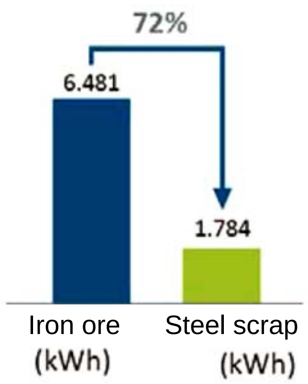
Emissions by the operation of metal shredders – Is it possible to reduce it?

Metal shredders in the circular economy

Circular economy and resource efficiency are characteristic features of a sustainable economy. Both concepts are based on the recycling principle. Recycling is generally defined as the re-use or repeated use or recovery of wastes or residues from a production process or of products or parts of products [1].
Today, recycling is often made difficult by constant further developments in the manufacture of products. For instance, composite materials combining metal and non-metal materials, which lend products beneficial properties in many respects, pose considerable challenges upon the end of their original service life.
Such challenges are then being faced by metal recycling businesses, among others. Apart from plants specializing in the recycling treatment of monocharges from industrial production processes, there are many businesses which have to deal with composite materials, particularly in the scrap recycling sector.
However, it is one of the characteristics of metal recycling that metals can be extracted from primary and secondary raw materials alike, and in almost any case this is possible without any differences in quality. However, the energy input required for recycling-based production of metals from secondary sources is in most cases significantly lower than the energy input required for primary production on the basis of ore mining and subsequent processing and smelting (see Figure 1).



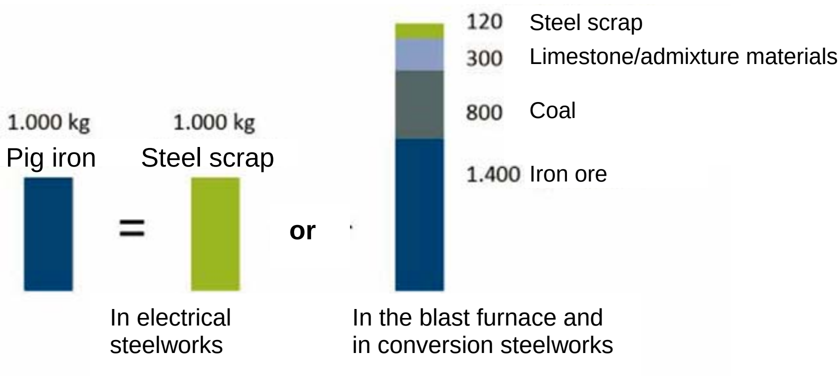


Figure 1: Diagram on the left: Energy consumption in steel production [4]. Diagram on the right: Savings in material input for production of crude steel [4]

In this way, recycling contributes to the protection of the climate and the conservation of resources. The savings achieved in each case depend on the state of the art implemented in the specific plant, on the used electricity mix and on the used input materials.

From the mentioned challenges posed by the input materials, the following tasks can be deduced for the material beneficiation process which is the first stage of the recycling process as such:

- *Composition, quality and condition of the feedstock material* – including the dimensions/lump size and wall thicknesses of the various residues, the physical composition, interfering materials, and explosion hazards sometimes involved in the processing – are most diverse and increasingly call for special technical solutions.
- *Disintegration of the material components* – is a crucial prerequisite for the effective deployment of downstream separation processes.
- *Grain sizes and dimensions* required for downstream process steps.
- *High output of reusable material* – avoidance or reduction of waste.
- *Cost efficiency* – direct competition with raw materials from primary sources puts metal recycling plants under economic pressure.
- *Legal framework* – for the construction and operation of the plant, e.g. defined emission limits (in Germany by the “TA Luft” air pollution control and the “TA Lärm” noise control regulations).

From the requirements outlined above it is evident that the fragmentation process plays a key role for innovative metal beneficiation in the recycling process, especially for the disintegration of composite materials.
The necessity to maintain plant operation economically efficient despite ever greater demands being made by input materials, increasingly poses a challenge for plant operators. At the same time, also the amount of pollutants that can be emitted is increasing due to more complex feedstock materials and, consequently, the requirements for emission control measures are increasing as well. In this context, metal recycling businesses have come into the focus of public awareness due to recurring incidents at some plant sites.
This paper takes a look at the issue of emissions from the operation of metal shredders and on the possibilities and process steps available for emission control.

Overview of current shredder plants

Figure 2 shows an overview of stationary large shredders currently operated in Germany. The generic term “stationary large shredders” means stationary plants with a throughput of not less than 75 tonnes per day. Mobile plants deployed for processing of waste electrical and electronic equipment or refrigeration and cooling systems, and shredders for wastes that do not contain metal materials, are not considered in Figure 2.
The presentation differentiates between the various shredder designs currently available on the market: Kondirators (shredders with a discharge grate on the left side), Shredders (with a discharge grate arranged at the bottom) and Zerdirators (with discharge grates at the top and the bottom), although all these designs can be grouped under the generic term “shredder”.

