Sectoral Innovation Foresight
Automotive
Interim Report

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1 Introduction

This interim report is part of Task 2 (Sectoral Innovation Foresight) of the Europe INNOVA Sectoral Innovation Watch (SIW) project. It presents interim findings on possible future developments in the sector under study. Particular emphasis is put on the one hand on future changes that are likely to significantly influence the evolution and emergence of innovation activities and associated markets, and on developments that are likely to be of cross-sectoral relevance to innovation on the other. Sectoral innovation foresight thus complements Task 1 of the SIW project, which analyzes current sectoral innovation performance.

The main objectives of Task 2 can be summarised as follows:

- Explore and identify the main drivers of change in the nine sectors. These drivers will be both internal and external to the sectors, with several of them being of a cross-cutting nature.
- Identify and assess key future developments in the nine sectors as well as in terms of cross-cutting developments. The emphasis is put on likely future innovation themes and emerging markets, more specifically also on the requirements and impacts they raise in terms of skills requirements, organisational, institutional and structural changes in the sectors concerned.
- Develop scenario sketches for the sectors under study.
- Highlight key policy issues for the future, with a view to enhancing the innovation performance and competitiveness of firms operating in these sectors.
- Stimulate debate and contribute to the creation of expert networks, based on the participatory elements of this task.

The time horizon of these foresight papers is usually five to ten years (2015-2020), depending on the specific characteristics and the pace of change in the respective sectors. The typical innovation cycles in the automotive sector tend to fit within this timeframe, but in order to capture future developments beyond the current cycle, a slightly longer time horizon than ten years is applied in the analysis of this sector.

This Interim Report is based on a review of available foresight material on the automotive sector. Together with the corresponding report on the eight other sectors addressed by the SIW project (aeronautics and space, automotive, construction, food and beverage, knowledge-intensive business services, textiles and clothing, wholesale and retail trade), it serves as background material for a first expert and stakeholder workshop (June 2009). The report concentrates on drivers and innovation themes, but provides already some first findings and thoughts on emerging markets, requirements and future scenarios, i.e. as far as these issues can be derived from the review work. The first workshop aims on the one hand at reviewing the interim findings and on the other at exploring future scenarios of the sector in an interactive mode. The results of this first workshop and some further interviews with experts and stakeholders will then be incorporated in a draft final report that will serve as input to a second foresight workshop (November 2009). This second workshop will focus on the main policy issues that arise from the exploratory scenarios, both within the individual sectors and at their intersection. The final report will bring together in a consistent form the results generated in the different phases of the foresight exercise, i.e. will be based on revised and amended versions of the initial chapters of this interim report and additional chapters dealing with refined scenarios, future requirements and policy issues.
The interim results are presented in six chapters, starting with a situational analysis where the sector stands today to contextualize possible future developments (Chapter 2). Building on this context, Science & Technology (S&T) and demand drivers will be outlined (Chapter 3), as a basis for discussing emerging innovation themes (Chapter 4). These are expected developments resulting from the interaction of supply (technological advances) and demand (societal / customer needs) forces. In this chapter, implications of these innovation themes at firm level will also be addressed. Institutional and structural requirements and implications of the innovation themes for the sector will be highlighted in Chapter 5. This is complemented with first scenario sketches (Chapter 6) and some key questions to be addressed in the remainder of the Sectoral Innovation foresight task (Chapter 7).

A myriad of technologies contribute to future development of the automotive industry. We will focus in this paper mainly on powertrain technologies, technologies to increase security and assist driving, and new manufacturing technologies.
2 Current Situation

The EU-27 automotive sector represents about 8% of the total value added in the manufacturing industry and contributes to the EU trade surplus. European manufacturer produce about one quarter of the global output of personal and commercial cars. If the jobs in related industries are included, over 12 million EU citizens are employed.¹

Within Europe two countries dominate production, Germany and France, although Spain, UK, Italy and Sweden have as well important car manufacturers. Germany is the world’s third largest producer after the USA and Japan, producing about 5 million cars a year. The fourths largest producer is France, while the UK automotive industry declined in the 1970es and 1980es. A number of New Member States such as Hungary, Czech Republic, Slovakia and Poland have emerged in recent years as important manufacturers. The automotive industry is also characterised by a high degree of globalisation with increasing investments of European producers overseas and by Southeast Asian producers in Europe.

All estimations available to date report that the road will remain the dominant mode for travel and transportation; the number of kilometres driven in total, the total number of tons transported as well as the total number of passenger cars and commercial vehicles will grow in the next decade.

Historically, the automotive sector has established a couple of product and process innovations and served as lead customer for many new applications with an impact on the innovativeness of many supplying industries. For instance, the automotive industry established mass manufacturing in the 1920, internationalisation in the 1980s or lean manufacturing in the 1990s. Demand for new material, production technologies, electronics, and information and communication technologies (ICT) can be mentioned which delivered incentives for product development in other sectors such as the semiconductor industry. The dominance of global production and supply chain networks is an important feature of this sectoral innovation system.

The development of the automotive sector is influenced by actors external to the firms such as governmental activities (e.g. regulation) as well as it is driven by the oil industry and the development of the oil price, respectively. Moreover, the public sector, to smaller amount also private companies, invest in infrastructure, roads, tunnels, etc. which heavily influence the development of the sector. Taxation is an important factor as well, by setting specific incentives for private behaviour and investments of organisations.

Currently, the automotive sector is hit considerably by the economic crisis: Car manufacturers are worldwide in the midst of dramatic change with significant structural consequences and opportunities for establishing new radical technologies. The challenge to produce sustainable automobiles has already triggered the next deep change of the automotive industry where a further concentration may occur while at the same time new entrants could emerge.

¹ For a description of the sector as defined by the economic statistics see also the Interim Report of Task 1.
The development and production of environmentally friendly technologies is one way out of the crisis. The environmental and commercial pressure for alternative energy systems will lead to a number of competing alternatives to the internal combustion engine (ICE) such as electric vehicles, hybrids, hydrogen fuel cells. Most automakers have already put efforts into developing new technologies such as hybrid and electric vehicles. CO₂ emission charges and other legislative actions put pressure on car manufacturers to produce environmentally friendly products. A substantial amount of R&D is directed to achieve safety, emission and efficiency standards mandated by regulators worldwide (Wells and Nieuwenhuis 2001).

The sector is strongly driven by the economic and social development: aging, lifestyle, and working patterns amongst others affect the mobility behaviour and the desire for health, safety and security. Providing mobility and avoiding congestions is the core demand related to a car for private use, efficient and environmentally transport for commercial users. Safety, effectiveness, time, sustainability, cost and comfort are likely the main drivers for the development of the sector in the future. In order to adapt and keep competitiveness new strategies, co-operations and business models are required in the future.

