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Market analysis for the resource recovery of bottom ash in bed boilers

Master thesis

Production Science and Management

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In cooperation with:

ANDRITZ AG

STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

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date	(signature)

Kurzfassung

Die Firma ANDRITZ AG mit Hauptsitz in Graz will, sofern es sich kostentechnisch rentiert, seinen Kunden im Bereich der Müllverbrennung ein erweitertes Angebot anbieten und dabei eine Trennung der Stoffe, vor allem Metalle, nach der Verbrennung ermöglichen. Derzeit bietet die Power Plant Sparte der ANDRITZ AG Dampfkesselanlagen, Rauchgasreinigungsanlagen und verbundene Services an.

Nach einer Müll- oder Ersatzbrennstoffverbrennung ist es wichtig Fremdstoffe wie Metalle aus der Asche zu entfernen, um diese dann im Straßenbau, Deponiebau, Untertagebau oder auf anderen Verwertungswegen nutzen zu können. Diese Aufbereitung wird derzeit zumeist von externen Aufbereitungsfirmen durchgeführt. Externe Aufbereitung kostet den thermischen Reststoffverwertern jedes Jahr eine hohe Summe an Geld. Außerdem kann die aufbereitete Asche dann nicht verkauft werden und aus den separierten Metallen Erlöse erzielt werden.

Daher könnte es in Zukunft für die Müllverbrennungsanlagen attraktiv sein, in eine eigene Aufbereitung zu investieren und daraus Profit zu schlagen.

Aufgabe dieser Masterarbeit ist es herauszufinden, wie viel Eisen und Nichteisen- Metalle sich im Restmüll befinden, also vor der Verbrennung und wie viel Metalle nach der Verbrennung noch in der Asche vorhanden sind. Nächster Schritt war es mögliche Trennungsverfahren, die bereits am Markt etabliert sind, ausfindig zu machen und zu bewerten. Nachdem diese Daten eingeholt worden sind, wurde die Wirtschaftlichkeitsrechnung durchgeführt.

Die genannten Themen werden zuerst theoretisch abgehandelt und anschließend in einem Praxisteil durchgeführt. Somit kann ein fertiges Konzept erstellt werden, welches die Möglichkeiten der internen Aufbereitung widerspiegelt.

Die letzte Aufgabe war es, eine kalkulatorische Auswertung für die Rentabilität durchzuführen, die drei Szenarien beinhaltet. Ein Szenario beinhaltet die aktuell niedrigen Schrottpreise, das zweite weiter fallende Preise und das letzte Szenario beschreibt wieder steigende Metallpreise. Bei den aktuellen sowie bei leicht steigenden Schrottpreisen ist die interne Aufbereitung nicht zu empfehlen bezüglich Rentabilität, Kosten und Gewinnvergleich und Amortisation.

Abstract

The company ANDRITZ AG headquartered in Graz wants to offer their customers, if it is profitable, a broader basis of technology for power plants, including the separation of materials, especially metals, after the combustion process. At the moment the power plant division of ANDRITZ AG offers steam boiler plants and flue gas cleaning system as well as combined services.

After waste or refuse-derived fuel is incinerated, it is very important to separate foreign substances like metals out if the ash so that it can be used in road construction, landfill construction or rock filling. This separation is typically done by external companies, which costs a high sum of money. Another issue is that the incineration plant is therefore unable to sell either the ash or the separated metals, meaning the lose out in the possibility thereby to make profit.

Therefore in the future it would be lucrative to invest in an internal separation technology from which profits could be made.

One of the tasks of this thesis determine how much iron and non-ferrous metal the municipal waste consists of, and how much metal is left in the ash after the incineration process. The following step is to determine existing separation technologies evaluate them. After these data were collected, the economic calculation can be carried out.

The mentioned topics are discussed theoretically and then put into practice. From this a concept can be made which describes the possibilities of internal separation.

The last task is to carry out the economic analysis for the profitability by using three different scenarios. One scenario describes the actual low market prices for metals and the other two scenarios consist of a lower and a higher future scrap price for the metals. The current market prices lead to the result, that the internal separation is not recommendable concerning profitability, cost and profit calculation and payback period.

Acknowledgement

I would like to thank my supervisors for their help, support and guidance during the work on this thesis: DI Julia Soos from Graz University of Technology as well as DI Robert Schaumberger and Dr. Ulrich Hohenwarter from ANDRITZ AG.

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Table of contents

1 Introduction

Chapter one represents the definition of the task and the targets that should be investigated in this thesis as well as the planned output.

1.1 Initial situation

After an incineration of different materials the bottom ash of bed boilers consists also of diverse metals and precious metals which can be separated and recycled due to suitable methods. To do so additional processes have to be installed. These processes should be examined by a market analysis of existing separation methods in Europe. ANDRITZ AG actually develops and sells fluidized bed combustion plants and wants to offer separation techniques in the future as well.

1.2 Targets

1) Theoretical training and following research of market analysis for the ingredients of municipal waste before and after the incineration focusing on metals.
2) Analysis and evaluation of existing separation technologies for the resource recovery of stoker fired furnace and fluidized bed combustion.
3) Market analysis of potential customers who buy the ash, including the associated costs or profits of selling the bottom ash.
4) Basics of the static investment calculation and connected execution of a profitability analysis for the separation techniques considering the metal content and target separation efficiency.

1.3 Definition of task

For target 1: Evaluation of actual studies concerning ingredients of municipal waste which is used for incineration, targeting metal contents. The same should be done for metal contents in bottom ashes.

For target 2: Listing actual separation plants in Europe focusing on German talking countries with relevance statements of the market for ANDRITZ AG.

For target 3: Lining up potential customers of bottom ash for middle Europe and evaluating the common prices on this market.

For target 4: Determining possible profits by selling separated metals, to deduce a static cost calculation of the plants (static amortisation calculation).

1.4 Field of examination

This thesis focuses on collecting and evaluating data of existing markets of resource recovery as well as future markets (concentrating on Austria, Germany and Switzerland) plus the determining associated purity degree and effort leading to changes of the payback time of such plants.

The research area is not developing and constructing a resource recovery plant or at a later time market launches of these plants.

1.5 Company description

The company ANDRITZ was founded in 1852 by a Hungarian named Josef Körösi. He established an iron foundry in ANDRITZ which was a village next to Graz. In 1900 ANDRITZ became a stock corporation. 1999 brought another change to ANDRITZ when current CEO Wolfgang Leitner joined the company. For going public on the Vienna Stock Exchange they chose the year 2001.

Today ANDRITZ is globally leading company in its five branches. The branches are: Supplier of plants, equipment and services for hydropower stations as well as power plant services, the metalworking and steel industries, the pulp and paper industry, solid/liquid separation in the municipal and industrial sectors, feed and biofuel production of pellets. In the year 2016 ANDRITZ employed 25,000 people on 250 sites worldwide.

This Master thesis was written at the ANDRITZ power plant service department in Raaba-Grambach. The department focuses on steam generators and plants as well as air pollution control. Former times this department belonged to the Waagner Biro company till 1992. From 1992 till 2011 the department was owned by the AE&E Austria GmbH& Co KG. 2011 the company was took over from the ANDRITZ group and 2015 a merger between ANDRITZ Energy and Environment GmbH and ANDRITZ AG took place.

2 Process of incineration

Chapter two represents and describes the common garbage incineration strategies to get a feeling how such a system works and to understand what happens with the waste during the combustion process. ANDRITZ AG concentrates on fluidized bed combustion, but most of the installed garbage burning plants in Europe are stoker fired furnaces so this technology is also described. At the end the differences between the two technologies are highlighted and characterized for the input and output of the plants.

2.1 Fluidized bed combustion

There are two different fluidized bed combustion systems installed at power plants that are characterized in the next lines. These are the stationary and the circulating fluidized bed combustion.

2.1.1 Stationary fluidized bed combustion

Before burning the garbage at a fluidized bed combustion it has to be shredded and sorted out. The iron separation and shredding is normally done by the supplier but some plants also have a sorting station at their place. This prepared waste is then brought into a bunker discontinuously, while the feeding of the combustion chamber is done continuously. At a fluidized bed combustion the fuel inputs are municipal waste, sewage sludge, wood and many other types of fuels at plants. The bed material is usually sand which is cleaned and changed from time to time. A burner heats the primary air which is blown through nozzles to the combustion chamber. At the combustion chamber the hot sand is whirling and flying and ignites the shredded waste which is brought in at the side. Sand particles are flying with a speed of 1-2 m/s. (Strauß 2006)

The burning temperature is approximately 800°C whereas the temperature has to be a little bit more than 850°C for more than 2 seconds to eliminate unwanted gases, particles, smells and emissions. To fulfill this rule secondary air is needed arranged above the main combustion chamber. After the whole incineration process is completed, the flue gas is cleaned in several steps. Chapter 3.3.5 describes the two opportunities of discharging and the next step of sorting bottom ash. Figure 2.1 shows a simplified process. (Strauß 2006)

Separating the bottom ash is easier at the fluidized bed combustion compared to stoker fired furnaces and materials are tending to have a better purity. Also because of low burning temperatures, materials with low melting points are solid after the process. (Strauß 2006)

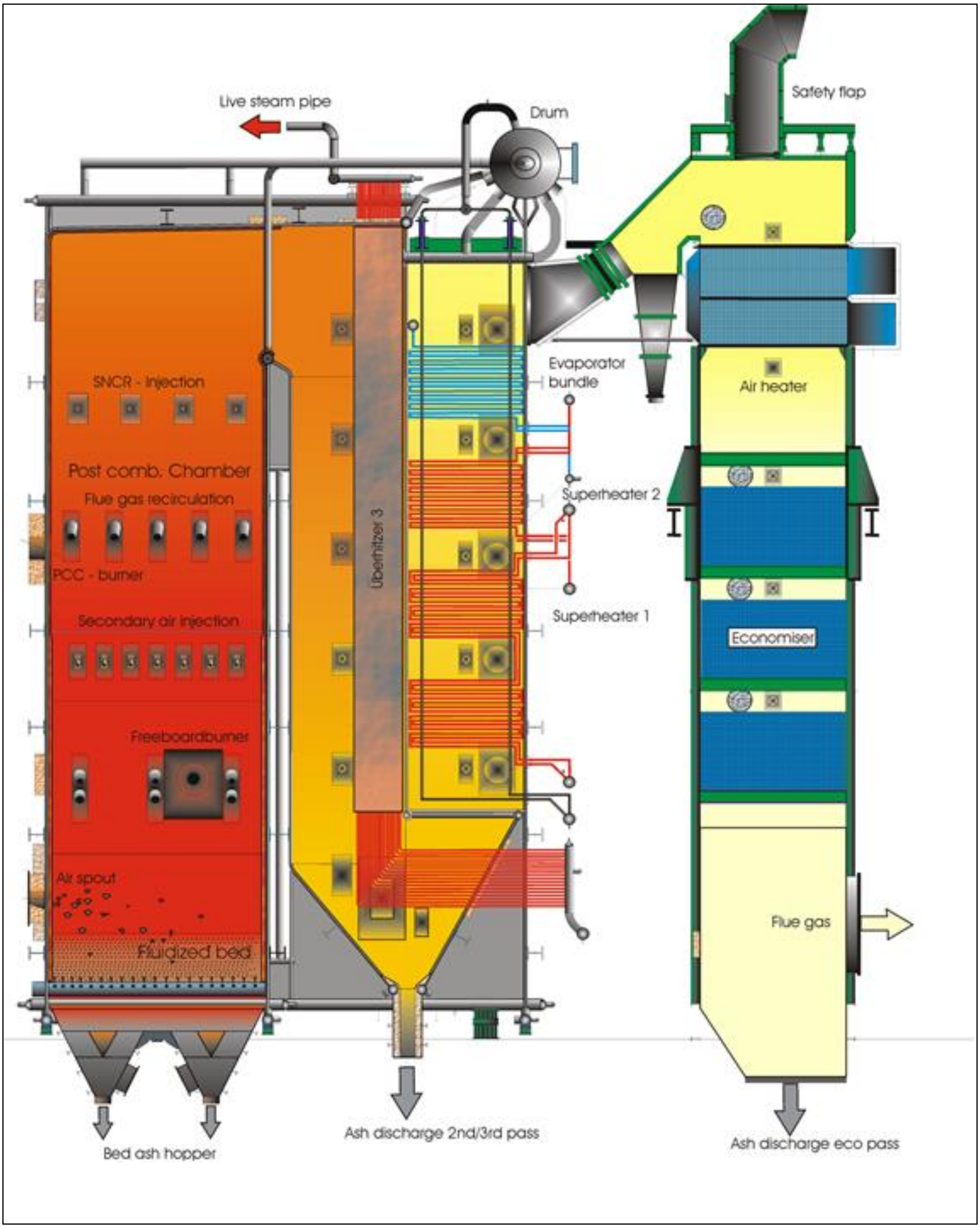


Figure 2.1: Stationary fluidized bed combustion process, source: ANDRITZ AG

2.1.2 Circulating fluidized bed combustion

At the circulating fluidized bed combustion process (figure 2.2) the gas velocity in the combustion chamber is 4-8 times higher than in the stationary fluidized bed combustion.

Here the mixing of the solid particles is much more intense. After the flue gas gets out of the chamber, a cyclone separates particles, whereby particle free flue gases stream out of the chamber and separated particles get back in the combustion chamber. Due to the better mixing and different burning conditions, materials like aluminium are more easily burnt and the separation after the incineration process is harder. (Strauß 2006)

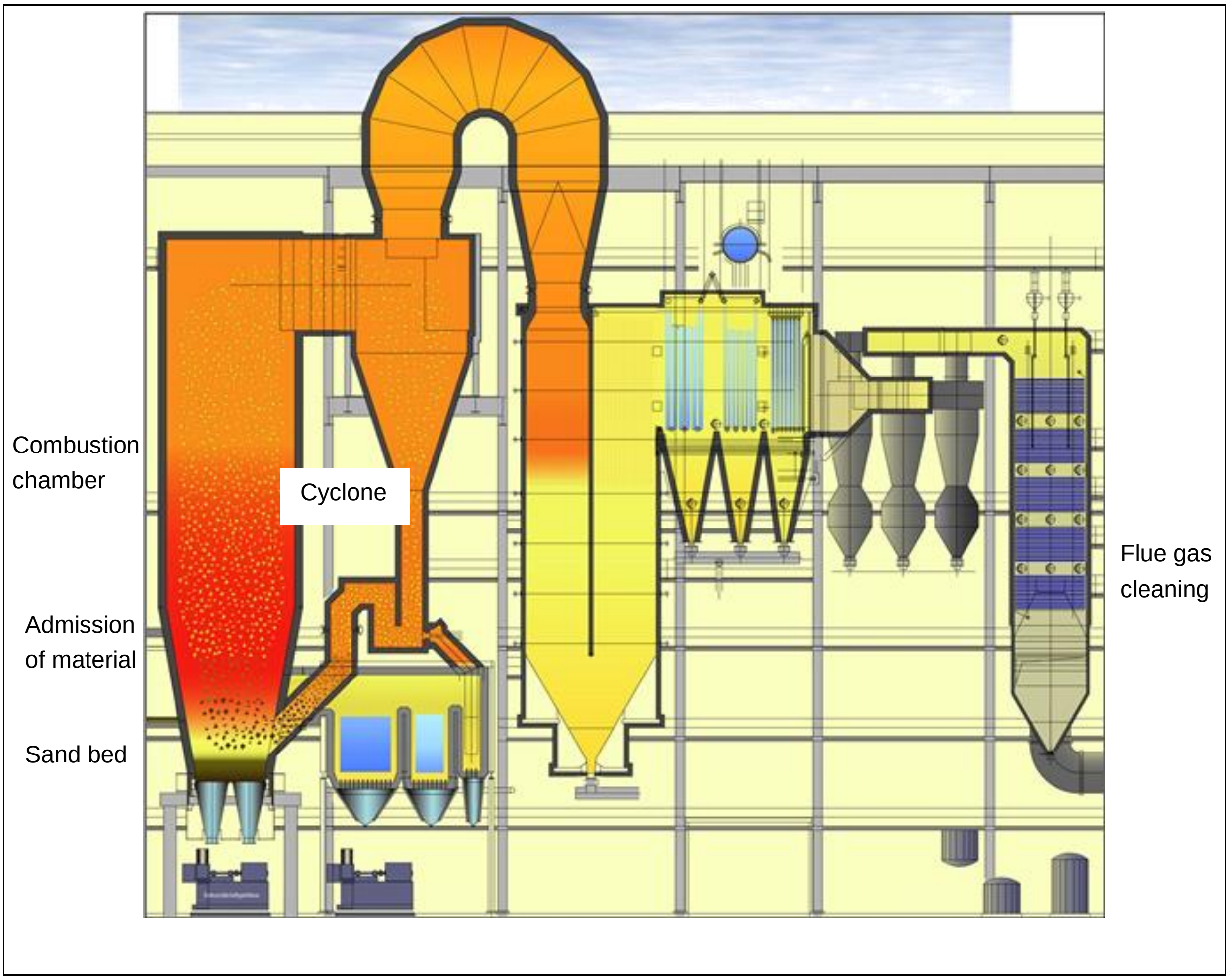


Figure 2.2: Circulated fluidized bed combustion, source: ANDRITZ AG

2.2 Stoker-fired furnace

The most common type for waste incineration is the moving infeed grate method where garbage is transported by constant velocity of 1,5–15m/h on a grate. To make sure the whole amount of waste is burnt, the grate bars have a relative motion. Due to this relative motion, the fuel is permanently circulated so that even unburnt parts from beneath get up and combusted. (Strauß 2006)

Also the length of the burnout path has to be long enough to ensure a complete incineration. Primary air is blown from underneath the grate and amounts 80-90% of the whole air supply. This air is also utilized as cooling air for the grate system and has a speed of 4-5m/s. The rest of the air is called secondary air and is blown further up the grate with a speed of 100m/s. In total the plant is operated by an excess air of 30-50%. (Strauß 2006)

Due to the missing starting fire, the fuel has to be ignited by radiant heat of hot bricks. Figure 2.3 shows a typical moving infeed grate. The unsorted garbage is put in the filling funnel where it falls down to the feeding grate. At the position of the feeding grate, the waste starts to dry. After this procedure the fuel drops down to the moving infeed grate where the degassing with following ignition takes place. (Strauß 2006)

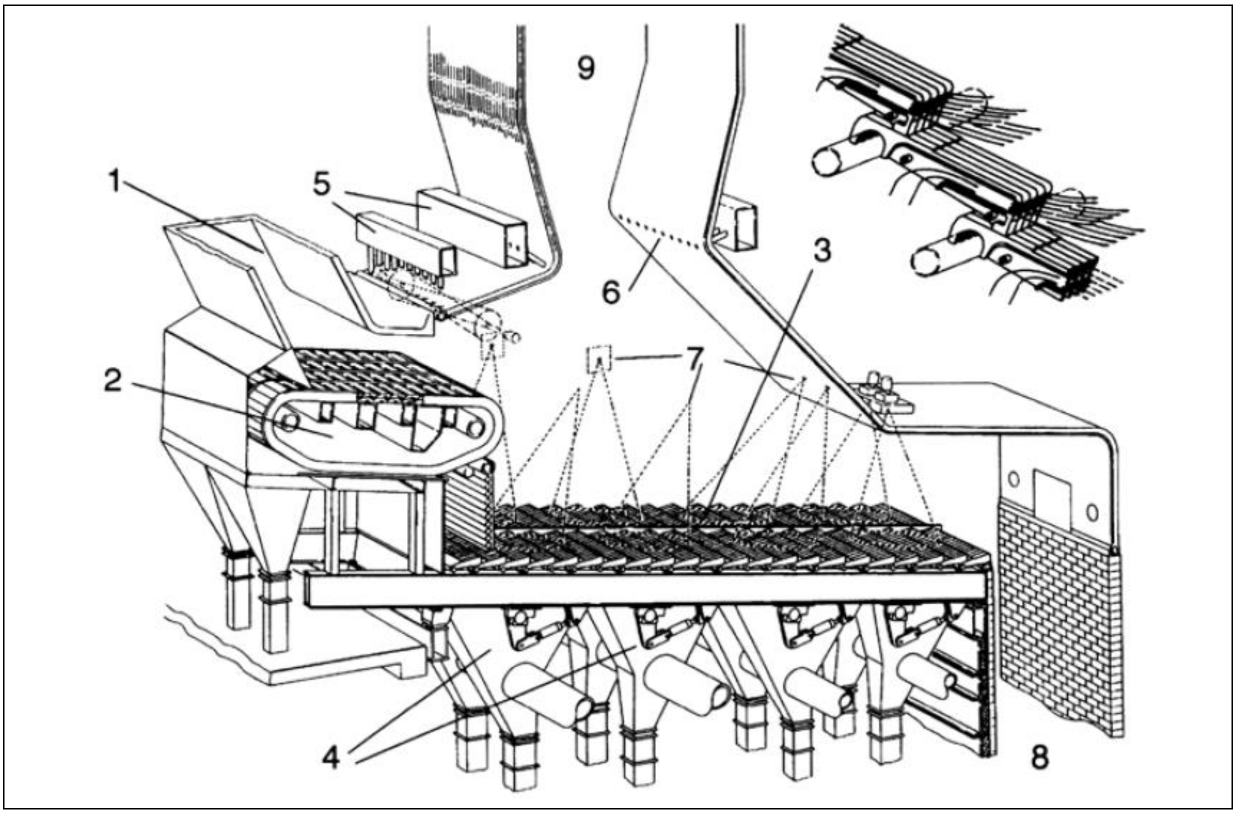
Primary and secondary air is placed as shown in the picture. The last step for the bottom ash is the ash funnel, whereas the last step for the gas is the flue gas canal with adopted flue gas cleaning. (Strauß 2006)

Stoker-fired furnaces do not need a pre-sorting and shredding of the garbage. Burning temperatures are approximately 1000°C (Strauß 2006).

Actually there are three different types of stoker fired furnaces in use:

- Reciprocating grate
- Moving grate
- Roller grate

(Strauß 2006)



1. Filling funnel	2. Feeding grate	3. Moving infeed grate
4. Primary air	5. Air ducts	6. Secondary air nozzles
7. Temperature monitor	8. Ash funnel	9. Flue gas canal

Figure 2.3: Stoker fired furnace principle, source: Strauß 2006 page 137

2.3 Main differences of combustion types

Stationary fluidized bed combustion systems provide the ash which is better for separating metals because of lower burning temperatures compared to stoker fired furnace and other incineration conditions as circulated fluidized bed combustion. Generally in all incineration types nearly everything can be burnt. (Strauß 2006)

Fluidized bed combustion needs a treatment of the input waste before it can be incinerated because the objects have to be smaller. This size decreasing of the materials is done e.g. by shredding and is important for the burning process since lighter particles lead to a better combustion with the flying sand. (Strauß 2006)

Shredding in general does not influence the metal purity or composition, which in this case leads to the same output quality. Stoker fired furnace combustion does not need any separation or shredding of the input material. Due to the better separation of the fluidized bed combustion fuel, the metal content is lower compared to the stoker fired furnace input. (Strauß 2006)

3 Theoretical background

Chapter three contains the theoretical description of a market analysis, because the main part of this theses is gaining information about the actual status of separation technologies and information about the ash as well as the cost accounting strategies. The input and output ingredients of an incineration process of municipal waste are very important to know because otherwise the cost accounting cannot be done. Another content of chapter three are separation methods of bottom ash and the following usage of these products as well as trends, chances and risks for power plants and its customers.

3.1 Market analysis

The first theoretical chapter starts a description of the process of a market analysis, which is needed to get to know what the customers want to have and which systems are already existing on the market, so the gaining of information about these topics is the central task of a market analysis (Olbrich et al. 2012).

Subchapter 3.1 describes a possible guideline of making a market analysis and is divided in some major steps. Figure 3.1 shows the major steps which are described in this thesis. The content of the guideline is simplified and generalized because in other studies some of these steps are missing or some other steps are implemented. In many cases people working on a market analysis realize during the implementation that there is something missing from the previous step or the step was not done right. Changes during an analysis are normal and failures and weaknesses of previous phases cannot be compensated by care and expense in the following phases. Which means having bad work at the beginning, the result is also bad, even if the last steps are done perfectly. (Kuß et al. 2014)

The guideline for a market analysis is shown in figure 3.1.

