Bachelor Thesis

Processing Analysis & Market Analysis on Company X Bentonite

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Abstract

Bentonite is a clay that is used in many industrial applications. Company X required an investigation on the bentonite that is mined by Company Y. Currently Company X produces cat litter only from her bentonite, but other applications might be of economical interest to the company.

After scoping down to 4 applications other than cat litter (drilling mud, foundry sand, soil improvement and bleaching earth), the possibility of processing bentonite to gain the physical properties required by these 4 applications was investigated. The information needed for this investigation is mostly gathered from scientific reports based on the processing of Country A bentonites.

From the results from earlier researches on Country A bentonites it is concluded that Country A bentonites can be made suitable for all 4 applications through several processing steps.

The second part of the report focuses on the market possibilities of the 5 applications (the cat litter application included). It is found that the bleaching earth and the drilling mud market are most likely to be fit for a market entry. It is also concluded that the bleaching earth application is of most economical interest when looked at the net present value of the investment after 15 years. The drilling mud application is of most economical interest when looked at the internal rate of investment.

The soil improvement application requires almost no change in processing steps when compared to the production of cat litter and might therefore be of economical interest to Company X.

There is a risk of turning up with a negative net present value (after 15 years) when Company X would choose to invest in the drilling mud, foundry sand and bleaching earth application.

Therefore the final conclusion is that Company X should do a deeper investigation in the soil improvement application, since it is found that the economic potential is very high for this application. When this seems to be an unrealistic or economical uninteresting investment, Company X should investigate a further expansion of cat litter export.

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1 An introduction

1.1 Introduction in the thesis

Country A bentonites have a very high whiteness, which makes it a high quality material in the cat litter industry. Company X is a market leader in the cat litter industry. The company produces high quality cat litter which is seen as top market product. Company X imports and produces its bentonite ores from and in Country A mainly.

The bentonite mined by Company X are mainly calcium bentonites. Calcium bentonites can be converted to sodium bentonites using an activating process called ion exchange. Sodium bentonites have a much bigger swelling capacity and are therefore much more suitable for pet litter.

Bentonite is a widely used clay because of its rheological properties and its big absorbing capacity. This clay is a montmorillonite and further mainly contains, depending on the geological deposit, the following elements sodium, calcium, potassium or aluminium.

The object of this report is to evaluate whether or not the bentonite mined by Company X can be applied in any other industrial application, and if this would be of economic interest. Therefore the required processing steps and relevant costs were evaluated. The number of evaluated applications was limited, in consultation with Company X, to 5 (cat litter included) due to the amount of available time for this thesis.

These applications, other than cat litter, are: drilling mud, foundry sand, soil improvement (fertilizers) and bleaching earth. This selection has been made after several meetings with Company X.

1.2 Objective of the thesis

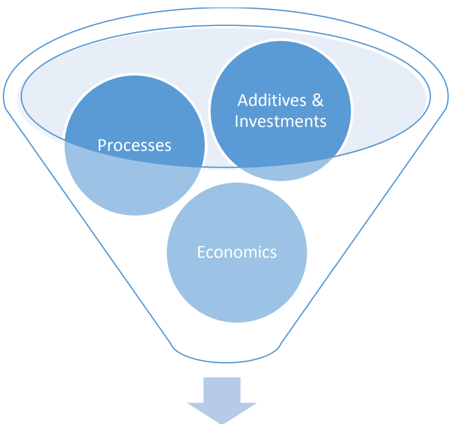
This document consists of a research report, including the results of the research on the processing and market analysis of 5 different applications of bentonite. The subchapters of 'cat litter' are not included in the report since this information is assumed to be known prior to this report. The cat litter application conclusions are included in the results and in the final recommendation.

The research on the processing of bentonite focuses on how bentonite has to be treated, or processed, in order to prepare it for different purposes since bentonite is used in many different industries. The knowledge used for this research is based on results from earlier researches that were done on Country A bentonites. At the end some suggestions will be presented on which processing steps should be taken to process the bentonite and on which additives should be added during these processing steps.

The research on the market analysis will focus on the economic market of the different applications of bentonite. The Company X bentonite might be found suitable for certain applications other than cat litter in the research on the processing analysis and this research will provide a conclusion on whether this will be of economical interest to Company X.

The overall report will give a recommendation on which applications Company X should start a further investigation so that they might enter a new market or new markets in the future.

Below a schematic view of the overall report is given:



Final recommendation on further investigation

1.3 Introduction in bentonite

The term Bentonite was first used for a clay found in about 1890 in upper cretaceous tuff near Fort Benton, Wyoming. Bentonite clay is a fine-grained rock composed of clay minerals, predominantly montmorillonite with minor amounts of other smectite group minerals. The formation of bentonite is an in situ alteration of rhyolitic volcanic ash. Pyroclastic material was ejected into the atmosphere by volcanic activity and deposited as sediment in a marine environment.

Bentonite clay is composed of microscopic platelets consisting of layers of aluminium hydroxide held between layers of silicate atoms. These platelets are stacked one on top of the other. If a gram of bentonite were spread out only one particle layer thick, its billions of particles would cover an area greater than a football field. There are two basic types of bentonite, sodium type (Na-bentonite) and calcium type (Ca-bentonite).

- Sodium Type - This type has sodium in the crystal lattice and is sometimes referred to as Wyoming Bentonite. This type swells when wet and can increase as much as fifteen times its original volume when wetted.

- Calcium Type - This type has calcium in the crystal lattice and is sometimes referred to as Southern Bentonite. This type will swell only 2 times their unwetted volume.

The Schlumberger Handbook (2014) states that 'The colour of bentonite ranges from white to black and includes shades of grey, light olive green, cream, yellow, earthy red, brown, sky blue and purple. Bentonite feels and appears greasy or waxy and when wet it is highly plastic and slippery.'

The industry uses bentonite for its inherent physical properties or for the physical properties it can develop in another material or product. The major applications of bentonite are those that involve mixture with water. By adjusting the water content, properties of the mixture can be developed which are utilized by industry for bonding, plasticizing, and suspending applications (Chisholm, F, 1960).

2 Applications of bentonite and their standards

2.1 Introduction

Bentonite knows many applications, however only 5 applications will be investigated during this research. The cat litter application is investigated to that it can be compared to the 4 newly chosen applications.

The applications drilling mud and foundry sand have been chosen since there are clear scientific standards available on which bentonite samples can be tested. The results from these 2 researches can also be used to draw conclusions related to other applications, e.g. iron ore pelletizing and paper.

The possibility of using Company X bentonite for soil improvement has been investigated because this was desired by Company X.

The application bleaching earth will be investigated since white bentonites tend to have a high bleaching capacity. The bentonite mined by Company X has a very high whiteness level.

2.2 Drilling mud

In petroleum engineering, drilling muds are used to drill boreholes deep into the earth. The boreholes are mainly used for the production of natural gas and oil.

The main purposes of these drilling muds are to cool and clean the drill bit, to provide hydrostatic pressure in the drilling column so that fluids will not enter the borehole, to carry out the drill cuttings and to suspend these cuttings when the drilling operation is in static state.

For these last two purposes it is important to choose a good clay with the right properties. Bentonite is often used in the drilling industry to create a so called ‘water based mud’. This is often referred to as ‘gel’ in the petroleum industry.

The term ’gel’ is used since bentonite muds have the properties of being a free flowing liquid in dynamic state and a gel in static state. This means that this gel has a certain yield point. These kinds of fluids are called ’Bingham plastics’.

A bentonite drilling mud is qualified as a good drilling mud if it meets the API standards (Appendix B.1). There exist 3 API standards for drilling muds, these are presented in table 1 and Appendix A.1.

	API Standards for Drilling Muds
Fann Viscosity at 600 rpm (in cP)	≥ 30
Filtrate Volume (in mL) after 30 mins	≤ 15
Moisture Content of bentonite powder (in %)	≤ 10

Table 1 API Standards for Drilling Muds

The Fann Viscosity is a value for the viscosity measured by a Fann viscometer, or a V-G meter.

The API definition of the filtrate volume is the volume of a mud filtrate measured after a 30 minute API static filtration test. Such a test consists of measuring the process of separating components of a slurry by leaving the suspended solids (dispersed particles from the drilling process) as a filter cake on a filter medium while the liquid passes through the filter.

The moisture content is the percentage of water in the end state of the semi-finished product.

2.3 Foundry sand

Synonyms for foundry sand are molding sand and green sand. A foundry sand is, as stated by Dungan and Dees (2009), 'an aggregate of sand, bentonite, pulverized coal and water. The main component is always the sand, a silica- or olivine. Foundry sand or green sand is not green in color, but 'green' in the sense that it is used in a wet state. Foundry sand with a suitable moisture content is known as the green molding sand.'

The term molding sand is used because a foundry sand can be molded (and hold its shape) after the required shape. When the molding sand is constructed, liquid iron or steel can be poured in the mold and when the liquid has solidified, the sand can be removed. The bentonite is used as a binder, so that the sand can indeed hold its shape and function as a mold. The unique properties of bentonite yield green sand molds with good flow ability, compatibility and thermal stability for the production of high quality castings.

It is very important that the bentonite does not lose its properties due to the extreme heat which is exchanged from the molten iron or steel. This is why a bentonite has to satisfy quite some standards (Appendix B.2) in order to be suitable for foundry sands.

Foundry sands are called high quality sands and are therefore of high economic interest, since bentonites suitable for foundry sands are sold at higher prices than most other bentonites.

2.4 *Soil improvement*

Scientists conducting studies in Australia, as stated by the International Water Management Institute (2010), found that adding smectite clays, especially bentonites, could help increase soil productivity by assisting in the retention of water and nutrients. Bentonite works as an ion exchanger for improvement and conditioning of the soil.

A key property of soil is its ability to provide nutrients and water to growing crops. Clays and organic matter are vital in this regard. However, it is often difficult to retain organic matter in tropical soils, so farmers need to routinely apply compost. Soils that contain high levels of particular clays such as smectites, are often very fertile.

Bentonite can be applied as an (untreated) clay which can be distributed over the infertile soil, or prills can be made by combining different minerals. In this research there will be focused on the clay as a fertilizer.

2.5 *Bleaching earth*

A bleaching earth is any fine-grained, naturally occurring earthy substance that has a substantial ability to adsorb impurities from fats and oils. Bentonite clays are known to have a moderate to high bleaching capacity.

The term bleaching earth is widely used in many industries, but in this report the term bleaching earths refer to vegetable oil and fat refiners.

The bleaching of vegetable or edible oils and fats is a part of the refining process of crude oils and fats, which removes contaminants that impact the appearance and performance of these fat based materials. Vegetable oils and fats, ranging from soybean and palm oils to lard and beef tallow, are extracted together with impurities in distinct quantities. Many of these impurities have to be removed from the oil to achieve the high quality oil standards necessary for various edible applications.

Bleaching earth are often composed of bentonite clays since these are known to have a high ability to adsorb (a mechanism by which the sorbent binds a contaminant) these so called impurities after they have been leached with acid. In the bleaching earth industry bentonite is often referred to as smectite clays or smectites.

3 Research on the chosen applications of bentonite

3.1 Introduction

Bentonite deposits are normally exploited by quarrying, and so are they in Location B (Country A). Extracted bentonite is distinctly solid, even with a moisture content of approximately 30 %.

The material is initially crushed and, if required for the application, activated (by an ion exchange process) with the addition of soda ash (Na2CO3). Bentonite is subsequently dried (air and/or forced drying) to reach a moisture content of approximately 15 %. According to the final application, bentonite is either sieved (granular form) or milled (into powder and super fine powder form). For special applications, bentonite is purified by removing the associated gangue minerals, or treated with acids to produce acid-activated bentonite (bleaching earths), or treated with organics to produce organoclays. (Industrial Minerals Association, 2014, [online])

Since the characteristics of the bentonite mined by Company X were unknown at the start of this research, assumptions had to be made. There are many bentonite excavation activities close to the mine site of Company X. Since the Country A bentonites were found to have roughly the same characteristics, it can be verified to assume Country A bentonites generally equal.

Muazzez Çelik Karakayaa, Necati Karakayaa and Seyfi Bakırb (2011) state that 'the physical and chemical properties of the Location B region bentonites indicate that they may be suitable as a raw material for several industrial applications. The swelling capacity of the Location B bentonites is closely related to the Cat ion Exchange Capacity (CEC) and the properties that are lower in the Ca bentonites than the Na bentonites. Because the presence of non-clay minerals reduces swelling and viscosity, the industrial development of this deposit would require selective mining. The brightness of the natural state of the Ca bentonite is unusually high. In addition to brightness, the particle size, CEC, swelling, specific surface area and viscosity properties make this bentonite potentially useful in high-value-added markets, e.g., as coating and filler additives and a filtering agent.'

In this chapter, some technical terms will be used that need some explanation in advance. A no. xx ASTM sieve (where 'xx' indicates the size of the sieve) is the industrial standard for indicating the size of sieves in sieving installations. The no. 200 ASTM sieve is mostly used in the processing of bentonite, this sieve has a mesh size of 75 µm. The mesh size indicate the size of the 'holes' in a sieve. ASTM stands for 'American Society for Testing and Materials'.

3.2 *Drilling mud*

Country A bentonites are known, as stated by Karagüzela et al (2010), to be used for drilling muds and many researches have been done on this topic. From scientific reports of researches of untreated bentonite originated from Location D the following values have been found as can be seen in Table 2.

The chemical composition of these bentonites ranged from 50–55 % montmorillonite, 10–15 % feldspar, 10–15 % amorphous material, 10–15 % quartz, 5 % calcite, 5–10 % opal, and 5 % gypsum.

	Values from Location D report(untreated)
Cat ion Exchange Capacity (in mg of Methylene Blue/g)	240–270
Swelling Index (in mL)	14.5–15.5
Fann Viscosity (at 600 rpm 20 min)	5.5–7.5 cP
Fann Viscosity (at 600 rpm 24 hrs)	7.0–8.5 cP
pH after 20 min	8.58–9.03
pH after 24 hrs	8.20–8.30

Table 2 Values from Location D report(untreated)

From table 1 and table 2 It can be concluded that the untreated bentonite which is found near Location D does not satisfy the API index, since the minimal values for API quality, as shown in table 1, exceed the values from table 2. From the same research it is found that a high MgO content is favorable in terms of the viscosity and swelling features.

Karagüzela et al (2010) also state that 'it was found that the optimal moisture content of the bentonite when activating with soda (Appendix C.2) is 40 %. The effect of the addition of MgO does not change with the moisture content. The research concluded that the combined activation of soda and MgO led to higher viscosities compared to the untreated bentonite while samples that were activated with only soda or MgO did not show any significant changes in the viscosities.'

From the results it was found that a combination of adding 2-3 % soda and 0.5 % MgO and applying extrusion (process in which bentonite is kneaded and pushed through a mold under high pressure) after that gave the best results concerning the API standards of drilling muds. The activation with the formula as mentioned above resulted in a drilling mud that is in accordance with the API Standards. (Appendix A.1, B.1)

Baki Erdoĝan and Şahinde Demirci (1995) showed that the use of polymers also results in Country A bentonites being suitable for drilling muds. The locations of these bentonite samples are shown in figure 1, inside the ellipse.

