Kantonsschule Zürcher Unterland

Accumulation of Recovered Gold from Bottom Ash

How Waste Management Can Turn into Resource Management

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EXPLANATION

Words in CAPITALS have a German translation as well as a short explanation in the glossary at the end of this report. The glossary also includes a short list with all the abbreviations used.

Fig. 1 The bottom ash is precious (Picture by F.Böni)

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1. ABSTRACT

In a society where waste is only what one throws away, it must be understood that with the right approach waste is precious. Metals and minerals which have to be mined under the worst circumstances and whose mining has terrible impacts on our environment should be brought back in the life cycle and not dumped into landfills. Dr. L. S. Morf (2012) claims that there is an annual mass flow of gold of about 81 ± 40kg through the KEZO INCINERATION PLANT. In addition, he claims that the total mass flow of gold through all Swiss incineration plants is about 1.3±0.6t per year. Recent improvements and new technologies enable to work on new options concerning waste treatment. Nowadays, with the THERMO RECYCLING PROCESS, it is feasible to separate different metal fractions from BOTTOM ASH, one part of the residue of a waste incineration plant, which can be melted and its metal put back in the cycle. Interestingly, no concrete answers can be given to the question where this great amount of gold comes from. However, one part certainly comes from all the electronic devices which were not recycled; another part comes from accidentally thrown away jewellery.

Until a few years ago, metals smaller than 7mm could not be separated. Thermo recycling's efficiency to recover the metals smaller 7mm out of the bottom ash is now already over 90%. Considering that most of the PRECIOUS METALS in the bottom ash end up in the fraction smaller than 7mm, it makes this process ecologically und economically very important. To achieve the best use out of these metals, it is assumed that the highest possible accumulation of the single metal fraction has to be reached. Therefore, the already existing bottom ash treatment plant needs additional separating steps.

The Dutch company Liquisort, B.V. has claimed to have created a separator, the MAGNETIC DENSITY SEPARATOR (MDS), to separate the gold out of the NON-FERROUS (NF) precious fraction which is currently the one fraction at the end of the line. Moreover, KEZO wants to compare this technology with a DENSIMETRIC SEPARATION TABLE (DST). The goal of this Maturitätsarbeit is to test both methods especially concerning the accumulation of gold, and considering also the economic feasibility and the ecological benefits for a possible application.

In order to round off the subject, this paper also contains general information about the waste business and about gold as a resource.

The test results show that both methods were able to accumulate heavy metals especially gold. However, the economic study shows that there is no additional benefit by separating the NF precious fraction with either one of the tested processes. In addition, no ecological benefits can be found. Therefore, KEZO will relinquish the idea of adding one of the tested process steps to their system.

2. ZUSAMMENFASSUNG

In einer „Wegwerfgesellschaft“ wie der unseren, ist es wichtig zu erkennen, dass Teile unseres Abfalls sehr wertvoll sind. Metalle und Minerale, welche in Minen unter prekären Zuständen abgebaut werden müssen und genau deren Abbau eine unzumutbare Belastung für unsere Umwelt ist, müssen im Kreislauf behalten werden und nicht auf Deponie verschwinden.
Dr. L.S Morf (2012) hat berechnet, dass etwa 81 ± 40kg Gold jährlich durch die Kehrichtverwertungsanlage KEZO in Hinwil fliessen. Zusätzlich geht er davon aus, dass demnach der Massenstrom an Gold in allen Schweizer Kehrichtverwertungen (KVA) 1.3±0.6t pro Jahr beträgt. Dies sind beachtliche Beträge. Über die Herkunft dieses Gold kann nur spekuliert werden. Sicher ist, dass es zum einen von all den elektronischen Geräten, die nicht recycelt werden, und zum anderen von Schmuckstücken, die zufällig im Abfall gelandet sind, stammt. Optimierungen und neue, modernere Technologien erschliessen neue Möglichkeiten in der Abfallverwertung. Abfall wird nun nicht mehr nur verbrannt, er wird thermisch rezykliert. Das Thermorecycling eröffnet neue Möglichkeiten zum Trennen der Metallfraktion aus der Schlacke, dem Endprodukt des Verbrennungsprozesses. Die Metallfraktionen können eingeschmolzen und dadurch im Kreislauf behalten werden. Bis vor ein paar Jahren, war es nicht möglich, Metalle mit einer Partikelgrösse kleiner 7mm von der Schlacke zu trennen. Heutzutage liegt der Wirkungsgrad des Thermorecycling für Metalle kleiner 7mm schon bei 90%. Da die meisten edlen Metalle in der Fraktion kleiner als 7mm landen, ist der Prozess ökologisch wie auch ökonomisch sehr wichtig. Damit man das bestmögliche Resultat erreichen kann, wird vermutet, dass eine grösstmögliche Anreicherung der edlen Metalle von Vorteil ist. Darum soll getestet werden, ob ein weiterer Verfahrensschritt dem bestehenden Verfahren angehängt werden muss.
Die niederländische Firma Liquisort B.V. behauptet ein Trennverfahren entwickelt zu haben, welches aus der Nicht-Eisen Edelfraktion der KEZO Metall mit einer grösseren Dichte, v.a. aber Gold, von Metallen mit einer kleineren Dichte trennen kann. Die Nicht-Eisen Edelfraktion ist im Moment die Endfraktion der KEZO, die zum Schmelzwerk geschickt wird. Nebst dem Test des Trennverfahrens von Liquisort, soll auch das Trenntischverfahren, mit der gleichen Fraktion getestet und die Ergebnisse verglichen werden.

Das Ziel dieser Maturitätsarbeit ist es diese beiden Verfahren vor allem auf ihre Goldanreicherung zu testen, sowie ihre ökonomischen und ökologischen Vorteile aufzuzeigen, falls sie in den Prozess integriert würden. Zudem enthält diese Arbeit allgemeine Informationen über den Kehrichtverwertungsprozess und über Gold als Ressource. Die Resultate der Tests zeigten, dass eine Anreicherung jener Metalle mit einer grösseren Dichte und v.a. von Gold mit beiden Prozessen möglich war. Jedoch zeigte die Studie, dass weder ein ökonomischer noch einen ökologischer Nutzen aus der zusätzlichen Trennung gezogen werden kann. Daher wird die KEZO bis auf weiteres darauf verzichten einen weiteren Trennungsschritt dem Thermorecycling anzufügen.

3. THESIS

The dry bottom ash from the incineration plant can be treated so that among other fractions one fraction with precious metals in the fraction size from 0.7mm-5.0mm can be separated. All hypotheses are based on this exact precious metal fraction attained by the incineration plant KEZO, Hinwil ZH.

Hypothesis 1:

Liquisort's magnetic density separator (MDS) is able to split the non-ferrous precious metal fraction in a low and a high density fraction and allows an accumulation of gold in the heavy fraction.

Hypothesis 2:

Recycling World's densimetric separation table (DST), which is installed at KEZO, is able to split the non-ferrous precious metal fraction in a low and a high density fraction and allows an accumulation of gold in the heavy fraction.

Hypothesis 3:

Adding one of these process steps to the existing treatment process at KEZO leads to an economic benefit.

Hypothesis 4:

Adding one of these process steps to the existing treatment process at KEZO leads to an ecological benefit.

4. BACKGROUND

Our world is marked by consumption, extravagance and wastage. We produce tons of waste. Some countries have real problems to cope with their garbage challenges. Other countries think they solved the waste problem by dumping it all into LANDFILLS where the waste can pollute ground water and air, and furthermore destroys the atmosphere by creating hazardous greenhouse gases.

In a few European countries, landfills for waste are banned mainly because of the pollution and lack of space. In fact, the members of the European Union are not allowed anymore to put waste into landfill. However, it will take decades until all the members will be able to fulfil this requirement.
Another well-known way to handle waste is to burn it. The first incineration plant was already built in 1874 in Nottingham, England. (Wikipedia, 23.12.2012) With the use of incineration plants only about 25% of the initial waste needs to be landfilled in a final step. In the first place thence, incineration is mainly a volume reduction process. Thereby carbon compounds react with the oxygen in the air and carbon dioxide CO_2 is formed. Initially, it wasn't realized that now the air was majorly being polluted as well. Fortunately, it has been noticed and in many countries today incineration plants have special filters over their chimney which have to treat the air current before it exits the plant.

The waste management system in Switzerland is considered as one of the best even though Swiss citizens are not producing less waste then other nations. The United Nations Environment Programme (UNFP) published Fig. 1 displaying that a Swiss citizen produces approximately 1.5 kg waste per day averagely and is therefore one of the top 20 waste producers of the countries shown. (2001)

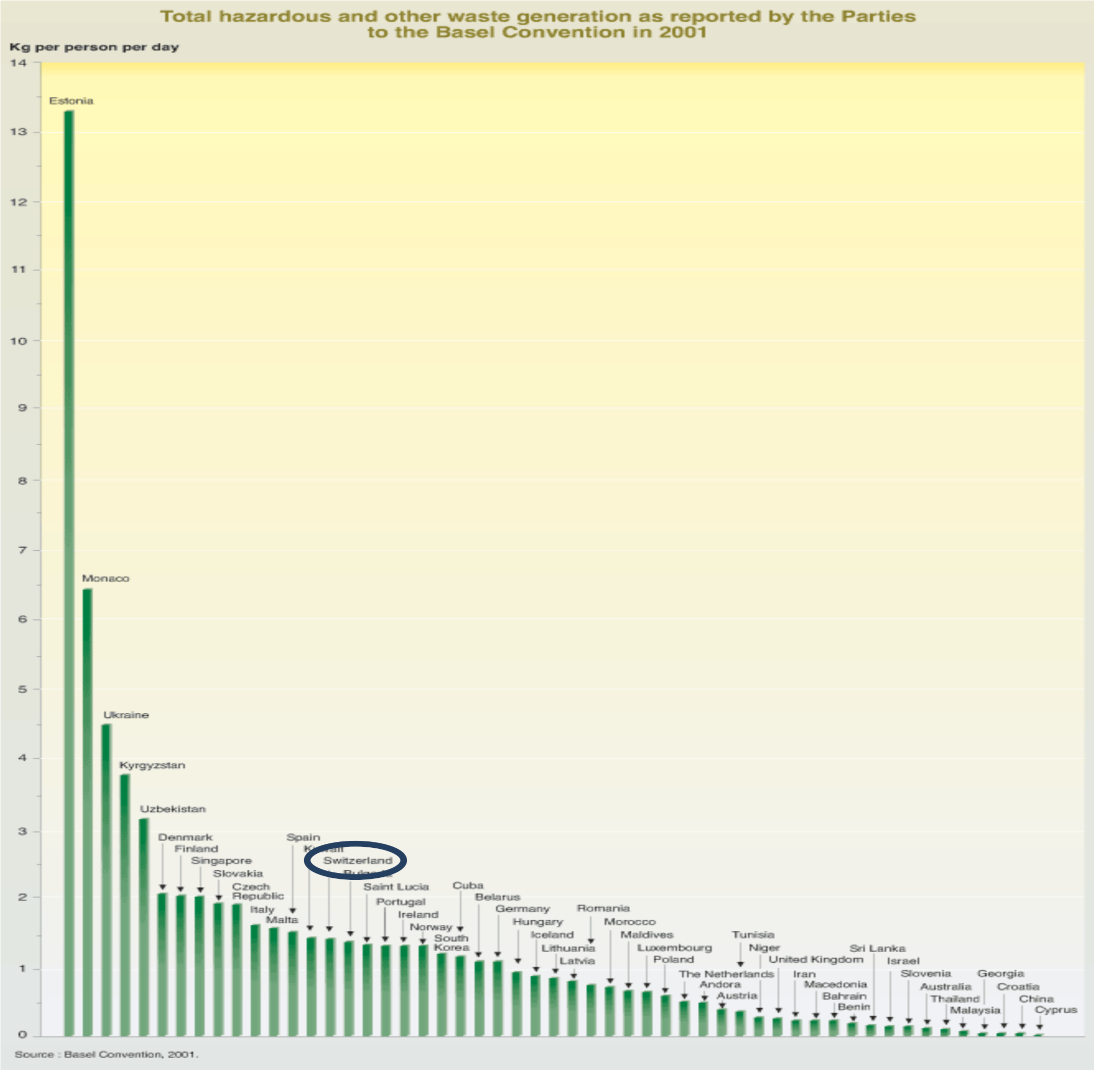


Fig. 2 Total hazardous and other waste generation as reported by the parties to the Basel Convention in 2001, UNFP

Considering that about 25% of every ton incinerated waste turns into bottom ash which contains minerals and metals, it will be possible to recycle an incredible amount of minerals and metals as soon as the right treatment is developed. That is what the incineration plant KEZO in Hinwil, Zurich is trying to do: develop a new process to improve the quality of their “waste product”, the bottom ash, and to recover its metals. This process is called Thermo Recycling. (See 5.3) The bottom ash contains at least 10% iron (Fe) and about 3.5% non-ferrous (NF) metals (see 5.5) and is therefore an important suppliers of resources. Two years ago, the development centre for sustainable management of recyclable waste and resources ZAR was launched to support the activities of the KEZO. Moreover, there are many other companies and public authorities in these research activities involved.

5. General Information on Waste

5.1 Waste and its treatment systems

"Waste is a left-over, a redundant product of material of no or marginal value for the owner and which the owner wants to discharge." (Christensen, 2011)

Many waste management systems exist worldwide. They are based on three concepts: Landfill, Recycling and Incineration. Every country has its own idea how to use these three concepts. The ideal would be a mix which has the best ecological benefits and is affordable.

5.1.1 Landfill

"A landfill site (also known as tip, dump, rubbish dump or dumping ground and historically as a midden) is a site for the disposal of waste materials by burial and is the oldest form of waste treatment. Historically, landfills have been the most common methods of organized waste disposal and remain so in many places around the world. Some landfills are also used for waste management purposes, such as the temporary storage, consolidation and transfer, or processing of waste material (sorting, treatment, or recycling)." (Wikipedia, 23.12.2012)

Today, there is no waste management system where a part of the waste does not end up in landfills at one point. However, there are a lot of different qualities of landfills. E.g. in Switzerland there are three kinds. There is one landfill type for INERT MATERIAL such as EXCAVATED MATERIAL. The other two types contain contaminated material. The landfills for contaminated material have to fulfill special conditions: They have to be built on geological stable ground, no groundwater sources in the area are allowed, and its LEAKAGE WATER has to be collected and treated before putting it back into the water cycle. Furthermore, there are limits for the amounts of contaminated and organic material which is put in a landfill. Only a few countries in the world know this kind of specification for landfills and its material. These regulations make landfilling also expensive. However, without any regulations, landfilling is the cheapest system existing if one thinks for the short-term. Therefore, states which have enough space like the USA or Canada have lots of landfill sites. They have nearly no regulations to minimize the impact on the environment. Even worse is the situation in second world countries hit by the industrialization. They are producing incredible amounts of waste while trying to be successful in the world market. They neither have the money for a proper waste treatment nor the needed understanding of the problem. Waste goes to landfills without any further treatment. Only external non-governmental organizations are concerned about the water and air pollution. This inconsiderate handling of waste is a hazardous legacy for future generations.

Just to show the dimensions: the worst Swiss example of a badly managed landfill is the landfill in Kölliken which now has to be restored and repaired for more than one billion Swiss francs. This money has to be disbursed by the tax payer and not by the polluter.

5.1.2 *Recycling*

Recycling is defined as the reutilization of waste, byproducts or (used) end products from industrial productions as resource for the manufacture of new products. Several materials qualify more than others.

In the year 2010, 349kg waste per capita was burned in a Swiss incineration plant. At the same time 357kg waste per capita was recycled. These 357kg of recycled waste are shown in Table 1.

Recycled amount per capita		**Collection quota**
165kg	Recovered paper	85%
120kg	Compost from central sites	Not specified
43.9kg	Glass	94%
15kg	Electronic devices	Not specified
6.6kg	Textiles	Not specified
4.7kg	PET bottles	80%
1.6kg	Tin from cans and their lids	84%
1kg	Aluminium package (0.9kg cans)	Not specified (91%)
0.3kg	Batteries	69%

Table 1 Recycling in Switzerland in 2010, www.bafu.admin.ch, 28.12.12

The materials listed in Table 1 are the most important recyclable ones. The numbers show that Swiss citizens do quite a lot of recycling. Furthermore, the column "Collection Quota" indicates how much was actually recycled. The difference to 100% ends in the furnace of the incineration plant. Fig. 3 shows the development of recycling of a certain material since 1970. It is easy to see that the recycling of every material has increased.

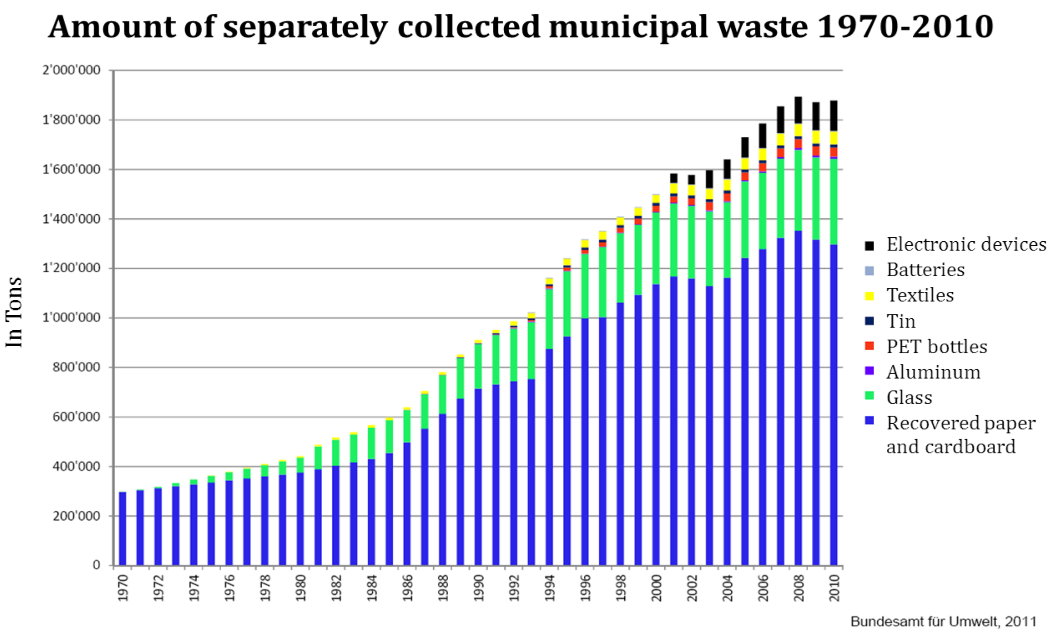


Fig. 3 Amount of separately collected municipal waste 1970-2010, www.bafu.admin.ch, 28.12.12

Today it is doubtful that the recycling collection quota can be increased further. There are mainly two reasons for this. On one side, the waste gets more and more complex and as a result the separation processes become economically and ecologically counterproductive. After more than 30 years of education the Swiss population has changed their recycling behaviour as much as they are likely to achieve. For that reason it is most important to develop new processes like thermo recycling to reduce the further impact on the environment.

