THERMO-RECYCLING

Efficient recovery of valuable materials from dry bottom ash

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1. SUMMARY

It makes no ecological or economic sense put recyclable materials in landfills. This also applies to the incineration residues that are generated in waste incineration. The ZAR Foundation "Centre for recyclable waste and resources" is a forward-looking supplement to the system of existing (separate) collections in Swiss waste management and, as a national development center, makes groundbreaking practical contributions. Since its foundation in 2010, the fundamentals for the world's first treatment plant for dry bottom ash from thermal waste recycling have been developed.

This plant is operated by ZAV Recycling AG. More than 15% of separated metals prove the potential. One third of the metals are non-ferrous metals of high environmental relevance.

The recovery achieved and the associated savings of 60,000 tons of CO_2 per year (equals 0.6 t of CO_2/t of dry bottom ash or 0.1 t CO_2/t municipal solid waste) set new standards worldwide. In addition to the major ecological advantages, the great economic potential of dry bottom ash has also been proven. In 2017, metal revenues of over CHF 95 per ton of dry bottom ash delivered have been realized. The treatment process also sets new standards for industrial plants regarding dust emissions.

2. PREHISTORY

The thermal recycling of non-recyclable waste is an important component of Swiss waste management. Despite the large reduction in volume and mass due to thermal recycling, 20 to 25% of residual materials remain. These have to be disposed in landfills and require a great deal of aftercare. The Swiss waste concept of 1986 has repeatedly motivated operators and developers to examine new approaches in order to maximize metal recovery from the residual materials and to optimize the quality of the residual materials. Bottom ash is one of the most studied waste fractions in Switzerland. Despite a great deal of effort, it has not yet been possible to produce a raw material for reuse or an aftercare-free landfill material from the bottom ash. Important milestones in the discovery process were the work "Landfilling of solid residues from waste management" from 1993[1] and "MWIP bottom ash sand[2]" from 2005 by the Swiss authorities.

Key findings:

- The subsystems of thermal waste recovery and bottom ash treatment must be coordinated with each other.
- The optimization of individual sub-processes, as currently practiced, will not lead to an aftercare-free landfill for bottom ash.
- The first feasible approach is a system change from the current wet bottom ash discharge to dry bottom ash discharge.

Based on these findings, the term "Thermo-Recycling" and the "thermo-re®" brand were quickly found.

3. ADVANTAGES AND DISADVANTAGES OF DRY BOTTOM ASH

If the advantages of dry bottom ash are to be understood, the disadvantages of wet bottom ash must be known. With the exception of a few applications, worldwide the standard bottom ash discharge in waste incineration plants is wet. The bottom ash falls into a water bath after the incinerator and is completely wetted. Why has the wet discharge of bottom ash become established worldwide?

- The water bath is an effective air seal to the furnace chamber.
- The water bath extinguishes burning organic parts and cools the bottom ash before it is discharged.

These advantages are relevant for the operator of thermal waste recycling but prevent efficient treatment of the bottom ash.

[1] Peter Baccini und Barbara Gemper (Hrsg.),(1994), Deponierung fester Rückstände aus der Abfallwirtschaft: Enlager-Qualität am Beispiel Kehrichtschlacke, vdf Hochschulverlag rlag

[2] Bunge R., Eggenberger, U., Dreher, P., Eggimann M. (2005): „KVA Schlackensand: Geochemische und physikalische Charakterisierung von KVA-Schlackensand zur Ablagerung auf TVA-Konformen Deponien“; Abschlussbericht UMTEC & Fachstelle Sekundärrohstoffe Uni Bern.

The advantages of dry bottom ash

- Dry bottom ash is a bulk material that can be transported and fractionated as required. It can also be sieved on an industrial scale to less than 0.3 mm.
- The metals in the dry bottom ash remain clean and are not covered by a moist mineral layer, which makes metal separation difficult or even impossible during the treatment process.
- The organic content in the dry bottom ash (TOC) is usually lower, since the combustion process is not stopped in the water bath and afterburning is still possible.
- The dry bottom ash is non-corrosive as the salts are in dry form.
- The dry bottom ash is about 20% lighter than the wet bottom ash and therefore has logistical advantages.
- Dry also means that less water is used (approx. 15% of the bottom ash mass).

The disadvantages of dry bottom ash

Dust formation is a disadvantage. Dry bottom ash must be fed in closed systems similar to flour or cement in mills or cement plants.