3 Drivers of change

3.1 S&T drivers

The automotive industry benefits a lot from basic research in fields such as physics and chemistry and well as in technology fields such as ICT, electronics and robotics. The main scientific and technological trends considered as particular important for the future are:

- Advances in basic sciences
- Electronics and New Sensors
- Advances in Information and Communication Technologies
- Material sciences

Advances in the basic science

Scientific progress in basic and applied science, particular in physics and chemistry are essential for the establishment of both incremental as well as radical new technologies. Technological progress related to the conventional powertrain (ICE) as well as alternative fuels such as hydrogen, biomass-to-liquids or electricity all exploit or rest on basic research findings: Advances with respect to the fuel burn within the combustions engine, electrolysis to produce hydrogen or the charging of batteries are physical or chemical processes which all benefit from new discoveries, models and theories. A recently published announcement by MIT researchers regarding how to speed up the charging process of batteries, for instance, can be mentioned in this context. Particularly, progress with respect to efficiency and effectiveness of many technologies is expected. Physics and chemistry are also relevant for questions related to how various kind of emission can be reduced.

Basic science forms also important building blocks for developing new materials; and material science itself rests largely on and combines basic scientific disciplines.
However, in the future the automotive industry will even use findings from neuroscience and humanities (e.g. bionics) in the future, for instance, in order to study the behaviour of drivers and other participants on road transport enabling the development of technology-assisted driving systems and new safety technologies.

**Electronics and new sensors**

Vehicles today have already a high amount of electronic components and the share is expected to rise in the future. The adaptive control of the engine, steering, safety equipment such as intelligent braking systems and intelligent lights all rest on electronic components (semiconductor, diodes, generator, video cameras, etc.). Advances in pattern recognition can be mentioned here, too. Due to the expected importance of electronic vehicles (see also below) research and development related to generators, motors, etc. is particularly relevant.

A specific technological trend is the use of various kinds of sensors. Sensors are and will be used for various applications and new products such maintenance, safety systems and drive-by-wire. Such sensors will measure and monitor all kinds of different phenomena such as traffic, noise, emissions, temperature, etc. Again, such developments are only possible in close interaction with basic and applied research in physics and chemistry.

Advances in electronics are also a key for the development of new manufacturing systems. In this context, mechanical engineering (not strictly a sub-discipline of electronics) has to be mentioned, too. Flexibility, quality and cost reduction are here the aims for scientists and developers. To some extent, nanotechnology, interdisciplinary field, will also gain some importance for specific applications.

**Advances in Information and Communication Technologies**

The majority of innovations within the automotive sector are related to Information and Communication Technologies (ICT). Research and development in ICT offers a wide array of new applications and products and is important for the control of the powertrain, safety, navigation systems as well as the design of new driver assisted systems. New hardware and software architectures, programming languages and security concepts are hence relevant for the automotive industry.

**Material Sciences**

New materials are significant for many future applications and products. New materials include lightweight alloys and polymers, fluids, coatings and nanotechnology are expected to be used increasingly which is on the agenda of many research institutes across Europe. In addition, different materials such as steel, aluminium, plastics will be combined which leads to multi-material design.

### 3.2 Demand-side drivers

In this paper changes in customer preferences, expected market developments and developments due to political activities are considered as demand-side factors. In that sense, it is assumed that needs of customers, public, and the society are often mediated by the government, for instance by new regulations. Thus, consumers as well as governments are considered here as “pull factors”.
General social trends and drivers include demographics, life styles, choices, mobility requirements, working patterns. The increasing demand for health, safety and security is as well a social trend but is also increasingly associated with environmental issues and hence treated separately. Moreover, the transport industry has specific demands which are discussed as distinct demand-side driver.

3.2.1 General social trends

There are a few broad social trends which will have a strong impact on the demand for vehicles in the future.

Currently, the economic crisis changes the consumption pattern which accelerates the demand for smaller cars. However, in the medium term it can be expected that the economy will grow again with further increased demand for mobility.

The demographic shift will change market demand: In 2020 more than 25% of the European population will be older than 60 years and about 70% will live in urban and suburban agglomerations. At the same time it can be expected that working life will be extended, with specific mobility requirements. In particular, the aging society in western countries will accelerate the demand for driver assistance systems as more and more older people will want to keep driving, despite increasing physical and impairments and slowing reactions. Increased mobile and home working and changing working and living patterns will create new demands as well.

Different national markets will require totally different vehicles and much more variety is expected in the future. While India and China will need inexpensive, safe cars, in industrialised countries OEMs have to serve the demand of a greying society. The increasing gap between wealth and poor will offer totally new market segments. Thus, there is a demand for more variants, individually tailor made vehicles and possibilities of usage.

There will be also a trend towards a stronger integration of customers into the design process and some customers may even become co-inventors and designers of their vehicles. This is in line with the broad trend of the individualisation of the society. Individuality is by no means limited to appearance or design of a car, it includes also electronics and software which allow to specify a car for the very individual demand of the user. Thus, a car will have individual “character” in the future, a vehicle will recognise their owners, be able to adapt, listen and understand, it will have personalised displays as well as transmission control systems that are capable of learning. Many additional services can be offered and will be demanded by the driver which encompasses navigation, entertainment and so on.

3.2.2 Sustainability-related trends

Between 20 and 30% of CO$_2$ derives from road transport. The reduction of CO$_2$ and other greenhouse gas emissions associated with road transport is an important goal of the European Commission and its Member States. The European Commission and ACEA have agreed voluntary targets for passenger car of 120g/km CO$_2$ new care fleet average in the EU by 2012. In the US the ZEV regulation and has been expanded to some other states is also important as the US is an important export market for European car manufacturers.
The environmental impact may also be avoided by significant reduction so vehicle-kilometres, which, though, people may not accept. Thus, reduction of CO$_2$ by alternatively fuelled powertrains and improved conventional engines will help to reduce the CO$_2$ emissions. However, future legislation will impose lower pollutant emission targets.

Surveys show that consumers which have to willingness to buy environmentally friendly vehicles such as hybrid cars, wish at the same time that is visible, e.g. by a specific label, brand, etc. (Landmann et al. 2009). Thus, car manufactures will also increasingly sell image and reputation in relation to sustainability, to some extent this can also substitute other traditional values associated with a car. However, the demand for environmental friendly and more fuel efficient vehicles is also dependent on the oil price and varies across countries within Europe and worldwide.

The reduction of waste and conservation of resources is another important demand-side driven trend. The European End-of-Life Vehicle Directive is already in force and will require the development of material and structures. Accordingly, by 2015 at least 95% by weight of vehicles has to be re-used or recycled. Hence, vehicle design will need to take into account the requirement for disassembly and reprocessing. The prohibition of certain materials for use in vehicles such as lubricants will lead to more environmentally friendly products. In addition, legislation on electronic equipment (WEEE) and waste disposal will also influence the design and use of materials in vehicles.

