Foresight Vehicle

Foresight Vehicle Technology Roadmap

Technology and Research Directions for Future Road Vehicles

Version 2.0

Foresight Vehicle

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Foresight Vehicle

The Foresight Vehicle Programme, which started in 1996, has been one of the most successful initiatives for supporting research, design and development projects in the UK automotive industry.

Initiated by the DTI, the programme has been supported by industry and several other government departments. It has a combined total committed spend of approximately £100 million and the programme is launching its 100th project.

SMMT has always been extremely supportive of the programme and is proud to be involved in the vast network it has developed. SMMT was delighted to be asked to take on the task of programme manager in the spring of 2003.

During the early development of the programme, it was decided by the Steering Committee that a Technology Roadmap should be developed to highlight the routes and strategy the projects should take. The highly acclaimed first edition was published in 2001. This document has received recognition in the international automotive sector as well as other industrial sectors.

As with all documents of this nature, there is a need to review and update the strategy on a regular basis. Version 2 has had further input from SMMT's Engineering Committee and we are pleased to endorse its findings.

We would also like to thank all those involved especially, the five Thematic Chairmen and Cambridge University, for their hard work and support.

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Foresight Vehicle Technology Roadmap Version 2.0

Technology and research directions for future vehicles

Contents

1 EXECUTIVE SUMMARY

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. Version 1.0, published in 2002 and based on data collected in 2001, brought together more than 130 experts from across the automotive sector, representing more than 60 organisations. Market and industry trends and drivers were considered against 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.

This Version (2.0) has reviewed the information contained in the original, and current views and updates on the technology directions and targets are now included. To ensure a genuine review, more than 75% of the people consulted for this exercise had not participated in Version 1.0. Although the information contained in Version 1.0 was found to be still broadly relevant, the UK commitment to the Kyoto Protocol and increasing global concerns about the use of vehicles in terrorist attacks has brought both these issues into focus. Also, although infrastructure performance measures and targets have not been included either in this or Version 1.0 of the roadmap, it is evident from the roadmapping process that bringing them together in a future version needs consideration. This includes both the physical infrastructure as well as the associated systems.

The overall goal of the technology roadmapping initiative has been to support the aims of Foresight Vehicle, providing a framework for ongoing investment in 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), 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, academia and networks.
- Mapping future innovation paths for a number of key technology areas, including:
    - Engine and Powertrain
    - Hybrid, Electric and Alternatively Fuelled Vehicles
    - Advanced Software, Sensors, Electronics and Telematics
    - Advanced Structures and Materials
    - Design and Manufacturing Processes

For this version, the major priorities associated with the trends and drivers have been identified, giving more focus to the technology development needed. However, it is not desirable to overly constrain the research agenda. This is because of 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. Rather, the roadmap should be 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.

In this summary, the investment required in road vehicle technology and research has been considered in terms of the contribution that the investment is expected to make towards the priority goals derived from the primary environmental, societal and economic themes during the roadmapping process. These goals are summarised as follows.

Environment	Global Warming, CO_2 reduction Conservation of resources Health, pollutant reduction Waste, re-use and recycling
Safety	Accident prevention Accident effect mitigation
Choice	Vehicle design Vehicle manufacturing
Mobility	Access and use of the system Infrastructure development
Security	Vehicle and occupant security Prevention of vehicle use in acts of terrorism
Economics	Manufacturing cost reduction Flexible manufacture Cost of ownership

Environment

Global warming

Reduce CO_2 and other greenhouse gas emissions associated with road transport. To achieve the UK commitment to the Kyoto protocol, a 12.5% reduction in CO_2 emissions (compared to the 1990 level) is required in the time frame 2008 to 2012. A stretch target of 20% by 2010 has been set by the UK Government, which has declared it will take the lead in Europe. As 22% of CO_2 derives from road transport, major development activity is required for vehicle propulsion systems, both conventional IC engines and for hybrid and fuel cell concepts. The European Commission and ACEA have agreed voluntary targets for passenger cars of 140g/km CO_2 new car fleet average in the EU by 2008. Subsequent targets are the subject of current negotiation and the European Commission has expressed a desire to see 120g/km by 2012. In the UK, there are low carbon vehicle targets for 10% of new cars and 20% of new buses by 2012. Whilst concentration has been on-road transport, off-road vehicles (construction, agriculture etc) are now becoming a significant part of total emissions and this sector will see an increase in development needs. For the future, the threatened environmental impact can be avoided by significant reductions in vehicle-miles, (which people may not accept) or by significantly improved g/km of CO_2 (which fossil fuel technologies may be unable to deliver).

Conservation of resource

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
The consumption of oil continues to increase. Expansion of national economies has a significant impact on demand, whilst international events have led to some supplies becoming unreliable. New sources of non-oil derived energy are required, which impacts the development of natural gas derived and bio-fuels as well as hydrogen. Improvements to conventional propulsion unit thermodynamic efficiencies will need continuing attention with the development of advanced, fuel efficient, high specific output, downsized engines a key. Advances in lubricants and

tribological coatings are needed to reduce friction. Vehicle weight is also a factor in improving overall energy efficiencies. Lightweight materials and structures, whilst retaining or improving safety, are needed to enable gains to be realised.

Health

Reduce emissions of substances which can impact health.
This is particularly important in urban areas with a high population and vehicle density. These include particulates, NO_x, benzene, carbon monoxide, hydrocarbons, sulphur dioxide and ozone. Road vehicles contributed 46% of the total NO_x pollution in 2000 (the largest contributor) and 18% of PM10 (second largest contributor). However, it is thought that smaller particulates are a greater hazard, for which vehicles make a more significant contribution. Particulates and NO_x emissions are greater from diesel engines than from gasoline, although capitalising on their CO_2 benefits requires the development of both combustion technologies and exhaust treatment. European directives, Euro 5 and Euro 6 (in the 2010 to 2012 timeframe) will mandate pollutant levels for gasoline and diesel engines, both for passenger car and commercial vehicles. As with CO_2 emissions, general IC engine and vehicle fuel efficiency improvements will help alleviate the situation, as will the introduction of hybrid, fuel cell and alternatively fuelled propulsion technologies. For manufacturing, development is needed for improved energy efficiency and also the reduction of emissions from industrial processes.

Waste

Re-use, recover and recycle a significant proportion of vehicle materials and structures.
This in accordance with the European End-of-Life Vehicle Directive already in force. It also prohibits the use of certain materials for use in vehicles. Coupled with the targets to improve re-use and recovery to > 95% vehicle weight, and re-use and recycling to > 85% by 2015, it requires significant development of materials and structures. Vehicle design will need to take account of the requirements for disassembly, as well as the environmental management from cradle to grave, including reprocessing techniques. Legislation on electronic equipment (such as WEEE) and substance waste disposal will also act as a constraint on the use of materials (including, for example, lubricants), leading to the development of more environmentally friendly products and systems.

Safety

Accident prevention

Reduce the number killed and seriously injured by road traffic accidents.
The UK has the second best record for road safety in Europe, after Sweden. However, there are still around 3,500 deaths and 40,000 injuries a year. With vehicle numbers still expected to rise above the current level of 27 million, preventing road accidents and mitigating their effect is mandated by the Government. Compared to the average for the period 1994-1998, a 40% reduction is required in deaths and serious injuries by 2010. For accident prevention, there are significant opportunities to develop and implement vehicle control strategies based on advanced electronics, sensors and telematics using both on-board and infrastructural based systems. This includes pedestrian and vehicle sensing, hazard analysis, adaptive cruise controls and active safety system deployment. Behaviour monitoring and performance alerting through advanced sensors and evaluation algorithms will help reduce potentially dangerous driver error events. Technologies will need to be capable of manageable degradation so as to fail safe, with global standards adopted both for operation and design.

Accident effect reduction

Reduce the death and injury rate for occupants of vehicles involved in accidents.
Further advances in vehicle and structural design will impact the mitigation of the effects of accidents, both for vehicle occupants and those external to them. New materials and structures developed for lightweight cost-effective application will need to be compatible with the need for improved safety standards. Improvements to the physical infrastructure, e.g. increased provision and use of motorways (with no pedestrians, small differences in vehicle speeds, no intersections and no on-coming traffic) can also significantly contribute to reducing accidents.

Choice

Vehicle design

Provide greater choice for vehicle purchase and usage.
Individual choice is leading to the need for a wide variety of tailor made vehicles, with pressure on the manufacturing to deliver made to order solutions in a short time frame with minimal inventory.

Vehicle manufacturing

Produce more vehicle variants.
Increasing modularisation technology is needed, as well as the possibility of configuration at the dealer. Vehicles which can be reconfigured, either for fashion or functionality, will need appropriate new design and manufacturing systems.

Mobility

Access and use of the system

Improve journey time reliability.
"Transport 2010. The 10 year plan" requires a modern, safe, high quality network better meeting peoples needs. Mobility and avoiding congestion is a key need, requiring improvements to be made through the development and use of advanced Intelligent Transport Systems (ITS) and vehicle flow control. New models for system usage, such as road use charging, avoidance of bottlenecks and limiting access to reduce pollution, likewise will be enabled by the application of ITS and associated control and information systems.

Infrastructure development

Provide an infrastructure capable of interfacing with emerging vehicle technologies.
Infrastructure and vehicle developments need to advance and be deployed at a similar rate to be effective, although without focussed road capacity investment, ITS of itself will not solve the congestion problem. Performance measures and targets for the infrastructure itself have not been included either in this or Version 1.0 of the roadmap and bringing them together in a future version needs consideration.

Security

Vehicle and occupant security

Reduce vehicle related crime.
Materials and systems aimed at prevention of access and theft continue to be required. 'Smart' technology must be developed to avoid both key theft and targeting of individuals being adopted as a means of taking vehicles without consent.

Terrorism	*Prevent vehicle use in acts of terrorism.* A growing global concern is the use of vehicles in terrorist attacks, brought into focus by events across the world, e.g. for use in suicide bombings, and how this can be prevented.

Economics

Manufacturing cost reduction	*Improve profitability for manufacturers.* The development of advanced manufacturing methods is required, particularly to take advantage of new materials and structures. Elimination of processes e.g. paint shops, will bring both environmental and economic benefits. *Reduce development time and increase value.* Design systems are required which will significantly reduce development time and raise value. The introduction of more sophisticated virtual engineering tools for all aspects of vehicle design is required, with the ultimate target of "zero prototypes prior to Job 1".
Flexible manufacture	*Transfer technologies from/to other industries.* Opportunities exist for economic advantages associated with the use of technologies from other sectors and use by other sectors. Use of Knowledge Transfer Networks (KTNs) will help facilitate take-up and implementation of such technologies. Advanced concepts will allow the introduction of multi-purpose manufacturing facilities, capable of servicing the needs of more than one industrial sector.
Cost of ownership	*Reduce or contain costs of ownership.* Technologies aimed at increasing effective life, whilst enabling the upgrading of emissions and safety systems, will be needed. Preventative maintenance via on-board diagnostics can reduce operational costs, whilst more durable components, capable of operation in a zero maintenance environment are required.

2 INTRODUCTION

Foresight Vehicle, now administered by the Society of Motor Manufacturers and Traders (SMMT), is the UK's prime knowledge transfer network for the automotive industry. It 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. Version 1.0 of the Foresight Vehicle technology roadmap was developed in 2002 to identify the 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 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.

It is 2 years since the publication of Version 1.0 of the roadmap, which was intended to be kept 'alive'on an ongoing basis. This version, (Version 2.0), results from a review of the original and incorporates additional views, updating information where appropriate. Additionally, this version seeks to set priority goals for development, obtained from a top-down approach, leading to the major themes requiring attention. It is intended to be a self-contained document, but reference should be made to Version 1.0 to obtain a more complete picture. The roadmap is not intended to be a detailed review of existing and likely technologies, but rather an indicator of the needs for technology development to which an appropriate response can be made by industry and academia.