4. THE DRY DISCHARGE

During dry discharge, the bottom ash must be discharged dry and dust-free without unnecessarily disturbing the incineration process. At KEZO in Hinwil, the first line was converted to dry discharge in 2007. Operational requirements were taken into account. With the conversion of further furnaces, dry discharge has become more efficient and easier.

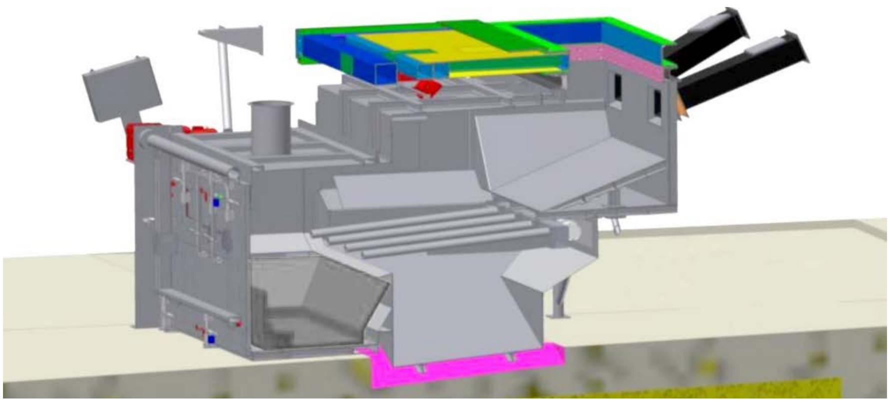

Figure 1: Dry discharge developed and installed by the ZAR Foundation (KEZO, 2015)

It is remarkable that major manufacturers of waste incineration plants have developed and commissioned various dry discharge systems without great time delay. Plant operators outside the Canton of Zurich have already recognized the advantages of dry bottom ash and converted their furnace lines accordingly. In addition to five plants already operating successfully in Switzerland, two plants have already been retrofitted in Italy and one plant is under construction in Sweden.

5. THE PROCESSING PLANT OF ZAV RECYCLING AG

5.1. Efficiency

Dry bottom ash and an efficient treatment plant are required to guarantee high efficiency in metal recovery. The separation of non-ferrous metals is carried out almost exclusively with induction separators (Eddy Current Separators). For the small metal parts, it is therefore crucial that the metals have a clean surface and not a mineral shell, which unnecessarily weaken the repulsion forces during separation.

Figure 2: Left: Non-ferrous metals from wet discharge, right: Non-ferrous metals from dry discharge

When planning the ZAV Recycling AG processing plant, the focus was on a high degree of efficiency in the separation of recyclable materials. This is achieved either by connecting the same separation machines in series or by circulating the material. Both principles have been implemented in the plant, i.e. for bottom ash fractions larger than 12 mm, the recycling concept is applied. For the bottom ash fraction smaller than 12 mm, the separation machines are connected in series.

