Waste Management xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Use of engineered nanomaterials in the construction industry with specific emphasis on paints and their flows in construction and demolition waste in Switzerland

Ingrid Hincapié [a], Alejandro Caballero-Guzman [a], David Hiltbrunner [b], Bernd Nowack [a,*]

[a] EMPA, Swiss Federal Laboratories for Materials Science and Technology, Technology and Society Laboratory, Lerchenfeldstrasse 5, CH-9014 St. Gallen, Switzerland
[b] FOEN, Swiss Federal Office for the Environment, Waste and Resources Division, Worblentalstrasse 68, CH-3063 Ittigen, Switzerland

ARTICLE INFO

Article history:
Received 27 January 2015
Revised 30 June 2015
Accepted 2 July 2015
Available online xxxx

Keywords:
Engineered nanomaterials
Construction and demolition waste
Recycling
Landfills
Paints
Material flow modeling

ABSTRACT

One sector where the use of engineered nanomaterials (ENMs) is supposed to offer novel or improved functionalities is the construction industry. During the renovation or demolition of buildings, ENMs contained in former construction materials will enter recycling systems or become construction waste. Currently, information about ENM flows in these processes is insufficient. The potential for the release of ENMs from this waste into the environment is unknown, as are the environmental impacts. To evaluate whether there is currently any nano-relevant construction and demolition waste (C&DW) originating from buildings, we evaluated the sources and flows of ENMs in C&DW and identified their potential exposure pathways. A survey of business representatives of Swiss companies in this sector found that ENMs are mainly used in paints and cement. The most frequently used ENMs in the Swiss housing construction industry are nano-TiO_2, nano-SiO_2, nano-ZnO, and nano-Ag. Using a bottom-up, semi-quantitative approach, we estimated the flows of ENMs contained in paints along the product's life cycle from buildings to recycling and landfill. The flows of ENMs are determined by their associated flows of building materials. We estimated an annual amount of ENMs used in paints of 14 t of TiO_2, 12 t of SiO_2, 5 t of ZnO, and 0.2 t of Ag. The majority of ENMs contained in paints in Switzerland enter recycling systems (23 t/y), a smaller amount is disposed directly in landfills (7 t/y), and a tiny fraction of ENM waste is incinerated (0.01 t/y). Our results allow a qualitative determination of the potential release of ENMs into technical or environmental compartments, with the highest potential release expected during recycling.

1. Introduction

The construction sector requires products like cement, steel, paints, insulation materials, window glass, and many others. The quest for sustainable development, including the construction of greener buildings, influences innovation and encourages the use of products exploiting the unique properties of nanomaterials. Engineered nanomaterials (ENMs) are used either to improve the quality of existing conventional products or to create completely novel products, functionalities, and applications. For instance ENMs tested in cement include SiO_2, Al_2O_3, Fe_2O_3, ZrO_2 and CNT (van Broekhuizen et al., 2011), they are used mainly to improve the quality and longevity of structures (Hanus and Harris, 2013). In insulation materials, nano-SiO_2 (aerogel) is used as a noise barrier and for heat loss reduction (Jelle et al., 2012). Properties such as easy-clean, antibacterial, scratch resistance, fire retardant, UV-protection, wood preservation and anti-corrosion can be introduced or improved in paints and coatings using the following ENMs: Ag, CeO_2, CNT, Fe_2O_3, SiO_2, TiO_2, ZnO (Hanus and Harris, 2013; Kaiser et al., 2013b; Lee et al., 2010a; Teizer et al., 2012; van Broekhuizen and van Broekhuizen, 2009). In windows, ENMs such as SiO_2, TiO_2 are used for anti-reflection, anti-fogging, heat loss reduction and easy-clean properties (Lee et al., 2010b).

However, most of the potential applications for ENMs (e.g. concrete, asphalt or insulation materials) have not yet reached large-scale commercial production, and rather represent niche market segments (van Broekhuizen and van Broekhuizen, 2009). In some cases, applications containing ENMs have only been developed on a pilot scale or are only to be found as experimental results in the scientific literature. Reasons for the limited spread of nano-applications include their high prices compared to conventional products, uncertainties related to their safety, and uncertainties related to their technical performance (van Broekhuizen

* Corresponding author.
E-mail address: nowack@empa.ch (B. Nowack).

http://dx.doi.org/10.1016/j.wasman.2015.07.004
0956-053X/

et al., 2011). In the near future, it is presumed that nanotechnology applications will help the construction sector to reach the following goals (Hanus and Harris, 2013; Kaiser et al., 2013b; Lee et al., 2010a; Teizer et al., 2012; van Broekhuizen and van Broekhuizen, 2009): development of stronger concrete structures; generation of healthier environments; protection of structural appearance and durability; and reduction of energy consumption and other resource use.

According to van Broekhuizen et al. (2011), the current applications of ENMs in Europe's construction sector are mainly in cement (concrete's basic additives), paints, and insulation materials. These authors also reported that nano-TiO_2, nano-ZnO, nano-Al_2O_3, and nano-SiO_2 were the predominant ENMs used in construction materials and that there was no evidence of the current use of carbon nanotubes (CNTs). However, further investigations showed that CNTs are potential candidates for enhancing the mechanical properties of cement-based materials and their resistance to crack propagation while providing such novel properties as electromagnetic field shielding and self-sensing (Sanchez and Sobolev, 2010). Silica fume is used in cement mainly to improve the quality and durability of structures (Hanus and Harris, 2013). However, the costs associated to the nanomaterial production process and the special equipment required to handle it make the cement more expensive than conventional types (van Broekhuizen and van Broekhuizen, 2009).

