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MINERAL WOOL WASTE IN AUSTRIA, ASSOCIATED HEALTH ASPECTS AND RECYCLING OPTIONS

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ABSTRACT

Mineral wool products are man-made vitreous fibres that are used as thermal and acoustic insulation materials and as substrates for horticulture. Mineral wool waste is generated from demolition activities by the building and construction industry. Unfavourable mechanical properties, such as low compressibility, elastic behaviour, high volume and low bulk density, cause problems in landfills when mineral wool waste is disposed of. Mineral wool waste with a certain content of carcinogenic fibres is classified as hazardous waste type 31437 g "Asbestos Waste, Asbestos Dust" in Austria, since some characteristics of such fibres are similar to those of asbestos fibres. An exception is those mineral wool materials that have been tested to be noncarcinogenic due to their characteristics of biological solubility or geometrical dimension. Such noncarcinogenic mineral wool waste is classified as non-hazardous waste type 31416 "Mineral fibres". Generally, it can be assumed that most of the industrial producers of mineral wool in the EU have not been producing carcinogenic material since 1998; however, carcinogenic mineral wool material has not yet been banned in Austria. Therefore, a segregation between so-called "old" and "new" mineral wool material is not necessarily possible. The medical aspects of mineral wool products are still controversial. The International Agency for Research on Cancer (IARC) evaluated mineral wool (glass wool and rock wool) as "possibly carcinogenic" in 1988 but revised this evaluation to "inadequate evidence in humans for the carcinogenicity" in 2002. Fibrous dusts that reach the alveolar region of the lungs undergo a congruent or incongruent chemical dissolution process. Alveolar macrophages ingest the intruded fibres and fulfil anti-infection and clearance functions. Biosolubility is a key property of this process. The recycling of mineral wool waste has not yet been performed in Austria due to economic inefficiency, technical problems and suspected health issues. However, some recycling and processing options already exist; other options are investigated in the project RecyMin, which compares different concepts with respect to environmental and economic criteria.

1. INTRODUCTION

Mineral wool is a man-made vitreous fibre that is primarily produced from glass, igneous rocks and slags. Mineral wool products are used as insulation material and in horticulture.

Mineral wool waste causes problems in waste management due to its high volume and low density, e.g., the lack of stability in the landfill body. Currently, most of the mineral wool waste in Austria is landfilled, and to date, no recycling is carried out. These problems have become increasingly urgent because of the higher quantities of this waste stream in recent years due to the separate collection of mineral wool waste and the higher amounts used for insulation.

Mineral wool waste is also under observation because of possible health aspects. In general, fibres of mineral wool can be released into the environment due to the production process, the usage of the product and the demolition and dismantling of buildings containing mineral wool products, which can cause health difficulties because of airborne respirable fibres with low biosolubility.

Mineral wool materials that have been produced with certain quality labels, such as the German RAL quality label for mineral wool products (approximately from 1998 and later), fulfil current requirements of biological solubility and may therefore not be listed as carcinogenic. All other mineral wool materials, at least those produced before 1998, might have a lower biosolubility and are classified by the

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European Union as "possibly carcinogenic to humans" (EU 2008). Therefore, it is very important to distinguish these two types of mineral wool materials due to hazardousness. The differentiation between glass wool and rock wool is even more important for the recycling process.

In this review, we provide an overview of the technical, health and legal aspects of mineral wool waste treatment.

2. MATERIALS AND METHODS

This article summarises the challenges of waste management, technical issues, and health aspects and discusses the legal aspects of mineral wool waste in Austria.

The literature research was performed by reading and summarising reviewed articles, books, legislations, guidelines and standards. Sources were selected based on their importance for the article in terms of waste- and health-related aspects as well as the concerning legislations.

A patent search has been performed in addition to the literature research to gather patent information regarding recycling and processing options for mineral wool waste and man-made vitreous fibres in general. Expert discussions with landfill engineers, waste collectors, waste processors and the mineral wool industry have been carried out to provide professional experience regarding the challenges of mineral wool waste in Austria.