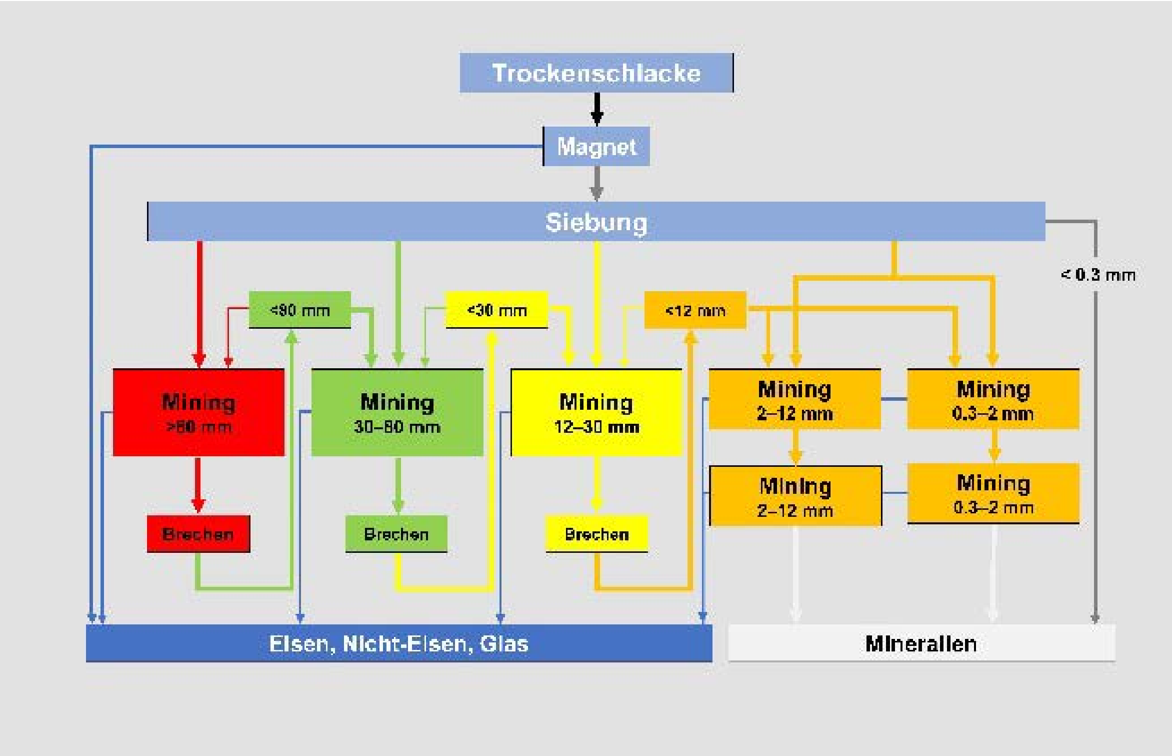

Figure 3: Process flow diagram of the bottom ash processing plant of ZAV Recycling AG (Translations: Trockenschlacke / dry bottom ash; Siebung / sieving, Brechen / crushing; Eisen / Iron; Nicht-Eisen / Non-Ferrous)

Due to the consistent sieving and selective crushing of the bottom ash, the metal parts of one fraction size can only be separated or recycled until they are separated. Thus, an efficiency of almost 100% is achieved for the metallically usable fractions. Other important conditions are met to ensure a consistently high metal output:

- Thanks to the sequential crushing process in three crushing stages, the metals enclosed in bottom ash agglomerates are almost completely exposed.
- The five processing lines guarantee an optimal adjustment of the fraction size ranges to the separation machines.
- The bottom ash flows constantly at an optimum level through the individual separation machines in order to guarantee the best possible process reliability.
- The 24-hour operation of the plant enables optimum utilization on relatively small, easily controllable sorting machines.

5.2. Quality of the Recyclable Materials

A high metal quality enables an efficient recycling of the metals into the material cycle. The products of ZAV Recycling AG are of high quality: A large part of the ferrous metals and aluminum as well as all non-ferrous precious metals can be delivered directly to the smelting plant without additional treatment.

Figure 4: Non-ferrous metals (12-30 mm), directly from the separation process

Figure 5: Stainless steel metals 30-80 mm

Figure 6: Non-ferrous metals heavy 5-8 mm

5.3. Emission-Free Treatment

For the first time, a bottom ash processing plant was built which runs continuously 24 hours a day and 52 weeks a year. Thanks to the high degree of automation, the monitoring effort of the system is very low. The totally encapsulated plant, operated under negative pressure, guarantees emission-free treatment of the bottom ash. It is therefore not surprising that dust immission values in ambient air are well below the limit value for dust exposure (maximum workplace concentration).

5.4. Energy Consumption

Despite the use of three crushers, many screens, conveyor belts, separation machines and extraction systems, the specific energy consumption of the plant (excluding compressed air) is less than 16 kWh per ton of bottom ash. An excellent value in comparison with other large plants.

5.5. Metal Output

From a bottom ash quantity of 100,000 tons per year, the following quantities of metal are recycled in addition to glass (540 t/a) and stainless steels (520 t/a):

Iron: 10'000 t

NF-Metals: 4'500 t

Due to the high copper and precious metal content, around 500 tons of these NF-metals are used in special smelting plants to separate gold, silver and palladium. Typically, one ton of these noble fractions are found:

Silver: 2'000 – 3’000 g/t precious fraction

Gold: 80 – 200 g/t precious fraction

Palladium: 10 – 45 g/t precious fraction

Various analyses carried out show that the non-ferrous potential in the bottom ash has not yet been fully exploited.

5.6. Additional Metal Potential

The bottom ash processing plant of ZAV Recycling AG has been in operation on an industrial scale for over a year.

