared to almost 75% in Los Angeles [74]

Broadband communications

Active traffic management systems
- congestion charging
- highway access

National Roads Telecomms System (NRTS) →

CCTV network extended →

The road network could cope with 10-15% more traffic through advanced traffic engineering and management [103]

What will the dominant GPS technology / standard be ?

The density of Britain's railway network is the lowest in Europe in relation to the size of its population [103]

Battery charging points more widely available →

2010: Infrastructure to supply and maintain high capacity batteries [19] →

2015: Infrastructure to supply and maintain gaseous fuel, liquid bio-fuels and fuel cell systems [19]

LPG widely available in Europe

What will the future road transport fuel be? - gas, liquid, electricity ?

Increasing measures to reduce number of short car journeys →

Capability and state of infrastructure ?

Government strategy for integrated transport ?

EU 'Marco Polo' initiative to support intermodal initiatives: 30 million euros over 4 years [37]

2010: 28% increase in congestion outside urban areas; 22% overall traffic growth [30]

2031: Journey times double on urban motorways [40] →

Public / private investment levels in infrastructure ?

Architecture for physical and information infrastructure ?

2010: Congestion 5% below 2000 levels, due to major investment in UK road infrastructure [30]

Key: Physical infrastructure | Information infrastructure | Energy infrastructure | Integrated system | Performance of system

Prioritisation of trends and drivers

The Foresight Vehicle Strategic Plan[5] identifies the following market requirements for future road transport, prioritised in terms of relative importance in 2020, with '5' representing the most important. This list is based on a Delphi survey carried out by the Foresight Transport Panel and a survey of selected groups of transport users.

These prioritised requirements can be used as an aid to interpreting and assessing the importance of the information contained in the roadmap. However, it should be noted that a similar exercise was attempted during the development of the roadmap, with the results showing a wide variation in what participants considered to be of high priority. Thus it was decided that prioritisation of market and industry trends and drivers should not form a core part of the process, but rather to provide a rich source of information and views that organisations could interpret and prioritise in terms of their particular needs and context.

Market requirements for future road transport

Requirements for travellers	*Importance in 2020 (relative)*
Accessibility of transport (from starting point through to actual destination)	5
Safety of traveller (accidents, personal safety)	5
Cost of travel (fares, fuel, repairs, capital)	4
Reliability of arrival time	4
Convenience (comfort, privacy, waiting times, status, enjoyment of travel)	3
Pride of ownership	3
Enjoyment of travel	3
Availability of transport (at the required time)	2
Shorter journey duration	1
Choice of mode of travel	0
Requirements for hauliers	
Light weight vehicles	5
Reduced operating costs (fuel, repairs, capital)	5
Predictable arrival times	4
Vehicle and load identification and location	3
Security of drivers and loads	3
Specialised vehicles (low volume manufacture)	2
Choice of mode (link with rail, dual purpose vehicles, load transhipment)	1
Requirements for society	
Law enforcement (compliance of products and services, public protection)	5
Efficient use of roads	5
Safety of travellers and bystanders	5
Air quality (pollutants, excluding CO_2)	4
Inward investment into UK	4
Global competitiveness of UK companies	4
Tax raising & avoidance of public spending	3
Exports from UK	3
Noise and vibration	2
Use of space for roads and parking	2
Energy use	2
Equitability ('Mobility for all')	1
Creation of new products and services for UK suppliers	1
Disposal (minimum landfill, recycling)	1

Appendix B

Performance measures & targets

This Appendix contains detailed information relating to performance measures and targets for the road transport system, summarised in Section 3. The information in these roadmaps was collected initially by workshop and then supplemented by reference to published information (Appendix D).

Six detailed roadmaps are included:

- *Social* performance measures and targets relate to mobility and congestion, lifestyle and attitudes, together with health, safety and security.
- *Economic* performance measures and targets relate to both business and consumer perspectives.
- *Environmental* performance measures and targets relate to the overall environmental burden of road transport, global warming, pollution, energy and material waste.
- *Technological* performance measures and targets relate to energy and power, electronics and control, materials and structures, together with the processes and systems that support development of these technologies. This theme is different from the others, in that it directly relates to the five technology areas considered in detail in Section 4.
- *Political* performance measures and targets relate directly to Governmental policy, regulation, legislation and action in the areas of energy and CO_2, health and safety, and waste management.
- *System* performance measures and targets relate to the road transport system as a whole, which includes consideration of the infrastructure and the level of integration. It should be noted that performance measures and targets for the infrastructure itself are not included in this roadmap, as the focus in on road vehicles.

Also included are a set of visionary ‘Beacons’ and a detailed table of targets for user requirements, from the Foresight Vehicle Strategic Plan[5], which have been incorporated into the roadmap.

Performance measures and targets — Social

2002 | 2007 | 2012 | 2017 | 2022 | Beacons

Public 'mobility' target ? → *2005: 70% user satisfaction with all transport modes (measure of 'convenience')* [5] → *2010: 80% user satisfaction with all transport modes* [5] → *2020: 85% user satisfaction with all transport modes* [5]

Aim for 'equitable' mobility (same price for same journey for all groups in society) [5] (and choice? disability?) → DTLR QOLC (quality of life) - mobility for all targets for different population groups

Increase ratio of public / private mileage ? →

Improve access to transport for 16-17 year olds ?

Absolute and relative increase in discretionary passenger miles ? (potential measure: track & off-road day participants?) →

2005: Road traffic noise reduced by 3dBA from 1998 levels [5] → ***2010: Road traffic noise reduced by 4dBA*** [5] → ***2020: Road traffic noise reduced by 6dBA; Homologated noise reduction of 4dBA and 8dBA for light and heavy vehicles, respectively*** [5]

Stress of journey experience - incidence of road rage ?

2004: Reduce vehicle crime by 30% [47] → ***2010: Vehicle security (resistance to attack)*** [5]
- ***Door locks: 5 minutes; Secure storage area in vehicle: 5 minutes***
- ***Alarm systems: 5 minutes; Immobilisers: 20 minutes; Window glass: 2 minutes***

Beacons

Vehicle adaptability
Configurable, upgradeable, modular, enabling vehicle characteristics to satisfy and enthuse customers throughout its life, fun to drive, requiring minimum driving effort, goes anywhere and suitable for young and old, has charisma

Urban people transport
Efficient transport concepts for urban use, exhibiting rapid response to passenger demand and low or zero pollution

Efficient selling and customer support
Processes to increase customer satisfaction throughout the whole period of product ownership

Key: Mobility & congestion; Lifestyle & attitudes; Health, safety & security

(Text in ***bold italics*** indicates targets from Foresight Vehicle Strategic Plan[5])

Performance measures and targets — Economic

2002 | 2007 | 2012 | 2017 | 2022 | Beacons

← Too late? (aim for 2005) ← ***2010: 24 months to develop a completely new vehicle; 18 months if significant carry over of parts*** [5,33] → 2020: 18 months to develop a completely new vehicle; 12 months if significant carry over of parts [33] ← Too late? (aim for 2012)

Goods vehicle costs: aim for 7 year vehicle lifetime (or 2 million km); maximum maintenance of 7 hours per year [5] →

2010: 35% reduction in cost of developing a new vehicle, compared to 2000 [5,33] → ***2020: 50% reduction in cost of developing a new vehicle*** [5,33]

DETR QOLC (quality of life) - targets for inward investment for automotive manufacturing

2010: Manufacturers [5,33]***:***
- ***30% improvement in ROI, efficiency***
- ***order to delivery of bespoke vehicle: 3 days*** (just in time / supply chain)
- ***significant improvement to quality***

Significant reduction in number of late engineering changes [5]

Real cost of ownership reduces by 10% ? → Real cost of ownership reduces by 20% ?

Residual value after 3 years: 30 to 65% → Residual value after 3 years: 45 to 65% ? → Residual value after 3 years: 55 to 65% ?

