

NanoDialogue
of the German Government

Nanotechnologies and Waste

Report by the Ministry of the Environment

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Content

1	Introduction	4
2	Terms – Wastes containing nanomaterials	4
3	Legislation on nanomaterials in wastes	5
3.1	Classification of wastes as hazardous	5
3.2	Connection between chemicals and waste legislation	6
3.3	REACH and the waste stage of substances	7
3.4	Consequences of the classification of wastes as hazardous	8
4	Assessment of possible risks from nanomaterials in wastes	8
4.1	Information on the content of nanomaterials in wastes	8
4.1.1	Wastes from manufacture and processing of nanomaterials	8
4.1.2	Nanomaterial-containing wastes from end-of-life products	9
4.2	Disposal pathways and possible environmental releases of nanomaterials	10
4.2.1	Landfill	10
4.2.2	Biological treatment	11
4.2.3	Thermal treatment	11
4.2.4	Use of sewage sludge	13
4.2.5	Material recovery	13
4.3	Ways to close knowledge gaps on potential risks from nanomaterials in wastes	14
4.3.1	Top-down approach on emission estimation	15
4.3.2	Bottom-up approach on emission estimation	16
5	Chances for the waste sector from nanotechnologies	16
6	Summary and recommendations from the expert dialogue „Nanotechnologies and Waste“	17

Figures

Figure 1:	Nanowaste and nanomaterials-containing waste	5
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1 Introduction

Nanotechnologies and nanomaterials are increasingly being used in products and processes. In relation to waste treatment, new opportunities for the environment, among others via resource savings (waste prevention) and efficiency gains in processes of the waste sector can be expected. However, also risks could occur if nanomaterials are released (to the environment) from wastes. Nanomaterials in wastes may originate from their manufacturing and use processes as well as from end-of-life products in which they are contained.

Up to now, the potential opportunities of using nanotechnologies in the waste treatment sector and the potential risks from the content of nanomaterials in wastes have hardly been discussed by the general public. Also the actors of the waste sector have not yet themselves dealt with the topic in detail.

The German Ministry of the Environment, Nature Protection, Construction and Nuclear Safety (BMUB) hosted an expert dialogue on the topic “Nanotechnologies and Waste” in the context of the German Government’s NanoDialogue¹. In October 2014 approximately 25 representatives from different interest groups engaged themselves in the topic from different perspectives.

This report gives an overview on the state of knowledge regarding different aspects of the topic „Nanotechnologies and Waste“. The content and results of core discussions at the expert dialogue are also reflected. The topic of potential risks at the workplace is explicitly not covered by the report.

2 Terms – Wastes containing nanomaterials

In this document the term “nanowastes” is used to address wastes which mainly consist of nanomaterials and which can be collected separately. Nanowastes normally originate from the manufacture and use of nanomaterials. Wastes from end-of-life products which contain nanomaterials are called “nanomaterial-containing wastes”². According to the legal waste definition in either case the disposal of the materials needs to take place or be intended or the disposal must be necessary to protect the public well-being.

¹ [http://www.bmub.bund.de/themen/gesundheitschemikalien/nanotechnologie/details-nanotechnologie/artikel/fachdialog-3-abfall-und-entsorgung/?tx_ttnews\[backPid\]=2227](http://www.bmub.bund.de/themen/gesundheitschemikalien/nanotechnologie/details-nanotechnologie/artikel/fachdialog-3-abfall-und-entsorgung/?tx_ttnews[backPid]=2227)

² The term “nanowaste” is sometimes differently used in other contexts. In the Nanotrust dossier “Nanowaste: nanomaterial-containing products at the end of their lifecycle” the term is used if nanomaterials come into contact with solid wastes and can be separately collected. (<http://epub.oeaw.ac.at/internal&action=highlight.action&Parameter=nanotrust&arp=0x003146a3>). This includes production wastes as well as sewage sludge containing nanomaterials which have been separated from wastewater and wastes from nanomaterial-containing products.