5.1.3 *Incineration and thermo recycling*

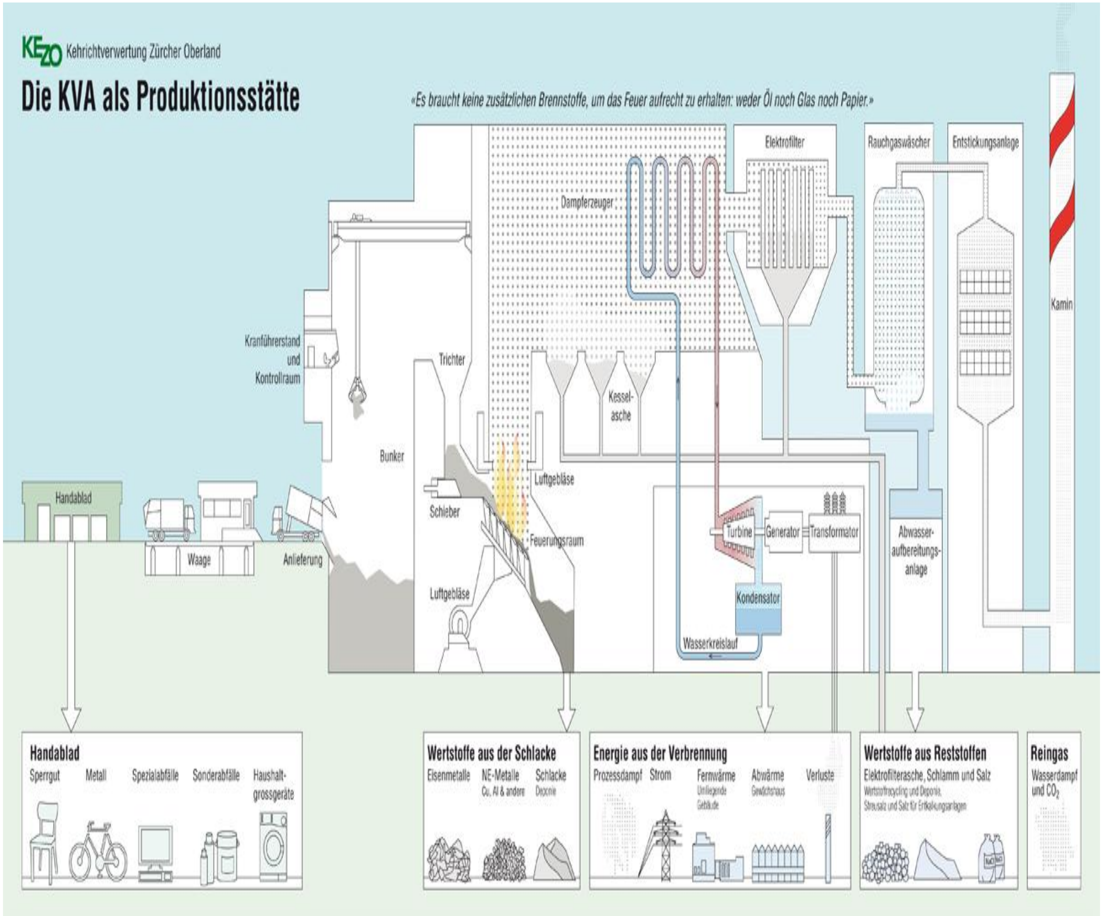


Fig. 4 The incineration plant as a manufacturing plant, KEZO (German)

Since the first incineration plant was built at the end of the 19th century, a lot of effort has been made to improve the system especially in Europe. Nowadays the KEZO is one of the plants leading innovation and environmental awareness. Incinerators are not only incinerators anymore; they are production facilities as show in Fig. 4.

KEZO's treatment system is continually improving. It works as follows:

Waste delivery

Businesses or private persons can deliver their burnable waste. The incoming waste gets randomly sampled to ensure a certain quality. The delivered waste is critical to the outcome. Table 2 shows the composition of KEZO's waste between 2008 and 2011.

Waste	2011 [t]	2010 [t]	2009 [t]	2008 [t]
Municipal waste	91'641	88'214	96'358	90'169
Industrial waste	65'306	61'347	61'010	58'295
Sewage sludge	20'585	19'689	20'509	22'345
Waste from abroad	63	6'836	15'798	15'783
Hazardous waste	28'712	14'946	6'943	4'333
Total	185’722	191’032	200’618	190’925

Table 2 Waste Mixture at KEZO between 2008 and 2011, KEZO

Infeed of the oven

The waste is deposited into the waste bunker. A crane operator has to make sure that there is always enough waste in the ovens. Furthermore, he has to mix the waste in the bunker guaranteeing a consistent heat value which allows an optimal incineration. The KEZO has two bunkers and three oven lines.

Thermic dissociation

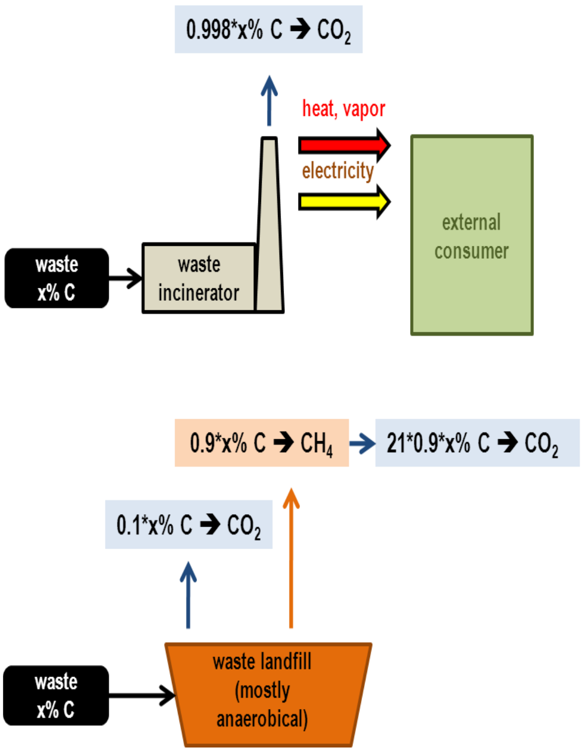
The thermic dissociation consists of six phases:

1. Drying
   The waste is heated up to about 100° Celsius because of a hot air flow from deeper down in the oven. At this temperature the approximately 30% water in the waste evaporates and leaves a dry burnable substance.
2. Degasification
   The water concentration sinks continuously and the waste heats up to about 250° Celsius. In this phase VOLATILE WASTE PARTICLES, such as HYDROCARBONS, get separated and LOW-TEMPERATURE CARBONIZATION GAS develops. Low-temperature carbonization gas develops when something burns slowly, without an open flame and with a large production of smoke.
3. Ignition
   Exactly these gases ignite above the waste and the waste starts to catch fire
4. Gasification
   All the COMBUSTIBLE PARTS in the waste are burning down and produce a combustion gas. Mainly, the bounded, fixed carbonate splits off and oxidises. The waste now has a temperature of 400° Celsius.
5. Incineration
   The incineration of the waste takes place in the fire room as long as there are low-temperature carbonization gases and enough oxygen which gets delivered by a primary airflow. The temperature above the fire is now about 1000° Celsius. It is important that as much waste as possible burns down! However, the temperature in the bottom ash with about 600° Celsius is too low for metals to remelt: ALLOYS remain alloys. At this temperature, only shrinking of the NF metals is observed.

6. Burnout
   In the burnout zone little fire can be seen. The last combustible parts burn down. No new low-temperature carbonization gases will flow back into the fire room. The output is called bottom ash. Generally, the cooled down bottom ash is now transported to a landfill. The FLUE GAS gets treated in a separate system so it doesn't emit any hazardous gases to the atmosphere.

The outcome of the incineration process by burning a ton of waste is 230kg bottom ash, 20 kg filter ash and a lot of energy. The energy amount equals about 300l heating oil. The 230kg bottom ash will receive further treatment, while the filter ash gets landfilled. The energy, which is created when the oven heats up secondary water, becomes steam and turns a turbine, is basically green electricity. Additionally, a part of the steam is used for district heating. At KEZO another part of the steam goes to a nearby greenhouse allowing producing CO_2 free labelled vegetables all around the year.

In Switzerland and all over the world, there are individuals or groups who criticize incineration plants. Often incineration is compared to recycling, and the critics state that incineration plants are bad for the environment and their CO_2 and fine dust emissions are too high. However compared to landfills, the impact on the environment is definitely smaller. Fig. 5 shows the CO_2 emission by a waste incinerator and a landfill. The bars clearly show the incineration plant's lower CO_2 emission. This is based on the fact that the incineration process transfers carbons of the waste directly to CO_2. This is contrary to the landfill where most carbons of the waste will transfer to METHANE. And it is well known that methane is 21times worse than CO_2 regarding the greenhouse effect.



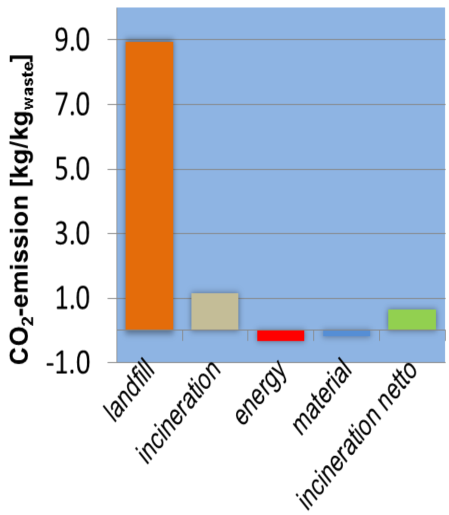


Fig. 5 CO2 Emission Comparison incineration plant and landfill, KEZO

5.2 BOTTOM ASH DISCHARGE

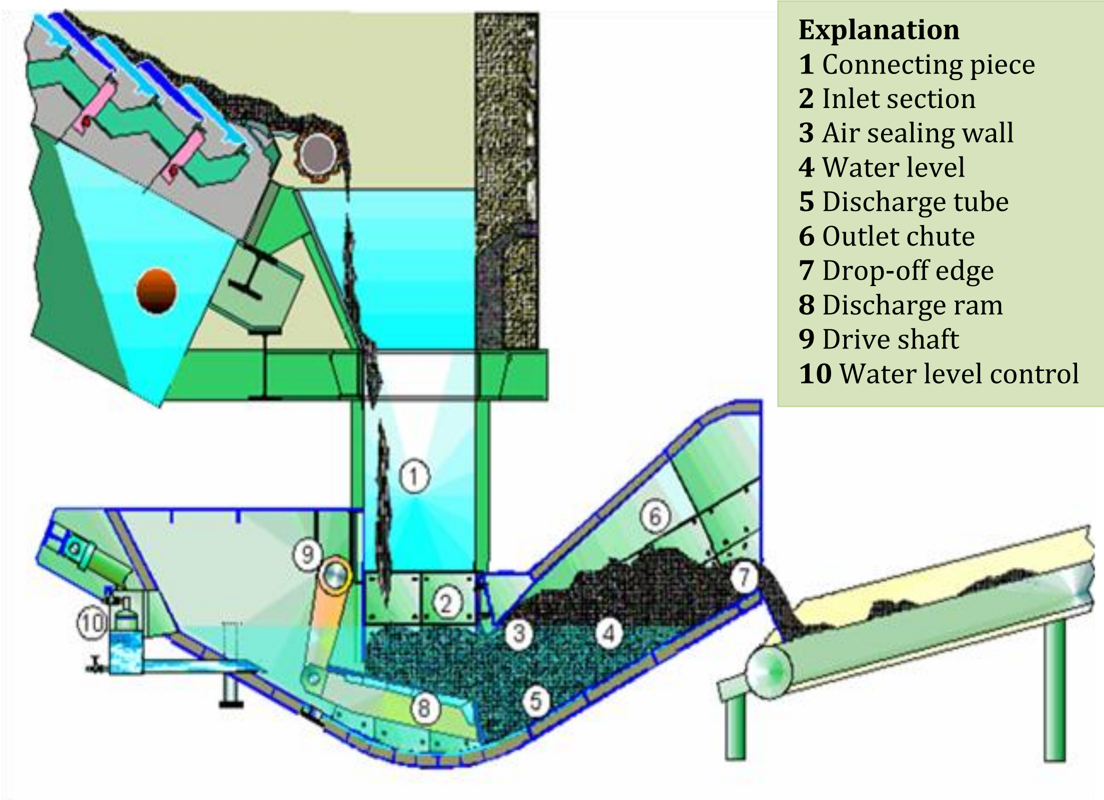


Fig. 6 Wet bottom ash discharge, Martin GmbH

The wet BOTTOM ASH DISCHARGER as seen in Fig. 6 is the well proven standard equipment in most incineration plants. Its basic function is as an air barrier, the cooling down section as well as discharging the bottom ash. When the water comes in contact with the heterogeneous bottom ash, there are many uncontrolled chemical reactions which result in poor quality of the bottom ash.

Wet discharged bottom ash makes it very difficult to recover efficiently its metals and minerals. Therefore, KEZO developed a few years ago a technology to discharge the bottom ash dry which finally allows access to particles smaller than 5mm, which contain more NF precious material than fractions with bigger particles. The dry bottom ash is a free flowing material and therefore allows the best possible separation and quality of metals and minerals. Fig. 7 is a schematic diagram of the process.

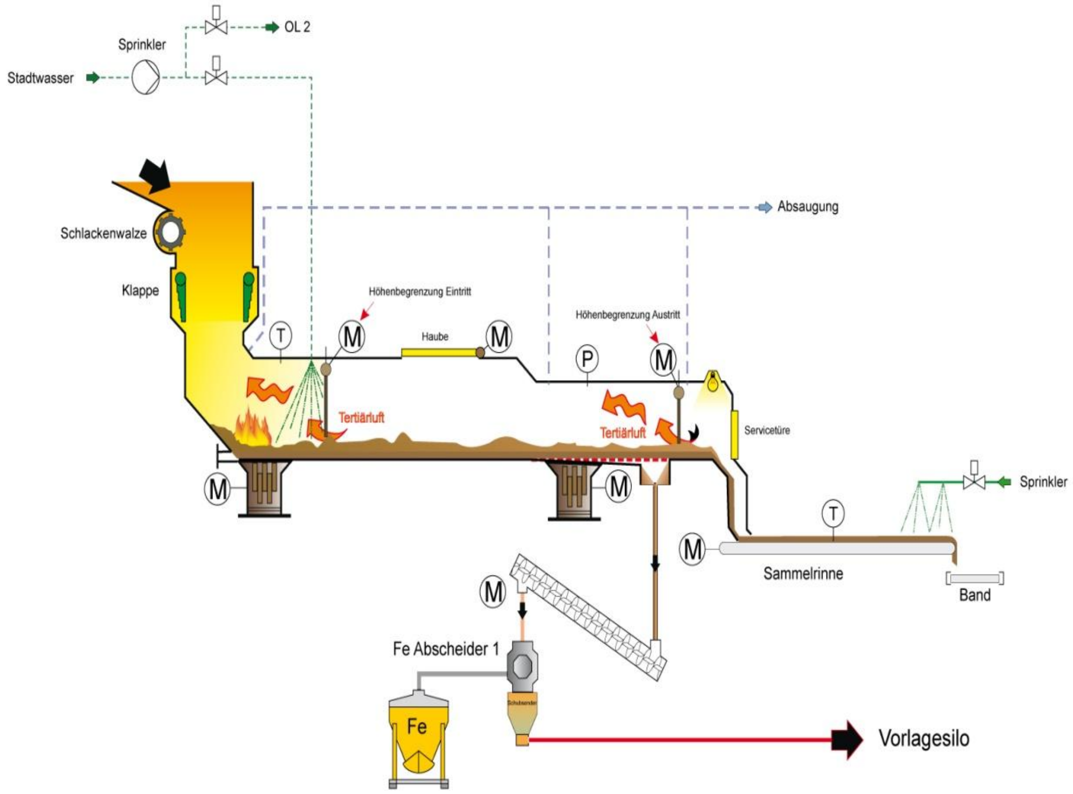


Fig. 7 Dry bottom ash discharge, KEZO (German)

As well as this significant advantage for the separation of metals, this process has further positives aspects:

- + No wastage of water
- + Higher energy efficiency
- + Lower organic content in the bottom ash
- + Significant reduction of the LEACHING RATE of bottom ash in landfills
- + Transport costs reduction because the water in the bottom ash is gone. (20% of the weight)
- + If needed the chemical reactions can be activated at any time by adding water under controlled circumstances

As in every process, there are disadvantages. One is the dust emission generated by the very fine dry bottom ash particles. Therefore, special care is needed. However, dust is only a minor problem because there are many industries, e.g. flour mills, cement plants and more, which are able to handle dust issues effectively. Therefore, a closed transport system is necessary which is not common yet in the incineration industry. For many furnace operators the new air flow through the dry bottom ash discharger is seen as a problem as well. The furnace operator wants a closed system and since the water barrier does not exist anymore, the furnace of a dry discharge as described above is actually open. However, there are technical solutions to prevent this new air flow. Though, without this new air, the after-burning-process, which lowers the organic content in the bottom ash will be very weak.

5.3 BOTTOM ASH CONDITIONING/TREATMENT

Once the bottom ash leaves the furnace and has passed the dry discharger, it is sieved in two fractions: the fine bottom ash, smaller than 5.0 mm, and the coarse bottom ash, bigger than 5.0mm. Based on the enormous potential of NF metals in the fine fraction as well as the lack of an apparent separation technology it was decided to focus the developments on the fine fraction. Fig. 8 shows this fact. With the wet discharge bottom ash treatment the fine bottom ash was never treated, only particles bigger than 7mm received further treatment. First it was mechanically treated and afterwards also handpicked. This way, it was only possible to recycle about 38% of aluminium and 32% of copper. By treating the fine bottom ash as well, around 90% of the metals (Fe, Al, Cu, and Cr) are now recoverable.