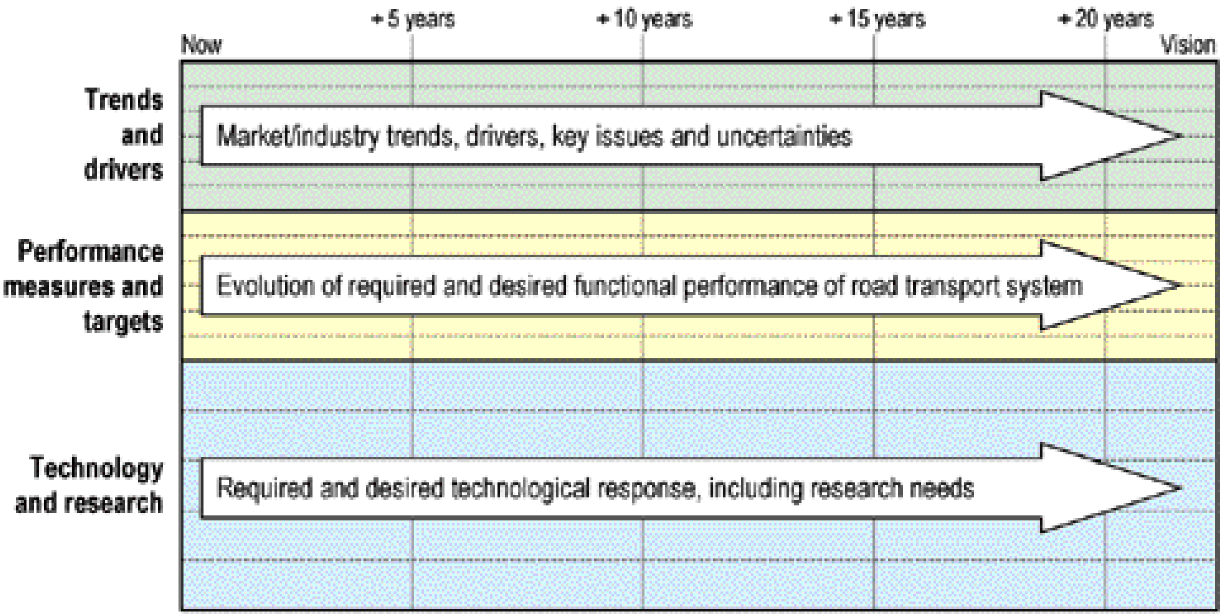


Fig. 1 – Foresight Vehicle technology roadmap architecture

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. 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.

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.

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 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.

- Advanced *Software, Sensors, Electronics and Telematics* technology development, leading to improved vehicle performance, safety, control, adaptability, intelligence, mobility and security.

- *Advanced 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 grave'.

This version of the roadmap builds on Version 1.0, updating information and including current views on themes and priorities. The roadmapping process followed the principles described in Version 1.0, but acting to review the original rather than re-create it. The Society of Motor Manufacturers and Traders, acting as representatives of vehicle and component manufacturers, provided definitions of the market and business needs. Thematic group and stakeholder workshops have provided the specialist input to address these, supplemented by questionnaires. In all, more than 75% of the input came from people who had not been involved in the generation of Version 1.0.

3 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, as shown in Figure 2.

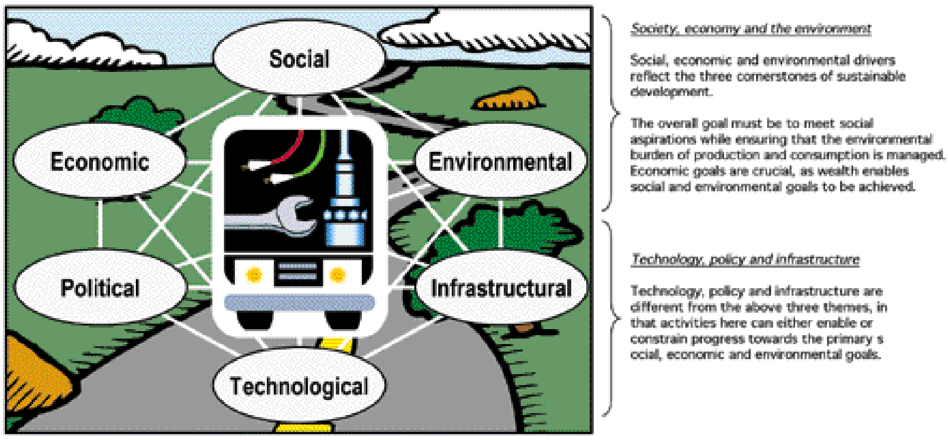


Fig. 2 – Trends and drivers that influence road transport system

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 trends and drivers identified in Version 1.0 of the roadmap have been reviewed for Version 2.0 and have not changed significantly since it was published. A tabular format, Table 1, has been adopted here to show the summarised trends and drivers brought forward from Version 1.0 for completeness, including new items identified in the current review.

	Trends and drivers	Queries	Vision
Society	Growing demand for mobility Congestion and pressure on infrastructure Changing working and living patterns Ageing population Longer working life Increased mobile and home working More single person households Continued growth of cities and towns Consumer demand for greater variety, quality and performance of products and services Increasing concern for health, safety and security Increasing concerns about terrorism Demographic shift in vehicle type and ownership patterns	Social attitudes towards transport and the environment Continued growth of South East Social attitudes to vehicle monitoring	Cheap, safe, convenient, comfortable, clean, secure and equitable road transport
Economy	Growth in economy and consumption More trade and transport of goods Congestion and pressure on infrastructure £65bn of public and £56bn of private investment needed by 2010 Energy costs rise 2-3% per year Stability of oil supplies UK productivity lags competitors Opportunities for high value products and services and financial markets stimulate increasingly networked global economy Increasing gap between wealthy and poor	Fiscal and monetary policy Impact of evolving European Union Public vs. private finance Will current trend continue New entrant vehicle makers Impact of environment and social opinion on economy and policy	Successful and sustainable road transport industry
Environment	Increasing global population and associated economic development Increasing energy consumption and greenhouse gases Increasing burden of transport on environment Reducing emissions as engines become more efficient and cleaner Pressure to utilise material and energy more efficiently Opportunities for alternative energy sources and power systems Opportunities for improved materials and processing technology	Impact of global warming, is it due to CO_2 is the response adequate? How long will oil and gas supplies last Social attitudes to environment and impact on business and government policy	Environmentally sustainable road transport system
Technology	Opportunities for innovations in fuel, engine and power systems Increasing performance of information and communications technology (speed, cost, size, functionality) Opportunities for innovations in sensors, electronics, communications and control systems (vehicle and infrastructure) Opportunities for innovations in materials (weight, strength, processing, intelligence Opportunities for high value design, manufacturing and engineering services	How far can the internal combustion engine go Which energy/power solutions will succeed in the long term Moore's law continues Need for international standards Disruptive technologies	Effective and appropriate technological innovation for road transport
Policy	Government initiatives, including ten year transport plan UK, European, National and Industrial policy, standards and legislation CO_2, energy, emissions, recycling and carbon legislation Role of UK in evolving and enlarging European Union Social expectations for public services, transport system, environment, housing, etc	Streamlined planning process Harmonisation of policy, standards and legislation Impact of geopolitical trends and disruptions	Effective, integrated, consistent and sustainable road transport policy
Infrastructure	Increasing demand on transport system (passenger and freight) Large investment required to maintain and develop road and other transport infrastructure Development of physical road and transport infrastructure Development of information and communications infrastructure Development of alternative energy distribution infrastructure	Development and harmonisation of standards Role of public and private sectors Privatisation of high maintenance cost roads Impact of social, political and technology developments	Effective, integrated and sustainable road transport system

Table 1 – 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). Projected growth in GDP will have an attendant growth in traffic to sustain it. The 10 year plan predicted GDP growth rates of around 3% per year to 2010. Associated road traffic growth was predicted to increase by 20% in the 10 year period. As well as the developments in vehicles and their systems, there is a need for investment in road, rail and air infrastructure and technology 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. Less tolerant attitudes towards "bad" driving will influence the take-up of counter measures.
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 retirement age by 2030. However, working life extension is anticipated because of pension issues which will impact on economic activity. 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. Increasing concerns about terrorism might influence attitudes towards vehicle and occupant monitoring. 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 has a difficult task to achieve in providing sufficient infrastructure to achieve its GDP objectives and in optimising the use of that infrastructure. Taxation of road usage, offset by other tax reductions, is likely to play an increasing part in efforts 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, with an engine manufacturing capacity of around 4 million units. 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 around 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^{0}C by 2050, which would have significant effect on quality of life and economic activity.

Pollution

Clean air is an essential ingredient of good quality of life, with implications for people's health, particularly respiratory diseases. 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. Longevity of vehicles inhibits the quick take-up of newer, more environmentally friendly technologies.

Energy	Fossil fuels supply 98% of transport energy demand, with world oil demand growing at between 1.1 and 2.7% annually. Estimates vary, but it is predicted that conventional oil supply may peak sometime in the next 15 years or so, after which demand will outstrip supply. In addition, there are uncertainties about the unstable production situation in some producing countries due to international events. 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 and waste disposal will have a positive impact on vehicle design, manufacturing, financing, maintenance and dismantling.

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 a 20 year time horizon the natural reserves of conventional oil may not be able to keep up with the estimated 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. Nevertheless, small scale use of hydrogen as a vehicle fuel can be expected to progressively increase.
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 content 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 international standards is a key enabler.
Advanced 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. Newer flexible, manufacturing technologies have the opportunity to service different industry sectors and provide better returns on investment. 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 needs improvements to infrastructure and vehicles, required 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 for use in the global market is important, particularly when combined with new vehicle developments. The development of vehicle and infrastructure systems needs to be co-ordinated.
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.

4 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 (Figure 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 5.

5. *Political* performance measures and targets relate directly to Governmental policy, regulation, legislation and action in the areas of energy and CO_2, transport, 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, although infrastructure developments need to advance in parallel with vehicle technologies for effective deployment.

The technology roadmap builds on previous Foresight Vehicle activity. The Foresight Vehicle Strategic Plan defined 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 Version 1.0. These Beacons are related to road transport system performance measures and targets as defined in the Strategic Plan.

Figure 5 in Version 1.0 shows the summarised performance measures and targets. These have been reviewed in this update and a tabular format used for presentation, table 2. Additions have been made, but no information has been eliminated from that contained in Version 1.0. Blue text has been used to identify those topics considered most important by the Engineering Committee of the Society of Motor Manufacturers and Traders, acting as representatives of the vehicle manufacturers and component suppliers. Specific issues highlighted in review are included in the text.

Table 2.1 ***Performance Measures and Targets***

		0 – 5 years	5 – 10 years	10 – 20 years	Issues
Society	User satisfaction	70% user satisfaction with all transport modes.	80% user satisfaction with all transport modes.	85% user satisfaction with all transport modes.	How to measure? What are reasons for dissatisfaction?
	Vehicle Security		Resistance to attack. Door locks, storage area, alarm systems 5 minutes. Immobilisers 20 minutes. Window glass 2 minutes.		Avoid moving crime focus from the vehicle to the individual.
	Noise	Road traffic reduction of 3 dBA from 1998 levels.	Road traffic reduction of 4 dBA from 1998 levels.	Road traffic reduction of 6 dBA from 1998 levels. Homologated noise reduction of 4dBA and 8dBA respectively for light and heavy vehicles.	Maintain noise characteristics over vehicle life.
	Customer Expectation		Top of range technologies in entry level vehicles e.g. collision avoidance.		Rapid development of low cost systems. Perceived value of environment, safety technologies. Freedom of customer choice.
Economy	Development time/cost	24 months for completely new. 18 months for significant carry-over. Significant reduction in number of late engineering changes.	18 months for completely new. 12 months for significant carry-over. 35% reduction in new vehicle development cost cf. 2000.	50% reduction in new vehicle development cost cf. 2000.	
			Manufacturing: 30% increase in ROI Order to delivery of bespoke vehicle 3 days, significant quality improvement. Need for low investment vehicle programmes 10 – 50 kpa.		
	Vehicle Cost	Goods vehicle: 7 year/2Mkm life. 7 hrs/y maintenance.			Safety and environmental impact higher priority than vehicle cost.
	Cost of travel	15 year/240 k km vehicle lifetime with emissions compliance.			Long vehicle life mitigates against rapid take-up of new technology. Modular incremental development capability?