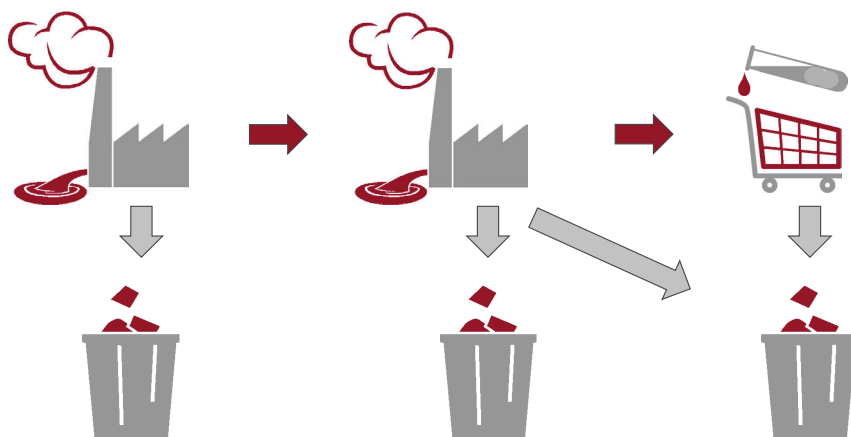


Figure 1: Nanowaste and nanomaterials-containing waste

Nanomaterial-containing residues from emission reduction devices in installations, for example sewage sludge or filter cakes from waste incineration plants, are also nanomaterial-containing wastes.

3 Legislation on nanomaterials in wastes

Nanomaterials are neither specifically regulated nor excluded from European and German waste legislation. Hence, all legal requirements for wastes also apply to nanowastes and nanomaterial-containing wastes.

3.1 Classification of wastes as hazardous

Waste legislation differentiates between hazardous and non-hazardous wastes. Each type of waste needs to be classified according to the German Regulation on a Waste Catalogue. The waste catalogue differentiates waste categories according to their origins and types. Wastes fulfilling one or several hazard criteria – the so called H-criteria – are considered hazardous. The waste catalogue's entries for hazardous wastes are marked with an asterisk (*). Hazardous wastes have to be handled and disposed of according to specific requirements. As the same waste types from the origins may be differently composed, two entries are frequently included in the waste

catalogue (mirror entries): one with and one without an asterisk. Specific entries for nanowastes or nanomaterial-containing wastes do not exist, yet.

In practice, the waste producers first evaluate the type and origin of wastes and thereby identify the adequate entry in the waste catalogue. If a mirror entry exists, he is to check the individual classification using the H-criteria to decide whether or not an asterisk shall be applied.

3.2 Connection between chemicals and waste legislation

Chemicals legislation and waste legislation are interrelated via the hazard criteria. Annex III of the European Waste Framework Directive lists a total of 15 hazard criteria. Twelve of these correspond to hazard criteria of the EU Regulation on the classification and labelling of substances and mixtures³. The EU Decision on the European Waste Catalogue⁴ which defines the H-criteria has just been revised⁵.

In both waste and chemicals legislation concentration limits are defined for almost all hazard criteria⁶. If one or several substances⁷ with a specific hazardous property are contained in wastes above the defined concentration limits the waste is to be classified as hazardous. Hence, information on the hazardous properties of a substance (chemical classification) is an important basis for the classification of wastes.

The criterion H14 specifies the conditions under which wastes should be classified as hazardous due to their ecotoxic properties. It is under assessment whether or not the M-factors of the EU Classification and Labelling Regulation should also be transferred to waste legislation. M-factors are defined in the Classification and Labelling Regulation for particularly ecotoxic substances, for example heavy metals. They may considerably reduce the concentration limits triggering classification of mixtures as ecotoxic.

The content of hazardous nanomaterials in wastes may be a reason to classify a waste as hazardous. This would be the case if the concentration of a hazardous nanomaterial as such or together with other substances which have the same

³ REGULATION (EC) No 1272/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2008 on classification, labelling and packaging of substances and mixtures

⁴ COMMISSION DECISION of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste

⁵ EU Decision 2014/955/EU: Amending Decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council

⁶ For some hazardous properties no concentration limits are defined, for examples for flammability.

⁷ For details on the classification and labelling rules of substances and mixtures reference is made to respective literature. In this report only some general principles can be presented.

hazardous properties exceeds the concentration limits. The content of hazardous nanomaterials in wastes as such is not a reason for a classification as hazardous.

3.3 REACH and the waste stage of substances

REACH requires manufacturers and importers of substances to assess their hazardous properties in the context of a registration, if they are placed on the market in amounts exceeding 1 t/a. The higher the registered substance volume per manufacturer or importer, the more information is to be generated. Consequently, REACH generates the data⁸ which are necessary to classify and label substances, which is an important basis for the classification of wastes.