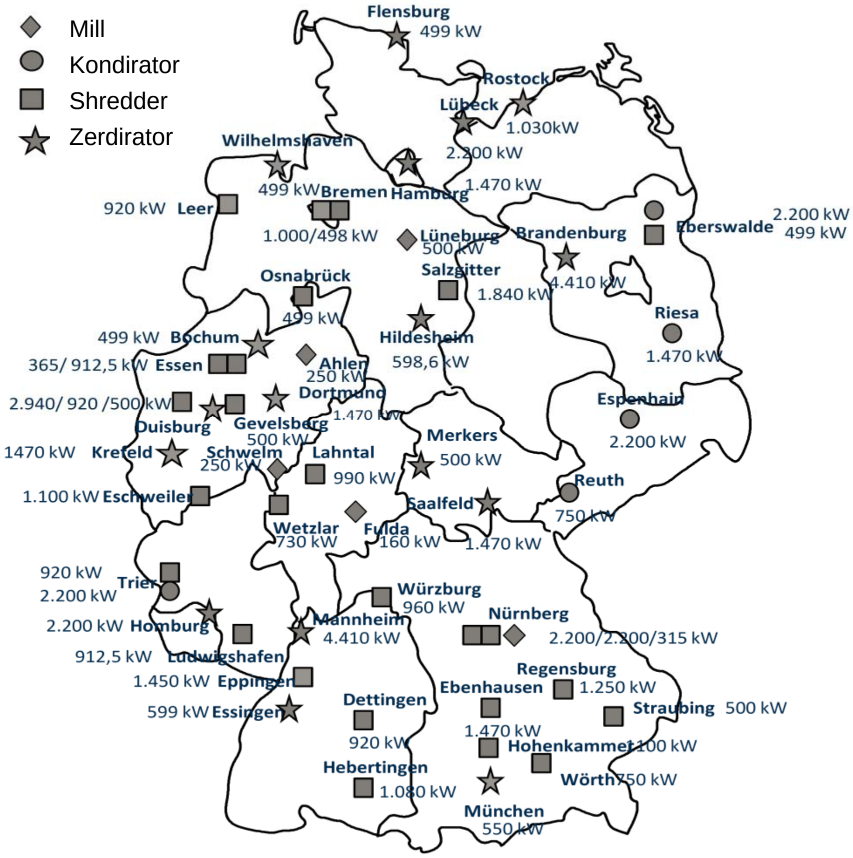


Figure 2: Shredder plants in the Federal Republic of Germany [3]

Across Germany, there are thus 44 plants with a drive power of between 160 kW and 2940 kW in service. 15 of the 21 companies operating these 44 plants have only one shredder. The other 29 plants are owned by six companies, each of which having between two and seven shredders in their respective groups of companies. In 2009, these 44 plants processed about 3.4 million tonnes of feedstock and produced a steel scrap output of about 2.2 million tonnes. Processing of the input material also produced about 500,000 tonnes of shredder light fraction ("SLF") material. [4]

The total number of large shredders in the EU-28 countries and Norway, which are among other purposes deployed for shredding of end-of-life vehicles, is about 352 plants (as at 2014) [5].

Figure 3 shows the volumes of crude steel and steel scrap produced in Germany per year in the 2011-2015 period. It can be seen that the produced volumes did not change in recent years. This applies to both the crude steel production and the amount of scrap.

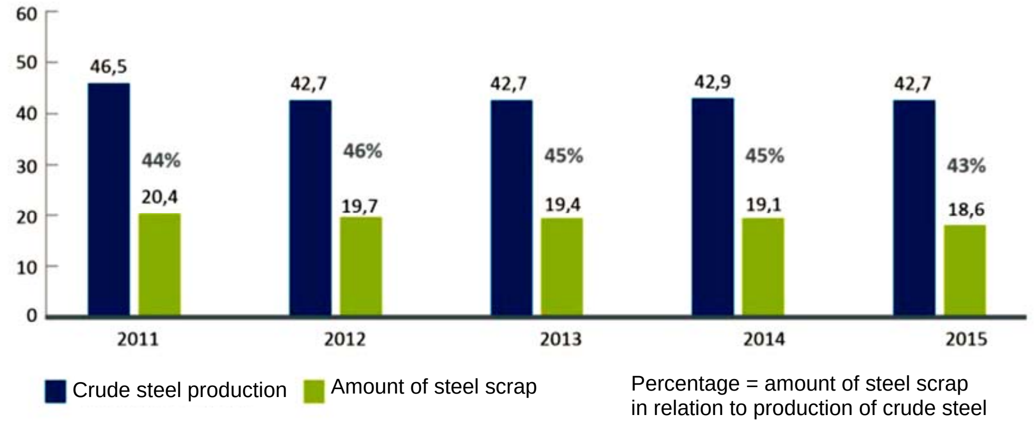


Figure 3: Crude steel production and steel scrap use in Germany, in million tonnes [4]

The situation is similar on the global level. Worldwide, the share of steel scrap input as the main product of metal recycling from secondary sources in relation to the crude steel input remained constant at levels between 34 and 37 percent over the past years (see Figure 4).

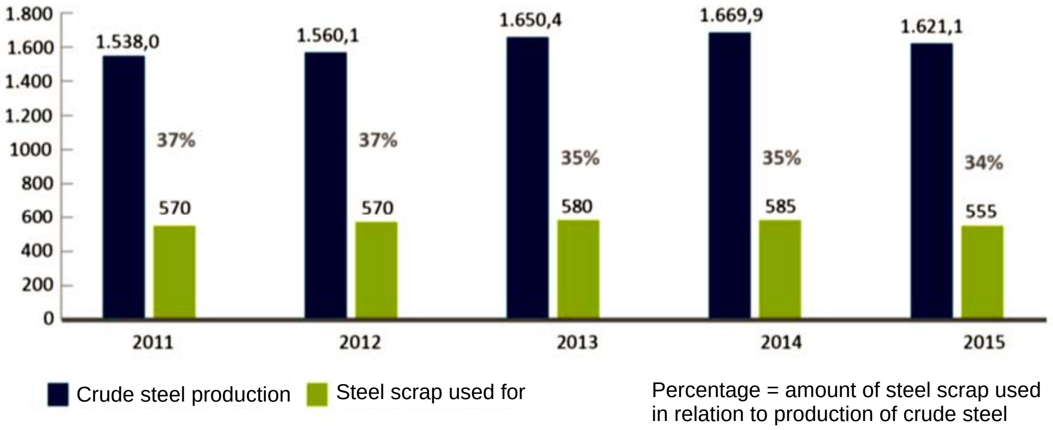


Figure 4: Crude steel production and steel scrap use worldwide, in million tonnes, according to [4]

