Nanomaterials in Waste Streams
Current Knowledge on Risks and Impacts

Chapter 2

Recycling of waste containing nanomaterials

This chapter reviews the current state of knowledge on the fate of nanomaterials in recycling operations and identifies the areas where further work on the environmentally sound management of waste containing nanomaterials would be needed. It explores the risks related to nanomaterials in waste, the effectiveness of best available techniques (BAT) and the consequences of non-standard treatment of waste. The chapter also identifies key knowledge gaps and possible areas for further research.

Today, the number of new commercial products containing nanomaterials is growing (PEN, 2013). Many such products are in the personal care/cosmetics/sunscreen categories. The unused leftovers and their packaging, as well as other products containing nanomaterials – such as electronic equipment, textiles or composite plastics – end their life cycle as municipal or industrial waste. They are treated by recycling, energy recovery, waste incineration or landfill, as defined in the hierarchy of waste management options. Recycling in general has a higher priority than incineration and/or landfill (EU, 2008), (OECD, 2004/2007).

Today, products containing nanomaterials are being recycled along with their analogous products without nanomaterials. No separation or separate collection of product containing nanomaterials solely due to their nanomaterial-content is known. Also, the existing recycling techniques do not take into account the possible nanospecific risks coming from waste containing nanomaterials.

Recycling operations are not always carried out with techniques that meet the standards of an environmentally sound waste management, with the associated risks for health, safety and environment, even with products that do not (or not yet) contain nanomaterials. If operations are not managed to environmentally sound waste management standards, this may give raise to a lot of potential other problems.

The main objective of this report is to review the current state of knowledge on the fate of nanomaterials in the course of recycling operations and identify the areas where further work on the environmentally sound management of waste containing nanomaterials (WCMN) would be needed.

The chapter first explains the importance of recycling in waste management and identifies key nanomaterials. It then investigates the fate of nanomaterials, explores the risks related to nanomaterials in waste and covers best available techniques (BAT) and issues of non-standard treatment of waste. The chapter concludes by identifying key knowledge gaps and possible areas for further research.

The importance of recycling in waste management

Recycling of waste is one element in strategies of waste minimisation or waste prevention (OECD, 2000) and of sustainable materials management SMM (OECD, 2012). Individual countries and international bodies are setting recycling goals and are taking measures to reach them. In the EU, several legal provisions exist with obligation for the member states (EU, 2008), (EEA, 2013) to recycle municipal waste and/or household waste. In the United States, the Environmental Protection Agency (US EPA) regulates household, industrial, manufacturing and commercial solid and hazardous wastes under the Resource Conservation and Recovery Act (RCRA). Effective solid waste management is a cooperative effort involving federal, state, regional, and local entities.

In the OECD, the average recycling rate (including composting) for municipal waste was estimated at 33% in 2011, with a range from less than 10 per cent to 63 per cent (OECD

Statistics[1]). In the EU, the overall rate of material recovery (recycling plus composting) amounts to 42%, the range in individual countries is given as going from 2% to 70% (Blumenthal, 2011).

Based on different sources, the main waste streams recycled in municipal and industrial waste are listed below [(Fischer and Davidsen, 2010), (US EPA, 2013), (FOEN, 2012), (OECD Statistics)]. In addition, there is a growing interest of the recycling industry to recover metals and mineral secondary raw materials from bottom ash ("slag") of Municipal Solid Waste Incinerators MSWI (Boeni, 2013). This waste stream is also included in the following list:

- ✓ Bio waste
- ✓ Food waste
- ✓ Glass (bottles)
- ✓ Metal
- ✓ Paper and cardboard
- ✓ Plastic (PET and various other plastics)
- ✓ Leather and textiles
- ✓ Waste electronic and electrical equipment (WEEE)
- ✓ Batteries
- ✓ Wood
- ✓ Construction and demolition wastes
- ✓ End of Life Vehicles (ELV)
- ✓ Tires
- ✓ Recycling of residues from waste incineration plants (recovery of metals from bottom ash by mechanical separation or from fly ash by acid washing)

Processes where nano-related waste streams can be generated include production, distribution, handling (and use) as well as waste treatment (NEEPH, 2011). It is anticipated that, as the production and number of nanomaterial applications increase, waste streams containing nanomaterials will also increase, and in addition to naturally occurring nanoparticles, engineered nanomaterials possibly might become more widespread in the environment, if insufficient knowledge about the fate and associated risks of nanomaterials released from waste treatment operations, as recycling, could result in inadequate management.