Substance registrations must contain a chemical safety report if they are registered in amounts exceeding 10 t/a. The chemical safety report is to identify risks from the substance's waste stage according to Annex I of REACH. Although a respective ECHA guidance⁹ exists, the waste stage has hardly been included in the registration dossiers up to now¹⁰. Therefore, REACH does not factually generate new information on possible risks from substances in wastes.

In their dossiers, registrants also have to specify the uses of their substances they support. Uses are defined at the level of sectors (for example textile processing), types of mixtures (for example textile finishing agents or washing and cleaning agents) as well as article types (for example plastic products or paper products). Hence, the uses are only roughly characterized and a derivation of real used amounts per application is not possible.

Nanomaterials also have to be registered under REACH. They may be registered as a use of a bulk material or - if no bulk material exists - such as for carbon nanotubes, can be individually registered.

The German federal authorities have submitted a proposal to the EU Commission¹¹ on the revision of REACH regarding nanomaterials. Among others they request changing testing requirements and implementing a simplified registration for nanomaterials in amounts exceeding 100 kg/a to improve the current data situation. It was unclear when the EU-Commission would make its proposal for the adaptation of

⁸ Due to the dependency of the testing requirements on the registered tonnage, information for substances in lower volumes is not sufficient for classify of all possible hazard classes.

⁹ http://echa.europa.eu/documents/10162/13632/r18_v2_final_en.pdf

¹⁰ There are several reasons for that, among others: a) some registrants are of the opinion that they may stop the assessment, if substances are diluted in mixtures / articles b) the lack of respective emission models for processes of the waste sector and c) the opinion of many registrants that REACH does not cover the waste stage and therefore a risk assessment is not required.

¹¹ <http://www.umweltbundesamt.de/publikationen/nanomaterialien-reach>

REACH when the report was written. However it was decided that the REACH text will not be changed and the annexes will be adapted.

3.4 Consequences of the classification of wastes as hazardous

Higher safety standards for the handling and disposal of hazardous wastes are required than for non-hazardous wastes. Higher standards apply to the separation, storage, transport and treatment of respective wastes. In addition, more comprehensive documentation is required for the disposal pathway. The permitting requirements are also stricter, if installations treat hazardous wastes; higher standards in protection measures for workers and the environment are necessary. Specific protection standards for nanowastes or nanomaterial-containing wastes do not exist.

4 Assessment of possible risks from nanomaterials in wastes

The assessment of potential (environmental) risks from nanomaterials in wastes requires information on the hazardousness of nanomaterials which can be emitted from wastes and data on their environmental fate and behaviour and / or possible exposure levels. In the following these aspects are separately discussed and possibilities are introduced to close existing knowledge gaps.

4.1 Information on the content of nanomaterials in wastes

4.1.1 Wastes from manufacture and processing of nanomaterials

Manufacturers of nanomaterials should well know the composition of their production wastes. However, due to high manufacturing efficiencies, wastes exclusively consisting of one nanomaterial are an exception. They may occur due to off-specification batches or if substances are stored too long and have to be disposed of. Formulators should know the input materials they use and therefore also have information on the composition of their wastes. Article producers, however usually do not know if and which substances / nanomaterials are contained in the mixtures, materials and parts they use. Hence, they also have little information on the composition of the wastes they produce.

At the expert dialogue „Nanotechnologies and Waste“ an example was presented of glasses coated with a nano zinc-containing mixture to shield UV-rays. The manufacturers and processors of the nano zinc-containing mixture have sufficient information on the specific properties of the nanomaterials and the generated wastes to safely handle and dispose it. After an on-site treatment, in this case an adjustment of the pH, the critical waste properties are changed and the waste is treated “normally”.

4.1.2 Nanomaterial-containing wastes from end-of-life products

The largest share of the waste streams consists of substance mixtures and end-of-life products (articles), the composition of which is hardly known or not known at all. For these waste streams, a classification based on substance contents and H-criteria can be difficult. Furthermore, wastes from end-of-life products (for example electronic wastes) are frequently not to be classified as hazardous not because they could cause an immediate danger but because specific disposal pathways should be selected in order to prevent risks and / or recover resources.

Knowledge on the composition of these wastes, including on the content of nanomaterials, could be obtained through information on the composition of the products constituting them.

In a Commission working paper on the review of EU legislation on nanomaterials¹² the following categories are formed of nanomaterials which are marketed in the EU in relevant amounts: nanomaterials which are inorganic, non-metallic; carbon-based; metallic; organic, macromolecular and polymeric.