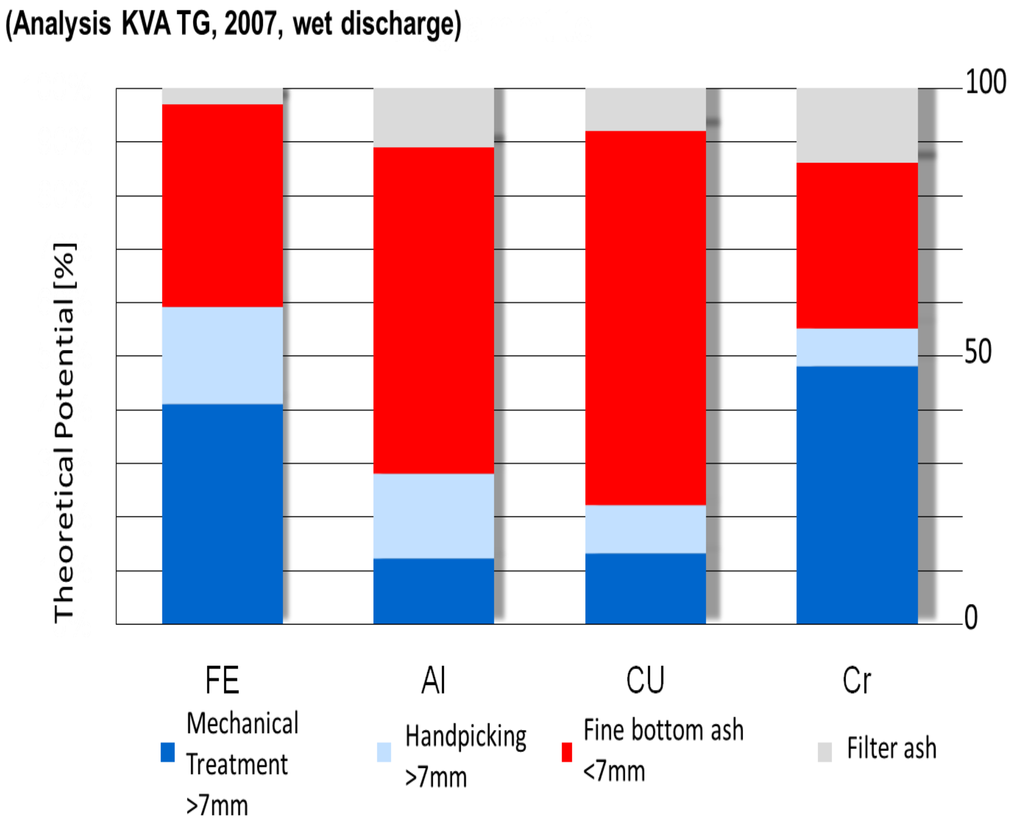


Fig. 8 Bottom Ash Monitoring 2007, Dr. L. Morf, GEO Partner AG

Therefore, in the first step KEZO and ZAR have built a bottom ash treatment plant for the fine fraction. Later on, it is planned to build a similar plant for the coarse bottom ash. In Fig. 9 is shown how the separation plant for the fine fraction works. First the fraction goes through another sieve. The particle smaller than 0.7mm are not treated at this point and are fed directly to the storage silo. The fraction then 0.7-5.0mm passes to two powerful, in series connected NEODYMIUM magnets which remove all the iron particles as well as the iron compounds and the oxide. It is especially important to remove these particles to guarantee best possible separation efficiency for further process steps. This fraction is fed to the storage silo as well.

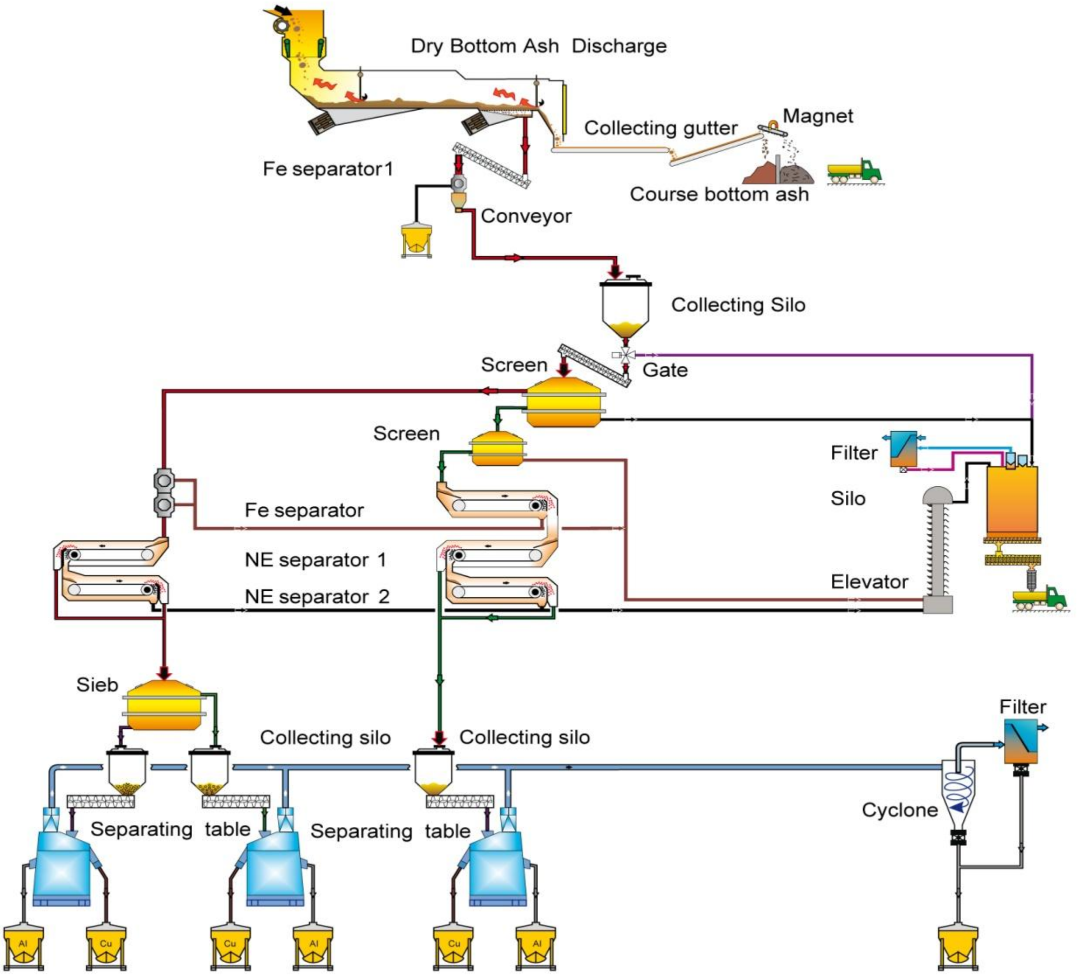


Fig. 9 Bottom ash treatment plant: From the bottom ash to NF precious bottom ash fraction and the aluminium fraction (<0.7mm, 0.7-3mm and 3-5mm), ZAR

The other fraction, now consisting only of NF metals and minerals, runs over two EDDY CURRENT SEPARATORS (see 5.4) which separates all the minerals from the NF metals. The mineral fraction which unfortunately still contains stainless steel and a small amount NF metals is also transported to the storage silo. All the material collected in the storage silos is moisturized and transported dustless to the landfill.

The NF metals leaving the Eddy Current Separator are screened in two fractions to achieve better results on the densimetric separation tables. The densimetric separation table splits the NF metals in an aluminium fraction and a precious NF fraction. (See 5.5)

Fig. 10 shows the bottom ash's way through the actual treatment system. By treating the coarse bottom ash e.g. breaking it down, it can be expected that the amount of fine bottom ash will increase again and all the small metals in the coarse bottom ash can be separated as well.

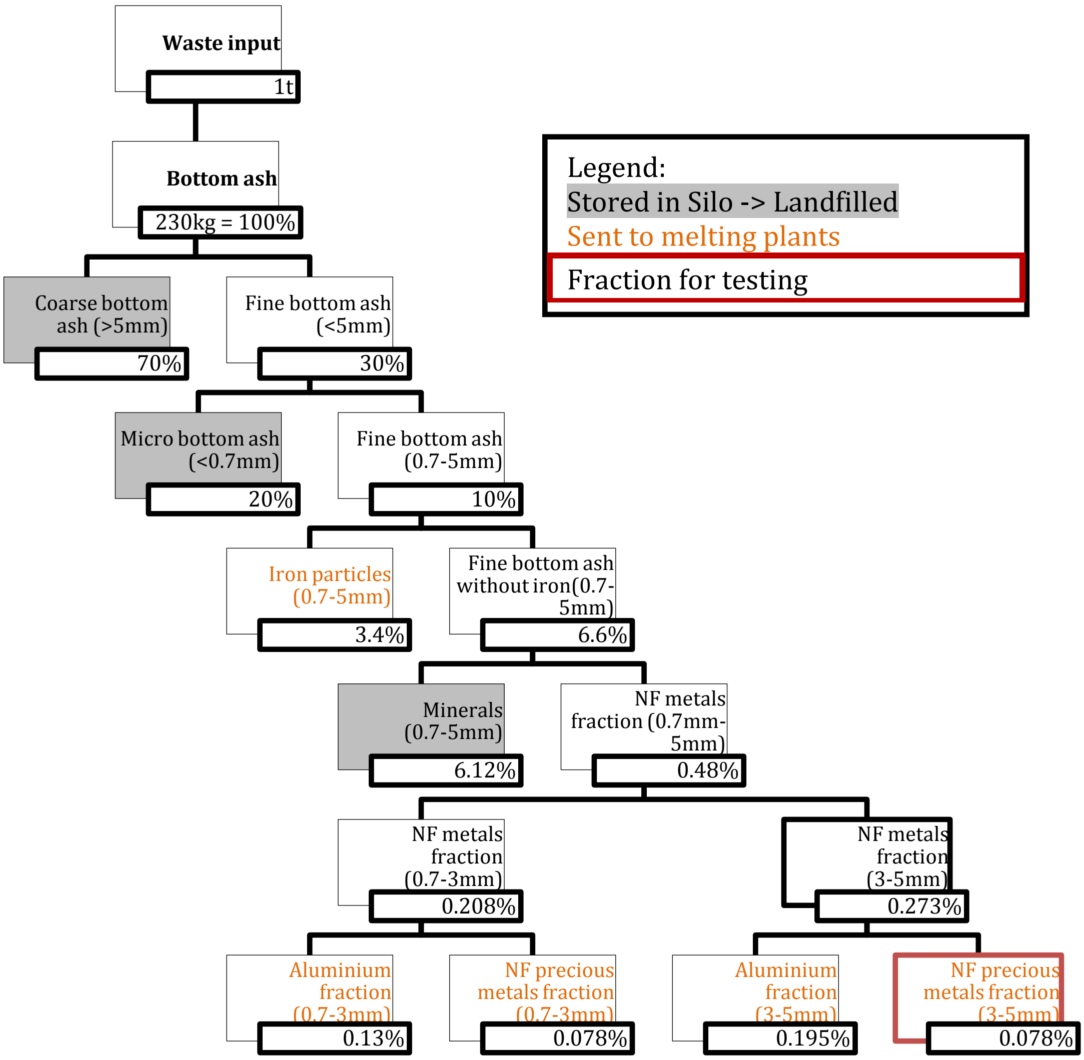


Fig. 10 Bottom ash treatment diagram with percentages by ZAR, Laura Böni

The percentages are based on other studies ZAR has made. The numbers are only valid for their plant. KEZO has just launched the same process for the micro bottom ash so in the future it will also be possible to extracted metals smaller 0.7mm.

The percentages at the end seem very small. Looking only at 1t of waste and its 230kg bottom ash, the NF precious metals fraction (3-5mm) weighs still 17.94kg. However, KEZO burnt 768'297 tons between 2008 and 2011. That makes 192'074 tons on average which concludes now in 3.45 tons NF precious (3-5mm) material per year. For the total amount of recovered aluminium from the both fractions it adds up to 14.36t per year on average.

5.4 Eddy Current System

The Eddy Current separator is a device known for its possibility to separate NF metals from non-metals. It has been used in the recycling industry for a long time. The rotating magnetic field in the device's drum creates in every electric conductive NF particle an eddy current which itself creates its own magnetic field. These two magnetic fields are repulsive to each other. As shown in Fig. 11, the magnetised NF particle is repulsed by the drum and therefore can be separated accurately because it flies further while the non-conductive particles such as minerals just fall off the belt because of gravity. It is important that ferrous metals are removed before hand because they could disturb the magnetic field and worsen the results.

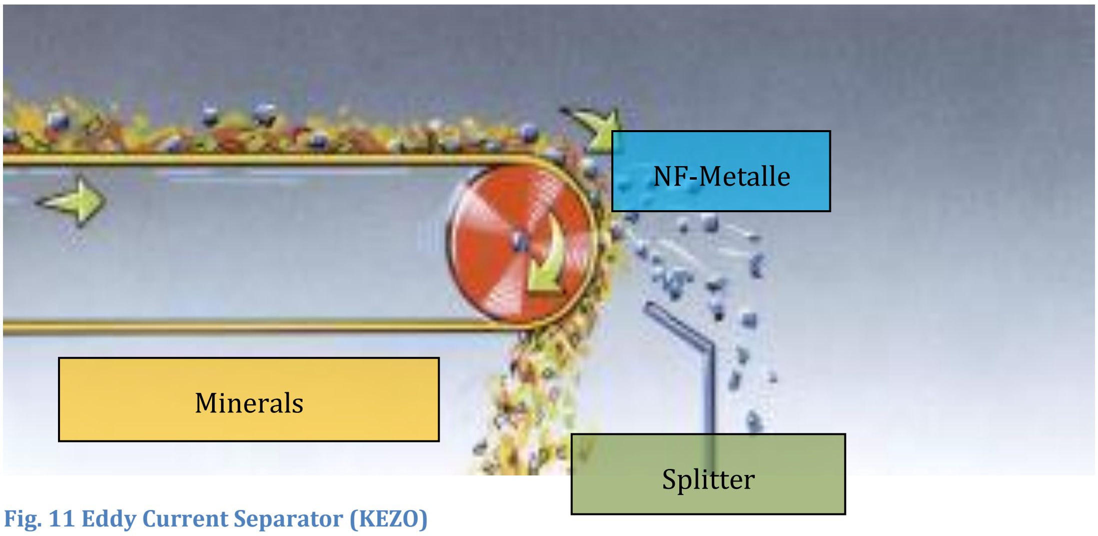


Fig. 11 Eddy Current Separator (KEZO)

The efficiency of the NF separation depends on the following parameters:

- Material
- Shape of the particle
- Force of the magnetic field in the drum
- Amount of magnetic poles in the drum
- Magnetic field‘s REVOLUTION per minute in the drum
- Direction of the rotation of the magnetic
- The conveyer belt's revolution per minute
- Position of the separation sheet

Material	Elec. conductivity [1/Ωm]	Density [kg/m³]	REPULSION [m²/kgΩ]
Aluminium	37‘000‘000	2‘700	13‘700
Copper	59‘900‘000	8‘960	6‘700
Silver	62‘100‘000	10‘500	5‘900
Zinc	16‘900‘000	7‘140	2‘400
Gold	41‘700‘000	19‘320	2‘200
Iron	10‘300‘000	7‘870	1‘300
Bronze	7‘100‘000	8‘900	800
Stainless steel	1‘400‘000	7‘800	180

Table 3 Significant values for the eddy current separator

Fig. 12 The Eddy Current Separator at KEZO, KEZO

The repulsion for a certain metal is calculated by dividing its electric conductivity σ by its density ρ. A high repulsion figure guarantees a very efficient separation by the eddy current. Thus, the aluminium can be easily separated even though the setup of the machine is not perfect. A repulsion figure below 7'000 $m^2/kg\Omega$ needs a perfect setup of the Eddy Current Separator to achieve a high efficiency rate. It is of importance that the efficiency of the Eddy Current's separation is judged by every single metal. To this day, it is still impossible for KEZO to separate stainless steel with the Eddy Current process, so it remains in the mineral fraction. Fig. 12 shows an Eddy Current Separator as it is installed at KEZO.

5.5 Non Ferrous-Metals

Non-Ferrous (NF metals) are all metals which don't consist of iron, e.g. aluminium, copper, zinc, etc. Therefore, they are nonmagnetic and conductive. With applicable processes recycled NF metals are absolutely comparable with metals made of primary resources. (Feister, 1985) Only the NF fraction goes a separation step further to the separation table. One can improve the added value of the NF metals by adding a further separating process as the densimetric separation table (See 286.2).

The NF (precious) fraction is the base for the tests and the results of this report.

5.6 Density

The density of an object describes the relation between the mass of a body and its volume. Mathematically described, it is: $\rho=m/V$. This concludes different materials have different densities. The densities of the material in the NF fraction can therefore be used as a helpful factor to separate the different NF metals.

Material	Density (20°C) [g/cm³]	Material	Density (20°C) [g/cm³]
Glass	2.5	**Bronze**	8.8
Aluminium	2.7	**Brass**	8.9
Zinc	7.1	**Nickel**	8.9
Chromium	7.2	**Copper**	9.0
Tin	7.3	**Silver**	10.5
Steel	7.9	**Lead**	11.3
Iron	7.9	**Gold**	19.3
Cadmium	8.7		

Table 4 Densities of relevant metals from http://education.jlab.org/itselemental/ (6.1.2012)

5.7 EXISTING METHODS TO SEPARATE THE NF-FRACTION

In the industry there are different systems used to accumulate certain NF metals out of the NF fraction.

+ Hand picking: Widely used in 2nd and 3rd world countries
+ Melting processes: highly industrialized process with a high energy consumption
+ Eddy Current Separator
+ Density separation
  - Wet systems: water, ferrofluids and others, mostly based on the SINK FLOAT PRINCIPLE
  - Dry systems: air

  Important to know: Wet density separation systems are proven to have remarkably better results than dry operated systems! On the other hand, if e.g. one is separating small particles of aluminium with a wet system, these particles react immediately and generate hydrogen which is a highly inflammable gas.

5.8 FERROFLUID

A ferrofluid is a water or oil based, colloidal liquid in which nanoparticles of iron, cobalt, nickel or magnetite are suspended. Once the liquid is in contact with a magnet these fine particles are attracted to it and thereby the water or oil molecules are pushed away from the magnet. During that state the suspension has different densities. This fact is used for several different applications in such as medicine, optics, electronic devices and more. Furthermore, ferrofluids have a low surface tension as well as a low viscosity which are especially important for the density separation.