Recent analyses of the processed bottom ash show that the residual content of non-ferrous metals in the magnetic fraction is still too high. Furthermore, considerable quantities of non-ferrous metals as composite metals are also lost through iron separation or lead to inferior iron qualities and thus to lower earnings for iron.

5.7. Iron Scrap Treatment

The iron scrap processing plant was put into operation in January 2018. The iron, which is separated from the delivered dry bottom ash with an overbelt magnet, is temporarily stored in a bunker. An automatic crane system with lifting magnet ensures that the separated iron can be distributed regularly in the bunker. The automatic crane system is also used to feed the iron scrap processing plant. The most important element of iron scrap processing is the drum screen, in which adhering bottom ash particles are removed.

The iron fraction larger than 40 mm is fed onto a sorting belt for manual removal of impurities, especially copper and aluminum-iron composites.

In the fraction smaller than 40 mm the iron scrap is additionally separated with a further overbelt magnet before it goes to a second sorting belt for manual removal of impurities. The mineral residues and slightly magnetic iron oxides are returned to the bottom ash stream.

First experiences show that the iron quality can be significantly improved by the treatment. In cooperation with the Swiss Federal Institute of Technology Zurich, a large-scale study is currently underway on the ecological and economic benefits of iron processing and the recycling of iron via thermo-recycling. We look forward to the scientific results that will be published this year. Due to the higher earnings achieved at the smelters (+ 50%) and the low energy consumption in iron processing, we assume that the annual balance sheet of the processing plant will be very pleasing both ecologically and economically.

Figure 7: Iron from dry bottom ash

5.8. Non-ferrous Treatment

The treatment of fine bottom ash smaller than 12 mm is based on the series connection of neodymium magnets for separation of the magnetic bottom ash and two eddy current separators for separation of the non-ferrous metals. This concept is applied for two lines (fraction size: 0.3–2 mm and 2–12 mm) similarly.

If "magnetic" non-ferrous metals are already separated from the neodymium magnet, they are lost with the magnetic bottom ash. Analyses have shown that magnetic bottom ash still contains up to 1% magnetic non-ferrous metals.

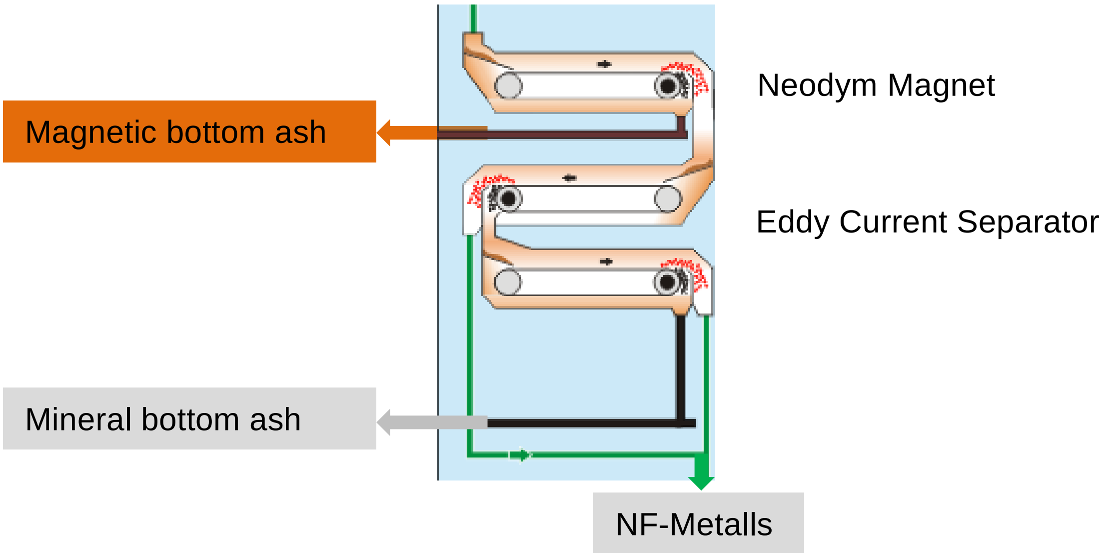

Figure 8: Concept of the treatment plant for NF-metals

It's the smallest iron inclusions in the non-ferrous metals that cause even larger non-ferrous metal parts to be attracted by the neodymium magnet and thus discharged with the magnetic bottom ash. The following picture shows various non-ferrous metals which have been attracted by the neodymium magnet.