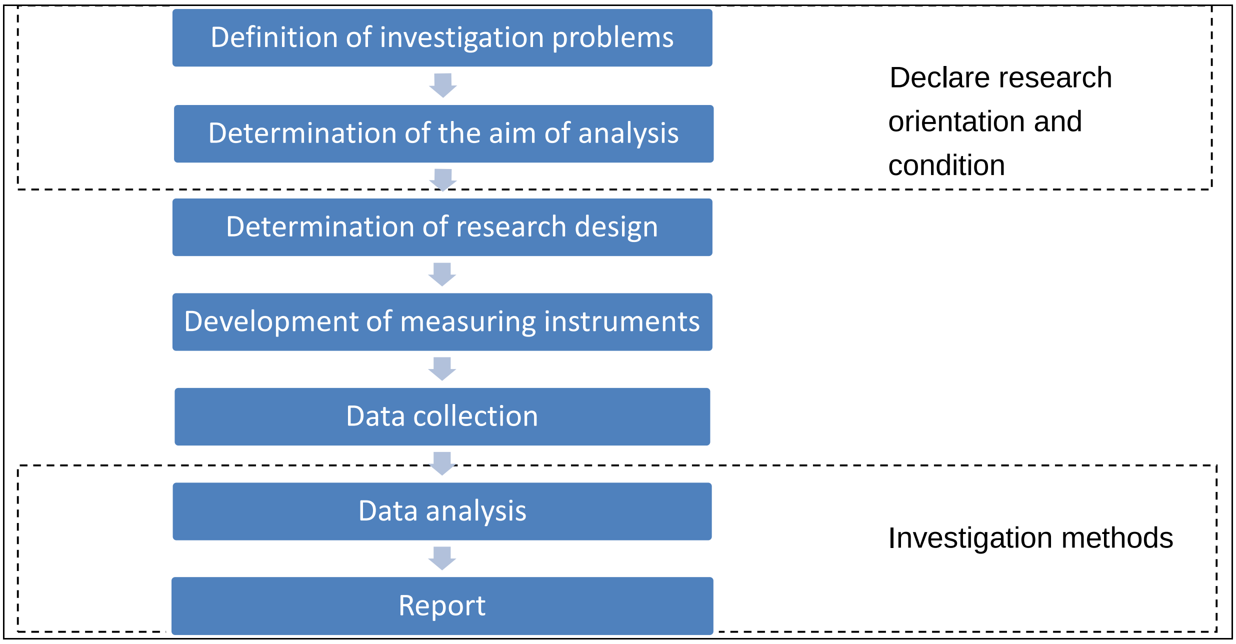


Figure 3.1 : Typical market analysis phases, source: Kuß et al. 2014 page 11

3.1.1 Description of market phases

Before starting with the detailed description of a market analysis scheme, the seven steps of Kuß and Kleinaltenkamp (2011) as described in figure3.1 are explained now shortly:

1) Definition of investigation problems

   The first step is fundamental for all following successes and needs a clear definition. Otherwise a vague formulation can lead to misunderstandings and ends in answering a problem which was not investigated. Therefore the communication between the marketing manager and the market researcher is very important. (Kuß and Kleinaltenkamp 2011)

   Managers have to estimate the potentials and borders of the market research on the other hand market researchers must know the estimation problem and the information needs of the managers. Typically the problem definition is in an explicit written form and is the agreement between client and market researcher. (Kuß and Kleinaltenkamp 2011)

2) Determination of the aim of analysis

   Now it is time for concretising the task which builds up on the definition of the investigation problem. Out of the problem definition, for example having a product that has qualitative disadvantages compared to the competitive product, the determination of the aim of analysis could be declaring the desired features of the target group and the estimation of relevance for the own product and the competitive product. (Kuß and Kleinaltenkamp 2011)

   Due to the limited financial resources of a market analysis, the second step has to be precisely defined well and strictly. Another aspect is the difficult usage of failure sensitive investigation methods which should imply few tasks, but therefore the most important ones instead of including a lot of tasks of little relevance. Defining the investigation target leads to the determination of the type of investigation. Griese and Bröring (2011) mention three types:

   Explorative investigation focuses on the problem's reason and determining the connection of variables. It is used to prepare researches and bigger projects. Getting to a solution normally needs a broad spectrum of questioning which leads to a certain inaccuracy of the methods and the outcome itself. (Griese and Bröring 2011)

   Descriptive investigation is the most frequently used investigation type. The target is to describe markets and customer behaviour of these markets by using e.g. sampling procedures, design of questionnaires and inferential statistics. (Griese and Bröring 2011)

   Causal investigation comparing the others is the most difficult method. Here not only the market and customer behaviour is investigated, but also the reasons for this behaviour. For reaching this goal, experimental designs are used typically. (Griese and Bröring 2011)

In scientific areas formulating a **hypothesis** is a typical method which is based on former investigations, theories and experiences of products, objects and customer behaviour. (Kuß and Kleinaltenkamp 2011)

3) <u>Determination of research design</u>

The determination of research design deals with the fundamental decision of the system of the carried out investigation (e.g. interview or observation, sampling size). Chapter 3.1.4 contains a more detailed description of this topic. (Kuß and Kleinaltenkamp 2011)

4) <u>Development of measuring instruments</u>

Measuring means the allocation of numbers to examination units (e.g. people). In daily business a standardised measure could be standing on a scale and get a value of the weight. Since market analysis is not comparable to this example, here other values are in use e.g. for adjustments, intentions or income and therefore different measuring instruments are needed (mostly questionnaires). Summarizing step four develops the measuring instruments. For example if in step three the decision was to take a survey then in step four the questions of the questionnaire are developed. (Kuß and Kleinaltenkamp 2011)

5) <u>Data collection</u>

Phase number five is the most expensive phase because interviewing thousands of people costs a lot of money. Normally market research institutions take this part and perform the task of data collection in chapter 3.1.5 describes the data collection more in detail. (Kuß et al. 2014)

6) <u>Data analysis</u>

Statistical methods mainly go into action in data analysis by using a broad methodology spectrum. Nowadays not only statistical techniques are used, but as new softwares graphical techniques are more and more in action because through its support situations can be treated more easily and faster. Also the so called multivariate processes are employed, because more complex marketing phenomena typically need more than one variable to be explained. (Kuß et al. 2014)

7) <u>Report</u>

The end of a research is typically presented by a report which is handed over to the management. So that it leads back to the problem definition and tries to answer all the questions asked at the beginning of the research process. Such an examination report contains minimum four parts (Kuß and Kleinaltenkamp 2011):

I. Short summary of problem definition and aim of analysis
II. Explanation of the research methods

III. Presentation of the investigation result

IV. Conclusion and recommendation

A report should be understandable as well as containing a high accuracy of the methods and results (Kuß and Kleinaltenkamp 2011).

3.1.2 Clarification of company standpoint

Before the market analysis and therefore a conduction in the phases mentioned above can be started, the standpoint of the company has to be declared.

One major point is checking the resources of the company to find out if there is enough (Naderer and Balzer 2011), (Freiling and Kollmann 2015) :

- Time (manpower for operatives, intern, and acquisition)
- Technical equipment (amount, properties, technical level, quality)
- Material (conditions, quality, amount, time, supplier contacts)
- Finances
- Know-How

If one or more of these requirements are not fulfilled the analysis should not be started anyhow, because recognizing that the research process cannot be implemented after it has been done would cost a lot of time and money. (Naderer and Balzer 2011)

A second major issue is to check the market positioning which defines where the company wants to put the price and technology focus on. Positioning means putting the focus on few differentiating characteristics of the brand which satisfies customer needs and wishes. To know where the company is standing in the society, thinking about the brand steering wheel (figure 3.2) is very useful. (Freiling and Kollmann 2015)

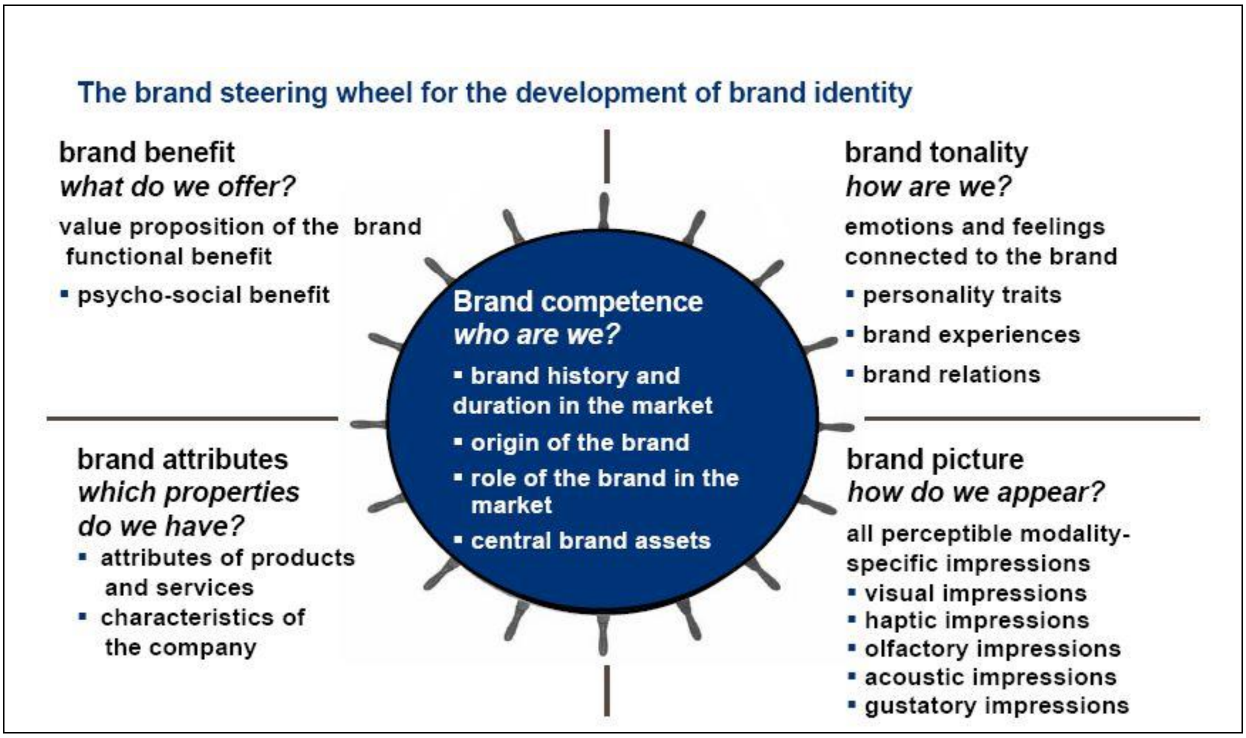


Figure 3.2: Brand steering wheel, source: https://frameworksfactory.wordpress.com/2010/12/29/the-brand-steering-wheel/ (23.3.2016)

The rational left side of the wheel constitutes objective and functional as well as psycho social brand benefit (what do we offer) and the brand attributes (which properties do we have). A differentiation of benefit and attributes is suitable, because customers do not want to buy attributes, but customer benefits. (Freiling and Kollmann 2015)

The right emotional and pictorial side of the brand steering wheel consists of the brand tonality (how are we) and brand picture (how do we appear). To reach a coherent picture of the brand it makes sense to have a reference between the individual areas of the wheel. Heart of the steering wheel is the brand competence which includes rational contents as well as emotional ones and represents the brand identity. Decisive for a brand identity can be the personality of the company founder, the corporate philosophy, vision and guiding principle and the competitive strategy, business model and business idea. (Freiling and Kollmann 2015)

The development of the brand identity depends on the aim, manifest and the view of the company. In return, the corporate philosophy describes the company's permanent character and highlights the company's purposes and values. (Freiling and Kollmann 2015)

Another part of clarifying the company standpoint is the market segment decision. In most cases there are three possibilities for a company to put the focus on (Binckebanck 2013):

- Low prices (Discounter)
- High technology standard (Specialist)
- Range of goods (Generalist)

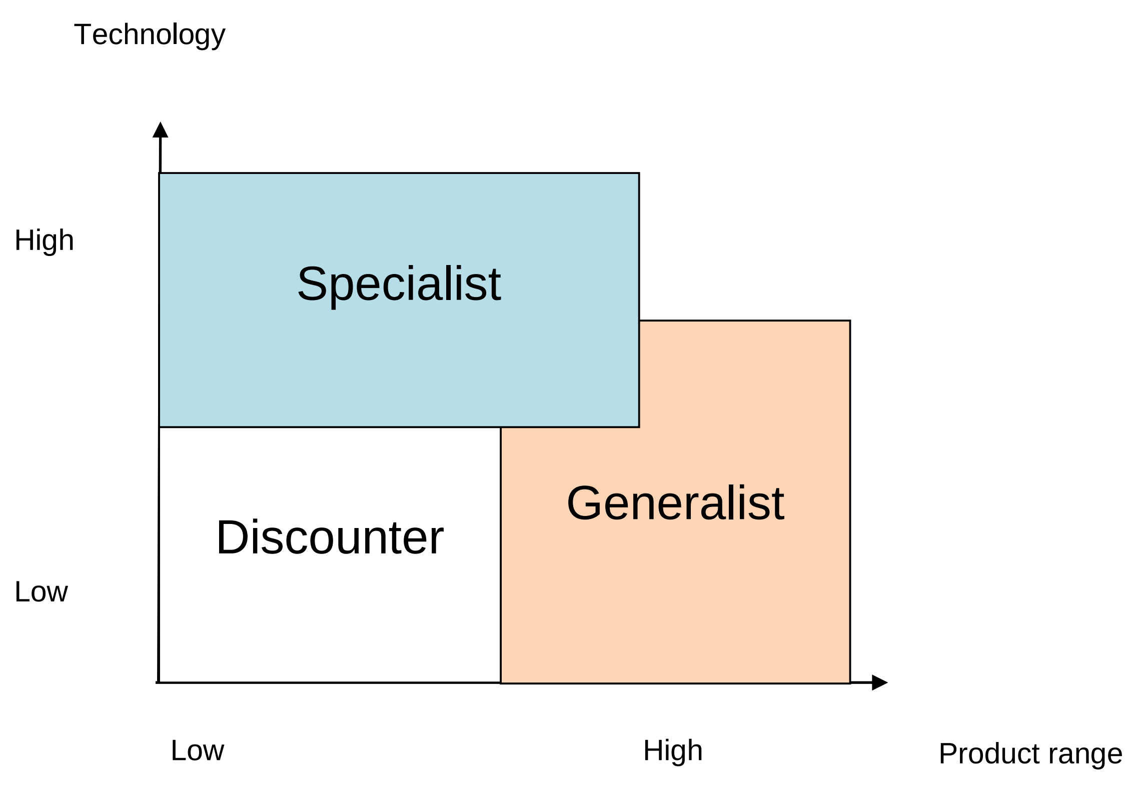


Figure 3.3: Discounter, Specialist and Generalist, source: own figure

Discounter:

Leaders of a company with the discounter philosophy strive for a low product price and high amount of sold goods due to its guiding position at the best price market. Discounters must have a clear and solid offer with few variations at a low price. Therefore they need a high amount of customers and product quantity which leads to stable supplier relations and good production efficiency with available goods. The employees should be competent and cheap with a high rate of availability whereas the demand should be high. (Binckebanck 2013)

Specialist:

Customers want the specialist to have the best technology and a solution to all of their problems at a high level. Therefore the specialist is able to sell his products at high prices. The character of such a firm is to have a very good reputation for offering the newest developments and solutions in every situation at any time. To reach his goals the specialist needs specialised suppliers and well organised ordering and delivery processes as well as the right distribution and communication channels. Employees must have a good Know-How and be flexible. (Backhaus and Voeth 2015)

Generalist:

Being a generalist means having a bright variety of products with a medium technology standard by selling them at a middle price level. Customers value the fact that they can buy everything from the generalist and accept the middle technology standard and average prices. The vendors must also be varied and sell the components on reasonable terms, whereas the generalist owns big warehouses and needs a suitable connection in a good catchment area. Thinking about financing is important because of the high amount of products which are treated either by employees with a bright Know-How or by many different specialised and flexible staff members. (Backhaus and Voeth 2015)

After the company knows in which segment it wants to operate and has checked their possible resources, the next major step is starting with the research focus.

3.1.3 Research focus

The following subchapter defines which market is the important one for investigation defined by the market segmentation and at which potential the examined market is at the moment.

3.1.3.1 Market segmentation

Market segmentation is a research area described by Rankl (2013) and deals with finding the relevant part out of the total market and raises the question which market has to be examined and serves to divide the market in submarkets through splitting the customers in target groups. The goal is to get a high accordance rate of matching potential buyers with the product offered. Therefore also competing companies have to be put in the focus as well as separating the B2B and B2C differences. (Rankl 2013)

Dividing a market in a relevant segmentation needs exactly defined borders of the filter. Market definitions with only little differences can lead to a total different output. For example, Porsche could declare their target market for sports cars which includes Ferrari and Lamborghini etc.as well as for luxury cars which also includes Bentley and Rolls Royce. Each segmentation is right but results in a different way. After the desired segmentation has been made, the next step can be done. (Kirch 2013)

The output of a market segmentation should be the information about the group of customers who are is interested in the product and also willing to buy it (Jaspersen 2008).

3.1.3.2 Market potentials

Kuß et al. (2014) mention that another important step is to define the four market factors:

- Market capacity
- Market potential
- Market volume
- Market share

Market capacity means the ability of the market to grow to its biggest size. Market potential, however takes the purchase power of people in consideration. Market volume is the actual market size and the market share is the company’s actual share of the market. (Kuß et al. 2014)

Market development divided in growing, stagnating and declining market is again a part of investigation to be prepared for the future. These markets can also be described in the following four names as young market, growing market, saturated market and established market. (Kuß et al. 2014)

A young market is a market where only few providers are acting at the moment which means a growing demand while the demand is bigger than the offer. In another way the growing market has to be described where now new providers are entering the market, the demand is growing further and the difference between offer and demand is getting smaller. The fight for market shares has now begun. The saturated market distinguishes itself by the fact that the predatory competition of the providers is daily business and the offer is now higher than the demand. The last possibility is the established market where yet the demand is fluctuating while providers have to concentrate on their competences and special Know-How. (Medelnik 2012)

When the definition of the actual market potential is finished, the company should know how to enter the market, how the market will develop in the coming years and following this how to act and react at the future market. (Medelnik 2012)

3.1.4 Research methods

When the company has already declared its standpoint and the research focus is fixed, then the research methods are the following step in the chain which have to be done. Therefore Thommen and Achleitner (2012) describe a possible division of the research methods as shown in the following figure 3.4.

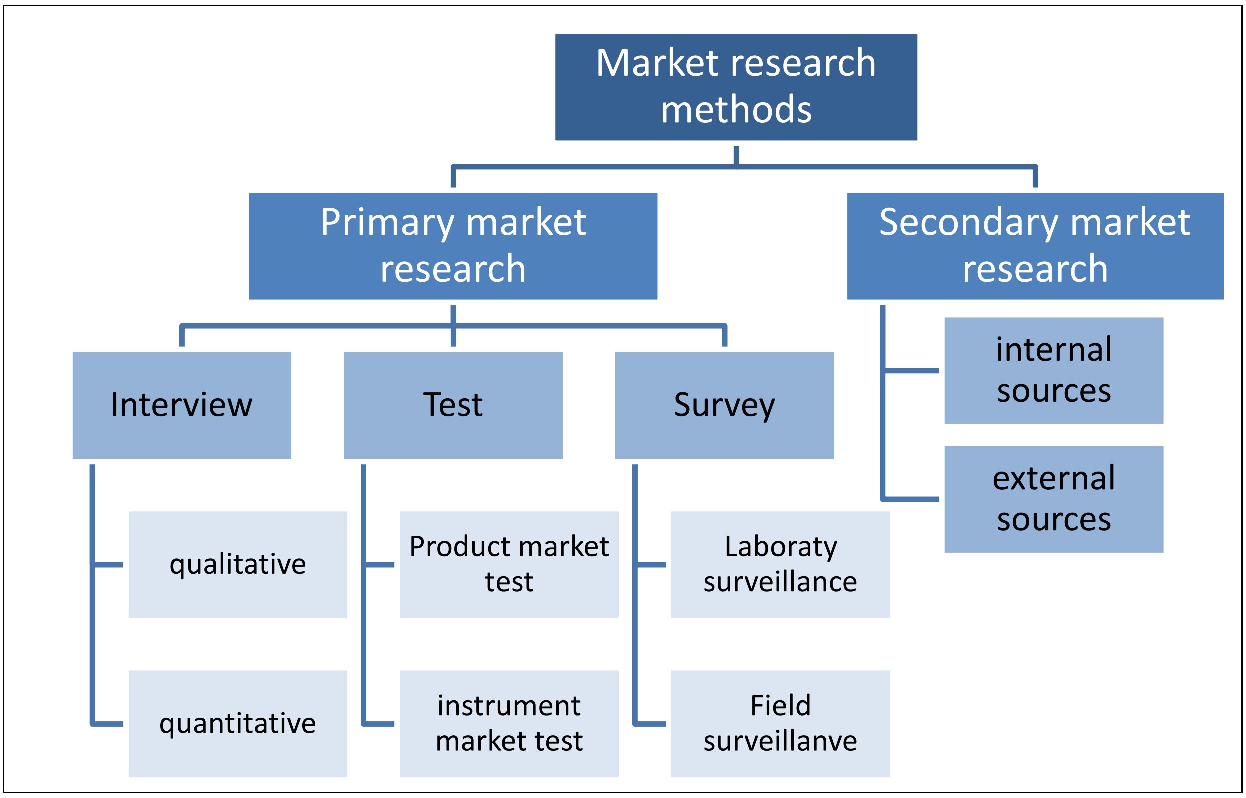


Figure 3.4: Overview of market research methods, source: Thommen and Achleitner 2012 page 155

Considering the tendency, secondary market research is mostly used as a first step and thus before the primary market research, because gaining data is easier and much cheaper. The secondary market research works with already existing data of similar projects or different projects in similar markets. This information can be collected internally as well as externally. (Thommen and Achleitner 2012)

Examples are publications of institutions or offices for internal sources and production statistics or information of the financial department for internal sources. Primary market research has to create new data especially for the actual case. It is much more cost and time intense and needs a lot more expertise knowledge than secondary research and often market research institutions take over this job. The data is gained mostly through special collection techniques. (Weis and Steinmetz 2012)

Another description can be done by direct market research which is pretty similar to primary research and indirect market research comparable to secondary research (Kotler and Keller 2012).

Direct market research (Kotler und Keller 2012):

- Focus group, customer survey
- Interview in parallel markets
- Visiting congresses, fairs etc.

Indirect market research:

- Internet research
- Data of federal statistical office, evaluation of trade journals, competition documents, annual reports, fair documents
- Publication of associations, chambers and banks

How these research methods are used in practice to gain information is described in the next subchapter.

3.1.5 Data generation

Data generation is the heart of a market analysis and gives answers to the question how to receive data for market research and focuses on the qualitative and quantitative survey as well as the data generation of internal and external sources. There are internal and external sources (Backhaus 2011):

Internal sources:

- Sales statistics
- Production statistics
- Planning documents out of diverse departments
- Information of accounting systems
- Reports of customer visit
- Already created market research documents

External sources:

- Official statistics
- Publications of institutes
- Books and reference work
- Trade journals
- Business and other newspaper
- Libraries
- Databases
- Fairs and Exhibitions

Quantitative surveys need a high number of respondents while using pre-formulated questions to get socio-demographic characteristics. Therefore personal interviews, telephone surveys, written surveys and computer-aided surveys are in use. A qualitative survey on the other hand does not a need high number of respondents, but needs educated interviewers who detect psychological, socio-psychological and sociological characteristics, to get information about the fundamental attitudes of the interviewee. Methods of qualitative survey are single and group discussions. (Kotler and Keller 2012)

3.1.6 Data analysis

Due to the fact that there is no statistical evaluation of surveys or other complex techniques in the practical part of this thesis, this subchapter is not further explained than already at the beginning of chapter 3.1.

3.1.7 Report

As mentioned on page 10, the report is necessary for representing the solution and its insights. The report of this thesis is summarized in the conclusion and the presentation. This presentation contains the investigation result and is done at ANDRITZ AG as well as at the technical University of Graz and not explained more in detail than already on page 10.