Fig. 13 Two pictures of a container inclosing ferrofluid and gold ring

Fig. 13 shows to the left a container in the air with ferrofluid and gold ring sunk to the bottom. On the right side, the container is on an extremely strong magnet. The iron ions are drawn to the ground pushing the gold up to the surface. Hence the gold ring is floating on top of the fluid.

5.9 Sample Splitter

The sample taking and the sample preparing is important to achieve repeatable analytic data. The SAMPLE SPLITTER is a device to prepare the granular compound for the laboratory examination. With one receptacle the compound gets equally dispersed into the dividing head. The material trickles through several alternating outlets in opposite direction into two other prepared receptacles. After every step, the material is bisected. This process can be repeated at will until the right amount of granular compound for the laboratory examination has been reached. Fig. 14, Fig. 15 and Fig. 16 show how the sampling was done.

Fig. 14 Sample Split Separator

Fig. 15 Sample SplitterFeeding

Fig. 16 Sample Splitter Installation

6. ACCUMULATION OF DIFFERENT METALS FROM WASTE

ZAR proposed to run tests with the NF precious fraction 3-5mm, as seen in Fig. 17, on the Magnetic Density Separator (MDS) and Densimetric Separation Table (DST). The test runs, the sample preparing and the interpretation was done by Laura Böni. For both separation methods ZAR wanted to know if they were possible processes to work with in the future. Therefore, they were not expecting exact result but a tendency how to proceed in the future.

Fig. 17 Initial NF precious fraction 3-5mm

6.1 LIQUISORT – METAL DENSITY SEPARATION

6.1.1 Test set up

The Magnetic Density Separation MDS is a process developed by the Dutch company Liquisort B.V.. The test runs were therefore executed in Alkmaar, Netherland and the picture of Fig. 18 illustrate the test run. Liquisort uses their system to separate metals or plastic by their density using a ferrofluid and a powerful magnet. It is based on the sink float principle. The NF precious metals 3-5mm were filled in a silo and then discharged onto a vibrating chute. This chute moves the material towards a powerful magnet which is located under a conveyer belt. The conveyer belt is floated with a type of ferrofluid consisting of water and "*magnetic iron oxide particles with a size of 10-20nm"* (liguisort.com, 28.12.2012). It is therefore a suspension and has a dark colour. Because of the powerful magnet the iron oxides float as close as possible to the magnet pushing the water molecules up to the surface. This is how different densities in only one liquid are created (density gradient): Close to the magnet the liquid has a high density; on the surface of the liquid the density is lower. The liquid flow is perpendicular to the conveyer belt that is covering the magnet. When the material is fed into the liquid, the heavy metals e.g. gold with a density of 19.3g/cm^3 sink onto the belt and are discharged by it. The lighter metals are floating on the surface and follow the liquid over the belt to another conveyer belt. At this point, we already have a light and a heavy NF fraction. After rinsing the metals with water, cleaning them from the ferrofluid, the separation process is finished. The ferrofluid can be reused. Fig. 19 gives an overview of the separator. According to Liquisort, the system consumes about 100L of ferro liquid per 100t material. The throughput of one line is about 2.5t/h. Liquisort assured a low energy consumption. However, there are no exact figures available. The densities of the liquid was neither measured nor controlled. As a pre-test, Liquisort's manager Dick de Jong put his golden wedding ring through the process and as it was coming out on the side of the heavy metal fraction, they declared that our experiment could start.

Fig. 18 Liquisort's MDS: Test run from left to right to the bottom

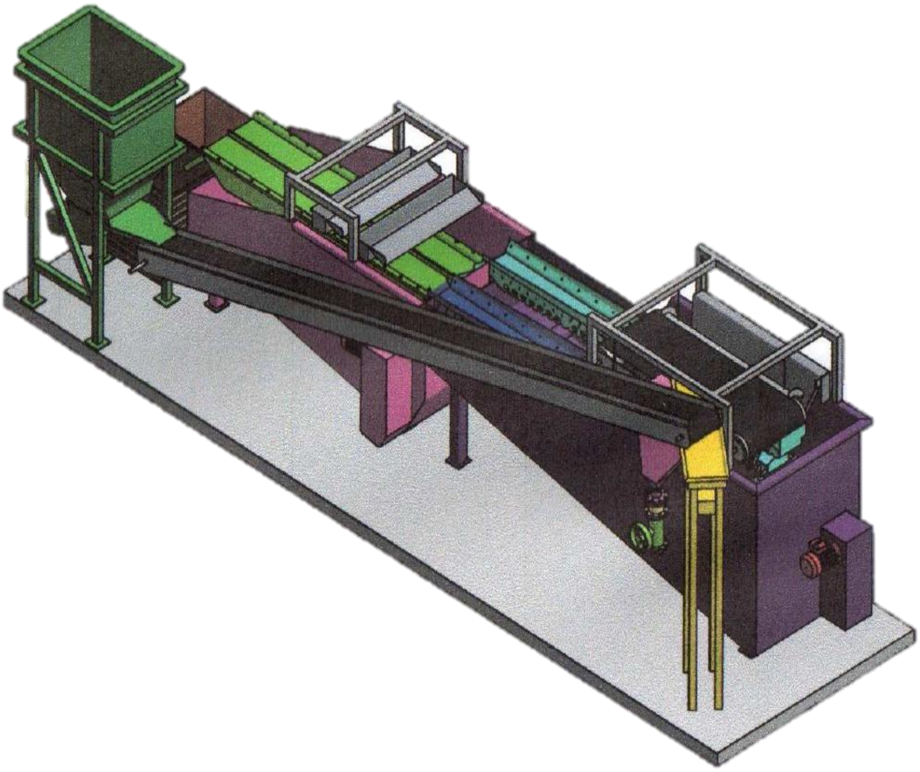


Fig. 19 MDS Liquisort schematic diagram

6.1.2 *Expected Result*

If the system separated as expected, one fraction would contain aluminium, zinc, tin, bronze, brass and copper (plus traces of silver and lead); and the other fraction silver, lead and gold (plus traces of copper, brass and bronze and magnetic parts).

6.1.3 *Sample Preparing*

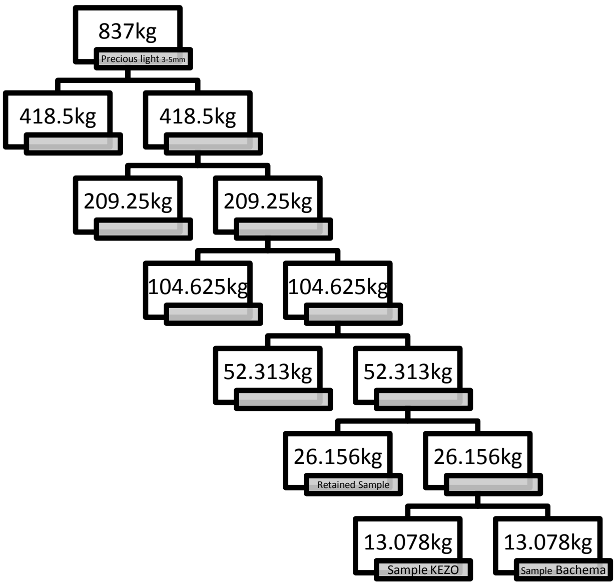


Fig. 20 Sample preparing

Bachema AG, the analytic institute, needed about 15kg of each fraction for the analysis. To achieve the best representing sample this was done with the sample splitter (see 5.9). In Fig. 20 it is shown how the MDS precious light fraction 3-5mm was bisected six times to get a sample for Bachema and one for KEZO each of 13kg. Furthermore, a retained sample was taken in case the material was needed for different analyses. These same steps were performed for each fraction which had to be analysed.

6.1.4 *Analytic work at Bachema*

The Bachema Institute is a laboratory which cooperates with ZAR and did all the analyses of the fractions. Initially, the laboratories were not able to analyse these new metal fractions from incineration plants. However, for more than one year Bachema worked on a procedure to prepare the sample in a new way to get reliable result. This was necessary because it was realized that the former sample preparation was not adequate to analyse metal in such small concentrations in the sample.

Short overview over the analytic procedure:

1. Fraction is weighted; volume, density and bulk density are calculated.
2. Fraction is put in a pulverising mill as seen in Fig. 21. The fraction particles are broken down to a particle size of 0.1mm. It is most important that no agglomeration is generated during the milling process. Any agglomeration would have a negative influence on the results.

Fig. 21 Pulverising mill at Bachema AG

3. Only 2 to 3g of the initial fraction is now analysed. This explains why particles have to be milled down to 0.1mm and only a good mixture gives representative results. Bachema owns special, chemical analytic equipment which can analyse the concentration of each individual precious metal. For this analysis Bachema used a technique called inductively coupled plasma atomic emission spectroscopy. *"It is a type of emission spectroscopy that uses the inductively coupled plasma to produce excited atoms and ions that emit electromagnetic radiation at wavelengths characteristic of a particular element."* (Stefánsson, 2007) This means the emission's intensity is the signal for concentration of the metal in the sample.

6.1.5 Description of MDS fractions

6.1.5.1 MDS Liquisort light 3-5mm (Fig. 23 and Fig. 25)

+ Mixed, nearly any unity concerning the shapes
+ Wire and drop-shaped particles
+ Colours similar to Liquisort heavy fraction, but brighter
+ After drying extremely dusty, probably because of aluminium's reactions

6.1.5.2 MDS Liquisort heavy 3-5mm (Fig. 22 and Fig. 24)

+ Very mixed, hardly any unity concerning the shapes
+ Wire and drop-shaped particles
+ Colours darker, probably because of the lead
+ Metals changed colours over time (chemical reactions)

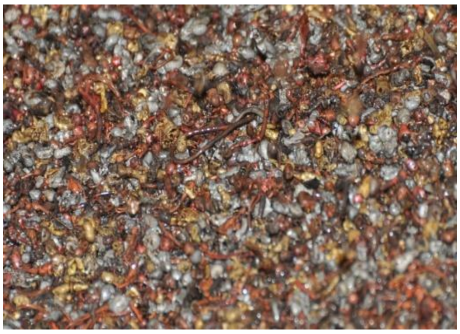


Fig. 23 Fraction MDS Light (wet)

Fig. 22 Fraction MDS Heavy (wet)

Fig. 25 Fraction MDS Light (dry)

Fig. 24 Fraction MDS Heavy (moist)

6.1.6 *Analytic results by Bachema*

Concentration of Elements and Heavy Metals in MDS Test Results 12.11.2012		Density [g/cm3]	MDS Liquisort NF precious 3-5mm light	MDS Liquisort NF precious 3-5mm heavy
Aluminium	mg/kg TS Al	2.7	44'800.0	2'690.0
Zinc	mg/kg TS Zn	7.1	283'000.0	84'500.0
Chromium	mg/kg TS Cr	7.2	381.0	891.0
Tin	mg/kg TS Sn	7.3	20'500.0	7'370.0
Iron	mg/kg TS Fe	7.9	10'400.0	15'500.0
Cadmium	mg/kg TS Cd	8.7	88.6	35.9
Nickel	mg/kg TS Ni	8.9	4'160.0	3'190.0
Copper	mg/kg TS Cu	9.0	649'000.0	553'000.0
Silver	mg/kg TS Ag	10.5	2'610.0	2'490.0
Lead	mg/kg TS Pb	11.3	14'300.0	369'000.0
Gold	mg/kg TS Au	19.3	21.0	847.0
Sum			1'029'260.6	1'039'513.9

Table 5 Concentration of elements and heavy metals in MDS Fraction (Bachema Institute's test sesults from the 12.11.12012, arranged by Laura Böni)

Explanation: "TS" stands for the German "Trockensubstanz" which means dry substance.

On November 12th, 2012 Bachema achieved reliable results. They were able to analyse the concentration of each metal listed in Table 5. All the concentrations are given in mg/kg which is the same ratio as g/t.

"MDS Liquisort NF precious 3-5mm light" fraction is the fraction which floated on top of the ferrofluid over the magnet. Therefore it should contain most of the metals with a density smaller 10g/cm^3. On the other side, the "MDS Liquisort NF precious 3-5mm heavy" fraction contains most of the metals with a density higher than 10g/cm^3.

The fact, that concentrations of aluminium as well as iron can be measured, shows how the thermo recycling process at KEZO can still be improved. There are still aluminium and iron particles which can slip through their separations steps.

It is of great importance to keep in mind that these concentrations are only valid for this used initial fraction: One certain ton of NF precious 3-5mm! The content of every ton of this fraction is different. Which means e.g. the gold content could vary immensely with another ton of the same fraction. The content of the fraction depends directly on the actual waste input. Looking at the results of the DST (see Table 7/Table 8) this "phenomenon" can be seen.

The only purpose of the row "Sum" is to show the correctness of the results. As long as it equals to about 1'000'000mg which is 1kg, the analysis results are considered reliable. The deviations between the analysis results and this kilogram are errors of measurement. For the light fraction it is 2.9% while for the heavy fraction it is 3.9%. These percentages are still in the error range which ZAR accepts.

6.1.7 Discussion of analytic results

Actual amount of metals in each fraction and Accumulation percentages	g	MDS Liquisort NF precious 3-5mm light in 837kg	MDS Liquisort NF precious 3-5mm heavy in 174kg	Initial fraction NF precious 3-5mm in 1.011t	Accumulation in light fraction [%]	Accumulation in heavy fraction [%]
Aluminium ($2.7g/cm^3$)	g	37'497.6	468.1	37'965.7	98.8	1.2
Zinc ($7.1g/cm^3$)	g	236'871.0	14'703.0	251'574.0	94.2	5.8
Chromium ($7.2g/cm^3$)	g	318.9	155.0	473.9	67.3	32.7
Tin ($7.3g/cm^3$)	g	17'158.5	1'282.4	18'440.9	93.0	7.0
Iron ($7.9g/cm^3$)	g	8'704.8	2'697.0	11'401.8	76.3	23.7
Cadmium ($8.7g/cm^3$)	g	74.2	6.2	80.4	92.2	7.8
Nickel ($8.9g/cm^3$)	g	3'481.9	555.1	4'037.0	86.3	13.7
Copper ($9.0g/cm^3$)	g	543'213.0	96'222.0	638'435.0	85.0	15.0
Silver ($10.5g/cm^3$)	g	2'184.6	433.3	2'617.8	83.4	16.6
Lead (11.3g/cm3)	g	11'969.1	64'206.0	76'175.1	15.7	84.3
Gold (19.3g/cm3)	g	17.6	147.4	165.0	10.7	89.3
Sum	g	861'491.1	180'875.4	1'031'025.3	-	-

Table 6 Actual amount of metals in each fraction and Accumulation percentages MDS

Table 6 shows the amount of metals of the light and the heavy fractions. The initial fraction was calculated by adding the metals of the light and heavy fraction. Looking at the weight of the light and heavy fraction (837kg and 174kg), it is noticeable that they equal to 1011kg instead 1000kg. This is caused by all the water which remained in the fraction after the ferrofluid was washed off. The fractions were only weighed right after they passed the separator. For the analysis the water was extracted from the metals. However, these 11kg, 1% of the whole mass can be disregarded for the accuracy the ZAR needs. Furthermore, ZAR does not mind the analytic deviation of 3.1% looking at the sum in the initial fraction 1'031'025g instead of the wanted 1'000'000g.

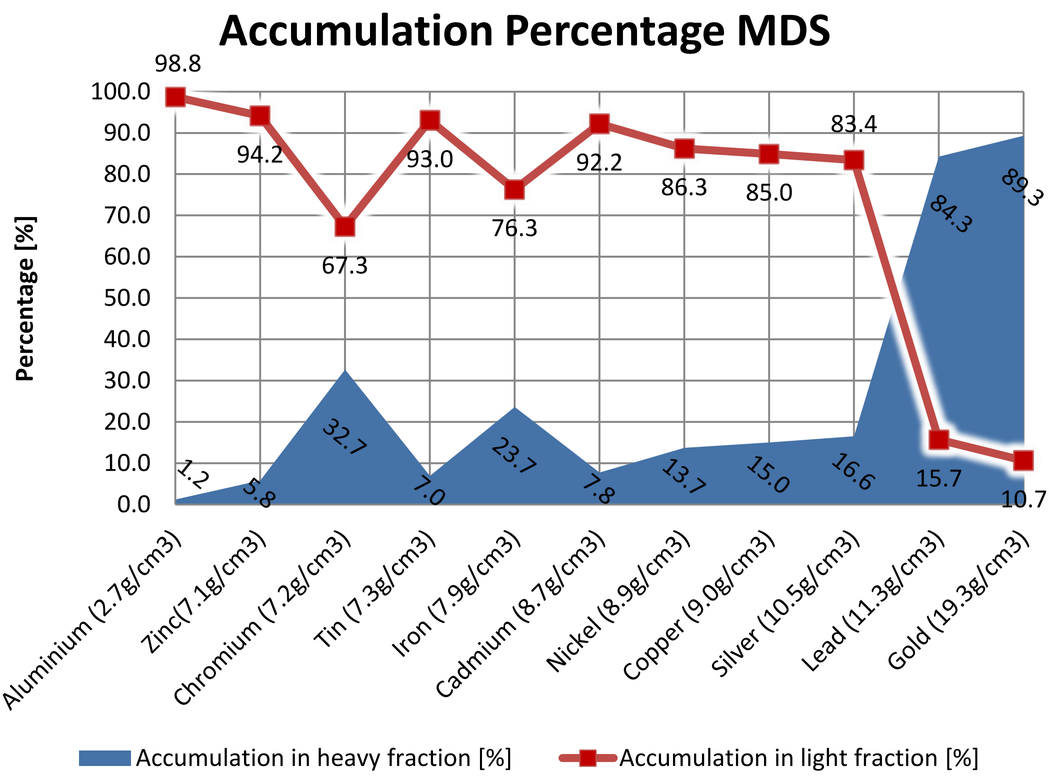


Fig. 26 Accumulation Percentages MDS

Fig. 26 shows the accumulations in both fractions. The metals are sorted by their ascending density. It is displayed in percentages. The percentages can be seen in Table 6. They are calculated e.g. like this for gold in the light fraction:

$$\%=(100/(x_{Au}\text{ g in initial fraction}))\times y_{Au}\text{ g in light fraction}$$

The heavy fraction contains 89.2% of the initial 100% gold and 84.3% of the initial lead. This is a significant accumulation. In the light fraction all other metals are accumulated with an average of 86.3%. Aluminium even is accumulated by 98.8%. Looking at the results, it seems the density of the ferrofluid was above 10.5g/cm^3, otherwise the accumulation of silver would have been better. Iron was accumulated because as a magnetic particle it was drawn to the magnet and therefore landed in the conveyer belt which carried it away together with the heavy fraction.