The reduction of emissions of substances which can impact health which is particularly relevant for urban areas is another environmental associated driver for change. Particulates, NO$_x$, ozone and hydrocarbons are emissions which have to be reduced. The European directive Euro 5 and Euro 6 will mandate pollutant levels for diesel and gasoline engines and it can be expected the further stringent regulations will be issued which will deliver incentives for car manufacturer of private and commercial vehicles. After treatment technologies and the introduction of hybrid, fuel cell and alternatively fuelled powertrain technologies will be the technological solution for this demand by the industry.

Furthermore, the EU aims to reduce the energy dependency and to substitute the oil-based fuel market by alternatives such as natural gas, biofuels, and hydrogen. This will further trigger the development of new technologies. In 2001 the Commission set out the goal to achieve 20% substitution of fossil fuels by 2020 and national governments had to set national indicator targets as well.

Customers are increasingly requiring low interior noise, too. Low noise tires, new powertrain systems and advanced materials offer new technological solution to reduce interior and exterior noise. The demand for lower exterior noise is mainly driven by the public and legislation.

### 3.2.3 Safety and Security

The increase of safety was a main trend in the automotive industry in the past decade and customers increasingly called for safer technologies. Airbags, intelligent wheel brakes (ABS), Electronic Stability Program (ESP) and other systems have become a standard equipment for many cars. Partly, these technologies have their roots or were initiated by regulations.
National governments and the European Commission have also set targets to increase safety. For instance, the EU aims to reduce road deaths by 75% until 2020. The number of accidents, deaths and injuries is thereby quite different in the various EU member states, whereas Sweden has the best record. The vision of an “accident-free driving” is therefore the ultimate long-term goal. More secure traffic will at the end also realise savings in terms of lives, damage and time.

Apart from security, customers also require technologies which help to reduce vehicle related crime: Smart technologies help to avoid theft of key and cars.

### 3.2.4 Availability of goods

Despite the growing importance of the train, goods transports with trucks will increase in the next decade. The EU integration and enlargement as well as economic factors such as Just-In-Time production and distribution, goods transport contribute to this development. Furthermore, deregulation will increase competition, decrease costs and will further accelerate goods transport. Increasing global production and trade mean that the demand for freight carried by road, train, air and sea will grow.

Intermodality and interoperability are important in this respect and transport policy in co-operation with infrastructure providers and transport companies will demand and co-develop new solutions and strategies for transporting goods.

Road charging (e.g. tolls on motorways), the road infrastructure (e.g. green transport corridors with supply pint for biofuels) and standardisation (e.g. driver cabin, containers) have also important influences on the specific demand. They offer new opportunities for technological, logistic and organisational innovations by car manufacturers such as e-freight concepts, new concepts to combine long distance and urban transport.

Depending on the experiences with long and heavy vehicles (mage-trucks), which are presently tested (demonstration projects) in some European countries and may lead subsequently to the establishment of new directives, there may be also a growing demand for mega-trucks within Europe. This should have positive effects on the environment but would also contribute to the quicker abrasion of roads.

## 4 Emerging innovation themes and their requirements

### 4.1 New products, processes and technological trajectories

Advances in scientific and technological research and changing demand patterns allow to identify the following three main innovation themes regarded as highly important for the automotive industry:\(^2\)

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4.1.1 Powertrain technologies

a. Further advance of internal combustion engines

The downsizing of spark ignitions engines and diesel engines (e.g. by turbocharging) is an important technological trend to increase efficiency of traditional engines in the future. Advanced internal combustion engines (ICE) technologies can give a 20 percent increase in fuel efficiency at a moderate cost increase per engine. By using adaptive control advanced combustion systems with auto-ignition also allow to use other forms of energy such as natural gas and hydrogen. These combustion systems have also very low levels of NO\textsubscript{x} emission. In addition, low cost belt driven starter generators operating at 14V currently offered as start-stop automatic reduce fuel consumption.

Heavy duty diesel engines will be challenged by increasing efficiency (fuel consumption) and lower emissions (NO\textsubscript{x}, particulates, CO\textsubscript{2}). Combustion process improvements (e.g. four valves per cylinder), electronic control, particle filters and oxidation catalysts will be improved. Generally, the development of advanced aftertreatment technologies will particular be important for heavy duty diesel engines. The combination of NOx trap and particulate trap in one system offers cost and fuel consumptions and is a promising development track.

Another trend is the development of “combined combustion system” where a traditional gasoline controlled spark ignition system and a diesel homogeneous charge compression ignition (HCCI) engine will merge into one system along with new fuel properties, partly renewable sourced fuels. A sophisticated powertrain management system is required for this type of engine in combination with advanced transmissions.

b. Alternative fuels

Alternative fuels such as natural gas, biomass-to-liquids (BTL), compressed natural gas (CNG) and liquid fuels made of biomass have been proposed as way to reduce the dependence from oil and to increase the sustainability of cars. Some of these fuels can also be used as a blend with conventional gasoline or diesel and thus gradually allow to decrease the CO\textsubscript{2} emission. However, large scale production facilities are not available today for these alternatives fuels, except natural gas. Moreover, these alternative fuels require investments in additional tanks in the car and a fuelling infrastructure. Liquid fuel which is made of biomass raises also concerns regarding food use. So-called second generation biofuels are hence those that use only parts of the plants which are not used for food production.

Hydrogen is the most intensively debated alternative fuel. Hydrogen can be produced and stored in various ways. The production from electricity via electrolysis of water requires large scale quantities in order to be price competitive although some companies are developing “home refuelling stations”. For transport application, hydrogen can be stored either in liquid or gaseous form, or in a hydrogen rich fuel such as methanol or petrol. Another possibility to store hydrogen are metal hybrids. Alternatively, hydrogen can be produced via reforming natural gas or methanol but also biomass. Generally, the production, storage and transportation are the main technological challenges. Safety, cost and public acceptance will decide about whether and
which technological variant may win the technological race. In general, real breakthrough innovations are needed to reduce size and weight and to increase energy efficiency.

Hydrogen can also be used to power a traditional combustion engine (Hydrogen Internal Combustions Engines). However, due to the low efficiency of the internal combustion engine this technology seems to be rather inefficient compared to other alternatives, though, it may serve as milestone towards the establishment of fuel cell vehicles.

Alternatively, hydrogen may be used to run fuel cells (Hydrogen Fuel Cell). Fuel cells combine hydrogen and oxygen to produce electrical energy, which drives an electric motor to fuel the vehicle. Fuel cell vehicles (FCV) running on hydrogen have the advantage of being real zero-emission vehicles, not considering how hydrogen is produced. Hydrogen fuelled fuel cells are hence only truly sustainable when the hydrogen is produced from sustainable energy sources such as photovoltaics or wind power.

A fuel cell driven car needs a battery both for start-up and for conditioning the fuel cell. Apart from the fuel cell stacks the thermal management, the electric machine, the power converter and the starting system are all together important to develop an efficient vehicle. In addition, a reformer may by used to produce hydrogen from other fuels on board.

Using hydrogen requires a new infrastructure. There are two options: Hydrogen can be produced off-board, which is then stored on-board as compressed or liquefied hydrogen gas or in absorbed form. Or hydrogen is produced on-board by reforming a hydrogen-containing fuel. These different systems have implications for the distribution infrastructure. In the case of off-board production at a central plant a pipeline or the use of tankers would be necessary.