Now the theoretical aspect of a market analysis and the linked data generation are explained. The described scheme was used for chapter 3.3 and partly for the practical part to collect information concerning the waste and bottom ash as well as exploitation and separation possibilities.

3.2 Cost accounting and investment appraisal

The output of the thesis should be an economic recommendation and therefore subchapter 3.2 describes the theory of cost accounting, investment appraisal containing the profitability calculation, cost comparison calculation, profit comparison calculation and amortisation. Especially static investment methods are mentioned because these methods are used in the practical part of the thesis. First of all, a general overview of cost accounting is given and then several special processes are described.

3.2.1 Cost accounting general aspects

This subchapter starts with a general overview of accounting described by Horsch (2015) and explains the difference between external and internal accounting system including the individual parts.

3.2.1.1 General aspects of cost accounting

The following table 3.1 on the next page shows the subsystems of accounting including the four different methods (Horsch 2015):

- Bookkeeping
- Cost accounting
- Financial accounts
- Investment appraisal

Subsystems of accounting				
	External accounting system	**Internal accounting system**		
	Bookkeeping	**Cost accounting**	**Financial accounts**	**Investment appraisal**
Dimension of time	Past (time = balance, period = profit and loss)	Past + Future Period	Future Period	Future Period
Calculation elements	Earnings and expenses	Revenue and costs	In payment and out payment	In payment and out payment
Core aim	Provision of information for: - Self information of the management - Taxation - Creditor protection - Report - Capital market - Evidence	Provision of internal information for planning and control: - Calculation products - Cost department - Short term success - Decisions regarding make or buy	Ensuring of liquidity and optimization of the profitability	Determination of an investment project's success for more periods
Results	Balance Profit and loss calculation	Cost-type accounting Cost centre acc. Cost unit acc. Income statement	Liquidity planning Profitability planning	Benefits of investment projects

Table 3.1: Subsystems of accounting, source: Horsch 2015 page 3

Further on in this thesis the main focus will be on investment appraisal because these calculations are done in the practical part as well.

The main function of cost accounting is the systematic and institutionalised quantitative identification and illustration of processes of operational service creation and utilisation (material transformation process). Fulfilling these operational cost accounting tasks (determination function of cost accounting) can serve for diverse purposes. (Horsch 2015)

A major task is to understand the difference between financial bookkeeping and cost accounting.

These differences are listed as following:

- Financial bookkeeping shows the business transactions between the company and its business partners. However the cost accounting creates the internal operation process of the performance creation and the result of the performance utilisation. Financial accounting writes down the whole financial transformation process of a company and describes it from the financial side (expenses and income), whereas cost accounting focuses on the material transformation process of the operational performance creation and the performance utilisation (costs and services). Sometimes the cost accounting department reverts to the notes of the financial accounting department to determine the income of sales or expenses for the production. (Zunk et al. 2013)
- Financial bookkeeping contains the whole legal framework of a company considering the economic activities of a business entity, whereas cost accounting does its calculation separated for all different fields of a firm. (Zunk et al. 2013)
- Typically, the annual financial statement created by the financial bookkeeping serves for calculating the annual profit of a business. Cost accounting mostly consists of monthly, quarterly or semi-annual reports and shows an ongoing imputed result of the various business activities during the year. (Zunk et al. 2013)
- The result of financial accounting in many cases is presented months after the end of a business or calendar year, whereas the reports of the cost accounting department are finished only few weeks after reaching the billing period. (Zunk et al. 2013)
- Financial bookkeeping is required by state laws, whereas the cost accounting does not follow any official statutes. (Joos-Sachse 2014)
- The annual financial statement in some cases (stock company) is subject to publicity obligation, however this is not the case for cost accounting. So financial accounting is primarily seen as a documentary calculation of the past whereas cost accounting is needed as a decision factor for calculation in the future. (Joos-Sachse 2014)
- For financial bookkeeping it is easier to find a general structure comparable to cost accounting because it is typical to create individually adapted guidelines in a business there. The reason are the different production processes and organisational aspects of companies. (Zunk et al. 2013)

3.2.1.2 Explanation of cost accounting’s parameters

Costs are defined as a resource consumption of the objects of a company. The term of costs contains of three significant characteristics: quantitative resource consumption, performance relation, evaluation (Joos-Sachse 2014).

There are different types of costs (Gottmann 2016):

- Direct costs are costs which can be assigned directly to a reference object
    - Direct material costs
    - Direct manufacturing costs
    - Special direct costs
- Overhead costs are costs which can be assigned only in an indirect way to the reference object
- Fixed costs are constantly the same and do not change by e.g. changing number of employees
- Variable costs do not stay the same due to a changing number of employees or amount of manufactured products.

Revenue means the development of goods and services out of the objects of a company. In former times, the word revenue had the same meaning as performance, but nowadays typically not. Performance stands for the quantitative output of an organizational unit. The term revenue also contains of three criteria: quantitative performance, matching the targets of the created performance, evaluation. (Joos-Sachse 2014)

Since the cost accounting is declared, the more important calculation for this thesis, the investment appraisal, is described yet.

3.2.2 Investment appraisal

This subchapter contains a general overview of the topic investment and a detailed description of the different investment calculation methods.

Hering (2014) deals with this topic and points out that investigation means the procurement of subjects or building up immaterial values which can be divided as shown in figure 3.5. (Hering 2014)

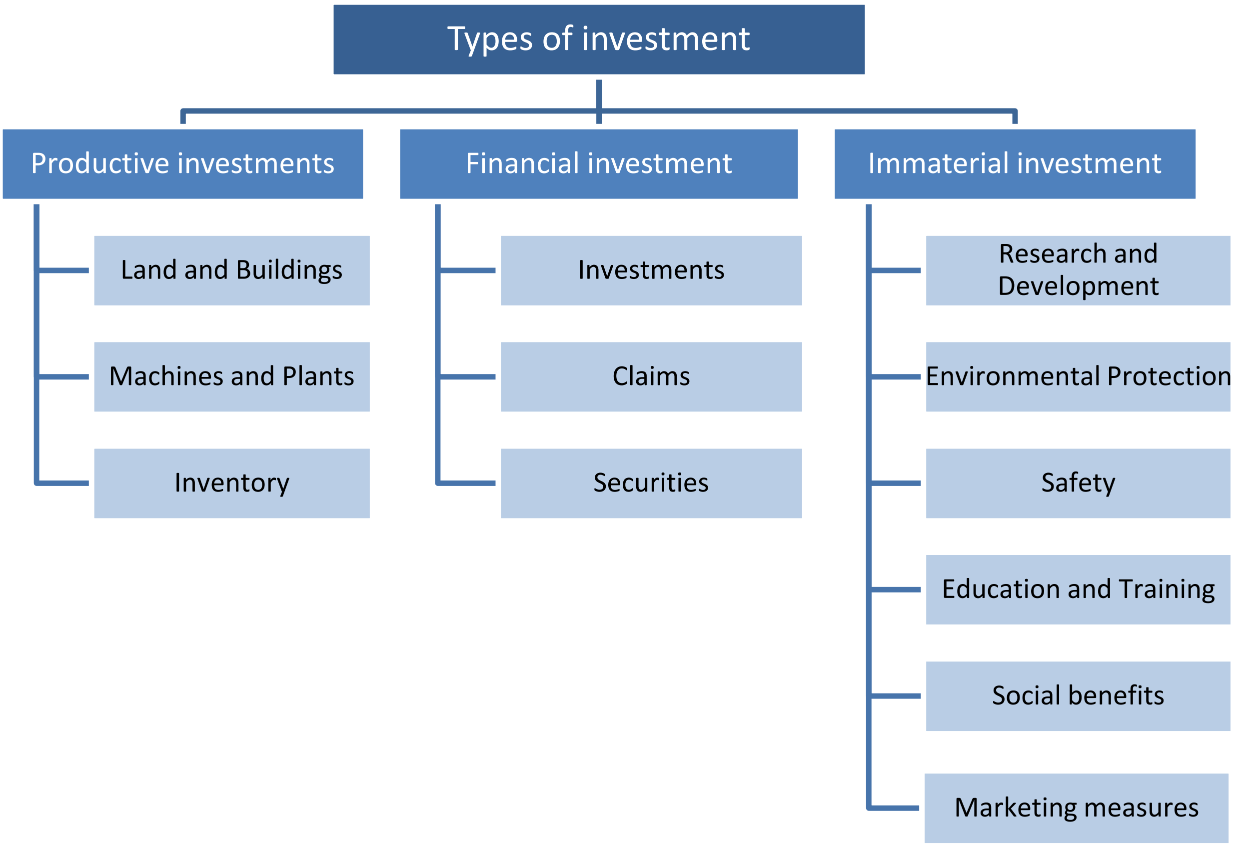


Figure 3.5: Investment types, source: Hering 2014 page 2

The types of investment can be divided in productive, financial and immaterial investment. Productive investment is meant when the company puts its money in objects like machines, buildings or inventory which can be sold later on. These investments are normally taken by all manufacturing companies. Financial investments are non-material values like money that can be claimed from the customers or investments in other firms or security papers at a bank. Immaterial investments are often understood as investment for the future and contain developments, safety, education and training of employees and marketing measures. These investments cannot be figured out by any value or amount of money. (Hering 2014)

For chapter 4 the productive and financial investments are relevant as well as the static investment appraisal on the next page to describe if an investment should be done or not.

A general aspect mentioned by Walter and Wünsche (2013) is, that normally new plants or machines have a better technique, that's why this is not a replacement investment, but an expansion investment. By means of such machines it is possible to manufacture a small or large number of pieces with higher safety and quality standards as well as more flexibly and cheaper. (Walter and Wünsche 2013)

Mostly these investments are very cost intense so that a bad decision must be absolutely avoided. Walter and Wünsche (2013) consider the following points to secure the situation:

Economic efficiency:

The economic efficiency measures the profit of a project or the profit of the whole company compared to the expenses. Thus the economic efficiency is an indicator how efficient a company acts. The various alternatives are compared with regard to costs, contribution margin and profits (per period of time or per piece)

$$Profit = revenue - costs$$

$$Economic\ efficiency = \frac{profit}{expenses}$$

Risk:

Risk in general is a factor which describes how high the possibility is to fail with a project or an investment. If the risk to fail is too high, than most companies decide against the investment. On the other hand, the faster the capital flows back to the business (which means the shorter the amortisation time), the lower the risk is and the higher the probability for an investment decision of the management.

Profitability:

Profitability is an indicator to declare a statement if a company’s actions lead to a profit compared to the used capital. The used capital has to flow back to the company and be paid interest on.

$$Profitability = \frac{profit}{used\ capital} * 100$$

Liquidity:

Liquidity describes the liquid funds and is an indicator if a firm is solvent or not able to pay its bills or labour costs of employees. Companies with a good liquidity are also tending to invest in machines or other material or immaterial investments. Depending on the financing model (e.g. leasing or bank credits) the liquidity scope is changing.

Other criteria:

For evaluating the investments also social, ethical or other moral concepts can be used. In some cases the investment is not taken because of these aspects even if the company has a good liquidity and economic efficiency.

(Walter and Wünsche 2013)

The mentioned aspects are considered in the following calculation methods and therefore figure 3.6 shows an overview of investment appraisal methods where the main differentiation lies between static and dynamic calculation. Dynamic procedures takes the interest rate of the capital into account, whereas static procedures do not consider interest rates. Both methods of cost and profit comparison are part of the economic efficiency calculation. (Poggensee 2015)

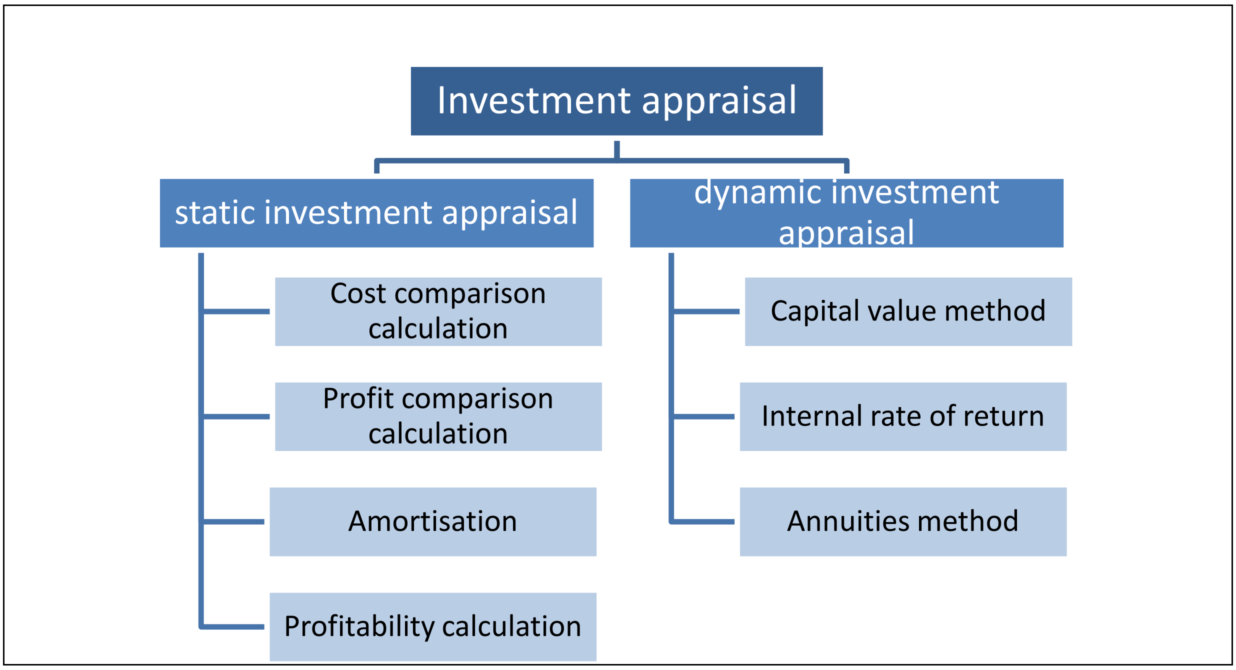


Figure 3.6: Investment appraisal, source: Opresnik and Rennhak 2015 page 105

3.2.2.1 Static investment appraisal

Static investment appraisals are characterised by not considering the time aspects of the calculation parameters and thereby renounce discounting and compounding. This leads to assuming the same values for all periods, so that the calculation focuses on one period. So the calculation is done by average values and pretty easy. It is very often used in practice because the information can be derived from the accounting results. (Opresnik and Rennhak 2015)

The four static investment appraisal methods which are also used in the practical part of this thesis are described in detail in the next subchapters including an example. Other methods would be the equivalence number method, break even analysis and the value creation calculation which are only mentioned here. (Eichhorn and Merk 2016)

3.2.2.1.1 Cost comparison calculation

On the basis of the significant costs, the diverse investment alternatives can be evaluated. Investments with the lowest costs have the highest benefits. For example the following parts are important for such a calculation (Götze 2014):

- Acquisition value (is the price which is payed for an investment e.g. a machine and therefore the value of this investment)
- Capital costs (are the whole amount of costs a company has to pay for an investment including interest rates and taxes etc.)

  - Depreciation

$$Depreciation = \frac{acquisition\ value}{lifetime}$$

  - Interest rates

$$Interest\ rates = acquisition\ value * rate$$

- Fixed costs (stay the same and don not change by time or number of produced part)
  - Fixed personal costs
  - Setup costs
- Variable costs (change by the number of pieces which are manufactured or by time)
  - Material costs
  - Labour costs
  - Tool costs
  - Energy-, electricity-, and water costs
  - Maintenance costs

The costs can be seen per time or per piece. Table 3.2 shows the method of cost comparison and compares the costs of the milling machines.

Costs		Machine 1	Machine 2	Machine 3
Acquisition value	[€]	560.000	300.000	220.000
Lifetime	[year]	10	8	5
Depreciations	[€]	56.000	37.500	44.000
Interest rates (5% of Acquisition value)	[€]	28.000	15.000	11.000
Capital costs	[€]	84.000	52.500	55.000
Programming effort	[€]	200.000	300.000	300.000
Setup costs	[€]	10.000	15.000	18.000
Sum fixed costs	[€]	210.000	315.000	318.000
Material and Hardware costs	[€]	15.000	12.000	11.000
External costs for services	[€]	20.000	25.000	30.000
Update costs	[€]	28.000	24.000	13.200
Sum variable costs	[€]	63.000	61.000	54.200
Sum total costs	[€]	**357.000**	**428.500**	**427.200**

Table 3.2: Cost comparison calculation per period of time for three machines/ alternatives, source: Hering 2014 page 6

Machine 1 has the most expensive investment of 560.000 € and also the capital costs are a little bit higher than for the other machines. The biggest advantage of machine 1 is the longer lifetime as well as the most comfortable program interface. Thus the programming effort is smaller by one third compared to the other two alternatives (200.000€ instead of 300.000€). The variable costs are material and hardware costs as well as external costs for services and are pretty the same for all three machines. As the evaluation shows, machine 1 is the best choice for the lowest total costs per period of time. In table 3.3 the cost comparison per piece is shown in euros and highlights the choice for machine 1 of table 3.2. (Opresnik and Rennhak 2015), (Hering 2014)

Costs		Machine 1	Machine 2	Machine 3
Acquisition value	[€]	560.000	300.000	220.000
Lifetime	[year]	10	8	5
Pieces per year		120.000	100.000	80.000
Depreciation*	[€/#]	0,47	0,38	0,55
Interest rates (5% of Acquisition value)	[€/#]	0,23	0,15	0,14
Capital costs per piece	[€/#]	0,7	0,53	0,69
Programming effort	[€/#]	1,67	3,00	3,75
Setup costs	[€/#]	0,08	0,15	0,23
Sum fixed costs per piece	[€/#]	1,75	3,15	3,98
Material and Hardware costs	[€/#]	0,13	0,12	0,14
External costs for services	[€/#]	0,17	0,25	0,38
Update costs	[€/#]	0,23	0,24	0,17
Sum variable costs	[€/#]	**0,53**	**0,61**	**0,68**
Sum total costs	[€/#]	**2,98**	**4,29**	**5,34**

Table 3.3: Cost comparison calculation per piece for three machines/ alternatives, source: Hering 2014 page 7

* Depreciation: 560.000/ 10 / 120.000= 0,47 €/#

3.2.2.1.2 Profit comparison calculation

Once the revenues and the achievable prices per piece have been taken into account, the profit of the different alternatives can be compared. The investments with the highest average profit per period is the most beneficial. If the revenues per piece are the same then the cost and profit comparison methods come to the same result. Therefore the following definition has to be done (Busse von Colbe et al. 2015):

$$\boxed{Profit = revenue - costs}$$

The next example describes the selling of the software of all three machines. Thus not only the costs for creating the NC-software are estimated realistically, but also the revenues of the different software packages. This leads to the profit comparison calculation as shown in table 3.4. (Hering 2014)

Costs		Machine 1	Machine 2	Machine 3
Acquisition value	[€]	560.000	300.000	220.000
Lifetime	[year]	10	8	5
Depreciations	[€]	56.000	37.500	44.000
Interest rates (5% of Acquisition value)	[€]	28.000	15.000	11.000
Capital costs	[€]	84.000	52.500	55.000
Programming effort	[€]	200.000	300.000	300.000
Setup costs	[€]	10.000	15.000	18.000
Sum fixed costs	[€]	210.000	315.000	318.000
Material and Hardware costs	[€]	15.000	12.000	11.000
External costs for services	[€]	20.000	25.000	30.000
Update costs	[€]	28.000	24.000	13.200
Sum variable costs	[€]	63.000	61.000	54.200
Sum total costs	[€]	**357.000**	**428.500**	**427.200**
Market price of NC software	[€]	18.000	22.000	25.000
Estimation of sold pieces	[#]	15	25	25
Revenue	[€]	**270.000**	**550.000**	**625.000**
Profit	[€]	**-87.000**	**121.500**	**197.800**

Table 3.4: Profit comparison calculation for three alternatives, source: Hering 2014 page 8

Table 3.4 leads to the result that the NC-software for machine 1 probably results in losses initially. The software development for this machine is very cheap and also the price for the software is comparatively low expensive. Machine 1 is new on the market and pretty costly, so the machine is not used that much in practice and due to this only fewer software packages can be sold. For the machines 2 and 3 profit is realistic because of pricey software and a high amount of machines on the market. Still a consideration for machine 1 should be done, since the growing potentials for the new innovative machine are much higher than for the established ones. (Hering 2014)

This example gives information about the fact that investment decisions may not be done only considering the investment calculation, but also including strategic targets and enterprise policy. In practice, the profit comparison calculation has the disadvantage of estimating the pieces and the market price which results in a not very reliable forecast of the profit and revenue. (Opresnik and Rennhak 2015)

3.2.2.1.3 Amortisation calculation

The benefits of investments are often measured by the payback period. Thereby is meant the time in which the capital for the investment comes back to the company. Bringing a return on the investments, the payback period must be shorter than the operating life. Due to this the amortisation time is an index for the risk and is characterised by the definition: The shorter the amortisation time, the lower the risk. (Moroff and Focke 2015)

This connection is especially important for software, because continuous improvement is the rule. Before an update can be given to the customer, the capital for the previous version must already have been earned. The amortisation time can be calculated as follows:

$$\boxed{Amortisation\ time = \frac{capital\ investment - remaining\ value}{average\ backflow}}$$

The average backflow is the difference between revenue and costs plus depreciations.

$$\boxed{Average\ backflow = revenue - costs + depreciations}$$

Depreciations must be added because they contain a part of the saved capital which is used for the replacement of the plant. Sometimes the depreciations are not only needed for investments, but for other purposes too. (Moroff and Focke 2015)

Table 3.5 contains the calculation of the payback period for the development of the NC-machine software and leads to the result that machine 3 has a payback period of 0,65 years. The software for machine 1 needs twice as much time for amortisation and thus has a two times higher development risk. Nevertheless, a consideration has to be made because the new machine 1 is part of a growing market and it could be possible that machine 2 and 3 are leaving the future market totally. The residual value was chosen as zero (Hering 2014)

Costs		Machine 1	Machine 2	Machine 3
Depreciations	[€]	56.000	37.500	44.000
Interest rates (5% of Acquisition value)	[€]	10.000	15.000	15.000
Capital costs	[€]	66.000	52.500	59.000
Programming effort (hours)	[€]	200.000	300.000	300.000
Capital investment	[€]	266.000	352.500	359.000
Residual value	[€]	0	0	0
Capital investment – residual value	[€]	266.000	352.500	359.000
Revenue	[€]	270.000	550.000	625.000
Sum total costs	[€]	111.000	113.500	118.000
Depreciations	[€]	56.000	37.500	44.000
Average backflow	[€]	215.000	474.000	551.000
Payback period	[year]	1,24	0,74	0,65

Table 3.5: Amortisation calculation for three alternatives, source: Hering 2014 page 10

3.2.2.1.4 Profitability calculation

If the surpluses not calculated absolutely, but in relation to the average used capital then this leads to the profitability calculation. The total capital profitability called ROI (return on investment) is declared as follows:

$$Profitability = \frac{profit}{used\ capital} * 100$$

(Ott 2011)

In the case of investment calculation, the used capital is equal to the costs of the purchasing of the investment item. The next example is derived from the numbers of the profit comparison calculation (table 3.4). In table 3.6 a profitability calculation is depicted and leads to the result that the turn on sales (profit/ revenue), the turnover ratio (revenue/ used capital) and the profitability for machine 1 are worst and best for machine 3. (Hering 2014)

Costs		Machine 1	Machine 2	Machine 3
Acquisition value	[€]	560.000	300.000	220.000
Lifetime	[year]	10	8	5
Depreciations	[€]	56.000	37.500	44.000
Interest rates (5% of Acquisition value)	[€]	28.000	15.000	11.000
Capital costs	[€]	84.000	52.500	55.000
Programming effort	[€]	200.000	300.000	300.000
Setup costs	[€]	10.000	15.000	18.000
Sum fixed costs	[€]	210.000	315.000	318.000
Material and Hardware costs	[€]	15.000	12.000	11.000
External costs for services	[€]	20.000	25.000	30.000
Update costs	[€]	28.000	24.000	13.200
Sum variable costs	[€]	63.000	61.000	54.200
Sum total costs	[€]	**357.000**	**428.500**	**427.200**
Market price of NC software	[€]	18.000	22.000	25.000
Estimation of sold pieces	[#]	15	25	25
Revenue	[€]	**270.000**	**550.000**	**625.000**
Profit	[€]	**-87.000**	**121.500**	**197.800**
Revenue profitability	[€]	-32,22%	22,09%	31,65%
Turnover ratio		0,48	1,83	2,84
Profitability	**[%]**	**-15,54%**	**40,50%**	**89,91%**

Table 3.6: Profitability calculation for three alternatives, source: Hering 2014 page 11

The turnover ratio shows which percentage of the investment costs flows back per annum. A turnover ratio of 0,48 means that only 48% of the investment costs flew back to the company. Yet even here operators have to consider that machine 1 is at the beginning of its time and brings growing potentials with it. (Hering 2014)

For rationalisation investments a simplified calculation is used. The savings of variable costs through new machines are the profits which are connected to the investment costs so that the profitability is calculated as follows:

$$\boxed{Profitability = \frac{variable\ costs\ old\ machine - variable\ costs\ new\ machine}{investment\ costs}}$$

(Hering 2014)

The next example deals with the examining of quality management documents. In our example the labour costs for the auditors has been 160.000 €. Two new test devices were investigated, one device costs 220.000€ and has annual labour costs of 120.000€. Device number two costs 340.000€ and has annual costs of only 80.000€. The profitability calculation of table 3.7 shows that device two in spite of high investment costs, but due to the low labour costs has a good profitability. (Hering 2014)

Investment costs		Actual situation	Device one	Device two
Investment costs	[€]	0	220.000	340.000
Variable costs in €/ year	[€/year]	160.000	120.000	80.000
Profitability	[%]		18,18%	23,53%

Table 3.7: Profitability calculation for rationalisation investments, source Hering 2014 page 11

Comparing the alternatives by different evaluation methods leads to the result that the solutions are different. The cost comparison method favours machine 1, the profit comparison method, the amortisation calculation and the profitability calculation however come to the result that machine 3 is the best one. As can be seen it is not advisable to trust these calculations blindly, but rather the methods give hints for an entrepreneurial decision. This decision must consider also chances for the future markets. (Hering 2014)

The static investment appraisal methods are already described and can be used as a basis and guideline for the practical part, so the dynamic ones are mentioned shortly in the next subchapter.

