Master's thesis

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Marlene Breistøl

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Manufacturing and Civil Engineering

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Potential Wastewater Treatment Systems and Carbon Recovery

The special case of the integrated charcoal-silicon/ferrosilicon process

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Sustainable Manufacturing
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Supervisor: Niels Peter Østbø
Co-supervisor: Christian Vogelsang

Norwegian University of Science and Technology
Department of Manufacturing and Civil Engineering

Preface

The master thesis is submitted to the Department of Manufacturing and Civil Engineering at the Norwegian University of Technology, Spring 2019. The master thesis has been a collaboration between NTNU, Elkem and SINTEF, since it has been written as part of the project pyrOPT, that is a joint project between Elkem and SINTEF, in the field of wastewater treatment systems and carbon recovery. The main supervisor was Niels Peter Østbø from NTNU, and co-supervisor Christian Vogelsang from NIVA.

Thanks to the supervisors Niels Peter Østbø and Christian Vogelsang, for patience, guidance and help to complete the master thesis. Thanks to Per Carlsson and Geir Johan Andersen from SINTEF and Elkem for participating in meetings and giving guidelines.

A special thanks to my beloved, my friends and my family for support and encouragement during the master thesis.

Marlene Breistøl

Kristiansand, 29.5. 2019.

Abstract

The master thesis was a collaboration between NTNU and Elkem, through the project pyrOPT, that SINTEF is a participant in, making SINTEF part of the master thesis as well. PyrOPT is part of Elkem's vision to reduce the use of fossil coal during the production of silicon and ferro-silicon, of which the integrated charcoal-silicon/ferrosilicon process produces tailor-made biocarbon that can replace the use of fossil coal.

The production includes several sources of emissions, leading to the need for process water to be treated before release to recipient. Therefore, the aim of this master thesis was to map potential wastewater treatments, and methods to recover the carbon within the wastewater treatment system. The method chosen was a collective case study, with the following participants: Norske Skog, SCA Örtviken, SCA Graphic Sundsvall AB, Kristiansand Municipal Water and Sewage Department and Borregaard. This method was chosen since it allows for multiple entries of data, which was needed as the wastewater from the production was not disclosed, and recipient undecided. During the visits to site, an a recorded interview was done to avoid misunderstandings. It was also taken notes and done observations. The literature was provided by SINTEF and Elkem, and found during searches in the following databases: Oria, SciendeDirect and GoogleSchoolar.

During the interviews, the questions were divided into general and in-dept questions to cover the methods of wastewater treatments, the discharge permits, what the representatives considered as key factors for sustainable production, and a beneficial wastewater treatment system. It was emphasized the importance of circular economy for sustainable production and anaerobic treatments for a beneficial wastewater treatment system, due to the creation of biogas for savings in production and potential profit if sold.

The results from the case study was the foundation for the scenarios of wastewater treatment system and carbon recovery. The following scenarios were made: anaerobe EGSB reactor, anaerobe digester, and anaerobe membrane reactor. All the scenarios are in accordance with the criteria made for the scenarios, meaning recovery of carbon as biogas and biomass providing circularity, and the scenarios managed to treat the wastewater to a be in compliance with the discharge permit's higher limit, that was created on the basis of collected permits from participants and the Norwegian legislation.

Sammendrag

Denne masteroppgaven er skrevet som et samarbeid mellom NTNU og Elkem, gjennom prosjektet pyrOPT som SINTEF er involvert i, og har derfor vært en del av denne oppgaven også. PyrOPT er del av strategien til Elkem for å redusere bruken av fossilt kull i produksjon av silisium og ferro-silisium, hvorav den integrerte trekull-silisium/ferrosilisium prosessen produserer skreddersydd bio-karbon som kan erstatte fossilt kull.

Den integrerte prosessen inneholder flere kilder til utslipp, som fører til at vannet fra prosessen må renses før det slippes til resipient. Dermed ble fokus i denne masteroppgaven å finne passende rensemetoder, og metoder for å gjenvinne karbonet fra produksjonen gjennom vannrensningssystemet. Metoden valgt var en felles case studie, hvor de delaktige bedriftene var som følger: Norske Skog, SCA Örtviken SCA Graphic Sundsvall AB, Kristiansand Kommune: Vann og avløp, og Borregaard. Denne metoden ble valgt fordi den tillater flere kilder av data, som var nødvendig da avløpsvannet fra produksjonen og resipient var ukjent. Under besøkene ble det gjennomført et intervju som det ble gjort opptak av for å unngå misforståelser. Det ble også tatt notater og gjort observasjoner til videre bruk i oppgaven. For å finne relevant litteratur det brukt følgende metoder: innhente litteratur fra SINTEF og Elkem, og gjøre søk i databasene Oria, ScieneDirect og GoogleScholar.

Under intervjuene ble spørsmålene delt inn i generelle og dyptgående spørsmål for å dekke vannrensningsmetodene, utslippstillatelsene, og hva representanten for bedriften anså som nøkkelfaktorer for bærekraftig produksjon og fordelaktig vannrensningssystem. Det ble lagt vekt på viktigheten av sirkulær økonomi, og anaerobe vannrensningsbehandlinger for et fordelaktig vannrensningssystem, grunnet dannelse av biogass for sparinger og potensielle fortjenester ved salg.

Resultatet fra case studiet var grunnlaget for scenarioene som ble laget for vannrensningssystemet og karbon gjenvinningen. Følgende scenario ble laget: anaerob reaktor (EGSB), anaerobe utråtningstank, og anaerob membran reaktor. Disse scenarioene var i henhold til kriteriene laget, da de gjenvant karbon i form av biogass og biomasse og behandlet avløpsvannet innen høyere grense for tillatelsen som ble laget basert på de innhentede tillatelsene fra de delaktige bedriftene, og det norske lovverket.

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List of abbreviations

AnMBR	Anaerobe membrane bioreactor
BOD	Biological oxygen demand
COD	Chemical oxygen demand
C	Carbon
EEA	European Economic Area
MBR	Membrane bioreactor
SS	Suspended solids
WWS A	Wastewater stream A
WWS B	Wastewater stream B
WWS C	Wastewater stream C
Wt	Weight total

1. Introduction

1.1 Background on the integrated charcoal-silicon/ferrosilicon process

The growing concern for the environment and the impact of emissions to air and water, has led to a search for new methods to reduce the emissions from production. To achieve this, a potential method is to use renewable raw material, such as biomass, instead of fossil fuels. Olszewski et al., stated in a research paper from 2017, that in the metallurgies industries the amount of pit coal briquettes, coal coke and semi-coke used in production was 54 199 and 253 818 ton. While, the use of renewable raw material such as wood charcoal was 26 000 ton the same year.

As one of the leading industries in metallurgies production, Elkem has made a strategy to reduce the emission linked to its production. The strategy involves using 40% renewable carbon in the mix of reduction material in the production of silicon and ferrosilicon within 2030 in Norwegian alloys. The integrated charcoal-silicon/ferrosilicon process is part of the project pyrOPT, where forest biomass is used as raw material to create charcoal(biocarbon), that can be used as substitute for coal and semi-coke typically used in metallurgical production.

Biomass is viewed as attractive feedstock of several reasons. The three main reasons are the following: first, the renewable perspective, that it is part of a sustainable future. Second, it have positive environmental properties with no net release of carbon dioxide and low sulfur content. Last, it have significant economic potential, with increased future fossil prices (Bulmâu *et al,*. 2010).

The integrated charcoal-silicon/ferrosilicon process use wood as raw material, and through fast pyrolysis create charcoal(biocarbon) with potentially 40-50% yield. The fast pyrolysis process create three products: gas, solids, and liquid, where the gas is burnt off, the solids are forwarded to silicon production and the liquid is forwarded to the wastewater treatment system. Due to the Norwegian legislation for pollution control, there is a requirement for treatment before release to recipient. The requirements are induvial for businesses, and are displayed through a discharge permit. However, the discharge permit for this production is not available.

The known content of the wastewater is based on the wood preparation processes, pyrolysis and charcoal cooling. Therefore, it is expected to contain COD, BOD, SS, Color and toxicity. The amount of these components are unknown due to the lack of data on the wastewater from the integrated charcoal-silicon/ferro silicon process.

1.2 Aim of master thesis

The aim of the master thesis was to map the potential wastewater treatments and possible carbon recovery for Elkem's integrated charcoal-silicon/ferrosilicon process, of which the wastewater was considered to include bio-oil. Since the information on content of the wastewater was limited and discharge permit non-existing, the main tasks to perform were as follows:

1. Make assumptions based on literature concerning the content of the wastewater streams.
2. Map the available wastewater technology to create potential scenarios for wastewater treatment systems and recovery of carbon within the system.
3. Make assumptions on how much carbon that can be recovered in terms of biomass[a] and biogas.
4. Create a potential discharge permit with a lower and higher limit.

The results from the tasks would give the basis for answering the following research questions:

1. What are the expected characteristics of the wastewater?
2. What are the potential scenarios for wastewater treatment systems and carbon recovery?
3. How much biomass and biogas are potentially produced, holding the recovered carbon?
4. What is the expected discharge permit for COD and SS?

[a] The secondary/bio-sludge from the potential wastewater systems is referred to as biomass

1.2.1 Delimitation

To narrow the scope the following delimitations for the master thesis were made:

1. There will be given a potential amount of carbon available to recover from literature, represented as the amount of COD in wastewater
2. The attempted calculations for recovery of carbon in the wastewater systems, only consider the removal rate provided in literature as factor for the reduction of carbon available for recovery in biomass and biogas.
3. The scenarios will not be simulated or tested to determine what type of product of the different methods in scenarios are best suited (for example type of thickener).
4. The recipient and location is not specific beyond normal recipient.
5. The economic perspective of the wastewater treatments are not considered.

