NanoDialogue
of the German Government

Opportunities and Risks of the Use of Nanotechnologies in the Automotive Sector

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Summary of the discussion

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Content

1 Background ... 4

2 Proceedings ... 4

3 Regulatory Framework ... 5

4 Potential Benefits and Risks from Nanotechnologies in Vehicles ... 7

5 Application Areas and Product Examples ... 8

5.1 Introduction ... 8

5.2 Air filters ... 9

5.3 Sol-Gel coatings ... 9

5.4 Sensors, Connectivity and Control ... 10

5.5 Lighting ... 10

5.6 Lithium ion batteries ... 11

6 Examples of Life Cycle and Risk Assessments ... 12

6.1 Environmental exposure and risks ... 12

6.2 Life Cycle Assessment of CNT in Lightweight Construction ... 12

6.3 Environmental impacts of batteries ... 13

7 Mobility in the Future ... 14

8 Summary ... 15

1 Background

Since 2006, the German Ministry of the Environment, Nature Conservation, Building and Nuclear Safety has organised the German stakeholder dialogue on opportunities and risks from the use of nanotechnologies. The dialogue started within the framework of the NanoCommission, which was supported by topical working groups.

Since 2011, the discussions have taken place in 2-day ExpertDialogues. In June 2015, the 5th dialogue phase started with a conference to reflect on the past 10 years of discussions and to collect topics for future debates. Among other topics, the use of nanomaterials in the automotive sector was proposed and was implemented by the ExpertDialogue, the results of which are summarised in this report.

2 Proceedings

After a short introduction, two speakers provided an overview of current and future applications of nanotechnologies in the automotive sector. As part of this, one presentation outlined the trends in mobility as a whole. Then, two stakeholders presented their views on the challenges of applying nanotechnologies in vehicles. The legal framework regulating the use of chemicals in car manufacturing was presented with a particular focus on instruments and possibilities to limit the use of nanomaterials. Following this, two speakers presented exemplary applications of nanomaterials in cars: nano fibres in air filters sol-gel surface coatings. The day ended with a presentation of preliminary results from modelling exposures and potential environmental risks from various uses of nanomaterials, among others as additives in fuels and tyre and as catalysts in exhaust gas cleaning.

The second day started with a summary of the first day and an introduction to life cycle assessments for the use of carbon nano tubes (CNT) in automotive applications. Further presentations in the area of microelectronics gave insight into exemplary applications that increase safety using electronic sensors and control instruments and improving the lighting of vehicles (LEDs). The next session focused on energy storage technologies, including a presentation on the use of nanoscale silica-based materials in batteries and one on the optimisation of potential environmental benefits in nanotechnology-enabled batteries. The ExpertDialogue ended with a summary presentation and discussion on the future trends and developments in the automotive industries and the role nanotechnologies play in them.

This report presents the content of the presentations and discussions at the ExpertDialogue in a topical order. The presentations are available on the internet (only German).

3 Regulatory Framework

The EU End-of-Life Vehicles Directive (ELV Directive)[1] and the EU Type Approval Directive[2] regulate market placement and the disposal of vehicles in the EU in general.

The ELV Directive aims at reducing environmental risks from waste treatment and increasing recycling rates. It defines requirements on the vehicle design from the waste perspective. The Directive specifies a general duty to minimise the use of hazardous chemicals (reduction of the hazardous waste amounts) and restricts the content of four specific heavy metals in vehicles. Its Annex II includes specific exemptions from these restrictions. The Directive does not specifically address nanomaterials but the duty to minimise the use of hazardous chemicals does cover nanomaterials if they have hazardous properties.

The ELV Directive defines quantitative recycling targets. With a view to achieving these targets, some participants of the ExpertDialogue asked if, and to what extent, nanomaterials can be circulated (as part of the car components and materials) or if they could hinder material recycling. These participants regarded this particularly important because of the increased use of plastics in vehicles (lightweight construction) and the large volumes of materials used in the automotive sector. These questions could not be fully answered during the ExpertDialogue. However, one stakeholder reported that most composites used in lightweight construction include microscale carbon fibres rather than carbon nanotubes (CNT).

Some stakeholders mentioned that it is important to consider the export of vehicles at the end of their service life. This could also result in the export of potential (workplace) risks from nanomaterials to countries with a less well-developed waste infrastructure.