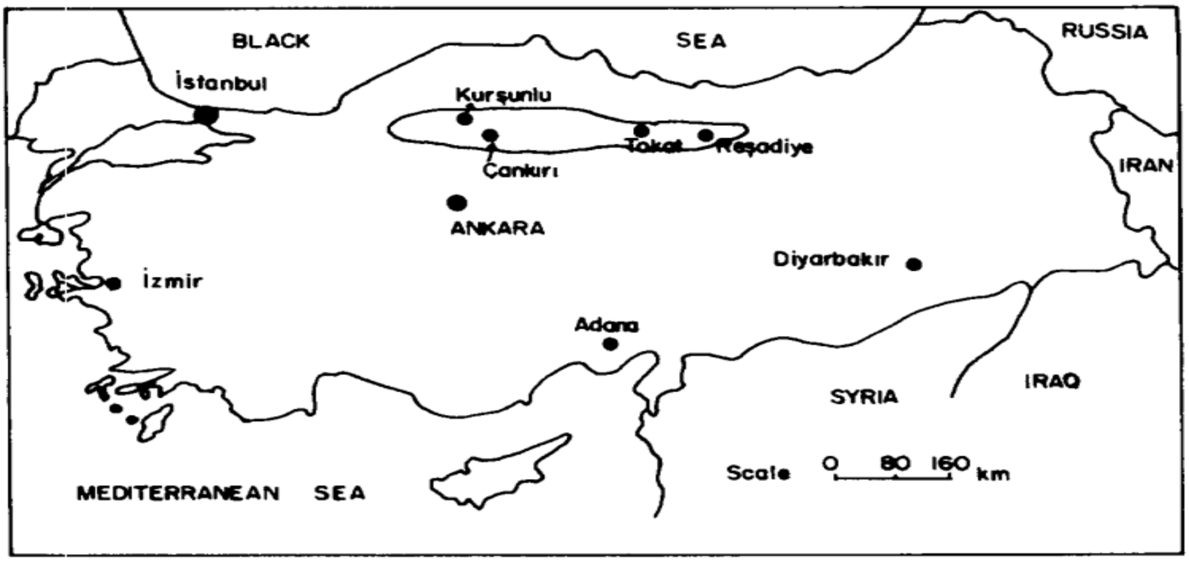


Figure 1 Locations of Bentonite Research

The research concludes that polymeric additives improved both viscosity and the fluid loss. Optimum viscosity was obtained for Location C and Location D (Region E) bentonite with Sodium Carboxymethyl Cellulose (Na-CMC), poly-acrylamide and polyacrylic of 3.5 %, 1.0 % and 0.2 %, respectively. The corresponding polymer percentages for Location D (Region F) bentonite were 2.7 %, 3.0 % and 0.4 %, respectively. Within the three polymeric additives polyacrylic was found to be the most effective one.

The Schlumberger Handbook (2014, *'Drilling* Fluids') states that 'the maximal practical concentration of bentonite (in water) is about 85 kg/m^3 to about 114 kg/m^3. Drilling Mud bentonite is sold as a very fine powder since the mud is very sensible for clumping. Milling has to be applied to the bentonite which will result in the semi-finished product. The finer the bentonite is processed, the better it is. Some considerations might be taken between the fineness grade, mill investment and the semi-finished product quality.'

3.3 Foundry sand

It is important to mention that the foundry sands industry is very diverse. For example, there is already the difference between iron and steel foundry. Each foundry has its own procedures, techniques and patents, therefore it makes sense to scope the research on the processing of bentonite for foundry sands down to the minimal standards set by the Bureau of Indian Standards (Appendix B.2). The Indian standards for foundry sands are given in Table 3.

	Indian Standards (IS) for Foundry Sands
Cat ion Exchange Capacity (in mg of Methylene Blue/g)	≥ 220 for Ca bentonites ≥ 370 for Na bentonites
Replaceable Ca^{2+} as CaO by mass % **Na_2O, K_2O**	0.75 – 3 for Ca bentonites 2.5 – 3 for Na bentonites
replaceable Ca^{2+} as CaO by mass % **Na_2O/CaO**	0.1 – 0.4 for Ca bentonites 1.0 – 1.7 for Na bentonites
Fineness in sieve retention %	≤ 3 for a 125 μm sieve ≤ 7 for a 63 μm sieve
Free Swelling Volume in mL	≥ 10 for Ca bentonites ≥ 28 for Na bentonites
Gelling time in minutes	≤ 5 for Ca bentonites ≤ 2 for Na bentonites
Green Compression Strength in psi	≥ 15
Liquid Limit with the SFSA method	100 – 200 for Ca bentonites 600 – 800 for Na bentonites
Moisture Content in %	7
pH at 2 % suspension	9.0 – 10.5
Swelling Index in mL	≥ 10 for Ca bentonites ≥ 25 for Na bentonites

Table 3 Indian Standards for Foundry Sands

Zrimsek and Vingas (1961) show that foundry sands are mainly created by trial and error.

Bentonites, the most common binders in synthetic foundry sands, are generally activated with soda to enhance their binding behavior. Although calcium-sodium bentonites are most common, because of their additional benefits on the Green Comprehensive Strength (Appendix C.3), Ca-bentonites are also used after soda activation. Activated bentonites are generally aged some time which influences the bentonite properties. The aging process plays an important role on the binding and molding properties of the bentonite.

Boylu (2011) revealed that both the bentonite and foundry sand properties were affected by the activation conditions. Soda dosage and aging time were found to be the crucial parameters controlling these foundry sand characteristics. This is important to maintain the same quality during production of activated bentonites. Even minor changes of soda dosage (0.5 %) and aging time (1-2 months) can significantly change the product quality and can reduce its consistency. The research states that 'The customers always complain about the consistency of product quality and sometimes cancel the orders just because of this reason'. Thus, identifying the activation conditions for production of the same quality products becomes crucial. This study revealed that response surface methodology (RSM) is one of the best methods to optimize the product quality.

Depending on the aging time and soda addition, the use of activated calcium bentonites with a swelling index higher than 18 ml required soda addition of 1-2 % and at least 2 months of activation. In this case, the degradation started after 4-5 months of activation. If the soda dosage was in the range of 2-3 %, no degradation was observed within the first 6 months while a soda addition of > 3.0 % degradated the bentonite properties. In the case of activation at 40 % bentonite moisture and curing under atmospheric conditions, bentonite producers should better apply 1-3 % soda addition and use or sell their activated products during the first 6 months after the activation process. These conditions, however, can be re-adjusted with varying foundry sand characteristics.

The summary below describes how bentonite is prepared for Indian foundry sands:

Bhavan (2012) states that 'the processing involves drying, grinding, sizing and at times use of additive for cat ion exchange. The mined material is first graded and sun-dried before pulverization. Bentonite is processed generally by simple milling techniques that involve removal of water and volatile matter like carbon dioxide, if present, and grinding it to the appropriate sizes. Small amounts of chemicals like soda ash are added sometimes before grinding to control the properties of bentonite. Raw bentonite when delivered to the processing plant contains 25 to 40 % moisture. It is, therefore, dried in dryers and the dried clay is ground in roll and hammer mills or other pulverizes and screened. Most of the bentonite is ground to approximately 90 % finer than a no. 200 ASTM sieve. In case local supply of bentonite is not available, synthetic bentonite can be prepared from fuller's earth; i.e., calcium bentonite, by treating it with anhydrous soda ash.'

This last line suggests that foundry bentonite can be processed from fuller's earths, or Ca-bentonites that are suitable for fuller's earth. This is very interesting for Company X since they excavate such a raw material.

After activation (the assumption is made that a bentonite is used with 40 % moisture and that 2 % soda is added) the bentonite should be treated the same as bentonite suitable for cat litter. Eventually the bentonite has to be sieved so that it passes through a no. 200 ASTM sieve.

3.4 *Soil improvement*

The processes that are needed to produce soil improvers from bentonite were investigated. Little treatment is needed to produce bentonite for this application and it can be easily produced next to the current production processes.

The Chinese standards (Shijiazhuang Kedahua, 2014) for bentonite as a fertilizer are formulated as the mineral composition as a percentage:

Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	MnO	Loss on ignition
Content (%)	70.2	16.6	1.77	2.01	1.63	1.32	1.85	0.01	0.1	4.47

Table 4 Chinese standards of bentonite as fertilizer

Looking at the Chinese standards is of interest since China is the world's primary user of (bentonite) fertilizers.

In figure 2 the chemical composition of some Country A bentonites (region Location B) are presented. It can be concluded that this composition is in comparison with the Chinese standards.

Element/ Samples	Na-bentonites				Ca-bentonites									STD	DL
	K-1	K-2	K-4	K-14	G-1	G-3	G-6	G-7	G-8	G-9	G-10	G-11	G-12		
SiO_2	64.0	59.2	58.1	60.0	67.3	68.9	68.4	68.4	66.6	64.6	66.2	65.2	68.0	58.1	0.01
Al_2O_3	17.9	16.0	16.6	15.9	12.4	11.5	13.0	11.8	13.9	13.1	14.6	13.4	12.9	14.1	0.01
Fe_2O_3	3.9	4.0	4.1	1.3	1.1	0.9	1.0	1.2	1.8	1.2	1.2	1.2	0.9	7.6	0.04
MgO	1.6	3.0	3.6	3.7	2.1	2.0	2.3	3.0	1.7	3.2	2.3	3.1	2.2	3.3	0.01
CaO	2.2	3.5	2.5	1.1	1.7	1.4	1.4	1.3	2.2	1.8	1.2	1.5	1.4	6.4	0.01
Na_2O	2.7	2.2	2.4	2.2	0.7	0.4	0.7	0.6	1.4	0.4	1.8	0.4	0.6	3.7	0.01
K_2O	1.4	0.6	0.6	1.0	0.6	0.6	1.5	1.1	2.3	0.8	2.4	1.0	1.3	2.2	0.01
TiO_2	0.4	0.4	0.4	0.4	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.7	0.01
P_2O_5	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.01
MnO	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.4	0.01
LOI	5.4	10.7	11.2	14.4	13.9	14.1	11.5	12.5	9.8	14.6	10.1	14.0	12.5	1.9	0.10
Sum	99.9	99.8	99.8	99.8	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.9	99.7	
TOT/C	0.02	0.45	0.24	0.04	0.13	0.06	0.04	0.05	0.06	0.05	0.03	0.06	0.04	0.02	
TOT/S	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	
Pb	5.4	10.3	6.1	14.9	9.8	9.6	7.1	7.8	6.6	9.7	4.6	6.1	8.5	70.6	0.1
Ni	0.2	0.5	<0.1	0.7	0.6	1.5	3.3	3.2	2.8	2.2	2.0	2.6	2.8	56	0.05
Zn	<1	14	11	18	10	21	13	19	15	22	13	16	12	411	0.3
Cu	1.4	19	11	6.6	1.0	1.2	0.6	1.0	2.1	1.4	1.5	2.6	1.2	109	0.1
As	2.0	<0.5	<0.5	6.1	5.7	2.0	0.8	0.7	3.2	2.2	2.0	2.6	<0.5	56	0.02
Hg	0.07	<0.01	<0.01	0.7	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.2	0.01
Na_2O/CaO	1.23	0.63	0.96	2.00	0.41	0.29	0.50	0.46	0.64	0.22	1.50	0.27	0.43		

Figure 2 Chemical Compositions of Location B bentonites, numbers are % by weight (below the Sum ppm)

The mineral composition is of the highest importance for the fertility potential of the bentonite. It is of no (economical) interest to process a bentonite to make it suitable as a fertilizer since this would cost more money than it would produce. Besides that it is found in different studies that almost all Ca-bentonites provide an acceptable fertilizer capacity.

The only strong requirement is, as stated by Gomez (2014), that the upper limit of heavy metals is not exceeded.

Heavy metals (Element abbreviation)	Upper limit for heavy metal (mg heavy metal/kg micronutrients) for straight or mixtures of B, Co, Cu, Fe, Mn, Mo or Zn fertilizers
As	1000
Cd	200
Pb	600
Hg	100
Ni	2000

Table 5 Max. limit values for heavy metals in micronutrient fertilizers by the European Commission

The bentonite has to be dried so that it has a moisture content of 12 % maximum. The bentonite has to be milled, to increase the effective surface, and sieved so that it passes through a no. 200 ASTM sieve.

3.5 Bleaching earth

Christidis, Scott, and Dunham (1997) concluded that a HCl (hydrochloric acid) concentration works as a good activator of Country A bentonites during an acid leaching process (Appendix C.1).

The highest bleaching capacity was obtained, as stated by Hussin, Kheireddine Aroua and Mohd Ashri Wan Daud (2011), for bentonite activated at a 0.5 solid to liquid ratio, contact time for 6 h, 1 N HCl concentration and 4 % moisture. This is in agreement with the literature study done during this project which concluded that bentonite clays need to be 'naturally bleached', or low degree bleaching in order to qualify for organic oil certifications.

The reports of these researches show a significant overlap in how the bentonite is treated to meet the standards that are used for bleaching earths (Appendix A.1).

The bentonite should be crushed first until it is fine enough to pass a no. 200 ASTM sieve. Bleaching is carried out in a HCl concentration of 1 N, at a 0.5 g mL^{-1} solid to liquid ratio and at a temperature of 95° C. The bleaching should take 6 hours, but this results in the fact that a huge bleaching installation should be installed to meet high production numbers. The bentonite should have a moisture content of 4 %, however this would result in extreme high energy costs. A consideration might be taken between degrading this 'ideal' recipe and lower energy costs.

Eventually the suspension has to be cooled, filtered and washed (several times) with distilled water. The washing has to be done so that excessive Cl^- ions are removed. Then the activated bentonite can be dried. Drying in constant weight at 100° C is suggested.

Taylor and Ungermann (1991) state that the conventional process for producing acid-activated bleaching clays utilizes calcium bentonite clays and requires relatively high acid dosages to achieve maximum bleaching efficiencies (Patent 'US 5008226 A').

This patent also provides a schematic view of how 'conventional' bentonite is treated to produce bleaching earths. This view is presented in figure 3. In this patent a new and innovating technique is described to process calcium bentonites for bleaching earths. This new technique will not be investigated further in this research since it is patented.

Test methods for evaluating calcium bentonite for bleaching soybean and cotton-seed oils are outlined by British Columbia 'Geological Survey Branch' et al. (1958) in the American Oil Chemists Society (AOCS).

These specifications include instructions on bench tests specifics, and require comparison with an official natural bleaching earth approved by AOCS.

Below the schematic view of the production of bleaching earth from calcium bentonites, due to patent 'US 5008226 A', is given.

U.S. Patent Apr. 16, 1991 Sheet 1 of 5 5,008,226

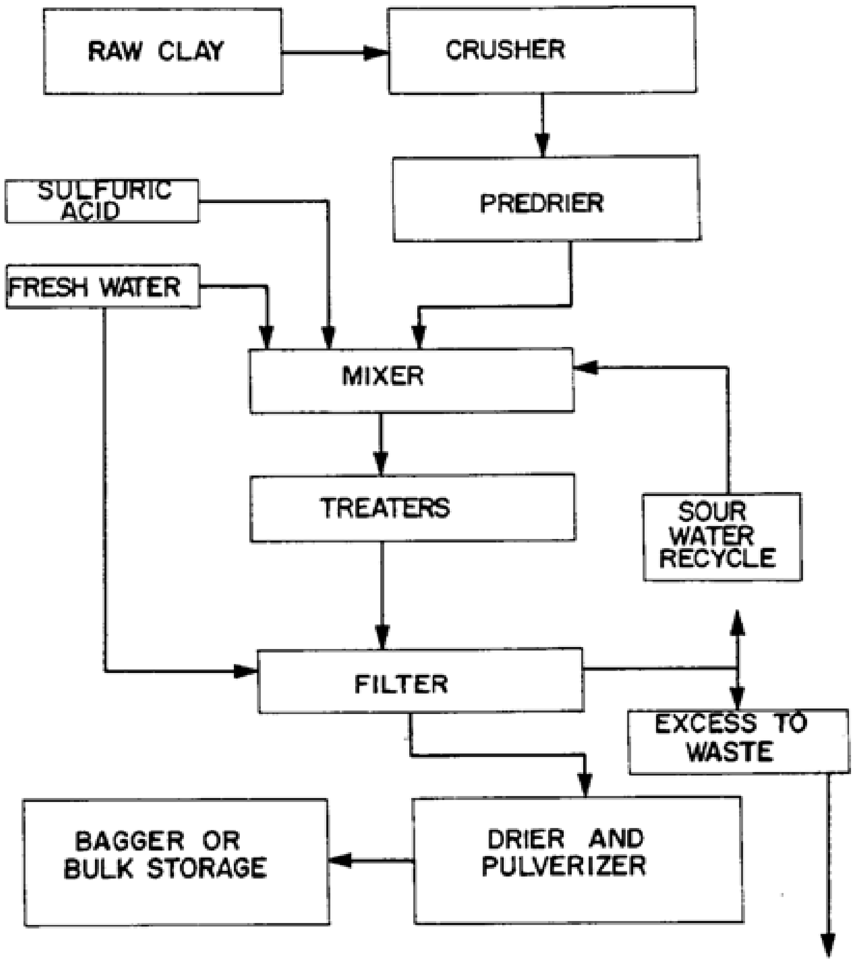


FIG.I

Figure 3 Treatment of 'conventional' calcium bentonite to produce bleaching earths

4 Results from the processing analysis

Figure 4 shows all the processing steps that need to be taken for the different applications. How these steps have come up with, is described in chapter 3. Green steps indicate that the current processing lines are suitable for this processing step. Yellow steps mean that minor changes should be made to the current processes, like drying the bentonite to a lower moisture content. Red steps mean that new machinery has to be purchased or different additives have to be added.