1.3 Outline of work and master thesis

The master thesis is limited to 20 weeks. Therefore, the master thesis was divided into three work-periods. The first two periods of six weeks and the last of eight weeks. The first, was set to collect relevant literature, contact eligible organizations and prepare interview questions. The second, to conduct company visits, interviews and transcription. The final part, was to analyze the results, create potential wastewater scenarios, find the potential carbon for recovery, and write the master thesis.

The master thesis is outlined with theory and background, method and material, results and discussion as it main parts. The background present the necessary theory, data provided before research, and background on the project. The method and material present the method and material for the master thesis. The results present the findings in the case study and the calculation of expected discharge permit, while the discussion present the scenarios for wastewater treatment systems, the potential carbon to recover, and the calculation of potential carbon recovery in biomass and biogas within the different scenarios.

2. Theory and background

In this section, relevant literature on renewable biomass conversion to biocarbon, and the industrial perspective of the use for biocarbon is presented along with the integrated charcoal-silicon/ferrosilicon processes. The legislation for wastewater treatment, expected wastewater characteristics, and common industrial wastewater treatment methods are described.

2.1 Biomass conversion to biocarbon

There are three main reasons for that renewable sources of biomass is viewed as attractive feedstock. First, it is a resource that can be sustainable in the future. Second, it seems to have positive environmental properties that results in no net release of carbon dioxide and very low sulfur content. Third, it appears to have significant economic potential provided that future fossil fuels prices are increased (Bulmâu *et al,.* 2010). There are several types of biomass feedstock, such as the following: forest and crops, agricultural crops and residue, indusial residue, and sewage.

According to the World Energy Council, the global share of biomass feedstock in meeting the world's primary energy mix was at 10% in 2010. The most common use of renewable biomass for energy is in relation to direct combustion, followed by gasification, carbonization and pyrolysis. There are three types of primary fuels that are produced from biomass: liquid fuels (biodiesel), gaseous fuels (biogas) and solid fuels (biochar) (Basu, 2013).

The term solid fuels contain both bio-char and bio-carbon, but they serve different purposes. Bio-char is a term used when the carbon produced after the pyrolysis is aimed to be used as a soil amendment. Bio-carbon is a relatively new term and it is used when the applications of this carbon are in an industrial environment. Applications of bio-carbon are aimed to reduce the use of non-renewable carbon-black (Arnold *et al,.* 2018).

2.2 Biocarbon in an industrial perspective

Statistics Norway states, metallurgical industries annually uses approximately 54 199 ton of pit coal briquettes, and around 253 818 ton coal coke and semi-coke. Wood charcoal is used, but annually around 26 000 ton (Olszewski et al,. 2017).

Elkem's process to concert quartz to silicon is a high temperature smelting process that require vast amounts of energy. The main energy source for the production at most smelters, is the renewable source hydropower, and the addition electricity supply is without climate effect. However, the production require carbon sources like fossil coal, charcoal and wood chips as a reductant in chemical conversion, that is responsible for emissions of CO2, NOX and SO2. The emissions cannot be successfully removed with current technology. Thus, Elkem has mapped a strategy to reduce them.

The strategy to reduce the environmental footprint is with use of the current technology, as feasible as possible, and develop technology that is carbon neutral. The strategy includes replacement of fossil carbon with bio-carbon by increasing the use of charcoal and wood-chips in the process, rebuilding furnaces to reduce NOX generated from smelting processes and using low-Sulphur raw material to reduce SO2 emissions.

Elkem pronounced a goal of using 20% renewable carbon in the mix of reduction material in the production of silicon and ferrosilicon alloys in Norway within 2021, and 40% by 2030. In 2018, the goal of 20% mixture was reached. However, the milestone of 2030 is still in progress. The integrated charcoal-silicon/ferrosilicon process is part of Elkem's vision to produce charcoal without emissions and 35% less overall energy consumption.

2.3 The integrated charcoal-silicon process description

The following information was provided by SINTEF and Elkem on the integrated charcoal-silicon/ferrosilicon process: it consist of the following processes: biomass debarking, biomass chipping, biomass drying, biomass pyrolysis, production separation, charcoal cooling. The charcoal is forwarded to silicon production. The wet debarking, condensing wood drier, pyrolysis process and charcoal cooling are emissions sources. The process is presented in figure 1. The main processes are presented separately in the sub-section below.

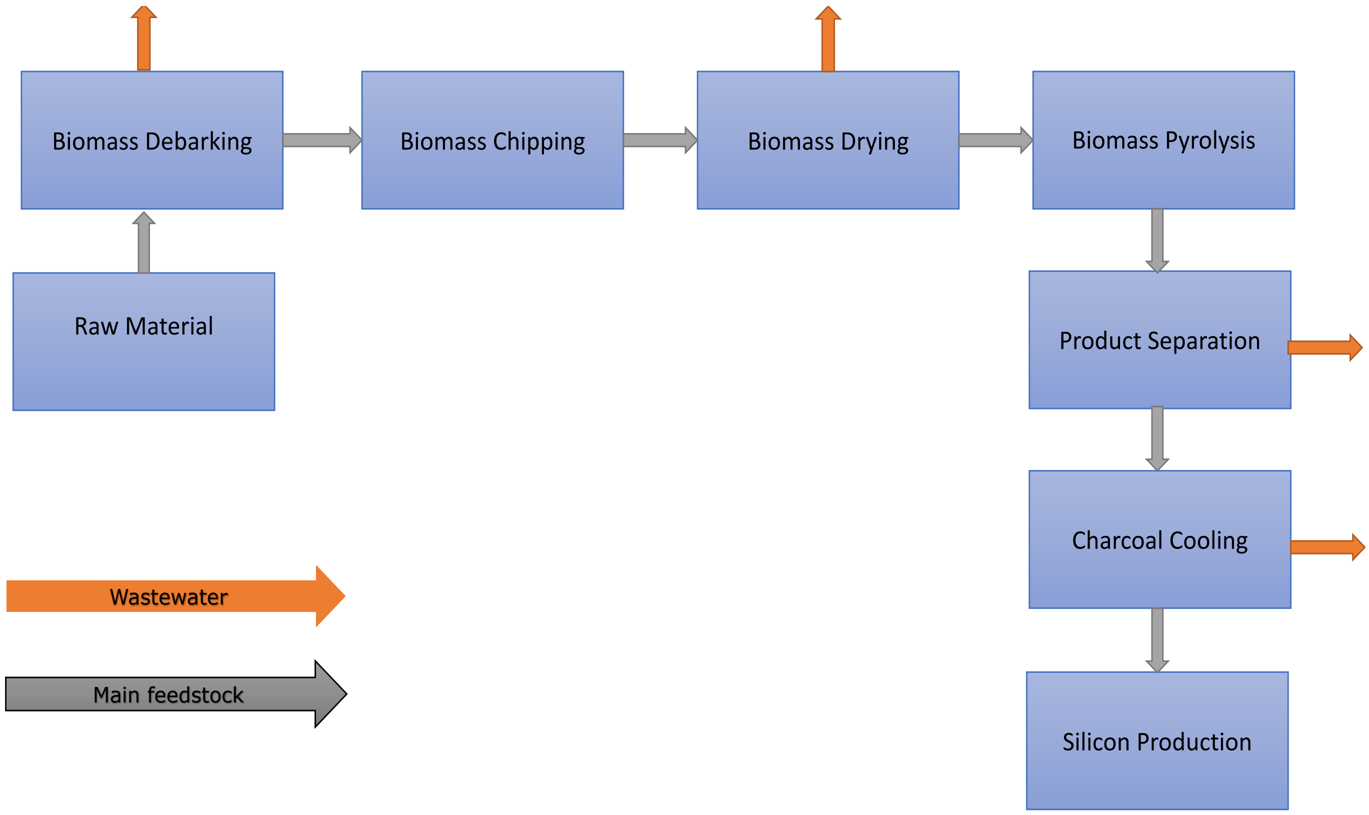

Figure 1. The integrated silicon-charcoal main processes and pollution sources

2.3.1 Raw Material

The most common source of bioenergy in Norway is forest biomass. The major source of trees are spruce, pine, birch and alder. Therefore, the potential for Norway to utilize forest wood as biomass for the production of charcoal or biocarbon is major (Olszewksi et al., 2017).

In the case of the integrated charcoal-silicon/ferrosilicon process, the expected raw material is spruce, that has a density with 15% of moisture is 0,47 g/cm^3 (Hofstad, 2019). SINTEF and Elkem expect that the usage of biomass with 40% moisture content is 83 500 ton/year, and dry biomass usage is 50 000 ton/year.

2.3.2 Biomass debarking and chipping

The most common method for debarking is drum debarking, meaning the bark is removed as the logs rub against each other inside a rotating drum. The bark, wood fragments, are separated from the barked log trough openings in the drum shell. The debarked logs are commonly showered with water before entering the chipping operation. The chipping is to form uniformed-sized chips, that will give a better product (Suhr, 2015). Elkem and SINTEF estimates that the wood processing will be responsible for 33 5000 ton/year of wastewater.

2.3.3 Biomass Pyrolysis

Pyrolysis involves rapid heating of biomass in the absence of air or oxygen at a maximum temperature, also referred to as the pyrolysis temperature, and holding it there for a specific time period to produce non-condensable gases, solid char and liquid product (Basu, 2013).

The integrated charcoal-silicon/ferrosilicon processes involves fast pyrolysis, that indicates that the process includes drying the feed to typically less than 10% water in order to minimize the water in the product liquid oil, grinding the feed to give sufficiently small particles to ensure rapid reaction, efficient separation of solids (char), and rapid cooling and collection of the bio-oil (liquids) (Bridgewater, 2012).