Key nanomaterials in products

When discussing the problem of recycling of WCNM, some product categories are particularly significant as potentially ENM-containing products and thus leading to WCNM. From different sources, nanomaterial containing products and nanomaterial types have been compiled in Struwe et al. (2012), PEN (2013) for consumer products, Lee et al. (2010) and Grebler and Gazso (2012) for construction material and NEEPH (2011) on the use of nanomaterials in composite plastics ("Nanocomposites").

Table 2.1 provides a list of nanomaterials which may be contained in consumer products, with specific examples.

Table 2.1. **Summary of reported nanomaterials in WCNM**

Nanomaterial	Consumer products (Struwe et al., 2012) (PEN, 2013) (NEEPH, 2011)	Construction material (Lee et al., 2010) (Grebler and Gazso, 2012)
Carbon Nanotubes CNT	Electronic devices, sports equipment, composite plastics	Concrete, ceramics
Fullerene	Semi-conductor technology	
nano-Silver (nAg)	Textiles, anti-bacterial kitchenware	Antibacterial coatings and paints
Carbon Black (CB)	Tires, printing toner, plastics	
nano Titanium dioxide (nTiO_2)	Paints, coatings, composite plastics	Self-cleaning coatings
nano Silicium dioxide (amorphous and crystalline (nSiO_2)	Coatings, composite plastics, tires,	Concrete, ceramics, window coatings
nano Zinc oxide (nZnO)	cosmetics, coatings and paints,	
nano Titanium nitride (nTiN)	PET-bottles	
nano Iron oxides (n FeO/Fe_2O_3)	Electronic devices	Concrete
Nano Ceriumoxide (nCeO_2)	Fuel additive	Anti-corrosive coatings
Nano Phosphate ® (n$LiFePO_4$)	Li-Batteries	
Nano Copper particles (nCu)		improved steel (anticorrosive)

Fate of nanomaterials in recycling operations and potential exposure

Waste recycling has many facets: there is a wide variety of recyclable materials within a waste stream; there are various recycling methods, more or less technically adapted to the specific waste stream and/or secondary raw material to be recovered. The appendix to this report includes a table listing some waste streams with possible WCNM, a short description of recycling procedures, and known nanomaterials.

The main concern about possible nanospecific risks of WCNM in recycling processes are nano-objects that might be released into the workplace atmosphere, or into the environment by way of the air, water and or soil (Struwe et al., 2012; NEEPH, 2011; FOEN, 2010).

Information about the fate of nanomaterials in recycling processes is only beginning to emerge. Mostly, exposure scenarios are based on modelling, and not on evidence. It is extremely difficult to quantify and monitor the long-term release of ENM during the final disposal of ENM containing products. (Gottschalk & Nowack, 2011). A "Tiered Approach to an Exposure Measurement and Assessment of Nanoscale Aerosols Released from Engineered Nanomaterials in Workplace Operations" has been proposed by a group of several German institutes (Tiered Approach, 2011), which may give guidance in assessing also the release of ENMs during recycling operations.

Potential risks of exposure depend on the specific recycling processes to which the WCNM is subject. Shredding, milling and thermal processing may result in high exposure potentials, if not operated in enclosed processes. If filters are not designed for nanoparticles, there may be exhaust to the environment. Manual dismantling may cause release of nano-objects and direct exposure of workers (Koehler et al., 2008). A transfer of unwanted or even detrimental nanomaterials to recycled materials ("cross-contamination") may occur and may possibly be detrimental to the quality of the recycled materials (Chaudhry et al., 2009).

Risks related to nanomaterial in waste

During the recycling of Waste Containing Nanomaterials, engineered nanoparticles, like any other particle in the recycling process, might remain individually isolated or form new bigger agglomerates. Nanorelevant potential exposure exists mainly in connection with free nano-objects that are in the nanoscale (smaller than 100 nm) in all three or in two spatial dimensions (nanoparticles, nanofibers, nanorods) (British Standards, 2007):

- Nanoparticles may penetrate biological barriers.
- They may show intensified effects in the case of substances with toxic properties.
- They may have increased bioavailability.
- They may have different chemical and physical properties from the "parent" material.
- Some types of CNT (carbon nanotubes) and nanowires may have similar effects in the lungs to asbestos fibres.
- Attention must be paid to the risk of dust explosions (as in all applications of inflammable powders or powdery substances).