The EU type approval is a procedure to verify if a new vehicle type conforms to all relevant standards. It does not define self-standing (nano-specific) and material-related requirements but refers, among others, to existing standards and regulations for example on safety and emission limit values.

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[1] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles

[2] DIRECTIVE 2007/46/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles

The Directive on Restrictions of certain Hazardous Substances in electrical and electronic equipment (RoHS Directive)[3] only addresses electrical and electronic devices that are not specifically designed for use in automobiles. The directive explicitly mentions nanomaterials as potential candidates for a restriction in electrical and electronic devices. With a view to the increasing content of electronic equipment in vehicles, some stakeholders criticised that the RoHS directive does not apply.

The EU chemicals legislation REACH[4] regulates the manufacturing, import and use of chemicals on the European market, including nanomaterials. Several mechanisms exist in this framework to control potential risks from nanomaterials in vehicles, for example: the chemicals safety assessment and the risk management measures derived from it, marketing and use restrictions according to Annex XVII or the communication and potential authorization requirements. These mechanisms can be relevant if nanomaterials have hazardous properties and if they are identified/known. In the presentation, it was stated that nano-specific risk management under REACH is hardly possible, because:

- There is no definition of nanomaterials in the REACH text;
- The tonnage thresholds for registration (1t/a) and chemical safety assessment (10t/a) of nanomaterials are too high;
- The requirements for chemical-physical characterisation of nanomaterials in the registration dossier are insufficient;
- The (eco-)toxicological test to be provided in the registration are not sufficient and the test guidelines are partly not adapted to nanomaterials.

Some nanomaterials[5] were or will be subject to an EU substance evaluation by member state authorities, which may trigger control measures if risks are identified.

Stakeholders mentioned in several of the ExpertDialogue's sessions that nanoparticles could also stem from abrasive processes, aging or waste treatment of end-of-life vehicles. For intentionally manufactured nanomaterials it is unambiguous where to allocate the (product) responsibility for potential risks from nanomaterials – at the producer's. Furthermore, risk assessment is supported by at least some knowledge on the uses. In contrast to this, the unintentionally released particles are addressed, for example, under legislation protecting worker's health and emission-

[3] DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast)

[4] REGULATION (EC) No 1907/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)

[5] SiO2 and Ag (The Netherlands), TiO2 (France) and ZnO, CeO2, MWCNT (Germany)

related legislation as no clear allocation of responsibilities and identification of “uses” is possible.

Several stakeholders regretted that the EU Commission has done so little to rectify REACH deficits until now. They indicated that the long delay in discussing and deciding on the adaptation of the REACH Annexes as well as the failure to start a consultation on the Commission’s recommendation on a nanomaterial definition as a major reason for legal insecurity. This would be one reason for the automotive industry not to update their central communication instrument on chemicals in vehicles – the international material data management system (IMDS) – for nanomaterials.

The representative of Friends of the Earth Germany (BUND) highlighted that, in addition to the above mentioned adaptations of existing regulations, the uses of nanomaterials should be made more transparent, e.g. via a product register or product declarations by producers. Apart from enabling informed choices and facilitating risk assessment, this information would also be necessary to more efficiently and safely manage future end-of-life products.

4 Potential Benefits and Risks from Nanotechnologies in Vehicles

There could be many different benefits of using nanotechnologies in vehicles. These include increased safety of passengers (and potentially their environment), more convenient driving and environmental benefits, reduced resource consumption or the prevention of using hazardous substances.

Some contributors felt that all innovations should be questioned as to whether a use would make sense to society and/or if a specific use could be achieved more efficiently (or) better in another way. Some examples mentioned include the use of nanotechnologies for emission reduction, which was seen as useful but not promoted enough in the past, whereas “optically improved surfaces” would be the subject of much research although the societal benefits were questioned.

Some participants emphasised the need to holistically assess innovations in general, including in the automotive sector and that besides life cycle assessments, the recyclability should be considered as well as ethical and economic aspects.