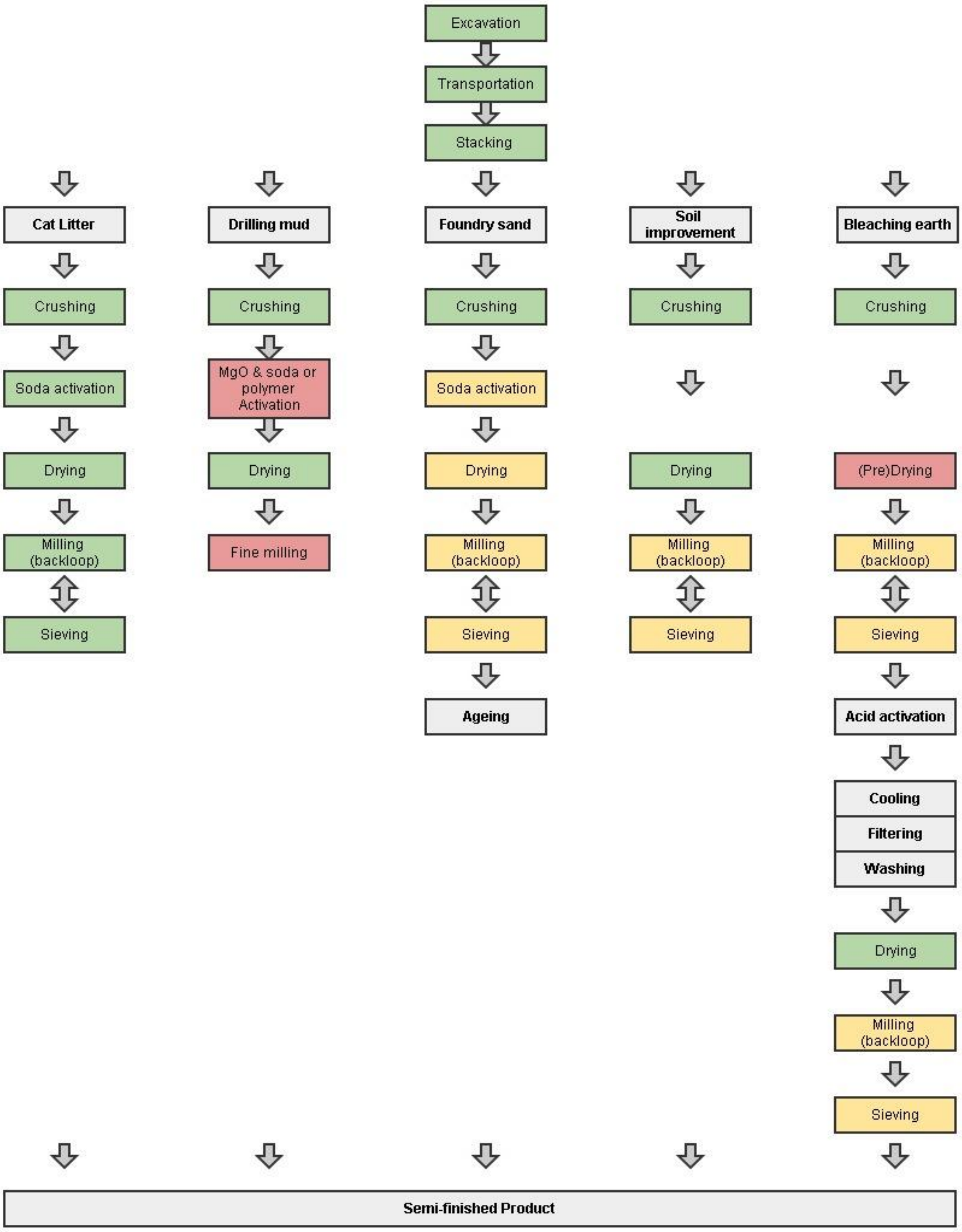


Figure 4 Summarized flowchart of all processing steps

5 Discussion on the processing analysis

This discussion is written from the point of view on what has to change in the current production line in order to be able to execute the suggested processing steps that need to be taken for the investigated applications. A flowchart of the (current) processing of the bentonite relevant for the cat litter application can be found in Appendix D.1.

Drilling mud
As discussed in the results from the processing analysis, 2 scenarios have been found for the processing of suitable bentonite for the drilling mud application.

This means that so called polymers (usually carboxyl methyl cellulose) are not necessary to upgrade the raw bentonite since a combined activation of MgO and soda might result in appropriate bentonites for drilling muds.

However, these polymers can be used and will also give the required effect.

It can be concluded that both activations can result in the desired effect on Country A bentonites. Since the current processing chain is developed for activation with only soda it might be more of interest for Company X to look at scenario 1.

Which of the 2 scenarios will work best, will have to be found by trial and error.

Not all characteristics were tested in these researches, but the reports conclude that API qualified bentonite was produced. Further investigation should be done to make sure that the bentonite mined by Company X is able to reach the API standards after the suggested processing chain.

The production of drilling mud bentonites is not very different from the cat litter production. Other additives have to be added and a mill should be installed that is able to produce very fine powder.

A flowchart of the physical changes of the bentonite relevant for the drilling mud application can be found in Appendix D.2.

Foundry sand
It is very hard to find information on the production of bentonite for foundry sands. However, this research was able to conclude a processing chain. Just like mentioned above in the drilling mud discussion, not all characteristics were tested in the researches on which this conclusion has been drawn. Further investigation is also suggested for the foundry sand application.

The production of bentonite that is suitable as an ingredient for foundry sand is, just like the production of drilling mud bentonite, not very different from the production of cat litter. Activation has to be done in different proportions and the drying requires more time and more energy since the bentonite should be dried more.

It has to be investigated if the current mill can be adjusted so that it is able to mill the bentonite to finer grades. It should be an easy step to adjust the sieve. After sieving the bentonite should be left on the terrain for the ageing process.

Further investigation should be done on how long the ageing process should take to produce the optimal (semi-finished) product.

A flowchart of the physical changes of the bentonite relevant for the foundry sand application can be found in Appendix D.3.

Soil improvement

Producing bentonite suitable as a soil improver is the simplest process of the investigated applications. No activation is needed but just like the production of bentonite suitable for foundry sands, another mill and a finer sieve should be installed.

Company X knows that her bentonite has a low heavy metal content and should therefore be suitable as a soil improver.

A flowchart of the physical changes of the bentonite relevant for the soil improver application can be found in Appendix D.4

Bleaching earth

The investigation on bleaching earths showed that some major processing steps have to be added in order to produce bentonite as bleaching earths. The first steps are the same as for the other applications, only after these steps, many very different ones should be taken.

It is very likely that a whole new plant should be installed and that some certificates have to be achieved because the processes that belong to a bleaching plant could be hazardous to the environment because of the acids that are involved. Further investigation is suggested on this matter.

A flowchart of the physical changes of the bentonite relevant for the bleaching earth application can be found in Appendix D.5.

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6 An introduction in the economics of the chosen applications of bentonite

6.1 Introduction

The EUBA (European Bentonite Association) provides statistics on the European market of bentonite. Figure 5 and 6 show a chart of the EUBA uses in 2011. The total tonnage (figure 5) is 2684 kT, the sum of the tonnage for the applications to be studied is 1738 kT (EUBA statistics: 2012).

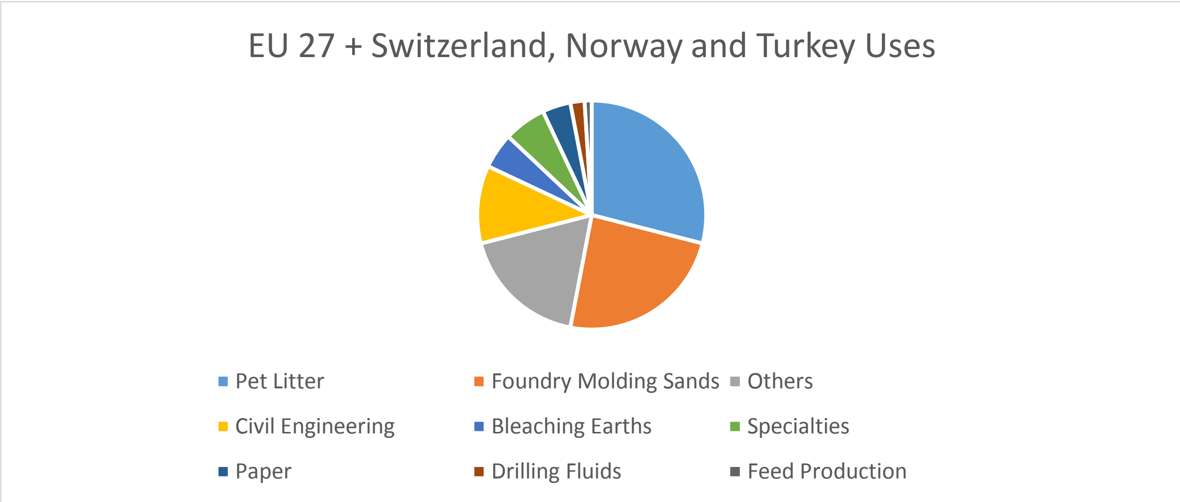


Figure 5 EUBA 2011 Uses (all applications; 2684 kT)

Figure 5 and 6 only show the uses of bentonite (in 2011), whether or not there is a higher or lower demand or supply will be investigated in chapter 6.2-6.5.

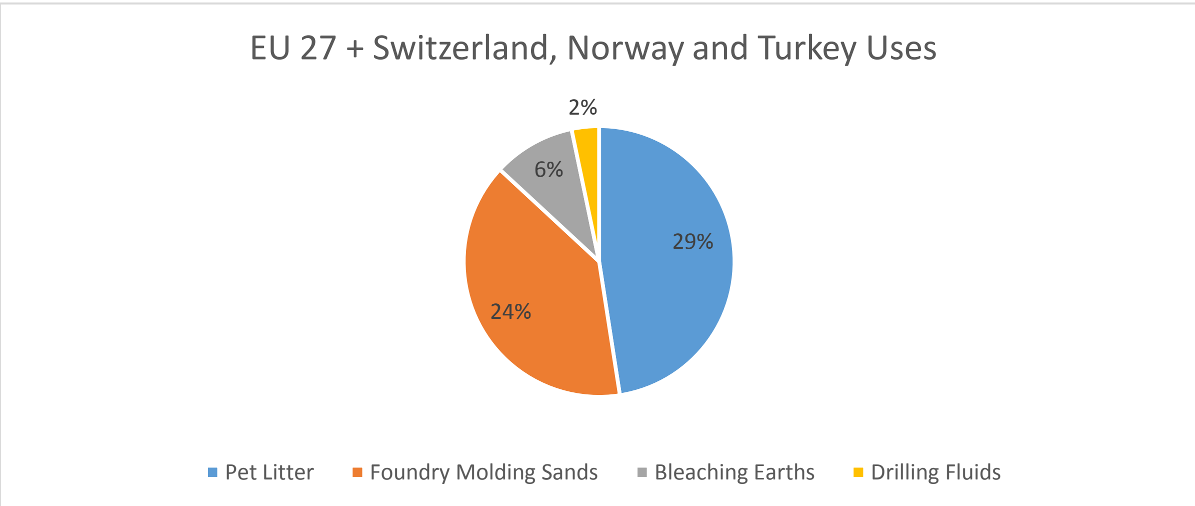


Figure 6 EUBA 2011 Uses (relevant applications for this research; 1738 kT)

The British Geological Survey (European Mineral Statistics by the British Geological Survey 2008-12) published the following figures, in which the EU35 production, import and export is presented. The numbers can be found in Appendix E.

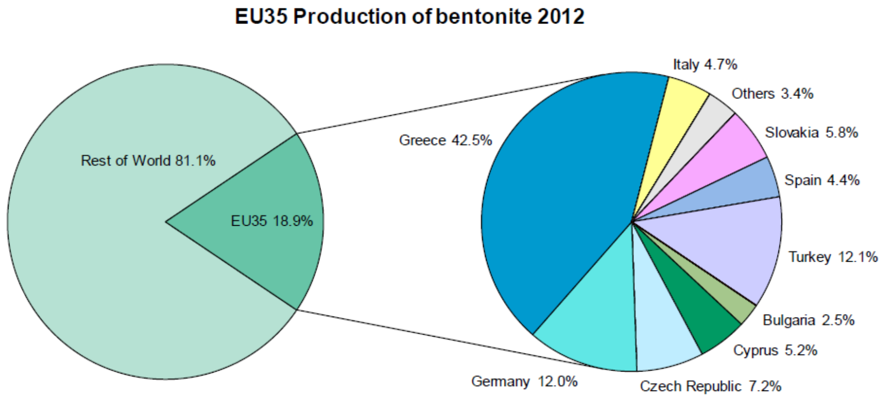


Figure 7 EU35 Production of bentonite 2012 (exact numbers are given in Appendix E.1)

Figure 7 and 8 seem to present conflicting numbers. Figure 7 shows for example that Greece is one of the biggest bentonite producers in the world, but figure 8 shows that Greece doesn't export that much bentonite at all. These contradictions can be explained by the fact that many countries use their own bentonite for several industrial applications. Greece is for example a very big olive oil producer, and uses almost all its bentonite as bleaching earth.

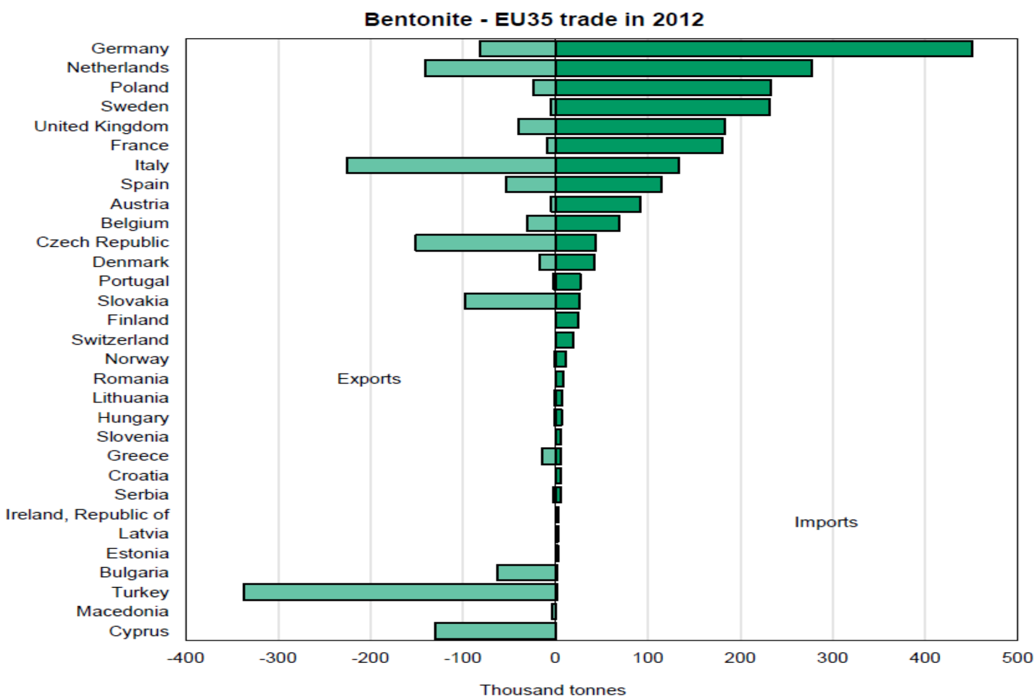


Figure 8 Import and export of bentonite in the EU35 (exact numbers are given in Appendix E.2 and E.3)

The American bentonite market looks as follows, as stated by Matos and Virta (2005):