Cost of travel: aim for 15 year vehicle lifetime (or 150,000 miles), with emissions compliance, 4kWh/litre [5] →

50% of all cars leased ? → 90% of all cars leased ?

Beacons

Vehicle efficiency
Convenient and efficient, providing cost effective transport; real affordability (step reduction in purchase price) and minimal cost of ownership

Efficient delivery
Effective urban light goods delivery with low or zero pollution an a major improvement in fleet operating cost

Efficient haulage
Heavy goods transport concepts for long distance freight with low running costs, optimum routing and all weather mobility

Efficient design and manufacture
Processes to reduce the time to market for new products and the costs of manufacture within the supply chain

Key: Business; Consumer

(Text in ***bold italics*** indicates targets from Foresight Vehicle Strategic Plan[5])

Performance measures and targets — Environmental

2002 | 2007 | 2012 | 2017 | 2022 | Beacons

Life cycle targets ?

All companies ISO 14001 [5,33] (many large firms and suppliers are already)

UN Agenda 21 sustainable development principles and targets (poverty, health, pollution, ecosystems) [52]

2050: Royal Commission on Environmental Pollution target for 60% reduction in greenhouse gas emissions [43]

2000: CO_2: 169 g/km (EU average for diesel + gasoline) [36] → ***2008: ACEA voluntary commitment to achieve target of 140g/km CO_2 emissions (new car fleet average) in EU - 25% reduction on 1995)*** [3,5,35,36] (approx. 50mpg UK) → ***2012: CO_2: 120 g/km*** [3,5] (approx. 60mpg UK) → CO_2: 100 g/km? [3] (approx. 80-100mpg UK) → ***2020: 10% improvement over German federal tax class target of 90gm/km*** [5]

2020: Particulates (as defined by EURO 4 directive) reduced to 20% of typical gasoline engine 1998 levels, for all fuel types [5]

2020: Carbon monoxide, hydrocarbon and oxides of nitrogen to be reduced to 50% of EURO 4 standard for gasoline engines (for all fuel types) [5]

2006: Regulated emissions from all vehicle types to reduce by 25% due to more stringent European emission standards [43]

NOx & PM10 emissions down by 15%

CO emissions down by 60% ?

Targets for vehicle manufacture: energy, material, waste and emissions reduction ?

2008: Average new car in Europe should be 25% more fuel efficient than in 1995 [43,44]

2020: 20% of conventional fuels in EU replaced by substitutes [37]

Corporate average fuel efficiency (CAFE): 27mpg US [3] (32.4mpg UK) → 2004: CAFE: 30mpg? [3] (36.0mpg UK) → 2007: CAFE: 33mpg? [3] (39.6mpg UK) → 2010: CAFE: 36mpg? [3] (43.2mpg UK)

UK average fuel /passenger mile reduced by 18% on 2001 levels ? → UK average fuel / passenger mile reduced by 30% ?

UK average fuel/tonne ? mile reduced by 10 on 2001 levels ? → UK average fuel / tonne ? mile reduced by 16% ?

End-of-life vehicle targets:
- land fill / reuse / recycling [51]

Beacons: **Social responsibility** Environmentally acceptable, safe to occupants, other road users and pedestrians, low pollution, secure and unstealable, addresses total environmental cost at point of impact

Key: Environmental burden | Global warming | Pollution | Energy | Waste

(Text in ***bold italics*** indicates targets from Foresight Vehicle Strategic Plan[5])

Performance measures and targets — Technological

2002 | 2007 | 2012 | 2017 | 2022 | Beacons

UK RDS-TMC digital traffic alerts by radio

Telematic systems 'plug & play' technology: 50% of vehicles ? → Telematic systems 'plug & play' technology: 90% of vehicles ?

Automatic steering for premium cars ? → Adaptive cruise control widely fitted to family saloons ? → Commercial vehicle platooning possible → Hands-free eyes-down for premium cars and commercial vehicles (EUCAR advanced driver assistance programme) ? → Intelligent speed adaptation ?

2020: Crime reduction [5]
- external means to identify vehicle (available now?)

Nil sprayed paint with 'A' class surface finish on vehicle body introduced ? (composite panels currently achieve this)

Goods vehicles lifetime 7 years or 2 million km; maintenance max 7 hours per year

→ ***Computer-based vehicle engineering dominates*** [5] (70% of vehicle engineering by 2009 [33]) → Possible to design new vehicles 100% by simulation (including durability, crash, component fatigue, etc.) ?

Unladen goods vehicles weights [5]***:***
Rigid vehicles:
2 axle: 4.5 t; 3 axle: 6.6 t; 4 axle: 7.7 t
Tractor units (class / weight):
38t: 5.5tt; 32t: 5.5t; 44t: 6.5t
(weight reduction targets for cars ?)

→ Design for 'X', including disassembly and life cycle assessment

Key: Energy & power | Electronics & control | Materials | Processes & systems

(Text in ***bold italics*** indicates targets from Foresight Vehicle Strategic Plan[5])

Performance measures and targets — Political

2002 | 2007 | 2012 | 2017 | 2022 | Beacons

Climate Change Levy [54] →

2008: European CO$_2$ emissions 140g/km (passenger cars) [5] → ***2010: EU - CO$_2$ emissions from new cars to average 120g/km*** [3,5,31]
EU vehicle standards - improve fuel efficiency and reduce CO$_2$ emissions by 33% [31]

2005: Biofuels must represent a minimum of 2% of fuels sold (draft EU Alternative Fuels Directive 92/81/EEC) [105] → 2010: Biofuels must represent a minimum of 5.75% of fuels sold [105] → 2010: Biofuels must represent a minimum of 5.75% of fuels sold [105]

2008-2012: Kyoto protocol, 12.5% reduction in greenhouse gases, compared to 1990 levels [7,27,31,43]

2003: EU targets [6]:
- Benzene: 5ppb
- 1,3-butadiene: 1ppb
- CO: 10ppm

2010: EU targets [6]:
- Nitrogen dioxide: 40 mg/m^3 mean to 200mg/m^3 peak

2015: EU Auto Oil Directive targets of reducing NOx, SO$_2$, CO, NMVOC and benzene to less than 20% of 1990 levels, and PM10 to 42% [37]

2005: EU targets [6]:
- Lead: 0.5mg/m^3 mean (0.25mg/m^3 by 2008)
- Particles (PM$_{10}$): 40 mg/m^3 mean to 50mg/m^3 peak
- Sulphur dioxide: 47ppb mean to 132ppb peak
- Ozone: 50ppb

Average emissions vs. individual vehicle performance ?
Periodic inspection vs. continuous measurement ?

2010: EU target to reduce road deaths by 50% [37]

Legislation: → Legislation on advanced active safety for vehicles →
- active safety on vehicles
- pedestrian protection
- ABS / daylight lamps

2010: UK targets to reduce road accidents [5,8,29]:
- 40% reduction in deaths and serious injuries
- 50% fewer children killed or seriously injured
- 10% reduction in minor injuries
- 3% reduction in pedestrian injuries

HSE target for occupational health and safety in manufacturing industry (effect on manufacturing processes and productivity ?)

Low sulphur fuel compulsory ?