3. RESULTS AND DISCUSSION

3.1 Technical aspects

Man-made vitreous fibres consist of fibrous inorganic substances. They are divided into glass fibres, glass wool, rock wool, slag wool and ceramic fibres. Mineral wool comprises glass wool, rock wool and slag wool (DGUV 2014). The term "wool" describes an omnidirectional accumulation of fibres with different lengths and diameters (DIN EN 1094-1 2008).

3.1.1 Production of mineral wool

Mineral wool is mainly produced from glass, slags and igneous rocks such as basalt and diabase. Waste glass is added as a secondary raw material (IARC 1988, BBSR 2011). The production of mineral wool products can be divided into the following steps: supplying the raw materials and energy sources, melting in a furnace, fiberization and collection, primary layer formation and finishing (Sirok et al. 2008).

Figure 1 shows the process of mineral wool production. The raw material is melted in a cupola furnace, and coal is mostly used as an energy source. The fiberization of the molten raw material is usually executed on spinner wheels (Sirok et al. 2008). The fibres are then collected in the wool chamber (Sirok et al. 2013). The primary layer is formed in the wool chamber and then folded by a pendulum. The stack of mineral wool is then brought to the required thickness and enters the curing chamber where the previously applied resin hardens (Sirok 2008). Following the preceding steps, the fibres are formed into different products, such as blankets, mats and other product types (IARC 1988).

3.1.2 Application of mineral wool products

Mineral wool is used for a wide range of applications, such as thermal and acoustic insulation material, fire prevention (DGUV 2014) and horticulture (TRGS 521 2002). Mineral wool products are primarily used at temperature ranges up to 300°C (TRGS 619 2013) but can also be applied at temperatures up to 600°C (DIN EN 1094-1 2008).

3.1.3 Waste-related aspects

Amount of mineral wool waste

A survey study on mineral wool waste in Europe (Väntsi et al. 2014) estimates that there are approximately 2.5 million tons of mineral wool waste produced in the European Union per year but the study notes a lack of data.

In Austria, an amount of 20,000-30,000 t/a of mineral wool waste was estimated by the Austrian Economic Chamber in 2018.

Challenges in practice

The management of mineral wool waste is technically challenging due to its high volume, low bulk density, high elasticity, poor compressibility and the consequential lack of stability in a landfill. Additionally, legal challenges arise from the distinction between old and new mineral wool waste. In contrast, during the collection of mineral wool, no distinction between glass wool and rock wool is made, which would be necessary for many recycling options.

The transport of mineral wool waste to a recycling plant or landfill is associated with high economic and ecological burdens due to its low bulk density.

The knowledge of mineral wool not being carcinogenic does not solve the problem from a waste management point of view. Mineral wool waste that occurs due to the dismantling of a building is primarily not relatable to a certain year of production or to a certain industrial producer. Because of the precautionary principle, this mineral wool waste must be classified as possibly carcinogenic or "old" mineral wool and therefore as hazardous waste (Wirtschaftskammer Österreich 2018), regardless of whether this is the case or not. For disposal, this mineral wool must be gathered in hermetically sealed packages, such as big bags, which results in an unstable landfill body.

No testing methods to analyse mineral wool waste at the construction site for its possible hazardous property (HP7, carcinogenic) have been developed yet concerning its biological solubility since the geometrical characteristics are unclear. Therefore, an unknown amount of mineral wool waste is wrongly assigned to the hazardous waste code. As a result of this situation, it is impossible to gather precise data on the specific amounts of hazardous and non-hazardous mineral wool waste in Austria.

3.1.4 Recycling options and patents

There has already been some research on the recycling options for mineral wool waste (Öhberg 1966) (Balkevicius et al. 2007) (Holbek 1987), but this only concerns mineral wool production waste (Väntsi et al. 2014) and not mineral wool waste from the demolition of buildings. Müller et al. (2009) developed a recycling method for slagging mi-