In general, there was a change in the fuel preference for fuel cell vehicles in the past decade: while in the beginning of the 1990es there hydrogen, methanol and gasoline were regarded as promising alternatives, in the last years there has been a preference on hydrogen-fueled FCVs.

However, for freight transport, the traditional fuels, i.e. gasoline and diesel, will likely dominate the propulsion system for the next 15 years or even longer. To some extent alternative fuels to propel ICE may also be used triggered mainly by regulations. Currently, there are some pilot demonstration projects using fuel cell buses for public transport in some cities worldwide.

c. Hybrid vehicles

The combination of electricity and hydrogen or the combination of electricity and advanced ICE technologies is another alternative for propulsion. While some experts see it as further step of refining the conventional engine technology, others see it as a bridge from the pure internal combustion engine battery electric vehicles (BEC) or fuel cell vehicles (FCV), the later ones are all electrical powertrains. However, there have been developed different hybrid concepts:

Hybrid electric vehicles (HEV) are regarded as important technology and milestone on the road to fully electrified powertrains. HEV combine a conventional combustion engine and an electric engine. Hybrids with an Integrated Starter Generator (ISG) and down-sized engines will become an interesting product particular for city traffic. This so called “mild hybrid technology” exploits engine shut off and break energy recovery to increase efficiency. The ISG will replace the starter and the generator and converts mechanical power into electrical power and vice versa. Research related to the Starter Generator, the electronic machines, control systems and weight reduction are crucial for this type of hybrids. In addition, new transmission systems, batteries and supercaps have to be developed.
The hybrid vehicle offered today (e.g. by Toyota and Honda) are hybrid electric petrol vehicles and hybrid electric diesel vehicles. The later ones are also of interest for trucks and busses, particular for urban areas.

A plug-in hybrid electric vehicle (PHEV) is another promising variant of electrified powertrains. The batteries can be recharged by plugging the car to the normal power grid. Another hybrid approach is to use efficient auxiliary power units (APUs) to supply basic power needs supplemented by a main internal combustion engine providing high power. The APU is used as a generator to recharge the batteries which is for instance of interest in the absence of a charging infrastructure. Alternatively, the APU may be also provided by a fuel cell (hydrogen). Thus, fuel cells or traditional combustions engines may serve as APUs. However, as already mentioned fuel cell systems require significant reductions in cost, weight and size to be commercially attractive.

Full hybrids with a higher share of electric power is another option but is associated with additional complexity and new components. Full hybrids require a larger battery and a larger electric motor and allow driving at low to moderate speed. Often, it is regarded as further step towards the full electrification of vehicles.

d. Electrified powertrains
Fully electric vehicles (EV) have been developed for more than a century and are produced so far for market niches. However, significant improvement and technological breakthroughs in energy storage technology are needed. The main cost driver of electrified powertrains will be the relatively high cost of the batteries. The infrastructure to load up batteries is a further key technological challenge. The existing power grid may also provide the infrastructure for the using onboard electricity powertrains.

With more CO\textsubscript{2}-neutral electric energy (from renewable or nuclear sources) and the battery technology available, the electric vehicle may become an attractive option for mass markets. However, studies (Book et al. 2009) show that unlike in Europe in many countries such as India and China the production of electricity is CO\textsubscript{2} intensive and the substitution of conventional cars by electric vehicles would not reduce CO\textsubscript{2}, neither today, nor in 2020. In Europe, due to the power generation mix, an electric vehicle produces about 60% less CO\textsubscript{2} emission than a conventional car. With more renewable energy production this amount becomes even better.

4.1.2 Traffic management systems, drive-by-wire, and new safety systems
New applications and progress in traffic management systems, technology-assisted driving and new safety systems are all technological related and hence treated as common innovation theme in this paper. Advanced software, sensors, electronic and telematics technologies using both onboard and infrastructural based systems will allow to increase safety, comfort and efficiency of driving, and hence mobility. Human vehicle interaction, neural network software, pedestrian sensors, interaction support systems, video and radar sensors, pattern recognition, dynamic routing etc. will be technologies developed in the next decade. These technologies are relevant for all types of vehicles: cars, buses and trucks.

Traffic management systems and ICT-assisted driving support the driver and many technologies and solutions have already been proposed in this context: navigation, route planning, smart cruise control, lane following, and ultimately full self-driving. Based on near-distance and far-distance radar adaptive cruise control (ACC) may be realised, and in combination with video
information such vehicles are capable of automated parking (partly already on the market) and driving. Studies expect that between 2030 and 2040 autonomous driving will be introduced (e.g. UK Foresight Vehicle Roadmap). The customer acceptance and legal problems are major barriers related to these technologies and solutions. The reliability of electronic, software and (mobile) communication technologies is highly important in this respect.

Advanced traffic management and intelligent transport systems will also allow offering solutions for specific applications for freight transport and various services for the transportation industry such as tracking of goods, on-trip driver information, electronic payment, fleet management, ACC, automated platooning, vehicle pre-clearance, etc. Such systems will also have positive impacts on environment and safety and could help to reduce cost due to traffic congestion. On the intersection between technology and demand new transport concepts such as cargo caps may be developed as well.

The establishment of traffic monitoring and management systems (e.g. dense, international network of sensors along the street) is a prerequisite for these innovations as such systems provide the data for various kinds of applications. Real-time traffic information is already available today and applications such as travel assistance, route planning, etc. are first successful ideas and innovations. However, in the future real-time date sources ranging from television cameras, traffic sensors and weather sensors will be used. Moreover, the car itself will have sensors as well and communicates with other agents of the system.

New passive safety concepts such as “intelligent” or “smart” restraint systems that adapt to the actual accident condition will be developed, too. Such systems are equipped with sensors that systematically manage the levels of restraining forces and how they are applied to the occupant. Accident statistics and investigations will be carried out to deliver the information necessary to develop such systems.

Further advances in vehicle and structural design and the use of materials will impact the mitigation of the effects of accidents, both for vehicle occupants and those outside. In addition, technologies which observe the behaviour of the drivers such as body sensors measuring skin conductivity, and eye movements will be used to improve safety and assist driving. Much research will be carried out to understand the drivers’ behaviour which delivers information to design reliable driver assistance system: Brain, recognition and pattern research is already on the research agenda of many large OEMs.

Active safety encompasses different technological solutions such as pre-crash warning, hazard analysis, pedestrian sensing and prevention to post-crash rescue management. The development of an “accident proof vehicle” for instance has been declared as an ultimate goal within the UK vehicle strategy.

To summarise, some typical products incorporating safety and driver assistance are: Intelligent information and navigation (“Car Intelligence”), Neurotechnological driver surveillance systems, High precision navigation, Intelligent lighting, Night vision and driver assistance, Pedestrian, protection systems, Intelligent networked vehicles, and Bionic identification systems.
4.1.3 Design process and manufacturing systems

Advanced structures and new materials are a technological driver for the automotive industry which provides a number of economic and environmental benefits, particular in terms of reduced weights, increased strengths, increased vehicle performance and lower energy consumption.

