Market analysis and economic evaluation of a mono incineration system for sewage sludge utilization

Master Thesis

Sigrid Swobodnik, BSc

Production Science and Management

Graz University of Technology

Faculty of Mechanical Engineering and Business Economics

Institute of Business Economics and Industrial Sociology

O. Univ.-Prof. Dipl.-Ing. Dr. techn. Ulrich Bauer

Graz, July 2016

In cooperation with:

ANDRITZ AG

EIDESSTATTLICHE ERKLÄRUNG

Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbstständig verfasst, andere als die angegebenen Quellen/Hilfsmittel nicht benutzt und die den benutzten Quellen wörtlich und inhaltlich entnommene Stellen als solche kenntlich gemacht habe.

Graz, am …………………………… ………………………………………………..

(Unterschrift)

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.

…………………………… ………………………………………………..

date (signature)

Kurzfassung

Die ANDRITZ AG mit Hauptsitz in Graz verfügt bereits über ein existierendes stationäres Wirbelschichtverbrennungskonzept zur Verbrennung von Papierschlamm und Klärschlamm, dem Small Scale Sludge Incinerator with Heat recovery Steam Generation (S³I with HRSG). Sofern zukünftig wirtschaftliches Potential für die Monoverbrennung von Klärschlamm vorhanden ist, möchte die ANDRITZ AG in die Weiterentwicklung dieser Monoverbrennungsanlage investieren und mit dieser anschließend in den Markt einsteigen. Einen großen Einfluss auf die Verwertungswege von Klärschlamm haben die gesetzlichen Rahmenbedingungen. Momentan liegen in Deutschland Gesetzesentwürfe für die verpflichtende Wiedergewinnung von Phosphor aus der Klärschlammasche, der Ausstieg aus der landwirtschaftlichen Verwertung von Klärschlamm und das Verbot der Ausbringung von Polymeren in der Landwirtschaft vor. Werden diese Gesetze umgesetzt, steigt der Bedarf an Monoverbrennungskapazitäten erheblich. Aufgabe dieser Masterarbeit ist es, einen Überblick über die Entwicklung des Klärschlammaufkommens und der Klärschlammverwertungswege in der Europäischen Union und speziell in den deutschsprachigen Ländern zu geben. Dementsprechend soll das zukünftige Marktpotential von Monoverbrennungsanlagen wie dem S³I with HRSG unter Berücksichtigung der gesetzlichen Entwicklung, insbesondere in Deutschland, identifiziert werden. Außerdem soll eine wirtschaftliche Bewertung des S³I with HRSG erfolgen, um potentiellen Kunden einen Überblick bezüglich Kosten und Erlösen zu ermöglichen.

Zur Einführung in die genannten Themen werden erst die theoretischen Grundlagen erarbeitet und diese anschließend im Praxisteil angewendet. Mithilfe verschiedener, auf die Gesetzeslage in Deutschland Bezug nehmenden Szenarien, wird der Bedarf an Monoverbrennungsanlagen aufgezeigt und ein Konzept zur wirtschaftlichen Betrachtung erstellt.

Die erarbeiteten Ergebnisse zeigen einen klaren Bedarf für Monoverbrennungskapazitäten in Deutschland und langfristig auch in der Europäischen Union auf. Das vorhandene Verbrennungssystem der S³I with HRSG der ANDRITZ AG erfüllt die Anforderungen an zukünftige Monoverbrennungsanlagen mit einer Kapazität von 44.000 Tonnen Trockensubstanz Klärschlamm pro Jahr. Folglich wird empfohlen, in die Forschung und Entwicklung einzusteigen und anschließend in den Markt einzutreten. Auch eine Berücksichtigung des Phosphor Recyclings in Forschung und Entwicklung des Brenners wird aufgrund der geplanten Gesetze empfohlen. Unabdingbar ist es, die Entwicklung der Gesetzeslage im Auge zu behalten, um gegebenenfalls auf Veränderungen schnell reagieren zu können.

Abstract

The ANDRITZ AG already possesses a fluidized bed boiler concept for the incineration of paper and sewage sludge, the Small Scale Sludge Incineration with Heat Recovery Steam Generation (S³I with HRSG). ANDRITZ AG plans to invest in additional research and development in case potential need for such systems exists. Subsequently, the market entering phase should be started. The development of the utilization ways of sewage sludge and the connected development of the need for mono incineration capacities of sewage sludge depends hardly on the legislative regulations. In Germany, legislative proposals for obligatory phosphor recycling out of the sewage sludge ash, the prohibition of agricultural sewage sludge utilization and the prohibition of polymers in agricultural use do exist. In this master thesis, an overview of the development of the sewage sludge occurrence and utilization ways in the European Union and especially in the German speaking countries is to be given. In the next step the market potential for mono incineration facilities, as the S³I with HRSG of ANDRITZ AG, considering the legislative regulations, especially in Germany, is analyzed and identified. In the last step an economic evaluation concept regarding costs and profits of the S³I with HRSG is created for potential customers.

To fulfil the given tasks first, the theoretical basics are figured out and afterwards are used to develop a fitting concept in the practical part. Different scenarios for the legislative regulation development in Germany are illustrated.

The market research with respect to the framework conditions results in a clear need for mono incineration capacities combusting sewage sludge in Germany for the next years. Additionally, a need in the European Union will be present, too. ANDRITZ AG`s concept, the S³I with HRSG, fits for the needed capacities with about 44.000 tons dry substance of sewage sludge per year. Consequently, the investment in additional research and development is recommended connected with the possibility of phosphor recycling. Because of the future need of mono incineration capacities a market entry is also suggested. The most important influencing factor which stirs the sewage sludge utilization ways, the legislative regulations, should be observed precisely.

Acknowledgement

I would like to express my sincere thanks to my supervisors for their help, support and guidance during my work for this thesis: DI Volker Koch from Graz University of Technology, DI Robert Schatzl and Dr. Ulrich Hohenwarter, both from the ANDRITZ AG.

Furthermore, I want to thank my parents for the support during my studies, my siblings, the rest of my family, my friends and especially my boyfriend, DI Konstantin Weller, for their motivation and support.

Table of contents

1 Introduction

The decrease of natural resources and the increase of energy use, pollution and waste endanger the sustainable development worldwide. Waste management and treatment are connected with these problems. Changing consumption pattern, urbanization and industrial development intensify the situation and conduce towards inappropriate traditional disposal and utilization systems. Due to these reasons there is already an increase of energetic and substance based use of waste in the European Union. The goals of this kind of sustainable waste economy are the generation of technical, financial and organizational concepts. The so called Waste to Energy Technologies are a promising approach[1].

Sewage sludge is for example waste which can be burned to generate energy. The problem with the utilization of sewage sludge consists in the ingredients like heavy metals and other harmful substances which are implemented through agricultural utilization into the ground and consequently end up in our food. As a result the utilization ways of sewage sludge are changing[2].

In Germany for example, the thresholds for sewage sludge utilization are stricter since January 2015, what already reduced the agricultural utilization possibility of about one third. Moreover, with the beginning of 2017 only decomposable polymers are allowed for sludge treatment, what additionally means that another part of the agricultural disposal way gets lost. With the energy revolution, the disposal option for sewage sludge in co-incineration plants decreases in the future due to the reduced running hours of the coal fired power stations. And finally, a planned amendment of the sewage sludge regulation includes the targets of the exit of solid based utilization and the introduction of a compulsory phosphor recycling out of the sewage sludge ash. These stricter regulations will lead to a change of the utilization ways of sewage sludge in the next years[3].

ANDRITZ AG, an international technology company, is already specialized in combustion systems, offers an existing concept for paper and sewage sludge combustion, the S^3I – Small Scale Sludge Incinerators with Heat Recovery Steam Generation (HRSG). Due to the probable changing utilization ways of sewage sludge, especially in Germany, the demand for energetically based utilization ways is rising. Consequently, the concept of the existing incinerator is going to be discussed in the following paper. Especially the historical development and the actual situation of sewage sludge amounts and utilization methods are illustrated to identify potential markets in the European Union. Conclusively, the economic efficiency of this system is calculated to get an assessment of the investment costs.

This chapter shows an overview of the initial situation, the targets of the master thesis and the actual definition of tasks. Additionally, the field of examination is focused and the strategy which is used for the elaboration of the task is explained.

[1] https://www.giz.de/de/html/index.html (01.02.2016)
[2] TRATTNER, K.; WINTER, M. (2011), S. 2 f.
[3] N.N. (2016), S. 13 ff.

1.1 Initial situation

The ANDRITZ AG is an international technology company and is a leading producer and developer of engineering facilities, services and equipment. The divisions KRP Austria and PKP offer a great variety of innovative solutions in the energy and the environment sector. The employees plan, supply and modernize steam-boiler plants and flue gas cleaning systems. The ANDRITZ AG Power Plant Service division PKP develops and maintenances mostly fluidized bed boiler concepts used to produce electricity from biomass, waste and other things.

In the last years the treatment of sewage sludge was divided into mainly two parts. On the one hand, the sewage sludge incineration was already a big topic with nearly half of the whole amount in Germany and Austria. On the other hand the solid based utilization nearly took 30% of the treatment. The planned exit out of the solid related sewage sludge utilization and the provided prohibition of synthetic polymers for 2017 equals an indirect prohibition of the solid related sewage sludge utilization. Therefore, the sludge has to be utilized in another way. ANDRITZ AG already developed a concept for compact sludge incineration, the S^3I – Small Scale Sludge Incinerators with HRSG. This concept is already implemented with paper sludge as fuel and now is to be extended. The market potential for the use in Europe is not known yet. Moreover the economic efficiency cannot easily be calculated because the influencing location factors are not yet identified.

1.2 Targets

Within the scope of this master thesis three main goals should be reached. First, an inquiry of a situation analysis considering the state of the art and different ways of sewage sludge treatment in the EU should be made. Especially German speaking countries are focused.

Moreover, the second target is to identify potential fields of application for the fluidised bed boiler system for the ANDRITZ AG regarding legal requirements, the historical development and the actual situation of the sewage sludge treatment, starting after the situation analysis. In this case also the German speaking countries and especially Germany are considered.

The third goal is to create an economic efficiency appraisal system of the S^3I bed boiler system of the ANDRITZ AG for sewage sludge incineration with consideration of the location factors and the basics of economic efficiency theory. This system can be used to show potential customers whether it is economically profitable for them to build up such a fluidized bed boiler system for a chosen location in consideration of the acquired location factors.

1.3 Definition of tasks

Within the framework of this master thesis a general overview of sewage sludge and its treatment should be approached. Moreover the historical development and the actual situation are investigated. To achieve the defined goals in 1.2 an acquisition of the sewage

sludge treatment basics and an analysis of the historical development of the sewage sludge treatment through research of statistics and studies treating these topics is performed.
For the second goal the actual situation considering fields of utilization of sewage sludge incineration, market potentials and the legal requirements of sludge utilization (German speaking countries and Europe) is analysed with the help of actual studies, papers and legislations.
To fulfil the third target a systematically elaboration of suitable market analysis- and economic efficiency calculation methods based on a relevant theory regarding influencing factors of the applied compact boiler concept by the help of existing data of the subsisting concept is evaluated.

1.4 Field of examination

For this master thesis the field of application of the Small Scale Sludge incineration (S^3I) fluidized bed boiler concept of the ANDRITZ AG Power Plant Service in Graz (PKP) for sewage sludge incineration is examined. The field of examination is limited to the European Union and especially to German speaking countries. For the EU only the countries with potential sites for the boiler concept for sewage sludge incineration are taken into consideration. The sewage sludge treatment before and after the thermal incineration is not analysed in detail in this study. The same holds true for the co-incineration of sewage sludge because it is not relevant for this master thesis. A detailed inspection of the potentials of improvement about boiler concepts and the incineration are not considered. The Phosphorus recovery processes are only viewed marginally, not the technical approaches.

1.5 Strategy

In the beginning of the examination a literature review on all including components is performed. The basics about sewage sludge, sewage sludge treatment, fluidised bed boiler system, market potential and economic efficiency are examined. The first goal of the research was to constitute the potential studies “Klärschlammentsorgung in Europa bis 2020” from “trend: research” and the third edition “Zukunft der Klärschlammverwertung” which focuses on Germany. Then a desk research was made to collect relevant data of sewage sludge amount and utilization methods in order to identify potential markets for the use of mono combustion systems in Europe, especially in German speaking countries. Afterwards the literature was evaluated to achieve the above defined aims. In the end the existing costs of the S^3I with HRSG concept were adapted to an economic efficiency calculation in order to illustrate the specific costs of this mono combustion system.

2 Theoretical base

In this chapter, the basics of important topics for this work are explained and analysed. First, the term sewage sludge is introduced and different treatment methods are evaluated. Afterwards the historical development of this methods and the actual situation are presented. Moreover, the actual legislative regulations are viewed to give an impression of the treatment regulations. Subsequently, the theory of the direct thermal chemical combustion and the fluidised bed incineration for understanding of the analysed product, the S^3I, are expounded. For the identification of the market potential, the basics of a market analysis are shown and finally the theory and influencing factors for an economic efficiency evaluation are mentioned. This chapter reveals an overview about relevant topics to achieve the given goals.

2.1 Characteristics of sewage sludge

For understanding the content of the work the basics of sewage sludge are summarized. Beside the characteristic treatment methods and important terms are elucidated.
The disposal of sewage sludge (communal and industrial) is restricted due to statutory provisions and gets more and more difficult. For all involved market players, who are particularly explained in 2.4.2, the question of actual and potential concepts for recycling structure and sewage sludge treatment is rising[4].

2.1.1 Term definition

This subchapter gives an overview of the definition of important terms for the thesis. First sewage sludge basics are explained and then important parameters for sewage sludge utilization are depicted.

2.1.1.1 Sewage sludge definition and composition

Every citizens needs water, in Germany about 120 litres per day, which is routed as wastewater to the canalization after the use. The wastewater is led through the canalization net until it reaches the sewage plant. The wastewater is separated from pollutants through rakes, sieves, and mechanical and biological cleaning steps. Afterwards the cleaned water is returned into the waters and the sewage sludge remains[5] (Figure 1). The formation of sewage sludge is a sink for pollutants from communal and industrial wastewaters[6]. Sewage sludge can be dehydrated, dried or treated in another way. Raw sludge is sewage sludge, which is extracted untreated from the wastewater treatment facility.
Sewage sludge is a mixture of materials. The high fluctuation of the amount of the compositions and the inhomogeneity make it difficult to define a uniform standard composition. The largest part of sewage sludge consists of organic substances. Additionally,

[4] N.N. (2010), S. 68
[5] WIECHMANN, B. et al. (2013), S. 6
[6] OLIVA, J. et al. (2009), S.10

the sewage sludge includes plant nutrients (e.g. nitrogen, phosphor) and organic pollutants (e.g. hormonally effective substances, heavy metals and pathogenic organism)[7].

Figure 1: Dried sewage sludge[8]

2.1.1.2 Communal and industrial sewage sludge

Sewage sludge can be differentiated depending on the origin. The communal sewage sludge comes from public sewage plants and the industrial sewage sludge from direct connected industrial facilities. Communal sewage plants are mostly run by communes or commissioned third operators. This kind of sludge includes a broad spectrum of ingredients, high organic amount, mineral components pollutants and heavy metals. Moreover the communal sewage sludge can consist out of industrial sludge as an input as well, depending on the wastewater regulation system. The sewage plants for industrial sewage sludge are constructed for specific wastewaters. They are mainly run by the owning companies or by specialized enterprises. The industrial sludge plants have a manageable amount of wastewater to handle. The industrial wastewater has more defined ingredients but they can exist in a much

[7] WIECHMANN, B. et al. (2013), S. 10 ff.
[8] http://um.baden-wuerttemberg.de/de/startseite/ (4.7.2016)

higher concentration. They are addicted to the kind of wastewater treatment and the fees can be very high[9].

2.1.1.3 Dry substance and dry residuals

Sewage sludge consists out of solid matter and water. Characteristic variables for the treatment are the water content and the dry residual. In addition the variables are necessary as reference value if analytical determined ingredients must be indicated depending on the dry substance. Through pre-treatment of the sewage sludge the water content can be influenced in different ways. For a consistent measure of the sewage sludge the contained solid matter, that means the dry substance, is used[9]. Here, a distinction is necessary which is shown in Table 1.

Dry substance (DS)	Special case of the dry residual, describes the dry matter concentration: after particular dry process contained mass concentration of suspended solids of the vitalized sludge; gathering suspended solids in the sludge (in g/l)
Dry residual (DR)	Remaining mass fraction of the sludge on solid substance after the dry process (in mass %); gathering particular and dissolved solids in the sludge
Sludge	Water content and dry residual
Dry matter (DM)	Received mass after finished dry process (g, kg)

Table 1: Overview about characteristic values of sewage sludge[10]

2.1.1.4 Calorific value

The heating value or calorific value defines the efficiency of a substance in energetic use through combustion. The dimension depends on the elementary chemical composition of the substance. The content of carbon, hydrogen, sulphur, oxygen and water especially influences the amount of the calorific value. The energy content of substitute fuels is indicated in kilo joule (1kJ= 1000J) or mega joule (1 MJ=1.000.000 J) and for solids referring to the dry matter or dry substance (kJ/kg in the DS)[10].

2.1.2 Treatment and utilization

The following subchapters should give a basic overview about the possibilities of sewage sludge treatment. Because mono combustion is the topic of this master thesis, it is described in more detail.

[9] N.N. (2010), S. 78 ff.
[10] N.N. (2010), S. 79 ff.

2.1.2.1 Overview

The treatment of sewage sludge often lies in the conflict area between legal provisions like water management law, waste management law, restrictions regarding soil protection and agriculture. To choose a fitting treatment beside the legal provisions also ecological parameters have to be considered. Costs are an important factor but not the only decision criteria. The selection of a treatment method depends whether the use of the reusable material or the exfiltration of the pollutants has priority. Therefore 3 basic strategies can be defined.

- Agricultural or disposed agricultural utilization of the sewage sludge. No separation of the heavy metals from the economic cycle. Certain quality criteria has to be fulfilled depending on the treatment way.
- Exfiltration of the pollutants through storage of the resource at landfills after far reaching inertisation (combustion and co combustion). Energy content of the sewage sludge is used. The recyclable material potential is not yet used.
- Use of sewage sludge in building material industry (cement, bricks). Energy content or recyclable material potential is used. No separation of the heavy metals[11].

The objectives of the sewage sludge treatment are:

- Reduction of the sewage sludge volume through separation of the water (thickening, drainage, drying and combustion)
- Sanitisation of the sludge to avoid pathogens in the environment
- Transformation of sewage sludge to a form in which the sludge can be deposited, without unpleasant smell, and given back to environment[12].

2.1.2.1.1 Utilization and disposal

In general there are two possibilities for waste management, the disposal and the utilization. The utilization is the preferred option. Here, specific features can be exploited and a renewed use through utilization is possible. The clear definition of the use is determined through regulations and laws which depend on the different countries and are explained in more detail in 2.2.3. The utilization is distinguished into the energy generation out of waste, and the substantial utilization; substantial means that the material of the waste is added to a new use (normally inferior value). The energetic utilization happens in energy production facilities through mono incineration or co-incineration of waste. A substantial utilization takes place if the main purpose lies in the use and not in the disposal (economic consideration), including replacement of raw materials through extraction of materials out of waste or use of the waste (except immediate energy extraction)[13].

[11] OLIVA, J. et al. (2009), S. 52
[12] OLIVA, J. et al. (2009), S. 18 ff.
[13] N.N. (2010), S. 18 ff.

2.1.2.1.2 Pre-treatment

For good combustion behaviour of the sewage sludge and some other reasons pre-treatment processes are recommended. Sludge treatment includes all methods by which the applicability or the transportation and storage capability can be improved. The methods are thickening, sanitisation, biological stabilisation, dewatering, drying and combustion[14]. The combustion is described in 2.1.2.2.2.

Thickening:
The objective of this method is the dehydration of the sludge as far as possible. The result is a volume reduction. For the processes, thickener are used which are sedimentation tanks in which the particles sink to the bottom and precipitate through gravity. Additionally, the flocculation should be accelerated in the tube extruder. The surplus water on the surface is removed and the sludge lying on the floor is sucked away[15].

Sanitisation
The reduction of pathogen organism (like viruses) in the sewage sludge is the target of the sanitisation. Consequently, the danger of contamination through agricultural utilization to humans or animals can be minimized. According to the amendment of the sewage sludge regulations, the application of sewage sludge is only allowed if the sludge did undergo a sanitisation treatment in advance[15]. Several methods already exist but will not further be explained in this master thesis.

Biological sludge stabilisation
To avoid odour problems, the reduction of self-disintegrating organic substances is the aim of this method. Here, it is differentiated into anaerobic (digestion) and aerobic processes. In Germany for example anaerobic treatment is normally used in the bigger plants. The anaerobic process takes place in so called digestion towers. The objective of the digestion of sewage sludge is the stabilization what is synonymous to the reduction of the biological activity and the odour development. By the use of digestion better dewatering of the sewage sludge can be reached additionally. Moreover a further advantage of the anaerobic treatment is the production of gas, which also can be used as an energy source. Besides, composting and humification of sewage sludge exists. With digestion, connected downstream dewatering processes, result in rising calorific values, a fact which is favourable in case of later following thermal treatments. Disadvantageously, the reduction of organic substances results in a decrease of the calorific value[15].

Dewatering
During the mechanical dewatering process the quantity of the sludge mixture is reduced via lowering the water content. This method is necessary, especially when the sewage sludge should be transported to further treatment or disposal locations. So, the advantages are on the one hand that the mass is reduced for the transported sewage sludge and on the other

---

[14] WIECHMANN, B. et al. (2013), S. 18 ff.
[15] WIECHMANN, B. et al. (2013), S. 18 ff.

hand the stiffer sewage sludge allows a better handling than the liquid one. The calorific value increases and therefore the economy of later following combustion. The dewatering takes places in decanters, centrifuges, band or filter presses. The solid content is measured as dry residual content and values between 20 and 45 % can be reached. The outcome depends strongly on chosen machines, quality and kind of the sewage sludge and on eventual conditioning. The dewatering ability of the sludge can be increased by upstream sludge conditioning with the aid of additives (flocculants). As flocculants inorganic (coal, lime or iron-aluminium salts) or organic (organic polymers) substances can be used. The iron aluminium-salts often are already added to the waste water cleaning process as a precipitant for phosphate removal. Before thermal treatment frequently organic conditioning agents are added because these salts increase the non-combustible amount in the dewatered sludge (ash amount) significantly[16].

Sewage sludge drying

The sewage sludge drying is a strongly influencing factor for the following thermal utilization of the sewage sludge. The advantages of the dried sludge in comparison to wet sludge, directly originating from the sewage process, consist in:

- Reduction of sewage sludge mass
- Better transportation and storage ability
- Better dosing and extracting
- Increase of calorific value
- Hygienic harmlessness and micro biological stabilisation

An argument against the drying of sewage sludge is the additional energy expenditure through dewatering and drying.

The already explained mechanical dewatering is only the first step of the drying process. Additional drying methods exist to increase the dry residual content to more than 50 %. The first separation is done into partly drying and full drying. The partly dried sewage sludge contains up to about 85 % dry residual. The sewage sludge is partly dried if the adhesion phase is passed. That means solids content of more than 50 to 55 % dry residual. After the full drying the sewage sludge contains up to about 95 % dry residual. As already mentioned the increase of the calorific value is especially important for the following thermal treatment. Often, the dry residual content which can be reached through mechanical dewatering is not enough for a self-sufficient incineration. Additional drying is necessary because of technical reasons. An energetic favourable location for the drying is next to a combustion plant, due to the possible use of the exhaust heat. As already mentioned the drying of sewage sludge is a very energy consuming procedural step, during which some of the remaining water in the sewage sludge is extracted with the help of thermal energy. The later use of the sewage sludge determines the chosen level of drying. For the different utilization concepts there are special requirements on the dry grade and the connected dry residual content[16] which are illustrated in Table 2.

[16] WIECHMANN, B. et al. (2013), S. 18 ff.