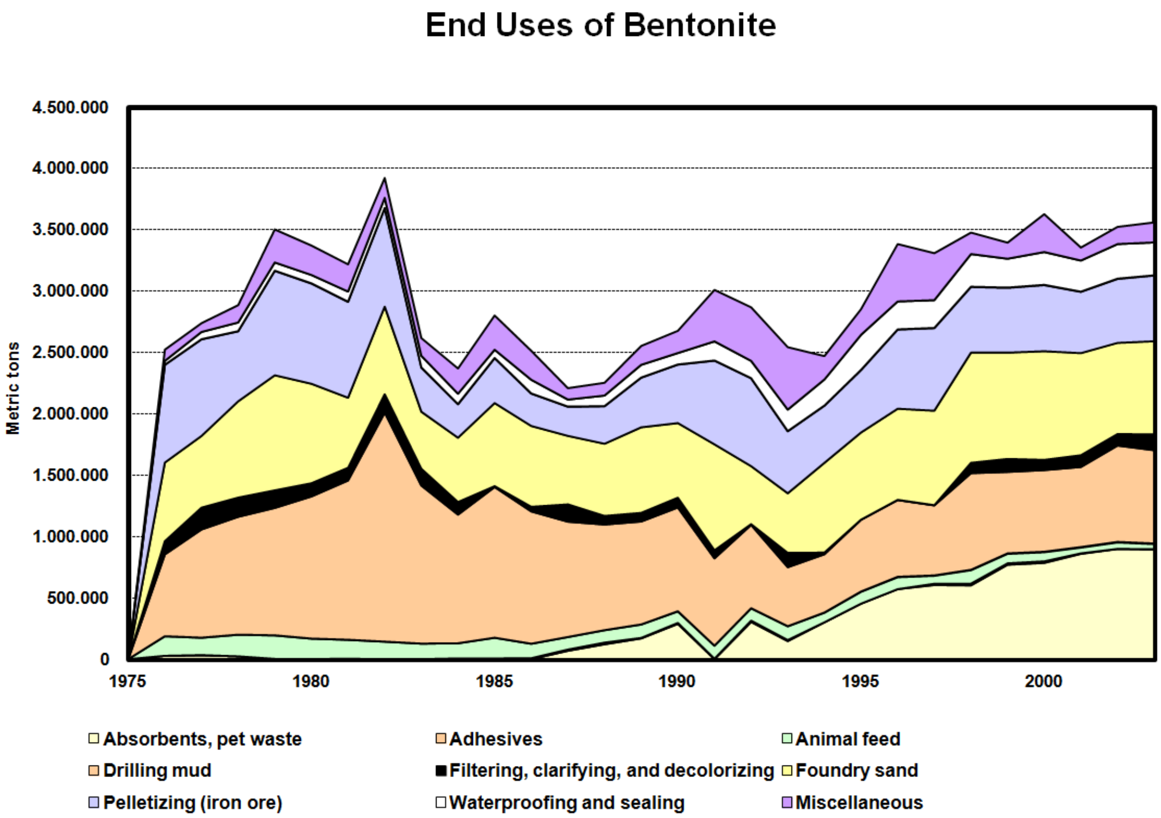


Figure 9 End uses of Bentonite in the American market

The total tonnage of the American bentonite market for bentonite usage is about 3200 kT in 2005. The 5 applications that will be investigated count up to a tonnage of about 1700 kT. This is roughly the same amount as in the European market, but the equity ratio differs a lot.

This research notes that 'In 1991, sales of bentonite for pet waste absorbents (clumping kitty litter) gained popularity resulting in a large increase in sales through about 2000 when sales leveled off. Sales for adhesives face competition from other minerals so they are extremely variable from year to year. Sales of animal feed declined over the 27-year period due to competition from other minerals and changes in feed formulations.

Drilling mud sales followed closely the use of rotary drilling rigs in the United States, which in turn followed consumer demand for petroleum products. Sales of bentonite for filtering, clarifying, and decolorizing oils and greases have been variable from year to year. Bentonite competes with fuller's earth and other clarifying agents and the market is competitive so sales fluctuate over time, following no set pattern.'

From this statement it can be concluded that the drilling mud market is the most stable market for bentonite in the United States.

The American bentonite market will not be investigated further since the market is self sufficient and the market is of a low interest to Company X because of the geographical position of Country A.

The Asian market however is of interest, especially the Indian market. However, no data could be found regarding the Asian bentonite market. There are several report and statistics available, but these reports have to be purchased in order to access them. This will be discussed later.

6.2 *Drilling mud*

Rohan (2013) states that the drilling muds and completion fluids market is driven by the increasing drilling activities another strong, profitable year for exploration and production (E&P) companies around the globe is expected, especially for those focusing on crude oil. The price trend of crude oil and natural gas will support greater liquids and shale exploration in a number of international areas. The relatively high price also supports large development projects offshore. The drilling mud market is expected to grow with 7.5 % from 2013 to 2018 which directly complements the drilling activities.

The market for drilling muds is not very big in Europe. Figure 6 shows that only 2 % of the manufactured European bentonite is used for the drilling mud application. North America has the biggest market potential by far.

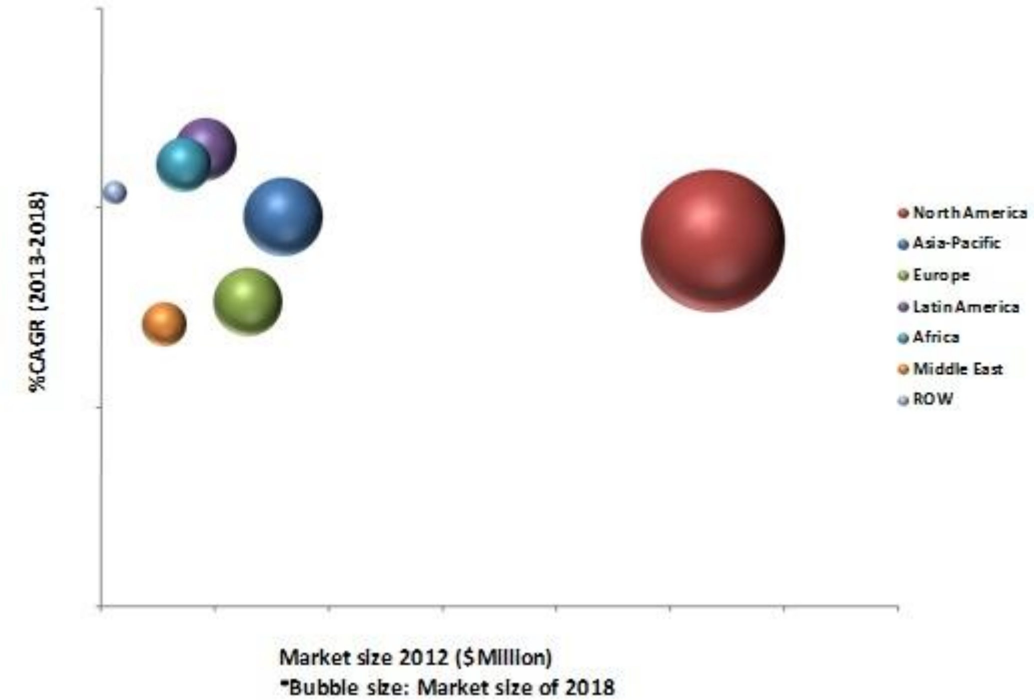


Figure 10 Drilling Muds and Completion Fluids: Market share by geography, 2013

Figure 10 shows the expected market size of drilling muds and completion fluids in 2018 and is expected to be worth 15.2 Billion (USA) dollars. Figure 10 also shows that the European market will grow in the coming 4 years to become the third biggest market in drilling muds, after North America and Asia-Pacific. This is a realistic expectation if we take into account that several countries might start drilling for shale gas in the near future.

Because of this big potential growth in the drilling mud market, the drilling mud application is definitely of interest to Company X.

6.3 Foundry sand

Like other foundry minerals bentonite was affected by reduced demand in 2009 due to the crisis, although its use in this sector was fairly robust compared to demand from its other end markets in oil and gas drilling and iron ore pelletizing. However the bentonite demand in the foundry industry is expected to increase because the clay is used in the solidification of materials contained in foundry wastes, reducing their leachibility (Kalmakoff, 1991). The foundry sand application could be of economic interest to Company X, if it can be sold for bottom market price (figure 13), since there is no current hole in the market to be filled.

6.4 Soil improvement

Processing bentonite as a soil improver might be a good backup solution for when the cat litter market, on which Company X depends, drops. The processing steps that need to be taken are very similar to the production of cat litter. At this moment the market is expected remain quite stable for the coming years and therefore this application can be of interest when sold at bottom market price.

6.5 Bleaching earth

Bleaching earth is presently imported from various countries. However, import data of bleaching earth has been aggregated with other similar materials, and it is difficult to disaggregate it.

World vegetable oil production has increased continuously, as stated by the United States Department of Agriculture, in the past decades, although unevenly. The main growth has been in palm oil (representing more than 30 % of vegetable oil production in 2007), soybean oil (28 %), rapeseed oil (15 %) and sunflower oil (9 %). The remaining share accounts for less than 20 % of the market, as can be seen in figure 11.

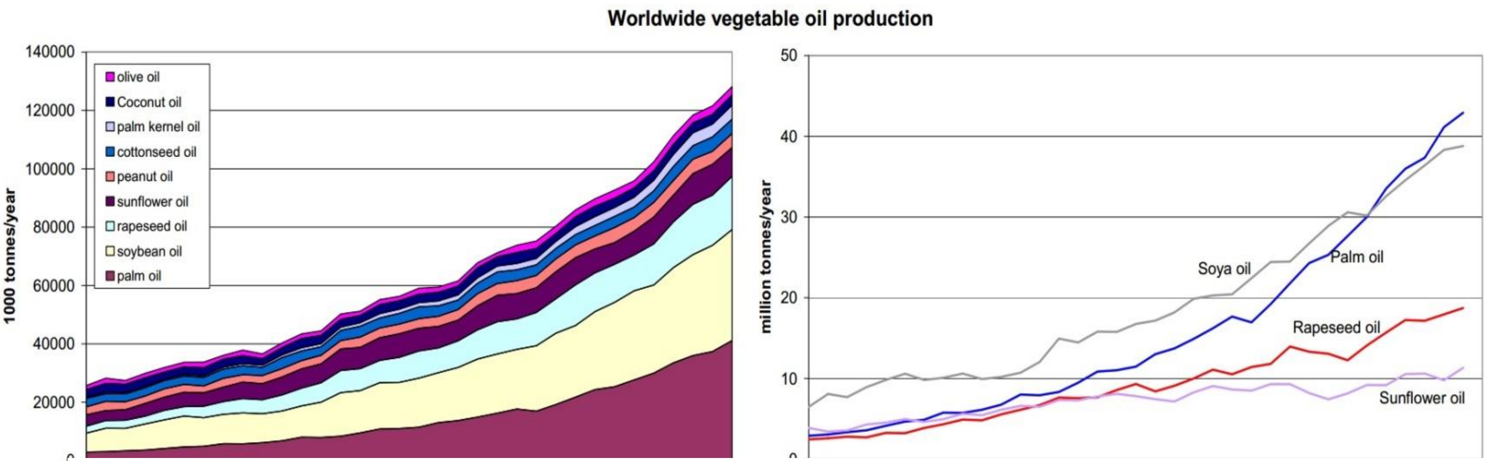


Figure 11 Worldwide vegetable oil production

The main users of bleaching earth are the edible oil mills of the country. The growth of edible oil production increases the demand for bleaching earth. Demand projection for this product can be made on the basis of projected growth of edible oil production. It does therefore make sense to have a quick look at the worldwide edible oil production. About 30kgs of bleaching earth is required to produce one ton of edible oil.

The data from figure 11 originates from the United States Department of Agriculture and a research executed by this department called *'A Global Overview Of Vegetable Oils, With Reference To Biodiesel'* from 2009 states that the worldwide demand and supply of edible oils are stable. Figure 12 shows the worldwide import of palm oil and roughly represents the worldwide import ratio of edible oils.

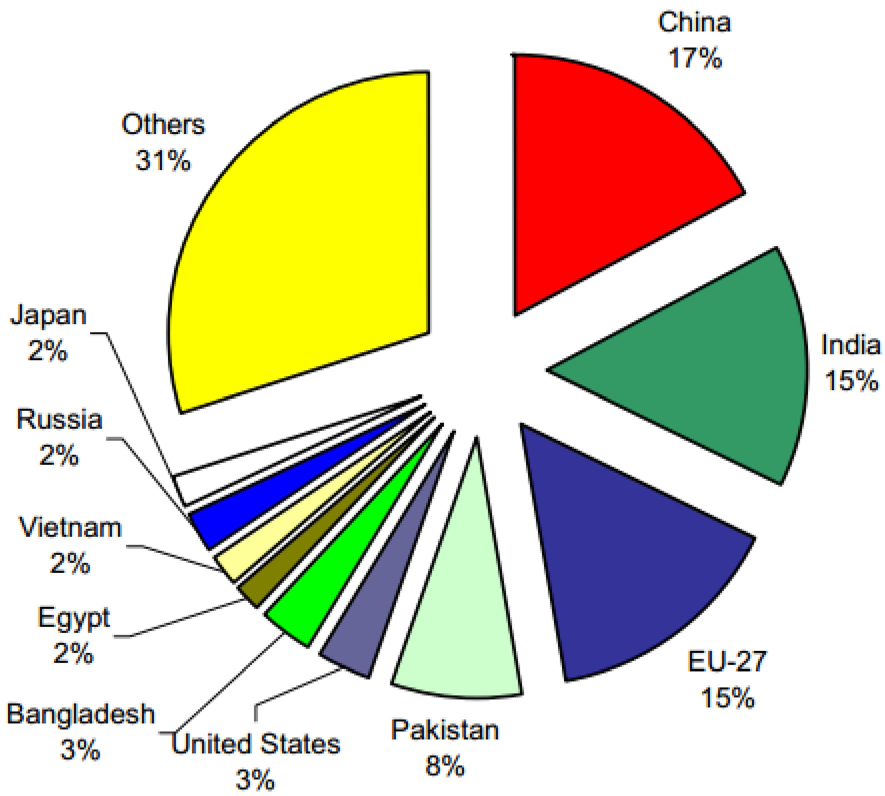


Figure 12 Worldwide import of palm oil

Furthermore, high quality Tonsil grade activated bleaching earth is sold at US $225-275 / Metric Ton (FOB Price), as stated by Alibaba trading (2014). Chapter 3.5 refers to some researcher which state that Country A bentonites, that were testes in this research, tend to have higher bleaching capacities than Tonsil grade bleaching earths.

This is why the bleaching earth application does have potential, depending on whether or not Company X might be able to produce and sell bleaching earth for a price that is interesting for the market.

7 Calculations on the market analysis

7.1 Introduction

Just like in the research on the processing of bentonite, a certain amount of assumptions have to be made due to the specification of the research. Company X requested to investigate the market potential of her production plant in Country A when a potential new line (production line 4) would be brought into use for one of the 5 chosen applications.

This production line would have a maximum capacity of roughly 9 tons per hour, but several processes like selective sieving lower the capacity. This means that Company X would be able to produce about 75.000 tons of new (semi-finished) product per annum. The assumption is made that the new line is able to produce around 50 % of its maximum production rate, due to the fact that the settings of the new line still have to be adjusted and optimized and due to (scheduled) maintenance.

The economical calculations will be based on an annual production of 40.000 tons of new (semi-finished) product. (The annual production of 40.000 tons was desired by Company X)

It is likely that the 5 chosen applications will result in different levels of economic interest to Company X. To come up with these results the following values have to be taken into account: Investment in (new) processing equipment, energy/transportation costs, price and amount of additives, and the market value of semi finished product.

Figure 13 is based on the current markets of several applications and originates from the database of 'Industrial Minerals' (2014). The complete figure gives an idea of the diversity in prices of the differently processed bentonites. Only a few of these prices were used for this research. These prices are highlighted in figure 13.