As mentioned above new material technologies are important for the future vehicle development and many different materials will be combined. Connecting technologies are hence an essential innovation topic.

There is a direct association between vehicle weight and fuel consumption. Lightweight design can be achieved by focusing on material usage and vehicle construction (e.g. body structure). However, at the same time, many comfort and safety devices increase the weight of a car and hence new design trade-offs will emerge.

Recycling is another important trend (see also below) which will create demand for specific technical solutions and the use of materials. Life cycle analysis is hence highly important during the design process and new separation and dismantling technologies will be developed.

These developments raise new challenges and the combination of partly contradicting issues, e.g. the use of light material reduces the safety and makes the recycling more complex. Nevertheless, the weight of the car is expected to be reduced by 17% by 2020 (Wengel et al. 2003). The use of new material will allow to produce “lightweight cars”.

Design and manufacturing process technologies become a key competitive factors in terms of both efficiency and effectiveness. Virtual product development, simulation, testing and the vision of the digital factory may be the third revolution within the automobile industry with respect to production technology.

Modularisation and the establishment of vehicle platforms is another broad trend which requires both greater flexibility in production plants and lower costs for conversion. Such manufacturing technologies allow to reduce costs which is one of the key drivers to sustain competitiveness on the global scale.

In addition, spin-ins from aviation and the transfer of technologies from other industries can be also considered as innovation theme.

4.2 Organisational change, firm strategies and skills requirements

A key challenge for automotive companies (OEMs) is to put considerable resources into the development of new powertrain technologies. Many companies have announced to introduce electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV) for 2012 which reflect that they are currently developing these products (considering the long development times for new innovations and products). Moreover, new manufacturing technologies have to be adopted as well in order to increase flexibility and reduce cost.
However, this is not just a technology race: The introduction of new product and process innovations requires organisational change and the implementation of new business strategies. Organisational change and the realisation of new business models is difficult, particular for large established firms. Organisational inertia, resource dependency, incorrect market assessment or cannibalization of own technology are typical reasons for resistance of large firms to invest and develop new radical technologies. In a recently published book, Ashford (2002), for instance claimed “dinosaurs don’t fly” reflecting also upon the organisational adaptability of large car manufacturers.

Organisational change requires that OEMs adapt their (successful) organisational routines and strategies. They have to unlearn current beliefs and routines and have to develop their core competencies in a way that they do not become core rigidities (Leonard-Barton 1992). Consultants and academics see the danger that OEMs struggle to change their business models, marketing strategies, the management of expectations and the management of suppliers networks and partners.

Although, for instance, many large OEMs have mastered successfully the increasing integration and exploitation of electronics, information and communication technologies, in the future a more comprehensive shift may be required, particular as many innovations such as electric vehicles or ICT-assisted driving are of systemic nature.

The automotive industry can also benefit greatly by using knowledge from the aircraft and aviation industry, particular regarding materials, navigation, driver assistance and safety systems. Generally, absorptive capacity is highly relevant for OEMs in highly uncertain technological environments.

Another challenge particular for the engineering teams will be the handling of inherent trade-offs in designing new vehicles. As already mentioned, the achievements of different goals related to sustainability, effectiveness and safety is associated with difficult decision-making, for instance in relation to the use of new materials. The need for recycling may limit the number of different materials and plastics being used and will also require labelling of components. The design process of the car needs to take into account at an early stage the requirement for recycling and improved dismantling technology. New logistic strategies and services in relation to the re-use may have to be adopted, too.

New powertrain technologies and the increasing role of traffic management and safety systems require new partnerships from car makers. Traditionally, the automotive supply industry itself is as large as the automotive industry (OEMs) itself. In the last decade vertical disintegration happened, as a consequence, car makers are increasingly reliant on suppliers. Existing supply chain relationships and networks may harm organisational adaptation and the search for new scientific, technological or market knowledge.

With the development of new technologies (powertrain, safety systems, materials) car makers have to integrate new suppliers and adapt their supply chains. Companies will have to establish (new) horizontal and vertical relationships with OEMs but also other organisations in order to establish standards and decrease costs. Co-operation between energy suppliers and car producers are already formed. In Germany, for instance, Daimler will co-operate with RWE, VW with e.on, and Toyota has formed a partnership with the French eDF.
Consumers worldwide, particular in Europe, increasingly buy more environmentally friendly vehicles and base their perception of brands in relation to environmental issues. Thus, OEMs have to implement new marketing and branding strategies. In this context, eco-labels currently used by many companies to differentiate such as “blue” or “eco” are on the long term not sufficient and do not deliver a sustaining competitive advantage. In the eyes of the customers these labels are interchangeable and difficult to allocate to the car manufacturer. In this context, customer surveys reveal that customers expect that it is visible when they drive a clean vehicle (Landmann et al. 2009). Thus, the new customer segments for new vehicles such as electric cars have specific characteristics (lead customers, opinion leaders) and the cars need a distinctive design.

Moreover, it is unavoidably to communicate honestly about what can be expected form new technologies. There is a huge danger that the creation of false expectation will lead to dissatisfaction and lower sales. Hyped expectations about the availability of new technology will lead to dissatisfaction and lower sales in short term, since customers tend to wait for the new technology. Thus, OEMs have to manage customer expectations. Accordingly, OEMs have to develop technological roadmaps and share them with their customers, partners and employees.

With respect to new environmentally friendly cars, currently companies are introducing either entirely new models (e.g. Toyota Prius) or launch models as part of the existing portfolios (e.g. Ford Escape Hybrid) where the alternative powertrain does hardly differentiate from the regular counterparts. At the moment, Toyota and Honda benefit from early launches of hybrid vehicles and customer surveys show that consumers require real buyable products and not just demonstration cars such as the BMW Hydrogen 7 or the Mercedes Benz F-Cell A-Class. As long as companies do not successfully commercialise such (niche) products spill-over effect on sister brands cannot be exploited. This is also one reason why consumers believe that large western premium brand such as BMW and Daimler are at least suited to develop hybrid or electric drive technology (Landmann et al. 2009).

Moreover, it can be expected that new players will enter the market, particular in the field of electric vehicles. These entrants have often lower cost structures (e.g. Tata) and other competitive advantages such as technological focus which challenges incumbent OEMs or come from the battery industry which is regarded as one of the key technologies.

In addition, global car manufacturers are acting in different context and environments and hence have to follow divergent strategies in order to respond to manifold challenges on different geographical markets and locations due to different taxations, environmental consciousness, regulation, etc. Due to diverging and more heterogeneous market needs manufacturer have to enlarge their portfolio and to invest in flexible manufacturing technologies.

New vehicles may change the business rules and we may even see a development such as in the mobile phone industry where companies sell solutions (mobility), hence OEMs will become more a service provider than an equipment manufacturer.