While comparing the data points, it must be kept in mind that especially all the numbers far below and far above 50% are good accumulations. If the initial fraction had been split e.g. with a sample splitter, the content would have bisected itself and both new fraction would have contained each 50% of the initial material. Seen as such Chromium has the worst accumulation. It is inexplicable why chromium was accumulated by 33.1% in the heavy fraction even though its density is comparably low. It can only be assumed that it might be caused by its very low content: 80.4g in 1.011t. And therefore a possible analytic failure is relevant.

6.1.8 *Assessment Magnetic Density System (MDS)*

MDS has several positive aspects:

+ The MDS separates lead and gold very well and therefore creates a significant accumulation.
+ The MDS has been tested several times and is proven to be a good separating method. With little further adjustments, it should be possible to improve the separation results for the NF precious fraction.
+ Wet separation systems have generally the better efficiency than dry separators.
+ Its energy consumption is presumably low since only several conveyer belts, a vibrating chute and a water as well as ferrofluid pump are installed.

Looking at the results, the MDS seems to fulfil the requirements: gold can be accumulated. However, the process and the procedure have a few negative aspects which are listed below:

- Since the density is not controlled, the quality of the separation depends very much on the operator. For an industrial process, a controllable system is preferred.
- Unknown is the impact of the form and size of the particle: Do small disks of gold, lead or silver float or sink?
- For small aluminium particles this wet process is not suitable because of the reactivity (oxidation) of the material.
- Since the material is wet after the process, it must be dried before the next process step. This needs additional energy.
- After a short time, the wet fraction started to smell because of uncontrolled chemical reactions (especially in the light fraction because of the aluminium).

6.2 DENSIMETRIC SEPARATION TABLE KEZO

6.2.1 Test set up

The test run was executed on the KEZO plant in Hinwil.

With a densimetric separation table (DST) it is possible to separate particles with different specific weights. Therefore, an air flow is passing through vibration table. The fraction is inserted through an apportioning channel onto the DST. This way a coincidental distribution can be guaranteed. The adjustable air flow is inserted from below the vibration table over the whole sieve plate. Due to the combined force of the vibration table and the air current, the friction between the individual particles is eliminated almost entirely. The particle mass therefore behaves similar to a liquid. The heavy particles sink down, and the light particle float on top.

The down-grade of the table is designed so that there is an incline between the lightweight fraction side and the heavyweight fraction side. The bedded down heavyweight grains finally get transported towards the higher levelled outlet because of the defined slope and movement of the vibration table. Thus the lightweight fraction exits though the lower levelled outlet. In Fig. 27 the DST is shown from the lower levelled table side and the picture of Fig. 28 is taken from the higher levelled outlet looking down to the lower one.

The separation efficiency of the DST really depends on the shape of the particle. If the particle is disk shaped, it flows easier on the air current than if it's a wire or ball shaped. So even if its density is high, and it should move on the vibrating table towards the higher levelled outcome it can float on top of the air current to the lower levelled outcome.

Characteristics of densimetric separation tables are (www.joest.com, 23.12.2012):

- Precise selectivity because of special sieves, optimized air current, and combined cross flow sifting
- Easy handling, easy cleaning, robustly built
- No product loss or dust deposit
- The material remains dry

Fig. 27 DST at KEZO, KEZO

Fig. 28 Looking at the table in DST, KEZO

6.2.2 *Expected results*

The DST was adjusted in a way that about a fifth of the initial NF precious fraction was supposed to end up in the heavy fraction, while the rest would be in the light fraction. This way, the operator assumed to get the best result, because the ratio between the weight of the light and the heavy MDS fraction was about 4:1. Therefore it was expected to have similar and comparable result as with the MDS.

The heavy fraction contains most of the gold, silver, and lead (plus traces of copper, brass, and bronze). The light fraction contains aluminium, zinc, tin, bronze, brass, and copper (plus traces of silver, lead and most particles which are disk-shaped).

6.2.3 *Sample Preparation*

See 6.1.3

6.2.4 *Analytic work at Bachema*

See 6.1.4

6.2.5 *Description of DST fractions*

6.2.5.1 Density Separation NF – Fraction: KEZO DST light, 3–5mm (Fig. 29)

+ Wire
+ Glass
+ Unregularly shaped and not uniform

Fig. 29 Fraction DST Light

6.2.5.2 Density Separation NF – Fraction: KEZO DST heavy, 3–5mm (Fig. 30)

+ Felt heavy
+ Ball- and drop-shaped
+ Hardly any wire and glass
+ Reddish, silver, golden
+ Rather uniform and regularly shaped

Fig. 30 Fraction DST Heavy

6.2.6 *Analytic results by Bachema*

Concentration of Elements and Heavy Metals in DST Test Results 12.11.2012		**Density [g/cm^3]**	**DST KEZO NF precious 3-5mm light**	**DST KEZO NF precious 3-5mm heavy**
Aluminium	mg/kg TS Al	2.7	193'876.2	9'762.0
Zinc	mg/kg TS Zn	7.1	198'267.4	245'505.5
Chromium	mg/kg TS Cr	7.2	542.9	442.0
Tin	mg/kg TS Sn	7.3	14'912.6	22'788.7
Iron	mg/kg TS Fe	7.9	12'472.1	6'724.6
Cadmium	mg/kg TS Cd	8.7	72.2	150.6
Nickel	mg/kg TS Ni	8.9	2'211.2	4'136.0
Copper	mg/kg TS Cu	9.0	542'551.1	669'821.8
Silver	mg/kg TS Ag	10.5	1'262.7	3'336.3
Lead	mg/kg TS Pb	11.3	7'147.4	90'212.7
Gold	mg/kg TS Au	19.3	35.2	318.9
Sum			973'351.0	1'053'199.2

Table 7 Concentration of elements and heavy metals in DST fraction (Bachema Institute's test results from the 12.11.2012, arranged by Laura Böni)

Bachema was able to analyse the concentration of each metal as shown in Table 7. All the concentrations are given in mg/kg which is the same ration as g/t.

"DST KEZO NF precious 3-5mm light" fraction is the fraction which floated with the air current towards the lower levelled outlet. Therefore it should contain most of the metals with a density smaller 10g/cm^3. On the other side, the "DST KEZO NF precious 3-5mm heavy" fraction contains most of the metals with a density higher than 10g/cm^3. These metals were too heavy for the air flow to be pushed up in the air; they stayed on the sieve and moved with the vibration upwards towards the higher-levelled outlet. Again, it is of great importance to keep in mind that these concentrations are only valid for this used initial fraction: one specific ton of NF precious 3-5mm. The content of every ton of this fraction is different.

The only purpose of the row "Sum" is to show the correctness of the results. As long as it equals to about 1'000'000mg which is 1kg, the analysis results are considered reliable. The deviations between the analysis results and this kilogram are errors of measurement. For the light fraction it is 2.7% while for the heavy fraction it is 5.3%. These percentages are still in an error range which ZAR accepts.

6.2.7 *Discussion of the analytic results*

Actual amount of metals in each fraction and Accumulation percentages	g	DST KEZO NF precious 3-5mm light in 617kg	DST KEZO NF precious 3-5mm heavy in 275kg	Initial fraction NF precious 3-5mm in 0.892t	Accumulation in light fraction [%]	Accumulation in heavy fraction [%]
Aluminium (2.7g/cm³)	g	119'621.60	2'684.56	122'306.2	97.8	2.2
Zinc (7.1g/cm³)	g	122'331.00	67'514.00	189'845.0	64.4	35.6
Chromium (7.2g/cm³)	g	334.99	121.56	456.6	73.4	26.6
Tin (7.3g/cm³)	g	9'201.10	6'266.90	15'468.0	59.5	40.5
Iron (7.9g/cm³)	g	7'695.30	1'849.26	9'544.6	80.6	19.4
Cadmium (8.7g/cm³)	g	44.56	41.42	86.0	51.8	48.2
Nickel (8.9g/cm³)	g	1'364.28	1'137.39	2'501.7	54.5	45.5
Copper (9.0g/cm³)	g	334'754.00	184'201.00	518'955.0	64.5	35.5
Silver (10.5g/cm³)	g	779.10	917.47	1'696.6	45.9	54.1
Lead (11.3g/cm3)	g	4'409.95	24'808.50	29'218.5	15.1	84.9
Gold (19.3g/cm3)	g	21.70	87.70	109.4	19.8	80.2
Sum	g	600'557.58	289'629.77	997'967.88	-	-

Table 8 Actual amount of metals in each fraction DST

Table 8 shows the amount of metals in the light and heavy fractions as well as the calculated amount in the initial fraction. Looking at the weight of the light and heavy fraction (617kg and 275kg), it is noticeable that they equal to 892kg instead of 1000kg. This is caused by a loss of material while adjusting and testing the separator. The initial fraction for the test run was unfortunately totally different to the MDS initial fraction. In comparison, the DST fraction contained less gold, less lead, less silver, less cupper, less tin and less zinc but more aluminium. For this reason it is of great importance to realize, DST's absolute figures cannot be compared to MDS's.

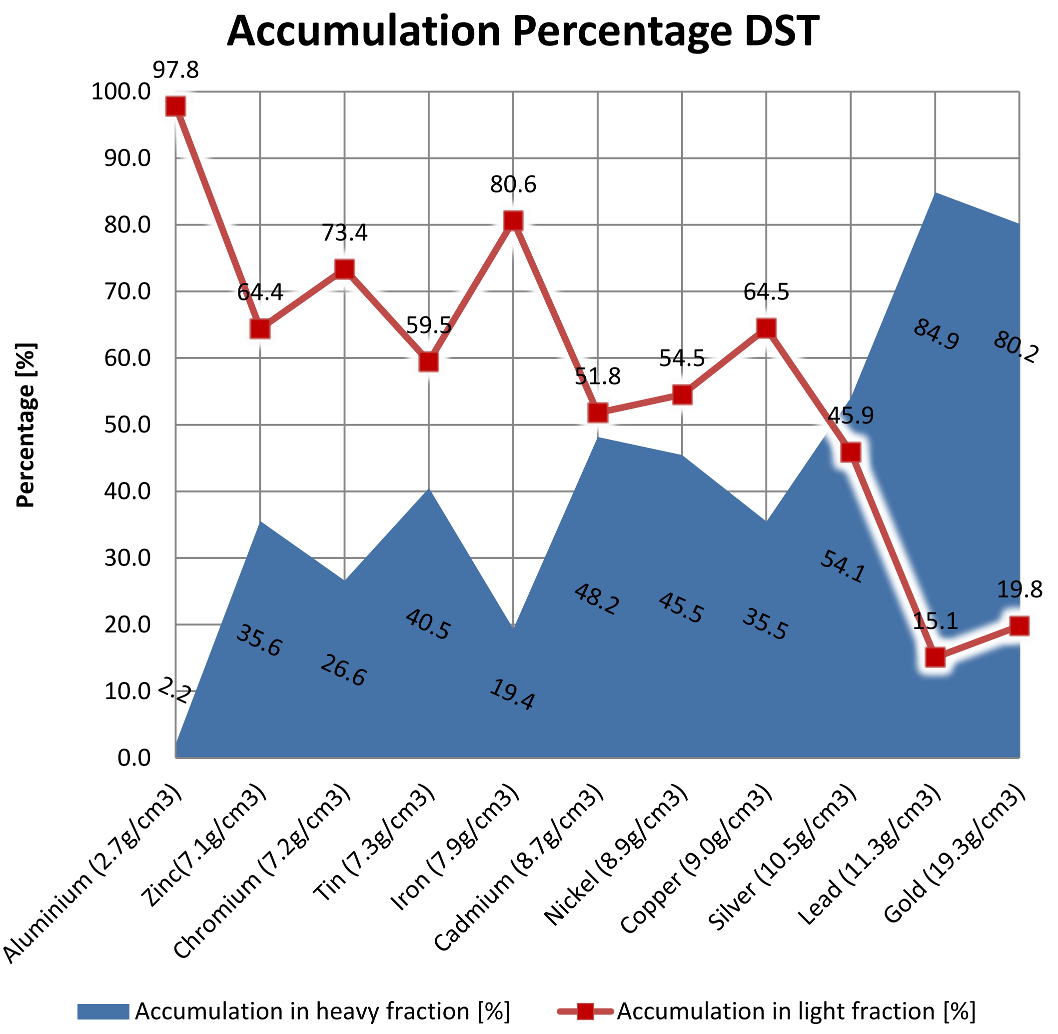


Fig. 31 Accumulation DST KEZO

Fig. 31 shows the accumulations in both fractions. The metals are sorted by their ascending density. Please notice the same scale is used compared to the coherent graph for MDS. It is displayed in percentages. The percentages can be seen in Table 6. (For the calculation see 6.1.7)

The heavy fraction contains 80.2% of the initial 100% gold content and 84.9% of the initial lead content. This proves an accumulation took place. In the light fraction all other metals are accumulated with an average of 65.8%. Aluminium is accumulated the best with 97.8%. 65.8% is not very significant because while comparing the data points with each other, it must be kept in mind that especially all the numbers far below and far above 50% are good accumulation. If the initial fraction had been split e.g. with a sample splitter, the content would have bisected itself and both new fraction would have contained each 50% of the initial material. Seen as such cadmium, nickel and silver have the worst accumulations.

Looking at the results, it seems that probably the shape had a huge influence on the results. The DST made it possible to accumulated silver to a small extent which means the DST was able to separate the metals at about 10g/cm^3.

6.2.8 *Assessment Densimetric Separation Table (DST)*

The DST has several positive aspects:

+ The DST separates lead and gold well and therefore creates an accumulation
+ The DST has been tested several times and is proven to be a good separating method especially for precious aluminium separations. With further adjustments, it should be possible to improve the separation results for the NF precious fraction
+ Its energy consumption is presumably low
+ It is a dry system; therefore no energy is needed for the drying process and no chemical reactions can occur
+ There is no loss of material

Looking at the results, the DST seems to also fulfil the requirements: gold can be accumulated. However, the process and the procedure have a few negative aspects which are listed below

- Since the density is not controlled, the quality of the separation depends very much on the operator. For an industrial process, a controllable system is preferred
- The impact of the particle size and form must be considered. Disk-shaped particles will float on the air stream upwards to the light fraction
- The accuracy of a dry separation is worse than with a wet treatment

6.3 Comparison of the Heavy Fraction MDS, Liquisort and DST, KEZO

6.3.1 Data

Element		MDS Liquisort NF pre-cious 3-5mm light	MDS Liquisort NF pre-cious 3-5mm heavy	Accumulation Percent-age in heavy fraction MDS [%]	DST KEZO NF precious 3-5mm light	DST KEZO NF precious 3-5mm heavy	Accumulation Percent-age in heavy fraction DST [%]
Aluminium	[g/t]	44'800.0	2'690.0	1.2	193'876.2	9'762.0	2.2
Zinc	[g/t]	283'000.0	84'500.0	5.8	198'267.4	245'505.5	35.6
Chromium	[g/t]	381.0	891.0	32.7	542.9	442.0	26.6
Tin	[g/t]	20'500.0	7'370.0	7.0	14'912.6	22'788.7	40.5
Iron	[g/t]	10'400.0	15'500.0	23.7	12'472.1	6'724.6	19.4
Cadmium	[g/t]	88.6	35.9	7.8	72.2	150.6	48.2
Nickel	[g/t]	4'160.0	3'190.0	13.7	2'211.2	4'136.0	45.5
Copper	[g/t]	649'000.0	553'000.0	15.0	542'551.1	669'821.8	35.5
Silver	[g/t]	2'610.0	2'490.0	16.6	1'262.7	3'336.3	54.1
Lead	[g/t]	14'300.0	369'000.0	84.3	7'147.4	90'212.7	84.9
Gold	[g/t]	21.0	847.0	89.3	35.2	318.9	80.2

Table 9 Data MDS Liquisort and DST KEZO in Comparison

6.3.2 Diagram

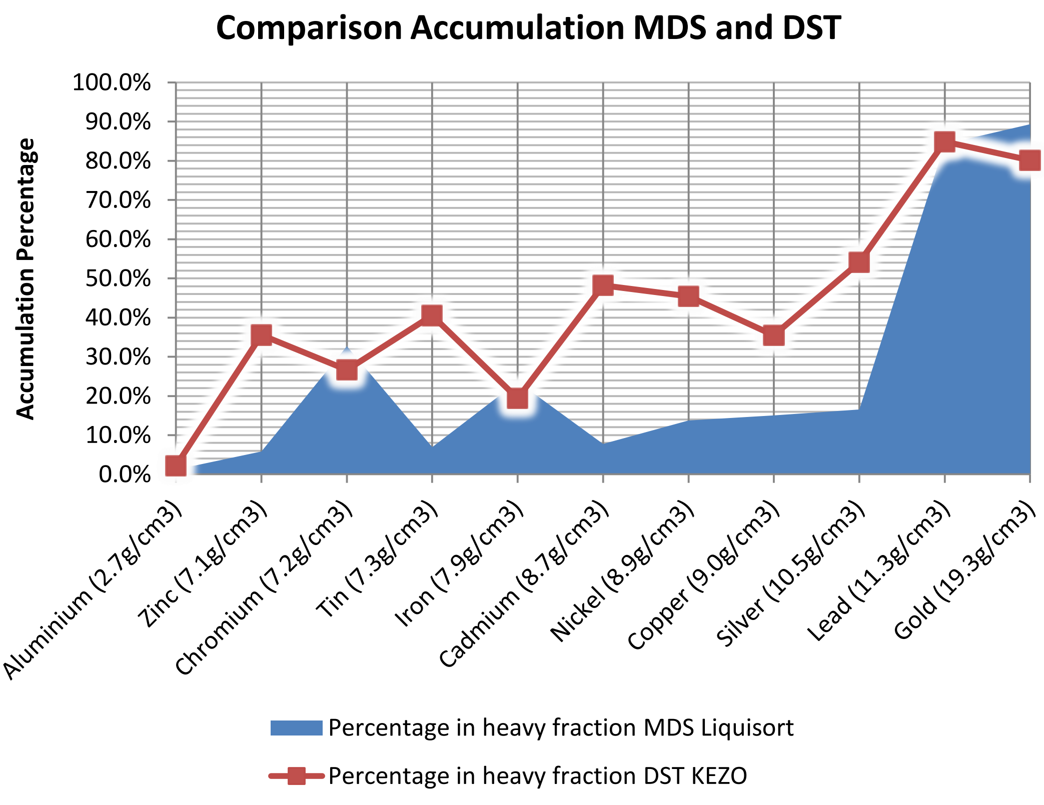


Fig. 32 Accumulation in heavy fraction MDS and DST

6.3.3 Explanation

Fig. 32 was created based on the analysis data from Bachema. The heavy fractions of both separation methods are compared. The percentage in the table indicates the accumulation in the heavy fraction. The light fractions behave complementary. While comparing the data points with each other, it must be kept in mind that especially all the numbers far below and far above 50% are good accumulations. If the initial fraction had been split e.g. with a sample splitter, the content would have bisected itself and both new fraction would have contained each 50% of the initial material.
The diagram shows clearly that MDS was able to distinguish more precisely between the heavy and the light elements. This is shown by the low percentages for all the metals with a density below 11.3g/cm^3, the sudden increase between silver and lead and the high percentages of lead and gold. DST shows results lower than MDS. The numbers for Zinc, Tin, Nickel and Copper are below 50% but not low enough to be significant. The data also indicates that the silver content is just a little above 50% which means almost no accumulation took place. The lead value is the only one where MDS Liquisort as well as DST KEZO have similar numbers. Additionally, it is possible to see in Fig. 32 at which density each system separated: DST at estimated 10.4g/cm^3 and MDS at estimated 10.9g/cm^3. MDS Liquisort with a high gold accumulation of 89.3% proves to be the better separation system for the wanted purposes.