2000: EU End of Life Vehicle (ELV) Directive, 2000/53/EC) [51] → 2002: ELV Directive implemented in UK, to be enforced by 2007, enabling owners to return vehicles free of charge (producers pay) [51] → 2007: ELV targets [51] (85% recycle, 15% landfill) → 2015: ELV targets [51] (95% recycle, 5% landfill)

2004: EU WEEE Directive prohibiting landfill disposal of electronic and electrical equipment [68]

2003: EU Directive prohibiting landfill disposal of whole tyres, and shredded tyres by 2006 [68]

Key: Energy & CO$_2$ | Health & safety | Waste

(Text in ***bold italics*** indicates targets from Foresight Vehicle strategic plan)

Performance measures and targets — System

2002 | 2007 | 2012 | 2017 | 2022 | Beacons

Maintain average journey speed (door to door) [5] →

2005: Accessibility of transport (average time to and from main journey mode): 10% improvement on 1998 levels [5] (three measures of time: time spent waiting at start of journey; journey time; variability) → ***2010: Accessibility of transport: 15% improvement*** [5] → ***2020: Accessibility of transport: 25% improvement*** [5]

Potential measure: proportion of population / journeys possible door-to-door using intermodal transport

2008: Reduce growth rate in UK traffic to 50% of projected level of 19% [5]

→ ***2020: Zero increase in traffic congestion*** [5]

2005: Availability of transport (proportion of person/journeys for which waiting time to journey commencement is no more than 50% of journey time) improves by 25% compared to 1998 [5] → ***2010: Availability of transport improves by 40%*** [5] → ***2020: Availability of transport improves by 50%*** [5]

20% improvement of motorway / trunk availability vs requirement, compared to 2001 → 40% improvement of motorway / trunk availability vs requirement

Shift freight from road to rail / water ? →

Arrival time +/- 5 minutes → Arrival time +/- 2 minutes

Infrastructure integration metrics ? →

2005: Reliability of arrival time: 10% reduction in average time variance vs expected [5] → ***2010: Reliability of arrival time: 20% reduction in average time variance*** [5] → ***2020: Reliability of arrival time: 50% reduction in average time variance*** [5]

Inter-modal efficiency
Vehicle concepts to deliver a step change in inter-modal connectivity, achieving reliable arrival times for multi-mode journeys and reductions in passenger waiting and mode access times

Key: Integrated system | Performance of system

(Text in ***bold italics*** indicates targets from Foresight Vehicle Strategic Plan[5])

Beacons

The Foresight Vehicle Strategic Plan[5] defines a set of nine 'Beacons' to promote exploitation of the results from the LINK research programme. The Beacons, which are based on technologies being developed within the LINK programme, point the way towards viable new commercial products. The Beacons show how a particular combination of technologies could crate an attractive offering to the market. They are not vehicles themselves but provide the basis for exploring the limits of a particular market concept. The Beacons satisfy the LINK requirement of being pre-competitive, but demonstrate the technologies in a credible form. The Beacons are included in the roadmap as visionary concepts, within the Performance Measures and Targets layer.

Vehicle efficiency

Convenient and efficient, providing cost effective transport; real affordability (step reduction in purchase price) and minimal cost of ownership.

Targets: Journey duration, cost of travel, energy use

Vehicle adaptability

Configurable, upgradeable, modular, enabling vehicle characteristics to satisfy and enthuse customers throughout its life, fun to drive, requiring minimum driving effort, goes anywhere and suitable for young and old, has charisma.

Targets: Pride of ownership and pleasure of travel, noise level

Social responsibility

Environmentally acceptable, safe to occupants, other road users and pedestrians, low pollution, secure and unstealable, addresses total environmental cost at point of impact.

Targets: Safety of the traveller (accidents, personal safety), safety of all road users (pedestrians, cyclists), law enforcement (compliance of products and services, public protection), efficient use of the strategic road network, air quality, energy use, noise levels, life cycle optimisation, vehicle security

Efficient delivery

Effective urban light goods delivery with low or zero pollution and a major improvement in fleet operating cost.

Targets: Journey duration, reliability of arrival time, energy use, goods vehicle lightweighting, goods vehicles costs

Urban people transport

Efficient transport concepts for urban use, exhibiting rapid response to passenger demand and low or zero pollution.

Targets: Availability of transport (at the required time), reliability of arrival time

Inter-modal efficiency

Vehicle concepts to deliver a step change in inter-modal connectivity, achieving reliable arrival times for multi-mode journeys and reductions in passenger waiting and mode access times.

Targets: Accessibility of transport (at the start of the journey through to the ultimate destination), journey duration, reliability of arrival time, convenience (comfort, privacy, status, enjoyment of travel), efficient use of the strategic road network in an integrated transport environment

Efficient haulage

Heavy goods transport concepts for long distance freight with low running costs, optimum routing and all weather mobility.

Targets: Journey duration, energy use, goods vehicle lightweighting, goods vehicle costs

Efficient selling and customer support

Processes to increase customer satisfaction throughout the whole period of product ownership.

Targets: Pride of ownership and pleasure of travel, cost of ownership, safety of the traveller and all road users, life cycle optimisation, vehicle security, energy use

Efficient design and manufacture

Processes to reduce the time to market for new products and the costs of manufacture within the supply chain.

Targets: Life cycle optimisation, vehicle lightweighting, energy use, pride of ownership and convenience (comfort, privacy, status, enjoyment of travel), noise level, safety of the traveller and all road users, vehicle security

Targets for user requirements

The Foresight Vehicle Strategic Plan[5] defines a set of targets for user requirements, which are related to both the Beacons and Market requirements for future road transport (Appendix A). These targets are provided to steer researchers towards appropriate technologies that may be able to meet essential performance requirements. They are not intended to be a comprehensive specification for the design of a product. These targets have been incorporated into the roadmap, together with other concepts proposed in the workshops, including legislative requirements. They generally reflect the required and desired performance of the road transport system.

1. Accessibility of transport

Average elapsed time to and from main journey mode (this reflects the degree of frustration in accessing the main mode). Note, the main mode is the time-dominant mode for a given journey. The elapsed time to and from the main mode is the total journey time, door to door, less the main mode journey time.

Targets:

2005 10% reduction in 1998 level
2010 15% reduction in 1998 level
2020 25% reduction in 1998 level

2. Availability of transport (at required time)

Proportion of person/journeys for which the waiting time to journey commencement is no more than 50% of the journey time.

Targets:

2005 25% reduction versus 1998 in non complying person / journeys
2010 40% reduction versus 1998 in non complying person / journeys
2020 50% reduction versus 1998 in non complying person / journeys

3. Journey duration

Average journey speed (door to door). Note, this is measured at a total level for the whole UK population, and embraces both single and multi-mode journeys, inclusive of waiting time. Alternative strategic solutions might result in subordinate sector and mode objectives. However, a static total average should be held as a prime target. Any ambition to increase average journey speed and reduce journey time would result in a compensating increase in journeys, to fill the freed time. Evidence is available to show that the total time spent commuting per day remains constant, both over time (<100 years) and across cultures.

Targets:

2020 No change to 1998 average journey speed over the period

4. Reliability of arrival time

Time variance versus expected arrival time for all journeys.

Targets:

2005 10% reduction in average time variance
2010 20% reduction in average time variance
2020 50% reduction in average time variance

5. Cost of travel

Vehicle lifetime costs (fuel, repairs, capital) with emissions compliance and fuel / useful power conversion; insurance costs.

Targets:

2020 Vehicle lifetime: 15 years or 150,000 miles
Emissions compliance: lifetime capability (15 years)
Fuel / useful power conversion: 4kWh/litre (gasoline)

6. Pride of ownership and pleasure of travel

Opinion surveys present a possible basis for target setting. Such an approach should consider the views of participants in all travelling modes, including walking.

7. Safety of traveller

Accidents and personal safety – DTLR targets.

Targets:
2010 See Appendix A

8. Safety of pedestrians

DTLR targets.

Targets:
2010 Reduction of 40% from 2000 in accidents to pedestrians

9. Convenience

Quality of transport experience, as measured by user survey (comfort, privacy, status, enjoyment of travel).

Targets:
2005 70% user satisfaction with all transport modes
2010 80% user satisfaction with all transport modes
2020 85% user satisfaction with all transport modes

10. Crime reduction

Vehicle and driver identity and behaviour detection.

Targets:
2020 An external (remote electronic) means should be available to read information such as Vehicle Identification Numbers (VIN), registration marks, vehicle make, model and type that satisfies the requirements of the Data Protection Registrar. Systems are also required to detect when a vehicle is speeding, violating movement or access restrictions or being driven by an unauthorised driver including one with an expired licence or invalid insurance.