Bentonite	Price Date	Low	High
Bentonite, Cat litter grade 1-5mm, bulk, FOB main European port, €/tonne	12 Jun 2014	42	60
Bentonite, Cat litter grade, crushed, dried and loose in bulk, FOB Kandla, India, $/tonne	12 Jun 2014	34	38
Bentonite, rail hopper cars, crude, bulk (all grades), ex-works Wyoming, USA, $/s.ton	12 Jun 2014	65	150
Bentonite, Foundry grade, bulk, del Japan, $/tonne	12 Jun 2014	140	220
Bentonite, South African., ex-works Fullers' earth, soda ash-treated, foundry grade, bagged, £/tonne	12 Jun 2014	60	85
Bentonite, fullers' earth, soda ash-treated, Civil eng. grade, ex-works, South Africa, £/tonne	12 Jun 2014	50	70
Bentonite, IOP grade, crude, bulk, ex-works Wyoming, $/s.ton	12 Jun 2014	68	72
Bentonite, South African., ex-works Fullers' earth, soda ash-treated, Cat litter grade,1-7mm, £/tonne	12 Jun 2014	27	40
Bentonite, Indian, FOB Kandla, crushed and dried, loose in bulk, Civil Engineering grade, $/tonne	12 Jun 2014	32	40
Bentonite, Indian, FOB Kandla, crushed and dried, loose in bulk, Iron ore pelletising grade, $/tonne	12 Jun 2014	36	38
Bentonite, cat litter grade, ex-works Wyoming, USA, $/s.ton	12 Jun 2014	52	60
Bentonite (dried material in bulk) FOB Greece, €/tonne	12 Jun 2014	65	75
Bentonite OCMA/Foundry grades crude and dried, bulk, FOB Milos, €/tonne	12 Jun 2014	60	80
Bentonite, foundry grade, bagged, rail cars, ex-works Wyoming, $/s.ton	12 Jun 2014	97	124
Bentonite, API grade, bagged, rail car, ex-works, Wyoming, $/s.ton	12 Jun 2014	92	130

Figure 13 Global (current) market prices of bentonite

Figure 13 provides price ranges for several bentonites with different grades. Not every price is constructed the same way. Some of these prices include transport to the mentioned country or region. These different price constructions are called ‘Incoterms’, see Appendix E.2.

The market value of the semi-finished product that is currently exported for cat litter is roughly € 100/ton. This price is the FOB (Freight On Board) price, Appendix E.1 and E.2 provide background information on the FOB price.

The estimation of the production costs (The Incoterm for production cost is ’ex-works price’) have been made with help from the ‘*Mining Cost Service, COSTMINE by InfoMine USA, Inc. Versions 2011 and 2006’*.

A few assumptions were made to make it possible to do the calculations for the cash flows. All the assumptions are verified by *’The Mining Cost Service, COSTMINE by InfoMine USA, Inc.’* and Company X. These assumptions are;

- The depreciation time of the potential newly invested equipment is set to 15 years.
- The operating costs of the processing plant are estimated (when they could not be found in the ‘Mining Cost Service’) to 60 % of the capital costs. This assumption is based on experience.
- The discount rate used in the cash flows is 10 %.
- The annual gas price inflation is set to 0.5 % per annum.
- The annual consumer price inflation is set to 1 % per annum.
- In year 2, 3 4 and 5 of the project, respectively 15 %, 35 %, 60 % and 80 % of the desired 40.000 tons per annum is produced. (The operation costs are corrected for this matter)
- Beside the investment costs (figure 14) and the operational costs (figure 15), the only other expenditures are € 300.000 for repairs/upgrades, once every 5 years.

The market prices of the semi-finished products were, if possible, used as shown in figure 13. Company X desired cash flows where low market prices were taken, since these low prices are needed to successfully enter a new market. Therefore an ‘optimistic’ and ‘pessimistic’ cash flow was determined for each of the 4 chosen applications other than cat litter. This is explained in chapter 7.2-7.5.

The market price of Company X cat litter bentonite is assumed to be very stable and therefore no positive or negative scenario was determined.

This report comes with a Microsoft Excel spreadsheet in which all the capital expenditures (CapEx) and the operating expenditures (OpEx) can be found for every individual processing step. The individual investments will not be discussed in this report. However, a short summary of the investment costs (CapEx) and the operational costs are found respectively in figure 14 and figure 15. These costs are based on the '*Mining Cost Service, COSTMINE by InfoMine USA, Inc. Versions 2011 and 2006*'. Below the capital costs, or investment costs, are presented that would be needed to expend for all the investigated applications of bentonite.

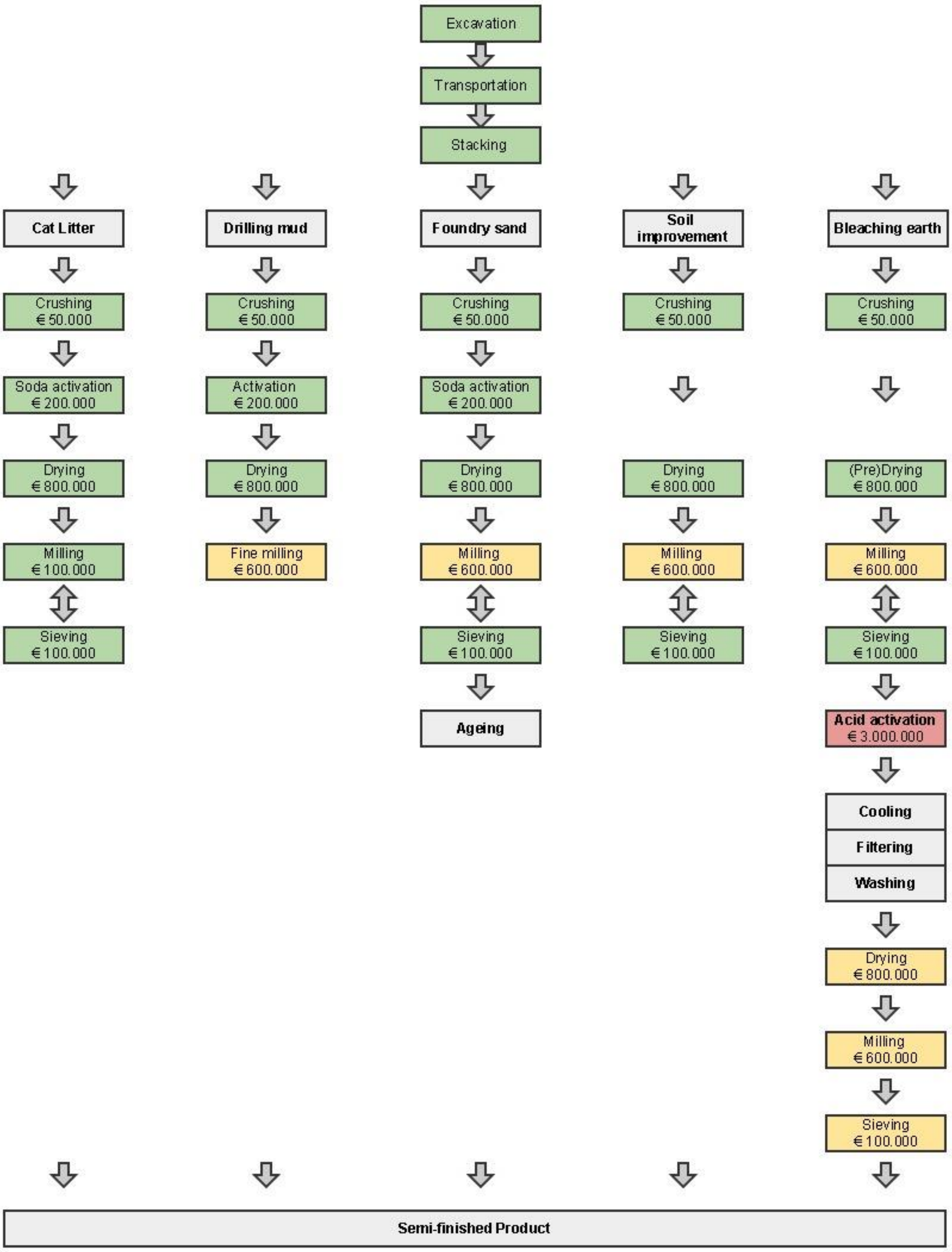


Figure 14 Summarized capital costs per processing step

Below the (annual) operational costs are presented that would be needed to expend for all the investigated applications of bentonite. The prices of the additives, where needed, are included.

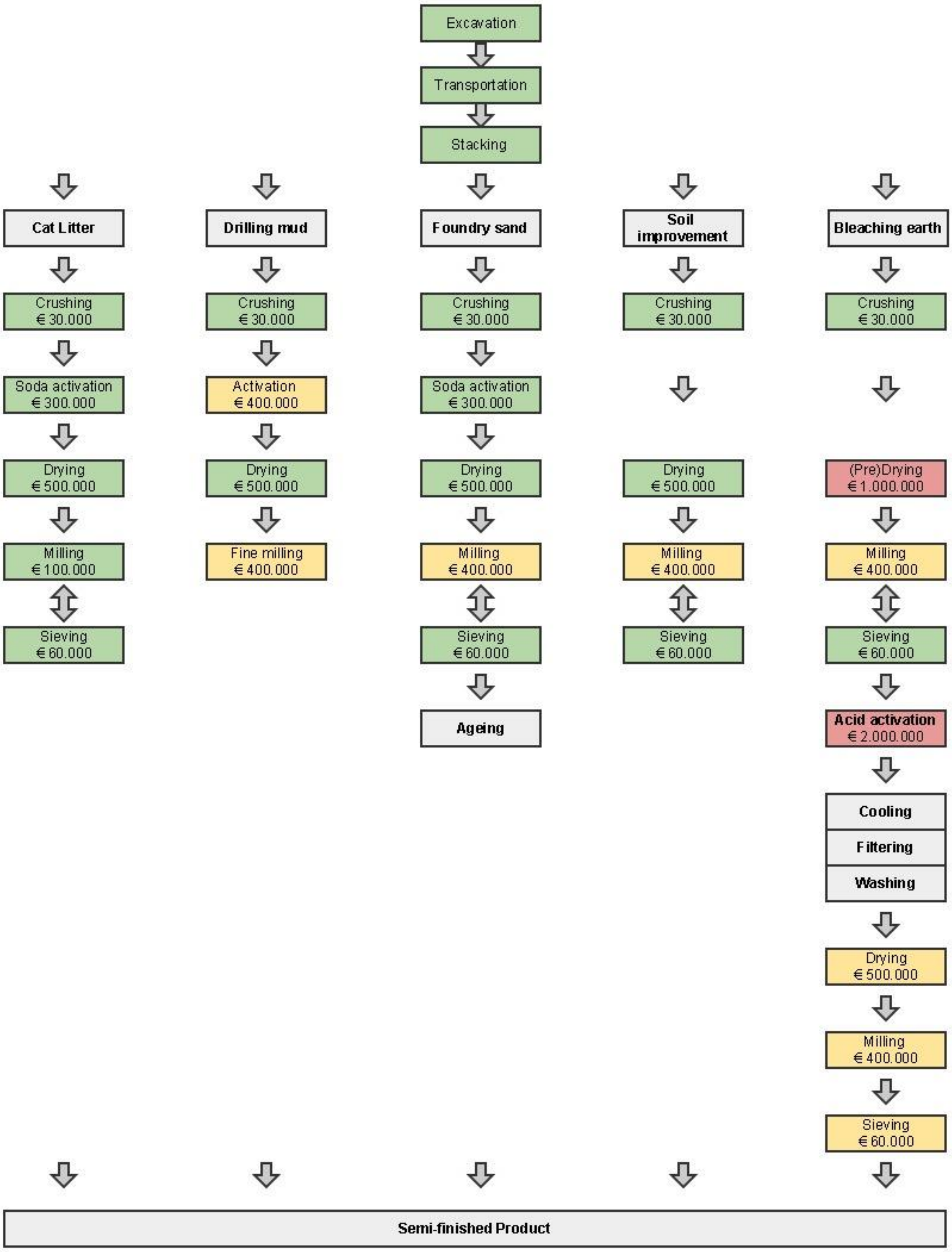


Figure 15 Summarized operational costs per processing step

7.2 Drilling mud

In order to satisfy the requirements for drilling muds set by the API standards, some processing has to be done on the bentonite. These processing steps are described in chapter 3.2 and summarized in Appendix D.2. The required investments and estimated processing costs are shown in Appendix G.1.

- The (ex-works) market price of the semi-finished product was found to be between $92 and $130 per ton (figure 13). These prices were converted into euro's and inserted in an ''optimistic'' and a ''pessimistic'' cash flow model.
- The total estimated capital expenditure was found to be € 2.300.000.
- The estimated annual operating expenditure of the processing plant was found to be € 1.300.000.
- The total estimated annual operating expenditure was found to be € 2.300.000.
- The costs of additives per ton were found to be € 7 per ton of untreated bentonite and are assumed not to change in price in the future.

The total estimated annual operating costs were found by doubling the estimated annual operating expenditure of the processing plant. This is in accordance with the gathered data during the visit at Company Y, may 2014.

The scenario where polymers are used as additives for bentonite has not been investigated since the prices of the polymers are unknown. They are expected to be higher than the MgO and soda ash prices combined and are therefore assumed to be of less economical interest.

7.3 Foundry sand

The processing steps that need to be done to produce bentonite that satisfies the Indian standards are described in chapter 3.3 and summarized Appendix D.3.

- The (ex-works) market price of the semi-finished product was found to be between $97 and $124 per ton (figure 13). These prices were converted into euro's and inserted in an ''optimistic'' and a ''pessimistic'' cash flow model.
- The total estimated capital expenditure was found to be € 2.400.000.
- The estimated annual operating expenditure of the processing plant was found to be €1.300.000.
- The total estimated annual operating expenditure was found to be € 2.300.000.
- The costs of additives per ton were found to be €4 per ton of untreated bentonite.

7.4 Soil improvement

The research on the specific composition of the bentonite mined by Company X will provide an answer on what the exact mineral composition is. From this result the fertilizer capacity can be extracted and from there an economical value can be linked to the bentonite.

- The (ex-works) market price of the semi-finished product was found to be between $90 and $110 per ton (alibaba trading database). These prices were converted into euro's and inserted in an ''optimistic'' and a ''pessimistic'' cash flow model.
- The total estimated capital expenditure was found to be € 2.200.000.
- The estimated annual operating expenditure of the processing plant was found to be € 1.000.000.
- The total estimated annual operating expenditure was found to be € 2.000.000.

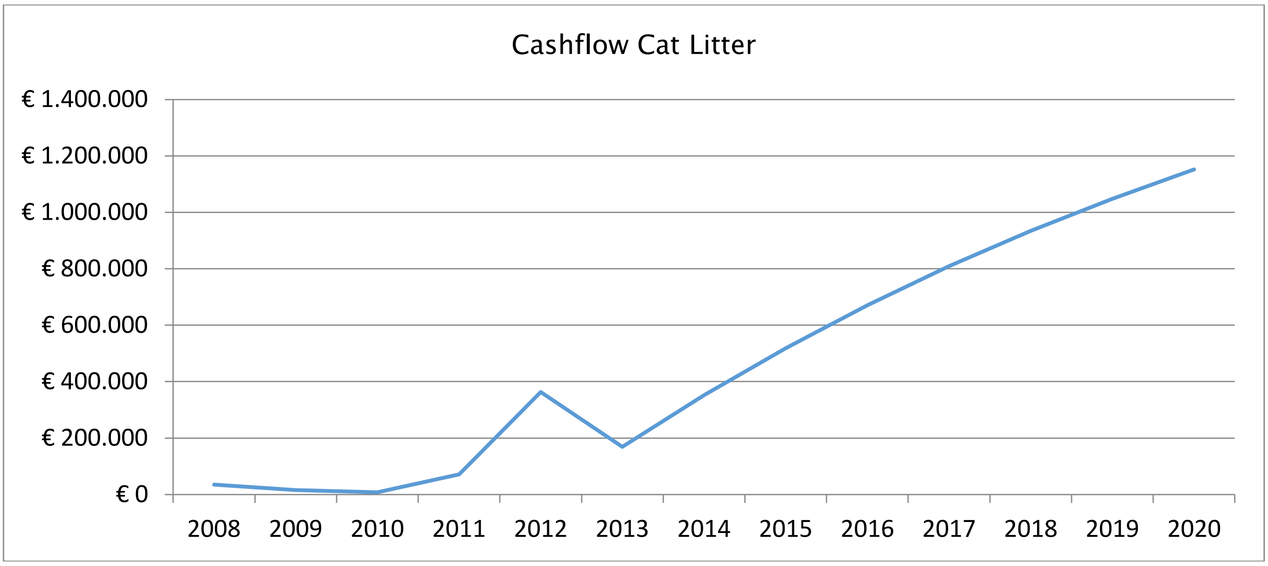
7.5 Bleaching earth

The processing analysis concluded in chapter 3.5 that a bleaching earth processing plant is a lot more complex than the other processing plants. A much bigger investment has to be done in order to build such a plant.