Topics considered most important by the SMMT Engineering Committee

Table 2.2 ***Performance Measures and Targets***

		0 – 5 years	5 – 10 years	10 – 20 years	Issues
Environment	CO_2	2008: 140 g/km new car fleet average in EU.	120 g/km?	90 g/km?	With freedom of customer choice, performance, etc.
	Particulates	Euro 4 Continuing reduction.	Euro 5 light vehicle, 2.5 mg/km Euro 6 heavy duty 3.0 mg/kWh European transient cycle.	Particulates from all engine types reduced to 20% of 1998 gasoline engine values.	Euro 5 and Euro 6 are proposals, 2010 to 2012 timeframe.
	Other gaseous	Euro 4 Continuing reduction.	Euro 5 light vehicle, e.g. NO_x 0.08 g/km Euro 6 heavy duty e.g. NO_x 0.5 g/kWh European transient cycle.	CO, HC, NO_x reduced to 50% of EURO 4 standard for all engine types.	
	Manufacturing	Achievement of manufacturing legislative targets.	All companies ISO 14001.		Without incurring significant cost increases.
Policy	Climate change	2008: 140 g/km new car fleet average in EU for CO_2 emissions.	Proposed 120 g/km new car fleet average in EU for CO_2 emissions.		Kyoto protocol. Targets needed for commercial vehicles.
	Pollutants	EU targets: Pb 0.25 mg/m3 particulates (PM10) 40 mg/m3 mean, SO2 47ppb mean, O3 50ppb.		AE Auto Oil Directive reducing NO_x, CO, NMVOC and benzene to < 20% 1990 levels, PM10 < 42%	
	Safety		UK targets to reduce road accidents: 40% reduction in deaths and serious injuries.		Development of infrastructure, not just vehicles. Product liability might restrain development.
	Reuse/recycling	2006: ELV targets 85% re-use and recovery, 15% landfill.	2015: ELV targets 95% re-use and recovery, 5% landfill.		Constraint on any material development.
System	Accessibility	15% improvement on 1998.		25% improvement on 1998.	Requires system and vehicle technology development to be in-step. Road user charging.
	Congestion	Reduce growth rate in UK traffic to 50% of projected level of 19%.		Zero increase in traffic congestion.	Requires system and vehicle technology development to be in-step. Congestion charging.
	Availability	Improves by 25% compared to 1998.	Improves by 40%.	Improves by 50%.	
	Reliability	Arrival time: 10% reduction in avg. time variance vs. expected.	Arrival time: 20% reduction in avg. time variance vs. expected.	Arrival time: 50% reduction in avg. time variance vs. expected.	

Topics considered most important by the SMMT Engineering Committee

Table 2.3 ***Performance Measures and Targets***

		0 – 5 years	5 – 10 years	10 – 20 years	Issues
Technology	Engine and Powertrain	Improve thermal and mechanical efficiency, performance and drivability, reliability, durability and speed to market, and to reduce emissions, weight and size.			Improved efficiency and emissions reduction.
	Hybrid, Electric and Alternatively Fuelled Vehicles	Develop viable alternative energy and power systems, including evolution of conventional engine systems and new alternative solutions, including consideration of infrastructure and fuel.			Alternative fuel availability. Capacity to generate bio fuels.
	Advanced Sensors, Software and Telematics	Improve vehicle performance in terms of control, safety, adaptability, functionality, reliability, intelligence, driver support and integration.			Infrastructure and vehicle system developments linked. Reduction of accidents is key.
	Advanced Structures and Materials	Improve safety, product configurability, flexibility and value, and to reduce costs and environmental burden of vehicle, in terms of vehicle weight, durability, re-use and recycling.			Priority to achieve simultaneous emissions, economy and safety. Re-use/recycling a constraint on development.
	Design and Manufacturing Processes	Improve the performance of the automotive industry sector, considering the full vehicle lifecycle from design to end-of-life, including manufacturing and business processes, and systems integration.			Flexible manufacturing capable of servicing different industrial sectors. Simulation of reliability and durability.

Topics considered most important by the SMMT Engineering Committee

Note that the technology theme is different to the others, in that it related directly to the five technology areas considered in detail in Section 5.

Performance Measures and Targets Themes

Specific comments on the performance measures and target themes are given below.

Society

Vehicle security. A challenge is to improve security without moving the focus of crime from the vehicle to the individual.

User satisfaction. Measurement systems are required which will allow trending an forecasting.

Customer expectation. Best available technologies need to migrate from "top of the range" to entry level vehicles, quickly and at low cost. This impacts rapid cost reduction of sophisticated systems such as collision avoidance and passive protection.

Economic

Manufacturing. Improvement of return on investment combined with a reduction of bespoke vehicle lead time from order to delivery of 3 days and with quality improvement is a priority. This has to be obtained against a background of containing end-customer price increases. Vehicle programmes for up to 50,000 vehicles a year are needed which have low investment needs, with the possibility of fully flexible manufacturing systems.

Vehicle Replacement. Vehicle longevity precludes the economic rapid take-up of new technologies which will have significant impact on emissions and safety. Retro-fit capability of technology is a challenge as an intermediate step before introducing more radical solutions.

Operating Costs. Within the constraints set by customer desires for cheap transport, this is not seen as having such a high priority as emissions and safety. However, although vehicles exist today with emissions performance at 2010 target levels, these are generally unattractive due to cost or performance or both.

Environment

Policy. Achievement of stretch targets above those set by policy for the reduction of emissions of greenhouse gasses, noxious substances and particulates is seen as a major challenge for the industry.

Legislation. European Directives for emissions coupled with voluntary targets for CO_2 reduction are setting the short term agenda.

Manufacturing. Compliance with legislation (e.g. emissions and waste regulations) without adding unduly to design and manufacturing costs is a priority.

System

Infrastructure Development. Although infrastructure performance measures and targets are not part of this roadmap, it is recognised that both vehicle and infrastructure technology development and implementation need to be carried out in parallel.

Technology

Priorities. These are seen as being technologies for emissions reduction, accident reduction (and the effects of accidents) and mobility, whilst providing freedom of choice for the consumers and customers of the vehicle sector.

5 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 it 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 review of Version 1.0 of the Technology Roadmap as undertaken by the thematic groups.

1. Engine and Powertrain (EPT)

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

2. Hybrid, Electric and Alternatively Fuelled Vehicles (HEAFV)

   - Fuel cells
   - Hybrid engines
   - Advanced internal combustion engines
   - Electrics and electronics for energy and drive systems
   - Conventional and alternative fuels
   - System integration and vehicle infrastructure
   - Design and manufacture

3. Advanced Software, Sensors, Electronics and Telematics (ASSET)

   - Shift to software
   - Access and use of vehicles
   - Architecture and reliability
   - Human vehicle interaction
   - Information management

4. Advanced Structures and Materials (FASMAT)

   - Safety
   - Product configurability/flexibility
   - Economics
   - Environment
   - Manufacturing systems

5. Design and manufacturing processes (DMaP)

- Lifecycle
- Manufacturing
- Integration

Technology introduction has been considered against 3 timescales:

0 to 5 years.
Existing technologies where significant barriers exist to commercialisation, such as standards or system integration, cost etc. Efforts should focus on the development of technology demonstrators.

5 to 10 years.
Significant improvements to current and emerging technologies. Efforts should focus on developing embryonic technologies to a point where they can feed into demonstrators.

10 to 20 years.
Current technologies are not suitable and new solutions are required. Efforts should focus on a new concept development to achieve long term goals, encouraging radical, innovative technologies for evaluation.

5.1 Engine and Powertrain

Scope

The Engine and Powertrain (EPT) 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 and climate control.

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

Social

Users are demanding greater vehicle adaptability (configurability, upgradeability and modularity) and vehicle performance (to meet different consumer needs and driving styles), and reduced vehicle noise. There is a need for less polluting vehicles with today's level of performance or better, without undue cost inflation. Urban pollution will also act as a driver for the introduction of quieter and less polluting vehicles of all types, car and commercial. Fashion is also dictating the purchase of some private vehicle types, e.g. the current popularity of SUV's. Safety of vehicles is a concern, with control technologies needed for engines and powertrains aimed at accident avoidance and mitigating their effects.

Economic

Competitive pressures exist 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. For users, capital and operational costs are important for all vehicle types, private and commercial, leading to improvement needs in engine and transmission efficiencies and with reduced maintenance requirements.

Environmental

Global warming is now widely accepted as a fact and the safe assumption is that the results will be unpleasant and undesirable. Substantial reduction of the greenhouse gas CO_2 is accepted to be a necessity to mitigate the effect. This is a major driver to the introduction of technologies to reduce CO_2 emissions, through improvement in efficiency, control strategies and the introduction of alternative combustion regimes (or combination modes). Pollutants from oil based combustion processes (such as particulates, carbon monoxide, nitrogen oxides, sulphur dioxide, lead, benzene and ozone) have detrimental health effects, particularly when concentrated in urban environments. Further development of technologies to reduce the origin of these pollutants in the combustion process, as well as post-combustion treatments, is required. Re-use and recycle targets for vehicles at end-of-life sets constraints on the materials used in their construction, and new solutions are required to minimise environmental impact.

Technological — Developments of innovative solutions are required in the areas of engine and powertrain, e.g. with 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 and manufacture).

Political — UK Government, European and International policies, regulations and legislation concerning transport, energy, CO_2 and other emissions, health and safety and waste management all affect the development needs. The UK has declared it will take a lead in Europe for the reduction of CO_2 with attendant wealth creation in the industrial and technology bases.

Infrastructural — The need to develop fuel and energy infrastructure in parallel to developments in new engine and powertrain solutions.

Note that there is some overlap with Section 5.2, (HEAFV).

EPT Technology Directions

The expert opinion obtained during the construction of Version 1.0 of the roadmap is still relevant and valid, and is given at the end of this section for completeness. Review of this information in a workshop highlighted the following as the important themes for classification of technology directions:

- Thermal and mechanical efficiency
- Performance and driveability
- Emissions
- Reliability and durability
- Speed to market and cost
- Weight and size
- Safety

Whilst not superseding the data obtained in Version 1.0, the information below adds to it and represents current thinking on those aspects of technology introduction which are considered important.

Thermal and Mechanical Efficiency

Continuing advances in thermal and mechanical efficiency of engines is essential to improving fuel economy, with its beneficial effect on CO_2 and pollutant emissions. Improvements to engine efficiency of about 10% should be possible within 20 years through developing combustion technologies. Diesel engines have a greater efficiency potential then gasoline, and increasing use is predicted in Europe to achieve low fleet average CO_2 for light vehicles, although the future is likely to require multi-fuel capability. Gasoline direct injection is already available, although improvements are still needed to achieve good emissions performance. Technologies enabling downsizing of engines giving performance levels equivalent to today's larger engine sizes are particularly important. Advances in variable transmissions and control will allow better matching to engine performance characteristics, allowing more energy efficient operation.

0 – 5 years	5 – 10 years	10 – 20 years
Advanced low viscosity lubricants Low friction surfaces Gasoline direct injection Downsized boosted engines Variable compressors Camless on some engines Bio-fuel capability	Flexible engines with respect to valve actuation, boosting, fuel Mixed combustion mode operation, such as 2/4 stroke Waste heat recovery Advanced cooling systems Variable valve timing for air control More camless engines High cylinder pressure engines Advanced tribological coatings Transmission enables efficient engine operation Optimised engines for powering hybrids, acting as a generator	More efficient transmissions, minimum loss Zero warm-up time IC vehicles with electric drivetrain

Performance and Driveability

Vehicle and engine manufacturers must meet consumer demand for improved vehicle performance and drivability whilst achieving the challenge of reducing fuel consumption and emissions. Downsizing engines to obtain thermal and mechanical efficiency will only become attractive when driving performance is maintained relative to the larger power units they replace, and without additional cost. Transmission improvements, e.g. automated manual gearboxes, continuously variable transmissions etc, will also enhance performance characteristics, particularly when coupled to advanced control strategies.

0 – 5 years	5 – 10 years	10 – 20 years
Advanced adaptive control methodologies Efficient auto transmission, continuously variable, infinitely variable Automated manual transmission with simple strategies	Smaller variable engines with high specific power Automated manuals with complex strategies Technologies for improved thermal loading Advanced system modelling tools Information enabled powertrain control for efficiency and driveability Fuel tolerant combustion technologies Improved gasoline engine mid-range torque to match diesel and hybrid	Engines capable of running on almost any kind of fuel Active control adapting to driving and road conditions, minimising pollution and response to safety systems, without affecting driver intentions

Emissions

This is a major issue because of legislation already in place and planned, and worldwide sensitivity to aspects such as global warming and the effect of pollutant emissions on health (particularly in urban areas). The UK is targeting CO_2 reductions to achieve its commitment to the Kyoto protocol. The ACEA fleet average CO_2 voluntary targets of 140g/km fleet average for 2008 coupled with the UK requirement of 10% new car sales in 2012 emitting < 100g/km is driving development into this sector. Although no targets are set yet for commercial and off-road vehicles, the industry is likewise expected to achieve significant CO_2 reductions from these vehicles as part of the UK commitment. In Europe, other pollutant emission reductions are the subject of Euro 4 legislation from 2005, with Euro 5 and Euro 6 timetabled for the 2010 to 2012 time frame. Technologies to improve engine efficiency, reduce pollutant generation during the combustion process, and post-combustion treatments to reduce and remove pollutant species are highlighted. Engine efficiency improvements imply more, smaller particulates, with attendant post-combustion clean-up required.