11. Efficient use of strategic road network in an integrated transport environment

Targets:
2008 Reduce the growth rate in UK road traffic to half of the projected 19% level by 2008
2020 Achieve zero increase in traffic congestion over 1998 levels, with no substantial expansion of the road network (based on forecast road traffic growth of 19% by 2008 and 50% by 2025)

12. Air quality

Pollutants, excluding CO_2.

Targets:
2020 Carbon monoxide, hydrocarbons and oxides of nitrogen to be reduced to 50% of the EURO 4 standard set for gasoline engines, but applied irrespective of the fuel used (note, this target is more demanding for diesel engines). Particulates to be reduced to 20% of the EURO 4 level and ultrafine particulates (0.1 microns or PM0.1) to be reduced to a level equivalent to 20% of a typical 1998 production gasoline engine, irrespective of fuel used.

13. Energy use

Reduction in CO_2 whilst retaining desirable vehicle characteristics.

Targets:
2008 25% reduction in 1995 European fleet average CO_2 levels, to 140gm/km (ACEA target)
2012 Reduction in European fleet average CO_2 levels, to 120gm/km (ACEA target)
2020 10% improvement over German federal tax class target of 90gm/km

14. Noise levels

As levels of traffic noise reduce, the correlation diminishes between homologated noise levels and measured traffic noise. Two target dimensions are therefore proposed.

Targets:

2005	3dBA reduction in 1998 traffic noise levels
2010	4dBA reduction in 1998 traffic noise levels
2020	6dBA reduction in 1998 traffic noise levels
	4dBA and 8dBA reduction in homologated vehicle noise for light and heavy vehicles, respectively

15. Equitability ("mobility for all")

This requires that all mobility targets must be realised for all groups in society who wish to make the same journeys and pay the same price. It therefore includes such groups as the elderly, young and the disabled.

16. Vehicle security

Resistance to attack.

Targets:

2010 2 minutes for window glass (under attack using tools commonly used by professional thieves)
5 minutes for door locks, secure storage areas (after the vehicle has been entered), alarm systems (minimum time for an unauthorised person to disable the alarm).
20 minutes for immobilisers (minimum time for unauthorised person to drive vehicle away using its own motive power, given access to driver's compartment). Immobilisers must not represent a danger to any road user even in the event of malfunction. They must not operate the brakes of the vehicle. The system must offer safeguards that operation cannot be initiated by unauthorised persons and will not affect vehicles other than the intended one.
Other security measures: visible VIN on chassis an all major components; in-car entertainment, telephone, navigation and tracker systems to be distributed and integrated into the vehicle electrical system; management system for replacement of security components compliant with ISO 9000.

17. Goods vehicle light weighting

Rigid:

Axles weight	*GVW (tonnes)*	*Power (BHP)*	*W/base (m)*	*Cab*	*Target (tonnes)*
2	18	200-250	5	Day	4.5
3	26	275-300	5	Day	6.6
4	32	300-320	6	Day	7.7

Tractor:

Axles weight	*GVW (tonnes)*	*Power (BHP)*	*W/base (m)*	*Cab*	*Target (tonnes)*
2	38	330-360		Day	5.5
2	32	300-320		Day	5.5
3	44	360-400		Sleeper	6.5

18. Goods vehicles costs

Fuel, repairs and capital.

Targets:

2020 Lifetime: 7 years or 2 million km
Maintenance: maximum 7 hours per year

19. Time to market for new designs

Development time for vehicles from first concept to the first production vehicle, including completely new vehicles and vehicles where there is a significant carry-over of existing parts and systems. Earlier involvement of suppliers will be required, together with increased use of computer aided analysis packages and a radically new approach to durability testing.

Targets:
2010 24 months for completely new vehicles
18 months for vehicles with significant carry-over of existing parts and systems
Computer based vehicle engineering as dominant development method
2020 18 months for completely new vehicles
12 months for vehicles with significant carry-over of existing parts and systems

20. Cost of vehicle development

Reductions in development costs and late engineering changes.

Targets:
2010 35% reduction in development costs compared to 2000 levels
2020 50% reduction in development costs compared to 2000 levels

21. Quality of manufacture

Further significant improvement in product quality at the component and system levels is required. The current wide variations in performance between manufacturers makes it impossible to set meaningful numerical targets.

22. Order fulfilment for cars

Time required for delivery of bespoke vehicles (the major part of this improvement will be achieved through more efficient order processing).

Targets:
2010 3 day delivery of bespoke vehicles, for significant proportion of orders

23. Overall ROI for vehicle manufacturers

Improved return on investment (to ensure automotive sector achieves at least the average rate of return for manufacturing as a whole).

Targets:
2010 30% improvement compared to 2000

24. Environmental impact of manufacturing operations

Good practice and compliance with standards.

Targets:
2010 Manufacturers (of vehicles and parts) should achieve ISO 14001 or its equivalent.

Appendix C

Technology

This Appendix contains detailed information that has been collected, relating to technology development and research requirements, summarised in Section 4.

A total of 16 detailed roadmaps are included, covering the following five Foresight Vehicle Technology Group areas and sub-themes. Each roadmap represents the creative output from a workshop, reflecting the expert knowledge and thinking of the participants involved.

1. Engine and powertrain (E&PT)
   - Efficiency, performance and emissions
   - Reliability, development and weight
2. Hybrid, electric and alternatively fuelled vehicles (HEV)
   - Fuel cells, hybrids and hydrogen infrastructure
   - Hybrid and advanced internal combustion engines
   - Energy and drive systems: electrics and electronics
   - Conventional and alternative fuels
3. Advanced software, sensors, electronics and telematics (ASSET)
   - Shift to software
   - Access and use of vehicles
   - Architectures and reliability
4. Advanced structures and materials (FASMAT)
   - Safety
   - Product configurability / flexibility
   - Economics
   - Environment
5. Design and manufacturing processes (DMaP)
   - Lifecycle
   - Manufacturing
   - Integration

Engine and powertrain technology (E&PT)

Efficiency, performance and emissions

2002 | 2007 | 2012 | 2017 | 2022 | 2032

Thermal & mechanical efficiency Integrated engine / transmission control Transmission efficiency Valves/gas flow management Compound heavy duty (HD) diesel engines HD pressure: 170 bar (max. cylinder pressure)	Efficiency: 40% Diesel 30 % Gasoline Smart cooling / lubrication system Throttling at inlet valves	Energy recovery hybrids Energy storage Flywheel starter - generator Efficiency: 45% Diesel 40% Gasoline Heat recovery Camless on 50% vehicles CNG fleet (trucks & buses)	Integrated systems to achieve higher system efficiency Thermal insulation Fuel improvements Combustion tolerates alternative/ renewable fuel blends 'Nth' generation direct injection gasoline -> Exhaust heat recovery on trucks Flexible engine cycles Materials available for higher temperature combustion Feedback control of combustion/ injection process Cylinder pressure measurement (routine on all cylinders)	Efficiency: 50% Diesel 40% Gasoline Other prime mover Hydrogen IC engine truck / bus fleet & efficient H_2 storage	Efficiency: 55% Diesel (peak) HD pressure: 250-300 bar (max. cylinder pressure)
Performance & driveability Airflow management How to provide feedback to driver if engine is very quiet? (e.g. gear change) Traction control Performance and driving experience of diesel compared to gasoline Fast start-up / warm-up	Compact lightweight gearboxes with more ratios Auto-shift manual gearbox on 50% of vehicles	Hybrid enables driveable downsizing Standard response / feel pool car Electric water & oil pumping	Downsizing and octane-boosting Cost is a significant barrier to delivery of technology (rate of implementation) Safe convoy driving 20% efficient CVT (continuously variable transmission)	Increasing demand for 'track day' leisure outings	
Emissions (pollution and noise)	CNG (compressed natural gas) loosing favour? PM traps on a few vehicles Noise (intake, exhaust, shields) Optimised after-treatment Conventional diesel combustion	Traps on some construction machinery Continuous focus on next worse Pollutant -> Self-diagnosis No cold start pollution Noise in heavy vehicles Low noise cooling fans Urea widely available as emissions-reducing agent	Control interface to telematics & GPS (emissions, safety) Sealed engine Particulates (< PM 1) Lubricant reduced wear Emissions control for PM size Traps on everything Cleaner air quality achieved (focus shift to CO_2 Engine okay recycling in-situ New break through NOx after treatment (biotech / nanotech / etc.) Full HCCI (homogeneous charge com-pression ignition	CNG making a comeback?	