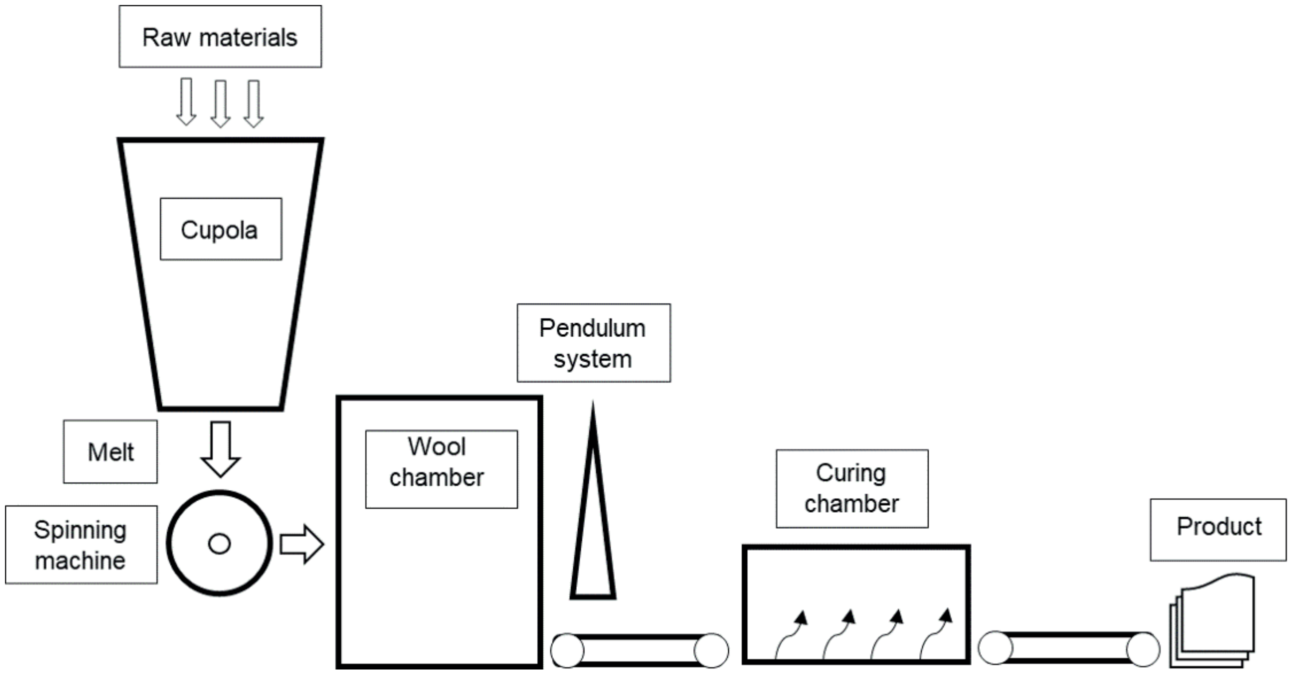

FIGURE 1: Schematic figure showing the production process of mineral wool (modified after Sirok et al. 2008, Institut Bauen und Umwelt e.V. 2012).

neral wool waste at the laboratory scale using a specific microwave technology. The slags created in this process might be used as products in the future as the hazardous property, i.e., the fibrous character in combination with low biosolubility, is destroyed.

The patented "re:cyKMF" process generates backfill material using mineral wool waste, binding agent suspension and water (Gröper & Lack 2016).

A mobile press to agglomerate waste of man-made vitreous fibres was patented by Wurzer Umwelt GmbH Eitting in 2016. The vehicle contains a compaction unit and is therefore able to execute the pressing of mineral wool waste where it accrues and to reduce the high volume of the mineral wool waste (Patent EP 3 168 037 A1). The agglomeration of mineral wool waste is an important preparation step prior to optimised disposal or recycling.

Project RecyMin

The project RecyMin focuses on mineral wool waste in Austria. It aims to develop innovative landfilling solutions and the recycling of mineral wool waste in backfilling and in the cement and glass/rock wool industries (Sattler et al. 2019).

The fundamental research approach is based on a waste management survey. Through a combination of waste management, process engineering and material science methods, a concept for the recycling of mineral wool waste will be developed. This concept, depending on logistical, economic and technical circumstances, includes an innovative disposal method, recycling through backfilling, in the cement industry and recycling in the mineral wool industry under consideration and the evaluation of ecological, economic and health aspects (Figure 2) (Sattler et al. 2019) (Vollprecht et al. 2019).