Potential (eco)toxic risks from the use of hazardous nanomaterials were regarded as generally possible:

- During the production of vehicles and their parts (exposure of workers);
- If nanoparticles as such (e.g. additives in fuels or lubricants) are used or

bound nanoparticles are released due to aging or abrasion of the material matrix in the use phase (consumer or environmental exposure);

- If the disposal of (matrix-bound) nanoparticles causes release of (individual) particles to the human or natural environment and/or if material streams are contaminated by the nanomaterials.

If and to what extent this could cause environmental risks is currently being researched only for specific aspects.

Several debaters stressed that nanomaterials are only problematic if they have (eco)toxic properties. The identification of (eco)toxicity would be hindered by the (partial) lack of standardised testing guidelines that are adapted to nanomaterials and the fact that different forms and types of functionalisation of nanomaterials are used, which could have different effects on humans and the environment.

5 Application Areas and Product Examples

5.1 Introduction

In his presentation, Mr. Haas (Fraunhofer Alliance Nano and Fraunhofer-Institute for silica research) explained that nanomaterials and nanostructures enable the development of innovative materials because of the (combination) of their partly new properties. Already today, nanomaterials would be essential components of the car body, the engine, the tyres, the electrical and electronic parts as well as the fluids used in vehicles.

The material functionalities achieved with nanotechnologies range from an increase in rigidity or reactive surface area to optical effects and changed thermal, magnetic and electrical properties. According to Mr. Haas, the aims of nanomaterial applications are, among others:

- Reduction of fuel needs and/or pollutant emissions through reduced abrasion (engine, tyres), more efficient incineration (fuel additives, catalysts), improved heat insulation or conduction, or the use of additional energy sources (very thin solar layers);
- Prolongation of product lifetimes through more stable materials (plastic composites, harder coatings), reduction of abrasion (lubricants) or corrosion protection (coatings);
- Improved cleaning performance of materials, among others via the use of nanofibers in filter materials, easy-to-clean surface coatings, phototcatalytic lacquers etc.;

- Increase in safety through sensors and electronic control systems;
- Improved convenience, visuals, haptic properties and equipment of the car interior in general.

Apart from applying nanomaterials in an unbound form in liquids, such as fuels or lubricants, mostly nano composite materials and nanomaterials bound in material matrices are used in vehicles. The relevance of the application areas and components improved by nanotechnologies has shifted in recent years towards electronic components, lightweight construction and battery technology.

5.2 Air filters

In his speech, Mr. Neumann (MANN+HUMMEL GmbH) presented air filters for the engine compartment and the car cabin that contain nano scale fibres, which are produced in an electro spinning process: polymers are spun from a solution and are directly fixed with adhesives to the filter material.

Due to the nano fibres, the air filters achieve higher filtration rates and dust storage capacities for different particle sizes compared to conventional filters. If these filters clean the engine induction air, damage from abrasion can be reduced and the air mass measurement device can work with less disturbances. If used inside the car cabin, these filters can better extract ultrafine particles (UFP) from the indoor air than conventional filters.

The nanoscale fibres are “endless” and elastic. Therefore, the generation of short fibres or particles during the use phase is unlikely. In addition, the fibres firmly adhere to the filter material, which prevents relevant releases of nanoparticles. The adhesion of the fibres is tested by the company in its quality assurance procedures. At the end of their service life, the filters are exchanged in repair shops and incinerated.

5.3 Sol-Gel coatings

Mr. Wagner (Nano Tech Coatings GmbH) introduced several applications of sol-gel coatings. Its main use is on car bodies, but it is also used on engine parts (e.g. turbocharger). As the structure of the coating hardens during the industrial production and directly on the car surface, it adheres so well that any pre-treatment with chromium can be omitted.

Sol-gel coatings perform better in the areas of “surface protection” and “easy-to-clean” than conventional coatings. In addition, the coating layer is very thin (resource reduction) and durable at extreme pH-conditions, such as what occurs in car washes. According to one participant, a study showed that the use of sol-gel coatings is environmentally beneficial in comparison to conventional coatings, because resources are saved (lower use amounts, reduced fuel needs) and the lack of solvent use.

5.4 Sensors, Connectivity and Control

Vehicles are increasingly equipped with electrical and electronic components improving the connectivity and possibilities to use digital services (e.g. navigation, connection to clouds etc.). Furthermore, electronics support basic functions of the car (e.g. lighting) and elements of Autonomous Driving (e.g. parking support). Mr. Hellenthal (Audi AG) explained that the customers increasingly expect a car to be equipped with different electronic functionalities, including in the area of connectivity and communication. He expects this trend to intensify, in particular in connection with "Autonomous Driving".