The development of alternative combustion modes and control strategies (for example mixed mode operation) are under development and expected to reach maturity. The technologies required for pollutant reduction are generally at the expense of CO_2 reduction, and continuing vigilance is required for prioritising the needs.

0 – 5 years	5 – 10 years	10 – 20 years
Integrated starter alternator mild hybrid systems on conventional engines Engine recyclability Feedback control of combined engine and powertrain optimising emissions consistent with driver intention Diesel NO_x catalytic traps Variable valve timing for diesel Particulate traps and treatment, matching to generation rate More GDI engines	Advanced combustion modelling tools After treatment modelling tools Low cost high durability particulate traps Full diesel HCCI with high BMEP Combustion sensors and feedback control Ultra high pressure diesel injection Flexible diesel fuel injection systems Off-road vehicle engines match automotive emission standards Development of zero ash lubricants capable of extended operational life and without additives considered harmful to the environment on disposal	Upgradeable vehicles to achieve emission specifications Global emission standards Hybrids require engine runs in most efficient mode all the time

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. This has been possible from a combination of design for reliability and improvement in component quality. The ultimate goal is to achieve 'self-diagnosing' and 'sealed for life'engines, benefiting longer life, reduced pollution (from lubricant disposal), maintenance, cost and material consumption.

0 – 5 years	5 – 10 years	10 – 20 years
Low ash fuels and lubrication for after treatment compatibility On-board diagnostics	Oil condition monitoring Control of combustion soot in lubricant Flexible service intervals Smart on-board diagnostics	Sealed for life engines

Speed to Market and Cost

The engine and powertrain represents a significant proportion of vehicle cost. Technologies to reduce design and development time, and improve the manufacturing process, have a significant role to play in reducing time to market and costs as (well as increasing value), therefore improving competitiveness. Advanced computation techniques are required which will aid virtual engineering, in areas such as combustion emissions and calibration.

0 – 5 years	5 – 10 years	10 – 20 years
Knowledge capture and management systems	Automated drivability calibration Modular engines and transmissions Advanced transmissions allowing wider application of engine types Virtual emissions engineering and calibration Increasing use of plastics/composites in transmissions	

Weight and Size

Weight savings to achieve fuel economy is a continuing requirement. Size reduction allows more flexibility in aerodynamic and safety designs. Application of new lightweight materials is a challenge, with value in use being a key parameter. Development of new materials will be constrained by the need to achieve legislated re-use and recycling targets, as well as performance under crash conditions.

0 – 5 years	5 – 10 years	10 – 20 years
Engine and powertrain materials audit identifying opportunities for new material use	Development of new lightweight and functional materials Low cost high stiffness materials Low cost Ti powder for some components Reduced size cooling systems Increasing use of plastics/composites in transmissions	Use of breakthrough materials, such as nano-materials

Safety

Engine and powertrain design, operation and construction affect the behaviour of vehicles involved in accidents. Design must allow for integration into the vehicle structure to give as benign an effect as possible under accident conditions. Advances in sensors and controls and infrastructure communication technologies will allow the engine and powertrain to act in an appropriate way to prevent accidents and mitigate their effects.

0 – 5 years	5 – 10 years	10 – 20 years
Pit lane technology to limit vehicle speeds Encourage end-of-life for old vehicles Development of power control systems	Engine and powertrain networked to other active safety devices on the vehicle and in the infrastructure	

Technology Targets

Technology target proposals appropriate to the EPT group were also considered in the workshop, and these are given in the following table. They should not been seen as definitive, but rather a view on suitable targets against which progress can be audited.

	0 – 5 years	5 – 10 years	10 – 20 years
Thermal and mechanical efficiency	Diesel fuel economy 5% better than EU4	High specific power output, 125 - 150 bhp/l Engine management and vehicle management capable of communication 50% Thermal efficiency diesel engine Total engine fleet CO_2 50% of current	50% waste heat recovery Diesel fuel economy 15% better than EU4 Gasoline fuel economy 20% better than EU4
Performance and driveability	Bhp/£ improves to 15% of 2002 level	Bhp/£ improves to 30% of 2002 level Modelling of combustion performance and systems in real time and full correlation with engine /transmission gives full virtual engineering capability Boosted downsized engine drivability as good as 2005 NAengines Diesel and petrol to have same perceived performance	Engines can run on any fuel Active performance control based on environmental road conditions Alternative engine and powertrains with performance perceived to match diesel and petrol

Emissions (pollution and noise)	NO_x after-treatment efficiency reaches 80%. Particulate filter life 240k km	Diesel NO_x 50% less than EU4 After-treatment (gaseous and particle) without the use of precious metals and with a total cost 75% lower than 2005 systems Diesel HCCI gives near zero particulates and NO_x with efficiency as 2005 diesel Zero ash lubricants capable of extended operational life and without additives considered harmful to the environment on disposal Zero cost combustion pressure sensing	All engine types capable of meeting emission standards Global emission standards harmonised Engine toxic emissions lower than ambient background levels 100% engine recyclability Particulates "banned" < 1% of baseline figure
Reliability and durability		Full CAE capability for all reliability/durability warranty issues	Truck engine life 200% year 2005 life 100% reliable 100% durable at 100k km Affordable zero maintenance powertrain
Speed to market and cost		Increase service intervals to 50k km, with sealed for life being the ultimate target Concept to job 1, 50% of current time: total system cost reduction of 25% Reduced cost high performance lubricant base stock Robust virtual emissions engineering recalibration	Full virtual engineering capability (prototype = job 1) Customer engine powertrain specification to delivery time 10% of 2005 level Concept to production time 25% of 2005 level All vehicles have powertrain sophistication of premium vehicles by use of low cost transmissions (plastic gears etc)
Weight and size		50% increase in power and torque/kg (from 2005 level)	100% increase in power and torque/kg (from 2005 level) Engines 50% of year 2005 size and weight
Safety		Engine management and internal and external safety systems capable of communication Reduced cooling system size	Engine and powertrain benign effect with respect to vehicle safety

Research Priorities

Improve combustion processes, to reduce CO_2, emissions and noise, with capabilities to use different fuel types. Example technologies include fuel injection, valve actuation, variable compression ratios, adaptive calibration, combustion condition sensing (in-cylinder), and improved knowledge of the combustion process leading to virtual engineering tools.

Develop alternative and combined combustion modes. A significant change in emissions performance of engines will be required to make further reductions. Example technologies include the introduction of homogeneous charge compression ignition, (HCCI also known as controlled auto-ignition CAI), and multi-mode operation to optimise performance with respect to emissions. For HCCI/CAI in particular, control technologies to extend the operating speed and load cycle are required, linking fuel mixing and combustion sensing.

Improve emissions controls in response to legislative targets, social demand and to reduce the environmental burden associated with vehicles. Challenges include achievement of effectiveness through downsizing, waste energy recovery, low cost efficient post-combustion after treatment and particulate traps.

Downsizing of the powertrain system is required for efficiency, whilst improving power density to reduce weight, material usage, cost and space requirements. Challenges include boost technologies, novel thermal management, use of new materials and lightweight structures, lubricant performance, and reduction of parasitic losses through the use of 'smart', independently powered auxiliary equipment.

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.

Overview

The technologies covered by the EPT Thematic Group will make a significant contribution to the following major drivers for the vehicle sector.

Environment

The UK is committed to international protocols targeting significant reduction in the emission of greenhouse gases, such as CO_2, to combat the perceived threat of global warming and its consequences. As the vehicle sector is a significant contributor to these emissions, development of engines and powertrains are required which will reduce their impact, by becoming more fuel-efficient. Targets are already in place for the UK passenger car fleet, and although no targets are set currently, commercial and off-highway vehicles are also required to make significant improvements as part of UK policy. The technologies covered by the EPT Thematic Group will have a significant impact on the achievement of these requirements, though improvement in efficiencies and the development of advanced combustion modes and controls.

Health

Legislation continues to drive the reduction in pollutant levels associated with health risks, with Euro 4 applicable from 2005, and reduced pollutant levels planned in Euro 5 and Euro 6 likely in the 2010 to 2012 timeframe. Engine and powertrain efficiency improvements will also impact this achievement of these levels, as will technologies to reduce or eliminate pollutants post-combustion.

Economics

Reduction in ownership cost, operational and capital, is required both by the commercial sector and private users. Improved engine and powertrain efficiency coupled with the drive for increased maintenance intervals and longevity will benefit from the technology developments in the EPT theme. Advances in manufacturing, including the use of computer modelling tools to give a virtual engineering capability, will aid development time and help contain capital costs.

Safety

Opportunities exist in linking advanced engine and powertrain controls to accident prevention and mitigation systems (as described in the ASSET technology theme), to benefit reduction in accidents and their effect.

EPT Technologies from Version 1.0

Engine and powertrain technology (EPT) — **Efficiency, performance and emissions**

	2002–2007	2007–2012	2012–2017	2017–2022	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 compression ignition)	CNG making a comeback?	

Engine and powertrain technology (EPT) — **Reliability, development and weight**

	2002–2007	2007–2012	2012–2017	2017–2022	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) Self calibration systems (maybe just partially…) Breakthrough fuel cell technology (biotech, nanotech, etc.) 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

5.2 Hybrid, Electric and Alternatively Fuelled Vehicles

Scope

The Hybrid, Electric and Alternatively Fuelled Vehicles (HEAFV) technology theme includes the following vehicle systems and functions:

- Application of new and alternative fuel types, such as hydrogen, LPG, CNG, LNG, bio-diesel and bio-ethanol/methanol.
- Conversion of energy in conventional and alternative fuels to useful mechanical power.
- Electrical motors for vehicle propulsion, storage systems, hybrids and fuel cells for converting fuels directly to electrical energy.

Note that there is commonality between some of these areas and those covered by the Engine and Powertrain Thematic Group, although the applications are different between the groups.

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

Social

Desire for less polluting vehicles with today's level of performance or better, without cost inflation. Although the public are becoming aware of the possibility of climate change through publicised extreme weather events (and in fictional films), it is not yet affecting vehicle purchase behaviour. Performance and cost effectiveness demonstrations are needed for this to happen. Increasing urban population density will also act to aid the introduction of quieter and less polluting vehicles.

Economic

Recent (2004) oil price instability caused by international events coupled with the supply/demand equation are likely to lead to oil price rises continuing as a long term trend unless significant new and accessible reserves are found. This will act as a driver for the introduction of propulsion technologies which use less (or no) oil-derived fuels. Recent improved efficiencies of conventional fuel and engine systems may represent barriers to entry in the short term for alternative solutions.

Environmental

Global warming is now widely accepted as a fact and the safe assumption is that the results will be unpleasant and undesirable. Substantial reduction of the greenhouse gas CO_2 is accepted to be a necessity to mitigate the effect. This is a major driver to the introduction of technologies to reduce CO_2 emissions, with a desired target of eliminating it completely.

Pollutants from the combustion process are known to cause detrimental health effects, particularly in urban environments. This leads to the development of methods for the reduction and treatment of gaseous pollutants and particulates.

Technological — There is a requirement to develop efficient new fuel and power systems, such as hydrogen and fuel cells, together with hybrid powertrains and fuel tolerant internal combustion systems. Many suitable technologies exist (at least at the laboratory stage), but are not yet mature enough for volume application, requiring substantial work to be done on cost effectiveness, efficiency, reliability and durability. Lack of maturity of the technologies is such that it is not yet possible to define a development path, so a broad research and development front is needed.

Political — UK Government, European and International policies, regulations and legislation concerning transport, energy, CO_2 and other emissions, health and safety and waste management all affect these vehicles. The UK has declared it will take the lead in Europe for the reduction of CO_2 with attendant wealth creation in the industrial and HEI bases.

Infrastructural — New engine solutions need to be developed in parallel to the establishment of associated fuel and infrastructure. New fuels and propulsion units can be trialled on captive, single base, fleets, e.g. buses and public service vehicles, and possibly also with construction vehicles.

HEAFV Technology Directions

The expert opinion obtained during the construction of Version 1.0 of the Technology Roadmap is still relevant and valid, and is given at the end of this section for completeness. Review of this information in a workshop highlighted the following as the important themes for classification of technology directions:

- Fuel cells
- Hybrid powertrains
- Advanced internal combustion engines
- Electrics and electronics
- Conventional and alternative fuels
- Systems integration and infrastructure
- Design and manufacture

Whilst not superseding the data obtained in Version 1.0, the information below adds to it and represents current thinking on those aspects of technology introduction which are considered important.