3.2.2.2 Dynamic investment appraisal

As already mentioned in figure 3.6 there are three types of dynamic investment appraisal. In contrast to the static methods, the dynamic methods include an interest of in payment and disbursement and can be distinguished in (Ermschel et al. 2011):

- Compounding: With this compound interest calculation the future value of existing capital can be determined.
- Discounting: Discounting determines the present value of income and outcome for the future.

Dynamical methods pay interest on donations and the following fiscal terms are important:

- Cash value, present value or capital value: A one-time payment or repeated payments are discounted from the present value
- Final value: A one-time payment or repeated payments are compounded by interest and compound interest.
- Annual value or annuity: The regular constant annual contributions serve for the repayment of interest and of the debt.

Since the theory of a market analysis and investment appraisal are declared, the next step of this thesis is the investigation of the lifetime cycle of materials.

3.3 Residual waste and bottom ash analysis

The following subchapter contains information about the actual situation of the resource recovery of bottom ash. Some plants have already installed a recycling system after the combustion process. Some institutions and universities do research in this field. Another content of this chapter is the analysis of waste ingredients at the input of an power plant, separation previous the combustion as well as the output ingredients and the following separation after the burning and usage of the slag. The last part of this subchapter are the profits and costs of ash.

3.3.1 General facts

To start this subchapter a short overview of the number of plants which are in use are given as well as problems with laws and CO_2 in general concerning municipal incineration. Europe is not the leader of manufacturing rare earth elements. Because of the increasing metal prices, more and more remnants are applied as a secondary resource which were for example landfilled formerly. (Thomé-Kozmiensky 2013)

3.3.1.1 Legal situation

There are many laws for landfilling and treatment of municipal waste. Lorber et al. (2006) explain the most important laws for this area in Germany and Austria. In 2005 depositing of untreated municipal waste was forbidden in Germany. For the year 2020 a new law is planned where municipal waste must be utilized completely environmentally safe and landfilling over ground will be banned. (Lorber 2006)

In 2004 Austria installed a law concerning landfilling. This law bans the landfilling of waste with more than 5% of organic carbon. According to this law, garbage incineration is the best method to fulfil this law producing at the same time energy and district heating as well as recycling the bottom ash. (Lorber 2006)

Förstner (2012) mentions that the EU wants a minimization of the total garbage amount and a utilization of reusable elements of the waste. Another EU law will be installed in 2020 calling for a recycling rate of municipal waste of 65% and an recoverability rate of construction and demolition waste of 7%. Förstner (2012) shows some examples how to fulfil the new laws, two of them contain the rising rate of waste incineration followed by bottom ash preparation. (Förstner 2012)

For ANDRITZ these laws do not play a big role yet, but for the future market of ash separation the new laws will have an influence on it.

3.3.1.2 Plants in use

In 2009 Germany had 72 waste power plants in use, which handled approximately 20 mio tons of commercial and household waste (Bilitewski and Härdtle 2013). These 20 mio tons of waste lead to a slag amount of approx. 4 mio tons per annum in Germany and for the whole world the mass of slag is about 420 mio tons (Dittrich et al. 2015).

In 2011 a study came to the result that in Germany 70 garbage and 34 refuse-derived fuel power plants where in use (Thomé-Kozmiensky and Goldmann 2011). The application of all waste power plants in Germany in the year 2011 is shown in figure 3.7. It shows that the most widely used method of waste treatment with heat is the classical garbage power plant (Trend Research 2014).

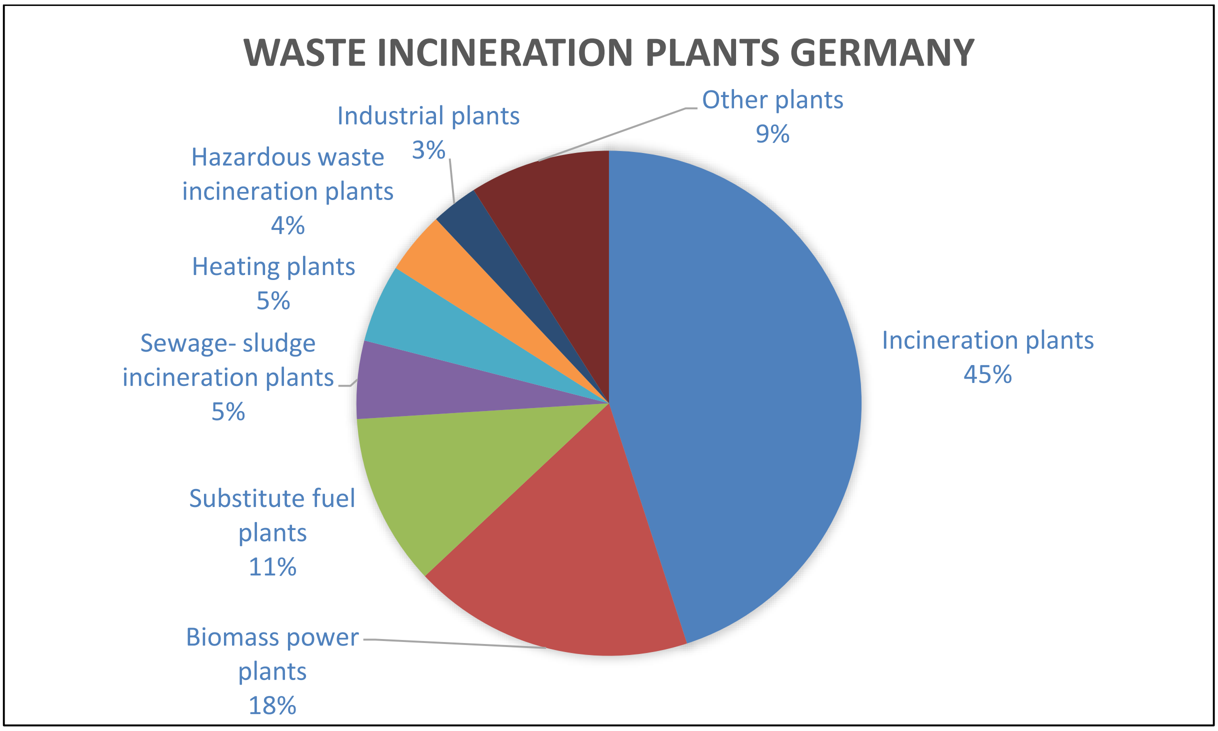


Figure 3.7: Waste power plants in Germany in 2011, source: Trend Research 2014 page 314

3.3.1.3 Energy and CO_2 problem

Antrekowitsch et al. (2008) highlight that due to the generation of metal there is a lot of CO_2 produced. Therefore some laws were installed by the EU (Kyoto protocol) and also some stricter country specific rules, for example in Germany or Austria. To decrease this CO_2 problem, it is important to recover metals even after the incineration. A reason for this is that in the primary production metals need ten times more energy compared to the secondary production. (Antrekowitsch et al. 2008)

A study of Alwast and Riemann has the result that after an incineration a better recycling of non-ferrous metals in Germany can amount to 17.000 t/a. This value is equal to an energy effort of a primary production of these non-ferrous metals of 50.000 MWh/a. All this energy can be saved when the recovery rate of remnants is enhanced. An example is table 3.8 where the energy demand for primary production is shown. (Alwast and Riemann 2010)

Metal	Cumulative energy input fossil [MWh/$t_{Raw. Mat.}$]
Raw iron	6,16
Raw aluminium	31,1
Raw copper	21,5

Table 3.8: Cumulated energy effort for metal production, source: Alwast and Riemann 2010 page 3

In the following table 3.9 Kozmiensky shows the emission through metal generation. For Germany taking the 20 mio tons of waste burnt per year and the fact that 20% of this waste is slag then the result is 4 mio tons of slag per annum. As described in chapter 3.3.4 ~7% of the slag is ferrous and ~3% non-ferrous metal (2/3 of non-ferrous is aluminium). (Thomé-Kozmiensky 2015)

This leads again to table 3.9 which also shows the total CO_2 saving due to slag recycling for Germany when supposing 100% recycling quota (more detailed in 3.3.5). A result of 1,7 mio tons of CO_2 savings for a 80 million people country only for metal recycling after an power plant is scaring. (Thomé-Kozmiensky 2015)

CO_2 saving due to slag recycling	CO_2 – emission through of metal generation [kg_{CO2}/kg_{metal}]	CO_2 Saving in Germany [Mio t /a]
Iron	2,5	0,28Mio t* 2,5= 0,7
Aluminium	10	0,08Mio t* 10= 0,8
Average of other non-ferrous metals	5	0,04Mio t* 5=0,
Sum		**1,7**

Table 3.9: CO_2 savings in due to slag recycling, source: Thomé-Kozmiensky 2015 page 146

3.3.1.4 World use and distribution of metals

The global demand for metal rose nearly exponentially in the last century and will also rise in the next years. An issue to think about is that the ore concentration decreased continuously in the last few decades. (Thomé-Kozmiensky 2015)

Europe, especially middle Europe does not have a lot of resources like metals and thus has a strong dependency on other countries which sometimes are insecure. China for example produces more than 90% of the global rare earth elements. Rare earth elements are all specific elements, excluding frequently used metals like gold and silver. Unfortunately they have a shrinking export quota and due to that all other countries are confronted with a rare earth elements supply risk. (Binnemans et al. 2013)

Deike et al. (2012) share the opinion that not the physical availability of the rare earth is the problem, but the political stability of the producing countries as well as the concentration level of the manufacturing of a country or a region. Another difficulty is the substitution possibility through other elements and compounds and the existing/ feasible recycling method and – rate. In the US and Australia new mines for rare earth production are installed to be more independent from China. Because of growing demand these new mines will not have an impact on the increasing metal prices. (Deike et al. 2012)

For the production of tools, cars, machines and so on, a lot of waste is produced which is not part of the machine. This fact increases the problem that the ore contents in mines are running out in the course of time. Experts estimate a 200% rise of this problem every 20-25 years. (Förstner 2012)

3.3.2 Ingredients of residual waste and input of power plants

The following pages will give an overview of the ingredients of residual waste and which input mixture is normally used for a garbage incineration, focusing on the metal contents and concentrations that are burnt.

3.3.2.1 Residual waste

First of all it must be clarified what is understood by residual waste. Förstner (2012) defines the following: residual waste contains all solid garbage from households and similar institutions, except bulky waste and already separated garbage (paper, glass, metal and plastics) as well as biogenous waste and problematic materials. Residual waste contains a lot of different substances which depend on regional and seasonal fluctuations just as the political and economic situation and the prevention effort. (Förstner 2012)

Since the definition of residual waste is declared, the next pages represent ingredients of residual waste and which kinds of metals are mainly in this waste.

In table 3.10 Kozmiensky (2001) gives some examples for metals in the residual waste. The Trend Research institute mentions that 40% of the metal in residual waste is ferrous metal packaging, 10% nonferrous metal packaging, 30% ferrous metal and 10% nonferrous metal and 10% rest. (Trend Research 2014).

Metals	
Batteries	Electronic waste, Crown caps
Car and bicycle parts	Aerosols, Salve tube and toothpaste
Aluminium and tinplate cans for drinks, canned goods and pastry	Wire, nails, pins, small parts out of ferrous and non-ferrous metal
Aluminium foil, Cooking dishes	Electronical devices, replacement parts

Table 3.10: Metals in residual waste, source Thomé-Kozmiensky 2001 page 372

A study from Upper Austria’s residual waste distribution for the year 2013 is shown in figure 3.8 (Bernhofer et al. 2013). An Bavarian study confirmed the results of Upper Austria (Bayerisches Landesamt für Umweltschutz und Fachtagung 2002).

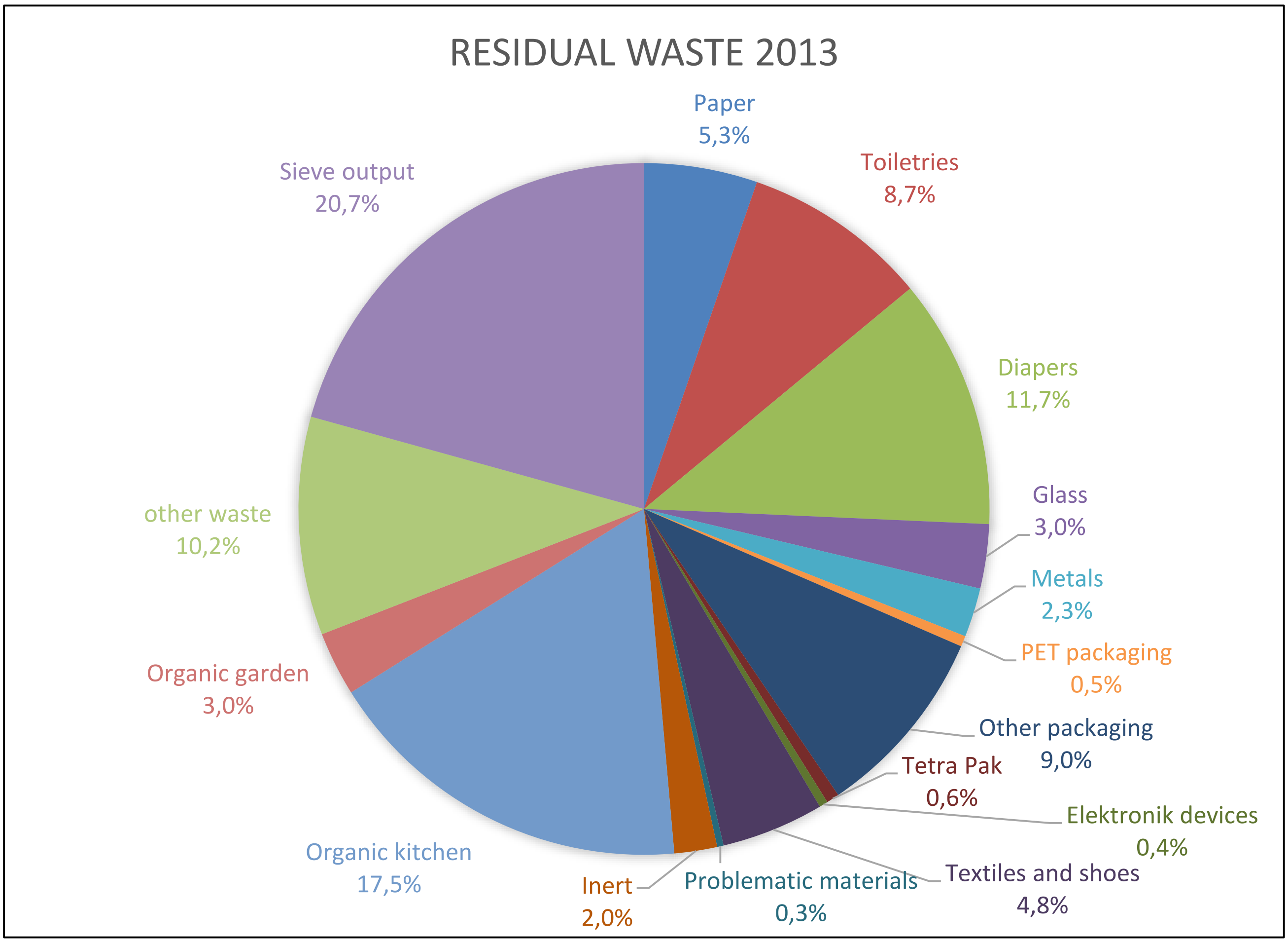


Figure 3.8 Residual waste contents in mass percentage 2013, source: Bernhofer et al. 2013 page 9

For ANDRITZ the most interesting information out of this study are the fact that 2,3% metals are included in such a waste as well as the fact that other types of waste like electronical devices or Tetra Pak also contain some metals.

More detailed studies from 2013 concerning the difference between city waste and waste in rural regions show that the metal distribution is ~5% in cities and ~1.5% in countryside (Bernhofer et al. 2013).

Bilitewski and Härdtle (2013) justify this phenomenon because countryside people are more willing to recycle their garbage and have also better possibilities to do so. Due to the fact that the big power plants are normally next to big cities and Upper Austria does not have real big cities, the average number of metal in residual waste coming to a plant is almost 4%. (Bilitewski und Härdtle 2013)

The general tendency of metal in residual waste is declining. For example in 1990 the Upper Austria’s waste contained of 7.5% metal and in 1999 the number shrank to 5%. (Bernhofer et al. 2013)

3.3.2.2 Metal-concentration in garbage

Morf et al. (2013) dealt with the composition of the metals in garbage in Switzerland which was investigated before burning in the Hinwil’s plant. The most interesting metals (concerning quantity and scrap price) are shown in table 3.11. Getting to these results, the team with Morf shredded the waste into small parts before analysing the materials. (Morf et al. 2013)

Name	**Symbol**	**Average value (mg/kg) +/- standard deviation (mg/kg)**
Iron	Fe	32’000 +/- 1500
Aluminium	Al	17’000 +/- 960
Copper	Cu	2’230 +/- 220
Zinc	Zn	1600 +/- 300
Barium	Ba	749 +/- 60
Lead	Pb	540 +/- 50
Chromium	Cr	180 +/- 14
Silver	Ag	5.3 +/- 0.72
Gold	Au	0.4 +/- 0.2

Table 3.11: Metal concentration in garbage, source Morf et al. 2013 page 637

An Austrian study for the power plant Spittelau in Vienna came to a similar scale for the metals as in Switzerland. As already mentioned the differences can be explained by regional differences and the fact that the Austrian study is ten years older than the Swiss study. (Morf et al. 2005)

Another factor is the different recycling method and strategy in Austria and Switzerland before putting garbage to the residual waste. Besides the fact that not every power plant has the same composition of material (bulky waste, residual waste, commercial waste) which is burnt has to be considered. The interesting material input of Spittelau from 2000-2004 is shown in table 3.12 below. (Morf et al. 2005)

Note that this table has its results in g/kg.

METAL	**2000** **g/kg**	**2001** **g/kg**	**2002** **g/kg**	**2003** **g/kg**	**2004** **g/kg**	**MW (00-04)** **g/kg**
Fe	28 ± 2	28 ± 2	27 ± 2	29 ± 2	28 ± 3	28 ± 9
Al	10,0 ± 1,2	11,2 ± 1,8	7,5 ± 0,6	11,8 ± 2	11,6 ± 2	10,6 ± 0,8
Pb	0,24 ± 0,05	0,33 ± 0,06	0,27 ± 0,03	0,26 ± 0,04	0,32 ± 0,08	0,29 ± 0,024
Zn	0,57 ± 0,07	0,61 ± 0,06	0,60 ± 0,05	0,52 ± 0,05	0,53 ± 0,05	0,56 ± 0,025
Cu	0,24 ± 0,05	0,31 ± 0,07	0,27 ± 0,02	0,29 ± 0,05	0,35 ± 0,07	0,30 ± 0,024

Table 3.12: Material input Spittelau, source: Morf et al. 2005

The following figure 3.9 created by Kozmiensky (2015) depicts the different metal concentration in garbage for Germany. Therefore in 2014 they made an analysis for residual waste, commercial waste, bulky waste and lightweight packaging to compare the metal content in these different forms of trash. (Thomé-Kozmiensky 2015)

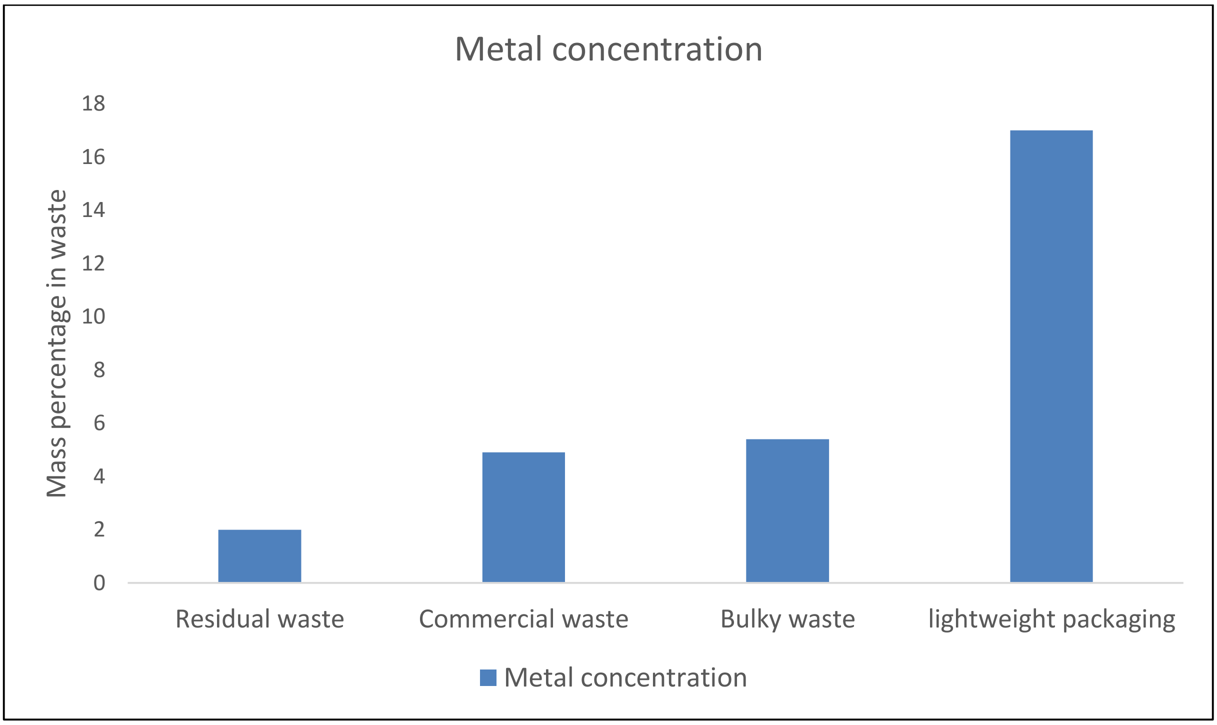


Figure 3.9: Metal concentration in waste, source: Thomé-Kozmiensky 2015 page 108

3.3.2.3 Input in power plants

Garbage is transported to the waste incinerator typically by truck or train in containers, bags or slackly. The input of waste incinerators is different from plant to plant because every plant operator has other suppliers and is in another region and uses a diverse burning strategy. In such a plant garbage like residual waste, bulky waste, commercial waste, compost, sewage sludge and other types can be burnt. (Stubenvoll et al. 2002)

Meinfelder and Richards estimated the typical input of power plants in Germany with 56% household waste, 37% commercial waste and 7% bulky waste. This combination leads to a metal concentration of 4% shown in figure 3.10 which matches comparing and joining figure 3.9 (Meinfelder and Richers 2008).