According to the working paper, carbon black holds the largest market share (use in tyres and rubber products). It is followed by functional fillers in polymers (mainly synthetic, amorphous silica as well as metal oxides and silver). Nanomaterials are used in high amounts in the electronics industry (amorphous silica and barium titanate), in cosmetic products (amorphous silica, titanium dioxide and zinc oxide) as well as in biomedical uses (different materials, among other gold and silver).

According to a study by Prognos AG¹³ the following waste streams contain relevant amounts of nanomaterials: electronics, paper, metals, textiles, electric devices, batteries, plastics and rubber. However, currently available data does not allow a more precise estimation of the type and concentration of nanomaterials in the different waste fractions.

An analysis of a database by the Austrian Institute of Technology Assessment on the content of nanomaterials in consumer products¹⁴ shows that titanium dioxide and nanosilver are the most frequently used nanomaterials in consumer products.

¹² COMMISSION STAFF WORKING PAPER Types and uses of nanomaterials, including safety aspects Accompanying the Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee on the Second Regulatory Review on Nanomaterials, SWD(2012) 288 final, Brussels, 3.10.2012

¹³ Jutta Struwe, Eva Schindler: Bedeutung von Nanomaterialien beim Recycling von Abfällen, Arbeitspapier 270, November 2012; http://www.prognos.com/fileadmin/pdf/publikationsdatenbank/121100_Prognos_HansBoecklerStiftung_Bedeutung_von_Nanomaterialien.pdf

¹⁴ See presentation of Dr. Gaszó, http://www.oekopol.de/wp-content/uploads/12_Gazso_MIA_Projekt_und_Stakeholderdialog.pdf

A Danish study¹⁵ elaborates that carbon nanotubes, nano silica dioxide, nano silver and nano titanium dioxide are the most frequent nanomaterials found in the waste streams metal, plastic, textiles, electric and electronic waste, end-of-life vehicles, tyres and construction wastes. Zinc oxide is frequently found in electric and electronic wastes, as well. In addition, tyres and plastic from consumer products include nano clays.

4.2 Disposal pathways and possible environmental releases of nanomaterials

Four disposal pathways can be distinguished:

- landfill,
- biological treatment,
- thermal treatment and
- material recovery.

The “disposal“ of “wastes“ via the sewage treatment plant is not considered here; however, the use of sewage sludge on agricultural soils is briefly discussed¹⁶.

4.2.1 Landfill

From 2009 all European landfills should be operating according to European Landfill Directive (Directive 1999/31/EC). The Landfill Directive defines the requirements on the construction and operation of landfills, including the type and thickness of the soil liners, pH-control and containment conditions of the landfill body, the drainage and treatment of leachate as well as the landfill coverage and capture of landfill gases.

It is difficult to model emissions of substances from landfills due to the different waste and landfill types as well as the various conditions that could exist in the landfill body. Existing models mainly relate to the formation and emission of methane.

The authors of the report “Nanomedicine – new solutions or new problems?“¹⁷ analysed studies on the behaviour of nanoparticles in landfills¹⁸ and concluded that

¹⁵ Danish Ministry of the Environment: Nanomaterials in Waste, Environmental Project No. 1608, 2014; <http://mst.dk/service/publikationer/publikationsarkiv/2014/nov/nano-affaldsrapport/>

¹⁶ The topic of water and wastewater treatment was subject of an earlier expert dialogue. A report is available at: http://www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Nanotechnologie/nano_fd2_wasser_bf.pdf

¹⁷ Healthcare without harm: Nanomedicine – new solutions or new problems? December 2013, Belgium <http://noharm-europe.org/sites/default/files/documents-files/2462/HCVH%20Europe%20Nanoreport.pdf>

¹⁸ Original source of Healthcare without harm: Bolyard, S. C. *et al.* Behavior of engineered nanoparticles in landfill leachate. *Environmental Science and Technology* **47**, 8114–8122 (2013).

nanowastes give rise to concern because they may have undesired impacts on the anaerobic and aerobic processes in the landfill (waste decomposition and leachate treatment). In addition, nanomaterials could be released from the leachate.

In the Danish study¹⁵ assessments are quoted according to which emissions of nanomaterials from the leachate are regarded principally possible but unlikely, because the conditions in the landfill body would support agglomeration and immobilization of nanomaterials. A study on the emission of carbon nanotubes by permeation of the landfill liner also suggests that this emission pathway is unlikely.