2.3.4 Separation of pyrolysis products

Due to pyrolysis effect on breaking down large complex molecules into several smaller ones, its products can be categorized as follows: Liquid (tars, heavier hydrocarbons and water), solids (mostly char or carbon), and gas. However, the amounts of the products depend on a variety of factors, such as the heating rate and the final temperature reached by the biomass (Basu, 2013). The products from fast pyrolysis is presented in figure 2, with the expected purpose in the production.

Gas

There are two types of gases produced in the primary decomposition of biomass; condensable gases called vapor and non-condensable gases called primary gases. The vapors consist of heavier molecules, that condense during cooling, adding to the liquid yield. The non-condensable gas consist of lower-molecular-weight gases, such as carbon dioxide, carbon monoxide and methane. These molecules do not condense during cooling. Additional non-condensable gases called secondary gases are produced through secondary cracking of the vapor at high temperature (Basu,2013).

Liquids

Bio-oil is a dark brown liquid that is a very complex mixture of oxygenated hydrocarbons with a portion of water from both the original moisture and reaction product. The typical organic yields differ from feedstock and their variation with temperature (Bridgewater, 2012). According to the information collected from SINTEF and Elkem concerning the expected bio-oil, it has a water content of 60% (low) and 90% (high).

Solids

The solid yield from pyrolysis is known as char or charcoal, and consist of mainly carbon, but can also contain some oxygen and hydrogen. However, in contrast to fossil fuels, the forest biomass contains very little inorganic ash (Basu,2013). Elkem and SINTEF assumes the annual production of charcoal is 20 000 ton with 40% yield, and 25 000 with 50% yield.

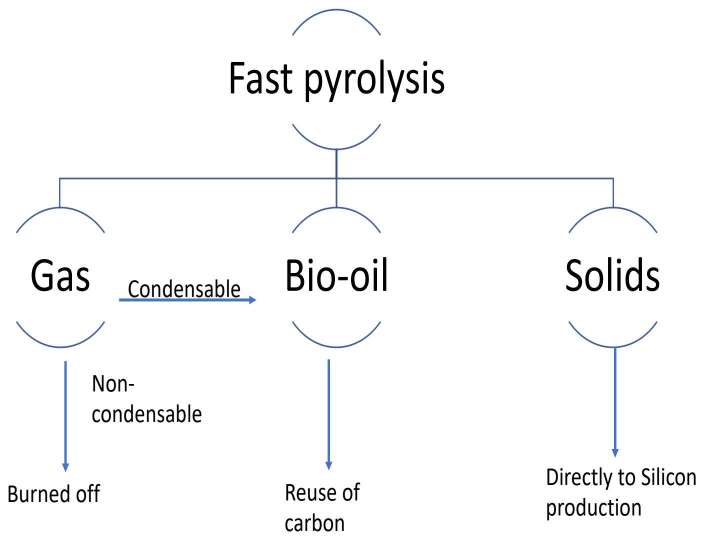

Figure 2. The products from fast pyrolysis of forest biomass and expected purpose in process.

2.3.5 Charcoal cooling

The solids from the fast pyrolysis process cools in water. Due to this, the cooling water contains fines and suspended. Elkem and SINTEF anticipate, that the cooling water is 50 000

m^3 and consists of 300 ton fines annually. From the pyrolysis process, charcoal-fines size is from 50 micrometer to 2 mm.

2.3.6 Silicon production

Elkem's goal is to use 20% biocarbon in the mix of reduction materials in the production of silicon and ferrosilicon alloys in Norway within 2021 and 40% within 2030. The Biocarbon product quality is normally assessed based on the fixed carbon content as the main quality index criteria in several metallurgical industries. Aluminum production requires very high fixed carbon content, above 95%. However, FeSi (Ferrosilicon) requires above 70% (Olszewski et al,. 2017).

2.4 Legislation for wastewater treatment

Methods of wastewater treatment were first developed in response to the adverse conditions caused by the discharge of wastewater to the environment and the concern for public health. Environmental laws have become stricter towards health, economy and reduction of pollution, since pollution often is a results of various organic and inorganic substances into the environment (Rajasulochana & Preethy, 2016).

The Norwegian legislation on pollution, is set in place to ensure a reasonable environmental quality, so pollution and wastes does not lead to damages to health or well-being, and natures ability to self-renew and produce. It is considered pollution when emitting solid matter, fluid, or gas to air, water or soil, that can or are damaging to the environment (Ministry of Climate and Environment, 1983). About 1500 facilities need to have a permit under the Pollution Control Act. Out of these about 600 have to report their emissions and their waste transfers every year as well as their energy consumption and production volumes (Norske utslipp, 2019).

The Norwegian regulations on water is referred to as the Water Regulation. However, as an EEA since 2007, Norway is obligated to follow the Water Directive, which was approved by EU in 2000. The Water Directive has been acknowledged as the most significant European environmental legislation to date. The Water Directive was established to function as a framework for the protection of European waters so that the member states could reach "good status” objectives for water throughout Europe (Voulvoulis et al., 2017). Elkem has put to meet the new Water Directive requirements in Europe as a step towards sustainability.

The Water Directive includes 45 prioritized environmental toxin, consisting of metals and organic compounds. The overall objective is that concentrations of these substances in an aquatic environment, is close to the natural levels of occurrence, and near zero for man-made substances. As a sub-objective, a boundary level for good chemical condition is established, and if these environmental quality standards-boundaries are exceeded by one or several of the substances, measures need to be initiated to reduce the concentration of them (Grung, 2013).

One of the largest environmental issues for the wood processing industry is the discharge of organic substances. It can be dissolved organic material, also known as, COD and BOD, or it can be fiber, known as suspended solids. When the organic material decompensate it consumes oxygen. Dissolved organic material can be readily or resistant to degradation. Fiber will sediment and consume oxygen in the sediments. It can also stop the supply and distribution of oxygen. As a results, the concentrations of oxygen in the water masses and sediment will decline and anaerobe conditions will emerge. The lack of oxygen leads to replacement of the original biota by species that are adapted to lower oxygen levels, which can cause species to disappear with strong influence (Grung, 2013).

2.4.1 Wastewater Analysis demands

In order for industries to discharge wastewater to recipient, they are required to regularly test the wastewater. According to the Water Regulation , there are seven demands for analysis of industrial wastewater (Ministry of climate and Environment, 2006). The demands are presented below in an summarized version.

The analysis and test-taking of wastewater needs to be validated and documented in accordance with the standard EN ISO/IEC-17025, which is an international standard for laboratories to ensure reliable results.

The measurement uncertainty of the analysis should not exceed 50% of the value of the current environmental quality standard, and the quantification limit should be 30% of the value of the environmental quality standards or lower.

When calculating the average, half of the quantification limit is used as the value for concentration, if one or several of the measured values are below the quantification limit. However, if the measured average value is below the quantification limit, the measurement should be considered as under the quantification limit.

If a substance is not included in the standard for environmental or method for analysis that satisfy the requirements in EN ISO/IEC-17025, the laboratories are required to control with the best possible techniques, as far as it does not lead to disproportionate costs.

Laboratories should participate in testing the substances. These tests should be arranged by accredited organizations, or international organizations that fulfil the ISO/IEC guide 43-1, results from these test are evaluated on behalf of the point system given in ISO/IEC guide 43-1 or ISO-1352 standard. The laboratories are required to analyze the existing reference material of the concentration relevant for the standard of environment.

2.5 Expected wastewater characteristics

There are certain wastewater parameters one needs to know to characterize the wastewater. These are: the source, the volume, the generation pattern and the contaminants. The last consist of: pH, flash point, temperature, heavy metal concentrations, regulated organic compounds present and their concentrations, fats, oils and grease concentrations, BOD and the variability of them (Edwards, 1995).

The wastewater from the integrated charcoal-silicon/ferrosilicon process have little data available. As presented in figure 1, there are four emissions outputs. However, since there are three main sources to emissions, the wastewater streams are divided into the following three wastewater streams: wastewater stream A for wood processes, wastewater stream B for bio-oil from fast pyrosis, and wastewater stream C for the charcoal cooling water. The division of wastewater streams are presented in figure 3.