Some plants use refuse-derived fuel with a typical metal concentration of 0.9% (Thomé-Kozmiensky and Goldmann 2013).

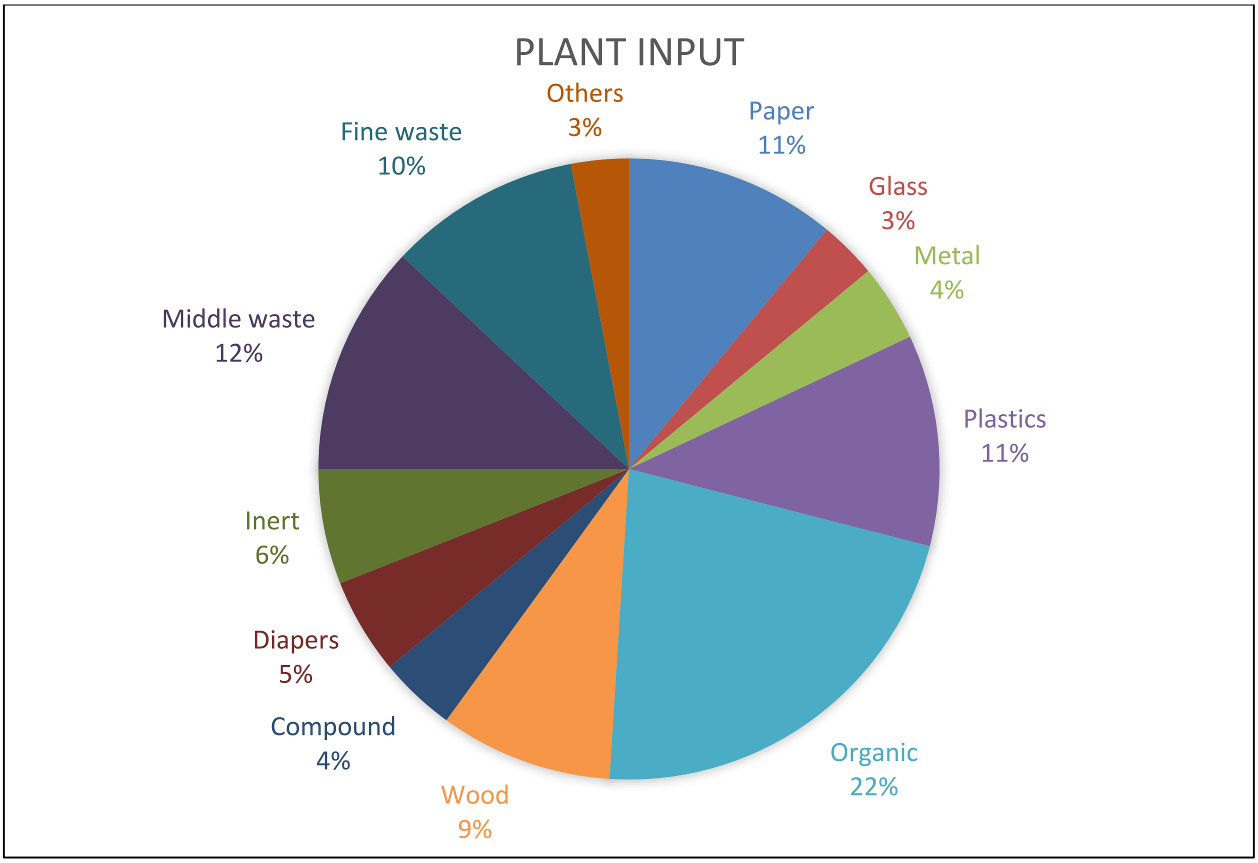


Figure 3.10: Material input in power plants in mass percentage, source Meinfelder and Richers 2008 page 25

So figure 3.10 shows that the input of an power plant is not the same as the content of residual waste, but pretty similar. Now this topic is declared and the next step in the chain of the metals in the waste is the separation before the combustion process.

3.3.3 Separation before incineration

Generally shredding the material before putting it in the incineration chamber (like the preparation for fluidized bed combustion) does not influence the properties of the out coming ash after the burning process (Meinfelder and Richers 2008).

Lorber (2006) separated the ferrous metal (normally done by a magnet) of the waste incinerator input material and noticed that this was 2% of the total mass and 78% of the total ferrous metal in the waste (Lorber 2006).

The main parts of this separated metal are tinned cans which are contaminated and due to this fact, the metal can only be put in the pig iron process (Bilitewski and Härdtle 2013).

Kozmiensky (2015) mentions that the typical separation of non-ferrous metals can be done by eddy current separation after shredding and reach a recovery rate of approx. 80% for tin plates and approx. 60% for aluminium (more detailed in chapter 3.3.5). These recovery rates are understood by the best possible separation and are a total maximum. Metal impurities are not considered in these numbers. (Thomé-Kozmiensky 2015)

3.3.4 Ingredients of bottom ash

This subchapter gives some information about the ingredients of bottom ash with the focus on metal elements (ferrous, non-ferrous and rare earth elements (REE)).

A general fact is that the volume reduction of slag is approximately 80% after burning and after preparation and utilization it is approx. 95% compared to the input. The mass reduction is between 60% and 70%. Per ton of waste 250kg to 350kg of slag and ash are left as well as 20kg to 40kg filter ash and 8-45 kg reaction product after flue gas cleaning. Half of the total ash is bottom ash, which leads to 15% of the input. (Förstner 2012)

The ingredients of the bottom ash strongly depend on the input of the plant and the incineration process. Untreated ash contains more or less (Förstner 2012):

- 3-5% unburnt
- 7-10% ferrous and non-ferrous metals (brass, tin plate, copper, aluminium etc.)
- 5-7% rough pieces > 32mm (concrete, bricks, stones etc.)
- 80-83% fine pieces < 32mm (glass, porcelain, ceramic)

Figure 3.11 depicts a typical distribution of ash ingredients in an incineration process.

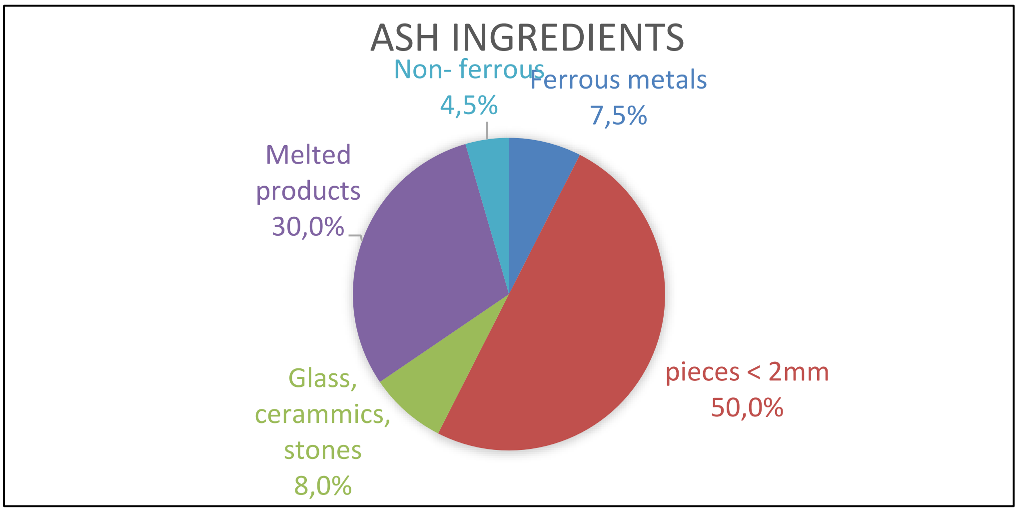


Figure 3.11: Bottom ash ingredients (mass percentage), source: Dittrich et al. 2015 page 4

Kozmiensky (2015) underlines this graph with their similar results of 1-3% of non-ferrous metals and 5-15% ferrous metal in the typical Swiss slag. The wide variance of the percentages can be justified with the explanation above. Metal contents of Swiss slag are shown in the table 3.13 below. (Thomé-Kozmiensky 2015)

Metals in bottom ash	**Raw metal [%]**
Iron	7,37
Non-ferrous metal mix 3-12mm	1,05
Non-ferrous metal mix 12-40mm	1,12
Non-ferrous metal mix > 40 mm	0,29
FE-CU parts	0,13
Stainless steel > 40mm	0,27
Sum metals	10,23

Table 3.13: Metals in bottom ash Switzerland, source: Thomé-Kozmiensky 2015 page 146

A detailed examination of the metal contents in slag parts smaller 6mm was done by Kozmiensky. One of the findings was that 45% of the mass is bigger 6mm and 55% is smaller 6mm. So a further analysis for parts < 2,5mm was done with the focus on aluminium and copper. The outcome was that the proportion of aluminium is growing with smaller particle size and for copper it is the other way round. (Thomé-Kozmiensky 2015)

Particles smaller than 2mm amount to 25% of the total mass and contain approx. 50% of the magnetic part (FE_3O_4 which is merged with other mineral fractions). Aluminium distribution in the most important sizes > 2mm is at the same level of 40g/ kg. (Deike et al. 2012)

Table 3.14 shows the most interesting dry metal concentration of slag after a normal detachment of iron by an overbelt magnet (sorting out 2/3 of the total iron content in the slag). These numbers also present the amount of material for the possible expandable separation. (Stubenvoll et al. 2002)

Metal	**Slag [mg/ kg dry]**	**Fly ash [mg/ kg dry]**	**Filter cake [mg/ kg dry]**
Fe	30’000 – 80’000	10’000 – 20’000	10’000 – 50’000
Al	30’000 – 75’000	40’000 – 80’000	1’500 – 30’000
Zn	1’200 – 5’500	7’000 – 20’000	700 – 4’500
Pb	500 – 5’500	2’500 – 7’000	100 – 2’000
Mn	300 – 1’100	500 – 800	100 – 900
Cr	100 – 500	400 – 700	20 – 100

Table 3.14: Distribution of slag, fly ash and filter cake, source: Stubenvoll et al. 2002 page 114

Due to the big differences in the input materials in an power plant, the quantity of metals can vary by the factor 15. The numbers in table 3.14 above are a good average value and were measured at the power plant of Spittelau in Vienna. (Bockreis 2014)

The copper content in a particle size <2mm is 0,3 – 0,4% which has the same concentration of copper as poor copper ores. Nearly 40% of the aluminium in slags was found in a size <4mm whereas an assumption shows that 80% of the aluminium waste is metallic (2/3 of the aluminium come from packaging residues). (Deike et al. 2012)

To sum up this chapter figure 3.12a and 3.12b are showing the distribution by size of the most common and important materials for the metal preparation. The iron fraction (mainly the big parts) was already separated by a magnet before this analysis was done. The values are average values out of more samples, anyway it does not make sense to have a fixation about a standard value because of the wide variance caused by factors already mentioned. Precious elements have a significant low slag share of around 20mg/ kg like Ag or 0,3 mg/ kg like Au in all particle sizes. (Allegrini et al. 2014)

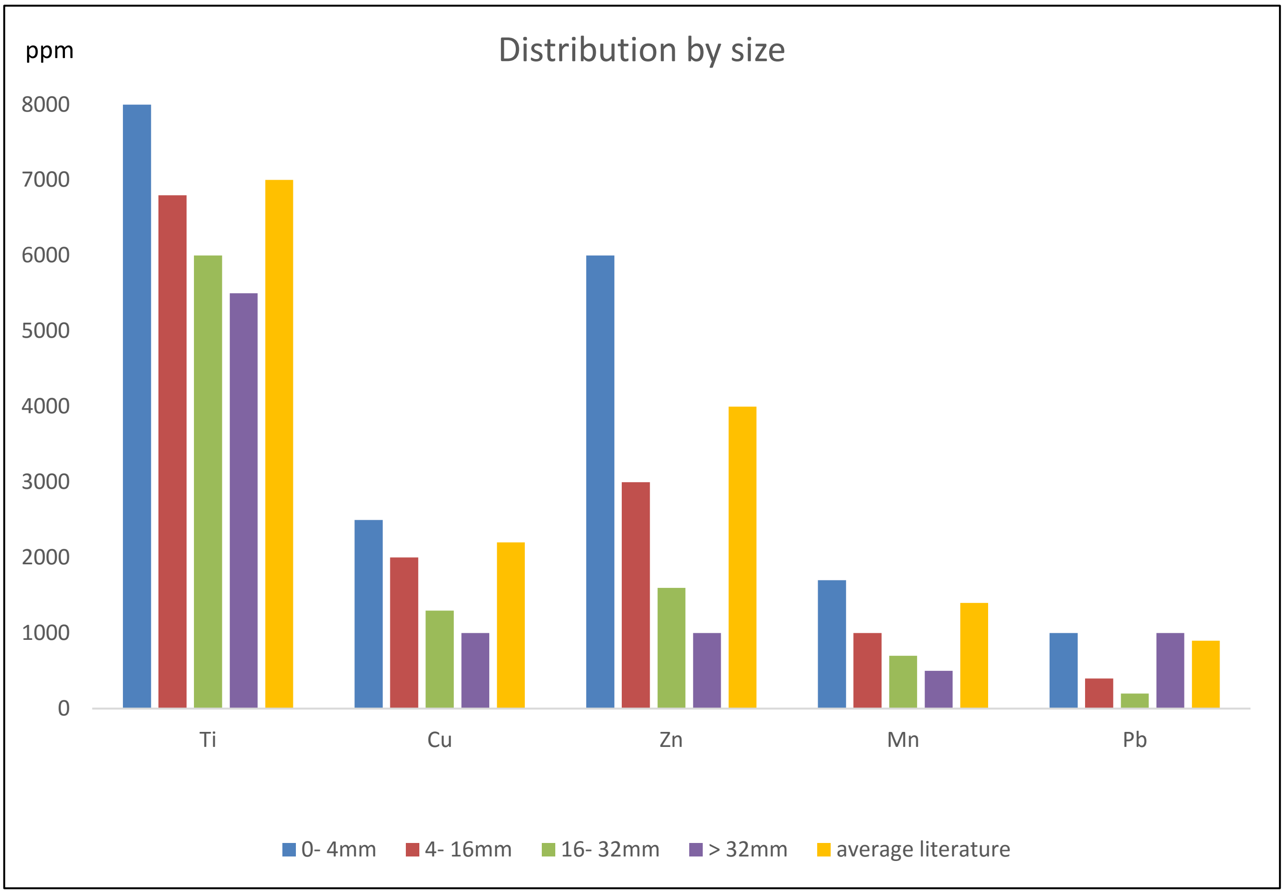


Figure 3.12a: Non-ferrous metal distribution in ash sorted by size, source: Deike et al. 2012 page 67-69

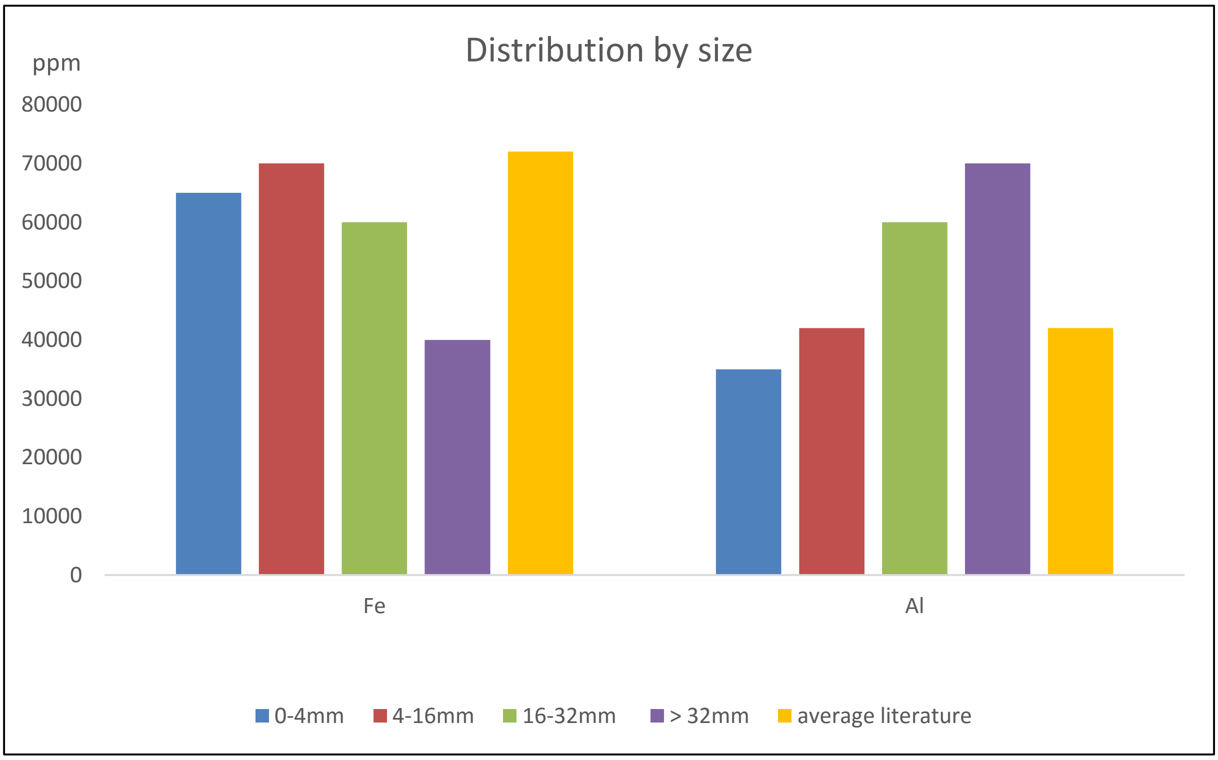


Figure 3.12b: Ferrous metal and aluminium distribution in ash sorted by size, source: Deike et al. 2012 page 67-69

As shown in these graphs, about 2/3 of the recycled NFE scrap is aluminium.

An investigation study came to the result that only 5% of the metals (mainly non-ferrous) oxidizes during the incineration process, the rest has a solid form. Reason for this is the fact that the high temperatures in a combustion chamber are not reached at the bottom, but in a higher place of the chamber, where the metals do not get to because of their weight. (Thomé-Kozmiensky and Goldmann 2013)

3.3.5 Separation after burning

This subchapter gives information about the typical separation methods in action and the studies of new separation technologies (mostly not actually used at plants).

Commonly metals can be recycled und reused as often as wanted without any loss of quality (Thomé-Kozmiensky 2000).

On average 92% of the total metal coming in an power plant can be recycled technologically. Iron with more than 92% and non-iron metals between 60 and 85%. Economically it does not make sense to separate rare earth in sizes of 20-100ppm out of the bottom ash. Theoretically more than 100% of the metals can be recycled which sounds strange, but due to the fact that wooden parts like clothes hangers or plastic parts like an umbrella contain metals that are not listed at the metal section before burning. (Deike et al. 2012)

Figures 3.13 a-c depict FE, aluminium and other metals separated out of the slag.

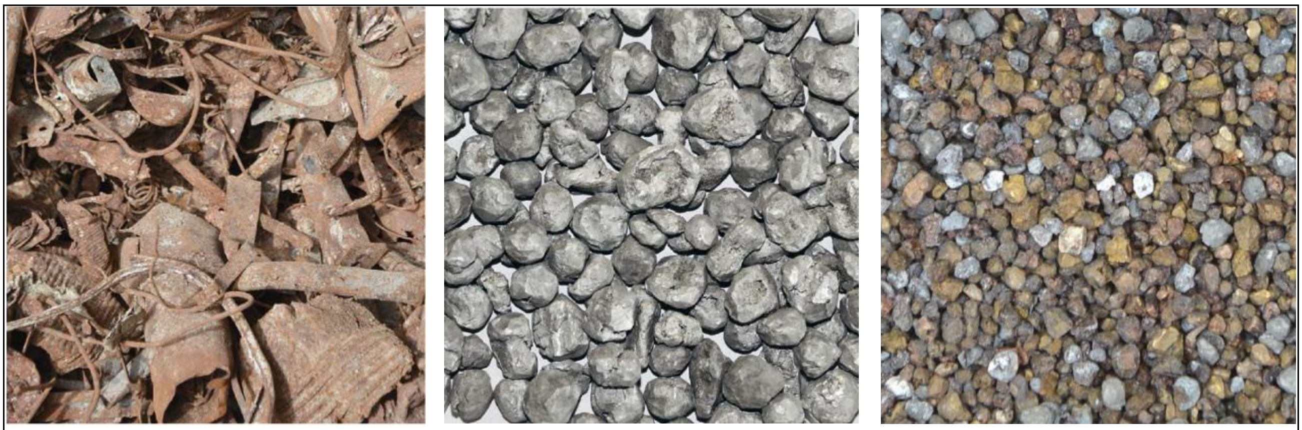


Figure 3.13 a-c: Separated materials, source: www.dhz.ch (20.02.2016)

Ash types:

Two main types of combustion ash exist which are bottom ash and fly ash. Bottom ash is the main part accruing after incineration and chamber it can be collected at the bottom of the combustion. This ash contains the bigger parts of unburnt waste like minerals, ceramics, metals, glass and so on. However fly ash is the result of the last filter system and consists of the small particles and in this way it is harder to recover metals out of it. In figure 3.14 a&b typical bottom ash is pictured. (Tang and Steenari 2016)

Figure 3.14a Rough ash, source: http://zar-ch.ch/zar/ (23.03.2016)

Figure 3.14b Mixed ash, source www.dhz.ch (20.02.2016)

The rough distribution of bottom ash compared to fly ash for some metals is shown in table 3.15 (Tang and Steenari 2016).

Metal	Bottom ash [%]	Fly ash [%]
Aluminium	50	50
Cadmium	5	95
Copper	70	30
Iron	75	25
Lead	30	70
Titan	45	55
Zinc	20	80

Table 3.15: Distribution of bottom ash compared to fly ash, source: Tang and Steenari 2016 page 317

Discharging:

There are two ways to discharge the ash, either wet or dry discharging. By wet discharging (installed in most plants and typically used for stoker fired furnace) as the name says the ash is sprinkled with water and can cool down faster, but a storage of 2-4 weeks is needed to optimize the moisture level before the treatment process can be done. Due to the fact that the furnace is airtight, tertiary air cannot penetrate. By contrast, dry discharging needs longer and leads to more fly ash, but there is no water in it, so the recovery potential is much higher and transporting the ash is cheaper because of lower weight. (Meylan and Spoerri 2014), (Alwast and Riemann 2010)

Figure 3.15 depicts an average recovery difference between wet and dry discharging.

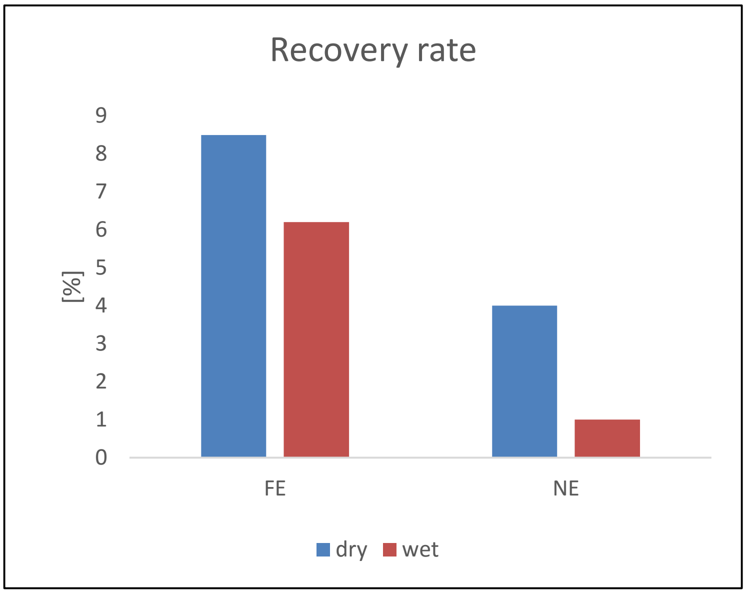


Figure 3.15: Recovery rate of dry and wet ash, source: Thomé-Kozmiensky 2013 page 336

To get a feeling what an ash distribution of particles smaller 64mm looks like, Figure 3.16 shows the ash distribution after a dry discharge process at the Monthey power plant in Switzerland.