Combustion type	Sludge treated through:	Dry residual content [%]
Mono incineration plant: Independent combustion	Dewatering and drying	About 35
Combustion of digested sludge	Drying	45 to 55
Waste combustion plant	Dewatering, partly drying or full drying	No information
Co incineration in power plants	Dewatered sludge Drying in coal mill or use of full dried sludge possible	20 to 35
Use in cement plants	Dewatering and full drying	No information

Table 2: Overview combustion types and necessary dry residual content[17]

The net calorific value at which sewage sludge burns independently is at about 4.500 kJ/kg to 5.000 kJ/kg. An independent combustion can take place at a net calorific value of about 4.000 kJ/kg, if the combustion facility uses the hot exhaust gas from the boiler for pre-heating of the combustion air. The net calorific value can be increased up to 13.000 kJ/kg through a drying procedure. Then the value is on the same level like the values of dry wood or brown coal. Heat mediums for drying can be a great range of mediums. The following table gives an overview including the possible drying systems[17]:

Heat medium	Example for drying system
Flue gas	Drum drier
Exhaust gas from thermal power station	Fluidized bed drier
Air	Drum drier, belt drier
Steam	Thin film drier, disk drier, fluidized bed drier
Pressurized water	Thin film drier, disk drier, fluidized bed drier
Thermal oil	Thin film drier, disk drier, fluidized bed drier
Solar energy	Solar drier

Table 3: Heat mediums and possible drying systems[17]

The selection of the “right” drying system is difficult because of the dependence on many boundary conditions and influencing factors which can differ from location to location. Besides integration in the whole sewage sludge utilization network, other factors like the expecting features of the end product, the economic and ecological aspects should be considered.

[17] WIECHMANN, B. et al. (2013), S. 18 ff.

In general a separation in direct and indirect driers can be made. In the process of the direct drier, also named convection drier, the sewage sludge gets straight in touch with the heat carrier (mostly air or flue gas). During the process exhaust vapours occur, which are a mixture of air, water steam and gases coming out of the sludge. They have to be cleaned afterwards to avoid odour nuisance or dangers for people[18].

The indirect drier (called contact drier) offers the needed heat through steam generation or a thermal oil facility where the oil acts as heat carrier. A heat transfer between the hot dry surface and the sludge takes places. The advantage of this process is that the heat carrier and the exhaust vapour do not mix and thus the cleaning of the substance flow is easier. In this case the dry residual content is normally between 65 and 80 %[18].

In the last years the use of solar driers using sun energy increased. In Germany nearly half of all driers are solar ones. The separation of drying methods there can also be performed via the middle throughput. The solar driers have fewer throughputs than other driers. In certain cases it may make sense to install such technologies, especially when no exhaust heat is available and the distance to the next combustion plant is too large[18].

2.1.2.2 Utilization methods

The utilization of the sewage sludge after an appropriated pre-treatment method, which have been explained in the chapter before can be basically differentiated in energetically and substantial utilization[19]. An overview about the different methods is shown in Figure 2 and is summarized in the following subchapters In particular, the mono combustion method is illustrated because the examined product is a mono incineration system.

[18] WIECHMANN, B. et al. (2013), S. 18 ff.
[19] N.N. (2016), S. 167ff.

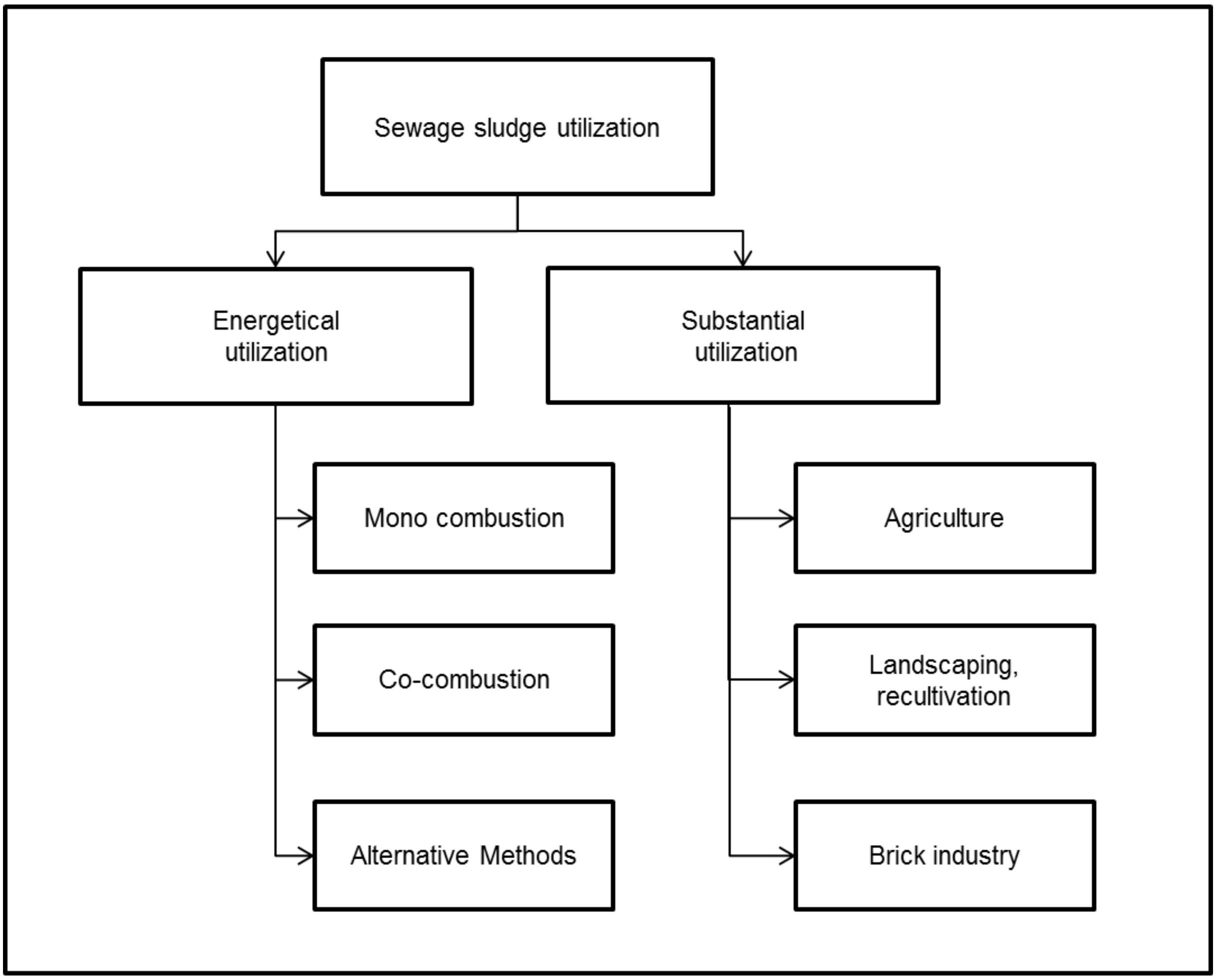

Figure 2: Methods of sewage sludge utilization[20]

2.1.2.2.1 Substantial utilization

As seen in Figure 2 the substantial utilization can be distinguished in basically three parts: The agricultural, the landscaping and recultivation including composting and finally the use in the brick industry.

Agricultural utilization

For this utilization method the sewage sludge is used as fertilizer while the sludge is spread at the fields by tractors. Phosphor and nutrients, which are included in the sewage sludge, are used by this application. The effect is similar to mineral fertilisers. To avoid ammonium losses, the sludge has to be incorporated into the ground immediately after the spreading. The disadvantage of this utilization way is the introduction of harmful substances into the ground and consequently into the food chain of humans and animals. The agricultural utilization is the only method for which the sewage sludge can also be used in liquid form, what means not dehydrated. The savings due to the unnecessary dehydration are connected

[20] N.N. (2016), S. 167ff.

to a substantial higher expense for the transportation. However, the liquid form has significant higher nitrogen content[21].

Landscaping and recultivation

In the landscaping the sewage sludge is used to produce topsoil. The organically carbon network of the sludge serves as a basis to generate soil substrates. For the recultivation of huge areas of lignite mines or landfill sites, mostly dehydrated sewage sludge, mixed with other substances, is applied. Humification happens with passing time at the place of use. The surface cover of landfill sites prevents negative out coming influences. The function of the composting in those microorganisms degrades organically substances to humus building. Therefore, the dehydrated sewage sludge is e.g. mixed with small brush cuttings and composites in reactors for rotting. Now the compost can be used for further applications like in landscaping. In comparison to the before named utilization ways this one is an elaborate process[21].

Brick industry

The sewage sludge can be utilized in the brick industry in two different ways. On the one hand the sludge can be applied directly, but the bulking effects, caused by the high organic amount, limit the use in this form. On the other hand the sewage sludge ash is used whose application is more widely. The problem of this utilization way is the odour pollution resulting of the combustion, necessitating exhaust gas cleaning[21].

2.1.2.2.2 Energetically utilization: Thermal sewage sludge combustion

The amount of thermal utilization of sewage sludge increased during the last years (2.2.1) mostly because of stricter governmental regulations and environmental protection. The thermal sewage sludge disposal is categorised in different processes as shown in Table 4.

- Mono combustion: Methods which process sewage sludge as fuel alone and not in combination with other calorific substances.
- Co-combustion: Methods which process sewage sludge besides utilization of other calorific substances in coal power stations, waste incineration plants or industrial facilities.
- Alternative methods: Wet oxidation, pyrolysis, carburation and combinations of the methods including mono combustion.

[21] N.N. (2016), S. 180 ff

Mono combustion	Co-combustion	Alternative methods
Without ash melt • Fluidized bed • Multi deck oven • Multi deck agitator • Grate firing **With ash melt** • Melting cyclone	**Coal-fired power station** • Dust firing • Fluidized bed firing • Grate firing • Melt chamber firing **Waste incineration plant** • Grate firing **Industrial plants** • Cement production • Paper sludge combustion	**Gasification** • Fluidized bed gasification • Packed bed pressure gasification • Entrained flow gasifier • Conversion gasifier **Pyrolysis** • Low stage temperature conversion **Wet oxidation** • Overground Methods • Underground Methods

Table 4: Thermal processes for sewage sludge utilization[22]

The term "alternative methods" is used because these types of energetic utilization are not as common and do not play a big role in the common use yet up to some exceptions. The target of all the methods is the mineralization of the sewage sludge, i. e. to vaporize the water content and to oxidize the organic amount. The combustion steps consist of the drying, the pyrolysis, the carburation and the gas sided and solid sided burn out in oven intern part steps[23] are explained more detailed in 2.3.

2.1.2.2.3 Mono combustion

The stationary fluidized bed incineration is worldwide the most common method for sewage sludge incineration and is superior to other methods because of its certain advantages. These advantages consist in the good adaption for high ash content fuels with relative low net calorific value. The independent combustion is possible, without additional energy and without combustion air pre heating, at a net calorific value of about 4.500 kJ/kg, depending on the sludge quality, i.e. a dry substance amount of up to 40 to 50 %. Pre-heating of the combustion air or oxygenation allows burning of sludge with even lower calorific values. The air pre heating can be performed over steam or hot exhaust gases. The pre drying of the sewage sludge is done separately in pre-drying facilities. If no pre-drying is done, admixture of coal or other substances with high net calorific value is possible to adjust a net calorific value of 4.000 to 4.500 kJ/kg. Afterwards combustion residual materials remain. The dry residuals of the sewage sludge consist of ash content up to 35 % using raw sludge and up to 60 % using digested sludge. The ash fraction is much higher when compared to burning wood, brown coal or hard coal. In Germany about 1.000.000 tons of sewage sludge DS are burned in mono combustion facilities with a result of about 500.000 tons of ash. Caused by

[22] LEHRMANN, F. (2013), S.903
[23] LEHRMANN, F. (2013), S.902 ff.

the incineration of the organic amount, the concentration of most of the heavy metals increases by a factor of 2 to 3. Some of the residuals can be utilized in the cement or asphalt industry but the larger parts have to be deposited. Disposal costs for the mono incineration with about 70 € per ton of sewage sludge ash are much higher than for co incineration. This results for a significant part of the costs in mono combustion. Moreover the phosphorous proportion of the ash is as high as up to 23 %. Consequently, this results in a potential need for additional phosphorous recycling at communal sewage sludge plants. Due to a mixture of substances, Phosphorous recycling in co combustion plants is not possible[24]. The operation temperature of the combustion process is between 850 and 950 °C. If the temperature is lower than the 850 °C odour emissions can appear and if the temperature is higher than the 950 °C the ash can be sintered. Depending on the energy content, the combustion air quantity and the amount of the fed sewage sludge, the temperature under level of the combustion is adjusted. Furthermore, the concrete incineration conditions are determined through country-specific governmental regulations. In Germany for example, according to the "17. Bundesemissionsschutzverordnung", the oxygen content must be at least 6 Volume %, the holding time of the exhaust gas in the combustion chamber after last air injection is minimum 2 seconds for an effective combustion and the afterburning temperature is minimum 850°C. According to the type of the system, raw sludge or digested sludge can be processed. The used sludge can be dehydrated and thus partly or full dried. Common firing systems which can be used (Table 4) for mono combustion consist in the fluidized bed, multi deck oven, multi deck agitator, grate firing and cycloid firing. The firing technologies, except the fluidized bed system, are not described in further detail because the fluidized bed system dominates the firing method. Different construction types have a huge influence on the emissions[25]. Table 5 gives a short overview of the strengths and weaknesses of the sewage sludge mono incineration.

Strengths	Weaknesses
• Long term utilization planning for sewage plant operators • Destruction of organic pollutants in the sewage sludge • Energy generation possible • Possibility of phosphor recycling out of the sewage sludge ash	• High costs compared to other utilization ways • Utilization costs for residuals of mono incineration significantly higher as for co-combustion • Eventually, long transport ways for the sewage plant operators • Research needs for phosphor recycling

Table 5: Strength and weaknesses of sewage sludge mono incineration[26]

[24] LEHRMANN, F. (2013), S.910 ff.
[25] WIECHMANN, B. et al. (2013), S. 26 f
[26] N.N. (2016), S. 178

2.1.2.2.4 Co-combustion

In contrast to the mono incineration, the combustion of sewage sludge is only optional in this case, because the main fuels are others, depending on the type. Co combustion can be distinguished into co incineration in coal-fired power station, waste incineration plant and cement plant[27].

Coal-fired power station

To reduce fuel costs and CO_2 emissions, sewage sludge is used as a supplementary fuel in coal and lignite fired power stations. Normally, for the coal incineration, the dry substance content of the used sewage sludge must be bigger than 90 %. Therefore, an effective sewage drying process has to be performed in advance. For the lignite, a mechanical dehydration of the sewage sludge is sufficient, resulting in a dry residual between 20 and 45 %, the net caloric value varies around 4,5 MJ/kg. In this case, the waste heat of the plant can be used for the drying process of the delivered sewage sludge. Despite of this advantage the use of other substitute fuels (like prepared waste) is becoming more attractive and consequently a competitor for the sewage sludge co incineration develops. An additional limitation for the capacity consists in the emission limit values for heavy metals caused by the use of sewage sludge. This can be compensated by the installation of a further exhaust gas cleaning system. In this type of combustion the fly ash is primarily used in the building material industry; even in here certain requirements must be met. However, the amount of the co- incineration with sewage sludge at around 5 % for lignite and 1,5 % for coal processes is very low[27].

Waste incineration plant

The net calorific value of sewage sludge lies in the range of the household waste and can be mixed in in small portions. Grate firing is the most common firing system. Advantageously, the used materials do not have to be prepared in advance. The delivered sewage sludge normally exploits a water content of 25 to 35 % and many waste incineration plants do not need an additional drying station. The co-burned sewage sludge can be fully dried, partly dried or even only mechanically dried. For this type of co-incineration, the sewage sludge amount is a bit higher when compared to the coal incineration sewage sludge amount, averaging about 10 to maximum 20 % of the waste volume. Otherwise no complete combustion can take place[27].

Cement plant

In cement plants the use of sewage sludge can be a replacement fuel for conventional energy sources. Here, normally mechanical dehydrated sewage sludge does not provide energetical use so only dried sewage sludge is used as supplementary fuel with a dry substance of more than 90 %. In general the sewage sludge has only a subordinated meaning because of the higher net calorific value of other alternative fuels like for example waste oil.[27]

[27] N.N.(2016), S.167 ff.

2.1.2.3 Energetic potential of sewage sludge

The proportion of the organic dry substance of the sewage sludge is an important determinant for the energetical potential of the sewage sludge. The energy content depends on the treatment of the sewage sludge. If the sewage sludge is digested before utilization, organic substance is removed from the sludge. The raw sludge has a dry substance amount of 50 to 60 % (percentage of organic substance) and disposes an averaged net calorific value of 17.000 kJ/kg. This value is valid for dried sewage sludge over 90 % dry substance. The digested sewage sludge only has a net calorific value of 11.000 kJ/kg under the same conditions. Table 6 shows different waste types with assigned net calorific values[29].

Kind of waste	Net Calorific value [kJ/kg]
Residual waste	8.000-11.000
Light fraction	16.000-18.000
Old tires	29.500
Sewage sludge, digested	11.000
Sewage sludge, not digested	17.000

Table 6: Net calorific values of different wastes[28]

After the digestion of the sewage sludge about 20 to 30 % of the organic proportion can be removed and is provided largely as sewage gas. Sewage sludge can be used as storable energy source in dried form. Its small transport volume thereby is advantageous.

If the whole yearly communal sewage sludge occurrence would be utilized completely thermally, a resulting energetically potential of 33.100 GJ per year could be generated. This assumption is valid for Germany with a communal sewage sludge amount occurrence of around 1.900.000 tons of dry substance per year. Additionally, the sewage sludge has to be dried (> 90 % dry substance). In comparison, the digested sewage sludge only possesses an energetic potential of 21.400 GJ per year under the same conditions[29].

2.1.3 Residuals and emissions from sewage sludge mono incineration

Residuals

The ash content of the dry residual of sewage sludge has an ash percentage of up to 60 % for digested slurries and for raw sludge and about 35 % for raw slurries, a rather higher ash percentage when compared to wood and coal. About 500.000 tons of ash occur during mono combustion of about 1.000.000 tons sewage sludge dry substance per year in Germany. The main components of the sewage sludge ash are[30]:

[28] N.N. (2016), S.195
[29] N.N. (2016),S. 195 ff.

- Silicon dioxide with 35 to 40 %
- Aluminium oxide with 13 to 20 %
- Iron oxide with 10 to 20 %
- Calcium oxide with 15 to 25 %
- Phosphate with 10 to 23 %

The concentrations of most of the heavy metals in the sewage sludge ash increase two to three times, due to the combustion of the organic amount, when compared to the sewage sludge dry substance. Because of the low boiling point of mercury, the biggest amount goes to the residuals of the exhaust gas cleaning.
The sewage sludge ash can be disposed in several ways (Germany in 2010 accounts for 220.000 tons ash per year)[30]:

- Above ground landfill (83.600 tons per year, 38 %)
- Underground filling (48.400 tons per year, 22 %)
- Recultivation (39.600 tons per year, 18 %)
- Building Material Industry (26.400 tons per year; 12 %)
- Fertilization (22.000 tons per year, 10 %)

Over the last years, the costs for the disposal increased rapidly because the disposal way in ore mining and hard coal mining, where the sewage sludge ash was used as backfill material, disappeared. These costs are higher than the costs for the disposal for residuals from the co combustion[30].
As already mentioned one component of the sewage sludge ingredients is phosphate with an amount of up to 23 %. Because of this high content the sewage sludge ash from a mono incineration plant for communal sewage sludge is suitable for phosphorous recycling. The development of procedures for phosphorous recycling out of sewage sludge ash is already in progress but not yet economically efficient. Phosphorous recycling is described in 2.2.4.
During the flue gas cleaning of the mono combustion system, salts, plaster, process waste heat and heavy metals occur in different concentrations, depending on the used methods. These components have to be disposed too. If salts occur, like NaCl, these have to be disposed underground or used in offset mines. Moreover the plaster is used in the building industry where the heavy metal slurries (small amount) have to be disposed as dangerous waste[30].

Emissions
Through a series of thresholds, defined by varying governmental restrictions in the different countries, the emissions in the air should be limited. Thus, exhaust gas cleaning systems have to be installed for the mono combustion of sewage sludge. In Germany the 17. Bundesemissionsschutzverordnung determines the emission regulation of dust, nitrogen oxides and mercury. During each incineration process dust arises, irrelevant which type of

[30] LEHRMANN, F. (2013), S. 918 ff.

combustion or firing system is used. The plants are normally equipped with a filtering dust separator for an effective dust emission reduction. The average dust content in the cleaned exhaust gas is 0,2 to 2,5 mg/m^3 and the determined threshold in Germany is 110 mg/m^3. The formation of the NO_x, the nitrogen oxide, is generated out of two different sources. On the one hand, they are introduced in form of oxygen and nitrogen through the combustion air: the oxygen and the nitrogen react with one another to $NO_{x,}$ at high temperatures. On the other hand the sewage sludge contains ammonium which for example can produce NO_x through oxidation. The measured average value is about 80 mg/m^3 but also values up to 180 mg/m^3 are measured in some special cases. The threshold for NO_x emissions is 200 mg/m^3. Furthermore, in environmental policy the mercury plays an important role[31].

2.2 Historical development and actual situation of sewage sludge treatment

To get an overview about the sewage sludge masses and their treatment methods in the past in comparison to the actual situation, the relevant data is listed and explained in this chapter. Firstly, the European development is examined and secondly German speaking countries are analysed in more detail. At least, especially Germany is figured out.

2.2.1 Historical Development

The historical development of the sewage sludge emergence depends hardly on the connection grade and the legal requirements. In this subchapter the development of sewage sludge amounts and treatment ways as well as the actual situation are clarified. Furthermore the legal framework is explained which is essential for further developments of the sewage sludge utilization ways. Finally, the basics about phosphorous recycling are shown, which will hardly impact the sewage sludge utilization ways in the future.

[31] WIECHMANN, B. et al. (2013), S. 26

2.2.1.1 Europe

The amount of sewage sludge occurrence rises from 1995 to a forecast value of 2020 continuously as can be seen in Figure 3. Besides the building of new sewage facilities the accession of additional countries to the EU are reasons for this obvious increase. In Figure 3, the amount of 2020 is a predicted value. For the next years the sludge masses will still rise because of better or new connections of the public to sewage plants. Especially in lower developed countries the masses will increase. The comparatively little increase of the sewage sludge masses for EU 27 countries to EU 15 countries from 1.410.800 tons DS in 2010 to predicted 2.500.000 tons DS in 2020 is reducible to the low connection rate of the additional countries[32]. The connection rate of the population to the public sewage plants is described more detailed in 2.2.2.