The existing information on the behaviour and releases of nanomaterials from landfills do not allow for final conclusions regarding potential risks from hazardous nanomaterials in wastes.

4.2.2 Biological treatment

A large share of household wastes consists of biological materials which are partly disposed of in composting and fermentation plants. Via the use of compost and fermentation products in agriculture and horticulture nanomaterials potentially contained in the bio wastes could be released to the environment. In addition, microorganisms responsible for composting and fermentation could be disturbed by nanomaterials in the treatment plants.

According to an assessment¹⁹ on the potential input of nanomaterials into biological waste treatment plants it was identified, that only few nanomaterials are authorised for use in food and feedstuff. Therefore, it is assumed in the publication that the respective waste streams hardly contain any nanomaterials. However, according to the author, nanomaterials could enter the waste stream through packaging materials and household appliances.

No studies are currently known on the behaviour of nanomaterials in composting and fermentation plants. According to current knowledge, specific emission models from biological treatment plants are missing as well.

4.2.3 Thermal treatment

Various materials (products, residues et cetera) with and without nanomaterials are incinerated at high temperatures in thermal treatment plants. According to the state of the art of incineration plants the exhaust gas is cleaned using filters and washers. Slags and ashes remain in the incinerator's furnace.

¹⁹ Information in this and the following paragraph derived from: Klaus Hoppenheidt: Einfluss von Nanomaterialeinträgen auf die Bioabfallkompostierung und –vergärung, DOI: 10.13140/2.1.4070.5920 Conference: Synthetische Nanopartikel in der Umwelt - Fachveranstaltung des Bayerischen, At München

The Fraunhofer Umsicht Institute is currently working on a project commissioned by the German Federal Environment Agency on the “Assessment of the emission behaviour of nanomaterial-containing wastes in thermal treatment plants”. Nanoscale titanium dioxide was dosed to the wastes incinerated in an experimental plant and an incineration plant. The chemical analyses capture the distribution of titanium in the various emission pathways from the plant.

Overall, a high share of the dosed nanomaterial could be traced (approximately 95%). The measurements show that neither the titanium concentration in the waste gas nor the share of titanium in the total mass of dusts was increased due to the dosing of titanium dioxide. The largest share of titanium is transferred during incineration to the grating slags (92%) and the fly ashes (5%). The study also shows that the waste gas treatment devices efficiently retain titanium. These results correspond to those of a Swiss study²⁰ on cerium oxide in incineration plants.

The Danish study on nanomaterials and waste¹⁵ summarises that inorganic nanomaterials can mainly be found in slags and fly ashes. If slags are used open in the environment, nanomaterials can be leached with rainwater. Carbon nanotubes are almost fully destroyed in incineration plants according to the study, if the incineration temperatures are sufficiently high. Carbon nanotubes which are not destroyed are mainly retained in the slags.

Two studies are quoted by the report „Nanomedicine – new solutions or new problems“¹⁷ on the influence of nanomaterials in incineration plants on the emission of other pollutants. The studies found indications that nanomaterials undergo various physical and chemical transformations and may catalyse the formation or destruction of other pollutants, such as dioxins and / or impact the efficiency of emission reduction technologies²¹. In addition, it is reported²² that emissions of polycyclic aromatic hydrocarbons (PAH) were measured at a 6-fold higher rate when nanomaterials were present in the incinerated waste than when the respective bulk materials were present. Furthermore, the presence of silver and titanium nanoparticles in wastes leads to an increased concentration of chlorinated furans in the waste gas.

The results on the behaviour of nanomaterials in incineration can be evaluated as an indication that state of the art thermal incineration plants retain nanomaterials from wastes and that hardly any environmental emissions occur. However, it should be

²⁰ http://www.ethlife.ethz.ch/archive_articles/120521_nanopartikel_kehricht_su/index

²¹ Original source of Healthcare without harm: Holder, A. L. *et al.* Nanomaterial disposal by incineration. *Environmental Science: Processes Impacts* **15(9)** 1652-1664 (2013).

²² Original source of Healthcare without harm: Vejerano, E. P. *et al.* Emissions of polycyclic aromatic hydrocarbons, polychlorinated dibenzo-p-dioxins, and dibenzofurans from incineration of nanomaterials. *Environmental Science and Technology* **47**, 4866-4874 (2013).

considered that these results cannot be extrapolated to all nanomaterials and all types of installations. Furthermore, the disposal of slags and ashes has not yet been assessed; if slags for example are used in road construction nanomaterials could be emitted to soils. In addition, it is not clear if and how far nanomaterials can catalyse or reduce the formation of other pollutants. Therefore, no final conclusions can be drawn on the risk potential from nanomaterials in waste incineration.