It should also be noted that the percentage of steel scrap in relation to the needed annual total steel quantity varies significantly from country to country (see Figure 5).

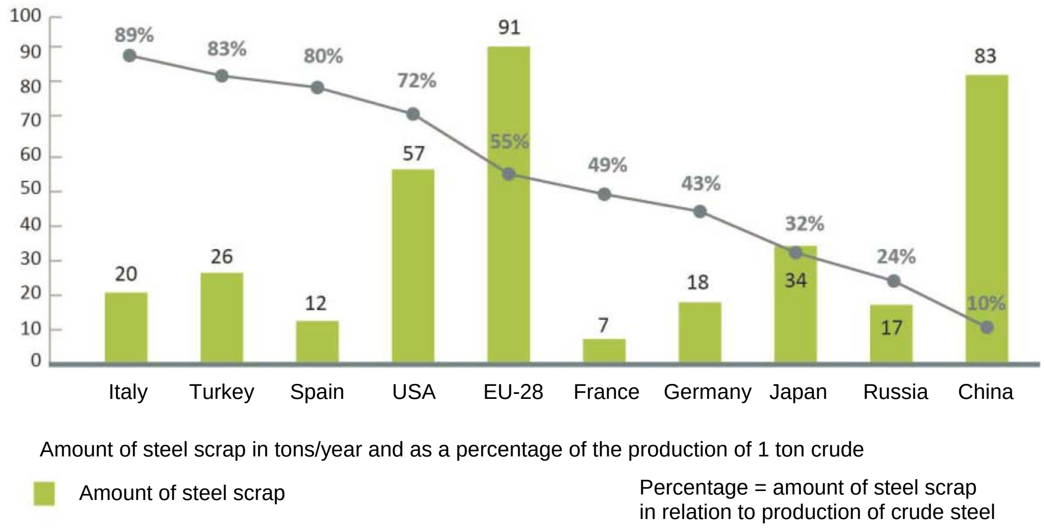


Figure 5: Country comparison – Use of steel scrap in crude steel production in 2015, in million tonnes [6]

From the data on steel scrap volumes in recent years both in Germany and on the global level, it can be concluded that the construction of new plants is given only little or no priority in the field of metal recycling, at least in those countries which already have a long-standing recycling tradition.
However, due to ever scarcer natural resources, there is an ever more pressing need to rethink waste management and recycle a greater proportion of waste in the resource cycles. This also implies a need for more recycling plants.

The metal shredding process

The metal shredding process can be broken down in five process steps. All of the metal shredding plants operated in Germany today have the process steps described in the following paragraphs.

- Delivery, reception and acceptance

The material treated in the shredding plant mainly consists of end-of-life vehicles (EoLVs) supplied by dismantlers after all fluids have been removed, collected scrap from commercial or municipal scrap collection, industrial scrap, pre-treated large household appliances, metal mixtures coming from treatment facilities, scrap from waste-to-energy plants, can scrap and scrap volumes traded on international scrap markets. The composition of the material flow to be processed is obviously heterogeneous and subject to significant variations, both in terms of time and region.
While the incoming material is still in the reception area, it is subjected to the legally required waste checks in accordance with the acceptance catalogue of the shredder plant. Missorted materials or harmful substances clinging to the incoming material can be identified by visual checking.

Another check involves measurement of radioactivity by means of mobile instruments. In this way, the amount of interfering materials and contaminants getting into the shredding process as such can be reduced as early as in the reception and acceptance stage.

- Pre-treatment

Depending on the operational requirements of the plant, pre-treatment of the feedstock material prior to fragmentation is necessary to maximize plant availability, minimize downtimes and achieve an optimized composition of input material as regards quality and quantity of the output material.
The pre-treatment performed includes the following measures:

Pre-sorting:
In pre-sorting, interfering materials and impurities are removed and the feedstock material is homogenized by separating it into different material streams. This sorting can be done either mechanically or manually. Pre-sorting is the most often implemented pre-treatment measure.

