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Analysis of metallic and metal oxide nanomaterial environmental emissions

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ABSTRACT

The current study presents evidence on metallic and metal oxide engineered nanomaterial (ENM) emissions into the environment and an analytic perspective of the outcomes of evaluated studies with respect to different individual end points along the lifecycle trajectory. The key findings suggest that 1) the published literature on emissions of metallic ENMs is limited in both the number and information available on the characteristics of emitted ENMs; 2) the studies are classified as experimental and computational studies focused on predicting ENM emissions; 3) the majority of studies investigated ENM emissions during nanomaterial use and waste management, followed by raw material manufacturing, and finally, nano-enabled product manufacturing; 4) the studies primarily reported the concentration/quantity of emitted ENMs, whereas the physical–chemical characteristics of emitted ENMs were rarely measured or reported; and 5) the published literature primarily focused on emissions of silver and titanium dioxide ENMs and lacked similar information on other surging metallic and metal oxide ENMs such as nano-zero valent iron (nZVI), aluminum (Al), and aluminum oxide (Al_2O_3) ENMs. The evidence suggests that emitted nanoparticles into the air cover a wide range of concentrations below and above the allowable occupational exposure limits. The concentrations of nanoparticles in water systems are considered in the toxic to very toxic range for a variety of biological species. Given the critical gaps in knowledge, one cannot read across different sources of emissions for metallic and metal oxide ENMs hampering efforts with respect to understanding realistic scenarios for transformations in the natural environment and biological media.

1. Introduction

Over the past two decades, the use of engineered nanomaterials and nano-enabled products has been abundantly on the rise in a multitude of industries including healthcare, energy, electronics, and consumer products (Gottschalk et al., 2013; Ju-Nam and Lead, 2008). This increased use has raised concerns over the potential increased emissions of ENMs into the environment with respect to their health, safety and negative effects on biological species (i.e., human and non-human) and natural environment (Bystrzejewska-Piotrowska et al., 2009; Keller et al., 2013; Klaine et al., 2008; Kühnel and Nickel, 2014). In this respect, it is important to characterize not only nanomaterial emissions, but also, the physical-chemical properties of the emitted particles in order to adequately understand engineered nanomaterials' (ENMs') potential chemical, physical and biological transformations in interaction with key environmental conditions (Handy et al., 2008; Hartmann et al., 2014).

ENMs are emitted into the environment from four sources, namely, raw material manufacturing, nano-product manufacturing, product use, and waste management. As shown in Fig. 1, each source of ENM emissions and releases may consist of several avenues. Prior reviews on the subject have evaluated production data for the prediction of ENM concentration levels during emissions and releases into the environment (Table S1, supplementary information) with little information documented on the physical-chemical properties of the emitted ENMs. In addition, the body of knowledge is built on individual ENMs. Currently, there are a large

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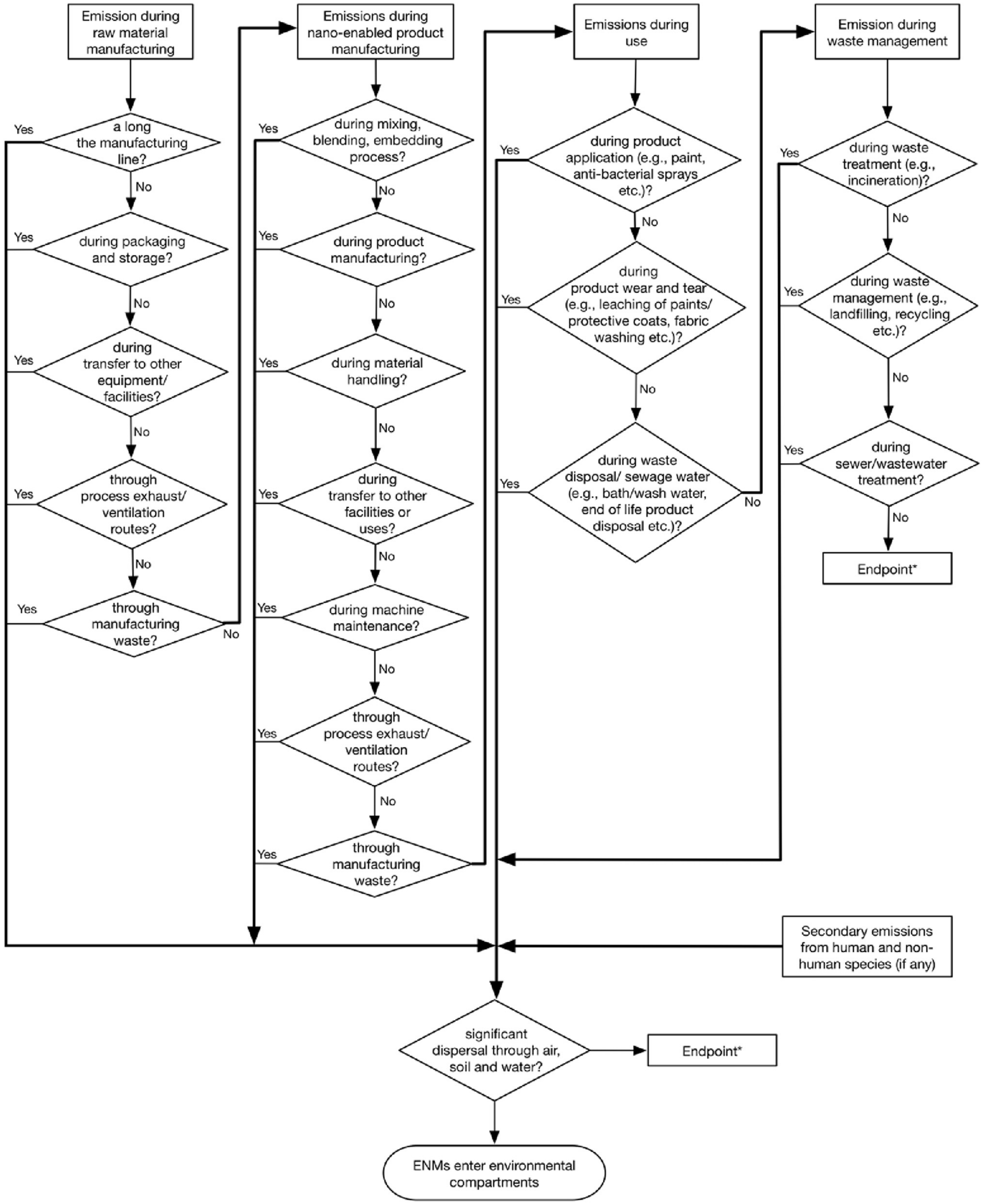

Fig. 1. Sources of emissions and releases for ENMs.

number of individual ENMs that are synthesized in research labs and manufacturing settings, and it is expected that they will continue to increase into the future. Rather than evaluating individual nanomaterials, scientists and regulators often categorize ENMs in groups that share some physical and chemical properties. While there is no standard ENM classification to date, various classification schemes have been proposed (Farré et al., 2011; Ju-Nam and Lead, 2008; Klaine et al., 2008; Peralta-Videa et al.,