The challenge of varying and unknown potential for recycling and possible hazardousness of mineral wool waste should be solved by a combination of methods, including waste management life cycle assessment (LCA) and chemical, mineralogical and morphological material characterisation of waste in the laboratory. The processing of mineral wool waste aims to enhance the properties of mineral wool waste for landfill technology, recycling options and health characteristics. Mineral wool waste can be disposed of in the form of briquettes, as the low density and poor compressibility are improved by preceding processing by a briquetting press (Sattler et al. 2019) (Vollprecht et al. 2019). Using processed mineral wool waste as a backfilling material is another possible application (Höllen et al. 2015). RecyMin evaluates another application to recycle mineral wool waste in the cement industry. In the case of recycling in the mineral wool industry, the consequences on the procedural properties of the melt are investigated, and additives applied for the compensation of chemistry are used. The consequences of the proposed processes on waste management systems are investigated through an ecological-economic evaluation and summarised in a waste management context (Sattler et al. 2019) (Vollprecht et al. 2019).

3.2 Health aspects

3.2.1 Waste-related aspects

Health implications due to exposure to man-made vitreous fibres might be the irritation of the skin and mucous membranes, as well as health effects on the breathing organs (Valic 2012).

Due to their composition, synthetic vitreous fibres are degraded in the environment only under acidic or alkaline

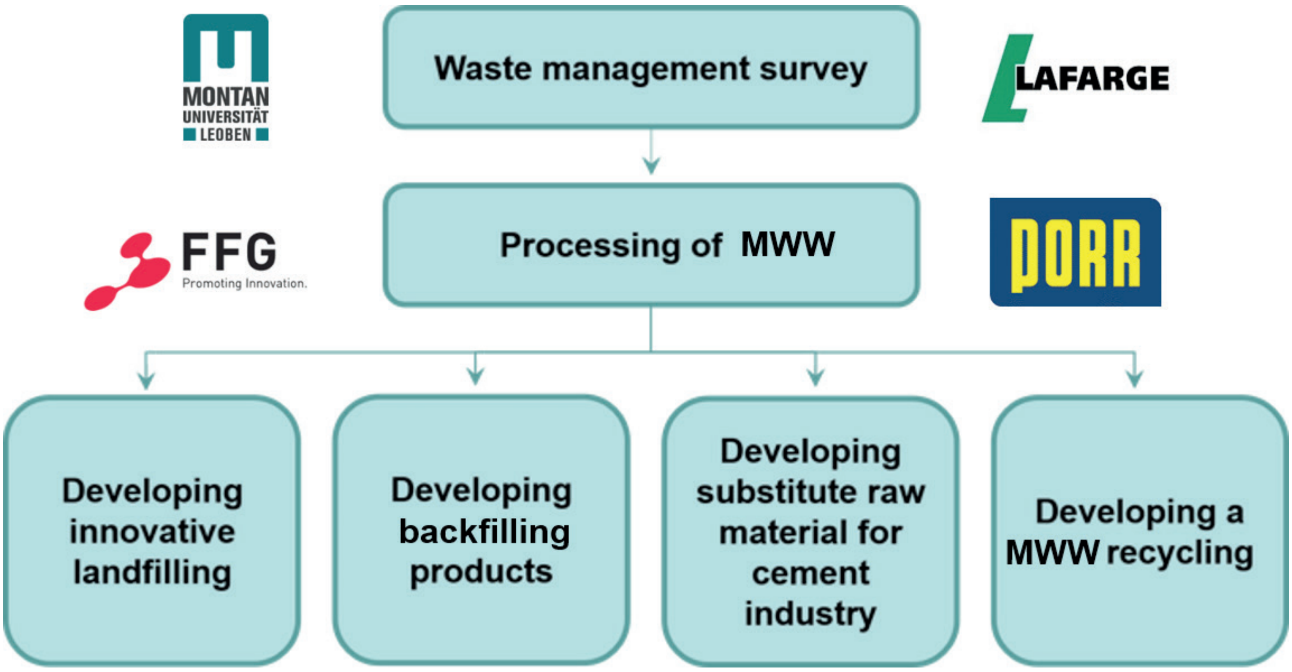

FIGURE 2: Schematic figure of the project RecyMin; MWW=mineral wool waste.

conditions by dissolution of the silicate network. Hence, the fibres can remain in soil and water over a long time. In particular, people working on construction sites (demolition, dismantling, building maintenance and repair) or in the fibre production industry can be exposed to synthetic vitreous fibres to a high degree (ATSDR 2004).