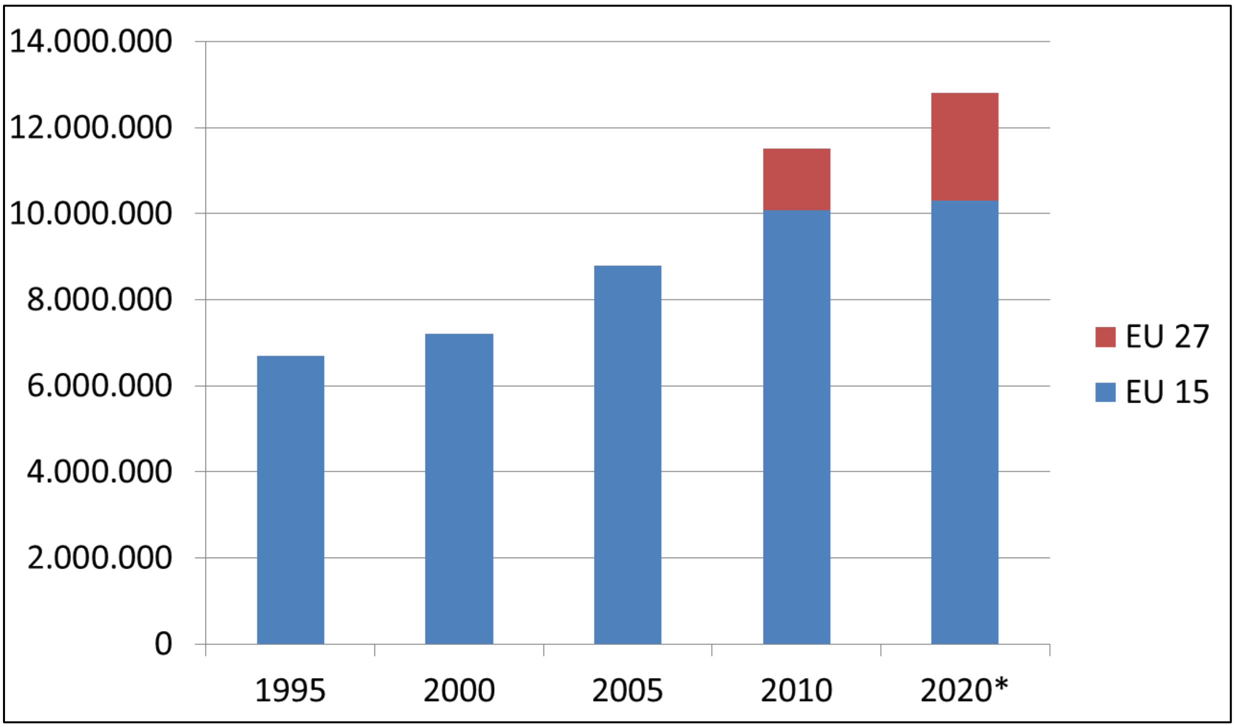

Figure 3: Sewage sludge development in tons dry substance[33]

[32] LEHRMANN, F. (2013), S. 905 f
[33] LEHRMANN, F. (2013), S. 906

2.2.1.2 Austria, Germany and Switzerland

In this chapter the historical development of the sewage sludge occurrence and the utilization ways are illustrated for Austria, Germany and Switzerland.

Austria

In general, the amount of sewage sludge in Austria is rising over the years. The total amount and the development of the different utilization methods of sewage sludge for sewage treatment plants ≥ 2.000 population equivalent (PE_{60}) from 1995 to 2012 are shown in Figure 4. In 1995 the total amount of utilized sewage sludge was about 190.000 tons of dry substance per year and in 2012 roughly 260.000 tons of dry substance per year. This constant growth is attributed to the expansion and extension of the sewage treatment plants. Over the years, the amount of combustion of sewage sludge is increasing from about 60.000 tons dry substance per year in 1995 to nearly 150.000 tons of dry substance per year in 2012, whereas the deposited sewage sludge amount continuously decreased from approximately 60.000 to 10.000 tons of dry substance per year. The yearly agricultural amount is staying nearly equal with about 40.000 tons of dry substance. Among the subdivision "Others", with a rising amount, for example compositing, temporary storage, landscaping and small volumes giving's fall. The direct allocation to the different utilization sectors in connection with the size of the sewage treatment plant is not possible due to the fact that in some provinces in Austria, the sewage sludge is treated and recycled through few external companies together. This figure only contains the communal sewage sludge amount of the industrial sewage treatment plants with communal proportions. The industrial sewage sludge amount is not included.[34].

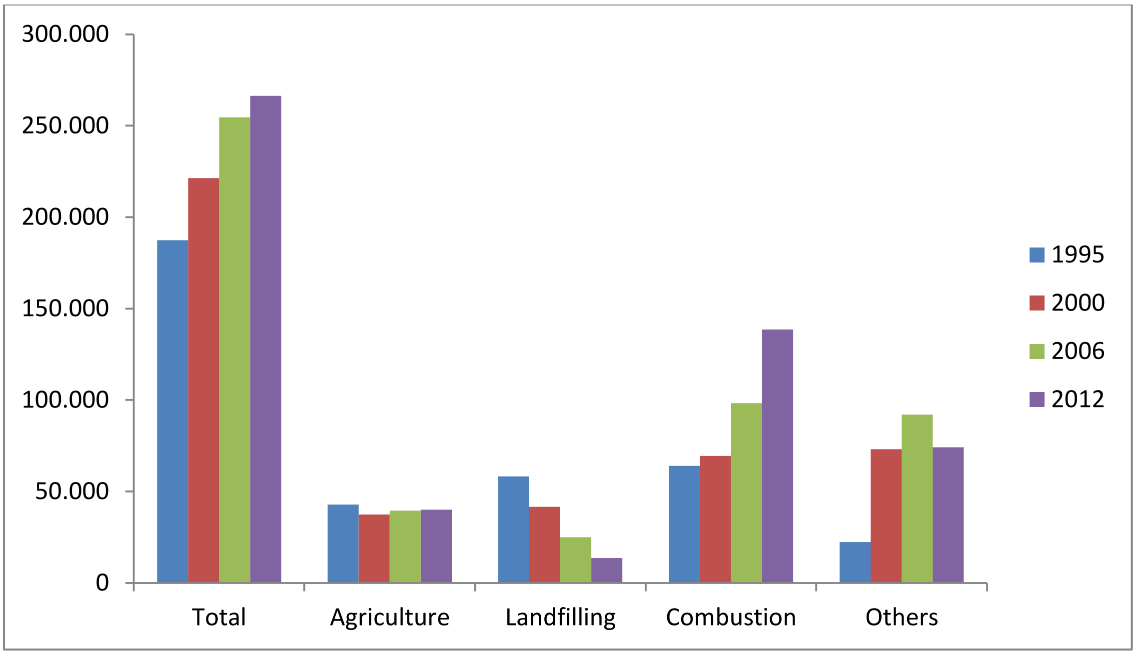

Figure 4: Development of the sewage sludge utilization in Austria in tons dry substance[35]

[34] ÜBERREITER, E. et al (2014), S. 29
[35] ÜBERREITER, E. et al (2014), S. 29

Germany

In comparison to the total yearly amount of sewage sludge in Europe and Austria, the amount of sewage sludge in Germany decreased over the years from 1998 to 2011. In 1998 more than 2.000.000 tons of dry substance sewage sludge appeared and in 2011 only a yearly appearance of less than 2.000.000 tons dry substance was observed. The continuous decrease of the total amount can be connected to the better treatment methods at the sewage treatment facilities which lead to a reduction of the total mass. Additionally, the connection grade in Germany was already very high and no new nameable masses were added. The development of the utilization ways turns towards thermal treatment of the sewage sludge, as can be seen in Figure 5. With the prohibition of the landfill for sewage sludge, with a transitional period of 10 years from 1995 to 2005, the temporary storage and the landfilling disappeared. Moreover the substantial utilization way, including agriculture and others, decreased too[36].

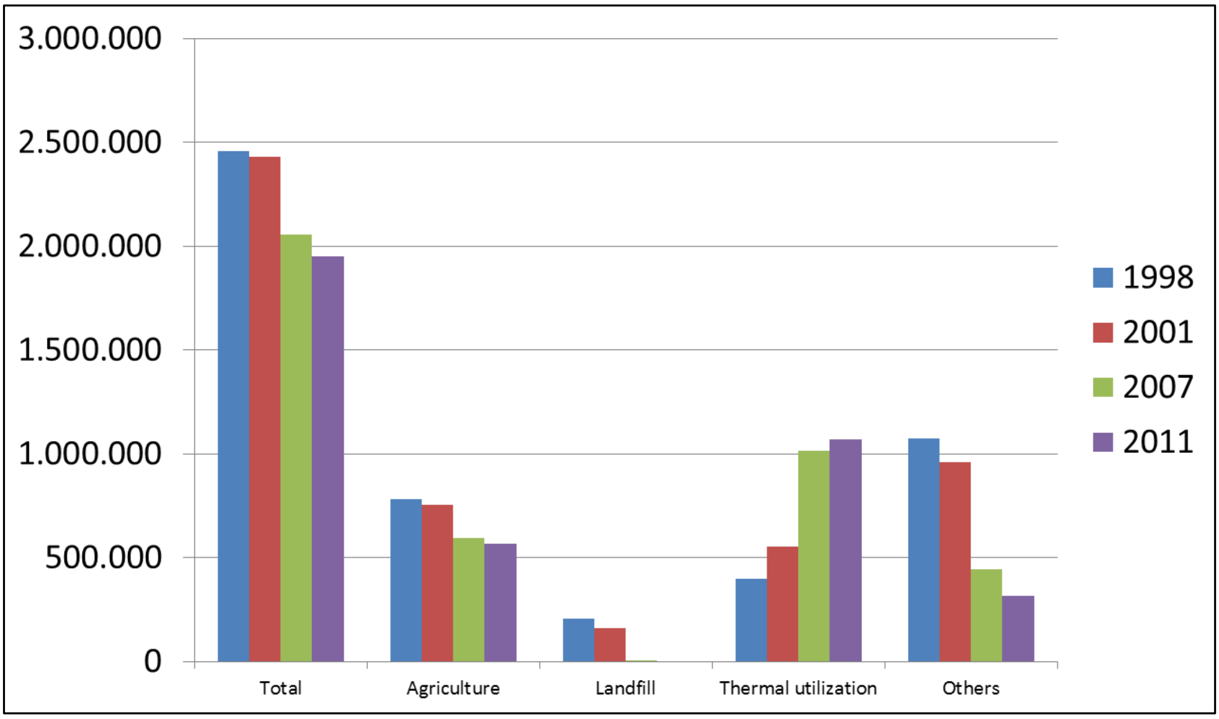

Figure 5: Development of the sewage sludge utilization in Germany in tons dry substance[37]

[36] LEHRMANN, F. (2013), S. 903 ff
[37] LEHRMANN, F. (2013), S. 904

Switzerland

In Switzerland the amount of the sewage sludge did not vary heavily, as can be seen in Figure 6. In comparison to the early years of the period under review, the total amount even decreased from 203.000 tons dry substance per year in 2000 to 194.534 tons dry substance per year in 2012. The development of the sewage sludge utilization follows the trend to the thermal combustion. In the year 2000 more than 40 % of the whole amount of sewage sludge was used for agricultural reasons, decreasing each second year until the use of this method disappeared at the latest in 2012. The prohibition of fertilization in 2006 led to the drastically decrease of the main utilization way, the agricultural use. The decline of the mono combustion in 2012 can probably be explained with the closing of a plant. The increased export is normally prohibited but sometimes possible through special exceptions [38].

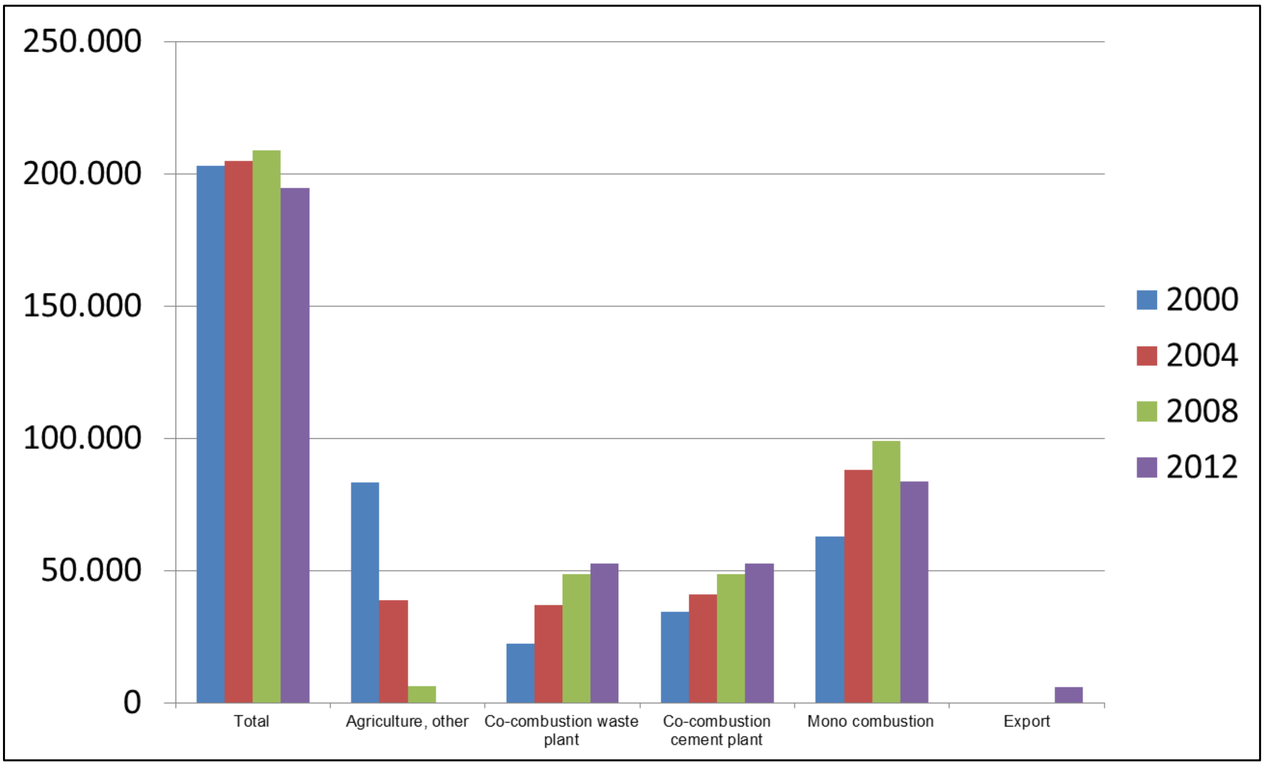

Figure 6: Development of sewage sludge utilization in Switzerland in tons dry substance[39]

2.2.2 Actual situation

To demonstrate the actual utilization methods in the EU, Austria, Germany and Switzerland, in this chapter the actual situations are described. Additionally, the capacities of mono incineration plants in the single countries are explained, as far as data is available. The capacities of mono incineration plants for sewage sludge combustion in each country are important for the identification of the market potential in the third chapter.

[38] TEZCAN, M. (2013), S. 12
[39] TEZCAN, M. (2013), S. 12

Europe

In Europe at the moment about 11.500.000 tons of sewage sludge is produced per year. The ways of utilization are shown in Figure 7. The data originates from 2005, due to the fact that no more actual data is available for Europe. The highest amount is achieved by the treatment in the agriculture as fertilizer accounting for 39 % of the whole mass. The reasons for this high agricultural utilization in Europe are that most of the countries do not have such strict regulations as for example Germany. In addition, the agriculture utilization is one of the cheapest and easiest ways. The incineration amount is 20 %, which includes mono and co-combustion. The composting and re-cultivation with 18 % nearly reaches the same percentage as the incineration. Furthermore, the way of landfilling counts to 13 % and others to 10 %. Others describe methods like interim storage and others[40].

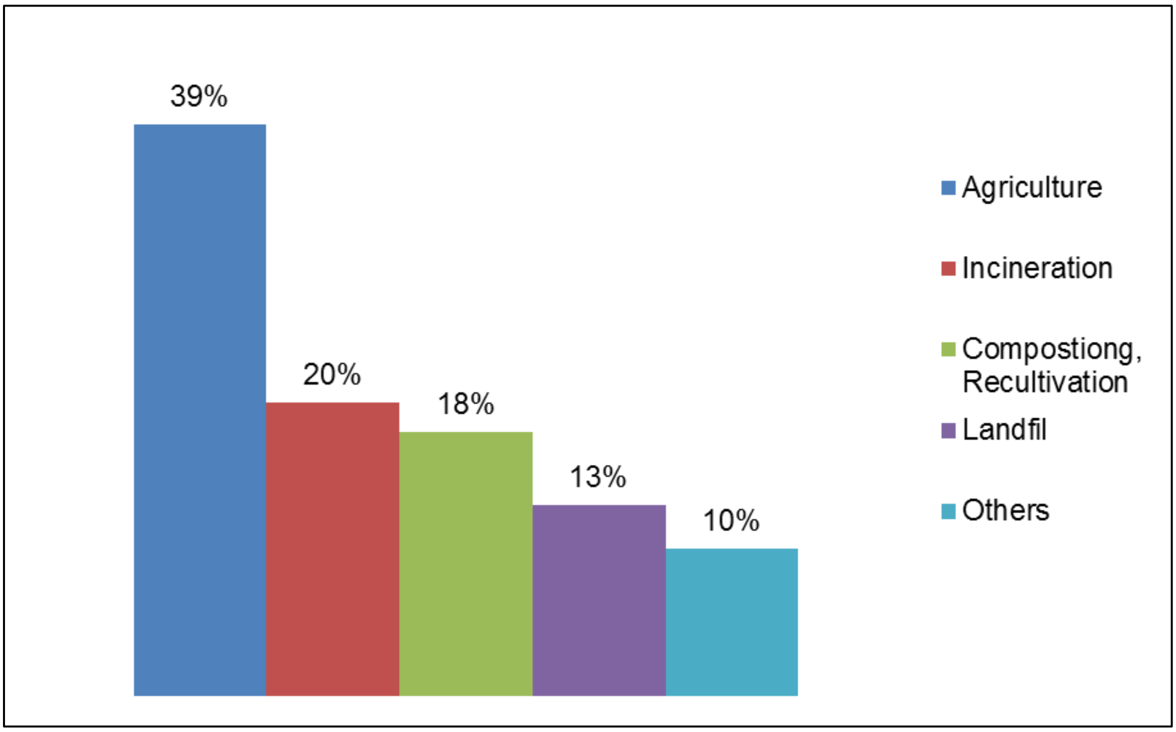

Figure 7: Sewage sludge recycling Europe in % of total sludge amount generated in EU[41]

To get an overview of the individual countries, their connection rate to public sewage plants, the total amount of sewage sludge occurrence and the utilization ways, the countries and the related data are listed in Table 7 for the year 2010.

[40] OLIVA, J. et al. (2009) S. 28 ff
[41] OLIVA, J. et al. (2009) S. 29

Member states	Connection rate to communal sewage plants	Total amount of sewage sludge	Proportion of European total volume	Agricultural utilization	Combustion	Landfill	Others
Unit	%	Mio kg dry substance/year	%	%	%	%	%
EU 15							
Austria	93	273	2,4	15,0	40,0	1,0	45,0
Belgium	69	170	1,5	10,0	90,0	-	-
Denmark	No info	140	1,2	50,0	45,0	-	-
Finland	81	155	1,3	5,0	-	-	95,0
France	80	1300	11,3	65,0	15,0	5,0	15,0
Germany	95	2000	17,4	30,0	50,0	0,0	20,0
Greece	87	260	2,3	5,0	-	95,0	-
Ireland	84	135	1,2	75,0	-	15,0	10,0
Italy	No info	1500	13,0	25,0	20,0	25,0	30,0
Luxembourg	95	10	0,1	90,0	5,0	-	5,0
Netherlands	99	560	4,9	0,0	100,0	-	-
Portugal	70	420	3,7	50,0	30,0	20,0	-
Spain	92	1280	11,1	65,0	10,0	20,0	-
Sweden	86	250	2,2	15,0	5,0	1,0	75,0
United Kingdom	No info	1640	14,3	70,0	20,0	1,0	10,0
EU 27							
Bulgaria	45	47	0,4	50,0	0,0	30,0	20,0
Cyprus	30	10,8	0,1	50,0	0,0	40,0	10,0
Czech Republic	76	260	2,3	55,0	25,0	10,0	25,0
Estonia	80	33	0,3	15,0	-	-	85,0
Hungary	57	175	1,5	75,0	5,0	10,0	5,0
Latvia	65	30	0,3	30,0	-	40,0	30,0
Lithuania	71	80	0,7	30,0	0,0	5,0	65,0

Malta	48	10	0,1	-	-	100,0	-
Poland	64	520	4,5	40,0	5,0	45,0	10,0
Romania	29	165	1,4	0,0	5,0	95,0	-
Slovakia	52	55	0,5	50,0	5,0	5,0	10,0
Slovenia	57	25	0,2	5,0	25,0	40,0	30,0
Total EU 15	85,9	10.093,0	87,7	38,0	35,8	18,3	33,9
Total EU 27	71,0	11.503,8		37,3	23,8	28,7	31,3

Table 7: Sewage sludge occurrence in Europe and utilization ways[42]

For the European Union no data for the capacities of mono incineration plants for the sewage sludge combustion is available.

Germany

Germany is the country with the highest amount of sewage sludge occurrence per year and has a very high connection rate to sewage plants in Europe. An overview about the sewage sludge utilization methods is shown in Figure 8. This data refers to the year 2010. As can be seen already 53 % of the yearly amounts are treated thermal, what includes the mono combustion, co combustion and alternative procedures. The substantial utilization methods still cover 47 % of the utilization amount[43].

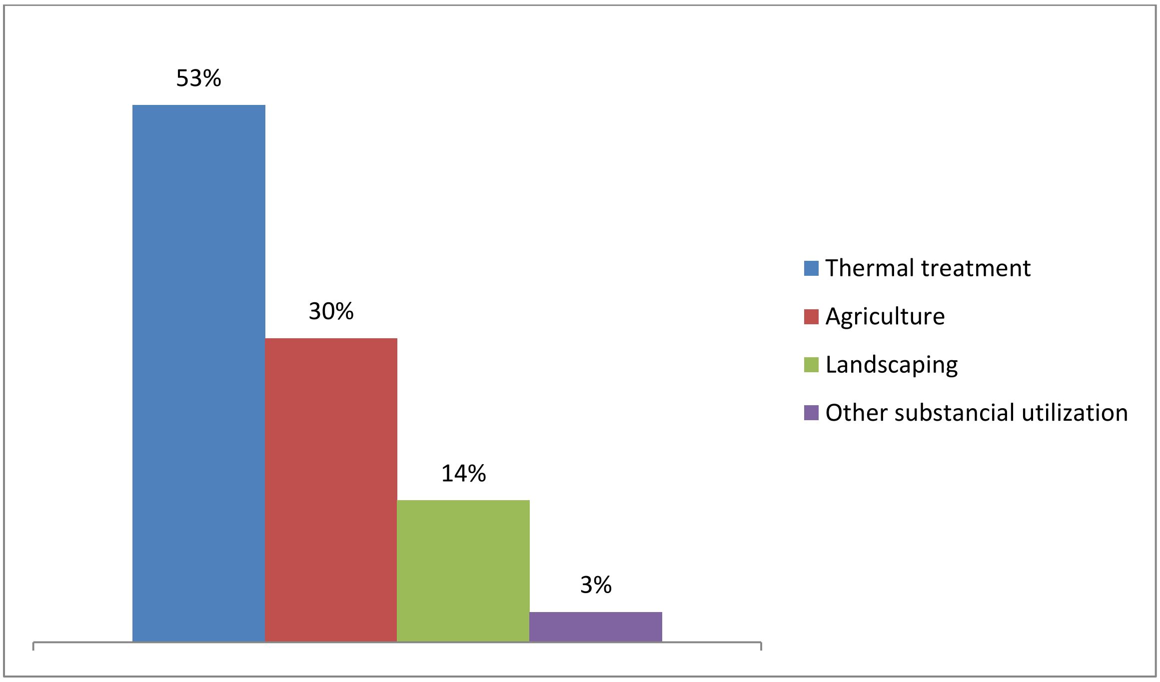

Figure 8: Sewage sludge recycling Germany in % of the yearly sludge amount[43]

[42] OLIVA, J. et al. (2009), S.
[43] LEHRMANN, F. (2013), S.904

To have a better overview about the masses of sewage sludge which are combusted, a division in the different combustion methods can be seen in Figure 9. Of the 1.003.749 tons of dry sewage sludge which were burned in 2010, 23 % (431.612 tons) are treated in mono combustion plants. In co combustion power plants 441.650 tons, also 23 % are burned too. The remaining part is divided in 2 % (20.112 tons) burned in co combustion waste plants and 5 % (100.375 tons) in co combustion in cement plants[44].