Figure 9: Magnetic NF-parts

Trials with the Eddy-Current separator have shown that a large proportion of these light magnetic non-ferrous metals can be separated. The strength of the neodymium magnet must now be reduced to such an extent that the magnetic non-ferrous metals are not separated with the magnetic bottom ash and the efficiency of the eddy current separator is not reduced by the higher content of magnetic bottom ash. Today we assume that it is possible to increase the proportion of non-ferrous metals by approx. 0.3 – 0.5% by means of a corresponding optimization.

5.9. Waste Quality

In addition to the processing technology, the metal content in the waste or bottom ash is important for the metal yield. With the recording of the waste composition and the processed bottom ash quantities of the various bottom ash suppliers, the average waste composition of the delivered bottom ash was calculated according to the table.

01.01.2017-16.07.2017	[%]
Residential waste	53.1
Industrial and market waste	32.9
Sludge	2.7
Wood	7.9
VEVA RESH Cars	3.3
VEVA Resh Electronic	0.1
Total:	100

Table 1: Composition of waste in the period under consideration

Due to the geographical distribution of the bottom ash suppliers and the broadly diversified waste mix, it can be assumed that the bottom ash supplied corresponds to a Swiss average.

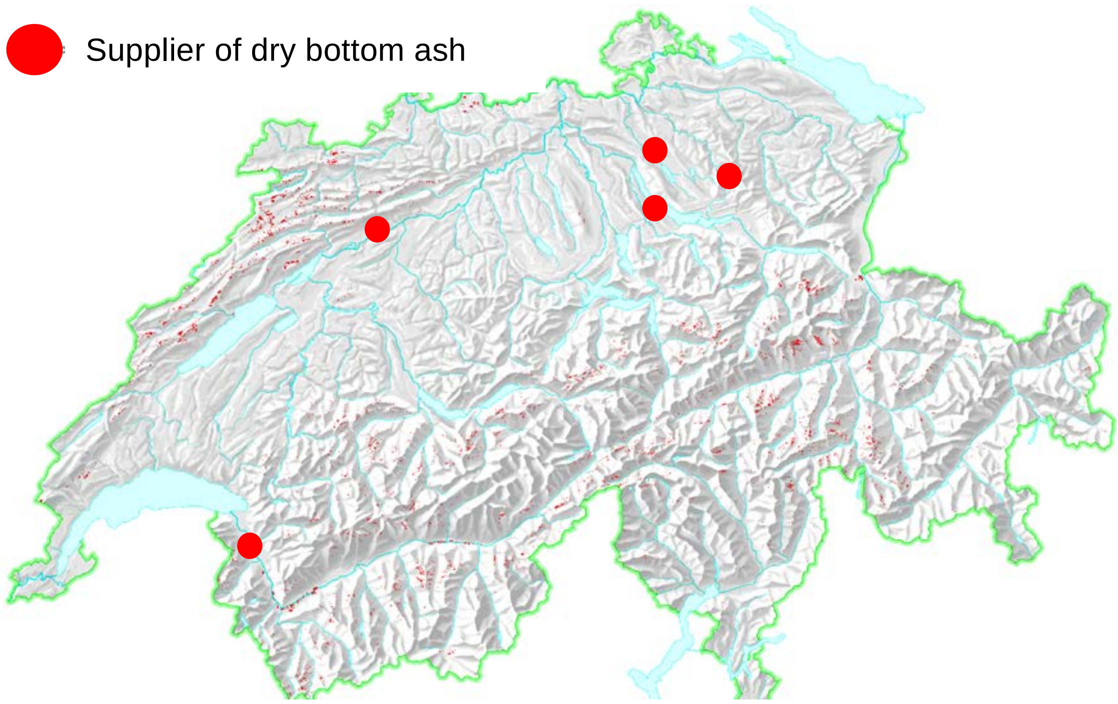

Figure 10: Geographical distribution of bottom ash origin (winddata.ch)

In order to demonstrate the efficiency of the **thermo-re®** *process* in comparison to the current state of the art of wet bottom ash processing plants, it is relevant that the comparison is based on a Swiss average bottom ash.