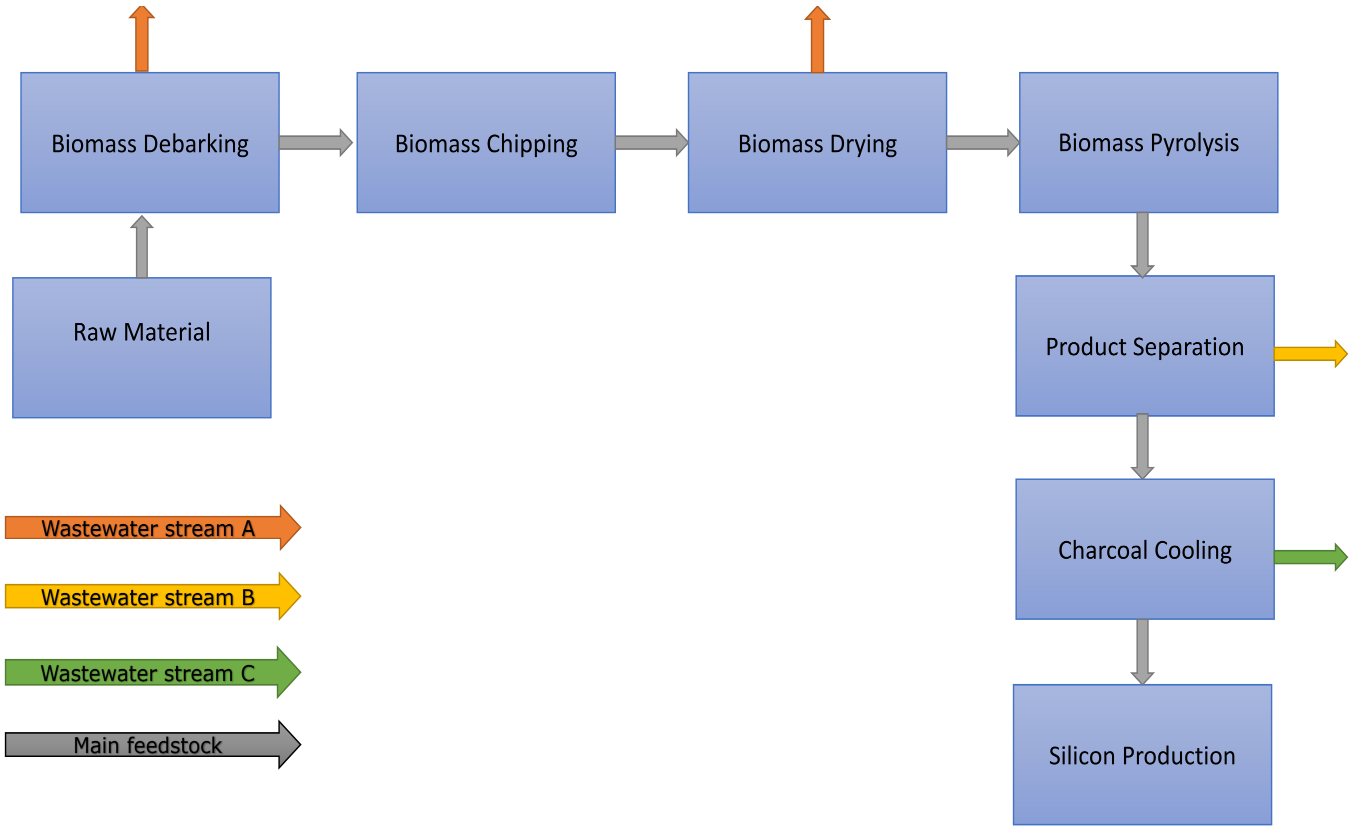

Figure 3. The division of wastewater streams in the process

An overview of the expected amounts of wastewater from the different streams, that was provided by Elkem and SINTEF, is available in table 1.

Table 1. Overview of the expected amounts of wastewater and solids.

Process	BOD	COD	SS	Wastewater	Reference
WWS A: Biomass drier condensate	Expected, but amount not disclosed	Expected, but amount not disclosed	Expected, but amount not disclosed	33 500 ton/year	SINTEF
WWS B: Condensate (bio-oil)	Expected, but amount not disclosed	Expected, but amount not disclosed	Expected, but amount not disclosed	5-15 000 ton/ year	SINTEF
WWS C: Charcoal cooling water	Expected, but amount not discoed	Expected, but amount not disclosed	300 ton/year Size: 50 micrometer to 2 mm.	50 000 ton /year	SINTEF

The amount of condensate or bio-oil from the fast pyrolysis is dependent on the yield of 10-30%, with a water content of 60-90%. The expected amounts of wastewater is related to an annual charcoal production of 20-25 000 ton/year, depending on the yield 40-50%.

The presented wastewater streams are expected to contain organic and in-organic components. Wastewater stream A, is expected to contain suspended solids, BOD, dirt, grit fibers and COD since wood preparation is a source to emission, due to soils, dirt's and barks removed from the wood, chips separated from the barks and the water used to clean the wood (Pokhrel & Viraraghavam, 2004). Wastewater stream B, is expected to have organic constitutes from the pyrolysis process, and the wastewater stream C is expected to contain suspended solids due to cooling of charcoal. The constitutes are explained in the sub-sections below, and the relationship between them in figure 4.

2.5.1 Organic Compounds

From an environmental standpoint, one favor biodegradable substances, but if these substances are released to rivers and lakes or estuaries in excessive levels, it can cause death of fish and other aquatic life. Organic material can be categorizes as easily degradable, slowly degradable and non-biodegradable.

The organic material content of wastewater can be measured by biochemical oxygen demand test and chemical oxygen demand test (Hubbe *et a*l., 2016).

BOD

The biological oxygen demand test determines the quantity of biodegradable substances by sealing a volume of water to be tested with a known amount of gaseous oxygen. The level of oxygen gas in the container is measured after five days. The BOD test one of the most frequent used to characterize untreated and treated wastewaters. However, the result of the test will be different if the wastewater sample contains difficult to biodegrade oxidizable compounds or toxic materials that inhibit biological activities. Therefore, the test is used to quantify the relative reluctance of the organic compounds in wastewater to decompose (Hubbe *et al*., 2016).

COD

Chemical oxygen demand is a test to estimate the capacity of water to consume oxygen during decomposition of organic matter. It takes advantage of the rapid reaction of strong chemicals, such as potassium dichromate with oxidizable material in the water sample (Hubbe *et al*., 2016). It measures both organic or in-organic matter.

Relationship between BOD and COD

BOD and COD are both parameters used to measure the quantity of organic material in wastewaters. However, the coherence between them are not constant, and will vary depending on facilities/plants. COD includes more of the organic material and will have higher value (Ødegaard *et al*., 2014). If the relationship reveal that the COD is much higher than BOD, it indicate that the wastewater contains organic or in-organic material that is reluctant to biological oxidation.

2.5.2 Inorganic Compounds

Organic compounds consist of carbon, hydrogen and oxygen, while the inorganic compounds can be nutrients, pH and alkalinity and metals (Tchobanoglous *et al,.* 2014). Most inorganic material in wastewater is soluble. However, certain inorganic substances can be particular. (Ødegaard *et al.,* 2014).

pH and alkalinity

The pH is a parameter that tells us the amount of hydrogen ion in the solutions, and is an important parameter since the biological and chemical processes depend on an optimal pH range to perform. The alkalinity measure the resistant the solutions has of change in pH (Ødegaard *et al*., 2014).

Temperature

The temperature of water is a very important parameter because of its effect on chemical and reactions rates, aquatic life, and the suitability of the water for beneficial use. Industrial establishments that use surface water for cooling purposes are particularity concerned with the temperature of the intake water (Tchobanoglous*et al.,* 2014).

Color

The term condition along with composition and concentration has historically been used to describe wastewater. Condition refers to the age of the wastewater, which is determined qualitatively by its color and odor (Tchobanoglous *et al.,* 2014). The color in natural water are mostly caused by organic material, which can be referred to as humus. In several surface waters, the humus content is so high that the water have a yellow and brown color (Ødegaard *et al*., 2014, pp. 111).

Toxicity

The sources of toxicity in untreated and treated wastewater are derived from the constituents added during usage, treatment and disinfection with chemical agents. Therefore, the wastewater can contain a wide variety of constitutes that can cause severe impacts to the environment when discharged. Toxicity is measured by the degree to which a single or multiple constitutes that may be present in untreated and treated wastewater can cause adverse damage to human and animal health, sensitive aquatic biota, and ecosystems (Tchobanoglous *et al., 2014*)

2.5.3 Solids

Wastewater contains a variety of solid material that range from rags to colloidal material. In the characterization of wastewater, coarse material are usually removed before the sample is analyzed for solids (Tchobanoglous*et al.,* 2014). Particles in the water are categorized by size. For particles to be suspended solids, they need to be >1,0 µm. The analyzing of suspended solids consist of filtrating the water through an membrane filter with an opening of 0,45 or 1,2 µm, drying the filter with the remaining material, and weighing it. The result is measured in (g SS/m^3) (Ødegaard *et al*., 2014, pp. 418).

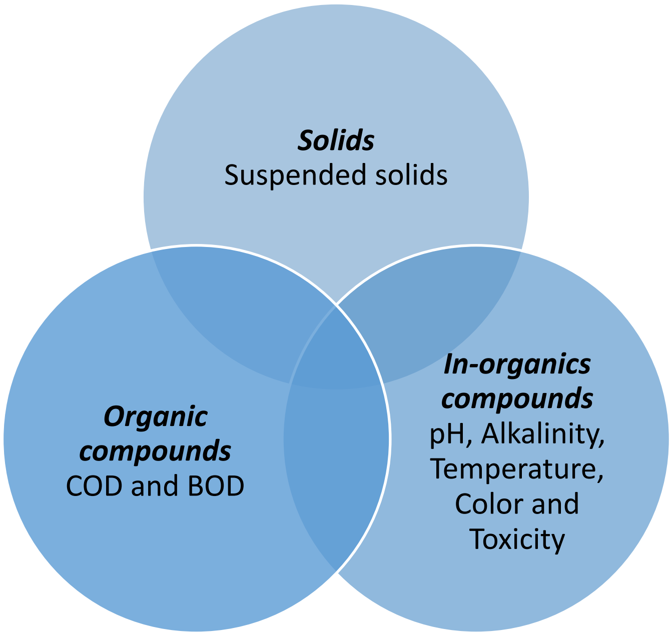

Figure 4. The compounds in wastewater and interaction between them (modified from Kiepper, 2013)

2.5.4 Sludge

Sludge can be produced by the production processes, and by the wastewater treatment methods. The method of primary and secondary treatment of wastewater have significant impact on quantity and quality of the sludge produced. There are three principle sources of sludge, that are as follows: grit and scrum from pre-aeration, primary sludge and scrum from primary sedimentation, and secondary sludge and scrum from biological treatment (Tchobanoglous *et al., 2014)*. In wastewater treatment the secondary sludge, that is often a results from a biological process, is referred to as biomass.