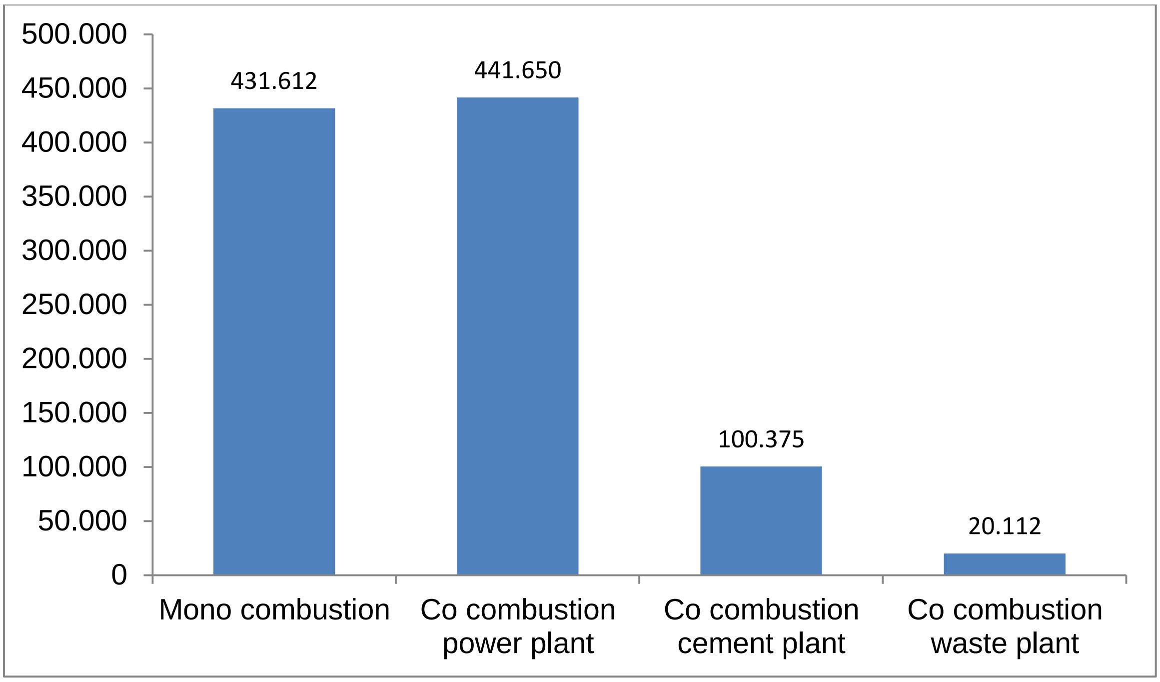

Figure 9: Thermal treatment of sewage sludge of the yearly amount in Germany 2010[44]

For the identification of the market potential, it is important to have information about the existing capacities of mono combustion plants for sewage sludge. In the year 2014, Germany had capacities for mono incineration of sewage sludge of 721.000 tons dry substance per year but only 510.000 tons dry substance of the sewage sludge occurrence were combusted in mono incineration plants. At the moment, approximate 20 sewage sludge mono incineration plants exist in Germany, with different capacities[45].

[44] LEHRMANN, F. (2013), S. 904
[45] N.N. (2016), S. 203

Austria

In Austria, the connection grade to the canal system and sewage treatment plants is already very high with 94, 5 %. On the one hand the reason for such a high connection grade is caused by the type of the Austrian scattered settlement structure. On the other hand the high connection grade is depending on the investments in new construction and reconstruction of the canalization and the sewage treatment facilities. The estimated investment for the future in the waste water infrastructure is very important, which will shift from more new constructions in the past to more conservation measures for the future (sewage treatment plants and canal systems). A marginal annual increase of the sewage treatment plant capacities and thus the sewage sludge amount can be predicted depending on the rise of the urbanization and the adaption to the growing population.

The total yearly incidental amount of sewage sludge in 2012 was about 260.000 tons dry substance, as already shown in 2.2.1.2. Furthermore, the quantity of the produced sewage sludge is distributed to the different utilization methods (Figure 10). In this figure, only the communal part of the three industrial wastewater treatment systems (Pöls, Gratkorn, Agrana) with communal share is considered. The percentage of the incineration of sewage sludge accounts for 52 %, followed by other utilization and disposal kinds like composting with 28 %. Moreover 15 % are used for spreading in agriculture for fertilization and the smallest amount (5 %) is utilized for landfilling purposes[46].

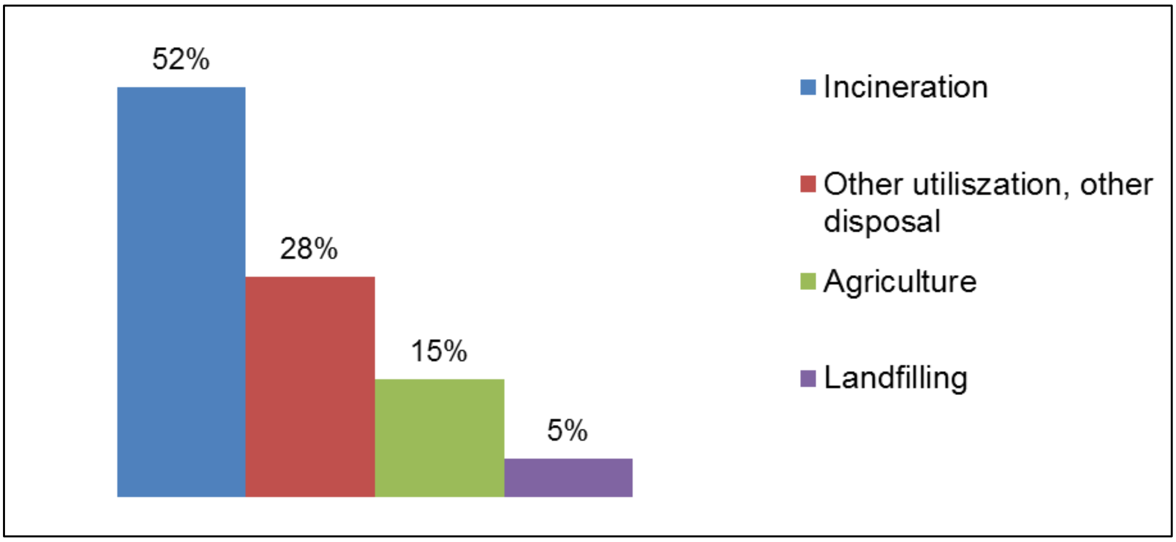

Figure 10: Sewage sludge recycling Austria in % of the yearly sewage sludge amount[47]

[46] ÜBERREITER, E. et al (2014), S. 30 ff
[47] ÜBERREITER, E. et al (2014), S. 30

Switzerland
The following data refers to the year 2012. The sewage sludge occurrence in Switzerland mounted to 194.534 tons of dry substance. Switzerland had 48 plants in use, including 12 mono combustion plants. Because of restrictions, which are explained in more detail in 2.2.3, combustion of the sewage sludge is obligatory in this country. Consequently 97 % of the sludge is burned in different incineration plants. The biggest amount is combusted in the mono incineration plants. 27 % each are combusted as alternative fuel in cement plants and in waste incineration[48]. The distribution is shown in Figure 11.

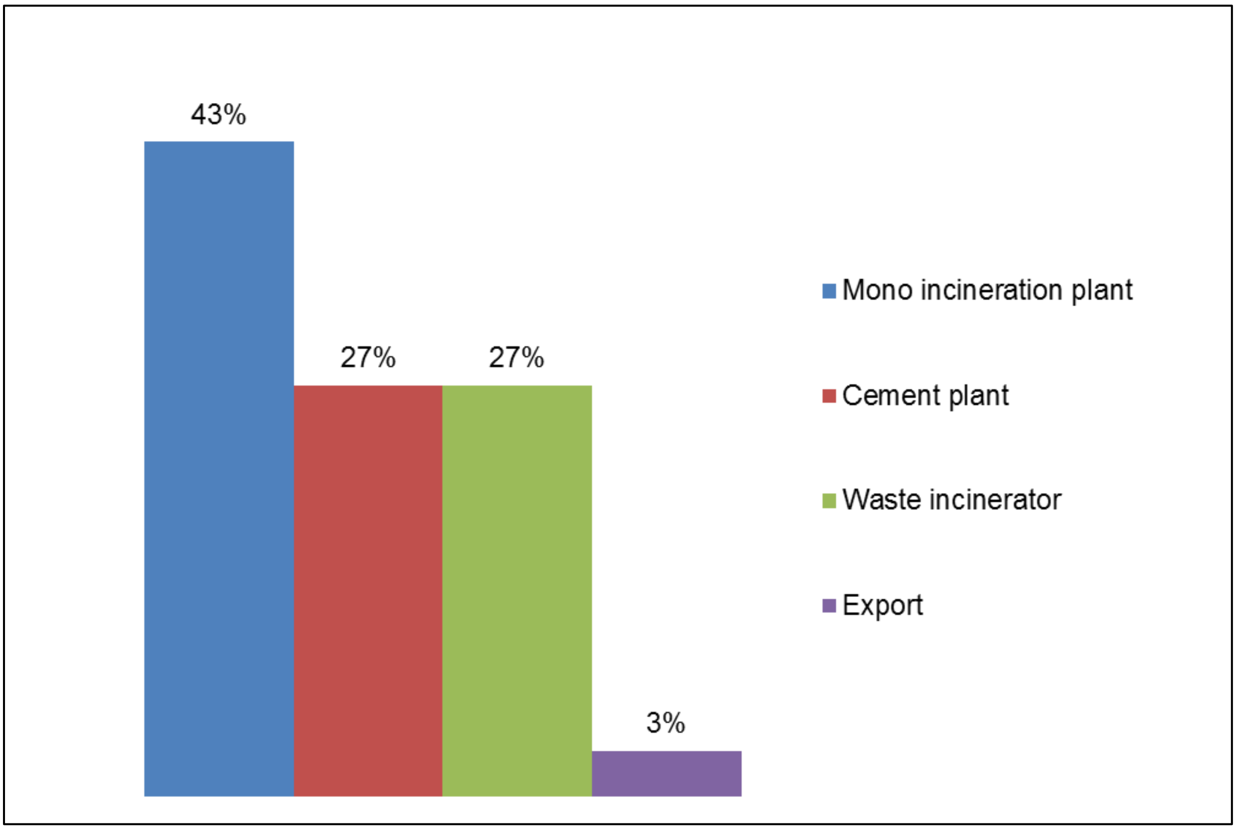

Figure 11: Sewage sludge recycling Switzerland in % of yearly sewage sludge amount[49]

2.2.3 Law

The most important influencing factor for the future development of the sewage sludge utilization ways is the law. Sewage sludge and the utilization of sewage sludge are depending on several different kinds of law: emission control, waste legislation and legal requirements for fertilization.

European Union
The individual countries of the European Union have to fulfil the legal guidelines of the European Union regarding the utilization of sewage sludge. The given thresholds and laws have to be fulfilled but the individual countries can intensify the regulations, as it has been in

[48] TEZCAN, M. (2013), S. 1 ff
[49] TEZCAN, M. (2013), S. 2

the case for Switzerland, Austria and Germany. Table 8 shows the main legal guidelines and regulations of the EU for thermal and agricultural utilization of sewage sludge[50].

Thermal utilization	Agricultural utilization
RL 2008/98/EG **Waste Framework Directives**	RL 86/278/EWG **Sewage Sludge Directives**
RL 2010/75/EU **Industrial Emissions Directives**	V 1020/2009/EG **Fertilizer Ordinance**
	Thematic Strategy for Soil Protection (KOM (2006) 231)

Table 8: Legal guidelines and regulations of the EU for sewage sludge utilization[51]

Germany

In Germany, the utilization ways already changed extremely due to legal requirements. Main important requirements are summarized as follows:

- As already explained in 2.2.1.2 the landfilling disappeared due to the **landfilling prohibition** of waste with higher inorganic amount since 2005.
- Moreover, with the amendment of the "**Düngemittel Verordnung**" (DüMV) with inception on the 1.1.2015, sewage sludge only is allowed to be used, if the given threshold values are not exceeded. The consequence is, that 1/3 of the until now used amount for agriculture, is not allowed anymore, due to the neglect of the threshold values for lead, mercury, cadmium and nickel.
- For sludge treatment - with the effect of the 1.1.2017 - **only degradable polymers** are allowed. That will result in an additional decrease of sewage sludge amount which is allowed to be utilized in the agriculture.

A legislative proposal for an amendment of the "Klärschlammverordnung" (AbfKlärV) was already given on the end of August 2015 from the "Bundesumweltministerium" (BMUB). The main proposals, with a transitional period of 10 years from inception, are[52]:

- Exit from the sewage sludge utilization in the agriculture (target of the coalition agreement)
- Obligatory phosphor recycling

[50] N.N. (2016), S. 88 ff
[51] N.N. (2016), S. 89
[52] N.N. (2016), S. 13 ff.

Switzerland

In Switzerland the fertilization with sewage sludge is already not allowed anymore since 2006. The actual law (1.1.2016) prescribes the thermal utilization of sewage sludge. Moreover, the phosphor has to be recycled and the temporary storage of sewage sludge is prohibited. Additionally, the sewage sludge ash has to be stored in special landfilling plants[53].

2.2.4 Phosphorus recycling

The increasing world population and the growing industrialization result in a rising use of limited and not regenerative raw materials. The thereby caused ecological effects can only be cured by a reduction of the resource misuse. Therefore, the closing of raw material cycles is necessary. Phosphor is a not renewable resource, but it is necessary for biological processes in humans and animals. The human body consists out of about 1 weight percent phosphor, what is calculated to about 0,7 kg. This amount is mainly included in the skeleton in the form of phosphate. The phosphor cycle of humans is regulated by eating and excretion for life support[54]. Phosphor is included in sewage sludge and reaches plants via fertilization of agriculture areas with this sewage sludge. As already stated, restrictions are introduced all over Europe decreasing the utilization way of sewage sludge in the agriculture more and more, thus reducing the phosphorus abuse. But nevertheless fertilization of the fields with essential nutrients like phosphor is necessary. The problem with phosphor is, that phosphor neither can be replaced through other alternatives nor can be produced artificially[55]. Nowadays the phosphor originates from mineral phosphor resources. Their amount is not critical yet, reserves which can be used count actually for about 67 billion of tons, the rough estimated worldwide occurrence consisting of more than 300 billion of tons of phosphate ore. The term “used reserves” describes the amount of phosphate ore which can be mined and produced economically at present. In Africa the biggest reserves are available but not yet all are mined. More than half of the actual phosphate ore mining takes place in Asia (2012). According to a static view the profitable mining is possible for roughly another 300 years. Due to the increasing world population and the consecutive need in phosphor this time period will decrease essentially. Out of this reason and because of the scheduled closure of the phosphor raw material cycle other solutions decreasing the phosphor waste have to be found. As outlined before, sewage sludge contains large amounts of phosphor caused by the excretions of humans and animals. Due to the already existing and future governmental restrictions other ways than direct fertilizing should be considered, like e. g. phosphor recycling from sewage sludge. In general there are three different methodological possibilities[54]:

- First, ***phosphor extraction directly from the waste water***, where the phosphor is selectively removed from the waste water in the sewage treatment plant. In this case, the obtained phosphor concentration is very low[54].

[53] TEZCAN, M. (2013), S. 1 ff.
[54] SCHÖNBERG, A.; RAUPENSTRAUCH, H. (2015), S. 477 ff.
[55] TRACHSEL, F. (2013), S.987 f.

- The second option is to ***recover the phosphor from the sewage sludge*** itself. The chemical and biological bounded phosphor in the sewage sludge is dissolved in a mostly liquid phase. Afterwards the phosphor is separated and transferred into a suitable compound, depending on the further use: this might be for plant availability or industrial purposes. In this method of phosphor recycling different forms of treatment can be distinguished, like water chemical treatment, thermochemical treatment and the utilization directly from the digested sludge[56].

- However, the most promising approach is the third recovery way, the ***recycling of the phosphor from the sewage sludge ash***. After the sewage sludge is burned, the phosphor is much higher concentrated compared to sewage sludge or waste water. Consequently the necessary mass flow for the recycling process is significantly reduced. Normally, the chemical phosphor formulation in the ash is P_2O_5, but conclusions to the real presented compound cannot be drawn. For analysis, the provided phosphor of the sewage sludge is assumed to be oxide but in real it is a phosphate of metals. The most important binding partners are calcium, iron and aluminium. The binding forms, composition and phosphor content of the sewage sludge ash depend on the origin. The average phosphor content varies between 5 to 10 weight percent. The challenge of this method consists in harmful components in the ash, as halogens, heavy metals and other unhealthy substances. To meet given requirements the sewage sludge ash has to be processed ahead of further treatment. The phosphor containing ash can be applied in different ways: the agricultural utilization, the utilization in the phosphor industry, water chemical processing or thermochemical treatment[56].

  Agricultural utilization
  The direct spreading of the not yet treated sewage sludge ash for agricultural use is not really a good method. On the one hand the phosphate in the ash is mostly from little plant availability and on the other hand the governmental regulations restrict this method extremely. Sometimes the ash is treated with acid which consequently leads to a separation of the heavy metals[56].

  Utilization in the phosphor industry
  Another obvious possibility is the use of phosphor containing ash as a substitute for raw phosphate in the phosphor industry due to the fact that the phosphate proportion in the sewage sludge ash equals the raw phosphate proportion. Mostly, the phosphor is chemically present as Ca phosphate, like in the raw phosphate, but also as Fe and Al phosphates, which are not desired. The big problem of this method consists in the fact that the whole sewage sludge ash has to be fed to the phosphor industry[56].

[56] SCHÖNBERG, A.; RAUPENSTRAUCH, H. (2015), S. 481 ff.

Water chemical processing

In this case, the ash is treated with acid or lye resulting in a separation of the phosphor from the heavy metals. Depending on the applied process the separation happens via ion exchange, precipitation or solvent extraction[57].

Thermochemical treatment

During the thermochemical treatment process, the sewage sludge ash is treated by heat. Hereby chlorides are formed by the high temperature application resulting in a separation of the heavy metals which then can be removed. Again different procedures are available at present. Some of the procedures already exist in industrial standardized forms. The thermochemical application is used to produce phosphorous acid, marketable phosphate fertilizers as well as high grade phosphor[57].

Depending on the type of phosphor recycling different phosphorous products are generated. Thermochemical and water chemical treatments result in calcium phosphate for the use as long-term fertilizer (i.e. a mineral substitute). Applying these two methods aluminium and iron phosphates can occur. Their use as fertilizer is limited. Through crystallization or precipitation in the water chemical process magnesium aluminium phosphate can occur, which is a very good fertilizer[57].

2.2.5 Costs of sewage sludge utilization in Germany

Transportation costs, dewatering and, if used, costs for the drying process provide for the most influencing factors for sewage sludge utilization expenses. Due to the distance to foreign utilization facilities and the possible availability of own drying facility prices for sewage sludge utilization are varying. Additional price influences can consist in broker fees for e. g. intermediaries. The main price elements for a sewage plant operator include the transport, the processing, the eventual broker fees for intermediaries and the disposal price which has to be paid to the operator of the chosen utilization way. The price for the disposal depends on following influencing factors[58]:

- Plant investment
- Operating expense
- Usability of the sewage sludge

The common distances for the sewage sludge disposal from the sewage plants are in a range from 50 to 100 kilometres. At the moment, the sewage plant operators decided which utilization way is chosen, depending on the lowest price for the utilization.

The different prices for the utilization ways are shown in Table 9. The average price is rising with the grade of drying, because of the additional investments. As already explained, the

[57] SCHÖNBERG, A.; RAUPENSTRAUCH, H. (2015), S. 482 ff.
[58] N.N. (2016), S. 215 f.

price range also varies according to the length of the transportation ways and due to the existence of own drying capacities. The following costs are the results of a survey[59].

Utilization way	Dry residual	Transport costs inclusive	Costs of the disposal	Costs of the disposal
	[%]		[€/t dry substance]	[€/m³]
Mono incineration	20-50	No	40-60	
Co incineration	25-50	No	40-50	
	25-50	Yes	60-65	
Gasification	30-35	Yes	70-100	
Agriculture	3-5	Yes		10-17
	20-30	No		25
	35	No	35-75	
Cultivation/ recultivation	20-30	No	25	

Table 9: Costs for sewage sludge utilization[60]

2.3 Direct thermal chemical combustion

The provision of useful energy generated out of solid fuel can take place directly or through transformation in secondary energy. The secondary energy can either be converted into useful energy at another place or in other times. The aim of the thermochemical transformation processes is the chemical change of the used biogenic solid fuels to provide thermal energy and/or refined, solid, liquid or gaseous energy carrier during heat impact. In this subchapter the basics of thermal chemical combustion are explained always regarding to the combustion of biomass.

2.3.1 Basics

The single phases of the thermal chemical change are the drying, the pyrolytic decomposition, the carburation and the oxidation. To divide the technical methods for the energy generation achieved products can be used, like: combustion, hydrothermal carburation, liquefaction, carbonization and torrefication. In literature and practical use the term definition is not clearly specified.

For a delimitation of the thermal chemical processes the excess air ratio is used. The excess air ratio λ is defined:

[59] N.N. (2016), S. 215 f.
[60] N.N. (2016), S. 216

$$\lambda = \frac{m(air, total)}{m(air, \min)}$$

To oxidize the organic compounds in the fuel completely, air is fed to the combustion process in excess. That means that for the reaction more oxygen than necessary (for a complete stoichiometric oxidation) of all organic components in the fuel is provided. λ is the degree of the air excess. It is the ratio between the air which is supplied to a combustion process m(air, total) and the minimum amount of air which is necessary to reach an complete stoichiometric oxidation m(air, min). Characteristics for λ[61]:

- Complete oxidation λ is at least 1
- Wood incineration $1,5 < \lambda \leq 2,5$: combustion over air excess
- λ bit under 1 (under stoichiometric) of engines: fuel rich conditions: in this case emissions of not burned components exist, which is undesirable nowadys because of environmental protection
- λ clear under 1 but bigger than 0: gasification
- λ=0 (no oxygen feeding from outside): pyrolytic decomposition

The basic process of combustion is that carbon (C) and hydrogen (H_2) are oxidised in the presence of oxygen (O_2) under energy release with the results of carbon dioxide (CO_2) and water (H_2O). If all components of the fuel are oxidised it is the speech of a complete incineration with λ=1[61].
This combustion has the biggest mean for the biogenic solid fuels. The incineration systems produce heat which can be used as

- secondary energy: for example as steam which can be transformed to electrical energy
- end energy: for example district heating or
- useful energy like the radiant heat of a tiled stove.

So, combustion is the oxidation of a fuel under energy release during which exhaust gases and ash occur. To reach high efficiency and low pollutants emissions there are some requirements to consider. The incineration technique has to take into account special characteristics of the biogenic fuel, like a high amount of volatile substances which are released during the pyrolytic decomposition. The constructive requirements for the combustion are demanding, due to the high amount of complex physical and chemical processes which are taking part in parallel. Basically the incineration can be divided into two different kinds of loading processes, the manually loaded and the automatically loaded incineration. For the manually loaded variant, the fuel is brought to the combustion chamber discontinuously by hand. Here enormous differences in the progress of the incineration occur because of the varying time between the refuelling. This method is mainly done in private households for fireplaces or ovens.

[61] KALTSCHMITT, M.; HARTMANN, H.;HOFBAUER, H. (2009), S. 375 ff

At the automatically loaded process the fuel is inserted into the chamber continuously and, if possible, constant proportioned. In this case the incineration process is constant and with a constant power. Because of that the air amount can be adjusted. Here a bigger thermal power can be reached and for the plant technology a division due to the relative velocity between fuel and air is made in fixed bed, fluidized bed and entrained bed furnaces.
Three different combustion types are common for the mono combustion of sewage sludge, the fluidized bed incinerator, the multi deck incinerator and the multi deck agitator[62]. Table 10 shows an overview about the different combustion types.