5.10. Comparison of wet and dry bottom ash processing plants

When directly comparing the performance of the various plants, it must be borne in mind that one actually compares "apples with pears" or "dry with wet bottom ash". The parameter metal content in the input material can only be neutralized by a comparable waste composition and a long observation time (over 3 months). In addition to the amount of separated non-ferrous metals, total metal revenues should also be taken into account, as the ecologically and economically important non-ferrous precious metals such as gold, silver and palladium do not appear in terms of weight due to the small quantities compared to the remaining non-ferrous metals. The realized metal revenues are a first-class criterion to judge the quality of the metals as well as the quality of the separation, but for reasons of secrecy these are reluctantly disclosed by the involved companies.

5.11. Comparison of NF metal quantities

The following performance data come from various Swiss bottom ash processors and were converted to a comparable basis (dry matter, purity). The values given are average values as realized in 2017. The bottom ash is based on an average Swiss waste mix. Significant differences exist in the plant technology and the condition of the bottom ash (wet/dry). The dry bottom ash processing plant of ZAV Recycling AG contains a proportion of separated non-ferrous metals (excluding VA metals) that is around 30% higher than that of the best-classified wet bottom ash processor.

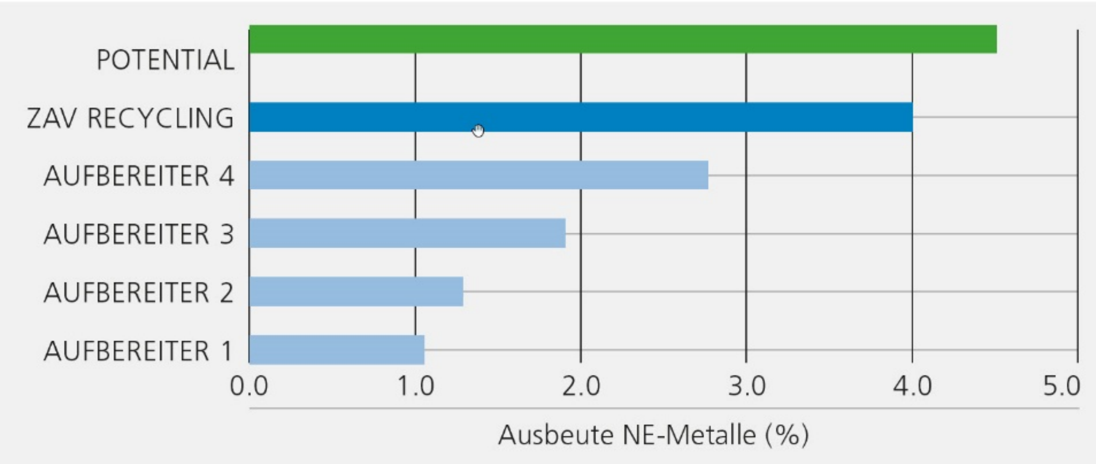

Figure 11: Output of non-ferrous metals from various bottom ash processors in Switzerland (Translation: Aufbereiter / Processor; Ausbeute / yield; NE-Metalle / NF-metals)

Although the output of non-ferrous metals from the bottom ash delivered to ZAV Recycling AG is significantly higher, there is still plenty of potential to improve the output.

5.12. Income from Metals

The revenues from the metals are directly dependent on metal prices, metal quantities, metal types and metal quality. Based on the same observation period, fluctuating metal prices can be neutralized quite well. The following graph shows the quantitative and monetary metal balance of ZAV Recycling AG for the year 2017. 15.6% of the bottom ash delivered was separated and returned to the material cycle. The recyclable materials are divided into 64.6% iron, 15.5% non-ferrous metals larger than 12 mm, 3.3% NE heavy, 9.7% Aluminum in sizes 0.3-12 mm and the remainder (Aluminum and glass) of 6.9%. With a total metal yield of around CHF 95, the heavy non-ferrous metals and Aluminum in the 0.3-12 mm fraction account for around 65% of the yield. A direct comparison with the metal yields from a wet bottom ash processor cannot be made due to a lack of data. However, we assume that the metal yield of CHF 95 per ton of input bottom ash is a good benchmark.