Mr. Hellenthal enumerated the advantages of differentiated sensor technologies and autonomous reactions of the vehicle in relation to accident prevention and the reduction of accident impacts. He also presented a system for detecting unevenness of the pavement and related shock absorbance systems that aim at increasing driving comfort and improved road holding. The electronic sensors and actuators consist, among others, of nano structures and are becoming smaller and smaller and more integrated. In addition, rare raw materials are used in their production.

Some participants mentioned that innovations for more convenience should be assessed differently from those that primarily contribute to increased safety and resource efficiency. The participants agreed that the electronic components in vehicles are unlikely to cause (eco-)toxic risks, because normally no nanoparticles are released. During the production of electronic components, risks could occur at workplaces if nanomaterials are handled in powder form (dust). It could not be clarified if nano-specific risks occur during the waste stage, for example through the release of nanomaterials from pre-treatment processes (shredding) or during thermal recovery.

Several participants asked if nanomaterials contained in the car components could hinder recovery and recycling of raw materials (circular economy). The repair of highly integrated electronic components was stated to be almost impossible and if broken, they would have to be completely replaced. According to the experience of some participants from the disposal of electronic and electrical equipment, recovery and recycling of resources does not (yet) work well.

5.5 Lighting

Mr. Hiller (Osram) elucidated in his presentation that all lighting and all displays in a vehicle consist of semi-conductor technologies. On average, each new car contains 200 LEDs. The combination of different semi-conductors, buffer layers and barriers results in different colours and strengths of light. The application areas include displays, optical sensors and traditional lighting, such as headlamps and interior lighting.

A life cycle assessment conducted in 2009 comparing light bulbs, compact fluorescent lights (CFL) and LEDs showed that LEDs cause the lowest environmental burdens, even if the toxicity of the mercury contained in CFL is not considered.

Mr. Hiller introduced a headlamp system, currently under development, which should achieve optimal lighting of the street without blinding any approaching vehicles and pedestrians. This “adaptive forward lighting system” integrates LEDs with electronic control units and sensors on one board.

It was criticised that due to the LED technology, the headlamp glasses already in use today cannot be exchanged separately when it is broken but rather the entire lamp needs to be replaced. This was confirmed true but the design of the lamps should prevent them from being (easily) destroyed.

5.6 Lithium ion batteries

Mr. Koller (Varta) presented possibilities and limitations of the use of silica-based nano particles as storage media in lithium ion batteries.

The use of Li ions is very challenging, because it causes a volume change of the storage materials in batteries of up to 50% from the loaded to the unloaded stage. This is due to the formation of Li metal phases. The use of silica-based nanomaterials as storage material was considered as an alternative to the currently used graphite. The integration rather than the adsorption of Li metal phases into these nanomaterials should limit the volume changes. However, apart from the desired properties, tests with different forms of silica at nanoscale - layers, particles and wires – also revealed several new challenges, such as higher costs, safety risks and lower achievable energy densities.

The assessment of silicon-coated graphite nanoparticles as storage media proved more promising, as with an increasing silicone content, the energy densities increased and the volume changes could be controlled. However, this technology causes losses in the number of possible loading cycles, because the anti-corrosion layer, which is essential for the functioning of the batteries, is damaged more quickly. In addition, the production costs of batteries containing these particles are very high.

6 Examples of Life Cycle and Risk Assessments

6.1 Environmental exposure and risks

Mr. Giese (University of Natural Resources and Life Sciences, Vienna) introduced the results of a project that aims to model possible environmental exposure levels for nanomaterials used in different applications, including in vehicles. For nanoscale cerium oxide and silica oxide, the emission amounts were calculated from all (known) uses, including fuel additives, catalysts (CeO2) and tyres (SiO2). Two scenarios were developed: 1) minimum exposure assuming that nanomaterials degrade in the environment and 2) maximum exposure assuming that nanoparticles accumulate in the environment. The modelled environmental exposure levels partly exceed the toxicity thresholds for silica nanomaterials; i.e. risks could occur from nano SiO2 in 30 years if releases from all (currently known) applications are considered, those of which constitute only parts in the automotive sector. Mr. Giese stressed that there are considerable uncertainties connected to the assumptions underlying the model and the input data used. It would be difficult to compare the modelling results with measured environmental concentrations, among others due to the natural background concentrations.