[62] KALTSCHMITT, M.; HARTMANN, H.;HOFBAUER, H. (2009), S. 375 ff

	Fluidized bed boiler	Multi deck incinerator	Multi deck agitator
Special feature	• No mechanical movable parts • minimal wear	• No separated pre drying • Movable parts • Complicate oven construction • Cooled hollow shaft	• No separated pre drying • Movable hollow shaft • Low fluidized bed volume
Operating behaviour	• Fast start up and shut down • short heat up and cool down time • intermittent operation possible	• Long heat up time →continuous operation necessary	• Middle heat up and cool down time
Combustion	• Low air excess required • Complete burn-out just until above fluidized bed	• Burn-out difficult to control • Resistant against fluctuations for feed rate and coarse materials	• Low air excess required • Good burn out control • Combustion as far as possible in fluidized bed completed • Compared to fluidized bed oven less sensitive to quality fluctuations of the sludge
Ash content in the exhaust gas	High	Low	High
Ash discharging	Via exhaust gas stream and sand deduction	Directly from the lowest deck	Via exhaust gas stream and sand deduction
Residuals	• Ash • Fluidized bed material	Ash	• Ash • Fluidized bed material

Table 10: Common combustion systems for sewage mono incineration[63]

The fluidized bed boiler is explained in 2.3.2 because this technology is superior when compared to the other combustion types for mono combustion plants. Moreover, the examined product of ANDRITZ AG also is a fluidized bed boiler system.

[63] N.N. (2016), S. 167

2.3.2 Fluidized bed combustion

This kind of furnace technique is characterised through a stronger incident flow of the solid fuel as at the stoker fired furnace. Thus the solid bed swirls up. The fuel is implemented exegetically in the hot bed material, which consists out of a grainy inert material, usually sand ash mixtures. Inert materials in the fuel do not take part in chemical processes; those could be stones, concrete or bricks. The process in the fluidized bed furnace is as follows: particles are set in a floating state (fluidization) through nozzles, which are installed at the bottom of the fluidised bed reactor, which blow partly preheated air into the bed. The released combustion heat is absorbed by the bed material and according to this a homogenous temperature in the whole fluidised bed can be guaranteed. Hence this kind of furnace can be used for a great variety of fuels, especially based on water and ash content. For a better integration of pollutant formatting elements like sulphur or chlorine in the ash, the addition of additives like chalk and dolomite is recommended. A limitation factor for the fluidized bed is the particle size of the fuel and the ash melting behaviour. Depending on the fluidized bed construction type a maximum particle size of 100 mm should not be exceeded. Furthermore to avoid agglomerations of the bed material the ash should not soften. Nowadays this could be reached through the addition of additives and the lowering of the incineration temperature. Compared to stoker fired furnace the fluidized bed boiler combustion shows a higher pressure drop of the combustion air of about 100 mbar. This results in a higher blower power. Moreover the start-up procedure is more elaborated because the bed material has to be heated from cold state to about 600 degree Celsius, depending on the kind of used fuel, before the feeding of the biomass can be started. Therefore, a start burner is necessary, which generally runs with fuel oil or natural gas. A division into two embodiments can be made, the stationary and the circulating fluidized bed boiler system[64]. Both are explained more detailed in 2.3.2.1 and 2.3.2.2.

2.3.2.1 Stationary fluidized bed combustion

The stationary execution operates with a gas velocity (empty pipe velocity) of 1 to 2 m/s. The included bed material has an averaged grain size diameter of about 0,7 to 1 mm. This construction type is used for fuels up to 100 mm particle size and in the field of 5 to 50 MW_{th}. The stationary system allows an almost complete oxidation of the fuel and most part of the ash does not stay in the bed but is captured as fly ash in the dust extraction system. This is mandatory necessary in the exhaust flow for fluidized bed furnace due to the high particles transportation (20 to 50 g/(m^3n)). The temperature in the fluidized bed can be adjusted in two ways. On the one hand through heat dissipation with in the bed integrated heat transfer (dive heat areas). On the other hand, via under stoichiometric air injection into the fluidized bed. The second way is used more often nowadays because the dive heat areas have the disadvantage of a lower bed temperature and a resulting lower combustion temperature in partial load operation. Furthermore the surface is subject to a big wear through erosion. In this process the λ is between 0,6 and 0,8. To control the temperature within the given limits and for regulation purposes an intensive work with the recirculation, meaning the

[64] KALTSCHMITT, M.; HARTMANN, H.;HOFBAUER, H. (2009), S. 515 ff

recirculation gas, must be harmonized. Thereby, the fuel is gassed at a temperature between 600 and 800 °C in the bed area. In the free space above the fluidized bed the arousing gaseous products from the gasification after burning with secondary air is operated Problems can occur through slagging in the upper bed area of the fluidized bed. This necessitates a good controlled temperature management in the bed and free space to be an essential prerequisite. The fluidized bed runs at a temperature of about 650 °C, through feeding of secondary air in the lower secondary air area, the temperature increases through combustion of the not burned substances arising from the bed. If the temperature is too high caused by too much oxygen supply the above mentioned problem of slagging can occur. If necessary, recirculation gas has to be blown in. The remaining air is supplied to the secondary air area to guarantee a complete combustion. The temperature at the exit of the combustion chamber is depending on the whole amount of air and recirculation gas. In the case that the total amount is too high (what can happen for dry fuels), the brickwork can be rerouted in the upper area of the chamber to lead away the heat. Also bio fuels with a low ash softening temperature can be regulated in such technical designs because of safe sinking into the bed to the required value[65].

2.3.2.2 Circulating fluidized bed combustion

If, in comparison with the stationary, the incident velocity increases, further entrainment of bed material and fuel out of the fluidized bed follows. Therefore, the circulating fluidized bed has to lead back the entrained bed material. In this case too, the bed temperature can be regulated via heat dissipation from the circulating bed material. Depending on the removed circulating flow a certain temperature can be adjusted. Ideal conditions for a carbon implementation are determined by high heat and material exchange in the fluidized bed. For sulphurous or chlorinated fuels the desulphurisation or rather chlorinate separation is possible through the addition of chalk. This system is usable for a great variety of fuels and thus is mainly used for the energetic usage of residues and wastes of all kind, besides coal. The disadvantages are the same as for the stationary fluidized bed systems, already explained in 2.3.2.1. Despite relative compact construction the upper end of the power scale is marked. Due to economic reasons circulation fluidized bed systems are at first used at about 30 MW thermal heat power[65].

2.3.3 Small Scale Sludge Incineration (S^3I) with Heat Recovery Steam Generation (HRSG)

The existing concept for sludge incineration (Figure 12) of the ANDRITZ AG is a stationary fluidized bed combustion system to burn sludge (originally paper sludge) and includes, as main components, the sludge incinerator, the heat recovery steam generation system and the air pollution control system. The incinerator is adiabatic with a bubbling fluidized bed system and heat recovery. Natural gas is used for start-up and support firing. The function of the whole incineration system is described shortly in this chapter.

[65] KALTSCHMITT, M.; HARTMANN, H.;HOFBAUER, H. (2009), S. 515 ff

In general, the bubbling fluidized bed boiler combusts the fuel in the adiabatic incinerator chamber and in the fluidized bed which consists out of inert material. The inert material is typically natural sand. The combustion is sustained due to the large heat capacity of the bed and balances the fluctuations caused by changing fuel quality. Low environmental emissions are reached through low combustion temperatures and an efficient combustion process. Furthermore, the whole system is easily constructed so that non-moving parts inside the incinerator prevent a simple and low cost maintenance. The sludge is fed to the combustion chamber via sludge pumps. In the feeding nozzle the sludge is distributed to the bed with atomising steam. The combustion air is initiated into the wind box on the one hand as fluidization (primary) air below the grid and on the other hand as combustion air into the furnace, the so called secondary air. Low NO_x emissions can be reached via combustion temperature control and effective air staging. The incineration furnace is adiabatic. The heat-transfer surfaces of the evaporators, the economisers and the super heaters are cleaned with shot cleaning system.

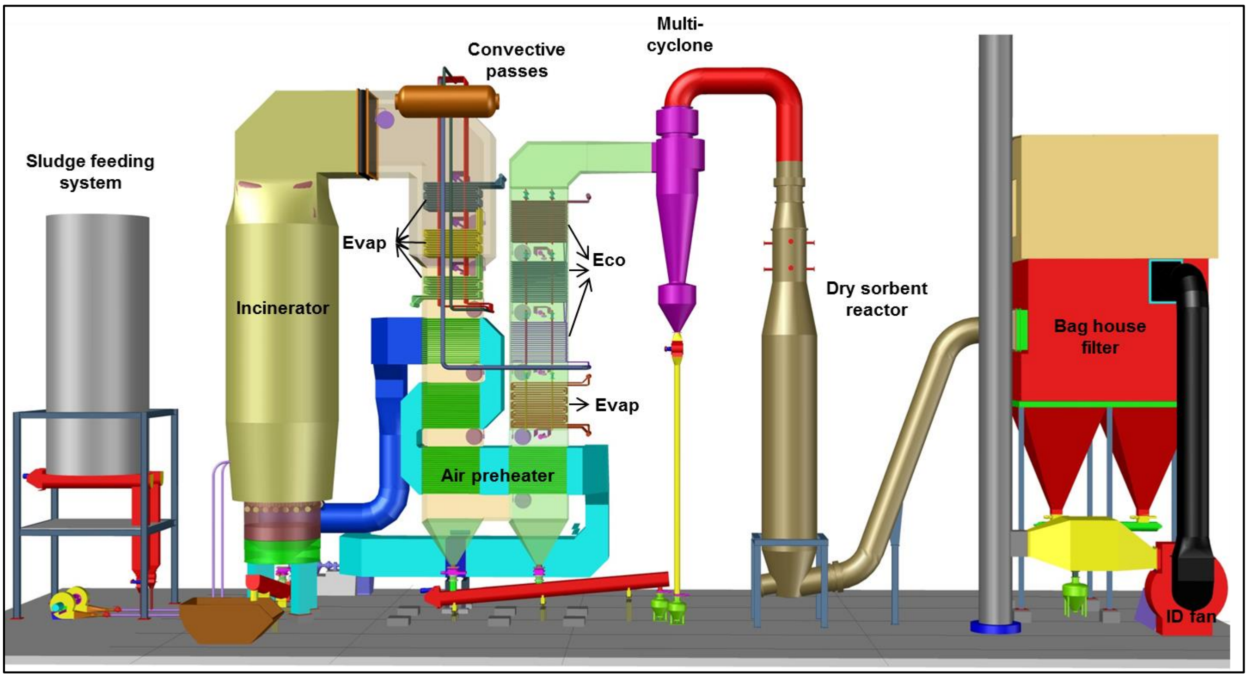

Figure 12: Structure of the S³I with HRSG[66]

The system consists out of the following parts:

- combustion system,
- water/steam system,
- combustion air system,
- flue gas system,
- fuel and additive feeding system,
- start-up fuel system

[66] ANDRITZ AG

- ash handling system

Combustion system

The combustion system includes the furnace, the nozzle grid and the refractory lining. The base of the boiler combustion technology is the bubbling fluidized bed combustion. The fluidized bed performs as heat storage. This keeps the combustion running and fluctuations which occur due to the changing sludge quality can be rather balanced. The amount of combustion-air, which is supplied to the bed, is less than the stoichiometric amount. Furthermore, the secondary air enters through the secondary air nozzles above the bed, in the higher part of the furnace. Most of the fuel`s fixed carbon is burned in the bed and consequently gasified. The fluidized bed is a layer consisting out of an inert material, which is typically natural sand mixed with fuel ash. Moreover the temperature of the bed can be controlled through supply of suitable combustion air amount. During operation the bed is about 0,8 meters high and the temperature should be about 700 to 850 °C. The fluidization of the bed material is reached with fluidizing air which is blown through the nozzle grid. The remaining combustion air can be used as secondary air, which is blown through air ports at the oven walls. The nozzle grid is situated at the bottom of the combustion chamber. In the wind box, which is located under the grid, fluidizing air is inserted with an air fan. Control of the temperature and the combustion process in the bed area can be reached through appropriate reduction of the oxygen amount of the fluidized medium. To avoid erosion and provide insulation of the adiabatic furnace, it is refractory lined. For a complete combustion, secondary air is inserted. Here, a limitation of the NOx formation can be reached by temperature control through good air stating. To guarantee the complete combustion, the temperature level must be adequate and good gas mixing is an advantage. During the combustion, the small particles are burned out quickly above the fluidized bed. The bigger particles enter the bed and are dried and gasified there. When the boiler is started, the furnace and the bed are heated up by one or two start-burners located in the lower part of the furnace. As a result of the start up the temperature of the cold bed material rises to the fuel release temperature. Then the slow injection of the fuel starts. The start-up burners can be stopped as soon as the temperature has reached about 600 °C.

Water/Steam System

The water/steam system produces saturated steam at controlled temperature and pressure levels and the main parts are:

- Feed water system: This system feeds the boiler with the needed amount of feed water. The needed amounts are about 5 t/h at a temperature of 125 °C.
- Economizer: The economizer heats up the feed water close to saturation temperature. To make sure that the water does not boil during normal conditions, the temperature difference is safe designed. Afterwards the feed water is supplied to the steam drum.
- Steam drum: In the steam drum water and steam are separated. Through down comer pipes the drum water is led to the next part, the evaporator system which is

designed as a natural circulation system. From the evaporator outlet headers the mixture of water and steam flows to the drum. In the cyclone separator situated in the drum, the steam is detached from the saturated water and the steam is dried in a lamella steam drier. The detached water is transported back to the evaporator. The drum has a safety relief valve to protect the natural circulation system against over pressure and a level measurement (pressure difference measurement) regulates the water level in the drum via the feed water pumps over the feed water control valve. To avoid too high salt and impurity concentration a blow down of drum water is done.

- Evaporator bundles: Water from the boiler drum comes through supply pipes from the drum to the second pass and further to the inlet header of the bundles. The main element of the evaporator is the boiler, which is a natural circulation boiler. In the natural circulation boiler the water circulates and is partly evaporated because of the density difference between the water in the down comer and the heated riser pipes. Moreover, a good recirculation of the water can be guaranteed through a sufficient amount of pipes.
- Super heater bundles: The arrangement of the super heater bundles is related to the live steam temperature and fuel properties and constructed individually. It is located in counter or co-current flow and is a horizontal tube bundle in the convective pass. Supporting tubes, arranged as evaporators, support the convective heating bundles. The main components are the unheated inlet and outlet heaters and the 1 bare horizontal tube bundles. For the drain and vent pipes double shut-off valves are used.
- Live steam and start up systems
- Blow out system
- Venting and draining system

Combustion air system

Another part of the incineration system is the combustion air system whose task is to provide the combustion air for the incineration of the fuel. This flow of air can be distinguished into two types. On the one hand the fluidization (primary) air and on the other hand the combustion (secondary/tertiary) air.

The primary air serves to fluidize the fluidized bed. The air is taken from the upper part of the boiler house and a dosed amount is blown to the wind box with the help of the primary air fan. The wind box is fixed under the fluidized grid. From the wind box the air is lead over nozzles to the bed cross section. To guarantee a good bed and fluidization behaviour, the air flow and pressure is held in a certain range and controlled by the primary air fan. Approximately 35 – 40 % of the total combustion air requirements are covered with the primary air.

Moreover, the secondary air should finalize the combustion in the furnace and also provide air for the start-up and load burners. Again air from the upper part of the boiler house is taken and now blown via the secondary air fan to the air preheaters. Afterwards the air stream is divided into secondary and tertiary air ducts. Thereby, the secondary air level is close to the fuel feeding points and the tertiary air level is higher in the furnace. To reach a total combustion and to reduce the NO_x air stating is done. In this case, the air flow is controlled through air-dampers in the main ducts to the air injection levels. In the injection levels nozzles are installed to provide a high velocity of the injected air and a good penetration of the flue gas. Each air nozzle duct has an individual manual controlled damper. The purpose is to regulate the air flow and consequently the velocity.

Flue gas system

For good flue gas handling this system includes flue gas ducting and a flue gas cleaning system to battery limit. To draft the flue gas a radial induced draft fan is installed. The flue gas ducting is located after the boiler and the cleaning system is located before the induced draft fan. The compensation of the loss of pressure, caused through the ducts, the cleaning-system and the boiler, is done via the induced draft fan. This occurs by the control of the furnace under-pressure via the speed controlled ID-fan (frequency converter).

After bag filter and induced draft fan recirculating flue gas is branched off for temperature control of the bed. The recirculated flue gas is added to the primary air. The required pressure of the recirculated flue gas is provided by the recirculation flue gas fan.

Additionally, a SNCR system for ammonia-water injection into the furnace is equipment of the boiler. The target of the SNCR is to reduce NOx emissions which occur when firing fuel with high nitrogen content or at high flue gas temperatures. For the flue gas cleaning a Turbosorb system is used for a dry type flue gas desulphurisation plant. The purpose of the system is the separation of dust, harmful acid compounds (SO2, HCl, HF, SO3 heavy metals) and dioxins/ furans from the flue gas. This can be realized through consuming of low consumables with a very high extent and finally a dry residual can be produced.

Fuel and additive feeding system

There are two feeding systems in the whole plant, the sludge feeding and the sand feeding system.

The sludge feeding system leads the fuel to the fluidized bed in the boiler. This happens through two feeding points about 3 meters above the bed surface at the boiler walls, which are oriented in direction of the surface of the fluidized bed. On the side of the boiler, drop chutes are located, which get fuel through feed screws. The drop chutes are cooled by carrier air and have manual slide valves, rotary feeders and expansion joints bellows. Moreover, the fuel carrier air causes a better fuel flow and supplies some of the combustion air. To prevent back fire from the furnace, rotary feeders are installed. Furthermore, the conveyers and the cutes have extinguishing water connections.

The other feeding system, the sand feeding, consists out of a bed material silo line. Here, the material gets to the fluidized bed over a fluidized bed feeding point at the boiler wall. The refilling of the silo happens pneumatically direct from silo truck over filling pipes at the bottom level of the boiler. The dosing of the material in the furnace is regulated by a screw conveyer. Bed material is periodically added to the bed or removed from the bed, depending on the bed pressure difference. The height of the fluidized bed is controlled through pressure difference measurement between furnace and fluidised bed. If the bed is empty after a standstill/maintenance shutdown the first filling of sand directly takes place from truck before the boiler is started.

Start-up fuel system

This component includes the start-up burner and the piping and valve groups for the burner. If the star-up burner is started, the temperature of the fluidized bed and also the furnace increase. The burner is oriented to the bed to heat up the bed during the process quickly. As soon as the desired temperature in the bed or the furnace is reached, the feeding of the solid fuel is released and additionally the start-up burner can be turned off. As already explained, the start-up burner is fired with natural gas.

Ash handling system

In the ash handling system two flows are affected, the bottom ash of the bed and the fly ash of the boiler back passes and the filter. In general, the boiler ash is bed material (sand and ash and impurities). These components occur due to the fuel which is fed to the boiler. The residuals of the combustion, bed ash and coarse material, can be removed from the bed during operation. Practically, the fuel ash is converted totally to fine dust during the combustion. The fine dust is entrained out of the boiler with the flue gas. Through bed temperature measurements, the coarseness of the bed material can be distinguished indirectly. The bed material turned core if the measured temperatures deviate significantly form another. This can lead to fluidisation problems and the bed material has to be changed. The removal of the bed ash is done through the open fluidizing grid. The bed material flows down to the ash hoppers and then to the ash chutes. The bed material is discharged through gate valves and expansion joints from the outcome of the cutes until water cooled screw conveyers. Then the bed material is transported to the ash containers with chain conveyers. The fly ash from the boiler back passes and filter is transported with screw conveyors to the chain conveyers of the bottom ash. Both are discharged together using collecting chain conveyers to ash storages pits outside of the boiler arrangement. To decrease the dust emissions of the storage pits, the coarse material is first separated (via vibrating or rotating screens) and then discharged to the ash moistening mixer. Both, screen and moistening mixer are arranged on the storage pit, which is covered in concrete. After passing the screen, the bed ash fines can be recirculated to the bed via a pneumatically conveyer system. The stored ash in the storage pits can be removed through front-end loaders to trucks.

2.4 Market analysis

To identify the market potential of compact boiler systems, the basics and different methods for a market research are elaborated in this chapter.

2.4.1 Market research phases

The market research is one of the longest established parts of the marketing science. The market research is connected with the marketing and has to show consideration for the customer wishes and enterprise offers. Information about customer and markets are necessary[67].

To succeed in the competition as an enterprise, the markets and their size should be known. The term market can have different meanings, like the product, demographical, geographical market or depending on the needs. The examined market must be characterised though few dimensions, otherwise, no meaningful forecasts can be made[68]

A market can be defined or explained in different ways but the most simple and direct description refers to the spatial and often also temporal fixed institution to guarantee and organize the best interchanging procedure consists in the functions of these institutions. From an economic view the market is seen more abstract as a meeting of offer and demand and the resulting exchange process. This happens under competition conditions of the providers and/or of the demanders[69].

A key position of marketing is the market research. To have a good overview about the market and the influence of the conditions, the provider has to have sufficient information about different markets and has to be aware of the own instruments of suggestibility. This data has to be collected and evaluated. Furthermore, for the planning of marketing the results of the market research are essential. The development process of the market research can be distinguished in several steps, which should simplify the examination of markets. These seven phases of market research are illustrated in Figure 13. Not all steps are always used in reality, sometimes steps are skipped or additionally added. Moreover recreation of links can occur between the individual steps, which are also not noted. The "Problem definition" and the "Determination of the aim of analysis" represent the conditions and orientation of the analysis definition. The determination of the used method includes the phases of "Determination of the design of analysis" and the "Development of measuring instruments", which are described more detailed following. All single parts of the market research phases build up on each other, with the consequence that mistakes are mostly serious and hardly repairable[70].

[67] KUSS, A.; WILDNER, R.; KREIS, H.;(2014), S. 1
[68] http://marketing.managertool.ch/ (22.04.2016)
[69] KUSS, A.; KLEINALTENKAMP, M.; (2013), S. 27
[70] KUSS, A.; KLEINALTENKAMP, M.; (2013), S. 96 ff

Problem definition

The first step of the market research process, the problem definition, is the basis of all additional actions. This phase should preserve against wrong researching topics. Here, the communication between involved players is essential[71].

Determination of the aim of analysis

In this phase, the task, which is already seen on the surface in the problem definition step, is concretised. The aim of the analysis occurs out of the problem definition. In general, for this step, time and finances are limited. The consequence is a narrow formulation of the aim of analysis. Further, this step includes very error sensitive analysis methods and is difficult to use. The difficulty is to inspect a little amount of important factors intensively and not to examine a huge number of factors only superficially. The way of analysis is connected to this phase, which can be divided in three types[71]:

- Exploratory analysis: The aim of the exploratory analysis is to identify the connections between variables or the roots of a problem. Such analyses are often used at the beginning of a big project and are helpful for additional actions. Normally, methods like group discussions or depth interviews are applied, which are called “soft” methods of data acquisition and analysis. These results in kind of impressionistic outcomes and the problems first have to be discovered. Consequently, the methods and results are kind of inaccurate.
- Descriptive analysis: The widest spread method is the descriptive one, which includes questions according the market size for example. Here, the behaviour of the market players and the markets are described and from the analysis results, the total market can be derived. Questionnaires and sampling procedures are applied for this kind of analysis. In summary, the target groups, markets and behaviour patterns can be shown with the descriptive analysis.
- Causal analysis: The statements and methods of the causal analysis are the most challenging, not only the common parts like the “typical customer” are described but rather the reasons for behaviour patterns e.g., are shown. This is very time consuming. Experimental designs are typically used here.

Finally, in the scientific area during the phase of “Determination of the aim of analysis” explicate formulations about variable connections, differences between involved players and hypothesis are made through assumptions from former analyses[71].

Determination of the design of analysis

Determination of the design of analysis is the third phase of the market research, at which fundamental decisions are taken, which affect the way of the chosen analysis. Primary or secondary research can be implemented. The primary research, also called field research,

[71] KUSS, A.; KLEINALTENKAMP, M.; (2013), S. 96 ff

includes the survey of new data for the particular field of examination. The data comes from empirical social researches. If a secondary research is done, existing data is newly analysed and prepared. The possibilities of secondary research increase continuously arising through growing online information. This type of research is also called desk research due to the fact, that the preparation of the data, like statistics, is done at the desk. Often, secondary research is done due to the advantages of time and cost savings. If the aim of research cannot be covered with the existing data or the data is not accessible, primary research has to be done before entering the next step of the market research[73].