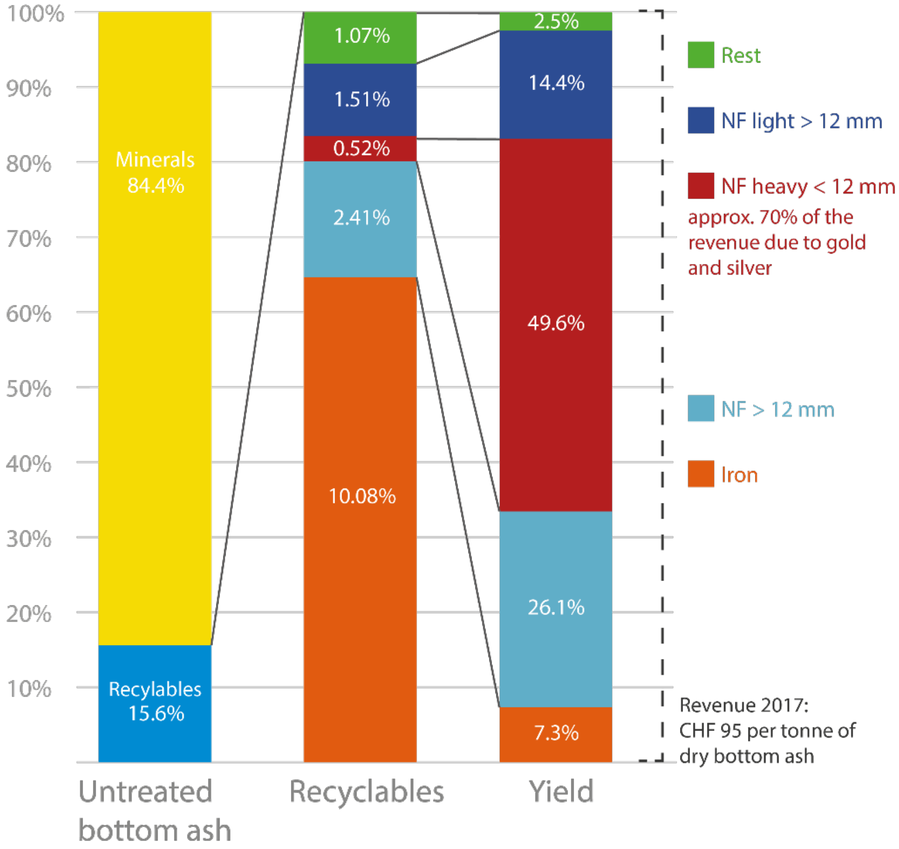

Figure 12: Quantities of recyclables and pro rata revenues

If the metal yields are divided among the types of metal, the following list per ton of dry bottom ash results:

- Copper: CHF 25
- Gold: CHF 21
- Silver: CHF 8
- Rest: CHF 41

The above-mentioned metal yields can be achieved primarily because of the process-related advantages of dry bottom ash during processing. The main advantages of dry bottom ash are:

a) finest metal parts can be separated from the dry bottom ash much more efficiently

b) the metal parts are largely free of mineral buildup

c) the fine, dry metals can be very efficiently separated into an Aluminum fraction and a NE heavy fraction using separation tables.


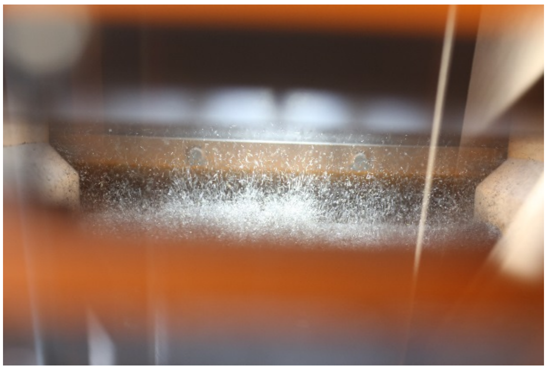

Figure 13: Separation tables (general view / detailed view)

5.13. CO_2 Reduction

By recycling the metals of ZAV Recycling AG into the material cycle, around 60,000 tons of CO_2 are saved per year. If the thermal recycling process were used throughout Switzerland, an additional 150,000 tons of CO_2 could be saved compared with the current level. This corresponds to:

- 0.3% of Switzerland's annual CO_2 emissions,
- the annual CO_2 emissions of 25,000 Swiss or
- 48 million liters of heating oil, equivalent to a district heating network with heat sales of around 500,000 MWh per year.

6. OUTLOOK

The efficient recovery of metals from the bottom ash is a first essential step. Further optimizations are being made in the course of operation. Now the ZAR Foundation is focusing its work on the further processing of the mineral fraction, around 85% of the bottom ash quantity. The declared goal is the after-care-free deposition of the mineral fraction. For this purpose, further pollutants must be eliminated from the processed bottom ash in order to avoid leachate emissions and therefore landfill-aftercare measures and future environmental risks.