Engine and powertrain technology (E&PT)

Reliability, development and weight

2002 | 2007 | 2012 | 2017 | 2022 | 2032

Reliability and durability	Increased service intervals (15,000 miles) Oil quality sensors	Combustion solutions for lower cylinder pressure Increased service intervals (30,000 miles) Lubricant quality management systems for zero disposal Structural solutions for high cylinder pressure, drive torque, etc.	Fail safe OBD (onboard diagnostics) / limp home (tolerate any sensor failure) 'Sealed for life' lubrication & relevant sensor Technology (wear, life) Intelligent condition monitoring & ageing compensation Car services itself via OBD & telematics	Dry lubricants & coatings How long should a vehicle last? (environment vs. undesirable obsolescence)	Zero faults for life
Speed to market and cost	Common platforms Modularisation Simulation of flexible manufacturing tooling Simulation of powertrain systems	Reliable life prediction for non-ferrous alloys Virtual powertrain calibration Virtual engine simulation Lower cost power electronics	Flexible manufacturing systems & tooling Low cost high pressure fuel injection (new concepts & materials) Breakthrough fuel cell technology (biotech, nanotech, etc.) Self calibration systems (maybe just partially&) Knowledge-based design Low cost batteries (including new technology) Low cost gaseous fuel storage (new materials & manufacturing processes) Faster technology roll-out (e.g. concurrent research & marketing)		Time-to-market reduced to minimum, eradicating all non-value-adding activities (e.g. 1 year) Zero lost market opportunity *Every* product makes a cost contribution to the business
Weight and size	Increasing specific power output New liner-less bore technologies for shorter engines	Non-ferrous gears Downsizing & good driveability Composite transmission structures (including 'plastic') Composite engine structure Delete ancillary drive (R Cam drive?) Integrated ancillaries	Systems control to avoid peak loads Lighter crank & rod materials Plastic 'gears' Compound gear paths - shorter gearbox Thermal management for high power density Ancillaries moved off engine		Weight & size never compromise the vehicle

Hybrid, electric and alternatively fuelled vehicle technology (HEV) — Hydrogen and fuel cells

	2002	2007	2012	2017	2022 – 2032
Fuel cell & ancillary - design & manufacture	Fuel cell (FC) / hybrid - needs to be able to drive off immediately Cryogenic H_2 storage Onboard reforming to H_2 Need to be able to withstand 3 weeks storage at -25^0 C Accident / safety H_2 explosive potential H_2 safety case (vehicle & infrastructure) Need super high pressure H_2 vessels 2006+ Fuel cell APUs for reliable pre-heating, cooling (& catalyst warm-up) & some onboard electronics	Hybridisation (H_2 (fuel cell) ---IC engine) Support Technologies & systems for FCs - air supply - control electronics - thermal Quite compressors developed Efficient chemical H_2 storage system 2010 -------> 50 KW FC & subsystems 'standard' vehicle power plant	Vehicle design - FC / electric drive - modular design - crash worthy - lightweight materials Recycling of FC materials (materials used in FC are chosen with 2nd use in mind) 200 KW fuel cell & subsystem 'standard' for heavy bus/truck vehicles Switch-in / switch-out FC engine design for MRO convenience	<----*hybrids* | *FC* ----> *(infrastructure in place)* FC economics (economies of scale) - competitive vs. IC engine PEM fuel cells replaced by solid oxide / ceramic fuel cells in heavy automotive	No oxide materials required = PEMs 'Next generation' FC design - materials - structures - subsystems - (20 KW/litre output)
'Total' vehicles	FC & motorsport FC van, -----------> bus ----------> car UK components, under road evaluation	Regional evaluation of UK - sourced FC vehicle fleets (10 buses, 100 vans, 1000 cars) Passenger transport system becomes acceptable	Urban bus fleets (50% hybrid FC operation?) City centre delivery vehicles (50% FC & hybrid use) Volume manufacture plant for FC vehicles in UK	TV audience Shown how to build FC from domestic materials Integration of public / private transpor-tation Long distance coach / freight vehicles (50% FC use)	
Infrastructure	Distributed generation of H_2 at the local level - prototypes 2004 - commercial introduction 2006 - issue of regulation changes required	Need resolution to problem of gas (only) powered vehicles not allowed in tunnels or on some bridges 2010 Bio-fuels - gasification for H_2 for production economic	H_2 supply infrastructure 'Switchable' H_2 tanks at re-filling stations (rather than re-fuel the vehicle) H_2 made at home from tap water & domestic electricity	Onboard electricity generating facility used to power household when standing in the drive	50% of transport energy needs from renewable sources

Hybrid, electric and alternatively fuelled vehicle technology (HEV) — Hybrid and advanced IC engines

	2002	2007	2012	2017	2022 – 2032
Market - IC pilot / demonstration (2000) - Fleet of 15 vehicles	Production of H_2 IC vehicles for sale to public Other manufacturers join BMW in developing H_2 IC engines Truck/bus with diesel or compressed natural gas (CNG) engine	H_2 IC engine developed for commercial vehicles 2.5 % of new cars with H_2 IC (dual fuel) Fleets of trucks / buses with H_2 IC engine	H_2 FC: 1% penetration - H_2 available for IC engine also (or vice versa)	Diesel & gasoline from renewables > 20% 100,000 FC vehicles?	Diesel & gasoline from renewables feasible to replace crude oil ---> 50% vehicle fleet running on H_2
Government - Zero tax on H_2 fuel (April 2002) - Consensus among vehicle manufacturers that H_2 is important fuel of the future (March 2002)			Zero tax on H_2 replaced by progressive well to wheel carbon tax (zero for H_2 from renewables) Emissions control of vehicle interlinked to telematics		
Combustion technology	Downsized IC engine & mild hybrid H_2 engine - lower mass - smaller engine - lighter vehicle - "virtuous cycle"	HCCI combustion gasoline / diesel (low emissions) Feedback combustion control for multi-fuel capability (H_2 vs. gasoline, crude derived vs. bio-fuel)	Downsized IC engine & hydraulic hybrid (bus / coach?) HCCI combustion H_2 IC engine IC engine bespoke design for hybrid H_2 only IC engine with increased compression ratio & cryogenic injection machines (FC efficiency)	Breakthrough technology? (exhaust heat recovery on IC engine) Disruptive technology? (battery – cheap, high power density)	
Energy storage - Chemical (conventional fuel / bio-fuel - Battery technology	2004: UK engine capacity reaches 4 million units	Mechanical (flywheel) and thermal storage systems Efficiency of generation of LH_2 improves to 20% energy loss	LH_2 onboard storage 2 weeks before boil-off begins 42V standard on most vehicles?	Breakthrough technology? (H_2 storage from nano-technology, bio-technology) Reversible FC energy storage	
Infrastructure - Method of H_2 production - Environmental cost of production - Provision of H_2 refilling stations - H_2 supply (bulk, locally generated, standards, safety regulations)	LH_2 IC engine vehicles operating as bi-fuel (simplify introduction of fuel infrastructure) Infrastructure for LH_2 starts - London, 2003	Use of H_2 as transport fuel dramatically improves renewable energy economics & stimulates investment Photo-voltaic cell producing H_2 directly goes into production 20 LH_2 filling stations	1,000 LH_2 filling stations LH_2 fuel infrastructure available for FC vehicles	H_2 produced at vehicle owner's home (from CH_4 supply)	

Hybrid, electric and alternatively fuelled vehicle technology (HEV)