4.2.4 Use of sewage sludge

According to various studies²³ approximately 90 to 95% of the assessed nanomaterials in wastewater are retained in sewage treatment plants. If and how far the results of the studies, which mainly concern metallic nanoparticles, can be extrapolated to other nanomaterials is currently unclear.

Sewage sludge is partly dried and incinerated in thermal treatment plants (see Chapter 4.2.3). The application of sewage sludge on agricultural soils is only possible under certain conditions. Due to the sometimes high concentrations of hazardous substances, ending the use of sewage sludge on agricultural soils is currently under discussion.

The results of the project „Umsicht“²⁴ show several critical aspects regarding the content of nanomaterials in sewage sludge which is used on agricultural soils, among others: nanosilver (and potentially other (similar) nanomaterials) are firmly bound in a sludge-soil mixture and can hence accumulate in soils. Nanosilver and iron oxide particles inhibit the activity of microorganisms, partly already in very low concentrations, and can therefore disturb natural processes in soils.

The above quoted results indicate that the use of sewage sludge on agricultural soils may lead to negative impacts of nanomaterials on soils. A final assessment and conclusion regarding the possible risks cannot be deduced from the available information.

4.2.5 Material recovery

Nanomaterials reach the processes of material recovery via end-of-life products (see Chapter 4.1.2) as well as from other material streams. The recycling processes depend on the product and material type and hence also the conditions are different to which the product matrices containing nanomaterials are exposed.

²³ Compare the documentation of the second expert dialogue
http://www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Nanotechnologie/nano_fd2_wasser_bf.pdf

²⁴ Abschätzung der Umweltgefährdung durch Silber-Nanomaterialien: vom Chemischen Partikel bis zum Technischen Produkt; <http://www.umsicht.uni-bremen.de/> (Estimation of environmental risks from silver nanoparticles: from the chemical particle to the technical product)

At present there are hardly any studies²⁵ analysing if and to what extent a release of nanomaterials from the different products and processes is likely. In the Danish study on nanomaterials and waste¹⁵ it is only stated that recycling processes also generate wastes, which are disposed of in the above described processes.

Very little information is available on the transfer of nanomaterials into new products during the recycling process. In the Danish study¹⁵ different cases are described, where a leaching of nanomaterials from recycling products is possible, for example the use of old tyres or old plastic in road construction or on outdoor areas.

If, to what extent and how nanomaterials could disturb recycling processes and influence the quality of the secondary materials is also not known.

Possibilities for a targeted reuse of nanomaterials from wastes are not yet available (at the expert dialogue only the recovery of nanosilver from photo-chemical waste-waters was highlighted). However, processes to recover valuable nanomaterials are being researched. Whereas fairly good possibilities seem to exist to concentrate and separate magnetic nanoparticles, the procedures for non-magnetic particles appear very extensive and not economic.

4.3 Ways to close knowledge gaps on potential risks from nanomaterials in wastes

There are two ways how further information could be generated on possible risks from nanomaterials in waste:

- Top-down: Estimation of human and environmental exposure via information on the use of hazardous nanomaterials and the respective disposal pathways of nanomaterial-containing products by modelling
- Bottom-up: Measurement of emissions of market relevant hazardous nanomaterials from different disposal processes and extrapolation of measurement results using market data

For both ways information on the nanomaterials' hazardousness is necessary for risk assessment. According to the participants of the expert dialogue, information on nanomaterials' hazards is not satisfactory, among others due to missing toxicity data and / or contradictory test results. However, the information is regarded sufficient to focus risk research on those materials which have been proven to be hazardous or for which respective indications exist.

²⁵ Mr. Danzebrink reported in his presentation at the expert dialogue that no zinc nanoparticles are released during melting of glass which is coated with nano zinc oxide.

New information on the hazards of nanomaterials is expected from the implementation of REACH (in particular after adaptation of the testing requirements). However, due to the limitation that substances manufactured or imported in amounts below 1 t/a do not have to be registered, the number of nanomaterials for which new information will be generated may be low.

Modelling of environmental exposure levels requires information on the behaviour and fate of nanomaterials in the environment. This information is also expected from REACH registrations.