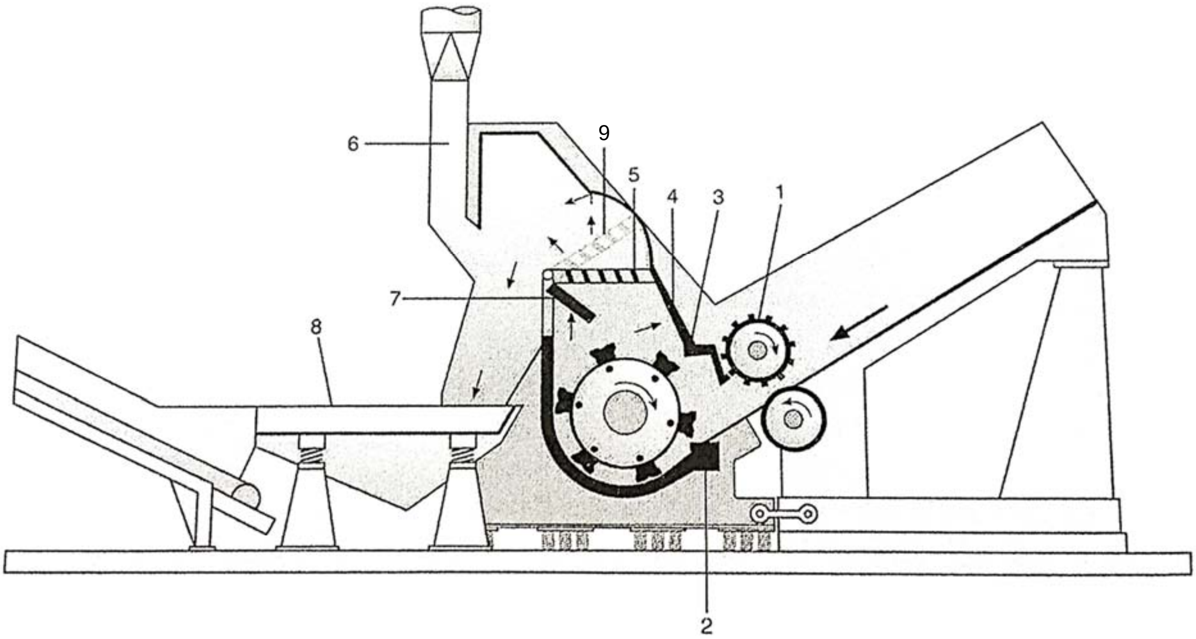
Screening/classification:
Screening of the feedstock primarily serves to separate the mineral fine fraction which often sticks to the feedstock materials. Such separation can extend the maintenance and inspection intervals for plant components susceptible to wear and tear.

Pre-shredding:
Pre-shredding is applied in order to reduce, prior to shredding, the size of excessively large and solid feedstock components which have been sorted out in the pre-sorting stage. Slow-running equipment is typically used for this purpose, so as to be able to rip up and reduce the size of scrap parts of high specific density.

- Shredder process

Different design types and variants of shredders are used, depending on the basic properties and condition of the feedstock material. Although these shredder types differ as regards their specific design configurations, the general design of shredders can be described as follows:
In the shredder box made of sheet steel, there is a fast-spinning rotor with shredding tools mounted in a swinging arrangement on several carrying axles. Bell-shaped hammers are typically used as shredding tools for metal shredding.
The feedstock material is continuously pushed into the shredder by two flexibly supported feed rollers, with the feed rollers additionally exerting some compression on the feed material. This form of feeding causes the shredder inlet to be virtually sealed by incoming feedstock material. Furthermore, the feed rollers permit the feed to be slowed down, depending on the capacity utilization of the equipment.
During the shredding process, the centrifugal force of the fast-running rotor causes the hammers in the shredder to be aligned vertically and achieve speeds as high as 70 m/s. At the same time, however, their swinging arrangement enables the hammers to evade interfering materials that cannot be fragmented. Apart from the impact loads of the hammers, the edge of impact and the shredder wall, also the bending and shearing loads

make a considerable contribution to fragmentation, compacting and disintegration of composite materials.
The shredded material exits the shredder via the discharge grate (shown in Figure 6 below) and is transported by the downstream discharge conveyor to further treatment steps. At the same time, dust-loaded exhaust air is continuously removed from the shredder and fed to the dedusting unit; also the lightest portions of the shredder light fraction (SLF) separated from the metal fraction also exit the shredder through the exhaust air duct, entrained in the exhaust air flow.
Interfering materials can be removed from the shredder through a discharge door that can be hydraulically opened by the plant operators, so as to reduce the load on the shredder unit and avoid damage to the equipment.



1) Driving pulley	2) Edge of the anvil	3) Edge of impact
4) Deflecting wall	5) Discharge grate	6) Exhaust flap
7) Discharge door	8) Discharge conveyor	9) Variable position of discharge grate

Figure 6: Schematic illustration of a shredder [1]

- Post-shredder treatment

In the post-shredder treatment process, the stream of shredded metal is initially separated from the SLF in a separator unit of suitable design, e.g. in an air classifier (sometimes also referred to as “windshifter”). This material stream is typically separated from the exhaust air flow by means of cyclones and used separately, e.g. as secondary fuel.
After separation of the SLF, a magnetic separator is used to separate the remaining material into a (magnetic) ferrous metal fraction (so-called “Fe fraction”) and a so-called “shredder heavy fraction”. Suitable separating devices, e.g. eddy current separators, can be

used to further separate the heavy fraction into a non-ferrous metal fraction and a fraction of non-metallic materials such as plastic, minerals or wood for separate recycling.