Finally, new technologies have also many implications for the OEMs’ service and sales networks. OEMs need also well-trained dealers which are able to support and advice the customers in relation to new clean vehicles and powertrain technologies. Otherwise the competitive advantage of having a service net cannot be exploited. In addition, high-voltage electricians are needed to work in electric powertrain components.
5 Institutional and structural co-development and implications

Technology can provide a source for the competitiveness of companies, industries and nations. However, innovation and technology researchers have repeatedly stressed that a focus on technology should not undermine changes on institutional and socio-economic level. Social structures such as norms, values, expectations, procedures, standards and routines are part of the institutional environment which are a strong driver for the development of the automotive industry. However, institutions generally are relatively resistant to change and have a high level of resilience. The transformation of systems often happens over a long period. The introduction of airbags, air conditions and low emission engines demonstrate institutional change, which are now accepted and internalized while they were unacceptable 20 years ago. Accordingly, different actors and institutions such as OEMs, suppliers, research institutions, other industries (e.g. oil industry), the government, and customers co-evolve together and negotiate and change rules and standards over time. Usually, new radical technologies, new market entries by entrepreneurial firms, shifts in market demands, and external crises or shocks have the potential to trigger and accelerate institutional change.

From the perspective of the innovation system, the automotive industry so far has often rather enacted the institutional environment and created new market needs and seldom responded just to customer demands, hence innovations were rather technology driven (push innovations). However, consumer preferences have changed and will change and may have a stronger impact on the business policy and product portfolio of companies in the future.

Modern organisational and institutional theory argues that institutions not only constrain the behaviour of firms but firms influence and enact institutions. This is for sure the case in the automotive industry. In this context, Levy and Rosenberg (2002), for instance, have argued, that strategic behaviour of firms related to climate change is highly political. They have shown that the automotive industry forms coalitions to shape public opinion, and alliances are built between companies and governments in order to exert influence and gain acceptance for their own strategies. New product innovations such as the Toyota Prius Hybrid have the potential to shift the regime and institutional rules and make hybrid cars accepted in the future. Interestingly, according to Toyota officials at an International Energy Agency (IEA) workshop in Tokyo 2008, the development of the Prius was partly triggered by the Californian ZEV regulation.

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3 There have been published and discussed many theories in economics, sociology and management which conceptualise and interpret organisational and institutional change and adaptation which entirely different interpretations about cause and effects.

4 Hoed (2004), for instance, defines the ‘institution of automobility’. He describes: “This does not refer to the physical artefact alone, it refers to the way a car is 'supposed' to look like, its dominant design, its function in society, or the distinction of different vehicle classes. … Also it refers to taken-for-granted aspects of automobiles, for instance the requirement of roads and tank stations. The institution of automobility also includes commercial aspects in terms of production (mass-manufacturing, scale production), shared business models (large scale production, platform strategies, model portfolio, multi-brand consortiums, supplier relationships) the way cars are distributed and marketed, and the image of different car brands. All of these factors form relatively stable norms, values, routines, beliefs and expectations surrounding the car” (Hoed 2004, 64).

5 The quote in a Siemens VDO Report: „What Consumers Want. Demand for driver assistance systems is also coming form consumers themselves …“ (Siemens 2002, p. 25) reflects the current attitude of the automotive industry which creates markets based on the potential of new technologies (technology-push) and nut just respond to market or customer needs.
However, market factors and market changes have played a rather modest role in explaining decisions to adopt alternative propulsion technologies such as fuel cell (Hoed 2004). Fuel cell (FC) technology, for instance, does not provide answers to dominant market demand such as cost reduction, safety and comfort. This may explain the modest R&D activities in FC technology. So far, some authors argue that environmental merits were only modestly appreciated by consumer in many countries which may become a barrier for developing new radical propulsion technologies. Hoed (2004 201) for instance argues that this has consequences for the institutional environment: “… carmakers may use the argument of limited marked demand to force regulators to loosen mandates and emission standards.”

The development and diffusion of new technologies such as advanced driver assistance systems, electric vehicles or hydrogen fuelled cars can be interpreted as radical innovations. These types of innovations and technologies build on a different set of engineering and scientific principles and substitute existing technologies and competencies of the established industry. The technologies and innovation themes described in this paper are all associated with a deviation from the current competencies of the established companies.

Many researchers (e.g. Utterback 1994, Thusman and Anderson 1986, Christensen 1997) have shown that established or incumbent firms have difficulty in dealing with radical technologies. Fuel cell technology and electric vehicles are radical technologies which overturn existing core competences of car makers. This change may happen in short period of time or incrementally over a longer period. Some innovation theories based on historical studies such as the one of Tushman and Anderson (1986) postulate that in the automotive industry there exist short periods with high level of variation and change with the selection of a dominant design which is followed by longer periods with minor changes. A recently published consultancy report of Roland Berger, in contrast, argues with respect to the electric vehicle that the change will be slow: “The much heralded electrification of the powertrain is not just hype. But it won’t be a big bang either. A gentle transition to the new technology will take place over a period of decades, ultimately reshaping the industry as we know it.” (Landmann et al. 2009, 6). Hence, the question, whether a change may be gradual (stepwise, incremental) or quick (radical) is an open issue and important factor for developing scenarios. We also have to keep in mind, that not necessarily the best technologies are selected by the market. Historical studies revealed also that the transformation of an industry due to technological change has often a phase were “hybrid technologies” are used for which mitigate change. The change from sailing to steam engines can be mentioned were some ships were used during a certain period which used both technologies in parallel and were a combination between sailing ships and steamships (Geels 2002, 1267).

Particular in relation to electric vehicles and hydrogen driven cars new infrastructures are required (e.g. refuelling or charging infrastructure) to foster market diffusion. This is a costly proliferation of different technologies. The large investments in fuel distribution infrastructure required are a significant barrier for the adoption of alternative fuel solutions. However, it is yet no clear which re-fuelling route (e.g. in the case of hydrogen) will be favoured ultimately.

Such an infrastructure may be build up in key regions in Europe, the US and Asia, focusing on urban areas, which may be regarded as potential lead markets. Recently initiated pilot programs in Denmark, Israel and France can be referred to in this context.

The availability of a specific infrastructure with sensors is another necessity for the development of innovations around the theme of driver assistance and safety. Such innovations and applications require an infrastructure which enables the communication and system-level control.
New partnerships with infrastructure providers, public authorities, private transportation providers, etc. will be needed in the future. Public-private partnerships will likely emerge as the public sector alone will not be able to finance the huge investments in the infrastructure. This requires an adequate business model from the side of private providers, governments are challenged to provide the infrastructure and optimize the use of that infrastructure.