It must be taken into account that it may be possible to estimate emissions at the regional level and for installations with a specific technical standard but that the nanomaterial-containing wastes are generated at global level. State of the art installations only exist in a few countries. Therefore, it should be further discussed which emissions are to be expected from countries, which do not have a state of the art disposal infrastructure and how this should be considered in the concept of “extended producer responsibility”.

4.3.1 Top-down approach on emission estimation

The environmental exposure from the waste stage of the nanomaterial’s lifecycles could be derived from market volumes and used in combination with emission and exposure models for the processes of the waste sector. For this approach, the amounts of nanomaterials which enter the processes of the waste sector would have to be identified from data on:

- production volumes
- content in products which become waste
- expected amounts of end-of-life products
- shares of end-of-life products in different waste streams and disposal paths.

The most complete data is likely to be available on the production volumes. They are compiled for example in a working paper¹² by the EU Commission.

In contrast, information on the applications of nanomaterials in products was stated to be available only for a few cases in previous expert dialogues.

Data on the content of specific nanomaterials in products could principally be extracted from existing product databases. However, these are incomplete because the notification of data is voluntary or based on publicly available product information. The notification requirements in France, Belgium and Denmark may deliver respective data in the near future.

REACH-information on uses of nanomaterials is limited, as for the registration only the potential uses are specified in a rough resolution and without use amounts.

The waste sector regularly analyses the shares of different materials and end-of-life products in different disposal pathways. However, there are significant uncertainties regarding the expected product amounts in the waste fractions which were placed on the market at a specific time or in a specific composition.

Estimating emissions from the waste processes requires respective models and emission factors for nanomaterials from wastes, which currently do not exist and would have to be developed. Therefore, only the worst-case can be estimated based on the nanomaterials' chemical-physical properties and the conditions in the waste treatment processes. If available, information from emission measurements could be used to refine the worst-case assessments or to develop validated emission models (see next chapter).

4.3.2 Bottom-up approach on emission estimation

A bottom-up approach for emission estimation requires measured data on nanomaterial emissions from some waste treatment processes, which could be extrapolated to all relevant nanomaterials and the entire waste sector.

Relevant hazardous nanomaterials and exemplary waste streams as well as concrete waste treatment process would be selected for representative measurements. The measurements would include input amounts of nanomaterials into the process as well as emission amounts into air, water and potentially soils (see the project on emission assessment from incineration plants; chapter 4.2.3).

In a second step an assessment would determine if the data can be transferred to other nanomaterials, other waste streams and potentially other treatment processes. Furthermore, the emission amounts would have to be extrapolated considering the production volumes, uses and the waste structure. Here, information of the top-down approach would be used.

5 Chances for the waste sector from nanotechnologies

Comparatively little information is available on the applications and benefits of the use of nanomaterials and nanotechnologies in the waste sector. Nano-coated heat exchangers in incineration plants which increase the heat yield are an example of possible efficiency gains. In addition, nanotechnologies and nanomaterials are used

in filters for waste gas treatment. Various nanotechnology-based processes are being developed or are already used to treat wastewater²⁶.

At the expert dialogue “Nanotechnologies and Waste” further potentials of the use of nanomaterials were seen in their application as marker for (polymer) materials, which could increase the sorting efficiency of (plastic) wastes.

The use of nanomaterials in products could give rise to new waste prevention opportunities, if more stable materials are used (among others polymer composites or carbon nanotubes), for example by increasing the life span of products.

It could not be clarified at the expert dialogue if the lack of information on concrete technical solutions and processes in the waste sector is due to the fact that these are still under development or if a general reservation exists to present and highlight the fact that they are based on nanotechnologies²⁷.

6 Summary and recommendations from the expert dialogue „Nanotechnologies and Waste“

The potential risks and benefits of the use of nanotechnologies in the waste sector has hardly been discussed and researched up to now.

A general consumer interest on the topic was reported at the expert dialogue “Nanotechnologies and Waste“. The companies of the waste sector appear to be divided: some waste treatment operators are generally concerned about potential risks for workers and the environment whereas others are convinced that the existing state of the art waste treatment technologies and installations are suitable to ensure a safe disposal also of nanomaterials in waste.

There was a consensus at the expert dialogue “Nanotechnologies and Waste” that a distinction should be made between wastes from the manufacture and processing of nanomaterials (nanowaste) and wastes from end-of-life products (nanomaterial-containing waste). Compared to nanomaterial-containing wastes,

- the composition of nanowastes, including the content of nanomaterials is generally known and
- nanowastes are comparatively homogenous and usually do not have a complex structure.