The paint and coating industry has successfully adopted nanotechnology (Evans et al., 2008; Kaiser et al., 2013b). Although there is an ongoing debate about whether or not the expected benefits of nanomaterials in these applications will materialize in the long run (Kaiser et al., 2013b), it is estimated that paints and coatings currently represent the biggest market for nanotechnology in the construction industry (NanoHouse, 2013; van Broekhuizen et al., 2011).

Although official recommendations on the definition of nanomaterials (i.e. at least 50% of the particles must be in the size range of 1–100 nm) were just published (EU-Commission, 2011), nanomaterials have been produced and used before the development of nanotechnology industries as we know them today, for instance, SiO_2 (Bosch et al., 2012), nano-Ag (Nowack et al., 2011), and carbon black (CB). In some cases, therefore, it may be difficult to confirm whether a given product contains nanomaterials or not. In some of these substances, e.g., SiO_2 or CB, primary nanoparticles of less than 100 nm are fused together into aggregates of more than 100 nm. Because EU definitions are based on primary particle size, these substances are now considered nanomaterials although they have been considered and used as conventional materials for many decades.

Despite the aforementioned benefits of integrating ENMs into construction materials, concerns about their use still remain open, including their effects on environmental and human health following potential release to air, water and soil. The currently available information makes it possible to quantify the flows of nanomaterials and to evaluate their potential releases during the whole products life cycle. A study by Müller et al. (2013) analyzed the flows of ENMs in the waste flows. The results provided the first estimate of the amount of ENMs in waste streams in Switzerland. The modeling suggested that an important flow of nanomaterials goes directly from construction waste into landfills and indirectly from waste incineration plants to the landfills as bottom ash. Based on that work and the Swiss waste management system regulations, the present study aimed to investigate what amounts of nanomaterials exist in the C&DW flows originating from buildings in Switzerland (i.e. we did not considered C&DW from roads, underground constructions and hazardous construction waste), and to analyze whether there is currently any nano-relevance in construction waste. We estimated the flow of ENMs in waste originating from building construction, renovations, and demolitions as well as the potential release of ENMs during recycling, with focus on paint applications. On one hand, paints appeared to be the most important application containing ENMs in the construction sector. On the other hand, only for this application enough data was available to carry out a quantitative modeling. The steps performed in this estimation were:

1. Collect data on sources of ENMs and flows of C&DW to landfill, waste incineration, and recycling, within the Swiss waste management system.
2. Estimate the current amounts of nanomaterials in Swiss C&DW originating from buildings.
3. Model ENM flows from buildings to landfill and the environment, according to the Swiss waste management system.
4. Evaluate the potential release of nanomaterials based on studies on ENMs release.

Only data for 2012 were available and collected for the application paint. Subsequently, we focused on the following nanomaterials: TiO_2, SiO_2, ZnO, and Ag, which are the ENMs most used in paints for the construction industry.

2. Materials and methods

2.1. Data collection

To obtain information about ENM applications and the amounts used in the Swiss construction industry, we surveyed a group of expert representatives from companies in this sector. The survey questionnaire was designed using the Internet-based platform, Surveymonkey, and was sent out to 60 construction sector experts between February 12 and March 13, 2014. The questionnaire asked for estimates of ENM use in the Swiss construction industry (i.e., use/non-use of nanomaterials, market sizes, and shares and amounts of ENM used in different construction materials). The specific questions of the survey are shown in the supplementary information, Section 1.

Questions were specifically related to the use of nano-TiO_2, nano-SiO_2, nano-ZnO, nano-Ag, nano-CuO, and nano-$CuCO_3$, and to the following materials used in the construction sector: adhesives, architectural membranes, asphalt, cement, coatings, flooring materials, geosynthetic barriers, insulation materials, paints, pipes, sealants, solar panels, steel, other metals, windows, and wood.

Besides our survey, additional information on the mass content of ENMs in construction applications (i.e. stocks of ENMs in the applications) was taken from Hischier et al. (2015), NanoHouse (2013) and van Broekhuizen et al. (2011), as well as from official registrations of nanomaterials (ANSES, 2013) where paints and cement were the main applications. In order to estimate the amount of paint containing ENMs sold in Switzerland, this information was complemented by data from the 2012 market reports of the Swiss Association for the Lacquer and Paint Industry, and other sources (Burkhardt and Dietschweiler, 2013; McCulloch, 2012; VdL, 2012; VSLF, 2013). As a result, the market data (i.e. sold amounts in 2012) of paint in Switzerland are the base data for our modeling.

2.2. Disposal and amounts of C&DW in Switzerland

According to the Swiss waste management system, C&DW is generated from the changes in infrastructure stocks (i.e., buildings, roads and underground constructions), and it also includes hazardous construction waste. For this study, we only considered the C&DW originated from buildings. According to the Swiss waste

Please cite this article in press as: Hincapié, I., et al. Use of engineered nanomaterials in the construction industry with specific emphasis on paints and their flows in construction and demolition waste in Switzerland. Waste Management (2015), http://dx.doi.org/10.1016/j.wasman.2015.07.004