Fuel Cells

It is becoming increasingly accepted that only a radical change in energy usage can bring about a reversal of global warming by significant reduction in CO_2 emissions. The vision of a future hydrogen based energy economy is gaining ground with the mobile fuel cell central to the conversion of chemical to electrical energy. Significant barriers remain to be overcome, and the continued development of fuel cells to improve efficiency and power will continue, with demonstration and evaluation of concepts being key to reducing uncertainties. Listed below are the actions which are considered most important.

0 – 5 years	5 – 10 years	10 – 20 years
Introduction of demos of fuel cell technology, bike, car, bus, truck Development of a range of fuel cell engines that can be integrated into vehicles Hydrogen storage and cost (high Pt content)	Alternative power generation Demonstration of high well to wheel efficiency FC component improvement increases system efficiency	Fleet development Significant market penetration High efficiency electrical machines, controllers and batteries

Hybrid Powertrains

Hybrid powertrains, particularly when coupled with advanced IC engines, offer a route to improved fuel efficiency and therefore reduction of CO_2 emissions and pollutants. They have a crucial role to play in terms of enabling migration to the widespread use of alternative fuels. The development of low cost hybrids capable of matching and exceeding conventional engine performance are necessary if they are to become acceptable to the public and provide a route to the acceptance of alternatively fuelled vehicle types. Application of hybrid powertrains to vehicles such as buses is already in use, and this gives a means for evaluation of technologies as well as improving emissions in an urban environment.

0 – 5 years	5 – 10 years	10 – 20 years
Mild hybrids Enabling research on magnetic materials for hybrids	Low cost high efficiency electric motors and controllers Low cost engines for hybrid vehicles In-home fast battery charging Battery life and cost Significant market penetration	High efficiency electrical machines, controllers and batteries

Advanced Internal Combustion Engines

Opportunities exist for the development of advanced IC engines optimised for powering hybrid vehicles, matched to the load cycles experienced in these applications. Highly downsized engines, with significant fuel economy are feasible in the short to medium term. Developments enabling migration to the widespread use of alternative fuels such as CNG, LPG, LNG and bio-diesel, are expected, as well as power units with multi-fuel capability. Common issues exist with the development path for more conventional engines as given in the Engine and Powertrain Thematic Group, with convergence of technologies a possibility. In the medium term, overcoming the control issues with HCCI/CAI engines will benefit pollutant and particulate emissions for oil derived fuel propulsion.

0 – 5 years	5 – 10 years	10 – 20 years
Highly downsized boosted engines Emissions control with reduced CO_2 penalty Optimum cycle (e.g. HCCI/CAI)	Gasoline engine CO_2 reduction Location based control for efficiency and emissions Throttleless engines GDI Multi-fuel Waste energy recovery Intake charge cooling	

Electrics and Electronics (for energy and drive systems)

Fuel cell and other new energy drive systems require parallel development of the electric and electronic systems for energy storage, engine management and control, power generation, conversion and transmission. Reduction of parasitic energy loss through independently driven auxiliary equipment gives opportunities, particularly if coupled with supplementary on-board alternative energy generation e.g. using photo-voltaic systems. High efficiency, low weight and low cost electric motors are required, as are efficient electrical storage systems capable of servicing the load cycle requirements of the vehicle.

0 – 5 years	5 – 10 years	10 – 20 years
Improvements in auxiliary systems Electric steering Advanced network control systems Enabling research on magnetic materials for hybrid/fuel cells application Longer life battery technology High power density low loss silicon	On board diagnostics to dealer. Repair options parts already ordered Sensor fusion for low cost and high reliability Fail safe and fault tolerant control systems Combustion feedback based control for flex fuel Electric braking and regeneration Higher efficiency lighting Advanced high power battery technology Improved efficiency electric motors High voltage vehicle systems Higher power density energy storage media	

Conventional and Alternative Fuels

The cost of oil derived fuels is continuing to rise, and as the global demand for energy depletes oil reserves, this trend is likely to increase in the longer term. Coupled with the need to reduce CO_2 emissions which is providing a significant stimulus to improve engine efficiency, there will be pressures to move towards low- or neutral-carbon fuels such as bio-diesel and hydrogen. New fuels, vehicle systems and supply infrastructure need development in parallel, and a number of competing solutions are likely.

0 – 5 years	5 – 10 years	10 – 20 years
Dedicated alternative fuels LPG, CNG, bio-fuels Lower sulphur diesel and gasoline Seal materials for bio-fuels H_2 in a few city stations	Fuel via the internet/home fuelling CNG capability Alternative fuels emerge in greater numbers oil/alt = 50/50 Bio-diesel infrastructure development (field to pump)	Oil based fuels minority rather than majority H_2 or alternative fuels from nuclear energy H_2 freely available

System Integration and Infrastructure

As well as the individual components of e.g. fuel cells, hybrid power units and drive systems, the integration of such systems into the vehicle infrastructure needs careful consideration. This needs to link into such themes as overall system thermal management, and the powering and deployment of auxiliary components.

0 – 5 years	5 – 10 years	10 – 20 years
Routing, OBD, digital tacho, communication engine and gearbox management Integrated management of energy available between all systems System approach to overall vehicle design Vehicle thermal management Focus on efficiency Integration of internal high integrity vehicle infrastructure Demonstration of clean hydrogen refuelling Hydrogen from natural gas	Vehicle thermal management Zero emission hydrogen refuelling Driver style/trip adaptation to enhance efficiency Hydrogen from electrolysers beginning	Vehicle thermal management Most hydrogen from electrolysers

Design and Manufacture

The introduction of hybrid, electric and alternatively fuelled vehicles requires effective design of the whole vehicle and economic manufacturing systems, linked through design for manufacture. Design and use of materials need to consider, particularly, crashworthiness and the requirements for recycling and/or reuse at the end of vehicle life. Use of lightweight structures and materials to capitalise on energy saving is seen as an enabler, linking with themes in the FASMAT and DMaP Thematic Groups.

0 – 5 years	5 – 10 years	10 – 20 years
Tools, techniques and processes for rapid product development and reduced time to market Supplier led vehicle concepts	Supplier led vehicle concepts Techniques and processes for rapid product development High specific strength materials to reduce vehicle mass	Low cost driver training simulators

Technology Targets

Technology target proposals appropriate to the HEAFV group were also considered in the workshop, and these are given in the following table. They should not been seen as definitive, but rather a view on suitable targets against which progress can be audited.

	0 – 5 years	5 – 10 years	10 – 20 years
Fuel cells	Adopt DoE targets e.g. > 300 mile range Whole vehicle design for fuel cell system Efficient low cost blowers for FC 5% of new car fleet	Efficiency of FC system (DoE) > 60%$_{LHV}$ at 25% load, > 50%$_{LHV}$ at 100% load Achieve “Powering future vehicles” low carbon targets for uptake 1 month 50% leakage gaseous H_2 storage Adopt US DoE target sets for automotive applications 25% of new car fleet	50% of new car fleet
Hybrid powertrains		Reduction in waste heat by 50% On-cost of hybrid systems justified by fuel savings in first 3 years	

Advanced internal combustion engines	Reduction in parasitic engine load by 25% > 35% efficiency Gasoline engine CO_2 equivalent to 2004 diesel car for same performance 20% of new vehicle fleet	> 35% efficiency 50% of new vehicle fleet	> 40% efficiency 90% of new vehicle fleet
Electrics and electronics	Advanced motors to improve packaging	Improvement in motor life, weight and efficiency by 20%, 15%, 5%	
Conventional and alternative fuels	Bi fuel gasoline alternative fuel engines optimised for alternative fuels CNG/LPG engines run gasoline as back-up Enough hydrogen for 15% of new vehicle fleet	H_2 storage retaining > 75% fill over 2 weeks Enough hydrogen for 50% of new vehicle fleet	20% biofuel in (alternative) fuel chain by 2020 Highly boosted H_2 fuelled IC engines Enough hydrogen for 75% of new vehicle fleet
Systems integration/ infrastructure	Integration of fuel cell system to vehicle with focus on auxiliary components e.g. power electronics, motors, air conditioning	Unpack vehicle targets into component and controller specs	Fully integrated system of of wind turbines, PV's, tidal power, electrolysers making renewable hydrogen
Design and manufacture	Design manufacturing processes for economic production of batch volumes	Major reduction in unladen weight of HGV's	

Research Priorities

Design verification actions requiring small fleets of identical vehicles, delivering statistical data on vehicle performance and gaining customer engagement.

Evaluation procedures for component performance and input data for models. Processes are needed for technology-neutral objective evaluation of proof-of-concept prototype components, systems and vehicles that are based on competing technologies.

Powertrain system control strategies and implementation.

Internal combustion engines and fuels designed for use in hybrid vehicles, recognising their load cycles.

Components for electric powertrains, particularly high efficiency, low weight and low cost electric motors, managing the heat problem as well as direct benefits.

Electric energy storage, recognising load cycles.

Hydrogen storage on board.

Fuel cell ancillary systems.

Vehicle/infrastructure systems for efficient and low emission vehicle missions and urban operation.

Overview

The technologies covered by the HEAFV Thematic Group will make a significant contribution to the following major drivers for the vehicle sector.

Environment

The UK is committed to international protocols targeting significant reduction in the emission of greenhouse gasses such as CO_2 to combat the perceived threat of global warming and its consequences. The pathways to the future have been well researched and documented. However, the technologies that are available today and which have the potential to significantly reduce or eliminate CO_2 emissions still have to come to maturity. Research and development work is needed on a broad front so that decisions can be made on the selection of the most appropriate route to a future low carbon economy. As well as advances in internal combustion engine emission characteristics, electrical machinery development plays a major part, with advances needed in efficiency of motors and charge and other energy storage devices.

Health

The combustion of oil based fuels in internal combustion engines produces noxious substances and particulates which are injurious to health. Although advances have been made in engine designs which have significantly reduced these, there are still opportunities to reduce these further both by advances in internal combustion engine technology, and the use of different propulsion systems such as hybrids or fuel cells. European Directives (Euro 5 and Euro 6) are expected in the 2010 to 2012 time frame which will set targets for pollutant reduction, both for light and heavy vehicles.

Economy

With oil price rises likely as demand increases and reserves become insecure and slowly decline, work is needed to both to improve engine efficiencies and to use alternative, non-oil derived fuels. This will include bio and natural gas derived fuels as well as hydrogen, eventually from renewable sources.

HEAFV Technologies from Version 1.0

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

	2002–2007	2007–2012	2012–2017	2017–2022	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 (HEAFV) — **Hybrid and advanced IC engines**

	2002–2007	2007–2012	2012–2017	2017–2022	2022–2032
Market - IC pilot / demonstration (2000) - Fleet of 15 vehicles	Production of H_2 IC vehicles for sale to public Several manufacturers develop 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 (HEAFV)

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); Hydraulic energy storage (improved energy storage in general); High temperature, high power (500W/Kg), low cost ($300/KWh); Lead acid: 800 W/Kg, 10 year life, $150/KWh	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 (HEAFV)

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

5.3 Advanced Software, Sensors, Electronics and Telematics

Scope

The Advanced 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

Safety. Although the UK has a good record for safety, there are still around 3,500 deaths/year, and 40,000 injuries. Advanced, sophisticated systems capable of monitoring the environment and interacting with driver and vehicle control can make a major contribution to the reduction of accidents and their mitigating effects.

Mobility (and congestion). With more than 27m vehicles on UK roads and rising, congestion is increasing with consequent impact on ease of mobility. Telematics will contribute towards systems which can ease congestion through communication with the road infrastructure and via fiscal or other measures, change travel patterns.

Security. Vehicle crime is an escalating issue for both passenger car and commercial vehicles. Improvement to vehicle security systems are leading increasingly to persons being the target of the crime in order to gain unauthorised access to vehicles. Intelligent security systems based on driver recognition have the potential to minimise such occurrences. The potential use of vehicles in terrorist activity is a recent concern.

Economic

The adverse economic effects of congestion will benefit from ASSET technology developments. Currently, cost effectiveness of systems are difficult to justify on all except premium vehicles, therefore rapid cost reduction of critical components and widening their scope of applicability is required, allowing for migration to a wider range of vehicles and increased take-up of the technology.