It is assumed that negative health effects are determined by certain fibre characteristics:

- Fibre length;
- Fibre diameter;
- In vivo durability and persistence (IARC 1988).

Fibres with dimensions of a diameter < 3 µm and length > 5 µm and a length to diameter ratio ≥ 3 : 1 can be deposited in the alveolar region of the lungs (IARC 1988); these fibres are called WHO fibres or critical fibres because the World Health Organisation (WHO) defined the respirable fibre dimensions in 1988.

Distinguishing between rodents and humans, in general, a larger amount of long respirable fibres are able to penetrate into human lungs compared to those of rats (Dai & Yu 1998).

3.2.2 Observations in humans

The inhalation of man-made vitreous fibres causes deposition of these fibres in the nasal, oral sections and upper lung airways at first. They are mostly transported to the stomach by a layer of mucous in the throat (ATSDR 2004). If respirable fibres are present, they can reach the alveolar region (Skinner et al. 1988) where they are exposed to the acidic intracellular environment with a presumed pH of 4.5-5 in the phagolysosome (ATSDR 2004) and undergo chemical dissolution or leaching processes due to the macrophages. The macrophages ingest the intruded fibres to fulfil anti-infection and clearance functions (phagocytosis). During phagocytosis, alveolar macrophages produce oxidising free radicals of many materials. They transport the absorbed materials through the lymphatic system to the lymph nodes (Skinner et al. 1988). Fibres are actively eliminated simultaneously by phagocytic cells. The fibre lengths are the decisive criterion for partial or complete removal (Lundborg et al. 1995).

The deposition of fibrous particles can cause inflammatory responses (Skinner et al. 1988), alveolitis, bronchitis and potentially fibrosis (Lippmann et al. 1971).

Pulmonary fibrosis is caused by man-made vitreous fibres of low biosolubility that stay in the lungs over longer periods of time (ATSDR 2004).

3.2.3 Observations in animals

Animal experiments showed that the lung reacts to the inhalation of foreign material such as fibres with a process called pulmonary inflammation, where macrophages increase and then remove the fibres. With increasing amounts of fibres, macrophages can also clump together (ATSDR 2004). This process may release reactive oxygen and nitrogen species, triggering potential DNA damage and therefore may foster tumour development (Coussens & Werb 2002). Further animal studies showed that repeated inhalation of certain types of synthetic vitreous fibres can cause scar-like tissues in the lungs and the surrounding membrane, making breathing more difficult, which is called pulmonary fibrosis. Such fibres stay in the lung over a long period of time and are therefore called durable or biopersistent. In addition to durability, the dose and duration of exposure and the fibre dimension are significant factors fostering pulmonary fibrosis, lung cancer and mesothelioma, respectively (ATSDR 2004).

3.2.4 Historical development

The discussion about the health aspects of mineral wool products started in the 1970s. The results of several studies (IARC 1988, Pott & Friedrichs 1972, Stanton et al. 1977) raised the suspicion of mineral wool being possibly carcinogenic (Draeger 2015). In 1988, the International Agency for Research on Cancer (IARC) published a monograph that reviews the carcinogenic risks to humans caused by man-made mineral fibres (IARC 1988). The IARC classified mineral wool (glass wool and rock wool) as "possibly carcinogenic" in this monograph based on epidemiological data and animal experiments (IARC 1988).

An IARC evaluation is executed as follows: the evaluations of the evidence of cancer in humans and the evidence of cancer in experimental animals are performed separately. The terms "sufficient evidence", "limited evidence", "inadequate evidence" and "evidence suggesting lack of carcinogenicity" are used. Other relevant data regarding the current evaluation are then considered. An overall evaluation is subsequently performed that implements the weight of evidence from the studies in humans and experimental animals as well as additional data (Baan & Grosse 2004).

Since 1988, there have been more long-term investigations, and these data were re-evaluated in the IARC monograph volume 81 of 2002 (IARC 2002).