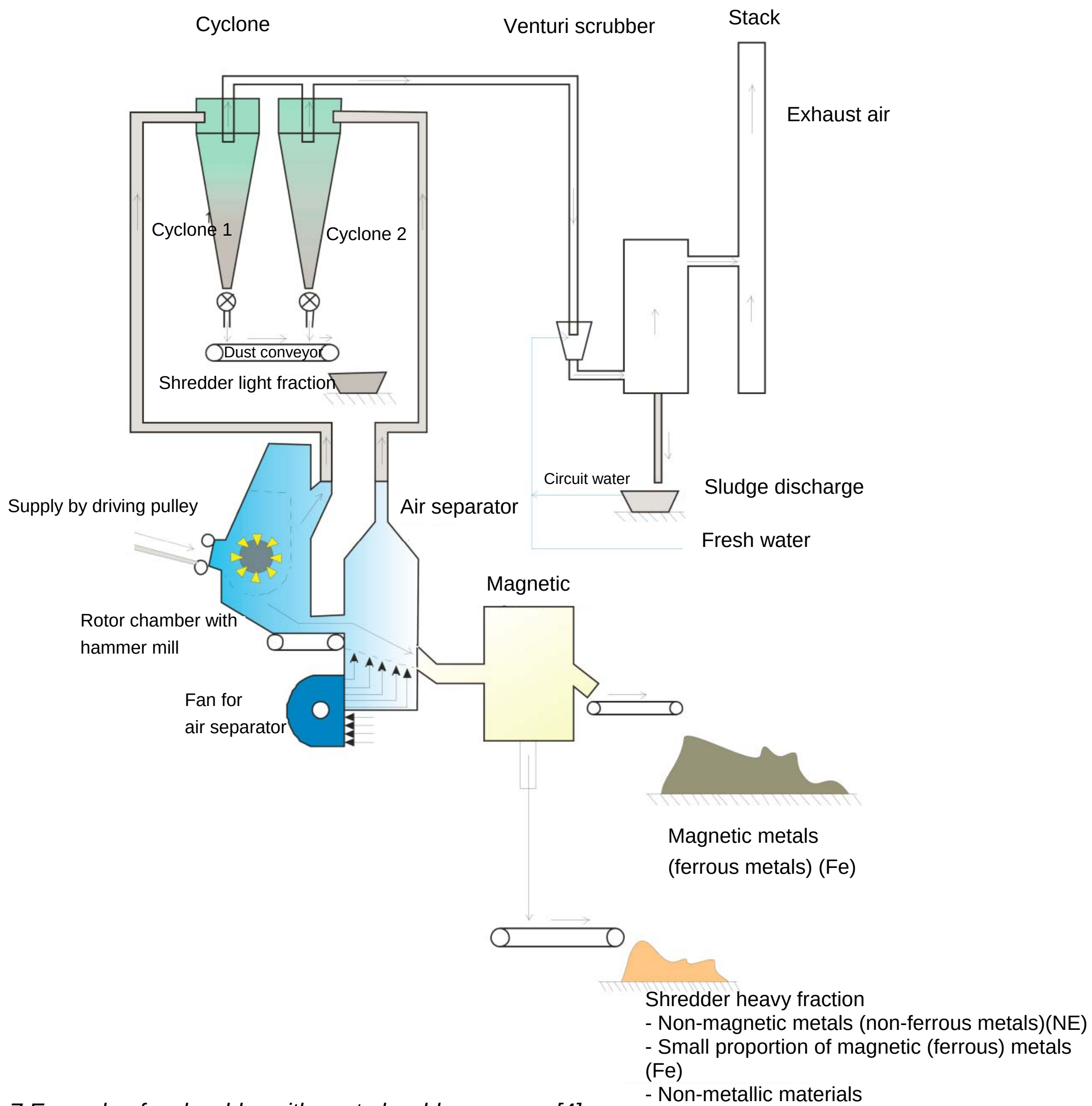


Figure 7:Example of a shredder with post-shredder process [4]

- Emission control measures

As regards emission control, first and foremost dust control equipment is used. Typically, in a first step, the relatively heavier SLF entrained in the exhaust air flow is separated by gravity separators. In a second stage, finer dust particles are separated, for instance by means of wet separation equipment such as Venturi scrubbers.

Emissions and emission sources in shredder operation

Apart from noise emissions, emissions from shredder operation include above all emissions to air.

Such emissions to air are mainly particulate dust emissions which result from the shredding process as such and also from dust-like input material components which are present from the moment when the feedstock material is received at the plant.
Several areas within the metal shredding process can be specifically identified as emission sources:

- Dust emissions occurring at all material transfer points in reception and pre-treatment of the metal scrap
- Pre-shredding process
- Shredder process
- Material transfer in post-shredder treatment
- Product handling, due to dust that may still be adhering to the product

Apart from emissions of mineral dust particles, the shredder process also gives rise to particulate heavy metal emissions caused by the intense mechanical stress on the various metal input materials during the shredder process.
Especially when the input material includes missorted materials, such as batteries, this can result in a serious short-term increase in heavy metal emissions which are harmful to health. Measurements carried out by the Bayrisches Landesamt für Umwelt (LfU – Bavarian Environmental Protection Agency) on the plant sites of several shredders in Bavaria and in their close proximity within the scope of a two-year biomonitoring programme showed increased heavy metal concentrations in standardized ryegrass cultures in close proximity to shredder plants [7].

Furthermore, considerably high temperatures can build up in the shredder process, caused by the high velocities. At the same time, the input material, especially with the increasing amount of composite materials containing different plastic materials, contains various organic compounds which due to the temperature rise can escape from the process in the form of particulate and gaseous emissions to air.
In this context, dioxin-like polychlorinated biphenyls (PCBs), which are present especially in composite materials in the form of plasticizers, insulating liquids, hydraulic fluids or impregnation agents, and polybrominated diphenyl ethers (PBDEs) used as flame retardants in plastic composite materials should be especially noted. Furthermore, polycyclic aromatic hydrocarbons (PAHs) were measured, which can be formed at the increased temperatures occurring during the shredding process [7].
Figure 8 shows an overview of the substances found in ryegrass cultures at the sampling locations near the shredder plants A, B and C, as annual mean values for 2005 ('5') and 2006 ('6') in relation to the thresholds (basis: six rural permanent monitoring stations, except for PBDE which is based on two stations).