These possible exposures must be taken into account when managing waste containing nanomaterials, especially nano-objects that are free or that are releasable (e.g. due to the recycling process). Guidance for the safe recovery and disposal of waste containing nanomaterials has been given for example in VCI (2012).

Much research has been done and is still done on health, safety and environment impacts of nanomaterials and on their toxicology and ecotoxicology (JRC/ESAC 2011, Mikkelsen et al., 2011). *"Health and environmental hazards have been demonstrated for a variety of manufactured nanomaterials"*, however "*Not all nanomaterials induce toxic effects. Some manufactured nanomaterials have already been in use for a long time (*e.g. *carbon black,* TiO_2*) showing low toxicity. Therefore, the hypothesis that smaller means more reactive, and thus more toxic, cannot be substantiated by the published data. In this respect, nanomaterials are similar to normal chemicals/substances in that some may be toxic and some may not. As there is not yet a generally applicable paradigm for nanomaterial hazard identification, a case-by-case approach for the risk assessment of nanomaterials is still recommended*" (SCENIHR, 2009).

The wide variety of consumer products makes it difficult to devise and verify a generic exposure assessment and risk management for nanoproducts as a class (JRC/ESAC, 2011). Publications which address the risk-potential associated with consumer products when they enter the recycling process are found in (Struwe et al., 2012; Ostertag & Huesing, 2007; Kuhlbusch & Nickel, 2010). Examples of studies on specific nanomaterials are (Burkhardt et al., 2011) on Silver, (Nanosustain[2]) on ZnO and Nanocellulose, (Mikkelsen et al., 2011) on Titanium dioxide; Cerium dioxide; Fullerenes (Carbon balls); Silver; Zero-valent iron; Silicium dioxide and Nanoclay.

There is still uncertainty about the effective nano-specific risks of ENM in recycled waste streams containing nanomaterials, because there exist no or only a few studies. In the best case, the data are just sufficient to make a preliminary assessment (Struwe et al., 2012). Examples are risks coming from carbon nanotubes which, due to their specific form, may show cancerogenic effects in the lung. Nanosilver is used in textiles and other products because of its biocide (antibacterial) properties, which may bring a risk potential if free nanosilver reaches the environment.

The potential risk of a specific ENM in a waste stream is not only a function of the toxicity or ecotoxicity of the nanomaterial. Additional factors may determine the risk potential of a nanomaterial during recycling, and further research is needed to clarify these issues:

- Quantity / concentration of the ENM in the product or in the waste stream.
- The mode of incorporation of ENM in the product: Are they in a free form, associated with other materials, or fixed by chemical binding?
- Will the ENM be set free with a specific recycling operation?
- Will free ENM stay as single nanoparticles or nanorods or will they agglomerate to bigger entities?
- Will secondary materials (e.g. plastics or construction materials) produced from recycling processes be contaminated in an uncontrolled manner by the ENM enclosed in the original products containing nanomaterials (cross-contamination) which have been recycled?

However, there is enough uncertainty and suspicion of harm to invoke preventive measures (FOEN, 2010; Japan Ministry of Environment, 2009; BSI, 2007; Luther et al., 2004) against the potential nanospecific risks for health or environment during recycling of waste containing nanomaterial.

Recycling procedures and Best Available Techniques (BAT)

Recycling operations shall be done in an environmentally sound manner, according to the Best Available Techniques and by the Best Environmental Practices (BAT/BEP) (OECD, 2004/2007; OECD, 2007); (EU, 2008). The EU proposes *the integration of assessment of risk to human health, the environment, consumers and workers at all stages of the life cycle of the technology (including conception, R&D, manufacturing, distribution, use and disposal) (EU, 2004)*. In view of the uncertainties concerning the fate of nanomaterials during recycling processes, this may also be useful as a precautionary measure to mitigate possible exposure to ENM.

During recycling operations, the main possibilities of exposure to nanomaterials in the recycling process of waste streams that may contain WCNM may be (Struwe et al., 2012):

- Exposure to fine or ultrafine dust containing free nano-objects emitted during transport, sorting, shredding, grinding or pouring of the WCNM.
- Exposure to nano-objects in liquid media (water, solvents) due to cleaning or rinsing the products before mechanical recycling; also exposure to contact with nano-objects on cleaning clothes from maintenance and cleaning of recycling equipment.
- Exposure to nano-objects that may be set free in the flue gas or to the ambient air with thermal processes (heating, welding, pyrolysis) when there is insufficient occupational control.