Development of measuring instruments

The development of measuring instruments is important for the design of e. g. surveys and the connected development of questionnaires because measuring means assignment of numbers to examination units. The measuring instrument is for the named example the questionnaire. This step is really difficult[73].

Data collection

This step is often sourced out from the companies to special market research institutes which have the required know how and educated employees. Therefore this process step is normally cost intensive[73].

Data analysis

For the data analysis normally static methods and a wide range of methods are used. Beside the static approaches, graphic techniques become an important role because of developing software occurrence. These techniques have the advantages of easier and faster understanding representation of facts and the illustration of multi variable methods. Consequently a larger amount of variables can be analysed, what is necessary for the description of the complex phenomenon of the involved market players and behaviour patterns, which mostly cannot be described through a few variables[73]. This step includes the systematically order, interpretation and analysis of the collected data. Recommendations of actions are given during this step which can be the basis of the marketing decision[72].

Report

The final step of the market research process is the report, which should be the completion of an analysis. Normally, the report should be presented to the management. Besides the problem definition and the analysis aims, the report should include the answering of the questions from the beginning steps of the market research. Furthermore, the report consists out of four parts: short problem definition and analysis aim, summary, analysis method declaration, analysis result representation and recommendation and conclusion. The challenge here is to find a compromise between clarity and precision of the representation of the approaches and results[73].

[72] MAGERHANS, A.; MERKEL, T.; CIMBALISTA, J.; (2013), S. 26
[73] KUSS, A.; KLEINALTENKAMP, M.; (2013), S. 96 ff

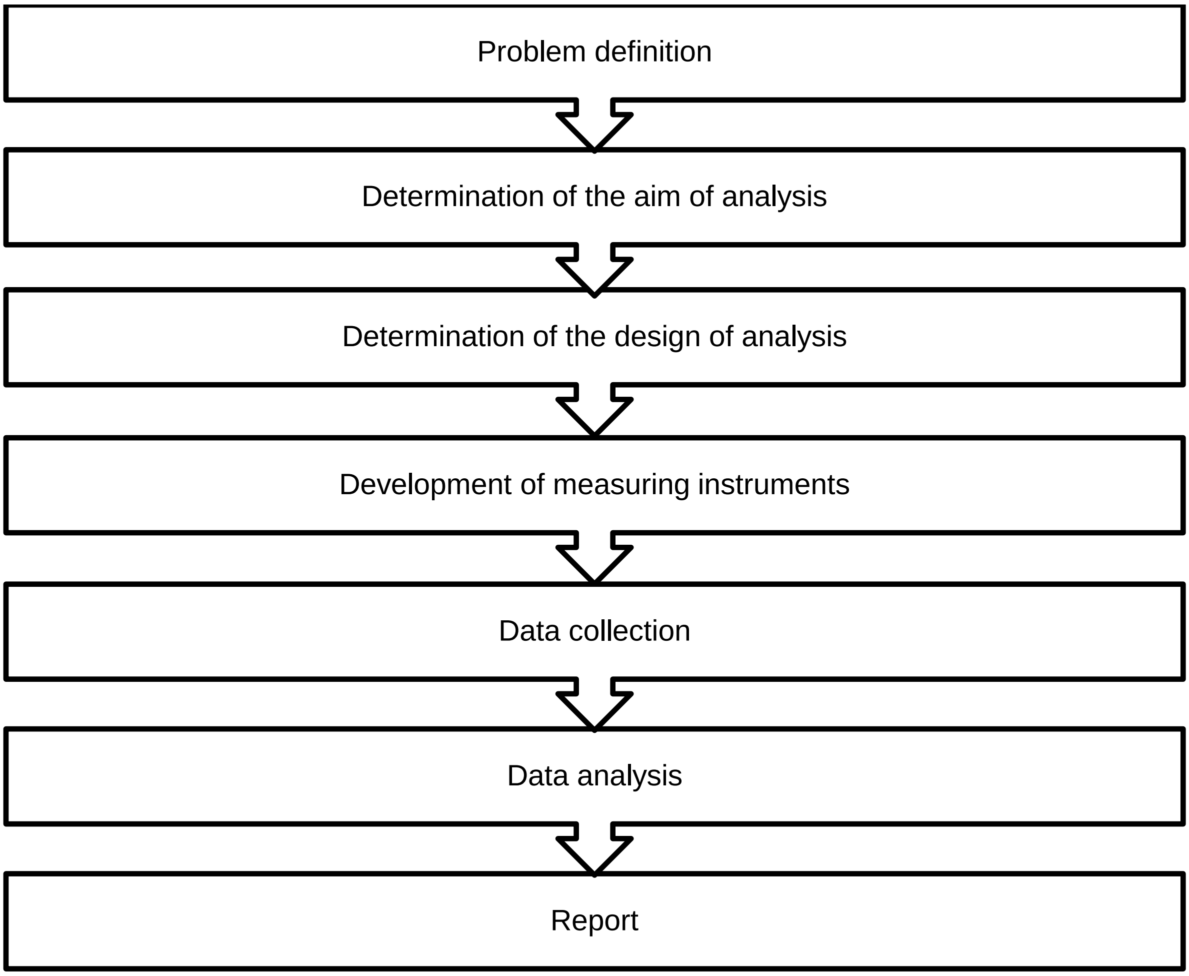

Figure 13: Market research phases[74]

The purpose of a market analysis is to understand and identify the market and further the optimization of the profit. That includes the permanent monitoring of the other players of the competition and a straight position in the market. The aim is to reach an advantage in the competition[75].

[74] KUSS, A.; KLEINALTENKAMP, M. (2013), S. 97
[75] VENZIN, M.; RASNER, C.; MAHNKE, V. (2010), S. 68

2.4.2 Market players

For the identification of the relevant market players Porter`s Five-Forces model is explained, which is illustrated in Figure 14. The model consists out of five elements[76]:

- Suppliers
- Costumers
- New competitors
- Substitutional products
- Industry competition.

According to the elements, an enterprise can analyse the attractiveness of a market.
The Five-Forces-model is a classic analyse tool and can be used for nearly each kind of market environment analysis. This can include the enterprise, a branch, a business area or a product. A holistically view to the actual and potential market environment.
The benefits of the Porter`s model are[76]:

- To analyse the actual situation in a market, including characteristic, driving force and balance of power
- To forecast the future market development regarding risks, hazards, opportunities and the probability of occurrence
- To forecast the market changes and dynamics
- To come to a strategic decision depending on the environment of the enterprise

The requirements for the Five-Forces-model are to define the regarded market and the comparability. Additional, the access to relevant data is important[76].

[76] SCHAWEL, C.; BILLING, F. (2014), S. 107 ff.

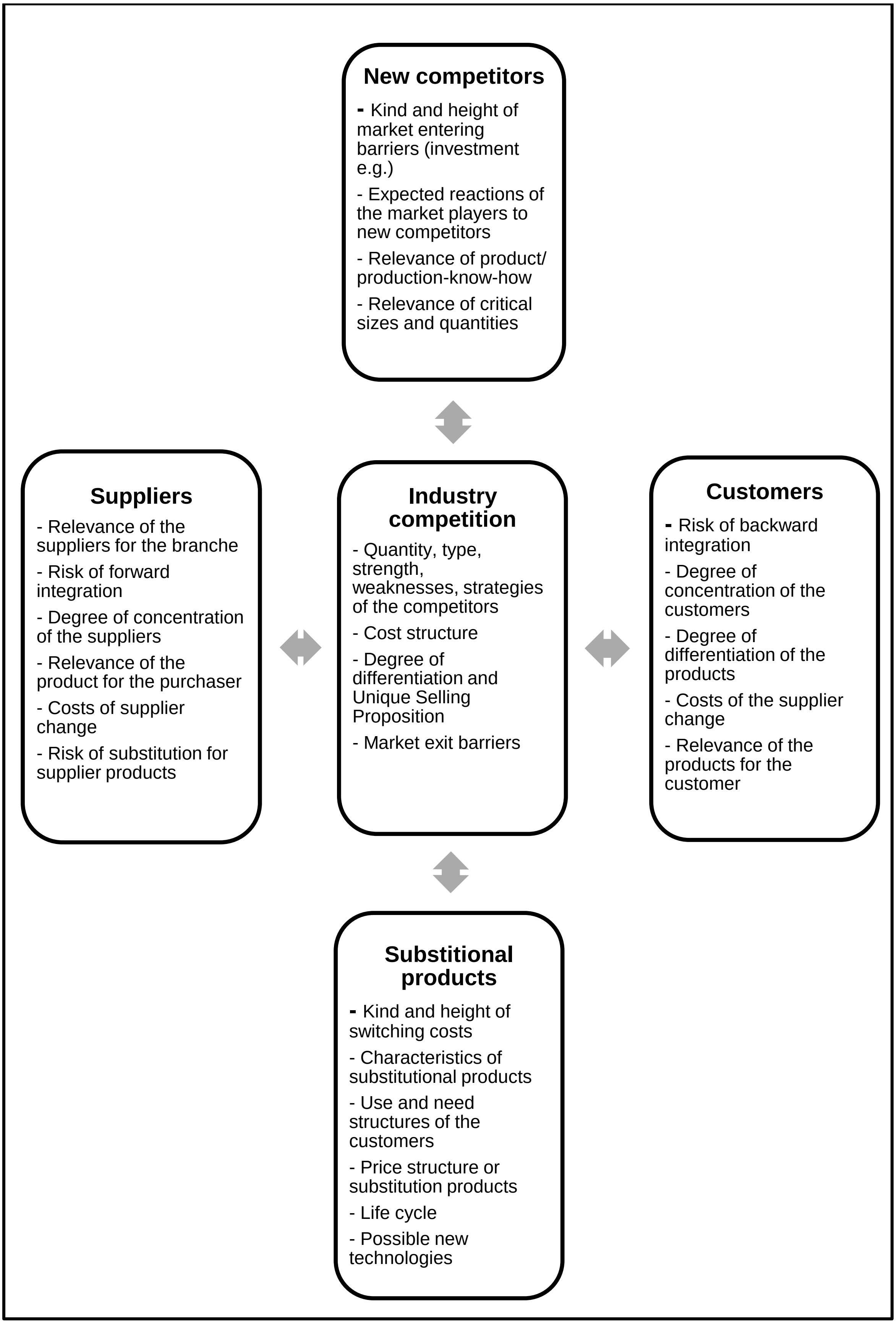

Figure 14: Porter`s Five-Forces-model[77]

[77] SCHAWEL, C.; BILLING, F. (2014), S. 108

2.5 Economic efficiency of the compact boiler concept

For the cost calculation of the S³I with HRSG the basics about investment calculation, the existing methods and steps of such a calculation are explained in this chapter.

2.5.1 Basics of the investment calculation

Whether an investment is rentable or not seems to be answered easily on the one hand but on the other hand sometimes it is very difficult to judge. Due to the influence of a made investment decision on the economic development of an enterprise, this question is very important. A bad investment can cause bad consequences that influence the investors. This bad investment can last over several periods and is therefore only hard to repair. In consequence, good evaluation methods are required to lower the risk for bad investment. These methods, which are developed in business administration, depend strongly on the approach and the framework. The investment calculation refers to a sub-process of the planning and decision making of an investment. Furthermore, the benefit of an investment project can thus be additionally evaluated. Moreover, a number of different investment projects can be compared thus helping to make a decision for the most profitable investment alternative.

An investment is the binding of financial resources therefore the economic advantages of a chosen investment project should be illustrated through the investment calculation. Different criteria can define the advantageousness. Generally, the target of the investment calculation is to identify the profitability of a planned investment. The investment calculation methods can be differentiated in static and dynamic techniques, which are explained in the next subchapters[78].

The methods can help with two topics:

- Figuring out the economic effects of a single investment
- Comparison of different investment projects, to make a decision.

2.5.1.1 Static methods

Static methods are popular due to the fact, that these methods are easy to use and simple to understand. The simplicity can be reduced to the strong degree of simplification of the calculations. The period of investment phase and connected fluctuations are not considered differentiated. The calculations just refer to typical or standardized periods for the whole lifetime of an investment. The disadvantage of the static methods consequently is, that the significance of a calculation is limited by the degree of its simplification. According to this disadvantage, the static methods are increasingly replaced by dynamic methods[78].

[78] SCHAUMANN, G. (2010), S.245 ff.

2.5.1.1.1 Cost comparison calculation

The idea of the cost comparison calculation is to compare costs of different investment alternatives. This can happen as well for replacement investments as for expansion investments. The replacement investment includes a cost comparison between an old and a new plant and the expansion investment compares the costs of several new plants.
This method only compares the costs assumable, the income of all investments must be roughly the same, like it is the case for quality and capacity.
Following costs have to be considered for all alternatives for one period[79]:

- Wages and salaries
- Raw material, additives and operating material
- Energy costs
- Maintenance costs and repair costs
- Insurance, fees and taxes
- Capital costs (from depreciation and interests)
- Overhead costs (for example administrative costs)

The chosen overhead costs depend on the operating structure. Normally, a linear depreciation is performed and the repayment is divided uniformly over the used capital. The depreciation for use results out of the division of the acquisition value by the useful life[79].

2.5.1.1.2 Profit comparison calculation

The profit comparison calculation is an extension of the cost comparison calculation. For this method the revenue and sales situation is additionally considered. The base of the profit comparison calculation is the principle of profit maximization. The profit is the subtraction of the incomes by the costs. Consequently, a positive higher profit is advantageous if different investment projects are compared[79].

2.5.1.1.3 Profitability calculation

The cost comparison calculation and the profit comparison calculation exclude the invested capital but the profitability calculation includes the invested capital. This method quite refers to results or elements of the two already described calculation methods. The profitability describes the relation of the profit which can be reached with the investment project in relation to the invested capital. For the comparison of different investment projects the acquisition values of the single projects have to be equal or similar. Furthermore, the useful lives of the different projects also have to be assumed as equal or similar[79].

[79] SCHAUMANN, G. (2010), S.249 ff.

2.5.1.1.4 Amortisation calculation

The amortisation calculation provides information about the time period in which the invested capital of an investment projects flows back. In this case an indicator for the project risk of a capital loss is defined and not the profitability of an investment project. The risk of a project is increasing over a longer running time because of the increasing uncertainty due to longer capital tie up. The difficulty of this method is the assumption of the back flow. The amortisation time designates the time period in which the invested capital for the project equals the back flow[80].

2.5.1.2 Dynamic methods

The dynamic methods are used for the valuation of financial impacts of an investment project. In comparison to the static methods several periods of the investment time are regarded. Moreover, the cash flows of the single periods are captured explicitly. These methods are of financial mathematic kind and are used more often in reality, because of their higher information value. To compare the alternative investment projects, compounding and discounting have to be done on a defined observation date, to guarantee a qualified data processing and passing to account. Two possibilities exist to guarantee the comparability, from the view of the investor:

- Discounting of the amount in each case to the present observation date
- Compounding of the other amount to the target date in several years

The results are different interest rates and running times.
Dynamic methods have implicit regard to some risk factors but do not guarantee the capture of all uncertainties[81].
The dynamic methods include the capital value method, the annuity method, the actuarial return method and the dynamic amortisation method[82].

2.5.2 Frame work conditions and economic efficiency

The economic efficiency calculations have to be used in the preparation phase, the execution phase and over the whole useful life of the plant to guarantee economic success. The results are that not the cost savings are the decisive factor but instead the right interpretations of the cost benefit analysis and the connected optimum use of financial resources. The economic efficiency calculations can be used on the one hand for the valuation of reconstruction, new construction or power adjustment of plants as[83]:

[80] SCHAUMANN, G. (2010), S.255 ff.
[81] SCHAUMANN, G. (2010), S. 261 ff.
[82] ERMSCHEL, U.; MÖBIUS, C.; WENGERT, H. (2011), S. 33
[83] SCHAUMANN, G. (2010), S. 287 ff.

- Basis for dimensioning of single components or the whole plant
- Basis for special dimensioning for plant components
- Basis to compare alternative projects

And on the other hand for the valuation of planned or existing plants to calculate e. g. the energy generation costs.
Such economic efficiency calculations can be used to optimize, to control or/and to compare a plant. As already explained in 2.5.1 it can be differentiated in static and dynamic methods for the economic efficiency calculations. A distinctive feature is for sure the connected calculation effort of the dynamic methods. A lot of parameters and other details, depending on the timely development, have to be fixed[84].

2.5.3 Economic efficiency calculation for incineration plants

The idea of doing an economic efficiency calculation is to specify the specific costs of a mono incineration plant regarding several influencing costs.
The economic efficiency calculation of mono combustion plants is divided as can be seen in Table 11. The net production costs result from summation of the process engineering, the construction technology and the E MSR technology. Additionally, the incidental costs of the plant have to be added to get the net investment costs. For the calculation of the specific costs the annual operation costs have to be divided by the annual capacity[85].

Designation	Unit
Process engineering	€
Construction technology	€
E MSR technology	€
Net production costs	€
Incidental costs	€
Net investment costs	€
Annual operational costs	€
Annual capacity	Tons dry residual per year
Specific costs	€ per ton dry residual

Table 11: Investment and specific costs for sewage sludge incineration plants[86]

For a later estimation in the practical part of the costs, an example is figured out. In the example a large scale plant and a small scale plant are compared to each other, which can

[84] SCHAUMANN, G. (2010), S. 287 ff.
[85] FRANCK, J., SCHRÖDER, L. (2015), S. 473 f.
[86] FRANCK, J., SCHRÖDER, L. (2015), S. 473

be seen in Table 12. Dewatering costs are not included because the dewatering is task of the sewage plants. Moreover, for the annual operating costs all incomes and costs are taken into account. As can be seen the specific costs for a small scale plant are significantly higher than the costs for large scale plants. In Germany, specific costs for mono incineration plants for sewage sludge are normally between 180 and 400 € per ton of dry residual. But this cost assumption does not include the small scale plants, only the present plants in Germany[87].

Designation	Unit	Large scale plant	Small scale plant
Process engineering	€	24.150.000	3.590.000
Construction technology	€	5.150.000	880.000
E MSR technology	€	2.250.000	1.130.000
Net production costs	€	31.800.000	5.600.000
Incidental costs	€	3.200.000	1.000.000
Net investment costs	€	35.000.000	6.600.000
Annual operational costs	€	5.490.000	1.020.000
Annual capacity	Tons dry residual per year	35.000	2.000
Specific costs	€ per ton dry residual	157	510

Table 12: Comparison of a large and a small scale plant[88]

2.5.4 ÖNORM M 7140

The ÖNORM M 7140 “Economic comparison calculation of energy systems based on dynamic calculation methods” describes the figuring out of the economic efficiency of different energetically systems. The ÖNORM uses dynamical methods for the calculation. The energetical systems consist of several components and variable parameters:

- Capital committed costs
- Consumption committed costs
- Operating committed costs
- Interest, price and cost factor of the cost groups (capital, consumption and operating committed costs)
- Useful life

This ÖNORM can be used for economic efficiency calculation for especially:

- Boiler systems
- Heat plants (Local heat, district heat and biomass systems and similar)

[87] FRANCK, J., SCHRÖDER, L. (2015), S. 473 f.
[88] FRANCK, J., SCHRÖDER, L. (2015), S. 473

- Heat-pump systems
- Heat recovery systems
- Thermal solar systems
- Other thermal energy systems in the industry

A cost group is the summarised costs of a system. These costs refer to the capital committed, the consumption committed and the operating committed costs.
The capital committed costs are a cost group and consider the acquisition value, replacement investment as periodical costs of the year and the residual value and supports.
The costs for the use of energy sources and other operating material of the whole system in the financial year are represented by the consumption committed costs. The last cost group is the operating committed costs determined by the costs for maintenance, cleaning, repair, service and operation. Furthermore, other operating costs like administration costs, taxes and proportional fees in the financial year have to be taken into account. The capital committed costs represent the fixed costs and the consumption and operating committed costs represent the variable costs.
The useful life describes the expected time period in which a system can be used. The useful life can consider single components of the whole system, if necessary. The useful life is mostly shorter than the lifetime of a system because of service or other influencing factors.
The determination of the acquisition value for all parts of the system has to be done through the offers for the different parts[89].

[89] ÖNORM M 7140 (2013), S. 3 ff.

3 Practical problem

After the explanation of the theoretical basics regarding the relevant topics and the collection of useful data, in this chapter the market potential for mono incineration plants for sewage sludge is analysed and identified. Moreover, an economic evaluation for the existing concept of the S³I with HRSG is conducted. The calculation is adapted due to relevant theory and experience values.

3.1 Identification of the market potential for compact boiler concepts in the EU

In this section, the applied steps of the market research are described and methods are explained. Moreover, the market potential for the use of mono combustion plants regarding the probable development of future scenarios, due to the law and other framework conditions, is identified.

3.1.1 Market research phases

In 2.4.1 the theoretical basis of a market research is already explained. The procedure contains seven steps which are applied for the identification for the potential markets for the installation of mono incineration plants for sewage sludge.

1. ***Problem definition:***
   The first step is very important for further actions and the basis for the whole market research. In communication with ANDRITZ AG the target of the analysis was defined. The target is to identify potential markets for the use of fluidized bed boiler system for sewage sludge mono incineration, more precise the existing concept of ANDRITZ AG, the S³I with HRSG. A more detailed description is given in 1.2.

2. ***Determination of the aim of analysis***
   After the clear definition of the problem, the target is determined more detailed. Sub targets were defined, like the illustration of the development of sewage sludge amount and utilization and the actual situation. Moreover, a target was to organise the studies from “trend: research” about sewage sludge. Additionally, the framework conditions and the law had to be analysed. Finally, the specification of the examined field was limited to the EU and German speaking countries with particular attention to Germany (1.3, 1.4, 1.5). For this phase the descriptive analysis method was chosen to show the market size and the involved players.

3. ***Determination of the design of analysis***
   For the third step of the market research a secondary research was done. The first try of a primary research was not possible, due to the lack of interest of potential relevant parties involved.

4. ***Development of measuring instruments***
   According to the decision from step three to focus on the secondary research no measuring instruments are needed.

5. ***Data collection***
   The fifth phase of the market research process is the data collection, which normally is sourced out to external market analysis companies. In this case ANDRITZ AG sourced it out to the University of Technology of Graz in form of a Master thesis.
   In relation to the chosen secondary research method from phase three, the data was collected from internal and external sources. Relevant books, papers and journals were searched in the internet and libraries. Moreover, a lot of data was generated from official statistics and the “trend: research” studies about sewage sludge which are shown in the theoretical part. First, relevant data about sewage sludge basics, amount and utilization ways was collected and analysed. Afterwards literature of incineration, especially mono incineration was generated. After the collection and analysis of the first data, the decision was made to concentrate especially on the German market, because there is the biggest sewage sludge occurrence per year within countries of the EU. Additionally, the legislative requirements are one of the strictest and will probably be enforced in the next years thus pioneering the legal developments in the other EU countries. These changes of the law regarding sewage sludge utilization will probably have a big influence on the utilization ways towards the mono incineration in future.

6. ***Data analysis***
   After the data collection the data was analysed. For the analysis Microsoft Word and Excel tools were used. As far as the needed numbers were given from the data collection, graphic techniques were applied to ease comprehensiveness and interpretation. The implementation is done in 3.2.

7. ***Report analysis***
   The final report of the developed results is summarized in this master thesis. Besides, the interim results were already presented in interim meetings with ANDRITZ AG and the Institute of Business Economics and Industrial Sociology of the University of Technology Graz.

3.1.2 Market players

To clarify the position of the sewage sludge mono combustion branch, the Five Forces model of Porter is used (Figure 15). The theoretical model is already explained in 2.4.2. With the help of the model the actual market situation, driving forces and the market in the future is illustrated according to the five elements. The Five Forces model is done according to expert knowledge of ANDRITZ AG`s engineers and the theoretical base.

- ***Industry competition***
  ANDRITZ AG is a worldwide known company and possesses know-how in combustion systems. Moreover, they have an existing concept, the S³I with HRSG, for the mono combustion of sewage sludge. Competing companies are already more established in the market of the mono incineration plants. Additionally, there are some companies which have already more experiences with the phosphorous recycling or at least concentrate on phosphor recycling research.