In this monograph, it is evaluated that:

- There is inadequate evidence in humans for the carcinogenicity of glass wool;
- There is inadequate evidence in humans for the carcinogenicity of rock (stone) wool/slag wool;
- There is limited evidence in experimental animals for the carcinogenicity of insulation glass wool;
- There is limited evidence in experimental animals for the carcinogenicity of rock (stone) wool (IARC 2002).

The results of the evaluation in 2002 for carcinogenicity in humans are based on epidemiological information (Baan & Grosse 2004).

The manufacturers of mineral wool products responded to evaluations and founded the Joint European Medical Research Board (JERMB) in 1975. They started discussions about appropriate testing procedures and biosolubility with the World Health Organisation and founded umbrella organisations of mineral wool producers in Europe (EURIMA) and North America (NAIMA) (Draeger 2015).

Due to changes in industrial production from approximately 1996 onwards, mineral wool products with higher biosolubility have been produced (Kropiunik 2004), which would constitute the so-called "new mineral wool products". Biosolubility was not tested before that time. The differences between the chemistry of old rock wool and new rock wool products have been examined by Wohlleben et al. (2017). They found that most of the new rock wool products are high in alumina and low in silica content. Dissolution tests were conducted for 32 days at pH 4.5 and pH 7.4 with and without binder and at various flow rates. The removal of the binder accelerated the dissolution of the fibre. Size fractions of old mineral wool products and new mineral wool products were measured and showed that the respirable fraction of new mineral wool is low, but not less than that in old mineral wool (Wohlleben et al. 2017).

3.3 Legal aspects

3.3.1 Product regulations

The classification for carcinogenicity of a product is described in Regulation (EC) No 1272/2008 of the European Parliament and of the Council; therefore, several hazard categories for carcinogens are defined. Mineral wool with a content larger than 18% per weight of alkaline oxides and alkali earth oxides falls into the category of "suspected human carcinogens". To prove that this classification does not apply, the Note Q and Note R have to be fulfilled. The mineral wool product can be placed on the market if one of the four in vivo tests of Note Q on the one hand or Note R on the other hand is complied.

Note Q and Note R are defined as follows:

"Note Q:
The classification as a carcinogen need not apply if it can be shown that the substance fulfils one of the following conditions:
- *a short term biopersistence test by inhalation has shown that the fibres longer than 20 µm have a weighted half-life less than 10 days; or*
- *a short term biopersistence test by intratracheal instillation has shown that the fibres longer than 20 µm have a weighted half-life less than 40 days; or*
- *an appropriate intra-peritoneal test has shown no evidence of excess carcinogenicity; or*
- *absence of relevant pathogenicity or neoplastic changes in a suitable long term*
- *inhalation test.*

Note R:
The classification as a carcinogen need not apply to fibres with a length weighted geometric mean diameter less two standard geometric errors greater than 6 µm. (EU 2008)".

Another testing method besides in vivo and in vitro tests is the "carcinogenicity index" (CI). The CI is a test based on the calculation of a formula that implies certain oxide contents of a sample and is only applied in Germany. Calculations must be performed using the following formula: $CI = Na_2O + K_2O + B_2O_3 + CaO + MgO + BaO - 2\ Al_2O_3$. If the CI is larger than or equal to 40, according to "Technische Regeln für Gefahrstoffe" (TRGS 905), mineral wool produced prior to 1998 can be classified as "not carcinogenic". The test has the advantage of being an inexpensive, simple and fast method. The disadvantage is the frequent misclassification, especially in the case of rock wool waste, because of the high Al_2O_3 content. Mineral fibres with high alumina contents tend to be classified as cancerogenic, although they often show high solubility in in vivo and in vitro tests. Fibres that passed the in vivo test and are classified as "not carcinogenic" might have a CI lower than 40 and should be classified as "carcinogenic" after the CI (Ausschuss für Gefahrstoffe 2016).

In contrast to Germany (ChemVerbotsV 2000), it is not forbidden to place mineral wool products without exemption on the market in Austria after Regulation (EC) No 1272/2008. As a result, so-called old mineral wool products with lower biosolubility and, consequently, possibly carcinogenic impact can still be sold.