Exceedances of the threshold are marked yellow (exceeded 1 to 5-fold), yellowish brown (5 to 20-fold), red orange (20 to 100-fold) and violet (>100-fold). Sampling locations outside of the plant premises are highlighted in green, missing values are highlighted in grey and marked with an X.

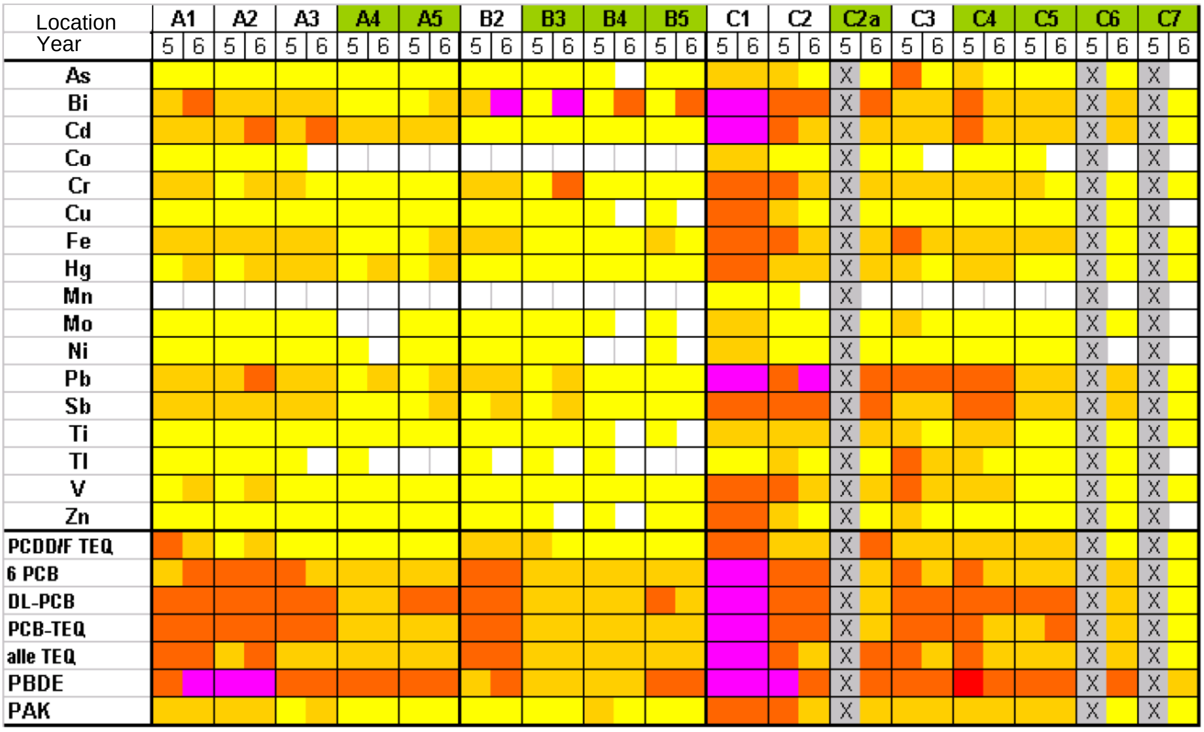


Figure 8: Overview of substances found in ryegrass cultures at the sampling locations [7]

The measurements by the LfU show that the thresholds are significantly exceeded at some sampling locations both on the plant premises and in the close proximity of the plants. Furthermore, the pollutant levels measured decrease quite quickly as distance from the plant site increases, so that emissions from normal operation can be considered to cause a locally limited impact.

However, apart from normal operating conditions, deflagrations or fires will occur periodically in the shredding process (so-called “other than normal operating conditions” – OTNOC). Deflagrations can either be caused by mechanical stress on hollow bodies which due to compression and temperature rise tend to sudden expansion of enclosed gases, or by the presence of residual combustible substances left in tanks or containers which can lead to the formation of ignitable gas mixtures.
In the case of a deflagration, large volumes of dust and pollutant-loaded air escape from the shredder box within a short period of time.
As it is not possible to completely rule out the risk of deflagrations in shredders, the shredder units are not hermetically sealed. In many cases, the shredder design includes dedicated pressure relief equipment for this purpose.

In such cases it will normally be hardly possible to retain the released pollutants, because the plant buildings (where the shredder is arranged inside a building) will likewise have pressure relief openings, for instance in the roof.
Apart from deflagrations, fires resulting from high proportions of flammable materials (for instance from the SLF) in combination with sparks caused by the mechanical shredding process, are a constant risk for shredder plants. The air pollutants thereby produced can usually not be effectively controlled by the installed dedusting equipment.

Emission control measures

In consideration of the above-described operating conditions resulting in increased emissions, various approaches to possible solutions are conceivable or have recently been pursued in practice.