- ***Suppliers***
  The suppliers for the mono incineration plants can be the sewage treatment plant operators themselves or intermediaries, which receive the sewage sludge from the operators of these plants. The suppliers chose the cheapest possible utilization way, which means the preference of the cheaper agricultural utilization. But the suppliers are dependent on legislative regulations regarding the possible utilization ways. Additionally, the suppliers have to respect the given infrastructure and locations of possible utilization ways: prices are increasing with longer distances.

- ***New competitors***
  New competitors for the mono incineration plants can be the development of new technologies for sewage sludge utilization and of course cheaper possibilities and products. In case the legislative regulations do not order the obligatory phosphor recycling out of the sewage sludge ash than co-combustion still can be used as a cheaper sewage sludge utilization method.

- ***Customers***
  The customer for mono incineration facilities can be the sewage treatment plant operators but such facilities are expensive and mostly not viable for single operators. Consequently, the single sewage plant operators can cooperate with each other and invest in incineration plants. For this option they do not have to pay for the utilization of the sewage sludge further on. Municipalities can also be customers in case the sewage plants are operated by the municipalities. Lastly, private investors also can be customers for mono incineration plants.

- ***Substitutional products***
  For the mono incineration systems other utilization methods of sewage sludge are a potential substitutional product. This is the case especially if the legislative regulation is not implemented as planned. Also co-combustion is an influencing substitutional product. All other utilization ways are cheaper than the mono combustion and, if possibly available, consequently more attractive for the suppliers. The development of other alternative methods can also be a risk for the mono combustion.

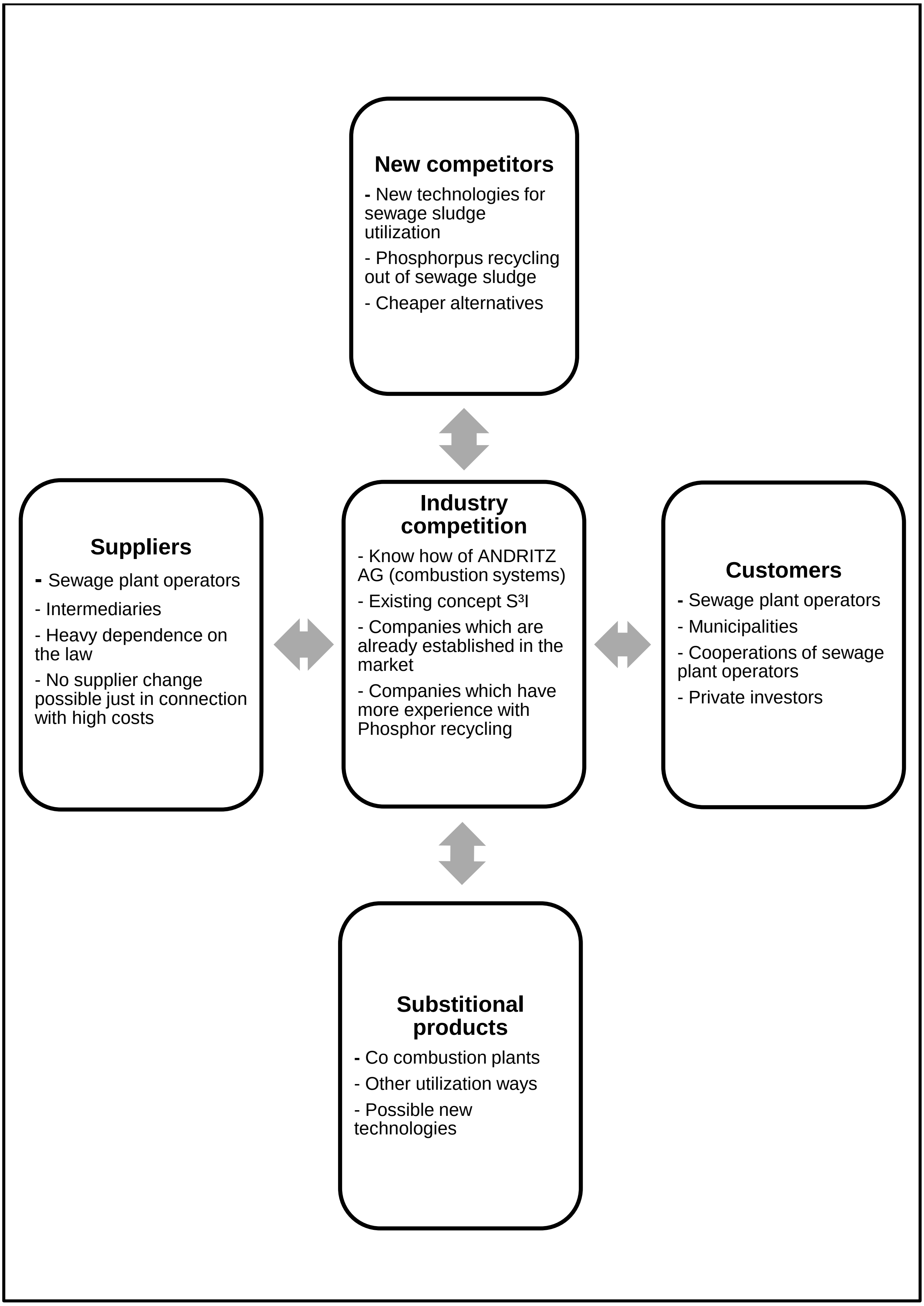

Figure 15: Five Forces model for mono incineration branch[90]

[90] Compare SCHAWEL, C.; BILLING, F. (2014), S. 108

3.1.3 Potential markets

To identify the potential markets for mono incineration plants supplying communal sewage sludge, in this chapter, first an overview about the European Union and the German speaking countries is given. Afterwards, a detailed consideration of Germany is performed, due to the fact that Germany has probably the most promising market potential.

3.1.3.1 Overview of European Union and German speaking countries

After the collection of the available relevant data in this subchapter the potential markets are identified. In Table 13, an overview about sewage sludge amount per year, the thermal utilization, the percentage of mono combustion utilization and the need for mono incineration in the particular countries is summarized. Table 13 shows there is no need for Switzerland for new mono incineration plants, due to the fact that their existing capacities satisfy their whole sewage sludge amount per year, if Switzerland makes use of the existing capacities.

	Switzerland	Germany	Austria	EU
Amount per year (tons dry substance)	195.000	2.000.000	260.000	EU 15: 10.100.000 EU 27: 11.500.000
Thermal utilization (%)	97 (2012)	50 (2012)	52 (2012)	EU 15: 35, 8 EU 27: 23,8
Mono incineration	43 % of the whole amount	23 % of the whole amount	No information	No information
Need for mono incineration plants	No	Yes	No information	Yes

Table 13: Overview about sewage sludge

3.1.3.2 Germany

For the following evaluation of the potential locations for sewage sludge mono incineration plants, Germany is considered because Germany produces the highest amount of yearly sewage sludge in the European Union. Furthermore, the probability of significant law changes which affect the sewage sludge utilization ways is high. The legislative framework is the most influencing factor for the future development of the sewage sludge utilization ways.

Prospective development of the sewage sludge amount

The development of the yearly sewage sludge amount can be predicted pretty exactly. The development depends on two influencing factors:

- Population development:
  Due to the already existing slow decrease of Germany`s population any further reduction of the population will consequently reduce the sewage sludge amount in the future too[91].
- Technological development:
  The technological development concerning the methods of the waste water treatment in the sewage plants will be improved as well. This can be achieved via a more intensive digestion. In consequences, the sewage sludge occurrence is reduced. Moreover, another reason for the decrease of the sewage sludge amount consists in improved actions which are taken to prevent industrial sewage sludge in the sewage plants[91].

In conclusion, due to the slow decrease of the population over the years and the improved technologies, the sewage sludge amount is going to decrease slightly until 2030. However, the technologic development is going to reach the optimum soon. In consequence, sewage sludge masses of about 1.740.000 tons dry substance per year can be predicted for the year 2030[91].

Law

As already explained in 2.2.3, the introduction of new legislative regulations regarding the sewage sludge utilization is quite likely. The legislative proposals include the exit from the sewage sludge utilization in the agriculture and the obligatory phosphor recycling out of the sewage sludge. Due to the uncertainty of the exact date of the commencement of the law and the likely increasing of legislative prohibitions, different scenarios are figured out in this chapter. Moreover, with the already existing threshold values of the “Düngemittelverordnung” dated 1.1.2015, 1/3 of the agricultural utilized sewage sludge has to be utilized in another way. An additional percentage of possible agriculture utilization will disappear with the prohibition of polymers[92].

Sewage sludge utilization

The development of the sewage sludge utilization ways is going to change extensively, in contrast to the sewage sludge amount. As already outlined the most important influencing factor for this change consists in the legislative regulations.

The future changes of the law are related to a big uncertainty. The changes cannot be predicted with accuracy. According to a survey from “trend: research” the substantial utilization ways will decrease over the next years. Moreover, the decrease will take place in favour of the combustion of sewage sludge, especially by the application of the mono combustion techniques. This demand for mono incineration capacities cannot be compensated in the next years, due to the fact that there are no mono combustion facilities under construction at the moment. Furthermore, the approval and construction time of such plants takes long. Another fact that indicates a trend towards mono incineration is that the

[91] N.N. (2016), S. 245 ff.
[92] N.N. (2016), S. 13 ff.

capacities for the co-combustion are limited due to approval and plant engineering regulations[93].

Different scenarios

According to the high uncertainty of the legislative sewage sludge regulations four scenarios are shown in Table 14. These scenarios were taken from the “trend: research” study and show different possibilities according to the planned law changes and the resulting appropriated need for new mono incineration capacities.

Scenario 1

The first scenario demonstrates the actual governmental plans for the sewage sludge utilization, which can be seen in Table 14. In this scenario, the timely development of the utilization ways turns exclusively to mono combustion until 2030. The obligatory phosphorous recycling out of the sewage sludge ash eliminates all other utilization ways but the mono incineration. The consequence is a necessary increase of mono combustion capacities for about 1.150.000 tons of dry substance sewage sludge per year. That could be reached by the new building of 23 mid-range facilities for a yearly amount of about 50.000 tons of dry substance of sewage sludge. Of course, also large scale plants can be built but this possibility is not closer explained in this thesis because the existing mono combustion system of ANDRITZ AG is in the range of the mid-scale facilities. The result of this scenario is the occurrence of bottlenecks, additionally strengthened due to the fact that some older existing facilities have to be replaced. This scenario constitutes an extreme scenario and the probability of occurrence for the other scenarios is higher[93].

Scenario 2

This scenario also includes the actual plans of the government for the law changes but those are softened. The use of polymers in agriculture is implemented with a transitional period what results in a slower decline of the agricultural utilization way. Furthermore, the phosphorus recycling is partially allowed out of sewage sludge before the combustion, which means that co-combustion is still possible. Nevertheless, the co-combustion capacities for sewage sludge will decrease from 2025 because of the energy revolution and the thereby forced shut down of the coal fired plants. The need for new mono incineration capacities is lower in the second scenario when compared to the first because of the named reasons. Moreover, the transition time period for needed capacities is longer. Mono incineration capacities for around 1.000.000 tons of dry substance of sewage sludge can be expected what includes the building of about 20 mono combustion facilities for 50.000 tons of dry substance of sewage sludge per year. In the second scenario, no bottlenecks are predicted but the planning of the new mono incineration plants should start soon. The approval procedures for a new plant take about four years[93].

[93] N.N. (2016), S. 248 ff

Scenario 3

The transition period for the prohibition of the use of polymers is additionally prolonged in the third scenario again. Furthermore, the utilization in agriculture is still possible for certified sewage sludge. This result in a lower amount of combusted sewage sludge in this scenario compared to the first two scenarios. Even in 2030 utilization in agriculture of 10 % is predicted. Consequently the need for new mono combustion plants is again lower than in the first and the second scenario. Between 2020 and 2030 capacities for 600.000 tons of dry substance are needed. A possible solution might be the building of 12 new mono incineration plants with a capacity of about 50.000 tons of dry substance per year. Still, the co-combustion capacities are decreasing in scenario 3. Because of the significant longer time period of the changes, there is more time for the new building of mono incineration plants and eventually new methods for phosphor recycling are developed[94].

Scenario 4

This scenario expects a delay of the legislative regulations with much longer transition periods as actually planned. The consequence is a clearly slower change of the single utilization ways of the sewage sludge. Nevertheless, the need of capacities for about 500.000 tons of dry substance is necessary, because of strict threshold for pollutants in the agriculture on the one hand and the decrease of the co-combustion capacities caused through the energy revolution on the other hand. For the need of the new mono incineration capacities new buildings of about 10 mid-scale facilities can be estimated. Even in this scenario a need for mono combustion plans is present[94].

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Agricultural utilization	Forbidden	Forbidden	Restriction	Delayed restriction
Phosphor recycling	Obligatory	Obligatory	Obligatory	Delayed obligation
Use of polymers in agriculture	Forbidden	Light delayed implementation	Light delayed implementation	Light delayed implementation
Material for phosphorous recycling	Only sewage sludge ash	Partial from sewage sludge	Partial from sewage sludge	Partial from sewage sludge
Future need for mono incineration capacities	1.150.000 tons dry substance per year until 2027	1.000.000 tons dry substance per year over longer time	600.000 tons dry substance per year over longer time	500.000 tons dry substance per year over longer time

Table 14: Different scenarios for the development of the sewage sludge utilization law

[94] N.N. (2016), S. 248 ff

Development of the prices

Related to the development of the sewage sludge utilization ways towards combustion, the prices for sewage sludge utilization will increase. Because of the rising amount of sewage sludge for co incineration and mono incineration and the connected higher occupancy of the facilities and possible bottlenecks, the prices for this utilization ways will increase. The combustion plant operators can consequently charge higher prices for the utilization from the sewage plant operators.

Existing and potential locations for sewage sludge mono combustion

After the explanation of the different development scenarios of the sewage sludge utilization ways regarding possible legislative requirements, actual locations, planned locations and potential locations for sewage sludge mono incineration are figured out in Figure 16. Furthermore, the sizes of the capacities are differentiated in smaller than 20.000 tons of dry substance sewage sludge per year, 20.000 to 40.000 tons of dry substance sewage sludge per year and more than 40.000 tons of dry substance of sewage sludge input (Table 15).
The figure is from 2014, what means that the map does not include all actual locations. In 2014 16 mono incineration plants for sewage sludge existed and potential locations for 14 new mono incineration plants for sewage sludge are figured out. Most of the potential locations are for capacities between 20.000 and more than 40.000 tons of dry residual sewage sludge per year. Consequently, the incinerator concept of ANDRITZ AG, the S³I with HRSG, again represented to be potential incineration system for the needed capacities.

Figure 16: Existing, planned and potential locations for mono incineration facilities of sewage sludge in Germany 2014[95]

[95] Compare FRANCK, J., SCHRÖDER, L. (2015), S. 462

Status	Location	Sewage sludge Capacity
Existing	Hamburg	>40.000 tons dry residual per year
	Berlin Ruhleben	
	Lünen	
	Bottrop	
	Elverlingsen	
	Frankfurt on the Main	
	Altenstadt	
	Herne	20.000 to 40.000 tons dry residual per year
	Munich	
	Stuttgart	
	Karlsruhe	
	Bitterfeld-Wolfen	<20.000 tons dry residual per year
	Düren	
	Bonn	
	Straubing	
	Gendorf	
Potential	Bremen	>40.000 tons dry residual per year
	Hannover	
	Kassel	
	Mannheim	
	Nürnberg	
	Ravensburg	
	Rostock	20.000 to 40.000 tons dry residual per year
	Lübeck	
	Magdeburg	
	Dresden	
	Chemnitz	
	Erfurt	
	Bielefeld	<20.000 tons dry residual per year
	Saarbrucken	
Planned	Mainz	>40.000 tons dry residual per year

Table 15: Existing, planned and potential locations of mono incineration plants for sewage sludge and the yearly capacity[96]

[96]Compare FRANCK, J., SCHRÖDER, L. (2015), S. 462

All analysed studies for this master thesis regarding sewage sludge predict a huge need of sewage sludge mono incineration plants in the future.

3.2 Economic efficiency calculation of the compact boiler concept

The cost analysis of ANDRITZ AG`s S³I with HRSG (Table 16) is based on the calculation for net investment costs and specific costs of a mono incineration plant applying the example from chapter 2.5.3. The process engineering costs for the system were taken from an existing offer from ANDRITZ AG for the S³I with HRSG. Additionally, the annual operation costs are calculated statically according to the ÖNORM 7140 and the expert knowledge from ANDRITZ AG. The different cost analyses and assumptions are explained in this chapter. Finally, a Microsoft Excel calculation was performed including all costs and revenues to calculate the specific costs and the net investment costs for the S³I with HRSG. The calculation was done for 3 lines and a connected capacity of 44.000 tons of dry substance of sewage sludge per year due to the results from the market research. According to the different scenarios and the connected need for mono incineration capacities for sewage sludge the recommendation was to build mid sizes plants for about 50.000 tons of dry substance of sewage sludge per year. Moreover, the annual operating costs and consequently the specific costs are calculated for two possibilities. On the one hand the calculation is done for the maximum receipt of the sewage sludge purchase and on the other hand for the minimum price. The following tables are a mixture of German and English language because the given declaration of ANDRITZ AG is used.

Denomination
Process Engineering
Construction technologies
E-MSR technology
Net production costs
Incidental costs
Net investment costs
Annual operation costs (Maximum incomes)
Annual operation costs (Minimum incomes)
Annual capacity
Specific costs (Maximum incomes)
Specific costs (Minimum incomes)

Table 16: Cost analysis for the S³I with HRSG

3.2.1 Process engineering costs

The process engineering costs for the incineration system of the ANDRITZ AG were already calculated for a former offer. The mono incineration facility includes three lines of the S³I with HRSG. Each line has a capacity for 22.000 tons of dry substance of sewage sludge per year. Two lines are running simultaneously what results in a total capacity for 44.000 tons of dry substance of sewage sludge per year. The third line is normally switched off and used only in the case of breakdown or maintenance of one of the other lines. The process engineering costs include the following costs:

- Engineering costs (internal)
- Project management costs (internal)
- Material and equipment costs:
    - Steel construction
    - EMSR (Elektrisch Messen, Steuern, Regeln)
    - External Engineering, diverse costs
    - Incinerator
    - Pressure parts
    - Reactor
    - Fan
    - Sludge system
    - Heating surface cleaner
    - Tanks, valves, hoists
    - Sand system
    - Ash system
    - Air flue gas system
    - External piping
    - SNCR
    - Transport
    - Bag filter, cyclone, injection mill
    - Insulation
    - Feed water tank and pump
    - Refractory
    - Devaporation

The costs for three lines can be seen in Table 17. The composition of the individual costs is figured out in Appendix 1.

Description	Costs (€)
Hours Enginnering	3.036.868
Hours Projectmanagemet	781.670
Internal Hours Total	3.818.538
Stahlbau	1.574.714
EMSR	659.859
Fremdeng. Div. Kosten	624.556
Brenner	298.241
Druckteil	448.905
Reaktor	403.371
Gebläse	253.505
Schlammsystem	1.286.669
Heizflächenreiniger	387.714
Tanks, valves, hoists	669.179
Sandsystem	129.138
Ashsystem	1.215.333
Air flue gas system	854.051
External pipe	175.217
SNCR	633.763
Transport	840.929
Bagfilter, cyclon, injection, mill	2.489.383
Insulation	932.302
Feedwatertank and pump	337.013
Refractory	1.163.141
Entschwadung	1.314.748
Total	20.510.271

Table 17: Costs for process engineering for 3 lines

3.2.2 Construction, E-MSR technology and incidental costs assumption

The construction costs, the E-MSR ("Elektrisch - Messen, Steuern, Regeln") costs and the incidental costs are not part of the statement of costs of ANDRITZ AG and the construction is done by other specialised companies. These costs are assumed, based on the calculation from 2.5.3 and on expert knowledge of engineers of ANDRITZ AG. The assumptions made are shown in Table 18.

Description	Amount	Unit
Construction technology	4.500.000	€
E-MSR technology	2.000.000	€
Incidental costs	3.000.000	€

Table 18: Assumption of the costs for construction technology and E-MSR technology and incidental costs

3.2.3 Annual operating costs

The annual operating costs for the mono incineration plant for sewage sludge are calculated and assumed due to the statistical methods, the ÖNORM M 7140 (2.5.4) and expert knowledge of engineers from ANDRITZ AG.
The ÖNORM M 7140 is originally designed for economic comparison calculations with dynamic methods, but here used for a static calculation.
First the relevant data for the combustion system has to be defined, as can be seen in Table 19. For the later calculated fixed costs, the depreciation is important. Therefore, the acquisition value and the useful life have to be given. The yellow boxes have to be defined, the others result from calculations. The acquisition value results from Table 16. The useful life is assumed with 15 years. The mono incineration plant runs 24 hours per day, 355 days per year. The running time can be reached, because of the three lines. Two are running simultaneously and in case of a break down or maintenance work of one line the third line can be switched on. In total the S³I has a running time of 8.520 hours per year. The capacity is about 44.000 tons dry substance of sewage sludge per year.

Data combustion system		
Description	unit	amount
Aquisition value	€	30.010.271
Useful life	years	15
Running time	days per year	355
Running time	hours per day	24
Running time	hours per year	8.520
Sewage sludge amout	tons dry substance per year	44.000

Table 19: Data of the combustion system

After the relevant data is defined, the costs are figured out in Table 20. For the capital committed costs, the depreciation for use and other fixed costs are defined. The demand committed costs; the consumption costs are calculated due to the data of the ANDRITZ AG S³I and explained more in detail in Table 21. The operating committed costs include the electricity costs, the maintenance costs, the disposal of the sewage sludge ash and wages.

Costs			
Cost type	Description	amount	unit
Fix costs:	Depreciation for use	2.000.685	€ per Year
Capital committed costs	Other fix costs	200.000	€ per Year
	Total fix costs	2.200.685	€ per Year
Variable costs:			
Consumption commited costs	Consumption costs	102.803	€ per Year
Operating commited costs	Elecrticity costs	681.600	€ per Year
	Maintanance costs	900.000	€ per Year
	Disposal	1.540.000	€ per Year
	Wages	300.000	€ per Year
	Total variable costs	3.524.403	€ per Year
Total costs		5.725.088	€/year

Table 20: Costs of the S³I

The consumption costs consist (Table 21) out of following items:

- Incinerator: Bed material, urea for SNCR, dilute water for SNCR
- Flue gas treatment: Natriumhydrogencarbonat, activated carbon
- Start up: Diesel
- Feed water conditioning: Sodium chloride
- Chemical dosing: Sodium hydroxide, Ammonia

The appropriated values and the prices are taken from calculations of ANDRITZ AG. The total estimated cost per year are 51.402 € for one line. For the statement of costs, this value has to be multiplied by the number of running lines, in this case 2.

Item	appropriated value	unit	appropriated value	unit	demand 355 days/year	unit	Price	unit	€/year 355 days/year
For incinerator:									
Bed material consumption	15	kg/h	360	Kg/day	127,80	t/year	60	€/ton	7.668
Urea consuption for SNCR	5	kg/h	120	Kg/day	42,60	t/year	200	€/ton	8.520
Dilute water for SNCR	20	kg/h	480	Kg/day	170,40	t/year	1	€/ton	102
For flue gas treatment:									0
Natriumhydrogencarbonat [Na(HCO3)]	6	kg/h	144	Kg/day	51,12	t/year	200	€/ton	10.224
Activated Carbon (HOK)	1	kg/h	12	Kg/day	4,26	t/year	3.300	€/ton	14.058
Diesel per start up:									0
(calc. Twice per year =1.150*2)	2.300	kg			2,30	t/year	1.000	€/ton	2.300
Feedwater conditioning:									0
Sodium chloride (NaCl)			120	Kg/day	42,60	t/year	200	€/ton	8.520
Chemical dosing:									0
Sodium hydroxid (NaOH)					8,00	kg/year	410	€/ton	3
Ammonia (NH3)					12,00	kg/year	500	€/ton	6
Total estimated costs per year									51.402

Table 21: Consumption costs for one line

The operation committed costs are figured out in Table 22. The electricity costs for one line with 500 kW, a running time of 8.520 hours and a appropriated electricity price of 0,08 €/kWh are 340.800 €/year. For the statement of costs this value has to be multiplied by 2, the number of running lines. The maintenance costs are assumed with 900.000 €/year due to expert knowledge. By burning sewage sludge the resulting ash is half of the amount of the sewage sludge mass, consequently 22.000 tons of ash per year are assumed (see 2.1.3). The wages are calculated for 5 workers with a yearly salary of 60.000 €. The yellow boxes can be adapted in the Microsoft Excel File, if the prices are changing.