²⁶ See the report on the expert dialogue on the aquatic environment.

²⁷ The preparation and conduction of various expert dialogues on different topics showed that the market actors are generally hesitant to pro-actively communicated the use of nanomaterials in their company presentation for the general public.

At the expert dialogue it was presented that safe handling and disposal of nanowastes is possible if information on the specific properties of the contained (hazardous) nanomaterials is available and modern waste treatment technologies are applied. It was also made clear that not all companies using nanomaterials and generating nanowastes can be expected to have the respective expertise. Furthermore, in most countries no respective highly developed disposal structures according to state of the art are available. Therefore, the participants at the expert dialogue opined that guidance documents and further help are needed on the safe disposal of nanowastes. The Swiss concept paper²⁸ is an example of such guidance. It was also stressed that the nanomaterial manufacturers' and formulators' communication of specific information on the pre-treatment and disposal of nanowastes with the safety data sheet is of very high importance.

The overall risk from nanomaterials in wastes cannot be estimated due to a lack of information on the content of nanomaterials in wastes and the emissions of nanomaterials from disposal processes. At the expert dialogue, some stakeholders recommended establishing notification requirements and / or product registers for prioritized nanomaterials and products in order to close the information gaps on nanomaterials' uses. In addition, the waste sector's information need on nanomaterials in products reaching waste treatment could be brought to the attention of the actors discussing opportunities and limitations of labelling requirements for nanomaterials.

At present it is not possible to prove or disprove whether the different disposal pathways of (hazardous) nanowastes and nanomaterial-containing wastes are adequate to control potential risks from nanomaterials to the environment.

First results of studies on the incineration of metallic nanoparticles show that they are well retained in the slag. However, it is not known if they are released during the further use of the slags. In addition, the impact of nanomaterials in wastes on the formation of (environmentally) hazardous incineration products and their retention is unclear.

Experiments show that the agricultural use of sewage sludge containing nanosilver could lead to an accumulation of the particles in soils as well as to negative effects on soil microorganisms.

There is also little information available about the impacts on and potential emissions of nanomaterials in landfills.

According to the opinion of the participants at the expert dialogue, further experiments on the emission behaviour of nanomaterials should be conducted, because

²⁸ Entwurf Konzeptpapier: Umweltverträgliche und sichere Entsorgung von Abfällen aus Herstellung sowie industrieller und gewerblicher Verarbeitung von synthetischen Nanomaterialien; <http://www.bag.admin.ch/nanotechnologie/12171/12177/index.html?lang=de>

based on existing information no risk assessment is possible (for different materials). The efforts to improve the data availability should focus on those nanomaterials which are commonly known to have hazardous properties. This information could be the foundation of a representative data basis and in the best case it could be used to derive emission models for waste treatment processes. Studies on the behaviour and emissions of nanomaterials from recycling processes would be useful to research the transfer of nanomaterials into products made from secondary materials and identify and prevent potential quality decreases in processes and materials.

The conduction of measurement campaigns requires, as already stated in previous expert dialogues on other topics that missing standardized measurement methods for nanomaterials (in complex matrices) are developed.

In some areas, important chances for the waste sector could be identified from the use of nanotechnologies. Examples of this are the use of nano-enhanced heat exchangers in incineration plants, the use of nano filters and nano membranes for the treatment of waste gas and wastewater as well as the use of “nano markers” to label materials for an improved sorting efficiency.

Various participants at the expert dialogue felt that the precautionary principle should be applied regarding possible risks from nanomaterials in the waste sector due to a (partial) lack of information and the different disposal conditions at global level. There was, however no unanimity on what this would mean in practice. Some examples of possible precautionary measures would be:

- Classification of wastes as hazardous, which contain nanomaterials classified as hazardous or nanomaterials for which respective indications exist or the identity of which is unknown
- Use of highest protection standards for workers and the environment in handling of (hazardous) nanowastes and nano-material-containing wastes
- Ensuring that nanowastes and nanomaterial-containing wastes only reach disposal processes, which ensure the destruction of their hazardous properties.

How this could be ensured for globally traded products is unclear. In any case the transparent communication of the content of hazardous nanomaterials in products and wastes is essential to enable all actors in the supply chains as well as the consumers to safely dispose of their wastes.