If by an assessment of possible risks it is known or suspected that nanoparticles are released during production, handling or further processing, workers' exposure to ENMs can be prevented by taking the following safety measures by this order of priority (Luther et al., 2004; BSI, 2007; Japan Ministry of Environment, 2009; FOEN, 2010; VCI/BAuA, 2012; BAuA, 2013):

1. Technical measures at the source, e.g. use of hermetically sealed apparatus; minimisation of dusts and aerosols; extraction of dusts and aerosols directly at the source; filtering of extracted air, if necessary isolation of the workroom and appropriate

modification of room ventilation; cleaning of recycling equipment by vacuum cleaning with suitable appliances or wiping with a damp cloth, but not by blowing off;

2. Organisational measures, e.g. minimisation of the exposure time; minimisation of the number of persons exposed; restriction of access; instructions of personnel concerning hazards and protection measures;
3. Personal protective measures: respiratory protection with particle filters P3; protection gloves; closed goggles; protection suit (non-woven).

Recommendations and guidelines on safe management of engineered nanomaterials have been published by several public and private organisations (e.g. Luther et al., 2004; BSI, 2007; FOEN, 2010; Japan Ministry of Environment, 2009; NEEPH, 2011), and the OECD recommendation *C(2004)100* on Environmentally Sound Management of waste (OECD, 2004/2007) includes exposure prevention measures.

The issue of non-standard treatment of waste

Struwe et al. (2012) distinguish between two categories of recycled WCNM:

a) WCNM with heterogeneous composition, containing different products in their waste stream. Additionally, the different products also contain multiple diverse nanomaterials, often not even known. This category includes for example WEEE, end-of-life vehicles, paper and most plastic waste.

b) WCNM with comparatively homogeneous composition, containing only few, normally known nanomaterials, e.g. PET-bottles, used tires, Li-ion batteries.

It seems reasonable to assume that emission control with WCNM of the first category will pose more difficulties, because of the diversity of products and nanomaterials and/or the complexity of the recycling technique (e.g. with WEEE, ELV or CDW).

We can suppose that the application of known techniques for workers and environment protection would also in a general way decrease the risk, when there are nanomaterials in the waste stream (Japan Ministry of Environment, 2009; FOEN, 2010; NEEPH, 2011; SRU, 2011; Struwe et al., 2012; Boeni, 2013).

By applying appropriate BAT procedures for waste treatment[3], emissions in general will be lowered, and it can be expected that possible exposure to ENM will also be lowered. The following list gives a short selection of elements mentioned in the cited document that may be considered as BAT when handling waste:

- Environment Management System in order to know the processes, the accepted waste and the waste and secondary products going out of the treatment installation;
- Ensure proper location and drainage of storage facilities;
- Unloading solids and sludge in closed areas;
- Perform crushing/shredding and sieving operations in areas fitted with extractive vent systems linked to abatement equipment when handling materials that can generate emission to air (e.g. odours, dust, VOCs);
- Proper management of waste water from the treatment plant;
- Air emission treatment;
- Management of process residues;
- Avoid soil contamination.

The following statement made by the British Health and Safety Executive about BAT/BEP to apply with WEEE-Recycling does not refer to WCNM, but to substances like mercury or lead. However, The principle formulated here may – "mutatis mutandis" – give good guidance when implementing BAT in recycling technologies where there is to expect WCNM in the waste stream:

"*As a result of this complex mix of product types and materials, some of which are hazardous (including arsenic, cadmium, lead and mercury and certain flame retardants) WEEE recycling poses a number of health risks that need to be adequately managed. For example, exposure to substances released during processing (such as mercury released from fluorescent tubes, lead and phosphorous pentachloride as a result of breaking cathode ray tubes). It is important to stress that if effective measures are taken to control exposure to mercury and lead, then normally the control of exposure to other hazardous substances should also be adequate*".[4]

This adequacy is true when releases and exposures to the nanomaterials may occur in the same recycling process steps that are specifically controlled to reduce or eliminate releases and exposures to mercury and lead.

Knowledge gaps and possible activities

The principal challenges with safe and environmentally sound recycling procedures for waste containing nanomaterials are:

a) controlling the health, safety and environmental risks arising from recycling processes of waste containing nanomaterials;

b) controlling the technical and environmental quality of secondary materials that may be contaminated with ENM from the original waste stream;

c) developing technologies that may be used for the recovery of the ENM from the products, given suitable quantities, concentrations and economic value of the ENMs.