Energy & drive systems: electrics & electronics

	2002–2007	2007–2012	2012–2017	2017–2022	2022–2032
Energy storage system	Research in improved cell chemistry & engineering, and H_2 storage Energy / power hybrids (lead acid & supercap) Lead acid for HEVs - high power (50W/Kg) - long life (3 years) - $150/KWh (including BMS)	Lithium for EV & HGV meets full temperature, specification, cost ($300/KWh), safety (organics recycling) High temperature, high power (500W/Kg), low cost ($300/KWh) Lead acid: 800 W/Kg, 10 year life, $150/KWh Hydraulic energy storage (improved energy storage in general)	Ultracaps (high energy storage) Flywheels - materials - safety - cost	Electrical power from roadway	Low cost superconductor based energy storage
Engine	Engine optimised for hybrid	Single piston engines	Maintenance free engine Gas turbine (efficiency as good as diesel) Composite engine Ultra high speed, low cost generator		FC cost at $ 3,000/vehicle
Power converter	Fully integrated power converter	New silicon switching devices Silicon carbide Power converter sharing engine cooling system AC power distribution system	Higher temperature Silicon (not Si Carbide) Very lightweight wheel motors at affordable cost	Super magnets & high temperature Super conductors High voltage utilisation on vehicles (2-3 KV)	
Control & interfaces	Journey models (accurate, range of journey types, etc.) Reduced complexity driver information systems (e.g. voice recognition)	Journey predictor for adaptive control Integrated control (engine, transmission, & hybrid systems) Radio links to central systems	Vehicle-to-vehicle radio links Estimates of traffic/ road usage infrastructure (models) Low cost (multiplex systems) Low cost, low range RF controllers - wireless car (signal wires)	Concepts for regional / national control infrastructure Neural networks (faster real-time learning) – CPU power?	Full control of vehicle systems via intelligent systems Driver-less car (congestion control)
Novel transmission concepts & auxiliary systems	CVT (continuous variable transmission) - clutchless Fully integrated electric drive	Capacitors (high temperature, lower volume, lower cost) All electric braking Auxiliary power suppliers/drivers			

Hybrid, electric and alternatively fuelled vehicle technology (HEV)

Conventional / alternative fuels

	2002–2007	2007–2012	2012–2017	2017–2022	2022–2032
Petrol			Not suitable for reforming (in long-term) Fuel production peaks ??? (2015-2050 --->	Need for rare earth metals/ catalysts - disposal & supply	Supply vs. demand Supply shortage pushes up prices & costs
Diesel Ultra-fine particles - health	2005: Ultra-low Sulphur (ULS)				IC engine still used till 2050 for HGVs
LPG Basic infrastructure in place (LPG, petrol, diesel)	Need for standards (LPG & NG)				
CNG NG infrastructure needs compressors		Advantage of LPG / NG diminishes			
LNG LNG specialist process					LNG still needed for HGVs ?
Bio-diesel		5% by 2010 to max of 10% (no import)	Pressure on land use Advanced bio-fuel & H_2 production technologies		
Bio-ethanol/ methanol	Flexi-fuel vehicles up to M85 Toxic (methanol), hydrophilic				
Gas to liquid/ Advanced fuels (Dimethylether/ Dimethylmethane)	Need for standards Consumer suspicion		Suitable for reforming		
H_2 Storage and supply		IC engine & FC available in quantity		FC commercial for light vehicles	Significant use of renewable H_2

Advanced software, sensors, electronics & telematics technology (ASSET) — Shift to software

	2002	2007	2012	2017	2022–2032
Lateral guidance / control	Video image processing Inertia navigation Blind spot warning 360^0 sensing systems Integration	Vertical motion control systems	Galileo (GSP) Electronic maps Lane keeping - magnetic nails - expensive to deploy - support - maintenance		110 GHz radar ? Vehicle adaptability - affective design (CV style profile to vehicle performance matrix) Adaptability for changing driver behaviour - infrastructure using map
Longitudinal guidance / control	Adaptive cruise control (ACC) 77 GHz Radar GPS Parking - ultrasonic Long range radar Standards required	5.8 GHz Infrastructure 63 GHz comms Short range radar	Ad Hoc Vehicle Networking 3D Sensors ACC Systems - roadside pedestrian detection - video - radar Infrastructure "IFF" (identification friend-or-foe)	Convoy driving	
Vertical control	<u>VC 1</u> ARC, RMD active suspension <u>VC 2</u> Vertical motion sensors		Reduction in road degradation		
	Trend: warning (lower integrity / comfort) –> support –> delegated control (high integrity, safe, high redundancy, socially acceptable)				
Vehicle adaptability	Driver condition monitoring Driver monitoring	Driver "DNA" Vehicle occupancy monitoring	Driving ability monitoring Infrastructure electronic topology	"Plug and Play" (workable) Applications on demand Sensor enabled vehicles	
System integration	Bespoke application Bluetooth DAB (DIG) broadcast	Information fusion Sensor fusion Open system vehicle IT platform 3G (GSM)	Vehicle motion control - sensor redundancy by communication with infrastructure to their vehicles X - wire systems - redundancy - control algorithms - actuators - sensors Auto generated Wearable technology	4G Transport failure management Lane merge support Automated highway systems	Integration 5G Full authority vehicle
Intelligence & learning	Prioritising information	Online mapping	Dynamic network management Probe vehicle Intelligence identification (of closed systems)	Vehicle "AI"	

Advanced software, sensors, electronics & telematics technology (ASSET) — Access and use of vehicles

	2002	2007	2012	2017	2022–2032
Access into car - legality / access rights - identification of driver - characterisation of driver (setting-up vehicle) - identification / characterisation of passenger		Bio-metrics Phase 1	Electronic licence/ insurance Position of insurers to technology Bio-metrics Phase 2	Fit-to-drive detection	Crime reduction & safety
Access car into…		Access to PSU (e.g. clear zones) Access of HGVs (e.g. height)	Clear / home / parking access	Vehicle prioritisation / driver (e.g. elderly, disabled) Tuned vehicle performance - driver selected - novice drivers	Tuned vehicle performance - infrastructure control Adaptive vehicle to 'individual'
Use - relationship of fuel policy to practical measures / taxation	Auto emergency alert - who 'owns' 999 call?	Vehicle usage - data collection - transmission - probe vehicle Data ownership - personal freedom - income generation Multi-modal information (transport mode options)	Black box technology - 'market demand'? - liability? Interaction of traffic information (including road signs) in-vehicle Advisory system for economical driving (environmental)	Journey time reliability (prediction & planning) Interaction with traffic management Dynamic route guidance	Minimised congestion (perceived value)
Crime reduction - problem of non-adoption of security measures	Technologies exist, but time to implementation? (politics, standards, public, insurance, etc.)	EVI - theft counter measure	Vehicle fingerprinting	Vehicle sub-system identification Vehicle control remote anti-theft	Crime reduction II
Medium / long distance, short range Assumptions: - road / infrastructure - ADAS	Adaptive cruise control (ACC)	Stop & Go Stop & Go ++ - integration - data protocol - standards	Standardised definition of system requirements - delivery of X-by-wire Intelligent speed adaptation (ISA) Urban drive assistant (UDA)	Sensing of road & environment Vehicle-to-vehicle communication Rural drive assistant (RDA)	Mobility handicapped advanced driver assistance systems (ADAS) Automated highway control driving

Advanced software, sensors, electronics & telematics technology (ASSET)

Architectures and reliability

	2002–2007	2007–2012	2012–2017	2017–2022	2022–2032
Sensors for self-diagnostic systems	Intuitive Undemanding Sensors with a common architecture -> for diagnostics Software-based diagnostics (i.e software functionality okay) Adaptive?	Centralised garage computer diagnostics Signal analysis (on-board diagnostics)	Self-diagnostic Reconfigurable Artificial intelligence Predictive / preventive maintenance	Human fault tolerant	Worry free car Self-repairing Cheap sensors - pressure - temperature - strain - flow
Architecture to “enable”	Improved simulation for faster development		For control flexibility (to aid manufacturing) Standards	Design for disassembly --------> Interchangeability - component - upgrade	Tailor made “morphing” vehicle