Pre-sorting/pre-treatment
An important starting point can be found in the pre-sorting and pre-treatment of the metal scrap. In this processing stage, composite materials such as metals combined with insulating materials should be separated. Metal hollow bodies, e.g. gas cylinders, should be pre-crushed in a mechanical pre-treatment stage in order to avoid gas compression during the shredding process. It should also be an objective of the pre-treatment process to ensure that input material is fed into the shredder continuously and that the input material stream is as homogeneous as possible. High-emission overload conditions can be significantly reduced by minimizing load fluctuations in shredder operation [8].

Water spraying
Already today, spray water is often applied to the metal parts to be shredded before they get into the shredder, in order to reduce dust formation and emission. Various manufacturers have even installed spray water nozzles within the shredder chamber (see Figure 8).

Figure 8: Water spraying in the shredder chamber [9] [10]

In addition to the dust preventing effect, the water spray injection also brings about some cooling which in some cases may prevent excessive heat build-up and thus avoid that the ignition temperature is reached. Also the formation of sparks as a source of ignition can be reduced by direct water injection. According to the manufacturers, the water vapour produced also is supposed to displace air from the shredder box and thus contribute to the avoidance of deflagrations [8].

BAT Reference document (BREF)

BREF or 'BAT (Best Available Techniques) reference document' means a document, resulting from the exchange of information organised pursuant to Article 13 of the Industrial Emissions Directive (IED) (2010/75/EU). BREFs are drawn up for defined activities and describing, in particular, applied techniques, present emissions and consumption levels, techniques considered for the determination of best available techniques as well as BAT conclusions and any emerging techniques, giving special consideration to the criteria listed in Annex III to Directive 2010/75/EU.

BREFs are the main reference documents used by the EPA when issuing operating permits/licences for the IED activities specified in the First Schedule of the EPA Act 1992, as amended.

The 'BAT conclusions' is a document containing the parts of a BAT reference document laying down the conclusions on best available techniques. Article 14(3) of the IED has made the BAT conclusions mandatory in the permitting/licensing process. A Commission Implementing Decision for BAT conclusions will be published for each BREF reviewed under the IED.

The Industrial Emissions Directive (IED) 2010/75/EU replaces seven existing directives including the IPPC Directive (2008/1/EC).

» Historically, the BREF process for the IPPC Directive produced guidance documents that member states had to have regard to when permitting (licensing) installations.

» However, the IED has made BAT conclusions mandatory in the permitting process (Article 14(3) of the IED).

»For existing installations, the IED requires that where a Commission Implementing Decision on BAT conclusions is published, within four years (relating to the main activity of the installation), the EPA must ensure that 'all permit/licence conditions for the installation concerned are reconsidered, where necessary updated' and 'ensure compliance with the BAT'. [9]

The BREF for large shredders is currently available as a draft version only which can be downloaded at https://clous.uba.de/index.php/s/SOpEUmGXdDbcxXL. The conclusions include a separate chapter for metal shredders. Furthermore, the general requirements for mechanical waste treatment processes and techniques apply. According to the BREF draft version, only emission limits for dust would be required. In current discussions on the draft, also emission limits for dioxins/PCBs are being considered to be stipulated either as emission levels associated with the best available techniques (BAT-AEL) or as monitoring parameters to improve the data basis for a future revision of the reference document.

Consequently, the exhaust air treatment stages described in the BREF typically consist of a cyclone and a wet cyclone or wet scrubber for the separation of coarse dust and particulate matter. Almost all of the technologies described in the draft involve pressure relief equipment in the exhaust air treatment stage, either in the form of pressure relief dampers (see Figure 9) or in the form of a bypass for protection of the installed components.

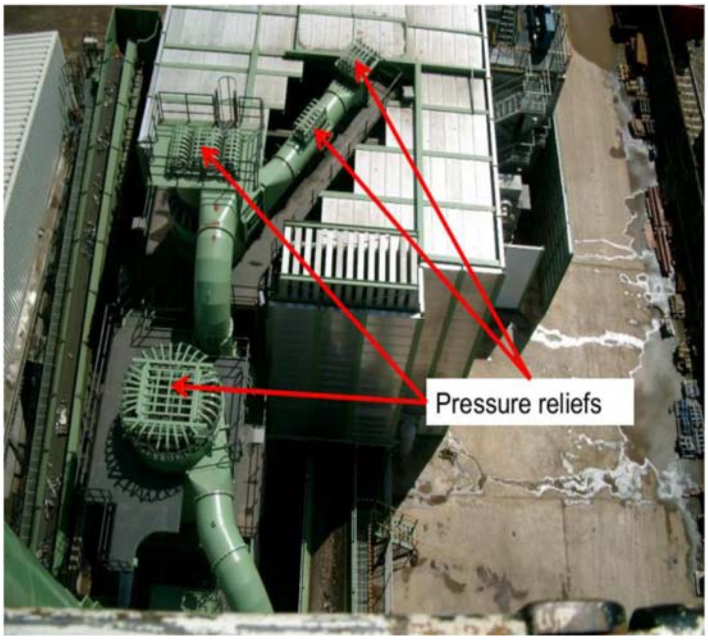


Figure 9: Bird's-eye view of pressure reliefs at a shredding plant [10]

Some operators and manufacturers of exhaust air treatment systems use or offer further treatment stages, some of which have already been used downstream of large shredders, see Figures 10 and 11.