Several authors who have identified knowledge gaps in the context of recycling of WCNM recommend actions that can be taken in order to improve the current uncertainty (Japan Ministry of Environment, 2009; Struwe et al., 2012; NEEPH, 2011; Gottschalk & Nowack, 2011; Kuhlbusch & Nickel, 2010; FOEN, 2010; Lee et al., 2010). From these statements, the most important knowledge gaps and proposed measures in the context of recycling of WCNM can be summarised in Table 2.2 as follows:

Table 2.2. **Knowledge gaps and proposed measures in the context of recycling of WCNM**

Knowledge gaps and open questions	Possible activities
Types and quantities of nanomaterials in products and waste and associated risk potentials?	• Evaluation of types and quantities of specific nano-materials in waste streams • Labelling of products containing nanomaterials • Produce experimental and analytical data about the main release sources during all ENM life stages: ENM production, manufacturing of nanoproducts, consumption and disposal of nanoproducts.
Behaviour and fate of the nanomaterials in products during the recycling processes (from collection to the preparation of the recycled products): do they stay in the material, are they set free and if so, are they in a form that is a risk for health, safety and environment HSE)?	• Research on the risk of release of NPR from composite products during waste treatment (e.g. with shredding) • Produce experimental and analytical data regarding the form the ENM are released, such as whether the ENM are agglomerated or present as single particles or if they are embedded within a matrix • Additional research on the possibilities that nanomaterials from WCNM "diluted" to other materials during the recycling procedure may impair the quality of these materials
The most suitable technologies for emission control and for protection of humans and the environment when recycling WCNM?	• Identification of possible sources of ENM emissions and of the concerned workplaces in the recycling industry • Preventive measures on the basis of existing guidelines and knowledge for health protection and workplace safety • Research on the effectiveness of the current waste management systems' suitability of dealing with new pollutants containing nanoscaled structures • Implementation of preventive measures on the basis of existing guidelines and knowledge for health protection and workplace safety • Development of dedicated guidelines for the recycling industry
Measurement and identification of ENM in products and waste streams	• Development of methods and standardisation of "emission measurements" with examination of the relevant parameters with respect to norms.
Effects of cross-contamination of recycled materials with nanomaterials from WCNM	• Additional research on the possibilities that nanomaterials from WCNM may be "diluted" to other, downcycled materials during the recycling procedure • Research on how far nanomaterials can interfere with or prevent recycling and other recovery processes
Possibility of recovery of nanomaterials from a waste stream	• Evaluation of eventual need for separate collection for specific types of waste containing nanomaterials, for example because of the quantities expected or because they are hazardous.

Notes

1. OECD Statistics *http://stats.oecd.org/Index.aspx?DataSetCode=WASTE*.
2. *www.nanosustain.eu/component/content/article/1-latest-news/128-nanosustain-factsheet-and-case-studies*.
3. For guidance on the implementation of BAT in the waste sector, see EU/IPPC-Document on Best Available Techniques for the Waste Treatment Industries (EU-IPPC, 2006, *http://eippcb.jrc.ec.europa.eu/reference/*), even if it is not mentioning Waste Containing Nanomaterial at all.
4. UK Health and Safety Executive *www.hse.gov.uk/waste/waste-electrical.htm*.