- The (ex-works) market price of the semi-finished product was found to be between $225 and $275 per ton (chapter 6.5). These prices were converted into euro's and inserted in an ''optimistic'' and a ''pessimistic'' cash flow model.
- The total estimated capital expenditure was found to be € 6.700.000.
- The estimated annual operating expenditure of the processing plant was found to be € 4.400.000.
- The total estimated annual operating expenditure was found to be € 5.400.000.

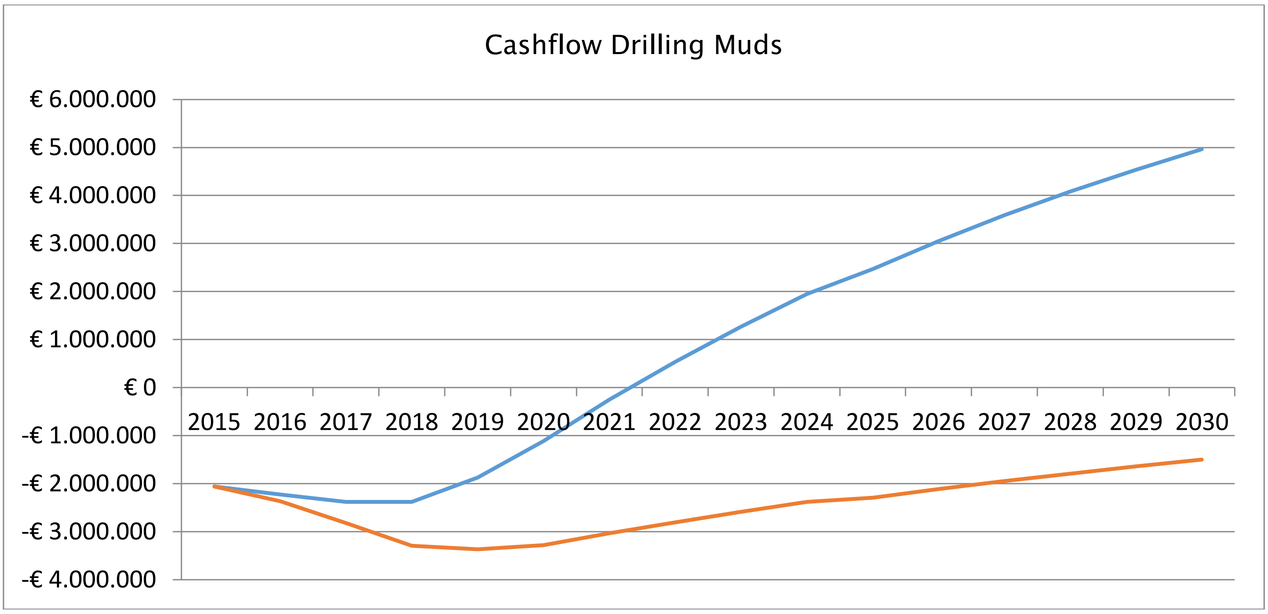
8 Results of the market analysis

8.1 Current process chain



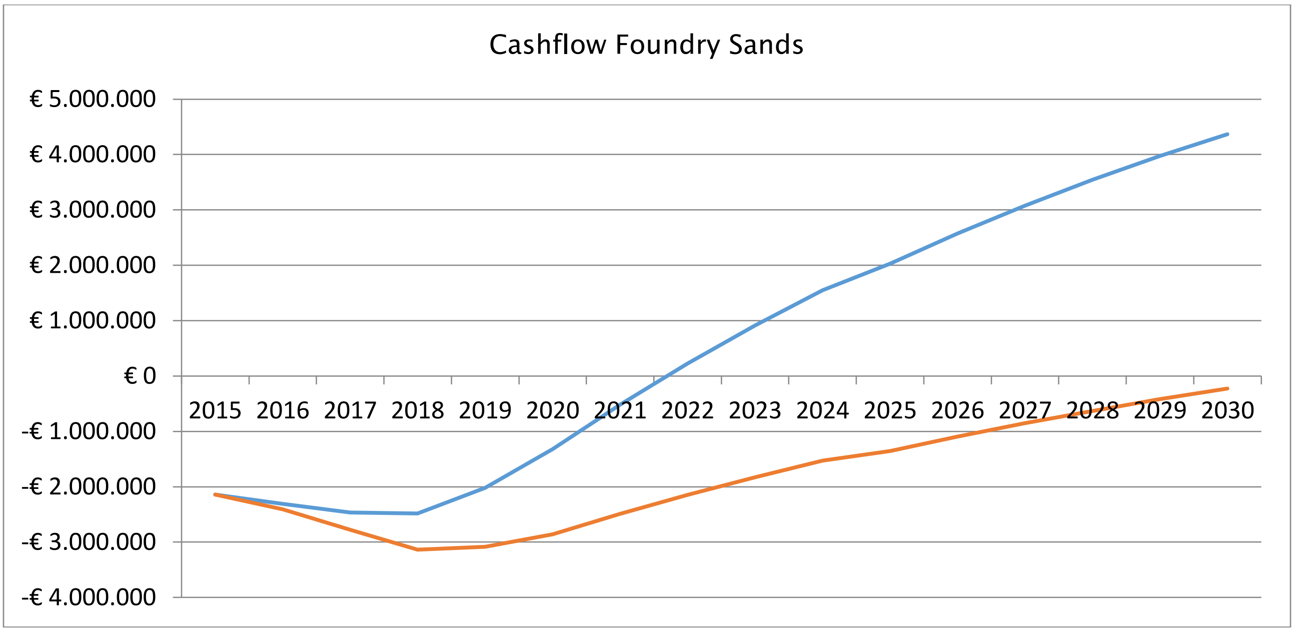
The net present value (NPV 2030) was found to be € 1.200.000. The internal rate of return (IRR) was found to be 16 %. The market price of Company X cat litter bentonite is assumed to be very stable. The data needed to calculate this cash flow was provided by Company X.

8.2 Drilling mud



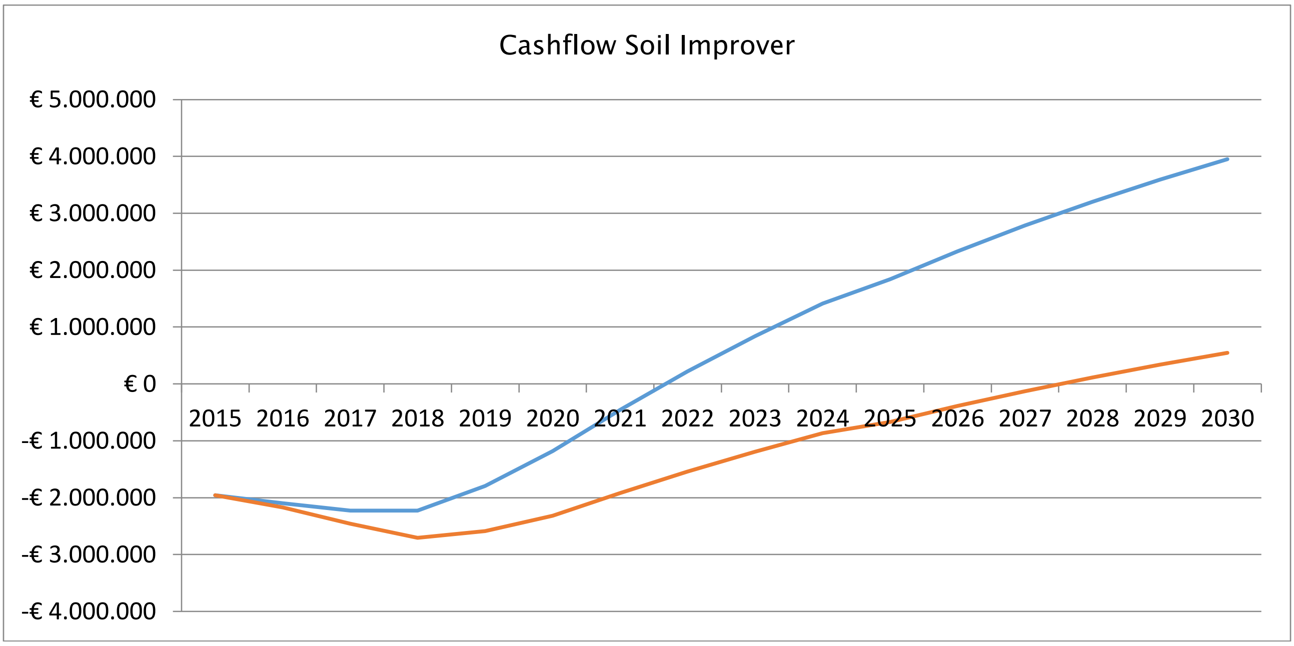
The net present values (NPV 2030) were found to be € 5.000.000 (optimistic scenario) and € 0< (pessimistic scenario). The internal rates of return (IRR) were found to be 27 % (optimistic scenario) and 3 % (pessimistic scenario).

8.3 Foundry sand



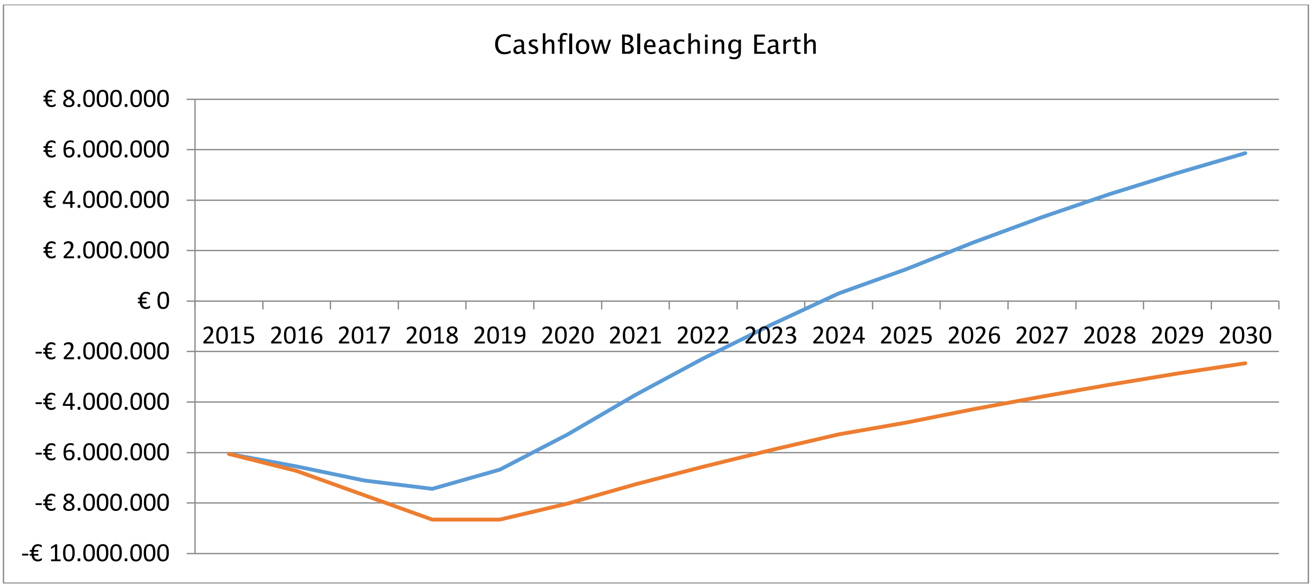
The net present values (NPV 2030) were found to be € 4.400.000 (optimistic scenario) and € 0< (pessimistic scenario). The internal rates of return (IRR) were found to be 25 % (optimistic scenario) and 9 % (pessimistic scenario).

8.4 Soil improvement



The net present values (NPV 2030) were found to be € 4.000.000 (optimistic scenario) and € 600.000 (pessimistic scenario). The internal rates of return (IRR) were found to be 25 % (optimistic scenario) and 12 % (pessimistic scenario).

8.5 Bleaching earth



The net present values (NPV 2030) were found to be € 5.900.000 (optimistic scenario) and € 0< (pessimistic scenario). The internal rates of return (IRR) were found to be 18 % (optimistic scenario) and 6 % (pessimistic scenario).

The results of the 5 calculated cash flows are presented in figure 16.

	Net present Value (pessimistic)	Net present Value (optimistic)	Internal rate of return (pessimistic)	Internal rate of return (optimistic)
Cat Litter	€ 1.200.000	€ 1.200.000	16 %	16 %
Drilling mud	€ –1.500.000	€ 5.000.000	3 %	27 %
Foundry sand	€ –200.000	€ 4.400.000	9 %	25 %
Soil improvement	€ 600.000	€ 4.000.000	12 %	25 %
Bleaching Earth	€ –2.300.000	€ 5.900.000	6 %	18 %

Figure 16 Final Results of market analysis

9 Discussion on the market analysis

All the calculations that were made in order to produce the cash flows as presented in chapter 8, can be found in the Microsoft Excel spreadsheet (Appendix F.2) that comes with this report. A short overview of all the costs is given in Appendix F.1. These calculations did not take into account whether or not there is a market potential for the semi-finished product, the process of entering a new market is integrated with the increase of the annual production. However, from the market analysis, it can be concluded that there is the biggest market potential for drilling muds and bleaching earths.

It is a bit more complicated to draw conclusions for the market potential of foundry sands and soil improvers since no representative data could be found for these markets, although these markets represent a big percentage of the total bentonite market.

As discussed in chapter 7.1, the cash flows were determined by using an optimistic and a pessimistic market price for the semi-finished product. All 5 of the calculated optimistic cash flows will result in a positive net present value, and from this it can be concluded that all four scenarios might be of economic interest for Company X. The level of interest is shown in figure 17, where green is the most favorable choice.

	Net present Value (pessimistic)	Net present Value (optimistic)	Internal rate of return (pessimistic)	Internal rate of return (optimistic)
Cat Litter	€ 1.200.000	€ 1.200.000	16 %	16 %
Drilling mud	€ -1.500.000	€ 5.000.000	3 %	27 %
Foundry sand	€ -200.000	€ 4.400.000	9 %	25 %
Soil improvement	€ 600.000	€ 4.000.000	12 %	25 %
Bleaching Earth	€ -2.300.000	€ 5.900.000	6 %	18 %

Figure 17 Final Results of market analysis (weighted)

In terms of the net present value, the production of bleaching earth by Company X would be the most favorable application of the 5 investigated applications, in case of the optimistic scenario. In case of the pessimistic scenario, the soil improver application would be the most favorable one.

In terms of the optimistic internal rate of return, the production of drilling mud would be the most favorable application for Company X. Soil improvement would be the most favorable application (besides cat litter) when looked at the pessimistic scenario of the IRR.

Figure 18 shows the Capex and the Opex for each of the investigated applications.

	CapEx	OpEx
Cat Litter	€ 1.600.000	€ 2.000.000
Drilling mud	€ 2.300.000	€ 2.300.000
Foundry sand	€ 2.400.000	€ 2.300.000
Soil improvement	€ 2.200.000	€ 2.000.000
Bleaching Earth	€ 6.700.000	€ 5.400.000

Figure 18 Summary of Capex and Opex (weighted)

From figure 18 it can be concluded that the production of cat litter requires the littlest investment. The operating costs of cat litter production are equal to the costs of soil improver production.

In combination with figure 17 it can be concluded that the application of soil improvement is of most economical interest to Company X of the 5 potential applications, since there is no risk of a negative NPV and the IRR is very high. It should not be forgotten that the cat litter application has low operation costs and that the IRR is very high compared to the other pessimistic scenarios.

Final recommendation

It was found that Country A bentonites can be processed so that it could be applied in other industries. Since the calculations after market analysis concluded that the soil improvement and cat litter application are of most economic interest to Company X, the following recommendation is done.