The discussion revealed that for CeO2 nanomaterials the vehicles' end-of-lives is the stage with the highest emission reduction potentials. These could consist of reduced nanomaterial-containing dust generation in waste pre-treatment (e.g. shredding of automobiles). However, some participants quoted studies on this topic that could not identify the release of any individual nanoparticles from waste pre-treatment.

A previous ExpertDialogue dealt with opportunities and risks from nanotechnologies in the waste stage. The presentations and discussions showed that titanium dioxide in waste incineration plants mostly transfers to slags and, via the flue gas to the exhaust gas treatment (filters). CNTs decompose/oxidise in waste incineration plants due to the high temperatures. No information was available at the ExpertDialogue on waste regarding the fate of nanomaterials in landfills.

Some participants reiterated that parts of car components or materials (e.g. tyre particles) could reach the environment through abrasion. If these material matrices age and decompose, the contained nanomaterials would (re-)enter the environment as free particles. If these are very persistent, such as CNTs, environmental risks could occur.

6.2 Life Cycle Assessment of CNT in Lightweight Construction

Mr. Steinfeldt (University of Bremen) presented life cycle assessment (LCA) results evaluating the replacement of carbon black by CNT in plastics (lightweight construction). The concentrations of carbon black and CNT in the plastic matrices were assumed as well as the weight of the concerned car components. The resource use and the emissions per driven distance were identified and the various environmental impacts quantified for the different LCA categories. As LCAs do not appropriately reflect toxic and ecotoxic impacts, these were not considered.

Due to the high energy consumption in the production of CNTs, their use in car components only creates environmental benefits if the weight of the car is significantly reduced (by the lightweight construction) and hence fuel can be saved during the use phase according to Mr. Steinfeldt's analyses. However, the type of the CNT production process is decisive because the energy consumption can vary between 87 and 90,000 MJ equivalents/kg material for single wall carbon nanotubes (SWCNT). The higher the purity and quality of the CNT the higher is the energy consumption.

A stakeholder reported that less energy consuming CNT production processes exist, in particular for CNTs with lower degrees of purity. In addition, some CNT plastic composite materials could be well recycled due to their antistatic properties.

6.3 Environmental impacts of batteries

Mr. Weil (Institute for Technology Assessment and Systems Analysis (ITAS) introduced the participants to LCA results for batteries. The demand for batteries for use in electronic devices and electric cars vehicles has been increasing for years. He added that higher energy densities in relation to the mass/volume of batteries are also required. Currently, different battery systems are under development, some of which also use nanomaterials.

According to Mr. Weil, the institute's qualitative exposure assessments identify the end-of-life as the main source of emissions from batteries, because only here can the closed system "battery" be opened, partly under uncontrolled conditions ("recycling" in countries without a respective waste treatment infrastructure). A release of nanomaterials could also occur, for example, during incineration or disposal in landfills.

The institute assessed, how the cumulative energy demand (CED) for a LiFePO4 battery changes for a given driving performance if the battery is optimised using CNT. Mr. Weil explained that the CED of the CNT-optimised battery would only decrease significantly, if in addition to the battery's power density its lifetime also increases. Similar to the example of lightweight construction, the energy consumption for the CNT production is decisive for the outcome of the assessment. An additional factor significantly affecting the CED is the charging and discharging efficiency, as identified in the same study.

Mr. Weil explained that the institute presented these results to the battery developers to initiate further optimisation processes. He stated that the used method of constructive technology assessment (CTA) is useful to illustrate the environmental consequences of different product variants to its developers and to show, which parameters should be improved from the environmental perspective.

7 Mobility in the Future

Mr. Hellenthal (Audi AG) showed his company's vision on mobility in the future. In his scenario, vehicles are taking over actually driving ("Autonomous Driving") step-by-step. The passengers would use the gained time for infotainment, communication and relaxation in the car. This would require more screens and interactive surfaces in the car than present today. Already now, connectivity and electronic infrastructure would have gained importance as purchasing criterion in comparison to the engine performance, which was most relevant in the past. Mr. Hellenthal explained that, among others, logistics, servicing and the capacity utilization of vehicles would fundamentally change due to the different usage behaviour in the scenario of future mobility (cars as "service companies on demand"). The use of redundant, highly integrated and efficient, electronic components, sensors and control elements in the vehicle would be a precondition for this development. These electronic systems must comprehend complex traffic situations and convert them into intelligent driving behaviour.