Advanced structures and materials technology (FASMAT)

Safety

	2002–2007	2007–2012	2012–2017	2017–2022	2022–2032
Clients for safety: - in vehicle - other vehicles - pedestrians and cyclists Passive safety - vehicles - infrastructure (vehicles and pedestrian) Active safety - vehicles - infrastructure		10 year Scenario: - ‘business as usual’ → more leisure travel - will telework reduce reduce business travel? → Current users: - cars - buses - trucks - cycles - motorcycles - pedestrians	Future trends (10 years +) → - more motorcycles / powered 2 wheelers? - increased cycling in more segregated areas - pedestrian segregation - increased Park & Ride - more car journeys but fewer urban journeys - increasing truck usage - increase of urban bus / truck Urban speed decreasing Rural speed unchanged Motorway speed unchanged	10-20 year scenario - more radical	
Key issues - active safety systems (telematics facilitates) - smart crash materials & structural design (bus & truck) - segregation & infrastructure (bus and truck) - flammability Emissions: - manufacturing systems - engine & powertrain		Generic issues: - legacy vehicles - more realistic crash & accident tests (impact & fire) - modelling of material and structural performance - smart crash materials (design for safe structures & materials which are efficient) - training - segregation of user clusters (weight and speed) – permits optimisation of all vehicle classes More powered 2 wheel vehicles Radar for location (cyclists & others) - reflective materials for bike & rider Safety cells on bike & rider - light and strong motorcycle materials Motorcycle design (3 wheelers? / airbags) Safety of impacted vehicle Electro rheological (ER) materials - inflatable materials Lane segregation Paving materials - lane highlighting Road obstacles	More pedal cycles: - better visibility - side impact protection - segregation Pedestrian segregation: - ER materials - materials and structures for pedestrian safety - car free zones - barriers between roads and paths Segregation & safety infrastructure Park & Ride safety (e.g. bus safety) More short rural journeys (cold engine & tyres) - bus design for pedestrian safety Fewer urban journeys Bus design for Park & Ride Safety for passengers - bus passenger safety Pedestrian safety against coach / bus Coach vs. car impact - bus design for frontal & side impact / roll-over Lane segregation - overtaking system (third party)	Truck hitting other vehicles (active & passive safety) - truck design for pedestrians & other vehicles - active safety for pedestrians (architecture) School run safety - active tyre pressure safety - school infrastructure Working in the car (mobile phone / laptop) Voice systems - voice activated systems (& deactivated) Speed limiters Door opening inhibitor while being undertaken	

Advanced structures and materials technology (FASMAT)

Product configurability / flexibility

	2002–2007	2007–2012	2012–2017	2017–2022	2022–2032
Pre-configure model / Mix & match	Material mix Joining technologies: - adhesives - hybrid - mechanical - fusion - friction welded Space frame Design techniques - validation - simulation Coating technologies	Recycling systems (identification / separation) Corrosion (durability) Turn on / off adhesives	3-year re-configuration option Chassis: - main structure - varied body High strength / lightweight materials One chassis, snap on body module	Configuration at dealer Power options - combustion - fuel cell Turn on / off joining techniques 'Low skill' joining technology	
Design to suit customer - elderly population - increased female ownership - increasing population - increasing income - increasing leisure - increasing travel	JIT modular assembly Product mix varied Platform based vehicle mix Pick & mix equipment interiors	Lightweight hang-on parts Repair issues: - ease of repair - location cost	Pick and mix module Low cost tooling / flexible tooling Low investment (affordable) process Low cost dimension change (e.g extrusion cut, short or long)	External design by customer (variety vs. complexity)	

Advanced structures and materials technology (FASMAT)

Economics

	2002–2007	2007–2012	2012–2017	2017–2022	2022–2032
Design		Lack of composite design knowledge Develop knowledge of properties of materials & composites Same energy absorbing properties from lighter weight % reduction in weight (safety issue)	Plastic structural parts (more than add-on panels)		
Manufacture		Flexible manufacturing (able to make wide range of model options) Pre coated materials (painted & galvanised) Low tooling cost, to suit low volume production	Re-configurability of tooling No-tooling manufacture Material does not degrade (no rust or corrosion) Fast-curing composites Self coloured materials (no over painting) Part integration & self-colour)	Moulded body (no assembly) Reduced composite material cost allows cheaper volume manufactured composite structures (stiffer, lighter)	Process for use of lighter materials (e.g. titanium) in conventional production methods
Cost	Tailored tubes	New materials / processes (infrastructure & capital cost of entry) Longer life for higher residual value & selling on / down		F1 material performance at cheaper price Development of nano-composites / exotic materials	Standardisation of safety regulations (particularly crash) Lifecycle cost (cost of ownership) Polytronics Reduce whole life cost by %
Volume		Capital recovery	Cost of adding style		Lifecycle cost (wider stakeholder consideration – make to recycle)
Use	Road surface materials (friction / rolling resistance / grip / noise)	Alternatives to glass (weight?, thermal?) Easy to repair or replace (low cost) Reduction in cost of bodywork repairs			
Recycling	Energy used in recovering material	Identifying scrap material (how to sort?)			100 % recyclable composites

Advanced structures and materials technology (FASMAT)

Environment

	2002–2007	2007–2012	2012–2017	2017–2022	2022–2032
Recycling & end of life vehicles	Now: - 80% recycle - 20% landfill	ELV target: - 85% recycle - 15% landfill	ELV target: - 95% recycle - 5% landfill	ELV target: - 100 % recycle (for composites and electronics)	All materials able to be identified, separated, & re-used (different use okay). Process financially viable within possible levy costs Cosmetic / colour either part of parent material or able to be disassembled
Sustainable materials	Flax / hemp reinforcements - experimental (DC close to serial production) Lifecycle analysis tools exist to give right answer		Create useful, financially viable, sustainable materials with defined automotive application Decomposition on demand? (note variation in operating limits for compounds)		Glues / sealants easily disassembled for are no longer required
Emissions & vehicle weight	CAFE 32.5mpg (UK)	CAFE 39.6mpg CAFE 43.2mpg	Body structure materials that provide approximately 40% weight reduction - cosmetics as good as current - no worse piece cost - applicable from 20 to 250kpa Roads that absorb air & noise pollution (improve fuel economy to vehicle) Nano particles as a means of optimising material properties, design rules & technology		Total structure = 50% of 1990 technology steel body Technology to: - meet legislation - meet customer & economic needs Zero emission vehicle not necessary or practical
Manufacturing health & safety emissions and post production	Non gassing plastic / rubber components (emissions & legislation) - post-production	Radiation curing of polymers (low temperature, fast, no emissions, no solvent) Low temperature processing of internal mouldings - elimination of secondary processing	Solvent free production No hazardous materials in vehicle assembly or recycling	Materials for comfort (with increasing age / infirmity) 'Delight' materials (feels good to tactile sense)	Environmentally neutral factory
Safety (occupant, pedestrian, and other road users)	Air quality in cars	Ultra strong occupant cell Interior of vehicle is all self-extinguishing for non-toxic … or non-flaming (occupant survival cell)	High / clever energy absorption materials (i.e. multi-modules, crash responsive) Crash barriers to meet all road user needs		

Design and manufacturing process technology (DMaP)