6.4 DISCUSSION

The calculations show clearly that the validity of hypothesis 1 as well as hypothesis 2 can be confirmed.
Hypothesis 1: Liquisort's magnetic density separator (MDS) is able to split the NF precious metal fraction in a low and a high density fraction and allows an accumulation of gold in the heavy fraction.
Hypothesis 2: Recycling World's densimetric separation table (DST) is able to split the NF precious metal fraction in a low and a high density fraction and allows an accumulation of gold in the heavy fraction.

With both separators it was possible to receive two distinguishable fractions whereby in both precious, heavy fractions the gold content increased. As seen in Table 9 the MDS's accumulation percentage for gold is 9.1% higher than DST's. In addition, Fig. 32 shows how MDS separates metals better because they are either accumulated in the NF precious heavy fraction or in the NF precious light fraction. DST's percentages are closer to 50% which would mean no accumulation. Furthermore, MDS's clear increase between silver (10.5g/cm^3) and lead (11.3g/cm^3) shows how the density of the ferrofluid must have been at about around 10.9g/cm^3.

From the technical point of view ZAR's requirements of accuracy, MDS Liquisort is clearly the more advantageous regarding Hypothesis 1 and 2. However, before looking at the economic and ecological feasibility study, no assumption of the better separation system should be made.

7. ECONOMIC FEASIBILITY STUDY

In order to make a generally valid calculation concerning the economic impact of a possible further process step on KEZO, several factors have to be incorporated:

- Investment for the process: amortization of the capital
- Additional use of space
- Additional labour costs for maintenance and operation
- Operational costs as electricity and working material

On the other side are the earnings from the sold metals. These depend on the melting plants and their transparency. Several separate melting plants have been asked for their conditions and prices. Unfortunately, only two melting plants have answered. To protect their privacy, their names shall not be mentioned. Furthermore, their conditions are so similar that the calculation are now only based on plant A's conditions. For the calculation only three metals are significant: Gold, Silver and Copper. For that reason, only their returns are shown, all other materials are disregarded. The next chapters will only contain the results and the discussion. The tables can be found in the appendix. The calculations are made so that in the end, the total return of both new fractions can be compared to the total return of the initial fraction. This way, it is possible to show if the additional step before the melting plant is economical useful or not. If the return for the two new fractions is high enough, the earned money will cover the costs of the installation and running the MDS/DST in a reasonable period of time. If that return is not high enough or even smaller than the return of the initial fraction, an investment would be inconsiderate as long as the ecological benefit is not immense. Generally, there are only a few figures needed for the calculation. The concentration of gold, aluminium, and copper in mg/kg or g/t, the price of gold, aluminium, copper in CHF/kg and the conditions set by the melting plant. The prices were looked up on January 5th, 2013 on following websites: www.goldprice.com, www.silverprice.com and www.lme.com (for copper). Bachema's test results were used for the concentrations. The melting plant's conditions are the following:

- Gold: Either a reduction of the measured gold content by 4% or a deduction of 8g/t, whichever is higher, will be applied
- Silver: Either a reduction of the measured silver content by 5% or a deduction of 125g/t. Whichever is higher, will be applied
- Copper: The final copper content, less 2.5% for every dry ton shall be paid for the fixing quotations for copper of the day of the fixing (5.1.2013)
- Processing costs are at 440CHF/t
- Sampling costs a set amount: 1'600.00CHF
- Transporting cost are at 110.00CHF/t
- Refining cost are at 360.00CHF/kg gold, 18.00CHF/kg silver, and 395.00CHF/t copper

The decisive factors will be the gold content, once 4% is more than 8g (gold concentration more than 200g/t); the melting plant improves its earnings on the cost of the seller.
The calculations for MDS and DST are based on one ton NF precious heavy 3-5mm. Since the MDS separated in a ratio 1:4.81, the theoretical, initial MDS fraction weighs 5.81t. Accordingly, the DST separated in a ratio 1:2.24; the theoretical initial DST fraction weighs 3.24t. This seems complicated but this way the total return can be easily calculated. Besides, in the end the weight only has an influence on the actual amount of the return but not how much gold, silver and copper the melting company can retain.

7.1 Economic Results MDS Liquisort

NF precious MDS initial		
Total return per t	13'214.09	CHF
NF precious MDS light		
Total return per 4.81t	30'576.59	CHF
NF precious MDS heavy		
Total return per 1t	43'337.09	CHF
Total return light + heavy per 5.81t	73'913.67	CHF
Total mass	5.81	t
Total return per ton light + heavy	12'721.80	CHF
Difference with MDS/ton	**-492.29**	**CHF**

Table 10 Economic Results MDS Liquisort

7.2 Economic Results DST KEZO

NF precious DST initial		
Total return per ton	10'057.36	CHF
NF precious DST light		
Total return for 2.24t	10'596.24	CHF
NF precious DST heavy		
Total return for 1t	20'139.44	CHF
Total return light + heavy per 3.24t	30'735.68	CHF
Total mass	3.24	t
Total return per ton light + heavy	9'486.32	CHF
Difference with DST/ton	**-571.04**	**CHF**

Table 11 Economic Results DST KEZO

7.3 Discussion

As the numbers show, for both processes the earning for the processed materials are smaller the earning selling the initial product to the melting plant. Sending two fractions to the melting plant instead of one would create a loss of 492.29 respectively 571.04 CHF per ton for KEZO. Therefore, the costs for an additional process step, MDS or DST, are not justified and no further economic calculations are necessary. It was possible to foresee that MDS would create the smaller loss because of the really high gold content. Even though the melting plant would take 4%, 813g/t of gold can still be sold. However, the best results would occur if the gold content is about 200g/t (4% equals 8g/t!). Otherwise, too much material and money is lost to the melting plant. Therefore, I would even recommend KEZO for the future, if there are any fractions with a gold content higher than 200g/t to lower the content of gold little below 200g/t by adding e.g. copper.

Conclusion: For KEZO, there is no economic benefit by adding an additional process step such as MDS or DST to their already existing bottom ash treatment process. It would even create a loss of money for the same amount of material. According to that hypothesis 3 is refuted.

This result is rather unexpected. A few years ago, when KEZO added the DST to their existing process to be able to separate the NF metal fraction in a NF precious and aluminium fraction, it was a huge economic benefit. Then, they did not have to send the entire NF metal fraction to the precious metals melting plant anymore but were able to send the aluminium fraction to an aluminium conditioning plant. It was beneficial for KEZO as well for the melting/conditioning plants. Now, after testing the possible steps MDS and a second row DST, there is no additional use for any parties. Sending two fractions instead of one to the melting plant even creates a loss for them.

8. Ecological Benefit of Recovered Metals

Since there is no economic benefit by adding one of the tested process steps to the existing treatment process at KEZO, it can be assumed that there would be no ecological benefit either. The new received metal fractions (light and heavy) generate no additional value for the metal melting plants. Both fractions have to be processed the same way at the metal melting plant and therefore no savings of energy or process work can be realised.

Thus, hypothesis 4, adding one of these process steps to the existing treatment process at KEZO creates an ecological benefit, must be refuted. Actually, the additional treatment process would consume more energy and the amount of energy needed for the melting process for the wet MDS fraction will be even higher. However, the existing process is already an incredible ecological benefit itself so it is worth to have a look at it.

Since the bottom ash smaller than 5 mm is no longer only sent to the landfill but treated beforehand, metals and not only iron can finally be recovered. Thus, the recovery became a thermic recycling process. Unfortunately up to today, KEZO is the only incineration plant which has installed the complete process. It is still a fairly new process for the industry which should be at its maximal performance before installing at other plants. KEZO produces a yearly amount of about 40'000t bottom ash which is 23% of their initial input. Great potential is still hidden since at the moment only the fine and the micro bottom ash receives further treatment. Once all metal fractions can be recovered, a great amount of resources, energy and CO_2 can be saved. Thanks to the recovery, less metal would need to be extracted from mines. Less mining would not only have a great impact on the mine's environment but also on the world.

Often the benefit of recovering metals is expressed in CO_2 savings or UBP ("Umweltbelastungspunkte) compared with the primary production of the metals. The UBP is a factor used in Switzerland to scale the impact on environment. The more points the worse is the impact. (For its exact calculation please visit www.bafu.admin.ch).

Jürg Liechti, Neosys AG published in 2007 a study with numbers for the CO_2 and UBP savings when metals from bottom ash are recovered instead of a primary production:

- Recovering one kg of aluminium saves 12.1kg CO_2 and 7'753 UBP
- Recovering one kg of copper saves 4.1kg CO_2 and 221'514 UBP
- Recovering one kg of gold saves 17'857kg CO_2 and 7'753'000'000 UBP

The numbers above show the great impact of the metal recovering. The high CO_2 savings for aluminium and gold can be explained because of its very energy consuming primary production. The extreme high UBP saving of copper and gold are caused by the extremely high ecological impact of the primary production of these two metals. In Fig. 33 CO_2 and UBP savings of different metals recycled with standard processes are displayed. The orange bars indicate the UBP saving per kg recycled metal, where the green dots indicate CO2 savings per kg recycled metal.

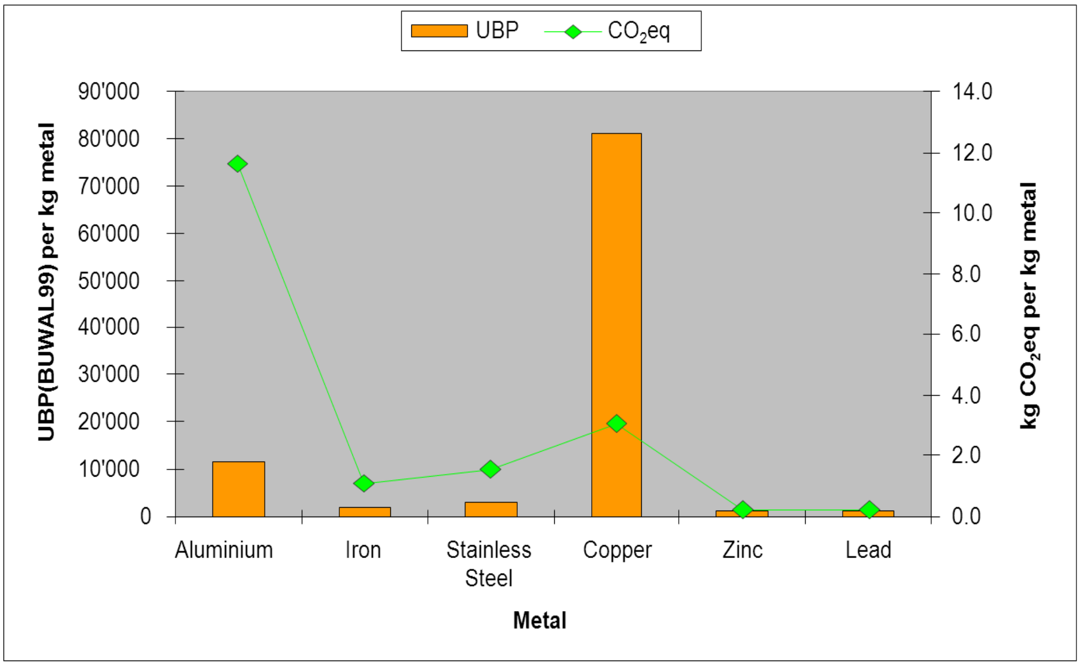


Fig. 33 CO_2 and UBP savings of different metals recycled with standard processes

Generally it can be said that recycled as well as recovered metals have a much better ecological balance than metals from primary productions. However, recycling cannot cover the world's demand on metals. E.g. recycled gold can only cover about 30% of the demand. (www.fairgold.org, 4.1.2013) The rest still has to be mined. Since the demand for gold is increasing because of its use e.g. in electronics, it is important to make sure the direct environment of a mine does not suffer too much because of the demands of societies living far away from the mines.

Liechti (2007) estimates the potential of additional metal recovering out of the bottom ash in Switzerland as shown in Table 12 CO_2 Reduction by J. Liechti, Neosys, 2007Table 12. He didn't consider the very small particles as well as the precious metals like gold which will have another significant impact on CO_2 and UBP savings.

	Al	Fe	Stainless steel	Cu
Potential Recovering [t]	18'000	22'200	4'750	3'000
UBP-Savings [Mio UBP]	210'000	40'000	15'000	245'000
CO_2 **Reduction [t]**	21'000	25'000	7'500	9'000

Table 12 CO_2 Reduction by J. Liechti, Neosys, 2007

Only the saving of CO_2 according the numbers above is equivalent to the use of 81'000 t of diesel fuel. Considering the huge CO_2 und UBP potential for Switzerland with a population of only 7.9 million citizens (2010), the potential for the world using this technology would be enormous.

9. Gold as a Resource

9.1 Geology, Source and Production

*"Gold originates at considerable depth and is carried upward by hot fluid and magma that force their way into rock fractures. Crystallization, most often in quartz veins, occurs as the fluids cool down and pressures diminish. […](Therefore) gold is widespread in the environment. It occurs in minute quantities in almost all rocks, especially igneous and metamorphic rocks. Gold is usually obtained from quartz lodes or veins, or from deposits derived from them by denudation into river gravel. […] Geological characteristics of commercial gold-bearings strata are related, in part, to proximity to volcanic settings, mobilization and transport rates of granitic magmas and fluid, pyrites of iron and other metals, and igneous rocks containing potassium. […] Gold occurs in about 40minerals, but only native gold (Au) and electrum (Au-Ag) are common. It generally occurs in native form, and also in combination with tellurium as the ore sylvanite [(Au,Ag)Te_2]. The mineral most commonly found with gold in lodes is iron pyrites, and other metal sulphides. […]Gold can be profitably extracted from ores containing 3.8 to 6.3g/t.[*This depends extremely on the used mining process and the gold prize*] […]*
Gold was recovered from the rocky desert of Egypt between the Nile and the Red Sea, according to the first known mining map dated 1100BCE . Hardrock gold mining on a large scale with thousands of workers was exercised here for the first time, with production estimated as high as 10 tons annually […] (Today the) Total world production of gold is estimated at 3.4 billion troy ounces (10'575'000 t) of which more than 67% was mined in the past 50 years and with 45% of the total world production coming from the Witwatersrand district of South Africa. […]
Accurate production figures for new gold are difficult to obtain, but probably exceed 39 million troy ounces annually (1209 metric tons). The major commercial producer for gold is the Republic of South Africa; others include the former Soviet Union, the United States, Canada, Australia, China, and Brazil." (Eisler, 2004)

9.2 Conventional Gold mining

Placer mining can be subdivided in panning, sluicing, dreading and rocker box. Panning gold is the easiest form of gold mining. With a flat pan, rocks and gravel which may contain gold are lifted out of the river bed. By moving the pan in the water, the lighter gravel and rocks fall off, while the denser gold stays on the bottom of the pan. This method cannot be used for large-scale mining because labour cost can hardly be covered since the gold content mostly is very low. Sluicing is mostly used by small scale miners. The mined material is placed on top of the sluicing box. The sluicing box is a man-made channel with riffles on the bottom. When the material and water run down the channel, gold and other dense material settle by these riffles while the gravel and water flow out at the end of the channel. This method is also not commonly used for large-scale mining. Dreading is a low-cost type of gold mining and also has a low impact on the environment. However, it has been replaced by more modern mining methods and is nowadays only used by some small scale farmers in New Zealand and Canada. Small scale dreading is done with a machine called suction dredge which floats on the water and comprise a sluicing box on one side and a suction hose which sucks gravel out of the river bed. The rocker box works like a sluicing box except that is a real box and not a channel. Rocker box have riffles on every side and the rocking motion makes sure the gold separates from less dens material. Rocker boxes need less water and therefore are more suitable in drier areas than sluicing boxes. Mercury is often used with rocker or sluicing boxes to enhance recovery even though mercury and especially its gases are highly toxic.