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ANNEX 2.A1

Waste streams possibly containing nanomaterials

Table 2.A1.1. **Selected waste streams with possible WCNM**

Waste type	Recycling procedure	Nanomaterials	Theoretically possible sources of nano object emissions in the recycling process
Metal waste (scrap)	Shredding, smelting	In coatings: Metal oxides, CNT, SiO_2	Shredding, if ENM can be set free from coatings Smelting: ENM that are not destroyed in the melting process, insufficient exhaust gas purification
Paper and cardboard	Pulping, de-inking (wet processes) *www.paperonline.org/environment/paper-recycling/the-paper-recycling-process*	Carbon Black (from the ink), TiO_2 (except for special papers, TiO2 is not in the nano-form)	Dust from collection, transport Aerosols of ink from pulping and de-inking
Plastic	Collect & sorting, or separate collection (e.g. for PET-bottles) mechanical recycling: shredding, washing, regranulation Feedstock recycling: depolymerisation, cracking (for basic chemicals)	CNT, SiO_2, TiO_2	Shredding and regranulation: if nano objects are set free. Feedstock (chemical) recycling: nano objects that are not destroyed in the process may be emitted or end up in the cracking residues (tar). Problem of dispersion of ENM to regranulated plastics
Textiles	Collect, reuse, sorting, preparing for reuse, shredding to get fibres	CNT, Ag	Shredding: if nano objects are set free
Waste Electronic and Electrical Equipment (WEEE)	Collect, dismantling, sorting by hand, shredding and separation of the fractions, processing of fractions (non-magnetic metals, iron, glass, plastics etc.), further processing of the components (metal melting, material recovery of iron and non-iron metals, extraction of metals from circuit boards	Carbon black (in plastic and in toners), CNT (in electronic devices and in plastic housings, nano-Iron oxide, ZnO, SiO_2, Ag (in coatings)	Any step of the procedure, depending on the nanomaterial containing component and on the specific type of nanomaterial.
Batteries	Collect, sorting. Mechanical/chemical and/or thermal treatment (various procedures, e.g. BATREC (Switzerland)[1] for alkali- and mercury batteries, Battery Solutions (USA)[2], Toxco (USA)[3] for lithium batteries, or INMETCO (USA) for Ni-Cd Batteries[4]. Another informative and educative website:[5] *http://batteryuniversity.com/learn/article/recycling_batteries*	Electrodes with CNT or Nano-Phosphate® *(nLiFePO$_4$)*[6]	In principle during mechanical, chemical or thermal treatment, dependent on the process and on the type of battery with nanomaterial.
Construction and Demolition Wastes.	Reuse of components, sorting of fractions (wood, concrete, brick, metal etc.), metal recycling, secondary building materials, incineration and landfill	CNT, SiO_2, TiO_2, Fe_2O_3, Cu, Ag	During destruction of buildings (dust emissions), shredding, grinding if nano objects are set free. Problem of dispersion of ENM fractions of recycled material

Table 2.A1.1. **Selected waste streams with possible WCNM** *(cont.)*

Waste type	Recycling procedure	Nanomaterials	Theoretically possible sources of nano object emissions in the recycling process
End of Life Vehicles (ELV)	Dismantling for reusable parts (incl. tires), removal of hazardous components (e.g. batteries), shredding and separation of fractions, metals go to smelting and refining, glass is recycled or landfilled, non-metallic shredder residues for incineration or landfill (Ostertag & Huesing, 2007)	CNT, SiO_2, TiO_2 (in plastics, coatings and paints)	Shredding and sorting of fractions, smelting of metals (ENM from coatings), disposal of non-metallic shredder fraction. Modern cars contain electronic components that are normally not removed before shredding, this is a possible source for ENM-emissions
Tires	Collect, storage (danger of ignition), refurbish and reuse, shredding, of metal, reuse of rubber for downcycled products or for energy recovery (according to *www.amni.de/de/anlagen/reifenrecycling.html*) 27% of tires worldwide were recycled 2005, only 6% in 1995; landfill dropped from 62% to 22 % in the same time) Information on Scrap Tires and environmental issues in: *http://en.wikipedia.org/wiki/Rubber_tires#Rubber_tires*	Carbon Black, silica; there are indications that future developments will include others, e.g. CNT, nanoclay (SiO_2) or organic nano-Polymers (ObservatoryNANO 2011)	In principle when shredding, actual tires contain ENMs that are bound to the rubber matrix (Peters 2012)
Recycling of residues from waste incineration:	separation of metals bottom ash from MSWI, (ca. 220 kg of Bottom ash are produced when incinerating 1 tonne of MSW, these contain metal residues (Iron, Aluminium, Copper, even Gold) from MSW. (Fierz and Bunge, 2007, Boeni, 2013)	ENM from WCNM in the municipal waste that are not destroyed or evaporated may stay in the bottom ash	The most efficient recovery of metals from bottom ash is done with dry ash, with dust generation: nano objects can be emitted during pouring, sieving, mechanical and magnetic separation

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3. Toxco Recycling Processes, *www.toxco.com/processes.html* (accessed Aug.28, 1013).
4. *www.inmetco.com/services_battery.htm*
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6. *http://en.wikipedia.org/wiki/Lithium_iron_phosphate#The_Physical_and_Chemical_Properties_of_LFP*

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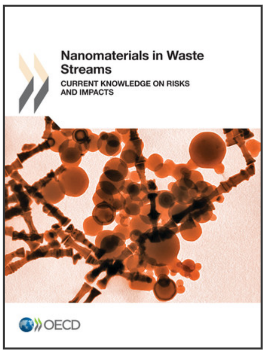

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