Lifecycle

	2002–2007	2007–2012	2012–2022	2022–2032
(Design by 100% simulation ?) **Lifecycle assessment (LCA)** Supply for demand (reduce stock) Design against crime (holistic – see Design Council project) Increasing use of technology at home ? Design as differentiator ? Strategy ? How to use fully-interactive, internet customer relationship management (CRM) to bring customer into vehicle design ? Supply chain: collaborative product development (CPD) Knowledge management in CPD environment Does design offer the potential to be a differentiator & win global contracts ? (how?) - UK as design-supplier, not cost-supplier Re-use Recycle	Simulation technologies: education; information gathering / research Move to more 'full-service-contracts'. What possible strategies are there? How can they benefit the sector in UK ? Advanced display / interaction technologies: 3D, photorealistic, intuitive Built at dealer How to know what users / buyers want & how to get it in the design ? How far can 'virtual' car replace real stock in retail scenarios ? How does this impact on manufacture ? What are the strategies / scenarios for sustainable personal vehicle systems ? (generating scenarios to help us react) Design for diversity: function, population, desire / need More than internet ? Home high-resolution displays; full scale in retail environments ? Increase accessibility to mobility Bumpers – re-use or new use	How does design alter in the world of global competition & internet Changing retail environment: dealerships, experience centres, internet Methodology & robust / usable standards to be established (library of standards) Communication between customer and OEM, input to design Simulation for assessing driver 'needs' and 'wants' Attitudes to extended lifecycle – 'lifestyle', 'fashion', 'sustainable'	There is a conflict: reuse increases weight, but low weight reduces pollution Fully integrated life cycle assessment End of life materials separation & fluid handling Design to enable end of life dismantling to be simple & low-energy consumption When & how does new ownership / use models change car design ? *'Lifecycle' is a new area – research needs to focus initially on understanding*	
Energy in manufacturing	Identify current energy consumption & alternative material options ->	find target technologies -> Flexible manufacturing systems, reconfigurable -> technologies -> Users accept different paint surface <u>or</u> 'No paint' or 'low paint' systems available to volume manufacturers	Opportunities for energy recovery	Reduce manufacturing energy consumption by 50% (2002 levels) ?
Pollution in manufacturing	Identify and quantify current sources of pollution (in manufacturing?) What is life cycle impact of servicing ? (real behaviour… e.g. substandard MOTs, oil in drains) Pollution sources in sub-contractors, suppliers, delivery and retail	Sustainability goal: what is use (+purchase) behaviour and how can we interact with this to reduce use-phase impact ? What might the strategies be to achieve near-zero landfill ? 1) for existing fleet / designs; 2) for future vehicles		Airborne emissions reduced to 5% of 2002 levels ?

Design and manufacturing process technology (DMaP)

Manufacturing

2002 | 2007 | 2012 | 2017 | 2022 | 2027 | 2032

Systems

Commercial & Market

Partnerships for capital intensive plant / process development

Management

Increase primary stock yield (metals)

Cost effective solutions ->

Component

Support and grow innovative techniques for UK plc

2002–2007

Modular construction

Design for disassembly

Low capital costs of manufacturing

Global / regional / local suppliers

In house disposal system

Electronic data exchange

Support for close-to-form structural metal components

Reconfigurable jigs

Virtual assembly training

Education & training in new manufacturing technologies ->

2007–2012

Rapid disassembly / joining technology

Construction materials and influence of assembly processes

Design tolerance management

Heavy plant security of availability (customer base high enough to sustain long term)

Parts integration

2012–2022

Flexible mixed model assembly lines -> Supply chain implications

Regional local assembly

Reconfigurable assembly systems

Rapid prototype manufacture systems

Integrated data exchange (design, shopfloor, dispatch, distribution)

Lighter component assembly

Volume
- choice of materials
- choice of assembly methods

Super dealers research information being able to visualised to the benefit of the manufacture r?

No paint shop vehicles

Changes in vehicle architecture
- conventional body in white
- space frame

Dealer fit option

Reconfigurable tools (low capital costs; rapid part introduction, lower energy)

Mouldable plastics – fewer but complex parts

New materials (e.g. composites)
- light weight, low cost tooling for efficient rapid configuration

42 valves

Electronic systems integration

Cost effective mass production of advanced composites

Ring main power, with device network signal / control

Virtual design for manufacture plant design and re-design – for changes in production methods

2022–2027

Modular vehicles (with local small scale configurability options). New reconfigurable manufacturing. Rapid model changeover

2027–2032

Process energy reduction

Total automated manufacture

Manufacture driven by the user ?

Sharing production processes – evaluation of data / research / future demands

Small production runs
- output geared to demand
- markets driven by users ?

Design and manufacturing process technology (DMaP)

Integration

2002 | 2007 | 2012 | 2017 | 2022 | 2027 | 2032

Product / system integration

Process integration

Information and knowledge integration

Integration of people, process, organisation, tools and technology cut across all of these themes

2002–2007

Recognition that current systems do not integrate well

Requirements mediation systems

Information security

Definition of local vehicle environment (needed by Tier 1)

Trade-off: standardisation vs. creativity

Improved information flow as design progresses

Design information overload? Someone still needs to make it work!

Suppliers pose and are involved in 'what if?' scenarios

Location of creativity in design process (and its support and enabling)

Large scale collection and garage use of on-board data

Greater on-board monitoring

Automated diagnostics from design

2007–2012

Product metrics

Make control by wire acceptable (brake, steering, etc.)

Integration of all processes (concept - engineering – manufacture – post sales) into integrated concurrent design

Process model directly influencing product model generation

Process understanding (across disciplines, geography, time, companies)

Process metrics

Standards for system integration (interaction, needs)

Open systems architecture for information sharing

Time compression for design process integration

Rules for performance of parts of the vehicle - capture the experience of engineers

Integration of information flow downstream of manufacture

Collaborative knowledge sharing

Data mining / preventative maintenance

Lifetime diagnostics (as vehicle changes)

2012–2017

One vehicle structure can be 'tailored' via interior or software to be different 'vehicles' for different people (youth, family, elderly)

Understanding of product system – cost of changing any bit

Product-level analysis tools

Design implications for integrated systems

Configuration for power--by-hour for product ?

Creativity & innovation

Will 2002 processes be refined (incremental change), or a completely new approach for design – prototype – specify – build ?

Understanding of process system & interdependences

Generalised information inter-working across manufacture / suppliers / consultants / etc.

Integration of embedded software design methods into design process

Integration of skills

Seamless and minimum design cycle

Integration of power-by-the-hour for process ?

Scenario: special purpose vehicle developed from scratch by local supplier using major manufacturers' technology base

Information encryption for control of convoy vehicles (ISA)

Information overload for the designer

ICT in design integration

Increase in automated maintenance

Systems integration architecture

2017–2022

Role of people & automation (product)

Linking design changes to implications for cost and lifecycle

Common standards

System reliability

Integration of human and machine

Scenario: independent platforms speculatively developed by major manufacturers

Role of people & automation (process)

Multi-dimensional optimisation (cost, reliability, security)

Design issues for integrated safety systems

Communication standards

Knowledge capture for integrated design process

Robot mechanic for 70% of problems

2022–2027

Target: minimum economic production volume for 'real' vehicle: 1000 (enablers)

2027–2032

Artificial intelligent systems will allow single unit companies

Multi-disciplinary integration (not just engineering)

Scenario: expertise on demand system identifies required expertise and mediates its procurement

Information systems (not referring to design systems) requirements of future integrated transport systems

Appendix D

Resources

The information contained in this technology roadmap has been largely derived from a series of ten workshops that brought together more than 130 experts from across the road transport sector, representing more than 60 organisations. This information has been supplemented with reference to a wide range of documents and web-based resources, mainly from the UK, USA and Europe, which are organised below in the order in which they were collected.

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Appendix E

Participants and Organisations

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The information contained in this report is based on a series of ten workshops that brought together more than 130 experts from across the road transport industry. More than 60 organisations were involved, including industry, academia and Government. The technology roadmap does not represent official company or Government policy, but rather individual perspectives.

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Organisations

3DayCar; University of Bath; University of Birmingham; Blitzgames; BMW; University of Bristol; University of Cardiff, CAIR; Cosworth Technology Coventry University; Cranfield University; CRL; Digital Design Studio; E4Tech; Energy Technology Services; Engineering and Physical Sciences Research Council (EPSRC); European Commission; European Secure Vehicle Alliance; Corus

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