The drilling mud, foundry sand and bleaching earth application cash flows show that there is too much of a risk to invest in one of these 3 applications. Unless it can be guaranteed that Company X can enter one of these 3 markets without having to ask the lowest price (as described in chapter 7), Company X should not invest in (one of) these 3 applications.

Based on this research it can be concluded that Company X should continue her investigation on one of the 2 following applications: cat litter and soil improvement. Even in the most pessimistic scenario, the soil improvement application is still of economic interest to Company X.

When it is found that the market entry for soil improvement application is unrealistic, Company X should investigate the possibility of expanding the export of bentonite suitable for cat litter.

Prior to this research it was known that the European market for cat litter is already mainly satisfied. Therefore Company X should investigate these expanding possibilities inside and outside the European market.

Appendices of the processing analysis

Appendix A

A.1 Requirements for bentonite applications (Based on API (2010) standards)

	Drilling Fluid	Foundry Sand	Soil Improvement	Bleaching Earth
Cat ion Exchange Capacity *[mg of MB/g]*		Min 220 Ca Min 370 Na		Min 190
Chemical Composition *[replaceable Ca^{2+} as CaO by mass %] Na_2O, K_2O*		0.75 – 3 Ca 2.5 – 3 Na	High % of Ca^{2+}, Mg^{2+}, Al^{3+} is preferred	Min 60 % montmorillonite
Chemical Composition *[replaceable Ca^{2+} as CaO by mass %] Na_2O/CaO*		0.1 – 0.4 Ca 1.0 – 1.7 Na		
Fann Viscosity *[at 600 rotations per minute]*	Min 30			
Filtrate Volume *[mL after 30 mins]*	Max 15			
Fineness *[sieve retention %]*		Max 3, 125 µm Max 7, 63 µm		Max 75 µm
Free Swelling Volume *[mL]*		Min 10 Ca Min 28 Na		
Gelling Time *[minutes]*		Max 5 Ca Max 2 Na		
Green Compression Strength *[psi]*		Min 15		
Liquid Limit *[SFSA method]*		100 – 200 Ca 600 – 800 Na		
Moisture Content	Max 10 %	7 %		Max 12 %
pH *[at 2 % suspension]*		9.0 – 10.5		4.0 at 10 % suspension
Swelling Index *[mL]*		Min 10 Ca Min 25 Na		
Whiteness				

Appendix B

B.1 API Standards

The American Petroleum Institute (API) is one of the world's biggest trade associations for the petroleum industry. The API distributes many technical standards every year. These standards are accepted by the whole worldwide industry and are therefore used as the standards to which the industry should obey. Because of this, the API standards will be used in this research as standards to which the corresponding semi-finished products must meet before they could be applied in their respective industries.

In this research it has been decided to neglect the OCMA standards. OCMA is an abbreviation for the now-defunct 'Oil Company Materials Association', an organization that for years set standards based primarily on what oil companies operating in the Middle East wanted in mud materials. Suppliers had little voice in OCMA. OCMA's specifications for bentonite clay were modified and taken over by API/ISO.

API specifications for this clay are similar to those of OCMA (Schlumberger Handbook: 2014).

B.2 Indian Standards

The Indian economy made a huge boost during the 20th century. With an economic burst comes usually a technological boost since a lot of new factories are built and a lot of new industrial techniques are applied. India was and is fully self-sufficient in her iron and steel production and therefore is the Indian foundry industry world leading.

The IS (Indian Standards) were acknowledged in 1986 as the safety standards for the (Indian) foundry industry. Just like the API standards are the globally accepted standards for drilling muds, are the IS globally accepted as standards for foundry sands.

Appendix C

C.1 Acid Activation

Naturally occurring bentonite clays may show very little efficiency in bleaching of oils and fats. It is for this reason that acid activation of these clays with inorganic acids is usually done in order to promote their adsorptive capacity of vegetable oils. Bentonite clays can be activated by using HCl concentrations or by H_2SO_4 concentrations. The reaction that takes place during acid activation can be generally described, as stated by Usman et al. (2012), as:

$$\text{Ca-bentonite} + 2H^+ \longrightarrow \text{H-bentonite} + Ca^{2+}$$

Acid activation enhances the properties of bentonite by manipulating its physical and chemical attributes without destroying the mineral's layered crystal structure.

C.2 Sodium Activation

The bentonite ability to cat ions exchanges is being used for a sodium activation of calcium bentonites for many industrial needs like for drilling muds and foundry sands. A calcium bentonite activation is performed by means of sodium carbonate according to the following reaction:

$$Na_2CO_3 + Ca^{2+} \rightarrow 2Na^+ + CaCO_3$$

Żymankowska-Kumon et al. (2012) state that the effect of this reaction is a significant increase of water absorption and an improvement of mechanical properties by the so-called activated bentonite. Calcium carbonate presence is characteristic for the activated bentonite.

C.3 Green Comprehensive Strength

Clay has an important role in making green sand casting mould beside water. Clay acts as binders, holding the sand grains together. Water is needed to activate the clay bond. Without the addition of water on clay, no strength would be achieved on sand mould, as the sand and clay would be just two dry materials. Bentonite clay was used in this study. Adequate clay content with suitable moisture in molding sand is important for optimum strength and casting quality. Too little or too much clay will not give proper strength. Green compression strength is one of the mechanical properties to be considered for making green sand casting mould. The green compression strength of foundry sand is the maximum compressive strength that a mixture is capable of sustaining when prepared, rammed and tested according to standard procedure. For this study, test is conducted according to Foundry Sand Testing Equipment Operating Instructions from Ridsdale and Dietert. Result from this study indicates that tailing sand has potential for making green sand casting mould in term of green compression strength. Other factors that must be considered are permeability and shatter index.

Appendix D

D.1 A flowchart of the current processing chain

The current processing chain (Cat litter production, 2014) is as follows:

Processing steps:	**Short description of processing steps:**
Excavation	Bentonite is excavated from the mines owned by Sivomatic
Transportation	Bentonite is transported to the processing plant
Stacking	Bentonite is stacked and crushes the bentonite. This is called primary crushing since the bentonite is initially crushed by its own weight
Crushing	Bentonite is placed in a crusher by an excavator
Activation/Extrusion	Soda Ash is added to the bentonite with a ratio of 22 kg soda ash per 1 ton of bentonite. This activation increases the cat ion exchange capacity and therefore the absorptivity of the bentonite increases
Drying	The activated bentonite is dried in a rotary kiln and reduces the moisture content from 28%-35% to 9.5%-11.5%. The absorptivity increases and the weight is reduced
Milling (30% backloop from sieving)	The bentonite is milled to reduce the size of the clumps that come from the kiln to 0.5mm-2.8mm for fine production and 0.5mm-5mm for coarse production
Sieving	The milled bentonite is sieved to 0.5mm-2.8mm (no. 35 ASTM sieve - no. 7 ASTM sieve) for fine production and 0.5mm-5mm (no. 35 ASTM sieve - no. 4 ASTM sieve) for coarse production. The residue (about 30%) is milled again
Semi-finished Product	The semi-finished product, the milled, dried and activated bentonite is put in big bags to protect it from moisture and dilution

D.2 Flowchart of drilling mud production processes

In the research for bentonites suitable for drilling muds 2 scenarios have been found.

Scenario 1:
Calcium-type bentonites are treated during grinding by adding: 2-3 % soda and 0.5 % MgO

Scenario 2:
Calcium-type bentonites are treated during grinding by adding: Sodium Carboxymethyl Cellulose (Na-CMC), poly-acrylamide and polyacrylic of 3.5 %, 1.0 % and 0.2 %, respectively.

Processing steps:	**Short description of processing steps:**
Excavation	Bentonite is excavated from the mines owned by Sivomatic
Transportation	Bentonite is transported to the processing plant
Stacking (Primary Crushing)	Bentonite is stacked and crushes the bentonite
Crushing	Bentonite is placed in a crusher by an excavator
Activation/Extrusion	Additives are added (depending on which scenario) as described above
Drying	The activated bentonite is dried in a rotary kiln and reduces the moisture content from 28%-35% to below 10%
Fine milling	The bentonite is milled to reduce the size of the clumps that come from the kiln to moderate to fine material with a no. 120 ASTM sieve (< 125 µm)
Semi-finished Product	The semi-finished product, the milled, dried and activated bentonite is put in big bags to protect it from moisture and dilution

D.3 Flowchart of foundry sand production processes

In the research for bentonites suitable for foundry sands this scenario has been found. The activation should be done with adding 1–2 % soda ash.

Processing steps:	**Short description of processing steps:**
Excavation	Bentonite is excavated from the mines owned by Sivomatic
Transportation	Bentonite is transported to the processing plant
Stacking (Primary Crushing)	Bentonite is stacked and crushes the bentonite
Crushing	Bentonite is placed in a crusher by an excavator
Activation	Additives are added as described above
Drying	The activated bentonite is dried in a rotary kiln and reduces the moisture content from 28%-35% to roughly 7%
Milling (backloop x %)	The bentonite is milled to reduce the size of the clumps that come from the kiln to 75 µm
Sieving	The milled bentonite is sieved to 75 µm (no. 200 ASTM sieve). The residue (x %) is milled again
Aging	The bentonite should be left in storage for ageing for at least 2 months
Semi-finished Product	The semi-finished product, the milled, dried and activated bentonite is put in big bags to protect it from moisture and dilution

D.4 Flowchart of soil improver production processes

The investigation on soil improvers suggest the following processing chain.

Processing steps:	Short description of processing steps:
Excavation	Bentonite is excavated from the mines owned by Sivomatic
Transportation	Bentonite is transported to the processing plant
Stacking (Primary Crushing)	Bentonite is stacked and crushes the bentonite
Crushing	Bentonite is placed in a crusher by an excavator
Drying	The bentonite is dried in a rotary kiln and reduces the moisture content from 28%-35% to 12%
Milling (backloop x %)	The bentonite is milled to reduce the size of the clumps that come from the kiln to 75 µm
Sieving	The milled bentonite is sieved to 75 µm (no. 200 ASTM sieve). The residue (x %) is milled again
Semi-finished Product	The semi-finished product, the milled, dried and activated bentonite is put in big bags to protect it from moisture and dilution

D.5 Flowchart of bleaching earth production processes

To prepare bentonite as a bleaching earth was found to be the most complicated processing chain.

Processing steps:	**Short description of processing steps:**
Excavation	Bentonite is excavated from the mines owned by Sivomatic
Transportation	Bentonite is transported to the processing plant
Stacking (Primary Crushing)	Bentonite is stacked and crushes the bentonite
Crushing	Bentonite is placed in a crusher by an excavator
(Pre)Drying	The bentonite is dried in a rotary kiln and reduces the moisture content from 28%-35% to 4%.
Milling (backloop x %)	The bentonite is milled to reduce the size of the clumps that come from the kiln to 75 µm, so that a bigger surface area is created which increases the effect of acid activation
Sieving	The milled bentonite is sieved to 75 µm (no. 200 ASTM sieve). The residue (x %) is milled again
Acid activation	Acid activation takes place by placing the fine bentonite in a basin with a ratio of 0.5 g mL^{-1} bentonite/hydrochloride concentration of 1 M at 95^{o} C for 6 hours
Cooling, filtering & washing	The activated bentonite should be cooled, filtering and washed to remove excessive negative ions
Drying	The bentonite is dried in a rotary kiln and reduces the moisture content from x % to 12% at 100^{o} C
Milling (backloop y %)	Again the bentonite is milled (also called pulvarized in this industry) so that is passes (at least) through a no. 120 ASTM sieve (125 µm)
Sieving	Finally the bentonite is sieved with a no . 120 ASTM sieve (125 µm) with a backloop of y %
Semi-finished Product	The semi-finished product, the milled, dried and activated bentonite is put in big bags to protect it from moisture and dilution

Appendices of the market analysis

Appendix E

E.1 Production of bentonite and fuller's earth from the EU35

Production of bentonite and fuller's earth tonnes

Country	2008	2009	2010	2011	2012
Bulgaria					
Bentonite	178 700	108 400	99 700	53 900	77 900
Croatia					
Bentonite	19 759	—	—	—	—
Cyprus					
Bentonite	155 125	152 722	162 969	160 625	160 180
Czech Republic					
Bentonite	235 000	177 000	183 000	160 000	221 000
Denmark					
Bentonite	22 458	24 040	23 832	38 300	30 330
France					
Bentonite	...	25 000	25 000	20 000	28 000
Germany					
Bentonite	414 336	326 461	362 623	375 332	366 220
Greece					
Bentonite	1 580 000	1 500 000	844 804	1 250 000	1 300 000
Hungary					
Bentonite	6 220	5 298	17 200	22 931	* 22 000
Italy					
Bentonite	124 419	114 212	104 279	105 952	144 710
Macedonia					
Bentonite	13 689	9 033	7 084	8 918	2 355
Poland					
Bentonite	3 000	2 800	2 000	900	800
Romania					
Bentonite	16 638	13 756	21 637	19 864	19 241
Slovakia					
Bentonite	145 000	109 000	153 000	213 000	177 000
Slovenia					
Bentonite	160	104	135	168	98
Spain					
Bentonite	154 534	147 090	157 001	110 371	135 445
Attapulgite	27 348	21 110	27 841	26 021	23 537
Sepiolite	737 659	573 937	557 862	566 270	748 863
Turkey					
Bentonite	683 253	753 155	718 260	379 917	* 370 000
Sepiolite	* 10 000	* 10 000	* 10 000	* 10 000	* 10 000
EU35 Total					
Bentonite	3 752 000	3 468 000	2 883 000	2 920 000	3 055 000
Attapulgite and sepiolite	775 000	605 000	596 000	602 000	782 000

E.2 Exports of bentonite and fuller's earth from the EU35

Exports of bentonite and fuller's earth

tonnes

Country	2008	2009	2010	2011	2012
Austria					
Bentonite	5 225	4 350	3 447	4 954	4 513
Belgium					
Bentonite	34 034	36 263	28 632	28 512	31 222
Bulgaria					
Bentonite	103 106	79 359	72 183	67 118	63 090
Cyprus					
Bentonite	92 089	95 674	98 803	114 923	130 413
Czech Republic					
Bentonite	105 403	99 584	120 859	143 788	151 474
Denmark					
Bentonite	15 734	13 004	13 787	13 827	17 711
Finland					
Bentonite	42	803	0	61	27
France					
Bentonite	12 231	9 211	12 709	11 472	8 826
Germany					
Bentonite	67 109	52 424	84 920	91 477	82 504
Greece					
Bentonite	8 885	5 116	13 203	33 306	14 233
Hungary					
Bentonite	1 191	555	954	782	1 047
Italy					
Bentonite	293 417	186 219	257 173	214 775	225 729
Lithuania					
Bentonite	1 929	266	442	1 628	1 386
Macedonia					
Bentonite	5 201	3 716	3 310	3 730	3 635
Montenegro					
Bentonite	1 384	24	48	27	26
Netherlands					
Bentonite	120 946	135 722	178 093	186 574	141 709
Norway					
Bentonite	157	294	3 726	318	1 318
Poland					
Bentonite	20 384	23 918	21 987	25 050	23 563
Portugal					
Bentonite	1 608	691	1 175	1 356	1 935
Serbia					
Bentonite	5 066	5 107	4 823	11 903	2 972
Slovakia					
Bentonite	79 936	65 429	32 981	85 760	98 257
Spain					
Bentonite	75 287	1 021 034	66 118	54 449	54 147
Sepiolite	460 485	418 644	...	...	...
Sweden					
Bentonite	11 640	5 588	3 457	3 300	5 492
Turkey					
Bentonite	244 177	250 082	307 891	319 189	337 860
United Kingdom					
Bentonite	43 261	34 622	41 323	38 478	39 535
Sepiolite	226	130	...	...	...