3.3.2 Waste regulations

Classification of waste in Europe

The European Waste Catalogue (2000/532/EC) regulates the assignment of waste types. Different waste types are described in the waste list. The types of waste are defined by a six-digit code for the waste and the corresponding two-digit and four-digit chapter headings (Table 1). A waste is considered hazardous when marked with an asterisk (EU 2000).

Classification of waste in Austria

The List of Wastes Ordinance regulates the assignment of a waste material to waste codes of the Austrian Waste Catalogue at a national level (BMLFUW 2003), with some exceptions to the waste codes of the European Waste Catalogue (2000/532/EC). This is necessary because of Austria's different waste classification system in contrast to the other EU member states.

Originally, a waste type has been classified by the OENORM 2100 in Austria (ÖNORM S 2100 2005); then, this classification has been taken over by the Austrian Waste List (AVV), which includes the five-digit code for the waste. Additionally, all hazardous waste codes are labelled with "g".

Waste codes for mineral wool waste

Hazardous mineral wool waste in Europe is assigned to "other insulation materials consisting of or containing hazardous substances" waste code 17 06 03*, and new mineral wool waste is assigned to "insulation materials other than those mentioned in 17 06 01 and 17 06 03" waste code 17 06 04.

Mineral wool waste in Austria must be assigned to the following three waste codes: 31416 "Mineral Fibres", 31430 "Contaminated Mineral Fibres" and 31437 g "Asbestos Waste, Asbestos Dust". Mineral wool waste consisting of mineral wool that has been produced with certain quality labels, such as the German RAL quality label (so-called new mineral wool), has to be classified as "Mineral Fibres", whereas mineral wool waste composed of mineral wool that was produced without any quality label (so-called old mineral wool) has to be assigned to "Asbestos Waste, Asbestos Dust" (Table 2). Old mineral wool waste is hazardous but may be disposed of in the asbestos compartment in a landfill for non-hazardous waste (DVO 2008).

TABLE 2: Chapters of the Austrian Waste List (AVV) and five-digit code for the waste.

Waste Code	Description
31416	Mineral fibres
31430	Contaminated mineral fibres
31437 g	Asbestos waste, asbestos dust

Asbestos is a naturally occurring fibrous inorganic material, and the hazards are attributed to the fibrous character (Skinner et al. 1988). These two parameters can be seen as similarities between old mineral wool waste and asbestos waste.

However, there are significant physical differences between mineral wool waste and asbestos waste, e.g., with respect to crystallinity, cleavage and biosolubility.

4. CONCLUSIONS

Mineral wool products of today with certain quality labels do show higher biosolubility due to the Regulation (EC) No 1272/2008 of the European Parliament and of the Council. Such new mineral wool products still contain respirable fibres with the fibre dimensions defined by the WHO. Mineral wool waste causes several problems in Austria. The impossible distinction between old and new, i.e., possibly carcinogenic and non-carcinogenic mineral wool waste, complex logistics and poor landfill stability are examples of occurring difficulties. An uncertain amount of mineral wool waste in Austria complicates an assessment of the recycling potential. To date, many studies have focused on the recycling potential of mineral wool waste from production. The technique of Müller et al. (2009) is realised at the laboratory scale. Compaction of man-made vitreous fibres by the patented press of Wurzer Umwelt GmbH Eitting might be a first step to improve landfill behaviour of the waste. The procedure of Gröper & Lack focuses on backfilling with products made from mineral wool waste. In contrast to these current recycling and processing options, project RecyMin is following a comprehensive aim and therefore addresses aspects such as landfilling, backfilling, recycling in the cement industry and recycling in the mineral wool industry. The comparison of the economic and ecological effects of the different examined aspects will allow an integrated evaluation.

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TABLE 1: Chapters of the list and waste codes for insulation materials (EU 2000).

Chapter	Description	Chapter	Description	Waste Code	Description
17	Construction and demolition wastes (including excavated soil from contaminated sites)	17 06	Insulation materials and asbestos-containing construction materials	17 06 01*	Insulation materials containing asbestos
				17 06 03*	Other insulation materials consisting of or containing hazardous substances
				17 06 04	Insulation materials other than those mentioned in 17 06 01 and 17 06 03
				17 06 05*	Construction materials containing asbestos

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