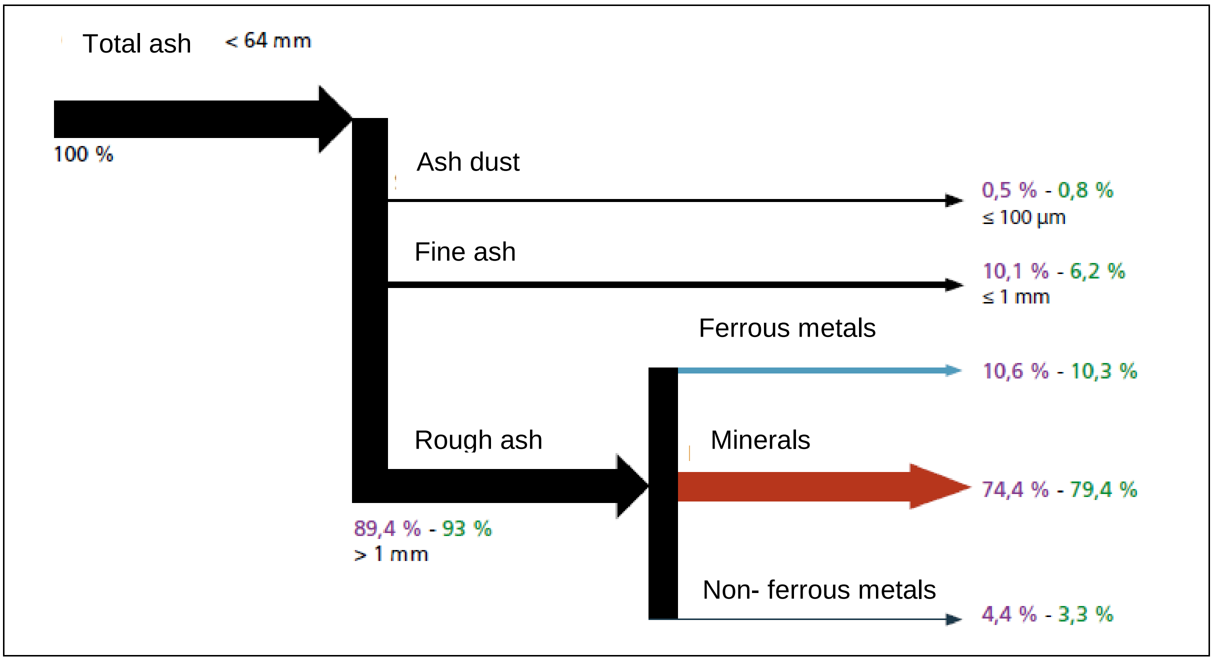


Figure 3.16: Ash distribution plant Monthey, source: Thomé-Kozmiensky 2013 page 335

3.3.5.1 Typical methods

The most frequently used separation technologies are various magnet types, eddy current separation, sieve and wind shifter. In the following lines these technologies are described.

Sieve:

To facilitate the following separation types, at the beginning of most separations a sieve is used to split the different grain sizes (e.g. >80mm, 40-80mm, 20-40mm, 8-20mm, 2.5-8mm and <2,5mm) This step can be done before and between the other types. (Deike et al. 2012)

Magnet:

In most cases an overbelt magnet or normal band magnet is applied to split the iron parts off the other materials. These separated ferrous parts can get rid of fine fractions and heavy metals by washing the heavy metals being sorted after drying by an eddy current separator. (Deike et al. 2012)

Optical separation:

Another opportunity to separate glass, ceramics or stones is possible by an optical control, done by machines as well by humans. (Thomé-Kozmiensky 2013)

Eddy current separation:

An eddy current separation is a standard process step after garbage incineration by now and separates non-ferrous metals bigger than 2mm. Magnet separation and eddy current separation can also be combined as shown in figure 3.17 below. (Thomé-Kozmiensky 2013)

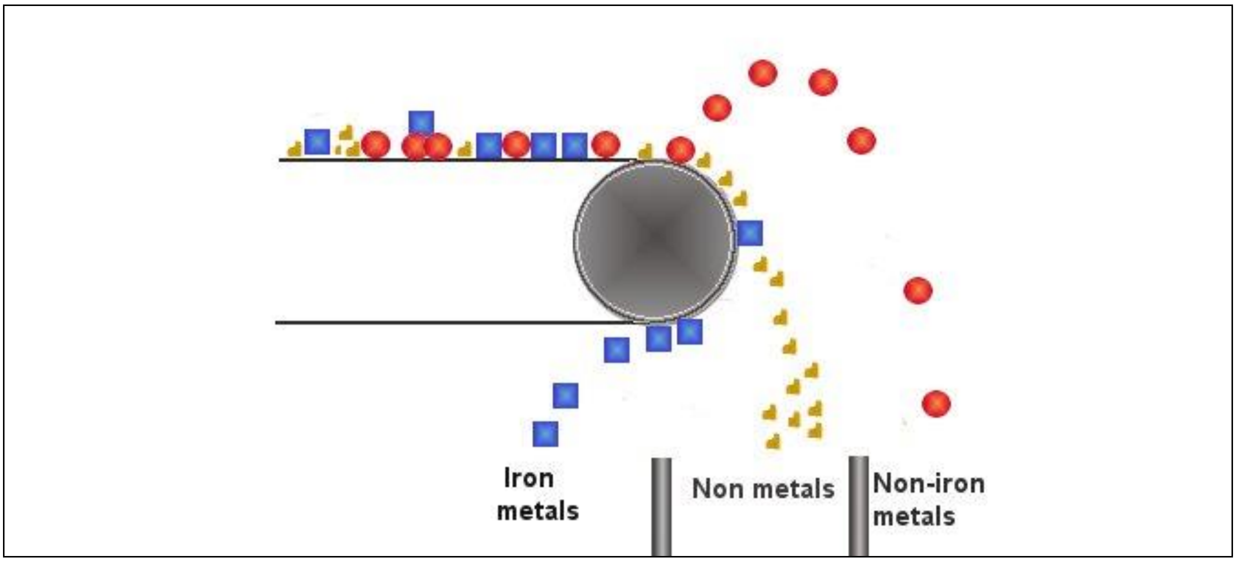


Figure 3.17: Eddy current separation, source: http://www.regulator-cetrisa.com/eng/products.php?section=r_spm (20.03.2016)

- The blue iron parts stick on the magnet and are dropped after leaving the drum.
- Non-iron metals are slung away by an effect of repulsion caused by the drum.
- All the other waste takes the normal route straight down the drum. (Thomé-Kozmiensky 2013)

Wind shifter:

To sort out light particles, a wind shifter is a common technique and its principle is shown in figure 3.18. An airflow blows the light fraction through the tunnel and the heavy fraction drops to the conveyor belt below. (Thomé-Kozmiensky 2013)

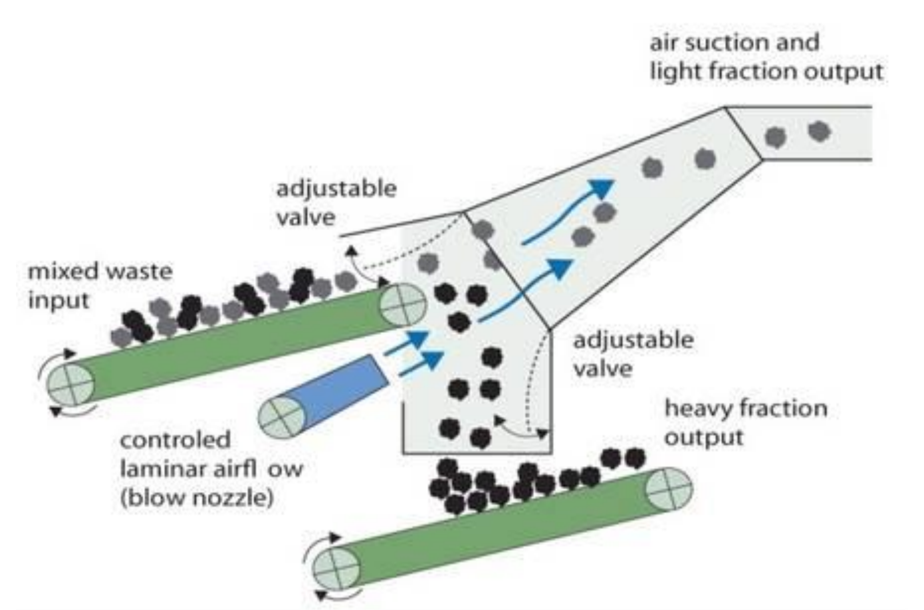


Figure 3.18: Wind shifter, source: http://www.nihot.co.uk/products/windshifters/diagonal-shifter/ (20.03.2016)

3.3.5.2 Separation example in Switzerland

Switzerland has already installed really good separation plants to sort the slag and bottom ash after incineration. One example for this separators is the company DHZ in Lufingen with a metal separation of 10% out of the total ash. (Thomé-Kozmiensky 2015)

Generally, most of the power plants have a wet discharging of the slag, the same applies for Switzerland (only 2 out of 30 discharging's are dry). For the slag (no matter if wet or dry) there is again the possibility to make a wet or dry preparation. Mostly the dry preparation method is used (also in the plant of DHZ). The so called "resource mining" technology at DHZ's plant has a metal recycling quota of 80-90% and in this way reaches a metal content lower 1% in the remaining slag. The sorting process is split up in three main parts which are described in the next lines (Thomé-Kozmiensky 2015):

1) A shredder breaks the slag lumps in smaller pieces with an overbelt magnet separation of the iron parts following. The remaining material is sieved in fractions of 0-3mm, 3-12mm, 12-40mm, and > 40mm, whereby the biggest fraction is sorted by hand. Parts >3 are separated three times by a sequence of eddy current separators and magnets. An additional wind shifter is used in the fraction of 12-40mm to sort out the organic stuff. Small parts <3mm are processed in the second step.
2) Sieving processes for wet parts smaller 3mm are not possible, because they clog the sieves meshes. So the materials are subject to a density separation which is done by

an acceleration machine. The output is a mix with high contents of non-ferrous and precious metals. This mix is again sorted by several non-ferrous separators.

3) The third step is an inward processing of the materials. Through the density separation the non-ferrous metals are split up in light and heavy metals which are detached from slag lumps and other contaminations, so that the output is nearly a pure non-iron fraction. Metals in such a purity can be sold directly to a smelting plant.

3.3.5.3 Rare earth element separation

REE concentration levels in ashes are three times lower than typical ore concentrations, so the separation of them is not a common process (Allegrini et al. 2014). The precious metal and REE content in ashes is suspected to rise, because of more customer specific products on the market containing different metals. In the future, when the market prices of gold and other precious metals will be higher the recovery will make sense, but yet it is not feasible. (Morf et al. 2013)

Magnet density separation:

In Amsterdam a pilot project is installed to recover gold, silver and REE out of ashes (<6mm) with concentrations of 10ppm for silver and 0,4ppm for gold. The magnetic density separation consists of many different sorting steps which are not explained in this thesis. Nevertheless the output of this project again gives conclusions of not being feasible yet. Before installing this complex separation the profit out of gold and silver selling was 3000 € per annum with standard techniques. By using magnetic density separation the profit was 5000 € per annum for the same plant with an input of 1,5 million tons of waste per year. (Muchova et al. 2009)

3.3.5.4 Other separation methods

The following described separation technologies are not standardised and frequently used, they are more examples of how the sortation in the future can be.

Pulsed Power technology:

This new technology can replace the shredder at the beginning of the sortation in an efficient way, because pulsed power technology separates the parts directly at the phase boundary and not only crushing them. So after the pulsed power technology the standardized ferrous and non-ferrous separation methods can be applied more efficiently. (Dittrich et al. 2015)

TITECH sorter (Deike et al. 2012):

TITECH has several separating technologies.

- TITECH-Finder is using a combination of an electromagnetic sensor and a recognition software to detect conductive objects on a conveyor belt and sort parts bigger than 1mm out of the ash.

- TITECH-X-TRACT exploits an X-ray sensor to separate light and heavy metals after an eddy current separation.
- TITECH-COMBISENSE utilizes a video camera to sort out the heavy metals (copper, zinc, stainless steel and coins) by means of size, form and colour.
- TITECH-AUTOSORT uses an infrared spectroscopic sensor to recognize individual spectral characteristic of particles.
- TITECH-X-TRACT (XRF): in future this principle wants to use X-ray fluorescence to sort metallic particles by its compositions.

Shooting wall:

When the slag is dry discharged than the slag does not have to be aged and can be handled directly. The principle of the shooting wall is an easy one, the small parts are shot against a hard wall with a defined velocity. Soft parts like lead do not spring back as harder parts do. (Deike et al. 2012)

RENE- Adapt-method:

The RENE process is used after an eddy current separation for particles sizes smaller 2mm and the recovery with the RENE method is divided into three steps. Its main focus lies on receiving aluminium and copper.

- Step 1: Dry mechanical separation to sort out bigger metal particles (2-0,5mm).
- Step 2: Wet mechanical separation of fine metal particles (0,5-0,16mm)
- Step 3: Wet chemical separation for heavy metal sorting (<0,16mm)

The recovery rate out of the sorted metal amount in this small part is 8% for aluminium and 50% for copper in the particle sizes lower 2mm. (Thomé-Kozmiensky 2015)

Fly ash recovery:

Also in the fly ash there is potential to gain metals like aluminium, copper, zinc, lead and cadmium. To get these metals among other technologies the washing of fly ash method or fly ash recycling method is possible. Using the fly ash recycling method, zinc with a purity of 99,99% can by recovered by electrolysis. (Meylan and Spoerri 2014)

The investigation of washing bottom ash and fly ash leads to the result that this method only makes sense for fly ash. Depending on the materials which want to be gained, the leaching process has to be adapted. For example in most cases zinc and copper are the desired metals and are recovered by other parameters than lead and cadmium. (Tang and Steenari 2016)

Flotation:

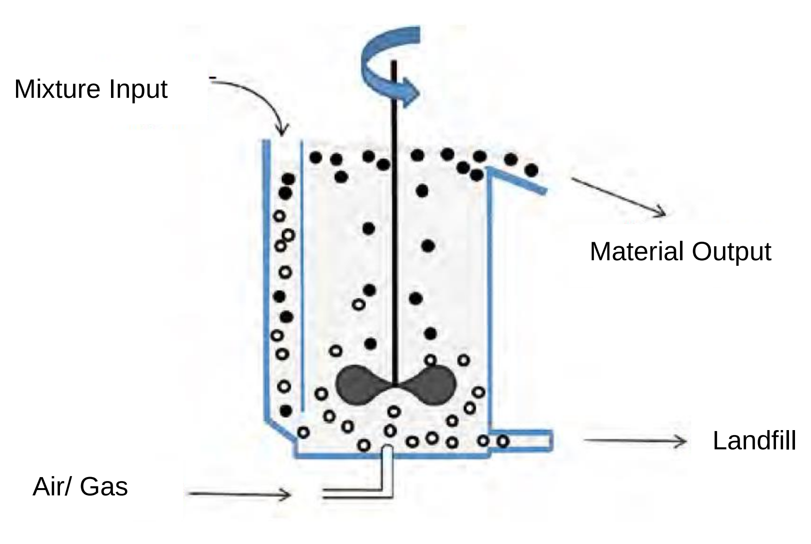


Figure 3.19: Flotation principle, source: Thomé-Kozmiensky 2013 page 303

Before the Ash is put in the fluid it has to be shredded and milled otherwise the success would be very low. Then the treated ash gets in the flotation process as depicted in figure 3.19 and due to the upstreaming air/ gas the particles like metals get in these bubbles and end at a foam layer at the top of the fluid. This foam including the intended particles is continuously deducted from the top. (Thomé-Kozmiensky 2013)

Usually additional chemicals to create more foam are not needed. Once the system is adjusted properly the particles can be sorted out with an extremely high degree of purity. These days the flotation process is typically used for separating interfering substances, but the application is getting more and more interesting for standard metal sorting out of bottom and fly ashes even though it is still a challenge yet. (Thomé-Kozmiensky 2013)

3.3.6 Landfill

After separating the ingredients of the bottom ash these different parts have to be treated in diverse ways. This subchapter describes the last ways of these products. Generally, the waste has to be landfilled and handled in a way that the next generations will not get any bad impact out of the disposal of nowadays. Even for landfilling it is important to get most of the metals out the slag because of chemical reactions of the metals during landfill. (Förstner 2012)

3.3.6.1 Usage of ash

After a good separation (when the slag compound is too high, the metals have to get rid of these compounds) by e.g. a mil the metals have a purity nearly as high as in primary production, so metals can be sold to different smelting plants or scrap merchants (Deike et al. 2012).

In figure 3.20 a typical usage distribution of bottom ash after the combustion is shown for the year 2009 in Germany (Alwast and Riemann 2010). Therefore the power plants dispose of or utilize their ash/ slag at 25% local, 55% regional, 11% nationwide and 7% Europe-wide (2% of the plant operators do not give information) providers (Trend Research 2014).

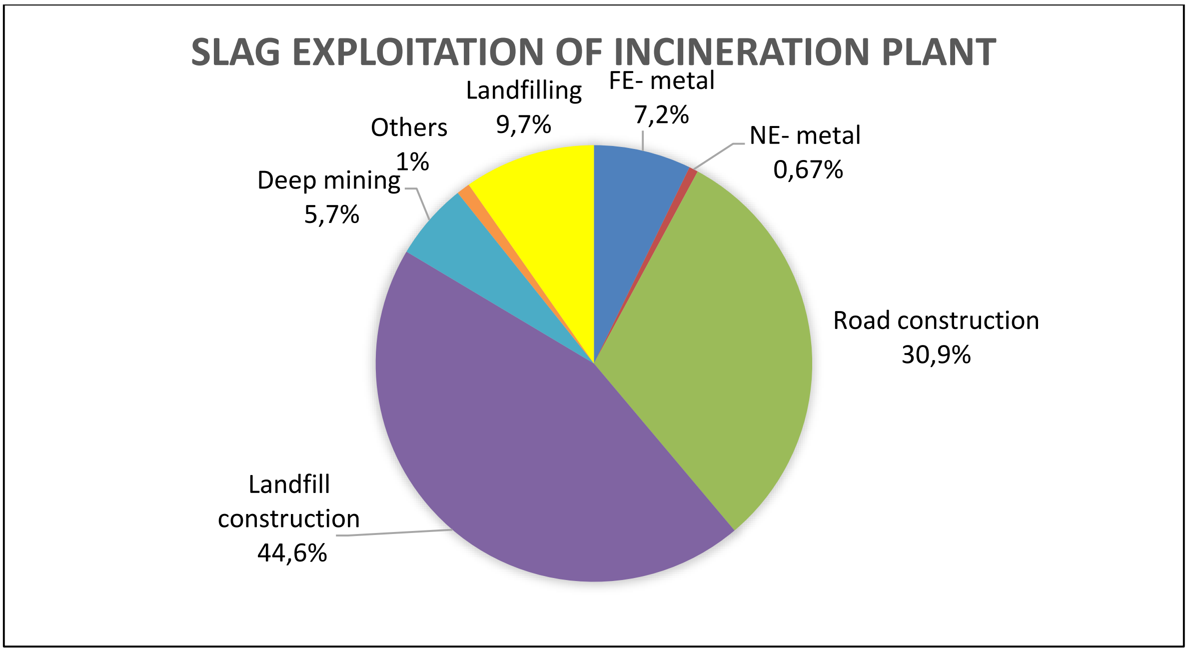


Figure 3.20 Slag exploitation of power plant operators in Germany, source: Alwast and Riemann 2010 page 20

Ash preparation companies have disposal strategies different from power plant operators like shown in figure 3.21. The geographical utilization of the prepared ash is 13% local, 13% regional, 27% national and 7% Europe wide (20% of the plant operators do not give information) which shows that this market acts in a bigger geographical range than mentioned before. (Trend Research 2014)

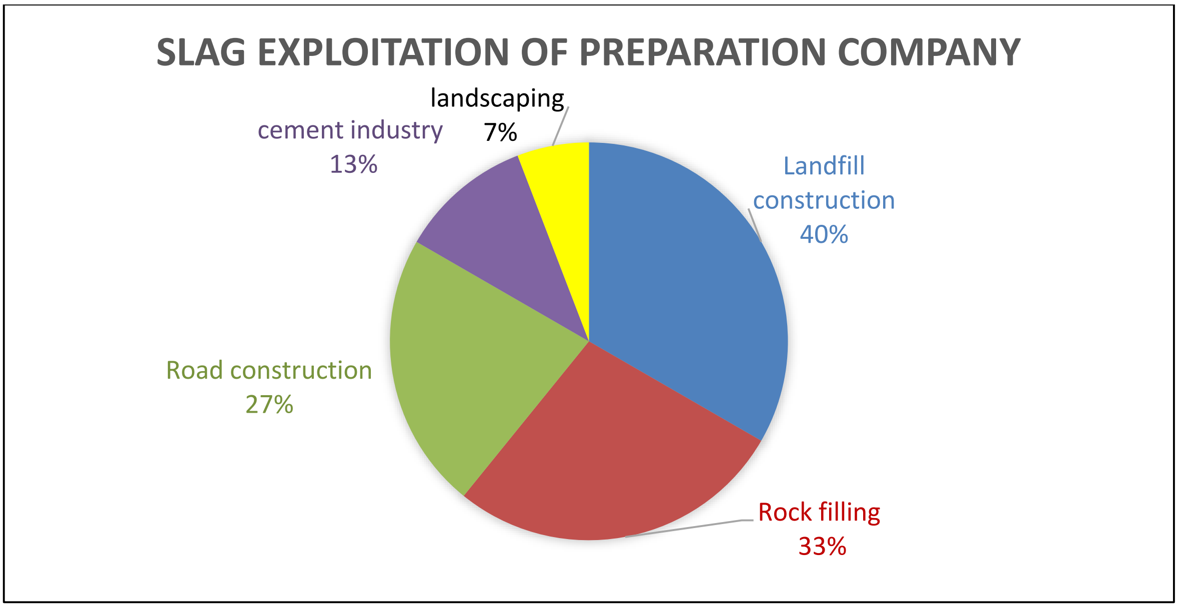


Figure 3.21 Slag exploitation of preparation companies in Germany, source: Trend Research 2014 page 283

3.3.6.2 Differences in countries

In Appendix 1 the waste treatment of the EU27 is listed. Split in the four different methods landfilling (untreated waste disposal above the ground), incineration, recycling and composting. In table 3.16 only the values of Austria, Germany, France and Bulgaria are shown. (Thomé-Kozmiensky 2015)

	Landfilling	Incineration	Recycling	Composting
Austria [%]	0	30	30	40
Germany [%]	0	38	45	17
France [%]	31	34	18	17
Bulgaria [%]	100	0	0	0

Table 3.16 Waste treatment in EU countries, source: Thomé-Kozmiensky 2015 page 216

3.3.7 Profit and Costs of ash

This subchapter gives information about the ways of how ash and slag can be disposed of concentrating on the costs involved as well as the possible profit from selling parts of the slag. Investment costs are also illustrated in this chapter.

3.3.7.1 Investment costs

The investment costs strongly depend on the size of the plant as well as the degree of processing and the linked separation technology. A simple separation in small plants has a cost minimum of 500.000 euros whereas in most cases the investment for these machines in bigger plants with better separation quotas is between three and five million euros. These numbers do not include the employee costs or other costs like maintenance or energy which are also needed after installing separation machines. (Trend Research 2014)

3.3.7.2 Ash exploitation costs and profit

As already mentioned in the pages above, there are many ways to dispose of and exploit combustion ashes. The various possibilities have different prices which are again not the same in all regions of a country (the following mentioned costs are for Germany in 2014).