2.6 Overview of common wastewater treatment methods

Commonly industrial wastewater treatments system consist of a primary, secondary and tertiary treatments, this can be referred to as an integrated system or hybrid system. It has gained considerable attention in an effort to enhance the efficiency of treatments and improve the quality of effluents. The hybrid system can be a combination of two physicochemical processes, a physicochemical and a biological process or two biological processes (Ashrafi, 2008). A simplified hybrid wastewater treatments system is presented in figure 5.

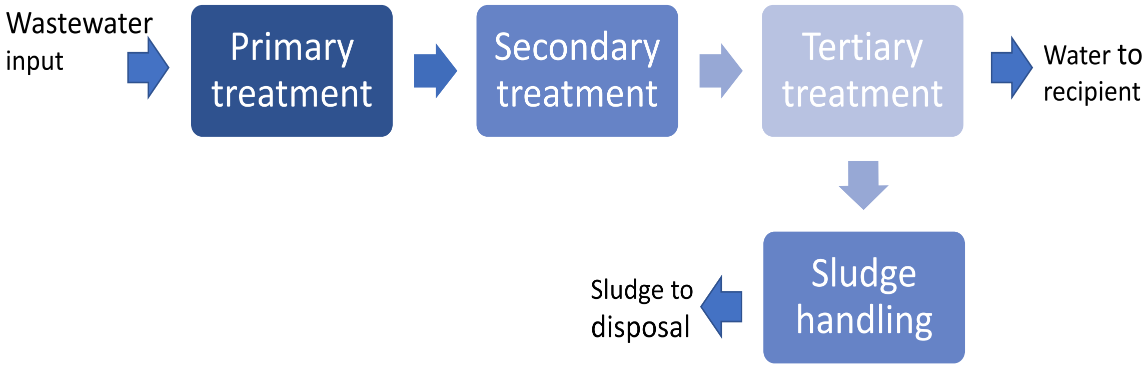

Figure 5. Simplified hybrid wastewater treatments system (modified from Surh *et al*, 2015)

2.6.1 Biological treatments

Most of the wastewater treatments have anaerobic and/or aerobe treatments to remove organic contaminants in wastewaters. Aerobe treatments have been favored due to ease of operations, and low capital and operational costs. However, anaerobe treatments have grown in favor due to lower sludge production than aerobic, biogas production, smaller area and facility requirements, and further degradation of pollutants. A disadvantages with anaerobic treatments is the sensitivity of anaerobic bacteria to toxicity (Ashrafi et al,. 2015).

The most common aerobic processes are activated sludge and aerated lagoon or aerated stabilization basins, due to their high COD removal. While, anaerobic wastewater treatments method have the key feature that the biologically degradable load is reduced in the absence of oxygen by digestion of microorganism, that generate methane and carbon dioxide, where the biogas produced can after desulphurization be used for production of energy. There are several different process design for the anaerobic wastewater treatment. Typically, the following reactors are applied: fixed bed reactor, sludge contact process, anaerobic up flow sludge blanket (UASB) and expanded granular sludge blanket (EGSB). In UASB and EGSB reactors sludge particles are kept fluidized by the up flowing influent. The common feature of these reactors is the need for high concentration of biomass within the reactor (Suhr et al, 2015).

An up and coming technology for anaerobe wastewater treatments is the membrane bioreactor technology (MBR), since it offers treated water of high quality and can reduce germs making the wastewater eligible for discharge at sensitive recipients. Most anaerobic MBR research have been carried out at laboratories or small pilots. However, when a case study was carried out on high strength industrial wastewater using full-scale AnMBR, the results was very promising. The COD removal was at an 99,9% and TSS at approximately 100% (Deowan et al,. 2015). Normally, anaerobic wastewater treatments are not enough to comply with the discharge permits. Therefore, it is rarely used as a stand-alone unit.

2.6.2 Physiochemical treatments

Physiochemical treatments are used to remove SS, colloidal particles, toxic compounds, floating maters and colors from wastewater by sedimentation, ultra-filtration, screening, coagulation, flocculation, ozonation and electrolysis. They are commonly used as preliminary, primary or tertiary stages. However, these treatments contribute to GHG generations either directly through the treatment process, or by their energy requirement (Ashrafi, et al. 2015).

Sedimentation have been favored by the pulp and paper industry as primary treatment, due to the pulp and paper wastewaters high content of bark particles, fiber, fiber debris, filler and coating materials. Sedimentation removed more than 80% of suspended solids on an average in the UK (Pokhrel, D, 2004). A method with great potential is the dissolved air flotation, sice it separate the solids and liquids in a process involving fine gas (air) bubbles to the liquid phase, where the bubbles attach to the particular matter and force the matters with higher density to the surface. (Tchobanoglous *et al., 2014).* Dissolved air flotation was reported with high removal rate of suspended solids, with 65-95 % removal rate when reported as an unstable unit. However, a different study reported an removal rate of 95% of SS (Pokhrel, D, 2004).

Adsorption have been reported with very high removal rate for COD and color using activated charcoal fuller's earth and coal ash. It was reported 90% removal of color, COD, DOC and AOX from bleaching wastewater by using activated coal as adsorbent (Pokhrel, D, 2004).

As a tertiary treatments, sand-filters have been reported with high removal rate for both SS, and COD, with a rate of 95 % and 99% removal for SS and COD in municipal wastewaters (Hamonda et al, 2004). There has also been reported high removal of turbidity and BOD using slow-sand filter as tertiary of UASB reactor effluent. The removal rate was 91,6 of turbidity, 89,1 of SS, 77% of COD and 85 of BOD (Tyagi, V et al, 2009). An overview of the wastewater treatments presented and their category, are available in figure 6.

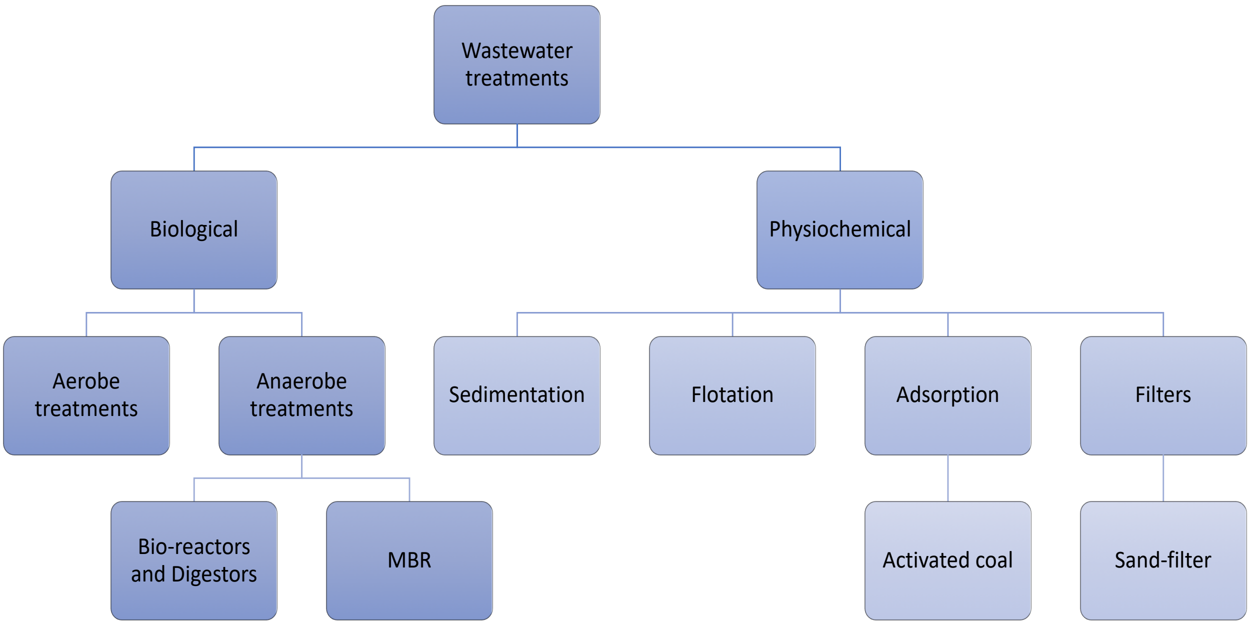

Figure 6. An overview of the wastewater treatments presented (by category)

There are some considerations required when choosing appropriate wastewater treatment methods. The methods should be chosen according to the instructions on the regulations relating to pollution control, and the discharge permit concerning local conditions. It has fundamental meaning to the economic and function that the method chosen, and dimension is based on information concerning the amount and the wastewater characteristics (Ødegaard et al,. 2009).

2.6.3 Sludge Handling

An important part of the wastewater treatment system is the sludge handling, which need to be considered when selecting a system. The three main disposal methods for wastewater sludge and sludge components are as follows: deposited, used or recycled.

If the sludge is deposited in land it refers to landfills or special sludge deposit. It can also be deposed to sea in ocean disposal or to air through incineration. The sludge can be used in different ways, the most obvious is directly applying treated sludge as fertilizer and soil conditioner. The treated sludge can also be used indirectly though the utilization of the ingredients in bio-soils. The recycling of sludge refer to productization strategy, which is a strategy aimed to make products from sludge to sell. These products include bio-soils, biogas, nutrients and metals (Ødegaard, et al 2002). The potential to recycle secondary sludge also referred to as biomass, could lead to reduction of operation costs and costs to either minimize or disposal.

To decide whether a compound can be recycled from sludge are divided into three driving forces: the urge to minimize the sludge, the demands vs. the general ability of this resource on the globe, and finally, the cost of the recycled product vs. marked price. There are resources in wastewater sludge that can be recycled directly, and there are resources that can arise from the conversation of sludge (Ødegaard et al 2002). A common resource that arise from the conversion of secondary sludge/biomass is biogas, through anaerobic digestion.