Aside placer mining there is another type of mining called hard rock mining with which most of the world's gold is produced. Hardrock mining can be subdivided in open pit mining and underground mining. Both are based on the same principal: gold is extracted as small particles from large amount of rocks. In open pit mines, the material used is over ground and as more and more rocks are taken, the whole gets bigger and bigger. Underground mining on the other hand follows an ore underground and extracts the material through shafts and tunnels. (Wikipedia, 23.12.2012) "No-Dirty-Gold" is a campaign by the non-profit organization "Earthworks" which is dedicated to the protection of the people and the environment from the impact of irresponsible handling with minerals. They claim *"Two-thirds of all gold in use is newly mined. Of this gold, two-thirds is from open-pit mines, several of which are big enough to be seen from outer space."* (www.nodirtygold.org, 3.1.2013)

Mine	Land	Average gold concentration	Type	Production costs	Production costs
		[g/t]		[$/ounce]	[CHF/kg]
Super-Pit-Goldmine	Australia	1.6	open pit	609	19164
Cowal Gold Mine	Australia	1.2	open pit	-	-
Yanacocha-Goldmine	Peru	-	open pit	-	-
TauTona Mine	South Africa	7.3	4000m underground	560	17622

Table 13 Large mines, their average gold concentrations and production costs, www.wikipedia.org, arranged by Laura Böni)

By mining gold, it is only rare to find "pure" nuggets. With large scale mines tons of raw materials incur. It is estimated that in one ton raw material there is currently 0.5 to 2g of gold on average. This means that for a gold ring, 25 tons of rocks have to be excavated. (Valda, TA 29.12.2012) Fig. 34 shows the ratio between rocks and ore of several metals in comparison. Therefore, gold extraction cannot be forgotten when looking at gold mining process. The most commonly used extraction process in large scale mines is the cyanide extraction. *"Cyanide extraction of gold may be used in areas where fine gold-bearing rocks are found. Sodium cyanide solution is mixed with finely ground rock that is proven to contain gold [...], and is then separated from the ground rock as gold cy-*

anide […] solution. Zinc is added to precipitate out residual zinc as well as the silver and gold metals. The zinc is removed with sulfuric acid, leaving […] a gold sludge that is generally smelted into an ingot then shipped to a metals refinery for final processing into 99.9999% pure metals." (Wikipedia.org, 23.12.2012)

The refineries are mostly smelters which remove the remaining impurities under intense heat. Toxic air pollutant gases are emitted by this process. Nodirtygold.com states: *"Worldwide, all metal smelting adds about 142 million tons of sulfur dioxide to the atmosphere every year -- 13 percent of total global emissions."* (www.nodirtygold.com)

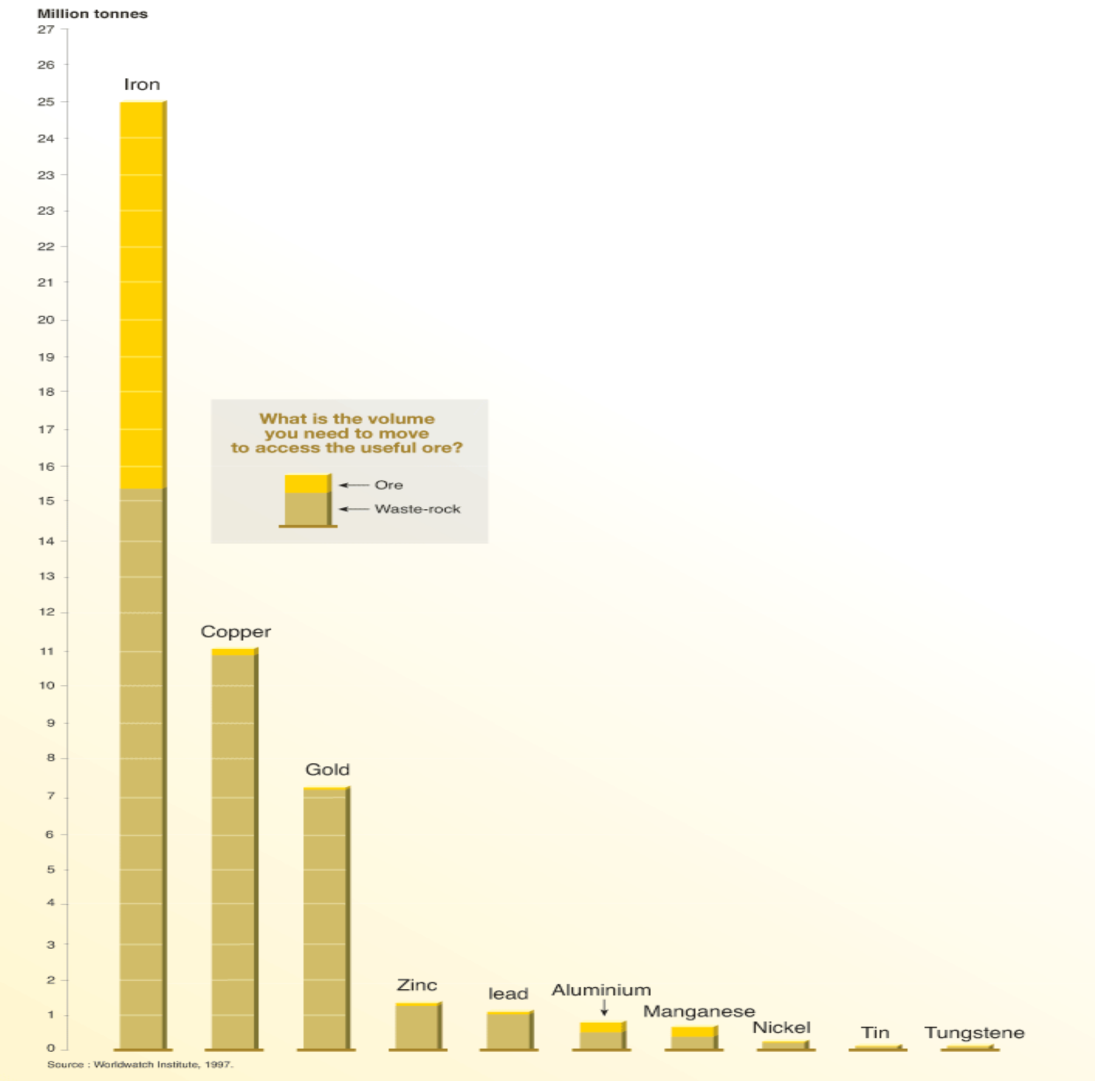


Fig. 34 Ratio between waste rocks and ore, UNFP

9.3 The Effect of Conventional Gold Mining on the Environment

Firstly, gold not only affects human beings, but also animals and plants. A high concentration of Au^{3+} ions though, can harm e.g. aquatic organism, marine teleosts (type of fish) are killed at less than 800µg Au^{3+}/L. For certain mice, a high gold concentration in their blood destroys the appetite centre in the hypothalamus and they become obese, or they die.

"Globally, over 100 million people depend on Artisanal and Small-scale Mining (ASM) for

survival. The 15 million ASM miners work in harsh and dangerous conditions to produce just 10-15 % of global gold supplies, but they make up 90 % of the global work force in gold extraction. These miners and their families are caught in a vicious circle of exploitation, illegality, and many lack the skills and resources to move forward." (www.fairmined.org, 3.1.2013) And this vicious circle destroys not only their lives but also the environment. The environmental impacts of ASM depend on where it occurs, but can include deforestation, land degradation through air, water and soil pollution from dust, mud or toxic substances, as well as impact on local wildlife. (fairmined.org) For all organism especially the mercury which is used to extracted gold is very dangerous. Eisler writes in his book: *"Health problem of gold miner who worked underground include decreased life expectancy; increased frequency of cancer of the trachea, bronchus, lung, stomach, and liver; increased frequency of pulmonary tuberculosis, silicosis, and pleural diseases; increased frequency of insect-borne diseases, such as malaria and dengue fever; noise-induced hearing loss; increased prevalence of certain bacterial and viral diseases; and diseases of the blood, skin and musculoskeletal system. The problems are documented for [miner all around the world] […]. In general, HIV infection or excessive alcohol and tobacco consumption tended to exacerbate existing health problems. Miners who used elementary mercury to amalgamate and extract gold were heavily contaminated with mercury. Among individuals exposed occupationally, concentrations of mercury in their air, fish diet, hair, urine, blood, and other tissues significantly exceeded all criteria proposed by various national and international regulatory agencies for protection of human health. However, large scale epidemiological evidence of severe mercury-associated health problems in this cohort was not demonstrable. To protect the health of underground workers, authorities recommend continued intensive monitoring of atmospheric dust levels in order to conform to recognized safe occupational levels, implementation of more frequent medical examination with emphasis on early detection and treatment of diseases states, and continuation of educational programs on hazards of risky behaviours outside of the mine environment […]."* (Eisler, 2004) As seen in this quote and also in Fig. 35, miners' lives are especially in danger because of the mercury which is used to extract the gold. Eisler estimates the total number of miners who work with mercury amalgamation ranges from 3 to 5 million. Furthermore, one should not forget that these miners not only poisoned themselves but the entire environment around them with mercury. People living in areas near gold mining activities also live at a high health risk, and soil and water become contaminated, which takes away everybody's livelihood. Children with high mercury content in their tissues become inattentive and have movement disorders. Agriculture slowly decreases because there is less and less clean land. The former farmers become miners. Sometimes they look for gold by themselves which is called small-scale farming, and use mercury uncontrolled of the consequences but only about their survival. *"Throughout the Brazilian Amazon, about 650'00 small-scale miner are responsible for about 90% of Brazil's gold production and for the discharge of 90 to 120 tons of mercury to the environment every year. "*(Eisler, 2004) It is a vicious circle.

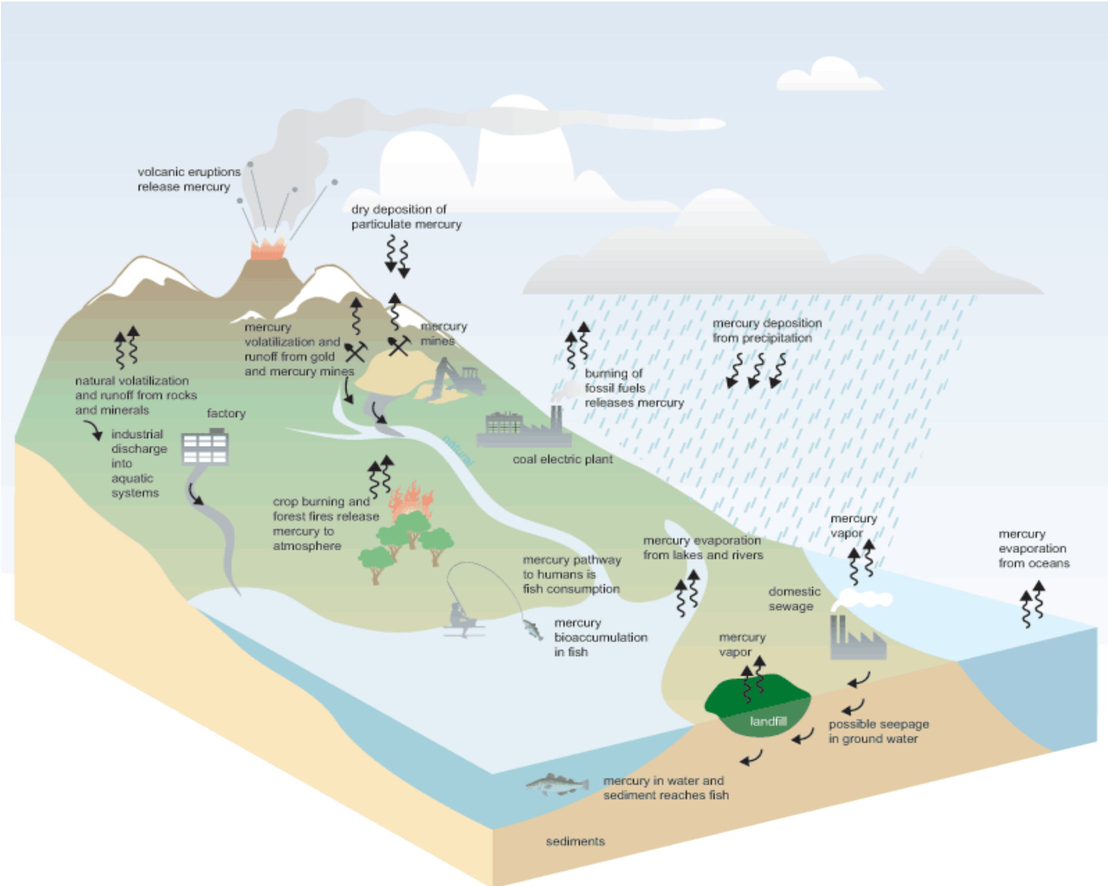


Fig. 35 Mercury in the environment of a mine, UNFP

9.4 GOLD'S PHYSICAL QUALITIES

Gold ranks fiftieth in abundance in earth's crust which makes it a rather rare native metallic element. It is exceptionally stable, however in nature it is rarely found in its pure form but mixed with other metals such as silver, tellurium, copper, nickel, iron, mercury, bismuth and more. When gold is broken down to little particles, the powder is black, like it is with most other metals. Interestingly, if gold is colloidally suspended its colour varies from ruby red to purple. In its pure, massive form gold is a soft yellow metal. Is a single troy ounce (=31.1g) spun in a wire, it can be 66km long without breaking, is it beaten to a film, it can cover approximately 100m^2. This facts show gold's great malleability and ductility, however traces of other metals can affect these qualities negatively. On the other hand, it is possible to create new, usable metal alloys when gold is mixed with e.g. silver, or copper. These alloys are especially used for jewellery. Gold mixed with copper is called red gold; however it is only red gold if it contains 95.41% gold and 4.59% copper. In any other concentration, the colour is not right and especially the brittleness makes the alloy useless. The most important alloys are yellow gold (80% Au and 20% Ag) and white gold (50% Au and 50%Ag). Gold as a precious metal is chemically inert and does not corrode nor tarnish nor rust. In its purest form (100% Au) equivalents to 24 carats. Gold is usually measured and also is dealt in the stock market in troy ounce wherein 1 troy ounce equals 31.1g.

Specific numbers:

Atomic weight	196.967
Atomic Number	79
Melting point	1063° Celsius
Density	19.32 g/cm³

Table 14 Several of gold's properties

Its high density can be shown with the following examples: A gold cube with 30cm sides weighs about 521kg. A milk bottle containing 1l of milk weighs one kilogram, whereas the same bottle filled with gold weighs 19.3kg.

9.5 GOLD AND ITS USE

The most common use of gold is in jewellery, coinage, electronics, radiogold, medicine, dentistry, delivery vehicle, and electron microscopy. Jewellery accounts for the largest use of gold nowadays and was already used by the ancient Egyptians to decorate tombs and statues and similar objects. The first metal used in currency was gold and this probably already since more than 5000 years. But not only gold coins were important in history; especially gold bars have become more and more significant. Today, a bar must be mark for the international market. The purity in four digits must be on it as well as the trademarked of the refinery and a serial number. Obviously, the usage of gold for electronics increased with the more common usage of electronic devices. According to Eisler gold is very suitable because it is the most corrosion resistant metal, has an excellent softness, ductility, as well as liability and most important it has a low resistivity. All these characteristics make gold a distinguishable substance for making thin wire and other connectors. As good example mobile phones shall be mentioned: Every mobile phone contains approximately 24mg gold. Thus 10g of gold could supply about 417 mobile phones. (Valda, TA, 29.12.12) *"Radiogold isotopes have been used to treat [tumours] […] of the mouth and […] of the prostate, to tag various species of wildlife […], to measure radiation exposures from nuclear accidents, as well as a chemical label for water-soluble gold-compound pharmaceuticals." (Eisler, 2004)* According to Eisler, the first nation which used gold as a medicinal agent in form of dust or flakes was probably the Chinese as early as 2500 BCE. Since then metallic gold, auric chloride and gold in all its other compounds have been tested as a cure for several diseases. The more and more successful tests have been made, the more the demand for gold and its prize increased. The same applies to the dentistry's use of gold. *"The biochemistry of gold has developed mainly in response to prolonged use of gold compounds in treating rheumatoid arthritis and in response to efforts to develop complexes with anti-tumour and anti-HIV activity." (p.47) […] Gold is not considered essential to life, although it distributes widely in the body and the number of possible reactions and reaction sites is large."* Merchant, the author of a study called *"Gold, the noble metal and the paradoxes of its toxicology"*, has measured and calculated a gold concentration of about 2.45mg in a healthy adult's whole body.

10. CONCLUSION AND OUTLOOK

The conclusion based on my work and the fact that the hypothesis 1 and 2 can be confirmed and hypothesis 3 and 4 have to be refuted is as followed:

1. To add a further accumulation process to the existing bottom ash treatment plant is neither economical nor ecological reasonable, even though both methods were able to split the NF precious metal fraction in a low and a high density fraction and to accumulate gold in the heavy fraction.
2. Based on the calculation for the specific melting plant, I would recommend KEZO to sell their NF precious metal fraction to the melting plant with a gold concentration very close to 200g/t. Therefore if there are NF precious metal fractions with a gold content of over 200g/t, they should dilute this fraction with copper till the target gold content is reached. On the other hand if the gold content is below 200g/t a mixing with a NF precious metal fraction with higher gold content would generate more income for the KEZO.
3. With this work I learned that it is always important to look at the whole process chain and how much influence the process boundaries have on results of such a study. If I had only decided after answering hypothesis 1 and 2, the conclusion would have been wrong. It was important to consider also the next process step, the melting plant.
4. Based on my work, I was surprised how much potential is hidden in our waste. Thermo recycling seems to me as a very good approach to recover this huge potential. Furthermore, I am concerned about the impact the conventional gold mining has on our world. From now on, I will always think twice before buying golden jewellery and unnecessary electronics.