Environmental

The requirement to reduce fuel consumption and emissions of CO_2 and harmful substances will benefit from more freely flowing traffic. ASSET technology for traffic flow control can help improve overall fuel consumption and has the potential to reduce local pollution build up in urban areas.

Technological

Rapidly increasing performance of information technology (electronics, software and communications) is improving the likelihood of ready and extensive application in vehicles. Because the technology is evolving so rapidly, matching product lifecycles to vehicle evolution needs careful management. Additionally, the pace of development is so fast that new possibilities become apparent continuously leading to a need for continuous reassessment of future capabilities. Modular manufacture and dealer configuration will aid assimilation of such developments.

Political	UK Government, European and International policy concerning transport regulation and legislation has a major impact on the performance requirements of ASSET systems. These cover congestion, energy, CO_2 and other emissions, health and safety and waste management. There are significant implications for system integrity and reliability for use in safety related technologies.
Infrastructural	There is a growing awareness that achievement of safety and congestion goals will require more than autonomous systems, dependent only upon what is available within each vehicle. Effectiveness will depend upon sharing information between vehicles as well as with infrastructure based information. This requires the eventual emergence of a coordinated infrastructure and vehicle system development strategy based on an acceptable business model for uptake of telematic technologies.

Asset Technology Directions

The expert opinion obtained during the construction of Version 1.0 of the Technology Roadmap is still relevant and valid, and is given at the end of this section for completeness. Review of this information in a workshop highlighted the following as the important themes for classification of technology directions:

- Shift from multiple hardware units central processing with a range of software
- Access and use of vehicles
- Architecture and reliability
- Human vehicle interaction
- Information management

Whilst not superseding the data obtained in Version 1.0, the information below adds to it and represents current thinking on those aspects of technology introduction which are considered important.

Shift to Software

The general trend towards increasing use of electronics and communications technology, and software replacing hardware, is continuing and will have a major impact on vehicle design and operation, and also of the transport infrastructure. All aspects of vehicle control and travel decision support are affected. The focus is on both the constituent technologies and the system integration required to merge functions together.

0 – 5 years	5 – 10 years	10 – 20 years
Low cost adaptive cruise control (ACC) Automatic emergency braking Pedestrian sensors Fusion of radar and vision 360• vehicle sensing Driving development simulator Lane keeping support ADAS simulator for driver training (Dealer, Driving School)	Interaction support system (both vehicle and infrastructure based) Minimum cost routing based upon knowledge of (dynamic) congestion charges Neural network software learns driver/car setup Control systems enabled by highly granular EIS/DBS	

Access and Use of Vehicles

Software, sensors, electronics and telematics technology lead to significant access related benefits to both vehicle and the road infrastructure. Reduction of congestion and crime, increasing mobility, accessibility and vehicle adaptability are areas expected to benefit. These will enable new models of ownership and control to be adapted, such as driver recognition, payment for road usage and insurance.

0 – 5 years	5 – 10 years	10 – 20 years
Road user charging (RUC) for trucks Black box road use logging Automatic parking Smart card entry Occupant injury tolerance sensing and adaptive restraints Automatic incident reporting to emergency services and traffic control	Biometrics driver recognition Electronic vehicle identification Electronic key and driving licence to reduce car crime Full automation in e.g. heavy congestion, urban driving Vehicle only admitted on pre-allocated priority routes Road user charging for cars Lease/rent rather than ownership if new energy sources are too expensive	Intelligent speed adaptation

Architecture and Reliability

Implementation of advanced electronic, software and communication technologies requires that systems can be easily integrated into the vehicle and road infrastructure.

Systems are growing in complexity and perform an increasingly mission and/or safety critical role, leading to a need for reliability and fail safe operation, whilst adaptable to particular user requirements.

0 – 5 years	5 – 10 years	10 – 20 years
Common architecture systems used by all manufacturers Autonomous on-board sensors only Electronics with low end-of-life impact	Infrastructure/vehicle and vehicle/vehicle communication Effective intermodal systems Safety critical support	Infrastructure/vehicle co-operative systems

Human Vehicle Interaction

This is an additional theme to those contained in Version 1.0, due to its importance. The driving task is becoming increasingly complex, both as a result of higher traffic intensity and the proliferation of systems in the vehicle. This leads to issues of driver distraction and control impairment, which applications of advanced information and control systems need to consider. Detailed behavioural studies of drivers are highlighted as necessary so that systems can be designed to given an appropriate response. A full artificial intelligence type solution (driverless vehicle) for suitable conditions (e.g. motorway) is an ultimate target. Customer acceptance of less direct control of vehicles is needed.

0 – 5 years	5 – 10 years	10 – 20 years
Methods for measuring driver workloads Voice Technologies Knowledge of driver "baseline" and verification	Dialogue management Adaptive systems for older drivers Driver alertness sensing linked to vehicle operation	Vehicle system intelligence compensates for human error External control of vehicle speed "Auto pilots" emerge

Driver intent detection Exploitation of new technology options – ease of use by driver Driver workload management Novel sensors for vehicle control and position management	Driving impairment monitoring Fatigue, drug and incident detection Information overload handling When does driver need less information (information overload) How to achieve customer acceptance of less direct control of the vehicle	

Information Management

This is an additional theme to those contained in Version 1.0, due to its importance. Communication between vehicle, driver and the road infrastructure, and the storage and processing of a wide variety of information are required to operate reliably, securely and in a timely fashion. Effective information collection, processing, display, management and interaction with vehicle control systems will become increasingly important.

0 – 5 years	5 – 10 years	10 – 20 years
Reliable traffic data with high resolution key trunk routes Mobile broadband internet (i.e. 802.20) Multi-application communications Distributed networks capability Highly granular EIS DBS Knowledge of info requirements (how much is enough?) Real-time traffic information with quantitative estimates of travel time delay Rational Infrastructure with correct max/min speed thresholds for use Co-existence and interoperability with other systems	Privacy preserving information security Knowledge enabled planning prediction Road conditions communicated to navigation system	Anti-terrorism/system sabotage prevention Managed travel

Technology Targets

Technology target proposals appropriate to the ASSET group were also considered in the workshop, and these are given in the following table. They should not been seen as definitive, but rather a view on suitable targets against which progress can be audited.

	0 – 5 years	5 – 10 years	10 – 20 years
Shift to software	ACC cost reduced to allow it as a price option from £500	2m accuracy for position for 99% of UK road network Pedestrian sensed at 50m in all weather conditions day or night	360° obstacle sensing on all new vehicles ACC 100% fitment rate
Access and use of vehicles	50% of journeys £ 100 miles take < 2hrs	Standardised infrastructure	95% of vehicles controlled to speed limits
Architecture and reliability	High bandwidth of integrity vehicle data bus	Zero recalls to fix software bugs CALM standard achieved for DSRC and GSM	
Human vehicle interaction		Agreed measurement method and criteria for too much distraction 50% of vehicles fitted with ACC as standard Vulnerable Road Users detected in range 0-25m by 25% vehicles on road	Driver only steers vehicle with speed set and controlled on motorways 50% reduction in fatigue related accidents (barrier is background accident logging and accuracy)

		10% reduction in driver perception failure accidents Accident logging is a barrier, needs black box?	100% reduction in TWOC, car theft and driving when banned/uninsured 80% predictability of driver behaviour No human machine interface required for vehicle control (except destination)
Information management	10Mb/s at up to 200km/h for 90% population coverage in 5 years The right information in the right place to the right people at the right time Average flows for all of Motorway network from PV's 15min/km	National road map including speed limits and other road data available digitally	

Research Priorities

Safety. Although a wealth of statistics is available about accidents, there is still a shortfall in details. Accident knowledge is required to inform how better to design systems for prevention. It can build upon similar work on how incidents are occurring but a specific understanding of the special circumstances pertaining to the UK context is also required. Despite the concern over driver distraction and the increasing complexity of the driving task, there is still insufficient knowledge in this area. Models are required for driver distraction and cognitive loading that can be used in the design and evaluation of new interfaces and driving support aids.

Cost of technology. The cost of ASSET based systems must be reduced for more widespread adoption other than in top-of-range premium vehicles. In some cases, there is a careful cost versus functionality balance to be sought that requires further investigation to accomplish. Additionally, cost reductions in the enabling technologies and constituent components help to make these systems affordable to a wider market. The challenge is in engineering these high performance constituents for low cost, volume manufacture.

System Integration. Much of the development to date has exploited single sensors to achieve each task. However, each sensor modality has its own advantages and performance drawbacks. Sophisticated techniques in multi-sensor data fusion can yield improvements in overall system performance and reliability that are greater than can be achieved by using each sensor separately. These techniques are well understood in other domains but are under-utilised and require further study to ensure their effectiveness in vehicle applications.

Reliability. The increasing complexity of ASSET applications places considerable demands upon how they can be tested. Systems will also need to interact with those in other vehicles and with infrastructure components, with a set of elements that may be outside the design control of one manufacturer, leading to standardisation issues. Exacerbating the problems, systems are becoming mission if not safety critical. Ensuring than they are thus operating correctly and safely becomes of paramount importance but concomitantly more difficult. System validation presents major challenges with many technical problems to be resolved. Areas for improvement include better modelling capabilities to assure and predict performance and rapid prototyping to give early feedback on functionality.

Technology Introduction. Solutions are sought on how to accommodate the mismatch in life cycles between vehicles and the telematics applications that are embedded in them. Further work on standards will underpin this work, as will progress in ways in which mid-life or in-service upgrades can be made to such systems in a cost effective and simple way. Other techniques that may assist new vehicle launches to intercept the latest technology breakthroughs would also be desirable.

Overview

Safety

Reduction in the number of deaths and serious injury is mandated by Government Policy. The technology developments highlighted in this section will lead to reduction in the number of accidents through collision avoidance with all users of the road infrastructure. On-board sensing and deployment of safety systems during collision will help mitigate the effects of an accident.

Congestion

Reduction of congestion is a key policy requirement for the future of the UK road network. Information collection and use through advanced communication and driver aids will aid in the avoidance of congestion. Linkage to road user charging and route planning will help with active management of congestion.

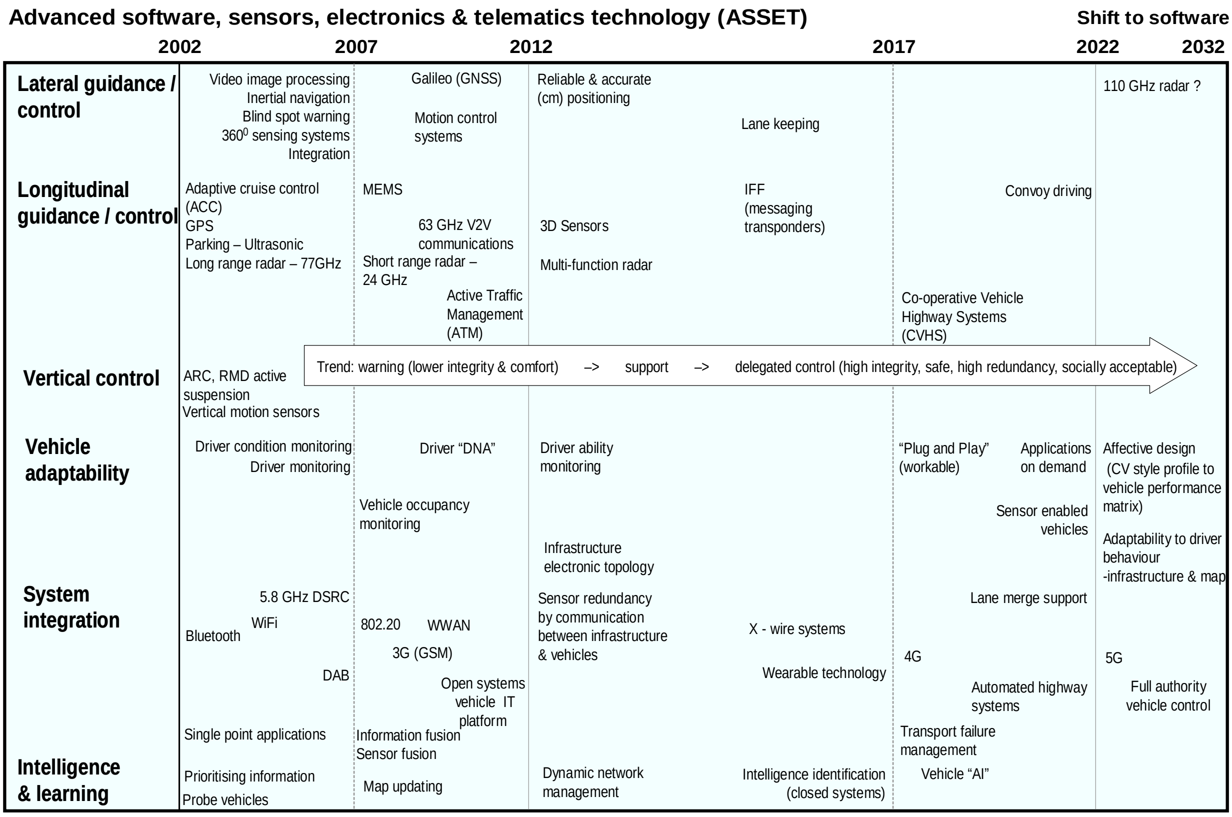
Environment

Use of advanced technologies can help to control CO_2 emissions and other pollutants by maintaining free flow of traffic, particularly in urban areas. Active traffic control to avoid pollution (particularly in the urban environment) is ultimately feasible using similar technologies to those used for congestion, particularly when coupled with real time measurement of vehicle emissions.