Anaerobic digestion is typically favored for sewage sludge, since it not only produces biogas, but also reduces sludge with 30-50%, remove pathogens and bad odor. Several costs are linked to transportation of sludge and the energy requirements, such as digester mixing require energy equipment, digester heating energy, and energy for pumping sludge (Gebreeyessus and Jenicek, 2016). Therefore, dewatering is necessary, which can be done by thickening the secondary sludge/biomass. A thickening process involves upgrading by different separations techniques in the wastewater treatments system. These methods include: gravitation flotation or mechanical upgrades (Ødegaard et al, 2009).

3. Method and Material

In this section, the case study research for the master thesis is presented with sampling. A short presentation of participants is provided, along with the type of data collection.

3.1 Case Study research

Due to the limited research on the subject, and restriction of information from Elkem concerning the wastewater, the method adopted was a collective case study. The method was selected since it allows for multiple studies to illustrate the issue, and accept several types of information. The information sources allowed are observations, literature, interviews and audiovisual observations (Creswell,. 2007, pp 74-75). The collective case study required several businesses to participate, in order to compare the results and find trends. Therefore, criteria for the sample group were made, and are presented below.

3.1.1 Sampling

When selecting participants the following criteria were made:

1. In order to have similarities in wastewater, wood processing should be part of the production processes.
2. It should have larger annual production than Elkem's annual expected production of charcoal (25 000 ton).
3. Ideally, the wastewater treatment methods includes anaerobe treatment

Due to, the first criteria, the pulp and paper industry was first priority as participants, but other businesses with wood processes were also eligible. The participants included two paper mills, one pulp mill, a biorefinery, and Kristiansand Municipal Water and Sewage Department. Kristiansand Municipal was added due to a new wastewater treatment system with an anaerobe digester.

All businesses studied had a larger annual production than the expected production for Elkem, meaning larger amounts of wastewater requiring treatment before release. Kristiansand Municipal have no annual production, since it function is to treat household wastewater. Therefore, it is expected to have a wastewater treatment system able to treat the largest amounts of wastewater. An overview of the participants are available in table 2.

Table 2. Overview of the Participants in the collective case study

Participants	Norske Skog: Saugbrugs	SCA Örtviken	SCA Graphic Sundsvall AB	Kristiansand Municipal Water and Sewage Department	Borregaard
Industrial Sector	Paper and cardboard production	Paper production	Pulp production	Sewage treatment plant	Sulphite cellulose, inorganic chemicals and other organic chemical substances
Annual production (2018)	400 000 ton mechanical mass and 630 000 ton of paper.	775 000 ton	Ca 900 000 ton	Max capacity of 140 00 (population equivalent)	778150 ton

3.2 Short presentation of participants

Each of the participating businesses are briefly presented below, concerning production to give insight to similarities with Elkem's' wastewater.

3.2.1 Norske Skog Saugbrugs

Norske Skog is a world leading producer of publication paper, which includes newsprint and magazine paper. Norske Skog has 8 wholly and partly-owned mills in 6 countries, which makes it one of the world's largest producers of publications papers. At the Saugbrugs facility, a biogas plant was finished in 2017. The biogas facility at Saugbrugs converts waste from the paper production into gas that can be sold or be used to power heavy vehicles that otherwise runs at fossil fuels (Norske Skog, 2017).

3.2.2 SCA Örtviken

SCA is Europe's largest private owned forest with 2.6 million hectares in northern Sweden, and has developed a resource-effective industry to successfully capture the greatest possible value from each tree. The production includes wood, pulp, kraftliner, publication paper and renewable energy. SCA Örtviken consist of paper mills and produces publication paper, with an annual capacity of 775 000 ton (SCA, 2017).

3.2.3 SCA Graphic Sundsvall AB

In the pulp market, SCA has positioned itself in the high-strength segment due to its excellent access to the Nordic long-fiber. The investment in Östrand pulp mill (SCA Graphic Sundsvall AB), will double the production capacity from 530 000 ton to close to 1 000 000 ton/year (SCA, 2017).

3.2.4 Kristiansand municipal sewage and water department: Odderøya

Odderøya is the largest of three sewage treatment plant in Kristiansand (southern Norway). It was completed in 1992 with a capacity of 62 500 households(Dahl, 2013). However, due the closure of one of the smaller sewage plants, new demands for wastewater treatments and expected increase in population, Odderøya was dimensioned to a capacity of 140 000 (personal equivalate) when upgrading the treatment plant.

3.2.5 Borregaard

Borregaard operates one of the world's most advanced biorefineries to produce biochemicals that can replace oil-based products. The main products include lignin-based and specialty cellulose, but the portfolio also includes vanillin, second generation bioethanol, fine chemicals and cellulose fibrils. Borregaard has one operation site in Norway located in Sarpsborg, and six production sites outside Norway (Borregaard, 2018).

3.3 Data Collection and Analysis

To achieve a triangular of findings (Chanias & Hess, 2016), the data was collected by literature (scientific papers and annual reports), semi-structured interviews, observations and notes at site. The methods for data collection is presented in the figure 7.

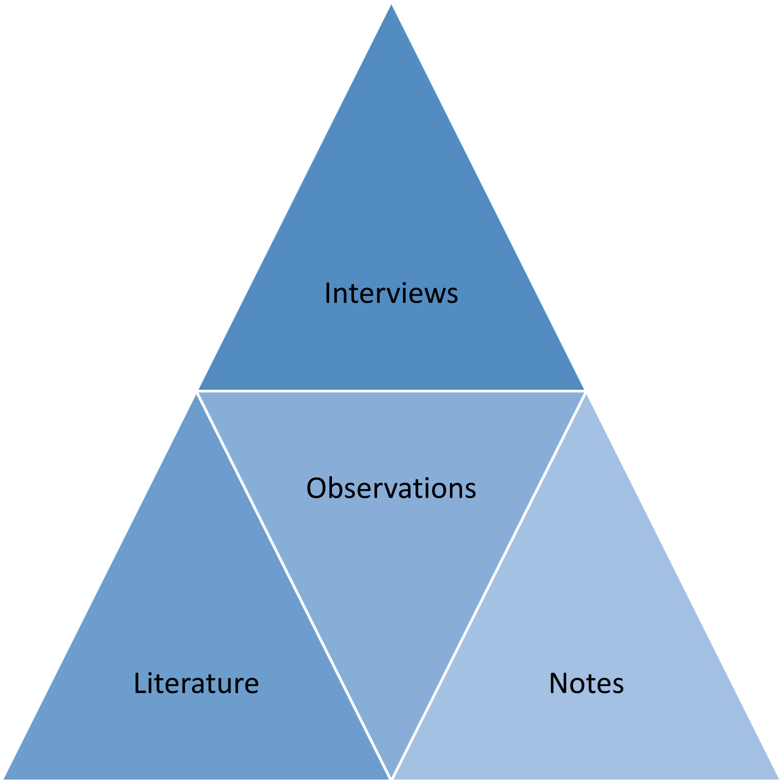

Figure 7. Collection methods of data for triangular of findings

The interviews and visits to site was conducted in the time period: February – March 2019. The interviews were requested to be done with someone of relevant background and extensive knowledge of the wastewater system in operation, and the sludge handling processes. The date, duration and location of visit to site, and the work position of the interviewees are presented in table 3.

Table 3. Date, duration and location of site visit, and the work position of interviewees.

Date, duration of visit and location	04.02.2019, 6h. Halden, Norway	15.02.2019, 3h. Örtviken, Sweden	15.02.2019, 3h, Örtviken, Sweden	20.02.19 and 01.03.19,3h Kristiansand	04.03.19, 2h. Sarpsborg, Norway
Interview subjects	Håvard Jellestad	(1)Bengt Westin (2) Theresa Andersen	Hanna Penttiä	(1)Per Borø (2) Tore Magnussen	(1)Simon Simonsen (2)Morten Lislerud

Work Position	Process Engineer	(1)Environmental technician, (responsible for the wastewater treatments in Örtivken) (2) Process engineer	Process engineer, department of environment/ wastewater treatments	(1)Operator (2)Department manager	(1)Researcher scientist (2)Process owner

The interviews were conducted face-to-face at company sites, with the durations of 60-90 minutes. The interview length was mostly influenced on how detailed the answers were, while duration of visit depended on the number of wastewater treatments available for observation. In some cases, follow-up questions or remarks were done through email. It was conducted one visit to Norske Skog, Borregaard, SCA Örtviken, and two visits to Kristiansand Municipal Sewage and Water Department. SCA Graphic Sundsvall AB representative participated in the interview at SCA Örtviken.

3.3.1 Data collection by interview and observations

The questions for the interviews were divided into two parts. The first was general questions to collect information on the production and wastewater treatments used, and consisted of 29 questions. The second part, had a focus on value creation of wastewater and sludge, and sustainable production. It consisted of 13 questions. Interviews were conducted in Norwegian with the exception for the interview with SCA, it was done partly in English to avoid misinterpretations. The questions used are available in the appendix I, along with transcriptions in appendix II, IV, V and VI.

The participants were informed that the interview was recoded to avoid any misunderstanding during transcription. The participants were asked to introduced themselves on the record, to distinguish the difference of the participants, when more than one person was present and ensuring a correct transcript.

The observations were carefully recorded by notes, since filming and photographing on sites were not allowed. In two cases the wastewater treatment methods were not observed: first, SCA Graphic Sundsvall AB wastewater treatment plant, and the wastewater after tertiary was not observed since it the representative was part of the interview at the site to SCA Örtviken. Second, at Borregaard the wastewater treatment was not able to be observed due to safety regulation. However, a picture of the wastewater after tertiary treatment was sent by email to be used in comparison to the other participants.