Apart from providing the infrastructure, regulation may shape the development of new automotive technologies and mobility solutions. In the past policy has played an important role regarding the introduction of new technologies and innovations, particular in respect to safety and sustainability. The Californian Zero Emission Vehicle (ZEV) regulation, for instance, delivered an important force to develop cleaner and more efficient cars. In 1990, ZEV regulation mandated carmakers to sell at least 10% of their vehicles without any local emissions (i.e. NO\textsubscript{x}, CO, etc.) in 2003. This regulation delivered the incentive for many OEMs to start developing alternatively propelled powertrains such as electric vehicles (EV) or fuel cell vehicles (FCV).

The European Commission has established more and more stringent policy measures in relation to environmental and safety issues (e.g. Euro I, II, III, and IV) with strong incentives for car makers to produce more sustainable and safe vehicles since the mid 1980es. However, due to the strong increase in car use, the air quality has improved only slightly in the 1990es. However, the regulation was not radical enough to deliver incentives to quickly develop new alternative powertrain technologies, so the industry mainly improved the ICE. Thus, in order to foster the development of new alternative technologies further and more stringent regulation may be needed which particular may challenge the ICE paradigm.

In general, the relationship between industry and policy is much debated and regulation may come too late or is carried out half-heartedly. The US ZEV regulation for instance shows that gradual adaptation (change and postponement) of the political goals mainly due to pressure form the automotive industry and to a lesser extent by the oil industry (Doyle 2000). However, studies have shown that the institutional environment (e.g. regulation) not necessarily favour a particular radical technology (Hoed 2004) and it can be debated whether government’s quest to induce (environmental) innovations could provide the necessary incentives to adopt radical new technologies. Although the Californian ZEV regulation has lost some credibility due to postponements and watering down of standards, it is still regarded as most important regulation to stimulate the development of alternative technologies. From the evolutionary innovation policy theory perspective, regulations such as the ZEV regulation, have the advantage that no technology is actively selected or prioritised. Thus, this factor is regarded as another important dimension (driver) for constructing possible future scenarios for the future of the automotive industry.

Governments have set different priorities and programs to promote the development of specific alternative fuels. In the US, Japan, and Europe alternative fuels and the development of powertrain technologies have been promoted. In these programs large as well as relatively small companies have been involved (e.g. GM, DaimlerChrysler, Toyota) and a couple of prototypes emerged.

Finally, the emergence of personalised, intelligent, networked vehicles will require the establishment of an appropriate legal framework, another challenge for governments.
The high dependency on the oil industry is another remarkable factor in the automotive industry and hence it will be heavily influencing possible scenarios of the automotive industry. Depending on the possible breakthrough of new alternative propulsion technologies, new complementary industries (production of biofuels, electric energy providers, etc.) will become more important and change the industry.

6 First elements of scenarios

We have described different drivers and developments which may influence the future development of the automotive industry. Taken jointly together these drivers may have accelerating, disturbing, counteraction or confounding effects.

The large technological uncertainty and possible breakthroughs, dependence on the oil industry, governmental activities (e.g. regulation) and public awareness for global warming are considered as key factors shaping the future development and possible scenarios. However, there are also other uncertainties such as the diverse consumer behaviour in different world regions, the development of countries such as India and China which have a strong impact on the future development and possible scenarios. The current economic crises accelerates the structural change of the global automotive industry and may transform the competitive landscape and position of the US, Europe, Japan and Southeast (China and India) car manufacturers.

In recent years a couple of projects, studies and papers have looked at the likely future development of the automotive industry, often focusing on alternative fuels and powertrain technologies (FURORE 2003, May 2004, Global Insight 2008, Landmann et al 2009, Book et al. 2009). Generally, statements about the future are associated with much speculation and there exist entirely contradicting assessments and beliefs within the industry. In this context one may remember title of the documentary film with the title “Who killed the electric vehicle?” and see the recently published study by a consulting company with the title “The Comeback of the Electric Car?”

Accordingly, estimations and prognosis about the cost and diffusion of alternatively powered vehicles such as electric and fuel cell vehicles have to be treated with care. However, most studies, market outlooks and scenarios published to date do estimate that the conventional combustion engine will still have the major market share and account for up to 70% in 2020. A recently published simulation model of Boston Consulting Group, for instance, estimates that electric vehicles will not have more than 6% market share in 2020, even if the oil price will raise to 300$ per barrel. Depending on the development of the oil price hybrid vehicles will have a market share of up to 40%. According to a market outlook of a consulting company many automotive companies plan to introduce hybrid vehicles and electric vehicles until 2012 (Landmann et al. 2009). Hybrids with an integrated starter generator (ISG) based on 42 Volt, for instance, will become an interesting product particular for city traffic. This study also reports similar figures for the diffusion of alternatively propelled vehicles as the former one: For instance, hybrid electric vehicles without plug-in functionality are expected to account for about 10% for the global market share in 2020, electric vehicle will make up about 5% of the global market.
There have been published a couple of scenarios for the “hydrogen economy” with entirely diverging perspectives, too. For instance, studies which estimate fuel cell costs range between 325 and 8,100 Euro/kW – a factor 25 difference – which makes any serious estimations awkward (Hoed 2004). Material costs and assumption regarding scale of production are difficult to make, apart from the fact that the infrastructure costs are immense. Estimations about a hydrogen infrastructure differ about a factor of 10 (e.g. up to 400 billion $ for the US for a wide penetration in 2030). Accordingly, published hydrogen scenarios range between a total flop on the one end or a full hydrogen economy on the other end. However, in the last two to three years more and more scepticism has emerged after a rather enthusiastic estimation during the end of the 1990es and beginning of the 2000s/century/millenium. Barriers in costs, complementary technology (e.g. hydrogen storage), infrastructure and even environmental performance (CO₂) have resulted that fuel cost vehicles lost its superiority status. The BCG Report writes in this context “Hydrogen-based propulsion is not likely to be commercially successful within the next dozen year because of its low overall efficiency and the extremely high investments needed for infrastructure and fuel cells” (Book et al. 2009, 3). Currently, the development of hydrogen vehicles or the establishment of a hydrogen economy bear the highest risks, and it is unlikely that companies and governments under the actual economic crisis may take this risk in the coming 10 years.

Moreover, announcement of car manufacturers have to be treated with care as the experience shows that projects and plans were not met, postponed or discarded. For instance, the Bavarian car manufacturer BMW announced in 2000 that it will produce hydrogen-powered luxury passenger for the 7-series in 2008, which was not realized yet apart form a small series leased to prominent people: BMW forecasted that 25% of the vehicles to be hydrogen-powered by 2020. On the other hand many competitors were surprised by the success of Toyotas hybrid vehicles introduced in 1997.⁶

The competition between US, European, and Japanese car manufacturer in regard to different technological solutions is another important driver for the future development. The large European manufacturer have adopted different strategies regarding powertrain technologies: DaimlerChrysler/Daimler Benz and BMW have focused on hydrogen, while PSA and Renault have favoured the development of BEV. Fiat and Ford were rather restrained so far. According to recently published surveys (e.g. Landmann et al. 2009) currently consumers are regarding Toyota as those companies with the highest reputation regarding producing clean drive technologies. In this context, there is the danger that US and European premium brands lose their competitive advantage being technological leaders.