Operation commited costs	amount	unit	runing time/ working time	unit	price	unit	total costs	unit
Electricity costs (Internal) one line:	500	kW	8.520,00	hours	0,08	€/kWh	340.800	€/year
Maintanance costs							900.000	€/year
Disposal and Transport costs	22.000	tons ash			70	€/ton ash	1.540.000	€/year
Wages	5	Persons			60.000	€/year	300.000	€/year

Table 22: Operation committed costs

The profits of the incineration system result from the sewage sludge purchase from the sewage plants. As already explained in the theoretical part, the sewage plant operators have to pay for the purchase of sewage sludge to the incineration plant operators. The prices are from Table 9 and the possible profits according to the capacities are showed in Table 23. The maximum and minimum receipts are illustrated. The minimum and maximum price is taken from studies, explained in 2.2.5.

amount sewage sludge (tons dry substance per year)	price (€ per ton dry substance)	receipts (€ per year)	Info
44.000	60	2.640.000	Maximum amount
44.000	40	1.760.000	Minimum amount

Table 23: Minimum and maximum receipts for sewage sludge purchase

For the total costs or profits of a year, the total profits (Table 23) are subtracted from the total costs (Table 24). The outcomes of the annual operating costs are divided in minimum and maximal costs depending on the receipts.

Total costs	5.725.088	€/year
Minimum receipts	1.760.000	€/year
Maximum receipts	2.640.000	€/year
Annual operating costs Maximum	3.965.088	€/year
Annual operating costs Minimum	3.085.088	€/year

Table 24: Minimal and maximal annual operating costs

3.2.4 Net investment costs and specific costs

After the explanation of the important cost for the S³I the net investment costs and the maximal and minimal specific costs for the sewage mono incineration plant are figured out in Table 25.

Denomination	Amount	Unit
Process Engineering	20.510.271	€/year
Construction technologies	4.500.000	€/year
E-MSR technologies	2.000.000	€/year
Net production costs	27.010.271	€/year
Incidental costs	3.000.000	€/year
Net investment costs	30.010.271	€/year
Annual operating costs (maximum incomes)	3.085.088	€/year
Annual operating costs (minimum incomes)	3.965.088	€/year
Annual capacity	44.000	tons dry sewage sludge/ year
specific costs (maximum incomes)	70	€/tTR
specific costs (minimum incomes)	90	€/tTR

Table 25: Net investment costs and specific costs for mono incineration plant

3.3 Results

The market research for potential markets illustrated that there is definitely a significant need for new mono incineration plants in the future. Especially, the German market was analysed due to the big amounts of sewage sludge per year and the planned regulations for the sewage sludge utilization laws. All viewed scenarios result in a demand for new sewage sludge mono combustion capacities in Germany. The planned legislative regulations include the compulsory phosphor recycling and the material out of which the phosphorus recycling has to be done, the prohibition of polymers in the agriculture and the agricultural utilization of sewage sludge itself. Depending on the transition periods and relaxing of the regulations the need of mono incineration capacities is varying between 500.000 and 1.150.000 tons of dry substance sewage sludge per year. Consequently, the need for mono incineration plants with mid-size capacity (about 50.000 tons dry substance per year) or large-size capacities (100.000 tons dry substance sewage sludge per year) is given. Up to 23 mid-size mono incineration plants have to be built in the future in Germany to cover the demand of capacities.

With respect to the gathered information, the existing concept of ANDRITZ AG, the S^3I with HRSG, has the optimal size for future demands in mono incineration facilities for sewage sludge combustion.

The economic consideration of the S^3I with HRSG results in specific costs between 70 and 90 € per ton of sewage sludge. Values between 180 and 400 € per ton of dry residual are given from literature for the specific costs of the mono incineration plants but also lower values are given from other literature. Here, it should be pointed out, that for the calculation in this thesis, a lot of assumptions had to be made according to literature research and expert knowledge. Consequently, the costs and profits do not represent the actual costs accurately. Moreover, the assumption for prices can vary depending on different locations. The calculation should give an overview and can be adapted due to the actual implementations.

4 Conclusion and prospects

The last chapter of the master thesis summarises the conclusion and contains the prospect of the future for mono combustion facilities in sewage sludge management. Furthermore, options of action for the ANDRITZ AG are presented.

4.1 Conclusion

The target of this thesis was the analysis of the development of the sewage sludge incineration in Europe with special respect to Austria and Germany. Furthermore, the identification of potential markets for boiler systems in the mono incineration of sewage sludge was evaluated. Finally, an economic analysis of the already existing concept of ANDRITZ AG, the S³I with HRSG, had to be created.

This thesis examines the European Union and the German speaking countries with regards to the development of promising sewage sludge utilization ways. In the end it concentrated on Germany for a detailed analysis of different scenarios with respect to future legislative regulations and the thereby resulting need for mono incineration capacities in sewage sludge utilization.

In conclusion, this thesis defines an increasing demand for compact boiler systems in the future legal management of sewage sludge combustion for the European Union. The existing concept of ANDRITZ AG, the S³I with HRSG with a capacity of 44.000 tons of dry substance per year meets this foreseen development for Germany. In case the legislative regulations are enforced in Germany, other countries probably will follow. The change of the utilization ways depends a lot on the transition periods and effectiveness of the enforced laws.

The prepared calculation of the net investment expenses and the specific expenses for the S³I with HRSG gives an overview of costs and profits for potential customers. The calculation can be adapted to different framework conditions. Assuming the above mentioned prices and profits, the S³I with HRSG, lies below the specific average costs for mono incineration plants between 180 and 400 € per ton of dry substance per year.

4.2 Prospect

Due to the increasing connection rate of the population to the sewer system the amount of yearly sewage sludge occurrence is going to rise. The increasing connection rate especially influences the occurrence in countries which are not well connected yet. Better developed countries like Germany, Austria or Switzerland will not create an increasing sewage sludge amount due to the already existing good connection rate and the used technologies for the sewage sludge treatment and associated sewage sludge mass reduction. The most influencing factor for the change of sewage sludge utilization ways consists in future legislative regulations. Especially in Germany the need for mono incineration capacities rises because of the newly planned legislative rules. These instructions obligatorily include phosphor recycling out of the sewage sludge. They define the required materials which have to be used for the phosphor recycling (waste water, sewage sludge or sewage sludge ash), the agriculture utilization and the prohibition of polymers in agricultural use. In case the laws are enforced as planned mono incineration capacities of up to 1.150.000 tons of dry substance sewage sludge are required. A possible new building of 23 mid-size mono incineration plants (50.000 tons dry substance sewage sludge) may therefore be necessary. The planned law includes:

- Prohibition of agricultural utilization
- Prohibition of polymers in the agriculture
- Obligatory phosphor recycling
- Phosphor recycling out of the sewage sludge ash

The prospected scenarios all predict an increasing demand for mono incineration capacities depending on the transition period and the severity of the enforced laws. Considering a scenario even with weak laws including longer transition periods and phosphor recycling only out of the sewage sludge ash, still capacities for 500.000 tons of dry substance per year are needed. This can be realized only by the new building of about 10 mid-size capacities.
ANDRITZ AG`s S³I with HRSG meets the requirements for the needed capacities. For the future, the profits received from the sewage sludge plant operator will probably increase due to the change of the utilization ways by new building of expensive mono incineration plants. Furthermore, bottlenecks are predicted, if the legislative regulations are enforced as planned.

Options of action for ANDRITZ AG

Finally, after the analysis of the sewage sludge market, different possible recommendations for the ANRITZ AG can be made:

- Keep the legislative regulations in view (most influencing factor for the development of the sewage sludge utilization ways)
- Establish contact to sewage plant operators to gain good market position
- Cooperate with research and development establishments regarding new combustion technologies and phosphor recovery
- Create own research and development in phosphor recovery
- Because of long approval procedures early entry is recommended
- Concentrate on German market first

The greatest risks of the market entering consist in the uncertainty of the length of the transition periods and the strength of the planned legislative regulations which can result in bad investment. Regarding the analysed literature, including many expert options, a future need for mono incineration capacities is predicted and consequently a research and development phase and an eventual market entry is recommended.

List of literature

ERMSCHEL, U.; MÖBIUS, C.; WENGERT, H.: Investition und Finanzierung. 2. Auflage, Berlin – Heidelberg 2011

FRANCK, J.; SCHRÖDER, L.: Zukunftsfähigkeit kleiner Klärschlammverbrennungsanlagen, in Energie aus Abfall, Band 12, 2015, S. 457-476

KALTSCHMITT, M.; HARTMANN, H.;HOFBAUER, H.: Energie aus Biomasse – Grundlagen, Techniken und Verfahren, 2. Auflage, Berlin Heidelberg 2009

KUSS, A.; KLEINALTENKAMP, M.: Marketing- Einführung: Grundlagen, Überblick, Beispiele, 6. Auflage, Wiesbaden 2013

KUSS, A.; WILDNER, R.; KREIS, H.: Marktforschung – Grundlagen der Datenerhebung du Datenanalyse, 5. Auflage, Wiesbaden 2014

LEHRMANN, F.: Überblick über die thermische Klärschlammbehandlung – Trocknung, Monoverbrennung und Mitverbrennung, in: Energie aus Abfall, Band 10, 2015, S.901-926

MAGERHANS, A.; MERKEL, T.; CIMBALISTA, J.: Marktforschungsergebnisse zielgruppengerecht kommunizieren – Ergebnisbericht – Präsentationen – Workshops, 1. Auflage, Wiesbaden 2013

N.N.: Klärschlammentsorgung in Europa bis 2020, Potentialstudie, trend:research 2. Auflage, Bremen 2010

N.N.: Zukunft der Klärschlammverwertung- Entwicklung in Deutschland bis 2030, Potentialstudie, trend:research, 3. Auflage, Bremen 2016

OLIVA, J.; BERNHARDT, A.; REISINGER, H.; DOMENIG, M.; KRAMMER, H.-J.: Klärschlamm - Materialien zur Abfallwirtschaft, Klagenfurt 2009

ÖNORM M 7140: Betriebswirtschaftliche Vergleichsrechnung für Energiesysteme nach dynamischen Rechenmethoden, in Austrian Standards Institute, Wien 2013

SCHAUMANN, G.: Kraft-Wärme-Kopplung, 4. Auflage, Berlin 2010

SCHAWEL, C.; BILLING, F.: Top 100 Management Tools – Das wichtigste Buch eines Managers - Von ABC-Analyse bis Zielvereinbarung, 5. Auflage, Wiesbaden 2014

SCHÖBERG, A.; RAUPENSTRAUCH, H.: Vom Klärschlamm zum Phosphor – die Zukunft der Verwertung von Klärschlamm, in Energie aus Abfall, Band 12, 2015, S. 477-489

TEZCAN, M.: Klärschlammentsorgung in der Schweiz – Klärschlammerhebung 2012, 2013

TRACHSEL, F.: Planung von Anlagen zur thermischen Klärschlammbehandlung, in Energie aus Abfall, Band 10, 2013, S. 987-996

TRATTNER, K.; WINTER, M.: Klärschlamm-Monoverbrennung - Möglichkeiten zur wirtschaftlichen Schlammverwertung mit der Andritz ECODRY Technologie, http://www.vivis.de/phocadownload/2011_wm/2011_WM_CD_46_Trattner.pdf, Abfrage vom: 13.7.2016

ÜBERREITER, E.; STORK, C.; WINDHOFER, G.; ZIERITZ, I.: Kommunales Abwasser – Österreichischer Bericht 2014, Wien 2014

VENZIN, M.; RASNER, C.; MAHNKE, V.: Der Strategieprozess: Praxishandbuch zur Umsetzung im Unternehmen, 2. Auflage, Frankfurt/Main 2010

WIECHMANN, B.; DIENEMANN, C.; KABBE, C.; BRANDT, S.; VOGEL, I.; ROSKOSCH, A.: Klärschlammentsorgung in der Bundesrepublik Deutschland, Dessau-Roßlau 2013

Internet

BUNDESMINISTERIUM FÜR WIRTSCHAFTLICHE ZUSAMMENARBEIT UND ENTWICKLUNG: Konzepte nachhaltiger Abfall- und Kreislaufwirtschaft, https://www.giz.de/de/weltweit/15109.html, Abfrage vom: 01.02.2016

MINISTERIUM FÜR UMWELT KLIMA UND ENERGIEWIRTSCHAFT BADEN WÜRTTEMBERG: Trockener Klärschlamm, http://www4.um.baden-wuerttemberg.de/servlet/is/18972/, Abfrage vom: 04.07.2016

X28: Marketing Grundlagen, http://marketing.managertool.ch/themen.htm, Abfrage vom: 22.04.2016

List of figures

List of tables

List of abbreviations

AbfKlärV	Klärschlammverordnung (Sewage Sludge Ordiance)
Al	Aluminium
BMUB	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit
C	Carbon
Ca	Calcium
CO_2	Carbon dioxide
DM	Dry mass
DR	Dry residual
DS	Dry substance
DüMV	Düngemittelverordnung (Fertilizer Ordiance)
e. g.	Exempli gratia (for example)
E-MSR	Elektrisch Messen Steuern Regeln
EU	European Union
etc.	Et cetera
Fe	Ferric
H_2	Hydrogen
H_2O	Water
HRSG	Heat Recovery Steam Generation
i.e.	Id est (that is to say)
NaCl	Sodium chloride
NO_x	Nitrogen oxide
O_2	Oxygen
S^3I	Small Scale Sludge Incinerator

Appendix

Appendix 1: Process engineering costs S³I with HRSG

Stahlbau		
Denomination	Pieces	Costs (€)
Stahlbau + wum.HEA300_25x22	3	671.043
Supporting steel for Reactor	3	167.761
Bühnen und Pdeste_1200m2	3	662.096
Bandagen	3	73.815
Total		1.574.714

EMSR		
Denimination	Pieces	Costs (€)
Feldgerät	3	559.202
Wirkdruckgeber	3	33.552
Steuerungen	3	67.104
Regelamaturen beim Zubehör		
Total		659.859

Fremdeng. Div. Kosten		
Denimination	Pieces	Costs (€)
Fremd-Engineering		
Deteil-Engineering	1	149.121
Stahlbau	1	62.134
Luft und RG Leitung	1	62.134
Verrohrung	1	62.134
Notified Body	1	62.134
Reisekosten		
Reisekosten und Auslösen Engineering	1	107.218
Reisekosten und Auslösen Abwicklung	1	64.818
Sonderkosten Abwicklung/Engineering		
Rechtsberatung	1	12.427
Dokumentation, Handbücher	1	24.853
Vdiv. Sonderkosten (Bewirtung etc.)	1	17.585
Total		624.556

Brenner		
Denimination	Pieces	Costs (€)
Dieseloilbrenner 1x4MW	3	149.121
BMS+BPS	3	149.121
Total		298.241

Druckteil		
Denimination	Pieces	Costs (€)
ECONOMISER_Material	3	38.909
Verdampferbündel_Material	3	49.870
Verdampferbündel_Fertigung	3	101.775
interne Verrohrung	3	78.288
ECONOMISER_Fertigung	3	79.407
Trommels_1,2x3mx15mm_M+F	3	100.656
Total		448.905

Reaktor		
Denimination	Pieces	Costs (€)
Reaktor blechcasing incl. Ductconn mat+fert.	3	309.425
Painting Reactor280m²	3	10.438
offener Düsenboden 9m2 fertigung	3	29.824
offener Düsenboden 9m2 material	3	53.683
Total		403.371

Gebläse		
Denimination	Pieces	Costs (€)
1 fan für PA + SA; 150 KW	3	55.920
1 motor for PASA fan 150 KW	3	29.824
1 Rezgasfilter_80KW	3	37.280
1 Motor für Rezgasfan_80KW	3	33.552
1 IDF 115 KW	3	67.104
1 Motor for IDF, 115 KW	3	29.824
Total		253.505

Schlammsystem		
Denimination	Pieces	Costs (€)
1 Schlammsilo with equipment 43m3	3	283.329
1 Silodischarge, sliding frame pds 11KW	3	141.665
1 Discharge screwconveyor 13 KW	3	113.332
1 Schlammlanze, inkl. Aizerstäuber+Arm1	3	53.124
1 manually actuated gate valve	3	53.124
1 Switch and control cabinet	3	297.496
1 schlammpumpe_26KW	3	88.540
Adaption piece outlet screw inlet pump	3	14.166
Connection piping and valve	3	145.206
1 Antriebspackage 55KW	3	96.686
Total		1.286.669

Heizflächenreiniger		
Denimination	Pieces	Costs (€)
sootblowers with compressed air first pass	3	223.681
shotcleaning 2.pass	3	164.033
Total		387.714

Tanks, Valves, Hoists		
Denimination	Pieces	Costs (€)
SMALL TANKS and dosing		
Block down tank 1m³	3	12.302
Contin. Blow down tank 0,4m³	3	11.930
Chemical dosing	3	33.552
COMPRESSED AIR STATION		
Air compressors 8 m³/min	3	52.192
Adsorption dryer	3	59.648
Compressed air tank .5.m³	3	22.368
Compressed air filter unit	3	5.965
Air main charger	3	9.320
Air receiver	3	19.013
Sequencer	3	14.166
Auxiliaries	3	7.083
HOISTS		
Hoists for erection opening boiler house	3	22.368
Hoists for feed water pumps	3	18.640
Hoists, manual	3	7.456
Hoists, electric 1000kg	3	14.912
CONTROL VALVES		
Feed water control valve	3	59.648
Feed water valve/bypass valve	3	12.302
Satrt-up valve (electr.)	3	48.464
Control valve steam air preheater	3	14.912
SHUT OFF VALVES		
Shut off valve before+after feed water control walve	3	26.096
Drum valve (vent, overflow man + el)	3	24.232
Live steam valve	3	18.640
Start-up valve (manual)	3	29.824
Vent+drain valves boiler	30	7.456
Live steam valve/bypass valve	3	3.728
OTHER VALVES		
Drum cont. Blow down valve group	3	2.237
Feed water non return valve	3	14.912
Drum safety valve + silencer	3	37.280
Drain sets with Kondensomat (4 el + 2 man)	3	11.184
Drum level (1local+1remote)	3	14.912
Drains and Vents, piping incl supports	3	22.368
Pressure gauge, local	3	1.491
Blowdowntank manual valves	3	8.574
Total		669.179

Sandsystem		
Denimination	Pieces	Costs (€)
Sand silo 20 m³ incl. Equipment	3	93.200
Slide gate 100x100, maual	3	1.640
Rotary valve DN 200	3	13.794
Screw conveyor	3	20.504
Total		129.138

Ashsystem		
Denimination	Pieces	Costs (€)
MECHANICAL ASH CONVEYING		
Bettascheschieber händisch	3	11.184
Vibro-conveyors 1m³/h	3	18.640
Bettascheschieber händisch	3	11.184
Bettascheschieber pneum	3	22.368
Bettasche Kompensator	3	11.184
Aschebefeuchtung	3	257.233
Bettasche Trockenkettengörderer	3	223.681
Rotary valve	3	14.912
Lump break/crusher	3	22.368
Rotary valve	3	14.912
Screw conveyor cooled	3	22.368
2./3.pass screw	3	18.640
Bettasche Trockenkettengörderer	3	167.761
Fly ash silo 20m³ net	3	74.560
PNEUMATIC ASH CONVEYING		
Sender bed ash 300 l, incl. all auxiliaries	3	48.464
Conveying piping bed ash, DN60, L=..m	3	44.736
Sender boiler ash 300 l , incl. all auxiliaries	3	74.560
Conveying piping boiler ash, DN60, L=..m	3	22.368
Sender fly ash300 l , incl. all auxiliaries	3	74.560
Conveying piping fly ash, DN60, L=..m	3	22.368
Control panal, documentation etc.	3	37.280
Total		1.215.333

Air Fluegassystem		
Denimination	Pieces	Costs (€)
LUVOS		
1 Dampfluvo GEA_0,5MW_KKAB	3	26.096
1 RG LUVO Willingshofer_1,2MW_KKAB	3	242.321
RAUCHGASKANÄLE		
ducting 2.pass	3	86.639
from ECO to cyclon	3	18.789
Reaktorhopper bottom inkl. Internals	3	52.192
Filterinlet	3	22.965
Flue gas duct from Filter to ID-fan	3	29.228
Flue gas duct from ID-fan to stack	3	12.526
ducting 3.pass 2,2x1,76x17	3	86.639
from cyclon to injection_5+7m	3	29.228
Adsorption zone 2,1mx10m	3	41.754
Recirculation gas duct to fan	3	17.745
Recirculation gas duct from fan to combuster	3	8.351
from Reactor to filter	3	24.008
LUFTKANÄLE		
Suction pipe to fan	3	14.166
fan to airpreheater	3	7.083
airpreheater to Nozzle grid	3	10.625
Tubular Air Preheater_connectrion	3	8.500
KOMPENSATOREN		
Rauchgas 3 je linie	6	29.824
Luft 3 je linie	6	22.368
AIR AND FLUE GAS DAMPERS		
primair damper DN100 manuel (air spout)	3	1.864
Secondary air damper DN250 manuel (level 1)	3	18.640
Cooling air damper DN80 manuel	3	7.456
Cooling air damper DN150 non return	3	7.456
Recirculation gas damper DN 200 manuel	3	3.355
Recirculation gas damper DN 800 pneum.	3	11.184
Recirculation gas damper DN 300 manuel	3	5.592
Recirculation gas damper DN 600 pneum.	3	7.456
Total		854.051

External Piping		
Denimination	Pieces	Costs (€)
Rohrleitungen, Speisewasser, Gas, SNCR	3	175.217
Total		175.217

SNCR		
Denimination	Pieces	Costs (€)
SNCR	3	633.763
Total		633.763

Transport		
Denimination	Rate EUR per hr., kg	Costs (€)
Transport	309	840.929
Total		840.929

Bagfilter+Cyclon+Injection+mill		
Denimination	Pieces	Costs (€)
Schlauchfilter inkl. Zyklon	3	1.930.181
Additivdosierung enthalten		
Big Bag Dosierstation für Aktivkohle enthalten		
Bicar Silo 20m3	3	74.560
Grinding mill	3	484.642
Total		2.489.383

Feedwatertank and pump		
Denimination	Pieces	Costs (€)
Feedwatertank_9m3_1,5x5m	3	145.393
Feedwaterpumps	3	74.560
Motors 2 x 15KW	3	11.184
2 Condensat circ pumps per boiler	6	89.472
Motors 2x5,5KW	6	16.403
Total		337.013

Refractory		
Denimination	Pieces	Costs (€)
Refractory Reactor + Connect duct 440mm; 101 m3	3	1.163.141
Total		1.163.141

Entschwadung		
Denimination	Pieces	Costs (€)
Entschwadung=Plume Removal	3	1.314.748
Total		1.314.748

Insulation		
Denimination	Pieces	Costs (€)
Insulation Reactor	3	111.840
Insulation 2.pass	3	89.472
Insulation 3.pass	3	89.472
Insulation air ducts	3	31.315
Insulation flue gas ducts	3	497.019
Insulation ash transport system (mech.+pneum)	3	22.368
Insulation ash silo(s)	3	17.894
Insulation vessels/tanks	3	14.763
Inulation piping	3	44.736
Insulation fans	3	8.947
Noise pritection hoods	3	4.474
Total		932.302