3.3.2 Data collection by Literature

Data collected by literature was conducted in two ways: to use scientific papers recommended by SINTEF and Elkem, and search using different strings in databases.
The databases used was: Oria, a database provided by NTNU, ScienceDirect and GoogleScholar. The papers provided by SINTEF and Elkem are available in table 4.

Table 4. Papers provided by SINTEF and Elkem for expected content of wastewater and bio-oil

Type	**Author**	**Title**	**Year**
Paper	Pokhrel, D and, Viraraghavan, T.	Treatment of pulp and paper mill wastewater – a review	2004
Paper	Diebold, J.P	A review of the chemical and physical mechanisms of the storage stability of fast bio-oils	2000

To collect the needed literature on content of wastewater and bio-oil, two different sets of searches were done. The first, to collect in-dept literature on fast pyrolysis and content of bio-oil. The second, to collect in-depth literature on wastewater treatments, potential COD, BOD and SS in the wastewater and sludge handling.

The first search for data resulted in 5 papers, 1 book and 1 master thesis, being used to understand the pyrolysis processes, and content of bio-oil. The papers used are provided in table 5.

Table 5. Papers found through database searches on content of bio-oil from fast pyrolysis

Type	**Author**	**Title**	**Year**
Paper	Arnold, S ,.*et al*	Slow pyrolysis of bio-oil and studies on chemical and physical properties of the resulting new bio-carbon	2018
Book	Basu, P.	Biomass gasification, pyrolysis and torrefaction: practical design and theory.	2013
Paper	Black, B.A, et al.	Aqueous Stream Characterization from Biomass Fast Pyrolysis and Catalytic Fast Pyrolysis	2016
Paper	Bridgewater A.V	Review of fast pyrolysis of biomass and product upgrading	2012
Paper	Bulâu C *et al*	Pyrolysis parameters influencing the bio-char generation from wooden biomass.	2010
Paper	Olszewski, M,. et al	The techno-economics biocarbon production process under Norwegian conditions.	2017
Master thesis	Seyedi, S.	Anaerobic Co-digestion of aqueous Liquid from Biosolids pyrolysis	2009

The second search with focus on wastewater treatments, content of potential wastewater and sludge handling, resulted in 11 papers, 1 report and 4 books used. The literature is presented in table 6.

Table 6. Papers on possible content of wastewater, common wastewater treatments and sludge handling

Type	**Author**	**Title**	**Year**
Paper	Ashrafi,O, *et al,*.	Wastewater treatment in the pulp-and-paper industry: A review of treatment processes and the associated greenhouse gas emission.	2015
Chapter in book	Deowan, S.A *et al,*.	Membrane bioreactors for water treatment	2015
Book	Edward D.J	Industrial wastewater treatment: a guidebook	1995
Paper	Gebreeyessus, G.D and Jenicek,P.	Thermophilic versus mesophilic anaerobic digestion of sewage sludge: a comparative review	2016
Paper	Hubbe A.M, *et al*.	Wastewater Treatment and Reclamation: A Review of Pulp and Paper Industry Practices and Opportunities	2016

Paper	Ifran, M *et al,*.	The Removal of COD, TSS and color of black liquor by coagulation-flocculation process at optimized pH, settling and dosing rate	2017
Paper	Koyuncu, I *et al,*.	Advances in water treatment by microfiltration, ultrafiltration and nanofiltration	2015
Paper	Mahmood, T amd Elliot, A.	Review of secondary sludge reduction technologies for the pulp and paper industry	2006
Paper	Meyer, T & Edwards, E.	Anaerobic digestion of pulp and paper mill wastewater and sludge	2014
Paper	Stocia, A., Sandberg, M., & Holby, O	Energy use and recovery strategies within wastewater treatment and sludge handling at pulp and paper mills	2009
Book	Tchobanoglous G *et al,*.	Wastewater engineering: treatment and resource recovery.	2014
Paper	Tyagi K. V. *et al,*.	Slow sand filtration of USAB reactor effluent: a promising post treatment technique.	2009

Paper	Rajasulochana, P and Preethy, V	Comparison on efficiency of various techniques in treatment of waste and sewage water – A comprehensive review.	2016
Book	Ødegaard, H., Norheim, B. & Norsk Vann, B. A.	Vann og avløpsteknikk	2014
Report	Ødegaard, H., Rusten, B, Storhaug, R. & Paulsrud, B.	Veiledning for dimensjonering av avløpsanlegg	2009
Paper	Ødegaard, H *et al,.*	Wastewater sludge as a resource: Sludge disposal strategies and corresponding treatment technologies aimed at sustainable handling of wastewater sludge.	2002

To ensure that the scenarios would be in coherence with the current legislations and regulation in Norway, the additional material was added:

- *Legislation on protection against pollution and waste (1981)*
- *Regulations relation to pollution control (2004)*
- *The Water Regulation (2006)*

The annual reports was requested or downloaded to have an insight to annual production and sustainability before company visits. The following annual reports were included:

- *Norske Skog annual report: 2016*
- *SCA annual and sustainability report (included both sites): 2018*
- *Borregaard annual report: 2018*

Kristiansand Municipal Sewage and Water department had no available annual report. Thus, a master thesis written for the department before final upgrade was included, and are available in reference under Dahl, 2013. The information concerning the new capacity after upgrade was collected during the interviews.

4. Results

In this section, the findings from the case study is presented, along with the calculations of carbon for recovery, the expected amount of content in the wastewater, and the expected discharge permit.

4.1. Expected amounts of COD, BOD and SS in wastewater

The expected amounts of content in the wastewater was found by searching for relevant literature, and presented in table 7, with reference. The content is divided into the parameters of BOD, COD and SS for each wastewater stream.

Table 7. Updated expected emissions from wastewater streams to wastewater treatments

Wastewater stream	BOD	COD	SS	Wastewater	Reference
A: debarking and drying	1 kg/per ton produced	5-20 kg/ per ton produced (1)	3,75 kg/ per ton of production (1)	33 500 ton/year(2)	(1) (Pokhrel 2004) (2)SINTEF
B: Bio oil 10-30% yield	-	31 000 – 300 000 mg/kg (3)	-	5-15 000 ton/ year(2)	(3) Blake, 2016) (2)SINTEF
C: Charcoal cooling water	-	-	300 ton/year (2)	50 000 ton /year (2)	(2)SINTEF

Wastewater stream A consist of the water from wood processes, which leads to high amounts of COD, BOD and SS. The amounts are found in the literature, while the amounts of wastewater was provided by SINTEF. The relationship between COD and BOD indicate that the wastewater contains substances that are resilient to digestion, meaning it can be difficult to recover some of the carbon by wastewater treatments.

Wastewater stream B consists mainly of the bio-oil after pyrolysis, that gives high COD value and little solid matter. However, little information was found on the content of BOD. The information on expected annual wastewater amounts was provided by SINTEF.

Wastewater stream C, is from the charcoal cooling water, which means that the wastewater consist of water and suspended solids. The information on expected solids and annual wastewater was provided by SINTEF. However, the literature provided little information on the COD and BOD values.

4.1.1 Potential Carbon for recovery in wastewater streams

Since the wastewater consist of three streams, the potential carbon varies depending on the stream. Therefore, the potential carbon for recovery is presented within the stream below.

Wastewater stream A

The COD presented in table 7, show the potential carbon available from wastewater stream A, since COD measure all the organic and in-organic substances, assuming the in-organic substances have carbon to recover.

Wastewater stream B

According to the literature, the bio-oil consist of a mix of substances and carbon, where the carbon is the primary object to recover. Since, the content of the bio-oil from the fast pyrolysis in integrated charcoal-silicon/ferrosilicon process was unknown, the expected content of the bio-oil was found in literature. Therefore, the compounds and substances that had no information on wt% were not included.

The content can be divided into the following compounds: acids, esters, alcohols, ketones, aldehydes, phenols, guaiacols, syringols, sugars, furans, misc. oxygenates and alkenes (Diebold, 2000). Nitrogen and aromatics was listed as content by the literature, but had no information.

To find the available carbon for recovery from wastewater stream B, the following equation was used:

$$(wt\% * 10) * \left(\frac{C}{Weight\ g/mol}\right) \tag{4-1}$$

Where:

Wt% is weight total
C is the carbon from the formula
Weight g/mole is the weight found for the compound

The results of the calculation is presented in table 8, where the carbon content is divided into low and high wt %. The section on degradability represent how well the compounds is expected to degrade during the wastewater treatments, and are divided into: readily degradable, meaning the compounds will easily degrade during the wastewater treatments, while resistant represent the contrary. The complete list of bio-oil compounds and substances with calculations are available in appendix VII.

Table 8. Expected compounds of bio-oil, carbon content and degradability

Compounds	**Carbon: Wt % low**	**Carbon: Wt % high**	**Degradability**
Acids	0,76	8,21	Readily degradable
Esters	0,19	1,12	Readily degradable
Alcohols	0,61	2,00	Readily degradable
Ketones	1,97	2,68	Readily degradable
Aldehydes	0,40	0,81	Readily degradable
Phenols	0,95	5,59	Resistant degradable

Guaiacols	1,23	8,97	Resistant to degradation
Syringols	0,32	2,02	Resistant to degradation
Sugars	1,95	4,73	Readily degradable
Furans	0,49	4,49	Resistant to degradation
Misc. Oxygenates	1,16	9,01	Resistant to degradation
Alkenes	0,50	0,50	Resistant to degradation
SUM	10,53%	50,13%	

The expected COD in wastewater stream B, can have a wt% carbon amount of either the low level, meaning it have 10,5% carbon to recover, or high level 50,13%.