11. LIST OF FIGURES

(http://www.grida.no/graphic.aspx?f=series/vg-waste/08-09_big-graphic.gif)

http://www.grida.no/graphic.aspx?f=series/vg-waste/16-17_grandgraphic.gif

12. LIST OF TABLES

13. LIST OF REFERENCES

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14. GLOSSARY

English	Deutsch	kurze Erklärung
alloy	Legierung	Werkstoff, welcher aus zwei Metallsorten besteht und somit günstiger ist als der einzelne und verbesserte Eigenschaften aufweist
BAFU	BAFU	Schweizer Bundesamt für Umwelt
bottom ash	Schlacke	Rückstände des verbrannten Abfalls
bottom ash discharge	Schlackenaustrag	Prozessschritt: Austrag und anschliessende Kühlung der heissen Schlacke, wenn sie den Verbrennungsraum des Ofens verlässt.
densimetric separation table (DST)	Trenntisch	Ein Verfahren, dass mit Hilfe einer vibrierenden, mit kleinen Löchern bestückten Fläche, Metalle nach ihrer Dichte trennen kann. Leichte Metall werden von den Luftströmen, die durch die kleinen Löcher kommen, nach oben gedrückt. Sie bewegen sich in Richtung des tiefer gelegenen Ausgangs. Die schwereren Metalle werden durch die Vibration zum höheren Ende des Tisches bewegt.
eddy current separator	Wirbelstromabscheider	Die sich drehende Trommel erzeugt in jedem Nichteisen-Teilchen einen Wirbelstrom, der ein starkes Magnetfeld generiert. Das magnetisierte Teilchen wird dann von der ebenfalls magnetisierten Trommel abgestossen.
excavated material	Aushub	-
flue gas	Flugasche	Entsteht im Ofenraum und muss speziell aufgearbeitet werden.
hydrocarbons	Kohlenwasserstoff	-
incineration plant	Kehrichtverwertungsanlage	Der Ort, wo unser Abfall weiter verwertet wird.
inert material	Ballastmaterial	-
KEZO	Kehrichtverwertungsanlage Zürcher Oberland	-
landfill	Deponie	Alles Material, das nicht weiter aufbereitet werden kann, landet in der Schweiz auf der Deponie. In anderen Ländern, bringt man den Abfall ohne weitere Aufbereitung auf die Deponie. Ohne Vorsichtsmassnahmen kann dies extrem schädlich sein.
leaching rate	Sickerungsrate	Nassschlacke hat eine grössere Sickerungsrate auf der Deponie als Trockenschlacke.
leakage water	Sickerwasser	Eine Deponie muss alles Sickerwasser sammeln und es muss zuerst aufgearbeitet werden.
low temperature carbonization gas	Schwelgas/Pyrolysegas	Ein Gas, welches bei der Pyrolyse von Biomasse entsteht

magnetic density separator MDS	Magnetische Dichte Trennung	Ein Verfahren, dass mit Hilfe einer Ferrofluid und einem starken Magneten Metalle nach ihrer Dichte trennen kann, da die Metalle mit einer kleinen Dichte auf der Oberfläche schwimmen und die schweren Metalle sinken.
Methane	Methan	CH_4 , das einfachste Alkan, 21mal schädlicher als CO_2 für unsere Umwelt, Treibhausgas.
neodymium	Neodym	Chemisches Element (Nd), wird v.a. für starke Magnete verwendet.
non-ferrous metals (NF)	Nicht-Eisenmetalle NE	Metalle, die nach dem Magneten auch schon den Wirbelstromabscheider passiert haben.
non-ferrous precious metal fraction	Nicht-Eisen Edelmetall Fraktion	Fraktion, welche schon den Magneten, den Wirbelstromabscheider und den Trenntisch passiert hat.
precious metals	Edelmetalle	Korrosionsbeständige Metalle: Silber, Gold, etc.
repulsion	Abstossung	Der Wirbelstromabscheider macht sich die Abstossung zwischen den Metallen und seiner Trommel zu Nutze.
revolution	Drehzahl	Gibt die Häufigkeit der mechanischen Umdrehungen an.
sample splitter	Probenteiler	Garantiert optimale, repräsentative Proben, weil das Material immer wieder halbiert wird und dadurch gut durch mischt ist.
sewage sludge	Klärschlamm	Endprodukt der Kläranlage
Thermo recycling	Thermorecycling	Name des gesamten Kehrichtverwertungsprozesses mit Trockenschlackenaustrag und Schlackenaufbereitung.
volatile waste	flüchtiger (chem.) Abfall	V.a. Gase, die bei Erhitzung des Abfalls entstehen.
ZAR	ZAR	Stiftung Zentrum für nachhaltige Abfall- und Ressourcennutzung

15. APPENDIX

Accounting MDS NF precious initial 3-5mm		Density [g/cm3]	MDS Liquisort NF precious 3-5mm light	MDS Liguisort NF precious 3-5mm heavy	DST KEZO NF precious 3-5mm light	DST KEZO NF precious 3-5mm heavy		Initial fraction NF precious MDS 3-5mm in 1t		Initial fraction NF precious DST 3-5mm in 1t
Gold	mg/kg TS Au	19.3	21.00	847.00	35.18	318.92		163.16		122.65
Silver	mg/kg TS Ag	10.5	2'610.00	2'490.00	1'262.72	3'336.25		2'589.35		1'901.98
Copper	mg/kg TS Cu	9	649'000.00	553'000.00	542'551.05	669'821.82		632'477.74		581'788.12
	05.01.2013									
Gold $	1'655.97	$/OZ	www.goldprice.com			daily changing factors				
Silver $	30.15	$/OZ	www.silverprice.com							
Copper $	8'140.00	$/t	www.lme.com							
Factor OZ/kg	32.25806452									
			US$/CHF	0.9200						
Metal Price										
Gold	49'144.92	CHF								
Silver	894.77	CHF								
Copper	7'488.80	CHF								
Test Results initial	Gold	163.2	g/t	Quantity	5.81	t		Heavy [t]	1.00	
	Silver	2'589.3	g/t					Light [t]	4.81	
	Copper	63.2	%					total [t]	5.81	
Reimbursement	Gold	0.96	0.04	6.53	g/t			0.0379	kg	
	Deduction	8	g/t	**155.16**	g/t			**0.9015**	kg	
	Silver	0.95	0.05	129.47	g/t	2459.879822	g/t	0.7522	kg	
	Deduction	125	g/t	**2464.35**	g/t			**14.3179**	kg	
	Copper	2.50	% deduction of the test results	**60.75**	%			**3.5294**	t	
Processing costs		440.00	CHF/t			2'556.40	CHF			
Sampling						1'600.00	CHF			
Transport		110.00	CHF/t			639.10	CHF			
Refining costs	Gold	360.00	CHF/kg			324.53	CHF			
	Silver	18.00	CHF/kg			257.72	CHF			
	Copper	395.00	CHF/t			1'394.13	CHF			
Total costs						6'771.88	CHF			
Revenue		USD/CHF								
	Gold	49'144.92	CHF			44'303.21	CHF			
	Silver	894.77	CHF			12'811.25	CHF			
	Copper	7'488.80	CHF			26'431.28	CHF			
Total Revenue						83'545.74	CHF			
minus costs						6'771.88	CHF			
Total Return						76'773.85	CHF			
Total Return per t						13'214.09	CHF			

Accounting MDS NF precious light 3-5mm		Density [g/cm3]	MDS Liquisort NF precious 3-5mm light	MDS Liguisort NF precious 3-5mm heavy	DST KEZO NF precious 3-5mm light	DST KEZO NF precious 3-5mm heavy		Initial fraction NF precious 3-5mm in 1t		Initial fraction NF precious DST 3-5mm in 1t
Gold	mg/kg TS Au	19.3	21.0	847.0	35.18	318.92		163.1602374		122.65
Silver	mg/kg TS Ag	10.5	2'610.0	2'490.0	1'262.72	3'336.25		2589.347181		1'901.98
Copper	mg/kg TS Cu	9	649'000.0	553'000.0	542'551.05	669'821.82		632477.7		581'788.12
	05.01.2013									
Gold $	1'655.97	$/OZ	www.goldprice.com			daily changing factors				
Silver $	30.15	$/OZ	www.silverprice.com							
Copper $	8'140.00	$/t	www.lme.com							
Factor OZ/kg	32.25806452									
			US$/CHF	0.9200						
Metal Price										
Gold	49'144.92	CHF								
Silver	894.77	CHF								
Copper	7'488.80	CHF								
Test Results light	Gold	21.0	g/t	Quantity	4.81	t		Heavy [t]	1.00	
	Silver	2'610.0	g/t					Light [t]	4.81	
	Copper	64.9	%					total [t]	5.81	
Reimbursement	Gold	0.96	0.04	0.84	g/t			0.0040404	kg	
	Deduction	8	g/t	**13**	g/t			**0.06253**	kg	
	Silver	0.95	0.05	130.5	g/t	2479.5	g/t	0.627705	kg	
	Deduction	125	g/t	**2'485.0**	g/t			**11.95285**	kg	
	Copper	2.50	% deduction of the test results	**62.40**	%			**3.00144**	t	
Processing costs		440.00	CHF/t			2'116.40	CHF			
Sampling						1'600.00	CHF			
Transport		110.00	CHF/t			529.10	CHF			
Refining costs	Gold	360.00	CHF/kg			22.51	CHF			
	Silver	18.00	CHF/kg			215.15	CHF			
	Copper	395.00	CHF/t			1'185.57	CHF			
Total costs						5'668.73	CHF			
Revenue		USD/CHF								
	Gold	49'144.92	CHF			3'073.03	CHF			
	Silver	894.77	CHF			10'695.10	CHF			
	Copper	7'488.80	CHF			22'477.18	CHF			
Total Revenue						36'245.32	CHF			
minus costs						5'668.73	CHF			
Total Return						30'576.59	CHF			
Total Return per t						6'356.88	CHF			

Accounting MDS NF precious heavy 3-5mm		Density [g/cm3]	MDS NF precious 3-5mm light	MDS NF precious 3-5mm heavy	DST NF precious 3-5mm light	DST NF precious 3-5mm heavy		Initial MDS fraction NF precious 3-5mm in 1t		Initial DST fraction NF precious 3-5mm in 1t
Gold	mg/kg TS Au	19.3	21.0	847.0	35.18	318.92		163.1602374		122.65
Silver	mg/kg TS Ag	10.5	2'610.0	2'490.0	1'262.72	3'336.25		2589.347181		1'901.98
Copper	mg/kg TS Cu	9	649'000.0	553'000.0	542'551.05	669'821.82		632477.7		581'788.12
	05.01.2013									
Gold $	1'655.97	$/OZ	www.goldprice.com			daily changing factors				
Silver $	30.15	$/OZ	www.silverprice.com							
Copper $	8'140.00	$/t	www.lme.com							
Factor OZ/kg	32.25806452									
Metal Price			US$/CHF	0.9200						
Gold	49'144.92	CHF								
Silver	894.77	CHF								
Copper	7'488.80	CHF								
Test Results heavy	Gold	847.0	g/t	Quantity	1	t		Heavy [t]	1.00	
	Silver	2'490.0	g/t					Light [t]	4.81	
	Copper	55.3	%					total [t]	5.81	
Reimbursement	Gold	96%	4%	**33.88**	g/t			**0.8131**	kg	
	Deduction	8	g/t	839	g/t			0.8390	kg	
	Silver	95%	5%	124.5	g/t	2365.5	g/t	0.1245	kg	
	Deduction	125	g/t	**2'365.0**	g/t			**2.3650**	kg	
	Copper	2.50	% deduction of the test results	**52.80**	%			**0.5280**	t	
Processing costs		440.00	CHF/t			440.00	CHF			
Sampling						1'600.00	CHF			
Transport		110.00	CHF/t			110.00	CHF			
Refining costs	Gold	360.00	CHF/kg			292.72	CHF			
	Silver	18.00	CHF/kg			42.57	CHF			
	Copper	395.00	CHF/t			208.56	CHF			
Total costs						2'693.85	CHF			
Revenue		USD/CHF								
	Gold	49'144.92	CHF			39'960.71	CHF			
	Silver	894.77	CHF			2'116.14	CHF			
	Copper	7'488.80	CHF			3'954.09	CHF			
Total Revenue						46'030.94	CHF			
minus costs						2'693.85	CHF			
Total Return						43'337.09	CHF			
Total Return per t						43'337.09	CHF			

Accounting DST NF precious initial 3-5mm		Density [g/cm3]	MDS Liquisort NF precious 3-5mm light	MDS Liguisort NF precious 3-5mm heavy	DST KEZO NF precious 3-5mm light	DST KEZO NF precious 3-5mm heavy		Initial fraction NF precious MDS 3-5mm in 1t		Initial fraction NF precious DST 3-5mm in 1t
Gold	mg/kg TS Au	19.3	21.00	847.00	35.18	318.92		163.16		122.65
Silver	mg/kg TS Ag	10.5	2'610.00	2'490.00	1'262.72	3'336.25		2'589.35		1901.98
Copper	mg/kg TS Cu	9	649'000.00	553'000.00	542'551.05	669'821.82		632'477.74		581788.12
	05.01.2013									
Gold $	1'655.97	$/OZ	www.goldprice.com							
Silver $	30.15	$/OZ	www.silverprice.com			daily changing factors				
Copper $	8'140.00	$/t	www.lme.com							
Factor OZ/kg	32.25806452									
			US$/CHF	0.9200						
Metal Price										
Gold	49'144.92	CHF								
Silver	894.77	CHF								
Copper	7'488.80	CHF								
Test Results initial	Gold	122.7	g/t	Quantity	3.24	t		Heavy [t]	1.00	
	Silver	1'902.0	g/t					Light [t]	2.24	
	Copper	58.2	%					total [t]	3.24	
Reimbursement	Gold	0.96	0.04	4.91	g/t			0.0159	kg	
	Deduction	8	g/t	**114.65**	g/t			**0.3715**	kg	
	Silver	0.95	0.05	95.10	g/t	1806.88083	g/t	0.3081	kg	
	Deduction	125	g/t	**1'777.0**	g/t			**5.7574**	kg	
	Copper	2.50	% deduction	**55.68**	%			**1.8040**	t	
Processing costs		440.00	CHF/t			1'425.60	CHF			
Sampling						1'600.00	CHF			
Transport		110.00	CHF/t			356.40	CHF			
Refining costs	Gold	360.00	CHF/kg			133.73	CHF			
	Silver	18.00	CHF/kg			103.63	CHF			
	Copper	395.00	CHF/t			712.58	CHF			
Total costs						4'331.94	CHF			
Revenue		USD/CHF								
	Gold	49'144.92	CHF			18'256.45	CHF			
	Silver	894.77	CHF			5'151.59	CHF			
	Copper	7'488.80	CHF			13'509.75	CHF			
Total Revenue						36'917.78	CHF			
minus costs						4'331.94	CHF			
Total Return						32'585.84	CHF			
Total Return per t						10'057.36	CHF			

Accounting DST NF precious light 3-5mm		Density [g/cm3]	MDS Liquisort NF precious 3-5mm light	MDS Liguisort NF precious 3-5mm heavy	DST KEZO NF precious 3-5mm light	DST KEZO NF precious 3-5mm heavy		Initial fraction NF precious 3-5mm in 1t		Initial fraction NF precious DST 3-5mm in 1t
Gold	mg/kg TS Au	19.3	21.0	847.0	35.18	318.92		163.16024		122.65
Silver	mg/kg TS Ag	10.5	2'610.0	2'490.0	1'262.72	3'336.25		2589.3472		1'901.98
Copper	mg/kg TS Cu	9	649'000.0	553'000.0	542'551.05	669'821.82		632477.7		581'788.12
	05.01.2013									
Gold $	1'655.97	$/OZ	www.goldprice.com							
Silver $	30.15	$/OZ	www.silverprice.com			daily changing factors				
Copper $	8'140.00	$/t	www.lme.com							
Factor OZ/kg	32.2580645									
			US$/CHF	0.9200						
Metal Price										
Gold	49'144.92	CHF								
Silver	894.77	CHF								
Copper	7'488.80	CHF								
Test Results light	Gold	35.2	g/t	Quantity	2.24	t		Heavy [t]	1.00	
	Silver	1'262.7	g/t					Light [t]	2.24	
	Copper	54.3	%					total [t]	3.24	
Reimbursement	Gold	0.96	0.04	1.4	g/t			0.0032	kg	
	Deduction	8	g/t	**27.2**	g/t			**0.0609**	kg	
	Silver	0.95	0.05	63.1	g/t	1199.580551	g/t	0.1414	kg	
	Deduction	125	g/t	**1'137.7**	g/t			**2.5485**	kg	
	Copper	2.50	% deduction	**51.76**	%			**1.1593144**	t	
Processing costs		440.00	CHF/t			985.60	CHF			
Sampling						1'600.00	CHF			
Transport		110.00	CHF/t			246.40	CHF			
Refining costs	Gold	360.00	CHF/kg			21.92	CHF			
	Silver	18.00	CHF/kg			45.87	CHF			
	Copper	395.00	CHF/t			457.93	CHF			
Total costs						3'357.72	CHF			
Revenue		USD/CHF								
	Gold	49'144.92	CHF			2'991.77	CHF			
	Silver	894.77	CHF			2'280.32	CHF			
	Copper	7'488.80	CHF			8'681.87	CHF			
Total Revenue						13'953.96	CHF			
minus costs						3'357.72	CHF			
Total Return						10'596.24	CHF			
Total Return per t						4'730.47	CHF			

Accounting DST NF precious heavy 3-5mm		Density [g/cm3]	MDS Liquisort NF precious 3-5mm light	MDS Liguisort NF precious 3-5mm heavy	DST KEZO NF precious 3-5mm light	DST KEZO NF precious 3-5mm heavy		Initial fraction NF precious 3-5mm in 1t		Initial fraction NF precious DST 3-5mm in 1t
Gold	mg/kg TS Au	19.3	21.0	847.0	35.18	318.9		163.160237		122.65
Silver	mg/kg TS Ag	10.5	2'610.0	2'490.0	1'262.72	3'336.3		2589.34718		1'901.98
Copper	mg/kg TS Cu	9	649'000.0	553'000.0	542'551.05	669'821.8		632477.7		581'788.12
	05.01.2013									
Gold $	1'655.97	$/OZ	www.goldprice.com			daily changing factors				
Silver $	30.15	$/OZ	www.silverprice.com							
Copper $	8'140.00	$/t	www.lme.com							
Factor OZ/kg	32.25806452									
			US$/CHF	0.9200						
Metal Price										
Gold	49'144.92	CHF								
Silver	894.77	CHF								
Copper	7'488.80	CHF								
Test Results heavy	Gold	318.9	g/t	Quantity	1	t		Heavy [t]	1	
	Silver	3'336.3	g/t					Light [t]	2.24	
	Copper	67.0	%					total [t]	3.24	
Reimbursement	Gold	96%	4%	**12.8**	g/t			**0.3062**	kg	
	Deduction	8	g/t	310.9	g/t			0.3109	kg	
	Silver	95%	5%	**166.8**	g/t	3169.441818	g/t	**3.1694**	kg	
	Deduction	125	g/t	3'211.3	g/t			3.2113	kg	
	Copper	2.50	% deduction	**64.48**	%			**0.6448**	t	
Processing costs		440.00	CHF/t			440.00	CHF			
Sampling						1'600.00	CHF			
Transport		110.00	CHF/t			110.00	CHF			
Refining costs	Gold	360.00	CHF/kg			110.22	CHF			
	Silver	18.00	CHF/kg			57.05	CHF			
	Copper	395.00	CHF/t			254.70	CHF			
Total costs						2'571.97	CHF			
Revenue		USD/CHF								
	Gold	49'144.92	CHF			15'046.54	CHF			
	Silver	894.77	CHF			2'835.93	CHF			
	Copper	7'488.80	CHF			4'828.94	CHF			
Total Revenue						22'711.41	CHF			
minus costs						2'571.97	CHF			
Total Return						20'139.44	CHF			
Total Return per t						20'139.44	CHF			