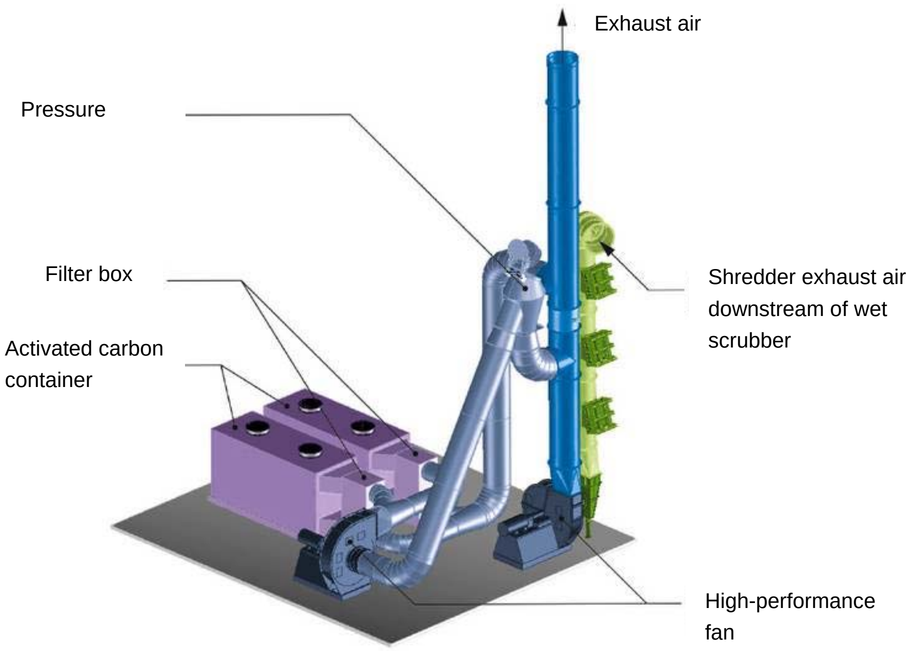


Figure 10: Exhaust air treatment system consisting of a wet separator and an activated carbon filter [11]

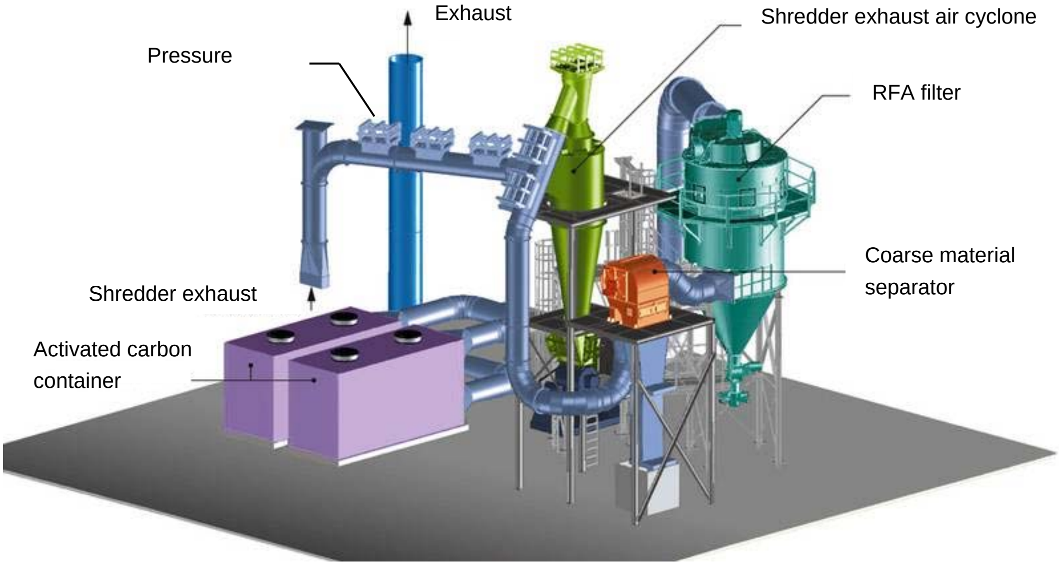


Figure 11: Exhaust air treatment system consisting of a filtering separator and an activated carbon filter [11]

It should be noted, however, that the exhaust air treatment system shown in Figure 11 also includes pressure reliefs allowing untreated exhaust air to escape to the atmosphere in the event of a deflagration.

Process stages for separation of toxic gas components, such as dioxins, PCBs or heavy metals are well known from flue gas treatment downstream of waste incineration plants, and they have proven their reliability and efficiency in many years of service. This means that the treatment of the exhaust air as such is not the problem, but the collection and containment of the exhaust air containing the pollutions, both under normal operating conditions and under other than normal operating conditions such as fires and conflagrations.

Summary

Metal recycling has acquired quite some relevance in the circular economy in Germany and some other European countries. Given the growing world population and the wastage of resources contained in waste even in highly developed industrial countries like the USA, for instance, metal recycling will be imperative in future.

The shredders developed and deployed for metal recycling work very well and serve as a major link in the overall recycling chain. However, depending on the quality of pre-sorting and pre-treatment, fires and deflagrations keep occurring from time to time, in which harmful gases are released. Until now, the applicable BREF draft document only mentions emission limits for dust emissions. The question whether or not further emission limits should be defined is still under discussion. The separation techniques necessary for this purpose have already been successfully implemented in waste incineration plants. The problem of minimizing environmental pollution from shredders consists in the containment and collection of diffuse emissions and of the emissions in other than normal operating conditions (deflagrations).

As metal recycling will be imperative in future, it is also an absolute necessity that shredders be operated in such a manner that the emissions still caused today are avoided.

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