To dispose of the whole amount of untreated ash (bottom ash and the ash out of the filter systems) to a separation company, the power plant operator has to pay about 30 euros per ton of total ash amount. The federal states Bayern and Nordrhein-Westfalen have higher prices because there are many more plants in these regions compared to the rest of Germany. (Trend Research 2014)

The disposal costs depend on the subsequent recovery method and the quality of the slag which can be influenced by the plant operator during the combustion process. Reaching a good quality needs a high burning temperature and a long time in the combustion chamber to reduce flightier heavy metal as well as not adding any boiler dust. Transfering the ash to a separation company needs a fulfillment of the legal frameworks. (Trend Research 2014)

A standardized metal separation after the cooling of the slag costs between 15 and 30 euros per ton of slag. After the preparation this ash has a purity to fulfill the laws that it can be used in rock filling and other disposal methods. If a more complex separation with combined slag washing, fractionating and aging (after the separation the slag is aged for three months to overcome the metastable state of the ingredients and due to this it can be used in every disposal variants) should be used the costs are 40 to 65 euros/ ton of ash. The main cost drivers are the energy needed, employees and maintenance/ abrasion of the plant components. (Trend Research 2014)

When selling the ash to road or landfill construction, the power plant operator gets a revenue of 16 euros per ton of slag whereas disposing of the slag by dumping brings along costs of approximately 6 euros per ton of ash. In general, the quality of separated metal after the incineration process is higher compared to separation of the residual waste, because after the combustion the adhesions on the metals are burnt. Moreover the metal recycling quota of about 90% out of the ash is very high. (Trend Research 2014)

Separated metals can be sold at a price of 20 to 30€/t ash. Here the revenues for FE metals are up to 100€/t and for NE metals up to 1200€/t. Please note that the scrap prices for ferrous and non-ferrous metals are very low at the moment and so can fluctuate extremely. In the last few years these prices have been halved till nowadays and thus the profit for separating metal out of the ash is not that high any more. (Trend Research 2014)

3.3.7.3 Logistical effort

Most of the power plant operators dispose of their ash at local or regional outside exploitation firms because of the high transportation costs. These transportation costs have again a bright variety because of the fluctuating fuel prices. Other parts of transportation costs are toll fees, personal costs and operating expenses. (Trend Research 2014)

Road transportation has an economic efficiency up to 200 kilometers and can be increased by return transportation. Railway transportation on the other hand has an economic efficiency starting at 200 kilometers and ship transportation starting at 300km. Differences between these transportation methods are the fact that railway and ship have a higher transportation volume and thus a lower price per ton. On the contrary trucks do not need a transshipment and temporary storage (which costs money) and are much more flexible. (Trend Research 2014)

Average transportation rates for all systems are between 0,08 and 0,20 euros per ton kilometers. (Trend Research 2014)

The main output of chapter 3.3 is that the metal content in waste is approximately 2,5%, whereby the iron content in the bottom ash is 7-10% and non-ferrous metals are approximately 2%. This are also the amount of metal which can be separated out of the ash, because the separation rate is nearly 100%. The most useful separation technologies are eddy current separation, magnets, sieves, wind shifters and for sure optical sortation. These separation is necessary to sell the ash to exploitation companies. To get a feeling which trends, chances and risks are actually at the market for power plant operators, external separation and exploitation companies, chapter 3.4 gives an overview.

3.4 Trends, chances and risks

Subchapter 3.4 contains the trends, chances and risks for power plant operators and exploitation companies. Therefore explanations as well as laws are mentioned.

Actually every power plant has some form of separation of metals after the combustion process, but nearly none of them is doing the separation on its own. External providers sort the metal out of the slag for them either at the area of the power plant by using mobile separation assets or on their own area. For the foreseeable future plant operators tend to use external providers. Metal separation not only leads to profit by selling the materials, but also to lower disposal costs because of the volume reduction and better usage for exploitation companies. (Trend Research 2014)

Modern separation plants have a separation efficiency of about 90%, sorting the other ten percent is neither ecological nor ecological and brings a high additional effort with it. Compared to the sorting of residual waste, generally the quality of the metals after the incineration process is much higher than the ones of sorted waste because most of the coatings and adherence are burnt there. Therefore the burnout of the slag is an important factor for quality. (Trend Research 2014)

Exploiting companies like rock filling or road construction are amenable to the laws and must do an aging process before using the slag as secondary product. For this purpose the ash delivered from the power plant has also to fulfil some quality standards. (Trend Research 2014)

Influencing factors for the price development of slag and ash concerning the profit of selling separated ash are the following (the order corresponds to the importance) (Trend Research 2014):

- Legal conditions
- Development of exploitation methods
- Commodity prices
- Development of disposal capacity/ costs
- Competitive development
- Transportation costs
- Landfilling capacity/ costs

Due to the introduction of the recycling bin, the amount of metal in the slag will be reduced slightly, which leads to a lower profit (assuming the same recycling quota) and therefore increasing costs exploiting the ash by a separation company. Landfill construction costs will also rise because in the future no more new dumps will be built and the existing ones are conformally secured. In the foreseeable future the possibility of landfill construction will be lost. Coming to a positive fact that in the near future metal prices will climb up again and lead to higher profit of selling separated metals. (Trend Research 2014)

Until the year 2011 the amount of ash and slag in Germany increased continuously, it will, however not rise in the same way within the next few years. Germany's power plants are working at high capacity at the moment so that the potential for further growth is technically limited. At the same time a the residual waste volume will decrease due to a generally better sorting of garbage and other factors which are listed below (the order corresponds to the importance) (Trend Research 2014):

- Development of waste volume (input)
- Capacity development
- Legal conditions
- No further construction of biomass heating plant
- Decreasing fuel quality

Slag separation companies will on the one hand have a competitive race on the demand side (slag of power plants) and on the other hand on the sales side (selling the separated products). (Trend Research 2014)

On the demand side, the slag separation companies compete for getting the slag. If the requested prices are too high, power plant operators will start separating their ash on their own because of the growing economic efficiency. Following that the separation companies try to design the prices in a way of getting as much money from the power plants as possible, but also stay in a price range not tempting the power plant operators to start separating on their own. (Trend Research 2014)

In western and southern parts of Germany, existing quarries deliver primary material for road and landfilling construction and thus the exploitation companies are prone to use primary instead of secondary materials. Federal states in northern Germany have a reverse relation. (Trend Research 2014)

Power plant operators see some success factors (or not) entering the market of in-house separation (the order corresponds to the importance) (Trend Research 2014):

- Commodity prices
- There are no success factors
- New ideas/ technology advantage
- Excellent offer on usually saturated market
- Marketing success

For sure there are existing and common market entry barriers (the order corresponds to the importance) (Trend Research 2014):

- Saturated market
- Legal conditions

- Cost- /revenue situation
- Uncertainties
- Decreasing acceptance
- No customers

Logically there are also some risks for power plant operators for entering the ash separation markets (the order corresponds to the importance) (Trend Research 2014):

- Legal conditions
- Market situation gets more difficult
- Price/ performance
- No risks apparent
- International market newcomers
- Scarcity of disposal channels

The amount of household waste and similar industrial waste in Germany will decrease on a long-term view due to the demographic decline. The number of single households however will increase which produce more waste. So this increase and decrease lead to a constant amount of waste. A quantity change of the various fractions will be sure because of the introduction of the organic waste and recycling bin. This leads to a higher number of organic waste and reusable materials (metal and plastics) but decrease the number of residual waste. (Trend Research 2014)

Energy and transportation costs have grown in the last few years. Transportation costs are main cost drivers for disposing of residual material which means that normally a regional exploitation company is chosen. Nowadays the oil price is low, but forecasts underline the rising prices in the coming years and due to this also the transportation costs will rise again, if there is no optimization of transport. (Trend Research 2014)

Some plans of power plants were rejected in the last few years through the economic crisis of 2008. Even in the following years various lines will be shut down and the implementation of formerly postponed projects is not realistic at all. Reasons for this are besides the difficult supply of the plant by municipal waste the negative price development of incineration and the communal effects of the politicians and the general public. For public acceptance a power plant would have to invest a too high amount of money to reduce emissions. So the coming years will not bring an extension of the power plant market. (Trend Research 2014)

For the second half of this decade the metal and commodity price is expected to rise again and due to a medium term economic growth, the need of secondary materials increase to get a cheaper alternative to expensive primary resources. Also new technologies on the separation market with higher recycling quotas will be expected. Even the separation of filter dust brings some new opportunities. (Trend Research 2014)

In connection with the efficiency increase of the separation facility and the stagnation of building new power plants there is the risk of declining amount of slag, ash and filter dust. On the one hand the extraction of secondary materials will get more lucrative due to the growing commodity prices, but on the other hand due to some new laws and the hesitant usage in public building there is some given risk of refinancing a new separation system. (Trend Research 2014)

Often plant operators do not dare to install additional separation systems because of the legal framework which strongly influences the future market of slags, ash and filter dust can be (Trend Research 2014):

- Regulation for substitute materials
- Stricter federal laws
- Landfill regulation
- Federal Emission Control Act and law for power plants
- Renewable energy law
- Stricter EU guidelines
- Law of recycling economy

An actual trend goes in the direction of dry discharging, however this method actually does not play a main role in the German market, compared to the pioneers of Switzerland. Changing from dry discharging to wet discharging includes a high investigation sum, so that a cost-benefit analysis has to be done. (Trend Research 2014)

The development of ash separation technologies deals with gaining a better sorting depth. Therefore a higher degree of automation is strived for. Near infrared spectroscopy and X-Ray transmission are the most touted technologies for automation, sorting smaller particles out of the slag and reaching a better quality. (Trend Research 2014)

4 Practical problem

Chapter 4 describes the practical part of this thesis and is structured in four parts. The contents are the strategy of how the thesis was done and the data was gained, the lifecycle management of metals in waste describing a typical way from an aluminium part before and after the incineration process, the economic calculation of separating metals on the plant and the last part is the discussion of the results.

4.1 Strategy of information procurement

Here the methodology and procurement of how the information for this thesis was gained are described on the next pages.

4.1.1 Clarification of company standpoint

First of all ANDRITZ has to define its standpoint concerning the separation technology. The main focus is not on being the cheapest or offering the best or the most different technologies, but to give their customers the service to offer them a full plant technology including the last step of an power plants task which is separating the ash. Therefore ANDRITZ does not want to develop new methods of how to separate ash, because there are already enough technologies on the market which can be used. So ANDRITZ wants to buy the existing technologies like eddy current separation, magnets and other variants from external companies and integrate and install them at the plants. These add-on devices can be integrated at already existing power plants as well as on power plants which are at a planning phase.

ANDRITZ does not want to compete with external separation companies and open their own separation plants, however they want to offer their customers (power plant operators) the possibility to sort the ash on their own at their site. So the clarification as mentioned in chapter 3.1.2 of being a Discounter, Specialist or Generalist is not necessary.

However defining the brand steering wheel brings some benefits with it and is depicted in figure 4.1. The brand competence is the well-known company reputation of ANDRITZ and the performance promise for their excellent products and services.

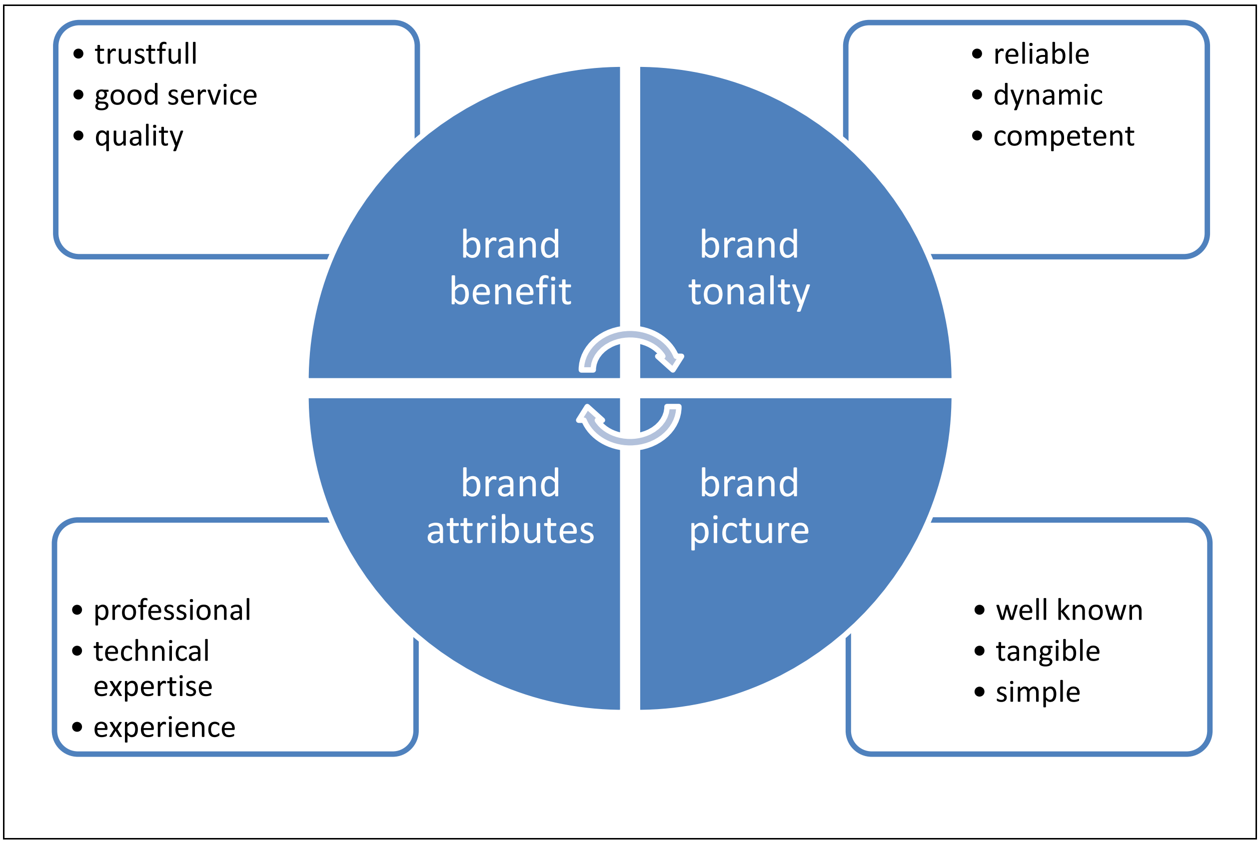


Figure 4.1: Brand steering wheel for additional service at ANDRITZ, source: own figure

4.1.2 The seven market phases

As mentioned in chapter 3.1 there are seven steps of creating a market analysis. Step one and two can be seen as the research focus, step five and six can be seen as the research methods. Therefore in the practical part no additional division is carried out for these parts, but it is included in the seven steps.
The next lines explain how the market analysis was done in this thesis and how the data was collected.

1) Definition of investigation problems:

   This very important first step is responsible for the ongoing success of the research and at ANDRITZ the main aim is getting to know if a separation of the ash after the incineration process at the plants side causes a loss or leads to profit.

2) Determination of the aim of analysis:

   The focus of the main target question was, as mentioned, to know if an in-house separation has a profitability or not. Therefore some sub-aims have to be answered like which separation technologies do exist on the market for resource recovery and their success rates. Another aim is getting information about the ingredients of the municipal waste and the ash focusing on the metals as well as knowing which companies act on the separation and exploitation market. The last part is collecting data about the profit and loss situation of separating the ash by the power plant operator. For the whole step two and the market segmentation, the descriptive investigation method is used. The market potentials for the separation market can be determined as a young market because nowadays only few plant operators separate the ash on their own.

3) Determination of research design:

   In step three the research design is fixed and for this thesis the secondary market research is used more than the primary research. Only some interviews are done, but this issues are described later on in step five.

4) Development of measuring instruments:

   The development of the measuring instruments is not used in this thesis because the research design is created to get the data out of secondary market research and not by e.g. a questionnaire. By doing so the development of measuring instruments is not necessary.

5) Data collection:

   The data for this research area mainly come from the secondary (indirect) market research by internal as well as external sources. Therefore different books and publications of universities and other research teams have been used. Generally most of the data are collected by the indirect market research (internet research, publications of associations, data of federal statistical offices, and evaluation of trade journals). The strategy is first of all getting a feeling of how the whole municipal waste market and the incineration processes work and then collecting data in the different fields. It starts with the municipal waste ingredients, before the ingredients of the bottom ash focusing on the metals are collected and analysed.

   The following step deals with determining information about the separation technologies on the market concentrating on the German market. After this information has been gained the next step in the chain are the exploitation possibilities and usage rate of the different types. The last important step is to collect the market prices of separation and exploitation methods of the slag.

6) Data analysis:

   For the data analysis no specific software is used, only standard tools like the Microsoft Office package. The analysis was done by the author of this thesis and the main output is written in chapter 4.4

7) Report:
   A report for the market analysis is so to say the whole content of this master thesis and therefore not additionally done.

4.2 Lifecycle management of waste

To summarize and understand the lifecycle of metals described in chapter three, this subchapter gives information about the lifecycle of objects starting at the production and ending up at the final destination e.g. exploitation of landfilling construction. Therefore the author has chosen an example of an aluminium box shown in figure 4.2.

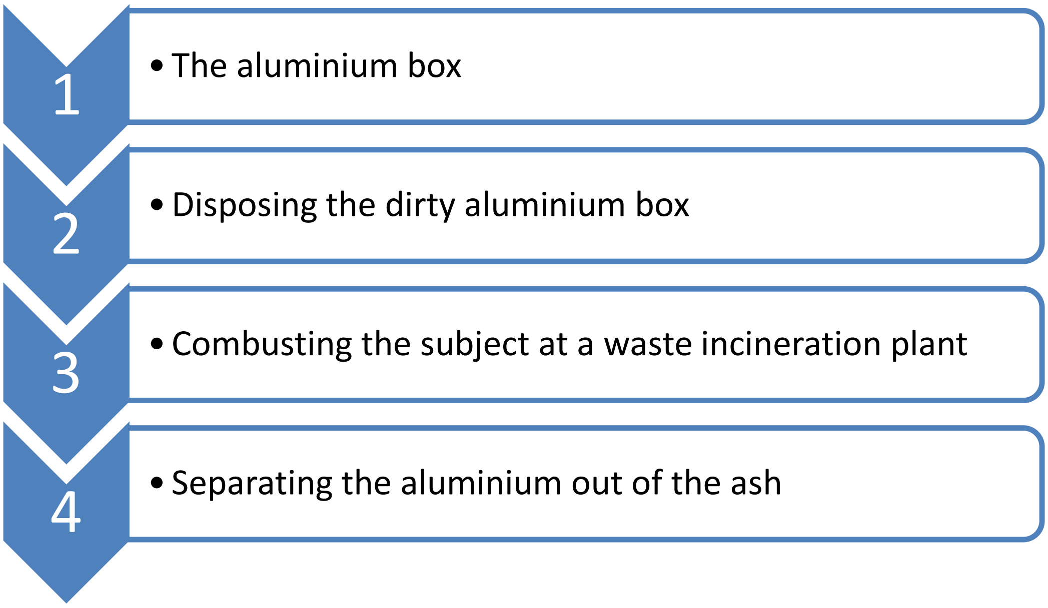


Figure 4.2: Life journey of an aluminium box, source: own figure

The very first step of the lifecycle would have been the gaining of the aluminium out of the mining, which is not part of the research area of this thesis.

In the following lines the six steps mentioned above are explained more in detail:

1) <u>The aluminium box</u>

   For sure the aluminium box is just an example and there are lots of other objects in the residual waste which lead to the same steps. Possible alternatives would be e.g. aerosol cans, screws, copper coins and so on (compare table 3.10). There are similar steps for plastics or glass and other materials, which are not content of this research field. Mostly the metals are combined with food or other materials.

2) <u>Disposing the dirty aluminium box</u>

   There are many ways to dispose of this aluminium box. The most environmentally friendly way would be washing and cleaning the box from food remains and then dispose of it at a local recycling centre. Living in a flat in a bigger city (like most of the people) this is sometimes not possible because such local recycling centres are normally only placed at countryside regions. So the best way here is to clean the box and then throw it to the metal container were all kinds of metals are thrown in.

Unfortunately, the majority of people dispose of their dirty aluminium as well as any other used and polluted metal in the residual waste container. From this moment on the box starts its journey to the combustion chamber.

3) Combusting the object at a waste power plant

    a) Stoker fired furnace

    At a stoker fired furnace plant the municipal waste and any other kinds of waste are brought to the plant as they are. The contents typically are not treated, shredded or separated before and reach from small tissues up to half washing machines. At such plants the burning temperatures are higher and the burning period is longer compared to the fluidized bed combustion. After the combustion the hot slag is normally wet discharge. Due to the high temperatures and wet discharging, it is harder to sort out the metals.

    b) Fluidized bed combustion

    The input of a fluidized bed combustion can also be all kinds of waste, even sewage sludge, but the waste has to be shredded before coming to the combustion chamber, because otherwise the particles are too heavy and are not able to fly in the sand bed. This shredding step is sometimes combined with a rough iron separation step. After the combustion the hot ash is dry discharged in most cases. Generally, the separation after the fluidized bed combustion process is easier and more efficient than after the stoker fired furnace process.

4) Separating the aluminium out of the ash

    As mentioned in step five, there is a difference of sorting out metals or other materials after the two combustion types. In general, the ash must be separated after the incineration process either at the plant or by external separation companies. If the ash is not separated, the exploitation companies do not take the ash for several reasons. For example the ash cannot be used for road construction when it contains foreign objects. The other exploitation methods like landfilling construction or rock filling or cement industry also need separated ashes and do not separate the ash on their own. To sell the ash or give it to external separation companies it must have a size between 0-32mm. Bigger parts are separated by sieves and sold or exploited by the power plant operator. For selling the gained metals (ferrous and non-ferrous) they have to be pretty clean, which is given after the incineration process, because most adhesions are burnt. Customers that buy the sorted metals are iron producing companies or similar smelting plants for non-ferrous metals like aluminium, copper and so on.

The transportation between the steps is normally done by trucks. All in all it is a long way for the metals from one smelting plant to the next one, but the quality and usability stays the same over the time.

4.3 Economic calculation

The following pages contain the four static investment appraisals already discussed in chapter 3.2, calculated for the ash separation in three scenarios. Scenario one uses the actual metal prices, scenario two uses lower prices and scenario three, the most realistic one, increasing metal prices.

Before the calculation can be started the actual average scrap prices for ferrous and non-ferrous metals are listed in table 4.1 for May.2nd.2016 as well as the other two scenarios.

- Scenario 1: actual scrap prices
- Scenario 2: 30% lower prices for the decreasing tendency
- Scenario 3: 150% of the actual prices for the near future which is the forecast and substantiated by experts of ANDRITZ AG.

Metal type		**Scenario 1**	**Scenario 2**	**Scenario 3**
Iron	[€/kg]	**0,02**	**0,014**	**0,03**
Aluminium	[€/kg]	0,6	0,42	0,9
Copper	[€/kg]	3,5	2,45	5,25
Tin	[€/kg]	6	4,2	9
Average non-ferrous	[€/kg]	**1,2**	**0,84**	**1,8**

Table 4.1: Metal scrap prices, source own table

For the average non-ferrous scrap price the amount of each metal in the ash is considered, but these prices have a daily and weekly fluctuation. The average value is needed for simplifying the ongoing calculation and does not influence the result.

4.3.1 Cost comparison calculation

This subchapter gives information about the cost comparison calculation for internal ash separation. The acquisition value is for a separation technology for middle sized fluidized bed combustion plants with 200.000 tons of waste per annum (30.000 tons bottom ash). Assuming a good resource recovery rate by investing in several technologies. The costs for disposing the output of the other filters are not considered because this costs do not change if an internal bottom ash separation is done or not and for bottom ash the power plant operator gets money from the separation companies. The running internal separation costs are calculated with 20€/ ton (compare chapter 3.3.7) with 30.000 tons of bottom ash per annum. These costs are for energy, employees, maintenance and wear parts. External calculation costs, with good contracts and no former separation, which leads to better conditions with the separation company because of better ash ingredients, are calculated with 30€/ ton of ash.