Security

Vehicle crime has attendant economic and personal effects. ASSET technology development has the potential to reduce vehicle crime without moving the focus of crime from the vehicle to the individual.

ASSET Technologies from Version 1.0



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

Access and use of vehicles

	2002–2007	2007–2012	2012–2017	2017–2022	2022–2032
Access into vehicle		Bio-metrics phase 1	e-Licence Bio-metrics phase 2 Tuned vehicle performance - driver adaptation	Fit to drive detection	Crime reduction & safety
Access of vehicle into...		Clear Zones/ home / car parks Access to PSVs Access by HGVs (e.g. height)		Driver based vehicle prioritisation (e.g. elderly, disabled)	Adapting vehicle to individual
Use	Adaptive cruise control (ACC)	Driver workload management Black box technology Road User Charging Use-based insurance Stop & go Stop & go ++	Intelligent Speed Adaptation Advisory system for economical driving Interaction with traffic information (inc. road signs) Urban Drive Assistant (UDA)	Tuned vehicle performance - infrastructure / fuel / environment Dynamic route guidance Journey time reliability (prediction & planning) Interaction with traffic management Rural Drive Assistant (RDA)	Minimising congestion Automated highway driving
Crime reduction	Technologies exist, but time to implementation? (politics, standards, public, insurance, etc.)	Electronic Vehicle Identification (EVI) as a theft countermeasure	Vehicle fingerprinting	Vehicle subsystem identification Remote vehicle control for anti-theft	Crime reduction II

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 OK) Adaptive?	Cheap sensors Centralised garage computerised diagnostics On-board diagnostics	Reconfigurable Self-diagnostic AI-based Predictive / preventive maintenance	Human fault tolerant	Worry free motoring Self-repairing vehicle
Architecture to "enable"	Improved simulation for faster development	Battery / power management Modular & standards-based architectures Time triggered protocol databuses	'Plug & Play' architectures Control flexibility (to aid in manufacturing) Standards	Design for disassembly - Interchangeability - component - upgrade	Tailor made "morphing" vehicle

5.4 Advanced Structures and Materials

Scope

The Advanced Structures and Materials (FASMAT) technology theme includes the following vehicle functions and systems:

- 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	*Safety.* As well as continuing efforts to reduce the number of road traffic accidents, vehicles must be designed and constructed in a manner which mitigates the effect of an accident both on vehicle occupants and those external to it. Materials and structures development is a key enabler contributing to this driver. Not only is the behaviour of materials in crash conditions important, but combining them into smart structures with tuneable, active safety systems has scope for development.
	Configurability. Freedom of customer choice is leading towards a greater number of vehicle styles and rapidly evolving models, with fashion being a driver for vehicle change. Materials and structure developments will give better targeted products, through product configurability and flexibility, with attendant opportunities to reduce investment costs and time to market.
Economic	Competitive pressures to reduce development and manufacturing cycle times and costs in the drive for greater profitability and return on capital is leading to requirements for highly modular structures applicable over a wide range of platforms. An additional requirement is the need for low investment vehicle/low volume programmes. The development of more cost effective materials and coatings are needed to maintain and improve profitability.
Environmental	*Waste management.* The European Directive on End-of-Life Vehicle and similar legislation requires continuing improvement to the ability to re-use and recycle materials, and the number of substances proscribed against use is growing. This acts as a constraint on the take-up and use of new materials, which will need to be vetted for compliance with legislation. Increasing consideration will be given to the environmental impact of all substances used and management "from cradle to grave". This in turn leads to the need for design for re-use and recycling, with the attendant dismantling issues. The use of polymeric materials, which can offer distinct advantages structurally, will need special consideration.
	Emissions reduction. The need for reduced CO_2 and pollutant emissions is assisted by the development of lightweight materials and structures, leading to lower energy needs for propulsion. Hybrid and fuel cell vehicles will benefit particularly from materials and structure development for optimisation of the vehicle architecture.

Manufacturing. Materials and coatings developments are required which are environmentally friendly in manufacturing processes.

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, regulations and legislation concerning transport, energy, CO_2, safety and waste management requires the application and development of suitable materials and structures. FASMAT can contribute to requirements to reduce the number of fatalities and serious accidents, and improve the environment by enabling re-use and recycling.
Infrastructural	Developments in the infrastructure that affect safety (telematics and physical infrastructure) require suitable materials and structures for deployment.

FASMAT Technology Directions

The expert opinion obtained during the construction of Version 1.0 of the Technology Roadmap is still relevant and valid, and is given at the end of this section for completeness. Review of this information in a workshop highlighted the following as the important themes for classification of technology directions:

- Safety
- Product configurability/flexibility
- Economics
- Environment
- Manufacturing systems

Whilst not superseding the data obtained in Version 1.0, the information below adds to it and represents current thinking on those aspects of technology introduction which are considered important.

Safety

The UK Government is committed to targets for 2010 of reducing deaths and serious injuries from road traffic accidents to 40% of the 1994 to 1998 average levels. Development of materials and structures which are effective in mitigating the effects of accidents to both those inside and external to the vehicle is seen as one of the enablers to achieving the target, in conjunction with measures aimed at reducing the likelihood or severity of accidents (see also the ASSET technology theme). A combination of passive and active safety systems are required, taking into account forecasts of future mobility requirements and vehicle types.

0 – 5 years	5 – 10 years	10 – 20 years
Increased concentration on the engineering and material choice Active safety systems begin to appear. New standards and assessment on how to test More widespread use of UHSS steels (e.g. TRIP) in auto structures - better energy absorption in crashes	Most vehicles have active safety systems to agreed standards but differing across regions Smaller, lighter cars drive safety standards Materials of structures work matched with joining technologies development Smart compliant structures On board system performance monitoring	Harmonised active and passive safety standards Flimsy vehicles for (only) urban operation

Product Configurability and Flexibility

A growing demand for greater product variety is anticipated to meet consumer requirements in terms of lifestyles and demographics. This is reflected in the trend towards greater configurability and flexibility, with modularisation being important in providing multi-platform capability in parallel with the reduction of manufacturing costs and development time.

0 – 5 years	5 – 10 years	10 – 20 years
Modularisation Multi-function structures - integrated electronics, switchable pigments etc More integration into component design Aim to develop multiple body configurations on single platform basis foolproofing for user changeover Design and simulation tools required, e.g. for durability, fatigue etc New and developed materials require cost-effective structural joining processes Design for manufacture to incorporate new technology benefits at an earlier stage of project	Short term reconfiguration (leisure use etc) Long life vehicles Re-manufacture/refurbishment of suitable/rare material intensive parts	Upgradeable vehicles to reduce waste Integral noise dampening

Economics

Structural systems and materials form a significant proportion of vehicle cost, in terms of raw materials, production, and disposal and recycling costs. 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), re-use and recycling.

0 – 5 years	5 – 10 years	10 – 20 years
Increased common platform/component/system sharing - cost down Develop cheaper, more ‘manufacturable’ low weight structural materials	Elimination of paintshop	Upgradeable vehicles to reduce waste Integral noise dampening

Environment

Suitable material development is key to achieving the reduction of environmental impact of vehicles, particularly at end-of-life, where targets for re-use and recycle are set by European Directives. The list of substances prohibited either for their environmental impact or direct health effects is ever increasing, such that all materials developed for use in vehicle manufacture need auditing for suitability at the outset. Consideration of needs for re-use and recycling requires a systems approach for “cradle to grave” component management, including design for disassembly and reprocessing. Polymeric materials in particular need consideration for this purpose. The environmental effect of processes also impacts materials, with a challenge for materials that can reduce or eliminate processes with a high environmental impact having costly control needs, such as paintshops.

0 – 5 years	5 – 10 years	10 – 20 years
Life cycle issues closely adhered to Low cost integration of lightweight composites into commercial sector (bodywork) Environment on the next NCAP Provide low cost alternatives to surface treatments which are now prohibited Challenges for EoLrecycling will require single piece as opposed to multi-piece assemblies Low cost manufacturing of large, lightweight commercial vehicle chassis Structural materials contribute to noise reduction Enable repair techniques for UHSS, aluminium and other low weight structural materials	Emphasis on re-use rather than recycling for key components, with appropriate systems in place Improved high strength lightweight structures Magnesium alloys used in a wider range of applications for weight and dampening (powertrain, A and B pillars) Design to withstand damaged roads Weight saving emphasis in parallel with take-up of new fuels, fuel cell, hybrid etc	

Manufacturing Systems

Development of suitable manufacturing systems to design, join, and assemble vehicles in a shorter timescale is driven by the needs for a competitive industry giving suitable profitability. Linked to this are the needs for modularisation associated with product configurability and flexibility, as well as the demands for easy disassembly for re-use and recycling at end-of-life, together with systems suitable to unlock the potential of newly developed materials and structures.

0 – 5 years	5 – 10 years	10 – 20 years
Design for dismantling Modularisation Component re-use Off-line virtual prototyping Manufacturing to order Shared production facilities between OEM’s to equalise production rates as customer demand varies Initial appearance of low volume vehicles with some elements of mass customisation Reductions in product development time to market	Wider use of magnesium and its alloys as the understanding of material and techniques increases Alternative material/coating combinations to make paint shop redundant for corrosion and cosmetics Manufacturing process simulation tools to avoid expensive surprises (and data to enable them to work) Product updating Contract assembly infrastructure Cost model for production methods change Ease of repair to damaged vehicles New materials and structures developed for low volume products	Only very large volume vehicles use “Budd” type assembly. These will be customer configurable and possibly modular Lower volume vehicle using low investment techniques - will be customisable and modular (including electrical system, A/C ducting etc in structure) Micro factories Flat pack

Technology Targets

Technology target proposals appropriate to the FASMAT group were also considered in the workshop, and these are given in the following table. They should not been seen as definitive, but rather a view on suitable targets against which progress can be audited.

	0 – 5 years	5 – 10 years	10 – 20 years
Safety	Selection of joining systems to match material performance capabilities e.g. energy absorption, stiffness, strength etc	Design/production and validation of “smart” crash structures	
Product configurability and flexibility	Component integration Easier separation of materials for recycling or re-use Effect of modular structures (and joining) on crash structures/NVH/stiffness Robust engineering solutions for rapid modular reconfiguration	Automotive industry relevant materials information database with all needs covered - one source Management of customer customisation and effect on design process/homologation and supply chain	
Economics	Reduce cost of moulded composites Component performance beyond single vehicle life Development costs Re-processing of metal mixtures to give pure metals for re-use A higher, safer and more environmentally sound vehicle development	Disassembly techniques Develop viable alternative to traditional paint finish for body panels	
Environment	Establish standards for environmental friendliness Development of polymer separation techniques ELV compliant composite materials Reduce vehicle weight Attachment strategies for dismantling Wider understanding of materials in the industry Overcoming energy saving vs. recycling perceptions Development of disbondable metal/composite interfaces National system for reuse of components Low cost CFRPpanels and structures	New magnetic materials for hybrid/fuel cell powertrain Develop re-use mechanisms/methodologies Identify higher value markets for recovered materials National systems for material re-use and recycle	Solve H_2 fuel infrastructure issues to enable widespread uptake and use Hardwearing, low friction coatings to eliminate lubricants from powertrains
Manufacturing systems	Joining hybrid structures Surface quality thermoplastic composites Develop low cost composite manufacturing process Cost effective joining/dismantling of mixed material structures Cheap, environmentally friendly system to join steel, aluminium and magnesium without corrosion issues Awareness of and access to process cost models and Life Cycle Analysis Establish central register of production routes to advise on potential facility sharing Single piece structure development costs	Coatings which survive production Reduce time to manufacture for novel technologies Materials that do not require paint protection Convergence of business and technology research models Flat pack/modularity requires ability to make cheaply, structural, sealed joints post-paint process	Die-less forming

Research Priorities

Key materials and structures technologies for development are expected to include the following:-

Low investment, short cycle time, single sided access joining technologies for metallic and composite materials and having an inbuilt process monitor/validation mechanism e.g. riveting processes that set the rivet, applying suitable process monitoring and non destrucive testing (NDT) strategies in cycle will enable automatic capture of the quality record for that specific assembly.