The implementation of "Autonomous Driving" and the outlined scenario of future mobility require large technological innovations in the area of microelectronics and the communication infrastructure between car systems. According to Mr. Hellenthal, nanostructures and nanomaterials would play an important role in these innovations. The introduction of "Autonomous Driving" would be possible in the short term for traffic situations of a low complexity, such as on the highways, if the respective communication infrastructure were available.

Already today, the developments are so fast that the supply chains could not react quick enough anymore. For example in the area of semi-conductor technologies, the automotive manufacturers are cooperating more and more directly with the semi-conductor manufacturers.

Mr. Kolaric (Fraunhofer Institute for Manufacturing Engineering and Automation IPA), who spoke about the future of the automotive industries, confirmed the increase in electronics in vehicles. In addition, trends in production technologies indicate the replacement of manual work by automatized processes. Mr. Kolaric also showed that many production steps and the technology development would already now take place in Asia and not in Germany. He stated that is currently unclear, how the German automotive industry would compete on the global markets in the future.

The participants shared the opinion that new mobility concepts are necessary. They regarded various aspects necessary to ensure a useful and resource conserving mobility and to prevent compensation of efficiency gains by an increase in overall traffic. Therefore, some participants stressed that different means of transport need to be combined and interlinked. In addition, intelligent solutions would be necessary to cover the mobility demand, which is unevenly distributed over the day. A more intense use of cars during a short time period requires a prolongation of the planned operating times of electronic components as they are currently designed for servicing a lower amount of operating hours.

If the outlined vision of future mobility became reality, all stakeholders expect far-reaching societal changes. These would range from changes in the quality and quantity of work places, societal demands on and possibilities of mobility up to a reorganisation of the German economy. The potential impacts on research, technology, industry and society could not be discussed in full depth, and therefore it was proposed to continue this discussion, potentially in a different context.

8 Summary

Already today, nanomaterials are an essential element in vehicle manufacturing. However, material sciences assess different technologies, and therefore the use of nanomaterials is one technology among many. The use of nanotechnologies may aim at improving safety, convenience, fuel consumption (batteries). It may also aim at reducing pollutant emissions or improving the visual appearance of vehicles. Hence, nanomaterials may be contained in the entire car fulfilling different functions.

The use of “individual” nanoparticles is limited to a few uses, for example additives in fuels or lubricants. In most cases, nanoparticles are bound to matrices. Therefore, it can be assumed that there are low (eco)toxic risks for humans and the environment during the use phase. Nanomaterials could also enter the environment if released within their matrices during car disposal or from abrasion during the use phase. If the released materials are destroyed quicker than the contained particles are degraded, the nanoparticles would exist individually in the environment. Little information exists on the type and extent of potential risks from these exposure pathways.

The discussion on toxic and ecotoxic risks from the use of nanotechnologies was much less important for nanomaterial applications in the automotive sector than in the past. Instead, issues around resource recovery and material recyclability gained importance. This is due to the use of critical raw materials, particularly for electronic equipment (e.g. Gallium or noble earths) and the large material flows in the automotive sector.

The current trends in vehicle construction indicate that the share of electronic components in cars will significantly increase. They will be (further) reduced in size and more and more integrated. This should enable “Autonomous Driving” of automobiles and enable the passengers to use their time for something other than driving. Criticism exists regarding the increasing number and relevance of electronic components in vehicles with a view to the decreasing reparability and the currently obvious lack of possibilities to recover and recycle raw materials and components.

The discussion of the scenario of future mobility and “Autonomous Driving” as well as the changed usage behaviour of vehicles showed that the technological innovations not only pose (eco-)toxic risks but also increase societal, ethical and economic questions. Since these implications were not fully discussed at the ExpertDialogue, a wish to continue this discussion was expressed. A holistic, interdisciplinary and interministerial cooperation is regarded necessary to accompany these developments in an adequate way.