The acquisition costs include the following technologies:

- Ferrous metal separation
    - Different magnet systems
- Non-ferrous metal separation
    - Eddy current separation
    - Wind shifter
- Conveyor system
- Transportation units
- Electronical devices
- Different sieve technologies
- Installation
    - Devices/ material
    - Manpower
- Bottom ash removal
- Spare parts
- Wear parts

For scenario 1, 2 and 3 the same investments have to be done.

Table 4.2 shows the difference between internal and external ash separation. The result has a big difference, because there are no costs for external separation. The acquisition costs can be lower as well as higher and the lifetime is hard to estimate because this strongly depends on the quality of the separation machines and the waste type which is combusted. Another influencing factor is the discharging method. Dry discharging is easier to handle than wet discharging.

Costs		Scenario 1/2/3	External separation
Acquisition value	[€]	3.000.000	0
Lifetime	[year]	10	0
Depreciations	[€]	300.000	0
Interest rates (5% of Acquisition value)	[€]	150.000	0
Capital costs = fixed costs	[€]	450.000	0
Running separation costs	[€/t]	20	0
External costs for separation	[€/t]	0	0
Amount of ash	[t]	30.000	30.000
Sum variable costs	[€]	600.000	0
Sum total costs	**[€/a]**	**1.050.000**	**0**

Table 4.2: Cost comparison calculation, source: own table

Due to the fact that logistical costs occur for transporting the unsorted ash to the separation company as well as for transporting the sorted ash to the exploitation companies, these costs are not taken into account.

For sure smaller power plants have cheaper investment costs for the sorting machines, but also have much lower variable costs. All in all this calculation has a strong variety, but the way of external separation includes much less risk than the internal separation because of the very high fixed costs.

4.3.2 Profit comparison calculation

In this calculation the same values of ash amount and costs are chosen as for the cost comparison calculation example before, but the profit comparison calculation includes all three different scenarios for the price development. Some power plant operators have contracts with the external separation companies for getting the sorted ash back to sell it, but this is not the rule. This could depend on the regional exploitation companies if there the ash is a cost factor or it is possible to gain money with it (compare chapter 3.3.7.2).

In this example the ash can bring profit with it, but not the full 16€/t of ash for selling it to the road construction. To get a realistic mean value, a profit of 5€/t is considered. For the external separation a profit of 10€ for the bottom ash is a realistic value. This value is gained from experts of ANDRITZ which have contacted some power plant operators.

The amount of iron is estimated with 6% of the ash which leads to 1800 t/a and the non-ferrous metal with 2% (good separation technology is taken for granted for the high investment costs) lead to 600 t/a . In table 4.3 the calculation for the profit comparison method is done.

The values for the costs are the same as in table 4.2 and not written in the following table.

Costs		Scenario 1	Scenario 2	Scenario 3	External separation
Sum total costs	**[€/a]**	**1.050.000**	**1.050.000**	**1.050.000**	**0**
Profit per ton of sold ash	[€]	-	-	-	10
Profit per ton of separated ash	[€]	5	5	5	-
Profit per ton of iron	[€]	20	14	30	0
Profit per ton of non-ferrous metal	[€]	1200	840	1800	0
Amount of separated ash	[t]	27.600	27.600	27.600	30.000
Amount of iron	[t]	1800	1800	1800	0
Amount of non-ferrous metal	[t]	600	600	600	0
Revenue *	[€]	**894.000**	**667.200**	**1.272.000**	**300.000**
Profit **	[€]	**-156.000**	**-382.800**	**222.000**	**300.000**

Table 4.3: Profit comparison calculation, source: own table

*Revenue scenario 1= 5*27.600+ 20*1800+ 1200* 600 = 894.00

**Profit= Revenue- Sum total costs

The profit comparison calculation leads to a better result than the cost comparison calculation, because scenario 3 nearly reaches the profit of the external separation. Investing in an in-house separation system on the plants site brings no real benefit with it. Comparing the results in this calculation figures out the big difference between the external and internal separation and shows how the separation companies earn their money. Of course this calculation only includes the depreciation rate and not the full price for the whole investment.

4.3.3 Amortization calculation

Here again the same values are used as in the calculations before. The amortization calculation is done for the scenarios 1, 2 and 3. For the external separation this does not make sense. For the calculation the residual value is taken as zero because after the usage time the separation machines do not have a real residual value and therefore the conservative consideration is taken.

As already mentioned in the theory part, the amortisation time is calculated as following:

$$Amortisation\ time = \frac{capital\ investment - remaining\ value}{average\ backflow}$$

However the average backflow is needed to calculate the amortisation time and is defined as follows:

$$Average\ backflow = revenue - costs + depreciations + interest\ rates$$

Table 4.4 therefore illustrates the amortization calculation for all three scenarios.

Costs		Scenario 1	Scenario 2	Scenario 3
Acquisition value	[€]	3.000.000	3.000.000	3.000.000
Capital investment costs	[€]	3.000.000	3.000.000	3.000.000
Residual value	[€]	0	0	0
Capital investment - residual value	[€]	3.000.000	3.000.000	3.000.000
Revenue	[€]	894.000	667.200	1.272.000
Sum total costs	[€]	1.050.000	1.050.000	1.050.000
Depreciations	[€]	300.000	300.000	300.000
Interest rates	[€]	150.000	150.000	150.000
Average backflow	[€]	294.000	67.200	672.000
Payback period	**[year]**	**10,20**	**44,64**	**4,46**

Table 4.4: Amortisation calculation for the separation technology, source: own table

The result from table 4.4 shows that the payback period for the scenario 3 is pretty short so that the capital investment comes back very soon to the power plant operator and does not bring a high risk with it. Scenario 1 and 2 on the other hand has a high payback period (nearly as high as the lifetime or higher), which means that the investment does not make sense, because the investment is too high. Even if the payback period of scenario 1 would be a little lower than the ten years of lifetime, the machine can break down earlier or the variable costs increase, so the investment in scenario one is connected with a high risk.

4.3.4 Profitability calculation

The last part of the economic calculation is the profitability calculation and is done in this subchapter. Therefore the profitability has to be determined again:

$$Profitability = \frac{profit}{used\ capital} * 100$$

Getting to the profitability also needs the so-called turnover ratio which is defined as follows:

$$Turnover\ ratio = \frac{revenue}{used\ capital}$$

The costs, profit, amount of ash and all the other assumptions for the profitability calculation are again the same as in the previous examples. In table 4.5 the profitability calculation and the associated results are depicted.

Costs		Scenario 1	Scenario 2	Scenario 3
Sum total costs	[€/ a]	**1.050.000**	**1.050.000 €/ a**	**1.050.000 €/ a**
Profit per ton of separated ash	[€]	5	5	5
Profit per ton of iron	[€]	20	14	30
Profit per ton of non-ferrous metal	[€]	1200	840	1800
Amount of ash	[t]	27.600	27.600	27.600
Amount of iron	[t]	1800	1800	1800
Amount of non-ferrous metal	[t]	600	600	600
Revenue	[€]	**894.000**	**667.200**	**1.272.000**
Profit	[€]	**-156.000**	**-382.800**	**222.000**
Revenue profitability	[%]	-17,45%	-57,37%	28%
Turnover ratio*		0,3	0,22	0,42
Profitability**	[%]	**-5,2%**	**-12,76%**	**7,4%**

Table 4.5: Profitability calculation for all three scenarios, source: own table

*Turnover ratio scenario 1= 894.000/ 3.000.000 = 0,3

**Profitability for scenario 1= -156.000/ 3.000.000= -5,2%

As table 4.5 shows, the profitability for scenario 1 and 2 is not given or negative. Only for the scenario number 3 the profitability is positive. The turnover ratio is pretty bad for all three scenarios which means that e.g. for number 1 only 30% of the investment costs flow back to the company.

For the rationalisation investment, the calculation looks as follows:

$$Profitability = \frac{(variable\ costs\ old - variable\ costs\ new)}{investment\ costs}$$

Comparing the internal separation with the external one, the profitability comes to the following result:

$$Profitability = \frac{(0 - 600.000)}{3.000.000} = -20\%$$

This profitability is the same for all three scenarios because the difference between the scenarios is only the metal price and this fact does not influence the acquisition value of an internal separation as well as contracts with external separation companies. So the general profitability is not given even for scenario 3.

4.4 Separation of refuse-derived fuel ash

ANDRITZ got a sample of ash from a refuse-derived power plant with dry discharging. This sample was sorted at the laboratory with an optical sortation, a tweezer and a standard magnet (figure 4.3).

Figure 4.3: Sorting tools, source: own figure

Figure 4.4 shows the fine bottom ash sample which was not further investigated because the particle size is too low.

Figure 4.4: Bed boiler sand, source: own figure

Figure 4.5 shows a rough bottom ash which was separated. The separation of non-ferrous metals was done optically while the ferrous sortation was done optically as well as by magnet.

Figure 4.5: Bottom ash, source: own figure

Due to the worse separation conditions the recovery rate is estimated at 75%. This means that 25% of the metals in the ash were not found, non-ferrous metals as well as ferrous metals. The main iron parts are the big parts which were already sorted previously by the plant operator. Figure 4.6 depicts some sorted metals out of the ash.

Figure 4.6: Metal scrap, source: own figure

The ash does not only contain screws, wires and other metals, but also small particles out of ash as shown in figure 4.7.

Figure 4.7: All metal parts, source: own figure

The result was approximately 3% metals out of the whole amount of ash. Reasons for the low percentage are the already mentioned ones, as well as the fact that for refuse-derived fuel the amount of metals is a little bit lower because of previous shredding and sorting. Another factor is that this was only one sample from one day from one plant, so the variety is very high.

4.5 Discussion and analysis of the results

The discussion of the results contains the separation before and after the incineration process as well as the incineration process itself and the exploitation methods. Last step is the analysis of the economic calculation and reflects the decision of investing in an internal separation technology or not.

4.5.1 Separation before the incineration process

Walter Hauer, an Austrian branch expert shared his experiences, that by eddy current separation it is technically possible to separate non-ferrous metal (mainly aluminium) before the burning process with a success rate of 25-50%. Actually this technique is hardly installed in any power plant. It is not possible to make an exact statement who separates the metals out of the garbage.

Sometimes plant suppliers separate the metals out of the waste and in some other cases the plant operator ensures that the metal separation is done at the plant. This means that before the combustion process is started in most power plants, especially by fluidized bed combustion, a part of the metals have already been sorted out. Also the decision of what is separated (only ferrous or ferrous and non-ferrous) and the separation rate strongly depends on the separator’s philosophy.

In general, the separation of metal out of the municipal waste makes sense before and after the combustion process. Prior to the incineration process the small metal parts or metals with a low melting point are not steamed or burnt like metals separated after the process and thus not usable any more. But the other point of view is that the amount of ash is lower than the amount of garbage, so sorting is easier and metals have a better quality after the combustion process, because adhesions like food or other stuff are burnt. The fact that before the combustion process starts, the amount of metals in the input is approximately 2,5% and after the incineration process the number is approximately 10% substantiates this statement.

4.5.2 Incineration process

There are two different ways of combusting waste, the fluidized bed combustion and the stoker fired furnace. In stoker fired furnace plants all kinds of waste in all different sizes can be burnt and does not need any previous sortation. Thus most power plants in Germany and

Austria belong to this kind of plants. The negative aspect is that normally the wet discharging method is used which leads to more difficult separation and worse recovery rates.
Fluidized bed combustion plants need shredded waste for the combustion process, but the burning temperatures are lower and so less metals are burnt. Typically the dry discharging method is used after this process which leads to better sortation quotas. The sizes of fluidized bed combustion plants can also be bigger than the ones of stoker fired furnace. Refuse-derived fuel plants are usually fluidized bed combustion plants because here the garbage has to be shredded anyway. ANDRITZ has specialised on the fluidized bed combustion systems.

4.5.3 Separation after the incineration process

Most of the mentioned separation technologies like the TITECH sorters or the shooting wall, RENE method or flotation are not economic at the moment. The recovery rate is better than for the common ones, but the costs and effort of reaching this are much too high yet. Also the fact that with actual separation a 90% recovery rate is reached and the high additional costs for these technologies reaching some more recovery quota is not attractive.

The economic and frequently used technologies are the following:

- Magnets
- Sieves
- Optical separation (only human separation is standard, the automated one not yet)
- Eddy current separation
- Wind shifter

The reason why these methods are typically used are the facts that they are cheap, easy to adopt and easy to handle. For the future other separation technologies sorting smaller pieces and also REE out of the ash will become more important for example due to the increasing metal prices.

Slag after the incineration process consists of approximately 8% of iron and nearly 2,5% of non-ferrous metals, whereby the iron recovery rate due to its simple separation technique is nearly 100% and the NE metals reach 80-90%. Two thirds of the non-ferrous metal is aluminium and the rest is copper, tin, zinc, lead, titanium and other materials.

At the moment most of the power plant operators separate their ash by external separation companies, because they fear the high investment costs and the bad market prices for metals. Minimizing the costs of this external separation companies is done by contracts with local or regional providers, because here the transportation costs are lower. For the future considering growing metal prices again due to several reasons and better separation techniques will reduce the risk and thereby lead to more internal separation of the ash.

4.5.4 Exploitation possibilities

There are many ways of exploiting the incineration output, but typical exploitation possibilities are the following:

- Road construction
- Landfill construction
- Cement industry
- Rock filling
- Landscaping

These and other methods need separated ash and cannot use slag containing foreign substances or metals because of technical aspects and also legal aspects given by the country's specific or EU specific laws.

The rates of the exploitation strongly depends on the distance between power plant and exploitation company. Therefore usually regional or local providers are chosen to minimize the transportation and thereby the total costs.

4.5.5 Economic calculation

This chapter describes and interprets the results of the economic calculation and how to deal with it in practical usage. There for, the market prices of ferrous and non-ferrous metals are very important, thus the three scenarios were chosen. The results are for middle sized power plant with an annual amount of 30.000 tons of bottom ash per year.

The cost comparison calculation came to the result that the annual costs of internal separation are very high and the separation by external providers does not lead to costs. So this solution strongly recommends the external separation. To make sure this is the wright decision, another three calculations are done.

The profit comparison calculation gives also information about the profit or loss which can be made by the two different ways of separation. External separation leads to a profit of 300.000€ per annum whereby only the profit of scenario 3 has pretty the same result, the other two scenarios lead to a high loss for in-house separation.

Separating the ash internally unfortunately is connected with pretty high fixed and variable costs, but has the advantage of selling the sorted ferrous and non-ferrous material and gaining money by selling these materials and the separated ash to exploitation companies. In two scenarios the company makes also a loss by doing so. Scenario 3 which assumes better market prices for the metals leads to a respectable profit, but does not make a really big difference between internal and external separation.

The payback period of scenario 3 is pretty good and an investment would really make sense. But the other two scenarios do not show a good payback period, whereby scenario 2 will not payback because this time is longer than the lifetime of the machine.

The last part of the calculation deals with the profitability of the internal separation and results in negative values for scenario 1 and 2. Scenario number three has the only positive profitability. Unfortunately, all three scenarios have a bad turnover ratio. Considering that the only alternative is handing the ash over to external providers for the sortation order suggests deciding for an external separation because even scenario three does not result in a good reason to invest in an internal separation.

5 Conclusion and prospects

The last chapter contains the conclusion and the forecast of the power plant and ash separation market for the next few years.

5.1 Conclusion

The conclusion of this thesis is that the internal separation of metals after the incineration process does not make sense for any power plant, does not matter if a big or small one. Bigger plants could also sort ash of other local power plants which often belong to the same owner. Thus the investment costs have a shorter payback period. Increasing metal prices in the future and better separation technologies will make the power plant operators think about investing in an internal separation system to save costs and gain money by selling the metals and the separated ash.

At the moment the metal prices are too low to decide for such a big investment and it only makes sense if the ash of other plants can also be separated and the scrap prices increase. The fixed costs as well as the variable costs are very high and the breakeven point is hardly ever reached. So power plant operators should wait till the metal prices have reached a higher level again.

5.2 Prospect

The prospect describes the development of the metal prices and its mining forecast as well as trends for power plant operators, separation and exploitation companies for the near future. Last part of the prospect is the description of the next steps of ANDRITZ.

In the future the availability of global reserves will get less due to the political and economic aspects and will increase the metal prices significantly so that the gaining process of ore with less metal content will get economic.

Reasons for this are the fact that only 1% of the rare earth elements are recycled and the dependency on China with a production of more than 90% of all REE in the world. Forecasts suggest reducing export quota of China because of own usage and thus the risk of too much reliance is given. A REE separation after the incineration process will have an effect contrary to this problem.

The resource recovery of REE, Au and Ag are technically possible nowadays, but the related costs are too high to use these technologies. Also the recovery rate is too low at the moment and therefore not economical. Due to the higher usage of these metals in the future also the amount in the waste and thereby in the ash will increase. So the resource recovery will make more sense and reduces the risk of losing these important materials which cannot be reproduced by the earth as fast as they are mined.

The metal separation quota out of the ash will grow over 100% in the future because of better separation techniques which are at the moment at the test phases. But not only better separation techniques cause this phenomenon, also the fact that very small metal particles can be sorted out which are not detected as metal before because of their small size. Clothes hangers, umbrellas and other materials containing a minor part of metal compared to the whole are not detected as metal but lead to some metal after the incineration process.

The amount of municipal waste in Europe will stay nearly the same in the next decades. On the one hand the birth rate is declining but on the other hand the number of single households is growing so this keeps a balance. For the amount of metal in the garbage, the forecast is also constant. The general separation of waste with sorting out glass, paper, plastics, metals and other materials will increase, however the amount of ferrous and non-ferrous in the waste will therefore also rise and compensates the better separation of garbage before the combustion process.

Prospects for power plants:

To minimize exploitation costs by increasing fuel and thereby transportation prices, the importance of contracts with regional companies will get more relevant.

If the power plant operator decides to separate the ash externally the following aspects have to be considered:

- Reduction of the costs due to long-term contracts with separation companies
- Lower costs for the separation by using regional partners
- Listing possible partners and decide due to negotiation results
- Constant costs by subscribing long-term contracts
- Consider market forecasts for cheaper or more expensive separation companies in the future.

If the power plant operator decides to separate the ash internally the following aspects have to be considered:

- Building own capacity for ash separation and search for long-term regional partners and customers
- Estimation of the annual amount of ash for better planning
- Economic calculation and comparing the offers for separation technologies
- Additional profit by selling ferrous and non-ferrous metals
- Separated ash can be sold to exploitation companies
- High investment costs and effort

Prospects for exploitation companies:

Also the exploitation companies have the possibility to start separating the ash in the future. So they do not have to buy the expensive separated ash from the separation companies but can gain money from the power plant operator for unsorted slag and additional money for selling the metals.

Prospects for ANDRITZ:

With the finished thesis ANDRITZ has a broad basis for offering their customers the additional separation possibility. They can explain to the customers how separation works, how much of the metals can be sorted out of the ash as well as how much profit is possible with the amount of the power plant's ash. Unfortunately the additional service of providing separation technologies does not make sense these days.

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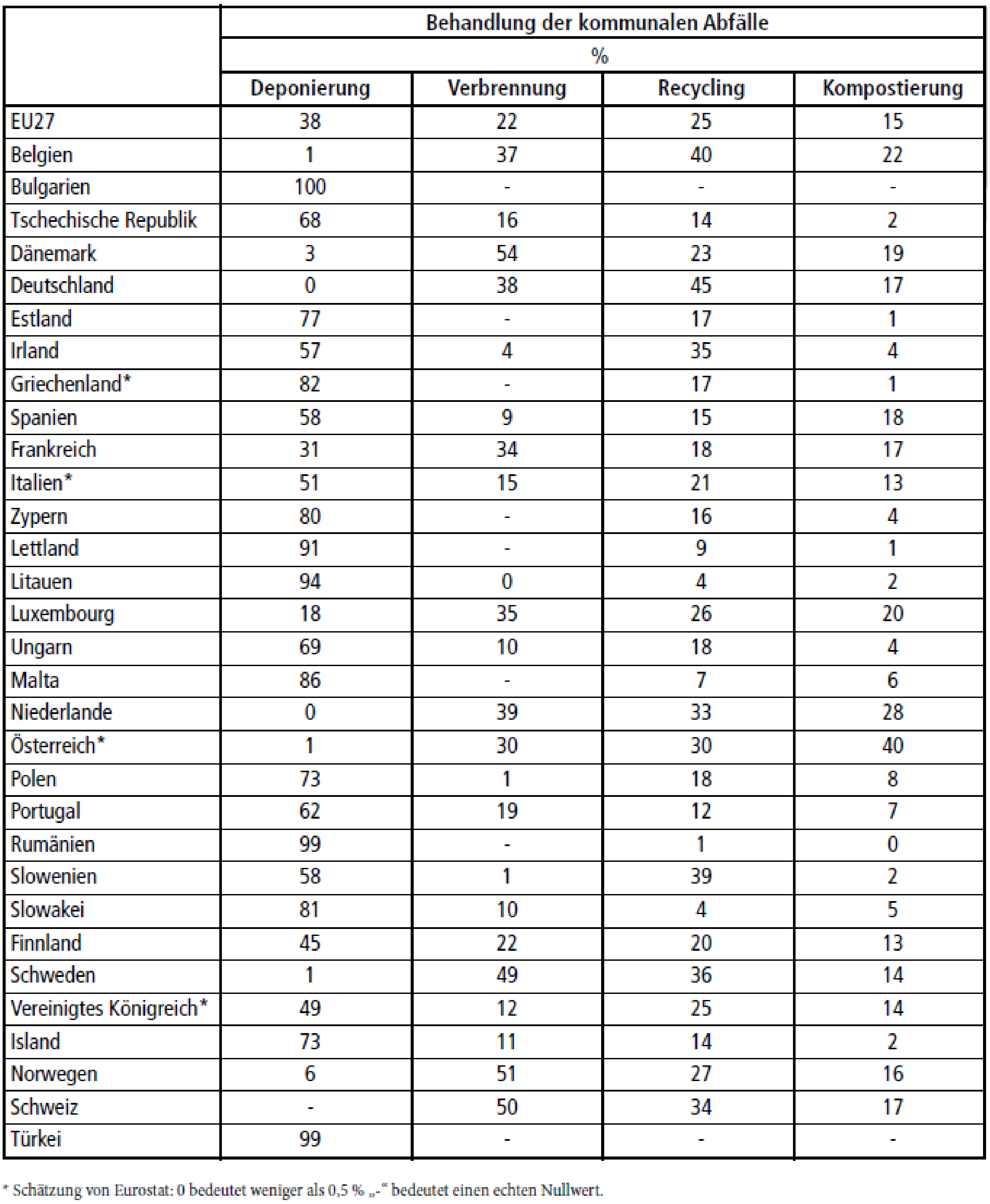
List of abbreviations

A	Annum
Acc.	Accounting
CNC	Computerized numerical control
e.g.	For example
Etc.	Et cetera
EU	European Union
Kg	Kilogram
Mio	Million
NC	Numerically controlled
REE	Rare earth elements
ROI	Return on investment
T	Tons

Appendix



	Behandlung der kommunalen Abfälle			
	%			
	Deponierung	Verbrennung	Recycling	Kompostierung
EU27	38	22	25	15
Belgien	1	37	40	22
Bulgarien	100	-	-	-
Tschechische Republik	68	16	14	2
Dänemark	3	54	23	19
Deutschland	0	38	45	17
Estland	77	-	17	1
Irland	57	4	35	4
Griechenland*	82	-	17	1
Spanien	58	9	15	18
Frankreich	31	34	18	17
Italien*	51	15	21	13
Zypern	80	-	16	4
Lettland	91	-	9	1
Litauen	94	0	4	2
Luxembourg	18	35	26	20
Ungarn	69	10	18	4
Malta	86	-	7	6
Niederlande	0	39	33	28
Österreich*	1	30	30	40
Polen	73	1	18	8
Portugal	62	19	12	7
Rumänien	99	-	1	0
Slowenien	58	1	39	2
Slowakei	81	10	4	5
Finnland	45	22	20	13
Schweden	1	49	36	14
Vereinigtes Königreich*	49	12	25	14
Island	73	11	14	2
Norwegen	6	51	27	16
Schweiz	-	50	34	17
Türkei	99	-	-	-

* Schätzung von Eurostat: 0 bedeutet weniger als 0,5 % „-“ bedeutet einen echten Nullwert.

(Thomé-Kozmiensky 2013)