Shocks and crises are regarded as possible trigger for technological, institutional and structural change (e.g. Hughes 1986, Hoffman 1999). They provide occasions where established practices and routines are reflected upon. Thus, the current economic crisis may accelerate technological, structural and organisational change and has to be considered as major factor in any scenarios building process. While in the 1970 the development of alternative powertrains were ambitious, triggered by the first oil crisis, due to stabilising oil prices, many programs were re-dimensioned or even terminate. Will the same happen due to the recent economic crisis?

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⁶ GM for instance stated in 2000: “Toyota and Honda are selling their [hybrid] models at a loss. HEVs are expensive due to its complexity and low production volumes.” (Interview Spearot, GM, February 2000)
This paper points out that public policy (taxation, grants, subsidies, regulation, providing infrastructure) has a strong impact on the development and diffusion of new environmentally friendly and safe vehicles. Accordingly, the role of public policy in shaping the agenda for technological development (e.g. R&D programs), regulation but also infrastructure investments have to be discussed when drafting scenarios.

New radical technologies may only be developed until 2020 if a couple of conditions are met such as stringent regulation, technological breakthroughs (e.g. batteries), competition between car makers and the involvement of entrepreneurial firms. Specific powertrain technologies such as Full Electric Vehicles or drive-by-wire systems certainly can be regarded as disruptive innovations which require entirely new competences from the firms which may be difficult to built up my established firms.

Considering similar drivers as described in this paper, May (2004) has published two different scenarios for the automotive industry in 2020. They are labelled as “Safe and sustainable transport” and “Consumer revolt”. In the first case the industry and government achieved together a much safer and sustainable transport system. Interestingly, this scenario has been published in 2004 assuming that the development will occur during a period of continuing prosperity. In the second case, the continuing availability of cheap oil has undermined the attempts of policy makers and manufacturers to promote alternatives to the conventional combustion engine in a significant way.

To sum up, it is proposed here that scenarios should be structured amongst others or at least around the following key (dependent) trends or drivers:

- oil development and price,
- economic development,
- climate change and associated CO₂ measures (regulation)
- consumer behaviour
- technological progress and breakthroughs
- organisational and institutional inertia

Based on the drivers oil price and need for taking actions due to global warming, scenarios for the automotive industry may look like illustrated in the Figure 1:
Figure 1: A possible scenario matrix for the automotive industry in 2020

Scenario I:
The public, governments, organisations and customers feel the need to reduce CO₂ and jointly interact to develop new sustainable products based on radical technologies. The quick economic recovery and subsequently rising oil prices enhance the need for truly sustainable vehicles. The high prices for the transformation are paid by the public and private. However, safety innovations may have a lower priority due to the high investments in sustainable vehicles.

Scenario II:
As the economy recovers only slowly, associated oil prices stabilised and deliver less incentives for a quick change. However, the public awareness for global warming triggers the introduction of environmentally friendly cars, which though happens only slowly. The conventional combustion engine is hence further improved to meet the goals. Product and service innovations regarding mobility, driver assistance and safety are more important as the customers have the willingness and can afford to pay for these innovations.

Scenario III:
The rising oil prices deliver incentives for customers and car makers to invest in alternative technologies. However, the change is incremental and it takes longer that environmentally and efficient vehicles are widely diffused. Vehicles use alternative fuels such as biomass-to-liquids due to cost criteria, which, though not necessarily reduce CO₂ emissions.

Scenario IV:
In this scenario energy security concerns have diminished, the oil price keeps low. Government is not able to put high taxes on oil or to subsidise alternative propulsion systems. Consumers concern is personal mobility. However, customers are interested in driver assistance and safety and car makers offer such innovations as they allow to successfully compete on the global market. There is a further concentration of the market.
7 Key questions

Based on the outlined technological trends and emerging market opportunities we regard the following key topics and questions as highly important to be discussed within the Foresight Workshop which at the same time are relevant for policy makers:

- Does Europe lose competitiveness compared to Japan (leadership in hybrid technologies) and Asia (low cost production) and what are the innovation themes to gain competitiveness?

- What are the most uncertain technological and demand-side related drivers which have at the same time a strong impact on the future development of the automotive industry?

- How can the crisis be used as enabler for the development of safer and more sustainable cars considering the constrained financial resources?

- What are the most relevant trade-offs with respect to design decisions (light, safe, ecological, etc.) by car manufacturers?

- Should R&D policy (already) favour the development of specific technologies such as material research, drive-by-wire, alternative fuels? Should the Commission develop a common strategy in co-operation with ACEA for the European automotive industry with respect to alternative technologies (priorities)?

- In which fields the most important new firms (entries) may emerge which have an impact on the traditional automotive industry and enables the transformation?

- How can new entries and entrepreneurial firms be supported? Policy should focus not only in the established firms but may spend a larger portion of (R&D) funds for new entries.

- Should policy focus on regulation instead of standard setting for a particular technology? (Set boundary conditions rather than selecting technologies)

- How do deal with trade-offs in policy making? Policy has an interest that the safe and sustainable cars are produced, at the same time it is also of interest to strengthen the competitiveness of the automotive sectors. This may be associated with some trade-off.

- How to strengthen policy in continuously setting stringent standards (environment, safety)? (Local) governments may introduce subsidies for low or zero-emission vehicles making the more attractive.

- Should policy support the creation of niches, small scale learning experiences and lead markets? Radical technologies often emerge in market niches and some local governments have already initiated pilot programs.
# Abbreviations:

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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ABS</td>
<td>Anti-lock Braking System</td>
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<td>APU</td>
<td>Auxiliary Power Unit</td>
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<tr>
<td>ACC</td>
<td>Adaptive Cruise Control</td>
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<td>ACEA</td>
<td>European Automobile Manufacturing Association</td>
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<td>BCG</td>
<td>Boston Consulting Group</td>
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<tr>
<td>BTL</td>
<td>Biomass-to-Liquids</td>
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<tr>
<td>BEV</td>
<td>Battery Electric Vehicles</td>
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<tr>
<td>CAI</td>
<td>Controlled Auto Ignition</td>
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<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
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<td>EC</td>
<td>European Commission</td>
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<tr>
<td>EV</td>
<td>Electronic Vehicle</td>
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<tr>
<td>ESP</td>
<td>Electronic Stability Control System</td>
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<tr>
<td>FCV</td>
<td>Fuel Cell Vehicle</td>
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<tr>
<td>HCCI</td>
<td>Homogenous charge compression ignition</td>
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<tr>
<td>HEV</td>
<td>Hybrid Electric Vehicle</td>
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<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
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<tr>
<td>ISG</td>
<td>Integrated Starter Generator</td>
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<tr>
<td>ITS</td>
<td>Intelligent Transport System</td>
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<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
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<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
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<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicles</td>
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<td>ZEV</td>
<td>Zero Emission Vehicle</td>
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