E.3 *Imports of bentonite and fuller's earth from the EU35*

Imports of bentonite and fuller's earth tonnes

Country	2008	2009	2010	2011	2012
Austria					
Bentonite	68 703	66 575	90 229	83 313	91 208
Belgium					
Bentonite	74 216	62 885	72 971	91 291	68 771
Bulgaria					
Bentonite	3 386	2 422	2 548	2 591	2 074
Croatia					
Bentonite	39 289	22 383	7 852	16 906	5 394
Cyprus					
Bentonite	12 496	5 709	4 629	142	280
Czech Republic					
Bentonite	24 239	25 129	18 472	39 439	43 334
Denmark					
Bentonite	34 012	35 089	43 049	34 130	41 931
Estonia					
Bentonite	1 506	1 631	3 352	2 937	2 670
Finland					
Bentonite	31 445	19 429	16 293	21 194	24 913
France					
Bentonite	198 787	158 715	159 096	194 555	180 301
Germany					
Bentonite	361 782	335 990	386 261	447 793	450 850
Greece					
Bentonite	21 261	8 593	3 668	7 193	5 831
Hungary					
Bentonite	3 095	3 608	4 360	4 648	6 527
Iceland					
Bentonite	2 392	1 259	432	563	281
Ireland, Republic of					
Bentonite	2 643	2 741	2 734	2 623	2 788
Italy					
Bentonite	136 417	96 698	130 508	140 458	133 041
Latvia					
Bentonite	2 628	2 148	2 787	3 434	2 701
Lithuania					
Bentonite	3 068	3 368	4 378	6 250	6 656
Macedonia					
Bentonite	168	142	219	302	725
Malta					
Bentonite	639	635	921	844	446
Netherlands					
Bentonite	314 298	* 190 000	237 683	289 615	277 221
Norway					
Bentonite	14 783	12 612	14 506	12 668	11 620
Poland					
Bentonite	171 633	122 165	155 173	212 585	233 200
Portugal					
Bentonite	20 304	12 788	18 205	23 436	26 466
Romania					
Bentonite	6 014	3 859	4 825	6 341	8 463
Serbia					
Bentonite	3 370	2 274	1 683	1 804	5 294
Slovakia					
Bentonite	8 987	5 890	6 416	26 935	25 923
Slovenia					
Bentonite	3 976	4 421	4 191	4 790	5 905
Spain					
Bentonite	103 602	72 993	108 066	146 344	114 421
Sweden					
Bentonite	178 308	120 079	200 422	214 173	231 973
Switzerland					
Bentonite	21 876	20 407	20 362	19 316	19 203
Turkey					
Bentonite	9 806	1 827	1 641	1 915	1 952
United Kingdom					
Bentonite	205 853	140 301	141 849	200 332	183 343
Sepiolite	227 453	70 651	...	...	...

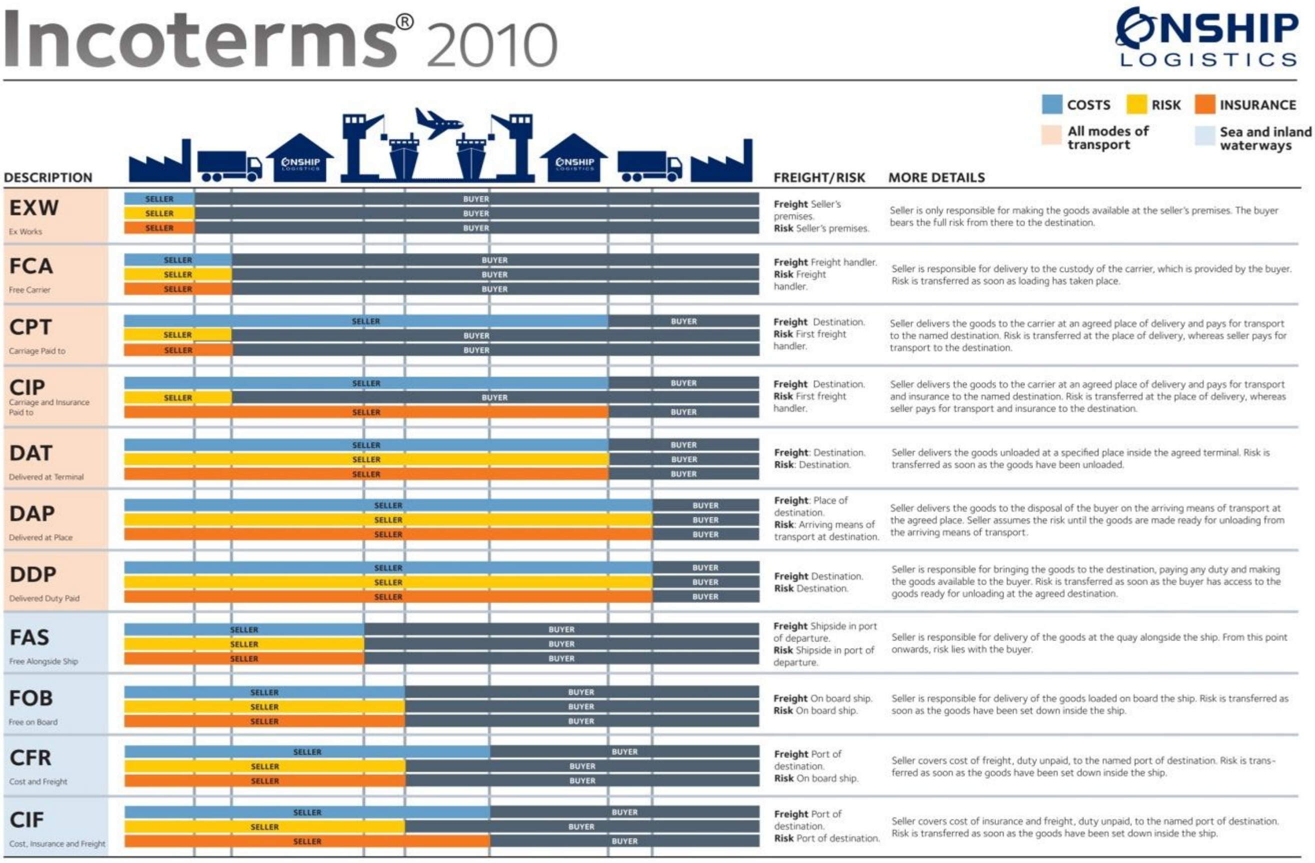
Appendix F

F.1 FOB (Freight On Board) price

The Freight On Board price, or sometimes referred as Free On Board, is a trade term requiring the seller to deliver goods on board a vessel designated by the buyer. The seller fulfills its obligations to deliver when the goods have passed over the ship's rail.

In other words, FOB costs include the cost of loading onto freight vehicles at the point of sale but exclude the cost of transporting the goods from this point.

F.2 Incoterms (Onship Logistics: 2010)



Appendix G

G.1 Cost estimation of CapEx and OpEx (printout from the excel file)

SOURCE FOR CapEx COSTS: Mining Cost Service, COSTMINE by InfoMine USA, Inc. Version 2011. Assumptions are verified in the report (comparison is done with Mining Cost Service, COSTMINE by InfoMine USA, Inc. Version 2006.)

Model designed and programmed by Kaj van der Waal, 2014

	Cat litter	Drilling Mud	Foundry Sand	Soil Improvement	Bleaching earth	
Crushing	std. hammermill 13.6 mt/h	std. hammermill 13.6 mt/h	std. hammermill 13.6 mt/h	std. hammermill 13.6 mt/h	std. hammermill 13.6 mt/h	
CapEx	44400	44400	44400	44400	44400	
OpEx	29600	29600	29600	29600	29600	
	1500	1500	1500	1500	1500	
Activation	Extruder suggested by Sivomatic	Extruder suggested by Sivomatic	Extruder suggested by Sivomatic	-	-	
CapEx	200000	200000	200000	0	0	
OpEx	339583	423333	283333	0	0	
	20000	20000	20000	0	0	
Drying	rotary gas fired dryer (rate of evaporatio	rotary gas fired dryer (rate of evaporatio	rotary gas fired dryer (rate of evaporatio	rotary gas fired dryer (rate of evaporatio	rotary gas fired dryer (rate of evaporation)	3.2-17.1 mt.water/hour
CapEx	755000	755000	755000	755000	755000	
OpEx	503333	503333	503333	503333	1006667	
	15000	15000	15000	15000	15000	
Milling	Mill suggested by Sivomatic	roller grinding mill 54" 10t/h 80% 200 m	roller grinding mill 54" 10t/h 80% 200 m	roller grinding mill 54" 10t/h 80% 200 m	roller grinding mill 54" 10t/h 80% 200 mesh	
CapEx	100000	563500	563500	563500	563500	
OpEx	66667	375667	375667	375667	375667	
	10000	10000	10000	10000	10000	
Sieving	Trommel incl. vibrating horizontal screen	-	Trommel incl. vibrating horizontal screen	Trommel incl. vibrating horizontal screen	Trommel incl. vibrating horizontal screen	(incl motor)
CapEx	90000	0	90000	90000	90000	
OpEx	60000	0	60000	60000	60000	
	10000	0	10000	10000	10000	
Ageing	-	-		-	-	
CapEx	0	0	0	0	0	
OpEx	0	0	0	0	0	
	0	0		0	0	
Acid Activation	-	-	-	-	Leaching plant suggested by Sivomatic	
CapEx	0	0	0	0	2000000	
OpEx	0	0	0	0	1333333	
	0	0	0	0		
Cooling	-	-	-	-	-	
CapEx	0	0	0	0	-	
OpEx	0	0	0	0	-	
	0	0	0	0	-	
Filtering	-	-	-	-	Refining suggested by Sivomatic	
CapEx	0	0	0	0	1000000	
OpEx	0	0	0	0	666667	
	0	0	0	0	-	
Washing	-	-	-	-	-	
CapEx	0	0	0	0	-	
OpEx	0	0	0	0	-	
	0	0	0	0	-	
Drying	-	-	-	-	rotary gas fired dryer (rate of evaporation)	3.2-17.1 mt.water/hour
CapEx	0	0	0	0	755000	
OpEx	0	0	0	0	503333	
	0	0	0	0	15000	
Milling	-	-	-	-	roller grinding mill 54" 10t/h 80% 200 mesh	
CapEx	0	0	0	0	563500	
OpEx	0	0	0	0	375667	
	0	0	0	0	10000	
Sieving	-	-	-	-	Trommel incl. vibrating horizontal screen	(incl motor)
CapEx	0	0	0	0	90000	
OpEx	0	0	0	0	60000	
	0	0	0	0	10000	
Air classification	0	300000	300000	300000	0	
Building	400000	400000	400000	400000	800000	
Engines machinery	1500	1500	1500	1500	3000	
Total CapEx:	1590900	2264400	2354400	2154400	6664400	Excavation/Transportation/Stacking excluded/BigBag excluded
Total OpEx:	999183	1331933	1251933	968600	4410933	Excavation/Transportation/Stacking excluded/BigBag excluded

		Soda Ash $/t	250	Source: alibaba trading		
		Cat litter (activation) $/t	6			
		Cat litter (activation) $/year	206250			
123456789:	transportation/other costs;	Magnesium Oxide (MgO) $/t	200	Source: alibaba trading		
	Conveyer belts	Drilling Mud (activation) $/t	1			
		Drilling mud (activation) $/year	40000			
		Soda Ash $/t	250		In case polymers are used as additives for drilling mud bentonite: (**SET MgO and Soda Ash to 0**)	
		Drilling Mud (activation) $/t	6		Polymer $/t	0
		Drilling mud (activation) $/year	250000		Drilling mud (activation) $/t	0
			290000		Drilling mud (activation) $/year	0
		Soda Ash $/t	250			
		Foundry Sand (activation) $/t	4			
		Foundry Sand (activation) $/year	150000			
		Thumbrule for OpEx : (Capex/depreciation time)*10, concluded from The CostMine Infomine USA folder				

	Cat litter	Drilling Mud	Foundry Sand	Soil Improvement	Bleaching earth	
Total CapEx:	1590000	2260000	2350000	2150000	6660000	
Total OpEx:	2000000	2330000	2250000	1970000	5410000	TOTAL

G.2 An introduction in the excel sheet

The Microsoft excel sheet that is provided with this report offers the option to experiment with several variables. The prices of additives, machinery, and semi-finished product can be easily adjusted. The annual production capacity, gas price inflation and consumer price inflation can also be easily changed in order to check the effect.

G.3 Summary of economic terms and their meaning

Discount rate:

The interest rate charged to commercial banks and other depository institutions for loans received from the Federal Reserve Bank's discount window. The discount rate also refers to the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. A third meaning of the term 'discount rate' is the rate used by pension plans and insurance companies for discounting their liabilities.

Net present value (NPV):

The net present value is the most intuitive and accurate valuation to capital budgeting problems. Discounting the after-tax cash flows by the weighted average cost of capital allows managers to determine whether a project will be profitable or not. The NPV rule states that all projects which have a positive net present value should be accepted while those that are negative should be rejected. If funds are limited and all positive NPV projects cannot be initiated, those with the high discounted value should be accepted.

Internal rate of return (IRR):

The discount rate often used in capital budgeting that makes the net present value of all cash flows from a particular project equal to zero. Generally speaking, the higher a project's internal rate of return, the more desirable it is to undertake the project. As such, IRR can be used to rank several prospective projects a firm is considering. Assuming all other factors are equal among the various projects, the project with the highest IRR would probably be considered the best and undertaken first.

Reference List

- BOYLU, F. 2011 *'Optimization of foundry sand characteristics of soda-activated calcium bentonite'*
- CHRISTIDIS, G.E., SCOTT, P.W. and DUNHAM, A.C. 1997 *'Acid activation and bleaching capacity of bentonites from the islands of Milos and Chios, Aegean, Greece'*
- CLEM, A.G. and DOEHLER, R.W. 1961 *'Industrial applications of bentonite'*
- DUNGAN, R.S., DEES, N.H. and MANAGE, J.E. 2009 *'The characterization of total and leachable metals in foundry molding sands'*
- ERDOĜAN, B. and DEMIRCI, Ş. 1996 *'Activation of some Country A bentonites to improve their drilling fluid properties'*
- HUSSIN, F., AROUA, M.K., and DAUD, W.M.A.W. 2011 *'Textural characteristics, surface chemistry and activation of bleaching earth: A review'*
- KARAGÜZEL, C., ÇETINEL, T., BOYLU, F., ÇINKU, K. AND ÇELIK, M.S. 2010 *'Activation of (Na, Ca)-bentonites with soda and MgO and their utilization as drilling mud'*
- KARAKAYA, M.Ç., KARAKAYA, N. AND BAKIR, S. 2011 *'Some properties and potential applications of the Na- and Ca-bentonites of Location B (N.E. Country A)'*
- MATOS, G.R., and VIRTA R.L. 2005 *'Bentonite End-Use Statistics U.S. Geological Survey'*
- ROHAN, 2013 *'Drilling Fluids (Drilling Mud) Market and Completion Fluids Market: by Types (Water-Based Systems, Oil-Based Systems, Synthetic-Based Systems, Other Based Systems), Application Areas (Onshore and Offshore), & Geography - Global trends and forecast to 2018'*
- UNKNOWN AUTHOR 2014, *'Improving soils and boosting yields in Thailand - International Water Management Institute'*
- UNKNOWN AUTHOR, 2014, *'Essential safety and quality requirements for fertilizing materials - Fertilizers Working Group meeting'*
- UNKNOWN AUTHOR, British Columbia Geological Survey Branch 1994 *'Market Study Of Bentonite Products'*
- UNKNOWN AUTHOR, EUBA statistics 2012
- UNKNOWN AUTHOR, European Mineral Statistics by the British Geological Survey 2008
- UNKNOWN AUTHOR, Official Indian Bureau of Mines, *'Bentonite'*
- UNKNOWN AUTHOR, Schlumberger Handbook, *'API/ISO'* [Online: September 2014]
- UNKNOWN AUTHOR, Schlumberger Handbook, *'What is bentonite'* [Online: September 2014]
- USMAN, M.A., EKWUEME, V.I., ALAJE, T.O. and MOHAMMED, A.O. 2012 *'Characterization, Acid Activation, and Bleaching Performance of Ibeshe Clay, Lagos, Nigeria'*
- VINGAS, G.J. and ZRIMSEKJ, A.H. 1964 *'Thermal stability of bentonites in foundry molding sand'*
- ZYMANKOWSKA-KUMON, S., HOLTZER, M., OLEJNIK, E. and BOBROWSKI, A. 2012 *'Influence of the Changes of the Structure of Foundry Bentonites'*