Predictive simulation of plastics, composites and foams under high strain rate conditions e.g. a prediction mechanism for foams would allow optimisation of energy absorption rates under impact conditions to protect the contents of the packaging or modify the response of the product or assembly that the foams forms a part of.

Low investment, environmentally acceptable corrosion resistant pre treatments for light metals (e.g. aluminium and magnesium) that would be suitable for low volume batch suppliers.

Medium and high volume techniques for the manufacture of low weight structural composite components and hybrid structural joining techniques to enable their use in predominantly metallic structures.

Robust manufacturing processes to enable the production of recyclable components and assemblies with structural, cosmetic and electrical/electronic functions integrated.

Low volume modular manufacturing techniques.

Overview

The technologies covered by the FASMAT Thematic Group will make a significant contribution to the following major drivers for the vehicle sector.

Safety
Reduction in the number of deaths and serious injury is mandated by Government Policy. The technology developments highlighted in this section will lead to reduction in the effect of accidents by the use of materials and structures better able to mitigate the effects of road traffic accidents to all those involved.

Environment
Waste. UK and European legislation on waste management and control, such as the European End-of-Life Vehicle Directive, already places restrictions on the use and development of materials. The proportion of re-useable and recycled components in vehicles has to increase, and design for disassembly becomes important. Environmental management of materials, structures and components is required from concept to end-of-life.

Emissions. The UK is committed to international protocols targeting significant reduction in the emission of greenhouse gasses such as CO_2 to combat the perceived threat of global warming and its consequences. The development and use of lightweight materials and structures is a key enabler for reducing the energy requirements for the propulsion of vehicles. Also, advances in materials and coating technologies will aid friction reduction, leading to improved efficiencies.

Economic
With industry facing major economic challenges, the need to improve profitability and achieve better returns on investment is highly important. Developments in materials and structures could enable the introduction of highly modular, flexible platforms. They may also contribute to low investment manufacturing systems for low volume production.

Customer Choice
The techniques and technologies covered in the section will allow more customer choice through their impact on modular structures capable of use over a wide range of vehicle platforms.

FASMAT Technologies from Version 1.0

Advanced structures and materials technology (FASMAT)

Safety

2002 2007 2012 2017 2022 2032

	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 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		10 year Scenario: - 'business as usual' → Current users: - cars - buses - trucks - cycles - motorcycles - pedestrians 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 leisure travel - will telework reduce reduce business travel? → 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	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 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	Urban speed decreasing Rural speed unchanged Motorway speed unchanged 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)	10-20 year scenario - more radical 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 2012 2017 2022 2032

	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		

5.5 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 There is a demand for greater mobility and changing patterns of working and living, together with demographic changes. For passenger cars, customers are demanding tailor made features leading to a great diversity of models and ranges, requiring fully flexible on-demand manufacture. Vehicles which can evolve and change configuration to meet changing fashion and lifestyle.

Economic Competitive pressures exist to reduce development and manufacturing cycle times and costs, improve value and 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). Low volume and fully flexible manufacturing systems are required, driven by manufacture to order with minimal inventory.

Environmental Requirements are to reduce energy consumption, material waste and emissions of CO_2 and other harmful substances, during manufacture and use of vehicles. Management of the complete vehicle life cycle from cradle to grave is required to conform to legislative requirements on waste disposal. Vehicles and components need to be designed with re-use and recycle in mind, and with manufacturing processes which are environmentally friendly.

Technological Competition exists to develop innovative solutions in the areas of vehicle design and manufacture, considering all aspects of the vehicle life cycle.

DMaP Technology Directions

The expert opinion obtained during the construction of Version 1.0 of the Technology Roadmap is still relevant and valid, and is given at the end of this section for completeness. Review of this information confirmed the themes for classification of technology directions:

- Lifecycle
- Manufacturing
- Integration

Whilst not superseding the data obtained in Version 1.0, the information below adds to it and represents current thinking on those aspects of technology introduction which are considered important.

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). Design of components for re-use either within the vehicle sector or outside of it requires special attention, with implications for long term reliability. Methods allowing for easy disassembly at end-of-life need to be integrated into the design process. 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.

0 – 5 years	5 – 10 years	10 – 20 years
Electronics/telematics in selected some areas of powertrain Single polymer high strength structural composites Legislation on reliability of parts? Modular Vehicle for ease of change Engine recyclability Life cycle issues more closely adhered to Challenges for EoLrecycling will require single piece as opposed to multi-piece assemblies Design for dismantling Component re-use	PSVheavy truck powertrain Target less than 2.5 years for engine program Full combustion prediction tools enable shorter lead times and reduced cost Improved measurement and statistical techniques to reduce validation requirements Advanced system modelling tools Long life vehicles Emphasis on re-use rather than recycling for key components, with appropriate systems in place Design for road damage Product updating	Single polymer high strength and modulus thermoplastic composites Target less than 2 years for engine program Upgradeable vehicles to reduce waste

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.

0 – 5 years	5 – 10 years	10 – 20 years
Advanced SMC (continuous high performance fibre reinforcement) Class A thermoplastic with high performance fibre reinforcement increased flexibility for more niche products No paint shops Modular build Light weight vehicle Knowledge capture and management systems New and developed materials require cost-effective structural joining processes Design for manufacture to incorporate new technology benefits at an earlier stage of project Increased common platform sharing - cost down Off-line virtual prototyping Manufacturing to order Shared production facilities between OEM's to equalise production rates as customer demand varies Initial appearance of low volume vehicles with some elements of mass customisation Reduction in product development time to market	Structural application of high performance composites in conjunction with metallic structures in niche and mid- volume Reconfigurable car Cameleon Car (colour change switch) Materials of structures work must be matched with joining technologies development Re-manufacture/refurbishment of suitable/rare material intensive parts Elimination of paintshop Modelling of whole vehicle system Manufacturing process simulation tools to avoid expensive surprises (and data to enable them to work)	Reduced use of high volume production techniques as volumes reduce and variability increases Upgradeable vehicles to achieve emission specifications, safety and fashion Only very large volume vehicles use "Budd" type assembly. These will be customer configurable and possibly modular Lower volume vehicle using low investment techniques - will be customisable and modular (including electrical system, A/C ducting etc in structure) Micro factories

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.

0 – 5 years	5 – 10 years	10 – 20 years
Modularisation of systems e.g. front end module inc. Lighting, cooling, electrical, low speed crash, nvh Easy parts change Multi-function structures - integrated electronics, switchable pigments etc More integration into component design Aim to develop multiple body configurations on single platform basis foolproofing for user changeover	Roof and/or door module including interior trim, exterior panel, plastic glazing, safety structure, nvh, ICE, antennae Modular engines and transmissions Short term reconfiguration (leisure use etc)	High investment UHSS long life vehicle 'tub' with lower investment multi material modular subframe elements to achieve product diversity

Technology Targets

Technology target proposals appropriate to the DMaP group have been considered, and these are given in the following table. They should not been seen as definitive, but rather a view on suitable targets against which progress can be audited.

	0 – 5 years	5 – 10 years	10 – 20 years
Lifecycle	Component performance beyond single vehicle life Re-processing of metal mixtures to give pure metals for re-use Development of polymer separation techniques ELV and composite materials Attachment strategies for dismantling All technologies with a strong energy conservation/reduced waste/reduced resource element	Disassembly techniques Develop re-use mechanisms/methodologies Identify higher value markets for recovered materials National systems for material re-use and recycle Less than 2.5 years for engine Energy conservation 40% of 2005 on a like for like basis All products have a 90% recycling element	Less than 2 years for engine Long lifecycle will stifle new technology
Manufacturing	Robust engineering solutions for rapid modular reconfiguration Reduce cost of moulded composites Faster, safer, more environmentally sound vehicle development Tooling life	Management of customer customisation and effect on design process/homologation and supply chain Develop viable alternative to traditional paint finish for body panels	
Integration	Component integration		

Research Priorities

- *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. Design of components for re-use and design of vehicles for dismantling are particularly important.

- *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 elimination of the paint shop (protection as well as cosmetic).

- *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. Knowledge based engineering continues to form the basis for advances in this theme. Example technologies include standards and protocols, safety and security systems, automated diagnostics, electronic and software design integration.

Overview

The technologies covered by the DMaP Thematic Group will make a significant contribution to the following major drivers for the vehicle sector.

Environment
Re-use and recycling targets required by National, European and International legislation is driving a need for design with complete lifecycle management of materials and components. Development of designs for disassembly are required, as well as consideration of re-use opportunities with the attendant lifetime issues of components. Manufacturing processes need to be continued to be developed for new materials and structures which are compatible with the needs for environmental friendliness.

Economics
Low volume and fully flexible manufacturing systems are required, driven by manufacture to order with minimal inventory.

Customer Demand
For passenger cars, customers are demanding tailor made features leading to a great diversity of models and ranges, requiring fully flexible on-demand manufacture. Vehicles which can evolve and change configuration to meet changing fashion and lifestyle.

DMaP Technologies from Version 1.0

Design and manufacturing process technology (DMaP) — Lifecycle

2002 | 2007 | 2012 | 2017 | 2022 | 2027 | 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
or
'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

Modular construction

Design for disassembly

Rapid disassembly / joining technology

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

Total automated manufacture

Manufacture driven by the user ?

Commercial & Market

Partnerships for capital intensive plant / process development

Low capital costs of manufacturing

Global / regional / local suppliers

In house disposal system

Construction materials and influence of assembly processes

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)

Process energy reduction

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

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

Management

Increase primary stock yield (metals)

Cost effective solutions ->

Electronic data exchange

Support for close-to-form structural metal components

Reconfigurable jigs

Design tolerance management

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

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

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

Component

Support and grow innovative techniques for UK plc

Virtual assembly training

Education & training in new manufacturing technologies ->

Parts 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

Design and manufacturing process technology (DMaP)

Integration

	2002–2007	2007–2012	2012–2017	2017–2022	2022–2027	2027–2032
Product / system integration	Recognition that current systems do not integrate well Requirements mediation systems Information security	Product metrics Make control by wire acceptable (brake, steering, etc.) Integration of all processes (concept - engineering – manufacture – post sales) into integrated concurrent design	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	Role of people & automation (product) Linking design changes to implications for cost and lifecycle Common standards		Artificial intelligent systems will allow single unit companies Multi-disciplinary integration (not just engineering)
Process integration	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!	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	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	System reliability Integration of human and machine Scenario: independent platforms speculatively developed by major manufacturers Role of people & automation (process)	Target: minimum economic production volume for 'real' vehicle: 1000 (enablers)	Scenario: expertise on demand system identifies required expertise and mediates its procurement
Information and knowledge integration	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	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)	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	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		Information systems (not referring to design systems) requirements of future integrated transport systems
Integration of people, process, organisation, tools and technology cut across all of these themes						

APPENDIX

Resources, Participants and Organisations

The roadmapping initiative was sponsored by the Society of Motor Manufacturers and Traders (SMMT). The roadmapping process was designed by Robert Phaal (Centre for Technology Management, University of Cambridge) who oversaw the project. The Foresight Vehicle Team involved in the construction of this roadmap were; Pat Selwood, Project Manager and initiator, Ian Massey, facilitator and author, and Lorna Trevethan, administration and production support.

The information contained in this report is based on a series of workshops supplemented by a web based questionnaire emailed to respondents. More than 70 experts from across the road transport industry representing more than 55 organisations were involved, including industry, academia and Government. The technology roadmap does not represent official company or Government policy, but rather individual perspectives.

This version of the roadmap draws heavily on Version 1.0, to which the reader is directed. The resources used to supplement the expert input are still relevant and are as contained in Version 1.0.

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Organisations

ATL; AutoTechnium; BAE Systems; BMW; Castrol; Caterpillar; Corus; Cosworth Technology Ltd; D2 Solutions; DTI; e2vTechnologies; Euro-Projects; Faraday Advance; Faraday Plastics;

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NOTES

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