Wastewater stream C

The charcoal cooling water consist of solids, and most likely COD and BOD. However, since the expected amounts of COD and BOD have no available data, the wastewater stream is considered to hold carbon for recovery through biogas production or biomass, but the amount available is not disclosed.

4.2 Collected discharge Permits to water

Each business needs to apply to the local government for a discharge permit. The permit is based on the *Legislation on Pollution and Waste* from 13.mars 1981, the recipient and local demands. Norwegian recipients have three categories: sensitive areas, normal areas and less sensitive areas, where the sensitive areas are the coastal area from Svenskegresen-Lindensnes, Nordåsvannet, Grimstadfjorden, Mathopden and Dolviken (Ministry of Climate and Environment, 2004).

As mentioned, discharge permits are given to all businesses that have emissions to air or water. However, all emissions to air and water, and noise and waste is unwanted even when businesses are within the discharge permits. Therefore, all business are required to reduce their emissions and noise, as far as possible without unreasonable costs (Ministry of Climate and Environment, 2004).

The discharge permits are permitted based on the production amounts for different products. Since Kristiansand Municipal Sewage and Water department follow a different legislation due to its wastewater coming from households, it has reduction percentage from emitted to released water divided into primary, secondary and tertiary treatment. The collected permits for the participant, is available in table 9.

Table 9. Collected wastewater discharge permits from participants of collective case study

Discharge permit (annual)	Norske Skog	SCA Örtviken	SCA Graphic Sundsvall AB	Kristiansand Municipal Water and Sewage Department	Borregaard
Annual production on permit	Mechanical mass: 400 00 ton Paper: 630 000 ton	775 000 ton	900 000 ton	140 000 households	Special Cellulose: 165 000 ton Ethanol and methanol: 22 000 m3 Lignin products: 175 00 ton Alkacell/vanicell: 90 000 ton Soda Lye: 55 000 ton Chlorine: 48 000 ton Hydrogen: 1500 ton Hydrochloric acid: 135 000 ton Sodium hypochlorite: 40 000 ton Sulphur dioxide: 40 000 ton Other medicines/drugs: 4000 ton

COD	16 ton/day	366 ton/year	16 kg/ton mass	75% reduction or not exceed or not exceed 125 mg O_2/l.	69 ton/day
SS	1,1 ton/day	26 ton/year	2,2 kg/ton mass	50 % reduction and not exceed 60 mg/l	6,8 ton/day
BOD				70% reduction or not exceed 25 mg O_2/l at discharge.	

The discharge permits were requested prior to the interview from all, which of most provided it. However, the information on SCA Graphic Sundsvall AB discharge permit was given during the interview. For the participants located in Norway, the discharge permits was available at the government run site: *Norwegian emissions*. Therefore, the permits that were not provided prior to the , interview, was collected from the site. To ensure that the latest updates was included, the discharge permit was among the interview questions .

Both SCA sites is located in Sweden, meaning it follows the local demands and legislation there, and have somewhat different discharge permits. Nevertheless, SCA is required to follow the Directive of Water, as the rest of the participants.

4.3 Wastewater treatments methods used by participants

Due to the different discharge permits and location, the participants used different technologies to remove unwanted substances. However, all participants had primary, and secondary treatments, and most used a tertiary or polishing step. The participants had the pH of approximately 7 with release. The methods adopted are presented in the subsequent sub-sections.

4.3.1 Primary wastewater treatment method

The primary treatment that was shared among the participants was the separation of suspended solids and wastewater. However, the methods used varied, with sedimentations as the most popular. An overview of the chosen primary wastewater method and purpose is presented in table 10.

Table 10. Overview of participants primary treatment and purpose

Company	**Primary treatment category**	**Method**	**Purpose**
Norske Skog	Physiochemical	Sedimentation	Separate suspended solids or larger particles from water
SCA Örtviken	Physiochemical	Sedimentation	Separate suspended solids or larger particles from water
SCA Graphic Sundsvall AB	Physiochemical	Sedimentation	Separate suspended solids or larger particles from water
Kristiansand Municipal	Physiochemical	Sand and grease collector	Collection of sand and grease before filter and pre-treatment of sludge
Borregaard	Physiochemical	Buffer tank	Even out the source and add chemicals before bioreactor

4.3.2 Biological secondary wastewater treatments

The secondary treatment is usually biological or a combination of biological and physiochemical. The participants either had aerobic or anaerobic treatment as their biological secondary treatment. The overview in table 11 present the type of secondary treatment and the purpose of it.

Table 11. Overview of participants secondary or primary treatments and purpose

Company	Secondary	Biological treatment	Purpose
Norske Skog	Anaerobic biological treatment	Methane reactor	Anaerobe to create biogas and Aerobe to remove COD
SCA Örtviken	Aerobic biological treatment	Multi-bio tank	COD and SS removal.
SCA Graphic Sundsvall AB	Aerobic Biological treatment	Multi-bio tank	COD and SS removal.
Kristiansand Municipal	Aerobic and chemical treatment	Bio-reactor and flocculation	COD, BOD removal and separation of SS to digester(sludge handling)
Borregaard	Anaerobic biological treatment	Bio-reactor	Removal of COD and creation of biogas.

4.3.3 Tertiary or polishing wastewater treatment

The tertiary or polishing treatment is the final treatment for the wastewater before it is released to the recipient. There participant used different types of tertiary treatment, where the biological treatment was used by four, with flotation adopted by two of them and sedimentation by two. An overview of the method, and purpose of it is available in table 12.

Table 12. Overview of participants tertiary or polishing treatment and purpose

Company	Tertiary/polishing step	Treatment	Purpose
Norske Skog	Biological	Flotation tank	Final removal of COD and larger particles
SCA	Biological	Flotation tank	Final removal of COD and larger particles

SCA Graphic Sundsvall AB	Biological	Sedimentation	Removal of SS
Kristiansand Municipal Water and Sewage Department	Biological	Sedimentation, Outlet well and Aerated tank	Final removal of COD, BOD and larger particles
Borregaard	Physiochemical	Disc-filtration	Removal of COD and larger particles

4.3.4 Sludge handling for participants

As mentioned in section 2.5.4, sludge can originate from production processes, and from the biological steps in wastewater treatments are called biomass. The participants with anaerobe biological method, experience less creation of biomass during the treatments than aerobic. Nonetheless, sludge handling is a vital part of wastewater treatment system even with anaerobic treatments. The participants sludge handling methods and purpose is available in table 13.

Table 13.Overview of participants sludge handling methods and purpose

Company	**Sludge type**	**Treatment**	**Purpose**
Norske Skog	Primary and secondary: Biological	Hydrolysis of biomass and boiler house	Some biomass is given to farmers, and the remaining is burned to avoid disposal.
SCA Örtviken	Primary and secondary: Biological	Silbands-press, sludge press for the fiber-sludge. Gravitation and centrifuge for biomass.	Pressed to remove water to 50% moisture, before all sludge is burned.

SCA Graphic Sundsvall AB	Primary and secondary: Biological	Reuse of sludge facility (aeration tank), and centrifuge	Some is reused in the biological process, while the rest is burned.
Kristiansand Municipal Water and Sewage Department	Primary and secondary: Chemical and Biological	Thickener, thermophilic anaerobe digestion and dewatering	The digester produce biogas, before the excess sludge disposed.
Borregaard	Primary and secondary: Biological	Thickener	The sludge is thickened to remove water and disposed.

The participant sent an overview of the wastewater treatment system either before or after the visit on site. Part of the interview was to find what savings the businesses experience through their methods, and what the quality assurance was in regard to the demand for analysis.

4.3.5 Comparison of case results of quality assurance and saving

An important part of wastewater treatments for the participants, were the quality assurance and savings. A comparison of the response from the participants is available in the table 14.

Table 14. Comparison of quality assurance of wastewater methods through testing and savings from methods

Participants	Norske Skog Saugbrugs	SCA: Örtviken	SCA Graphic Sundsvall AB	Kristiansand Municipal Water and Sewage Department	Borregaard
Quality Assurance	Daily testing of water sent to lab	Daily testing of water sent to lab	TOC-test every ten minutes	Test every day that are mixed together, and one sample is sent end of the week to show average	Daily test of water sent to lab

Savings through wastewater treatments	Savings in energy	Some savings in energy, since biomass and fiber-sludge is burned creating energy	Little savings, some reuse of water and biomass for biological treatments	Savings in energy, since biogas is used for heating	Savings, since the biogas in used for drying the lignin

4.4 Trends and possible future demands

Some of the questions in the in-depth part of the interview, covered the future plans concerning value creation within the wastewater treatment, and the key factor for sustainable production mainly within the wastewater system, but answers concerning production of goods were also accepted. That gave the foundation to investigate trends within wastewater treatments investments, and possible future demands.

The main questions were as follows:

- Are you planning to adopt reuse into your value chain/ production?
- What would you change within the processes to achieve a more sustainable production?
- What do you consider to be the most important factor to achieve a sustainable production, and does your employer do this?

For the first point, what was joint between the participants was the desire for a more sustainable production, and have the possibility of a well-enough wastewater treatment system that it would be in accordance with the increasing demands for treatments before release. Several of the participants mentioned that if the wastewater treatment methods were well enough, it would increase the possibility to reuse wastewater and biomass.

Three of the participants had biogas creation in their wastewater treatment system, that can be considered a method of value creation. SCA Örtviken and SCA Graphic Sundsvall AB use aerobic treatments, meaning they do not have biogas creation within their wastewater treatment system. It was mentioned as a desirable upgrade to the current wastewater systems. The main biogas processes are presented in figure 8.

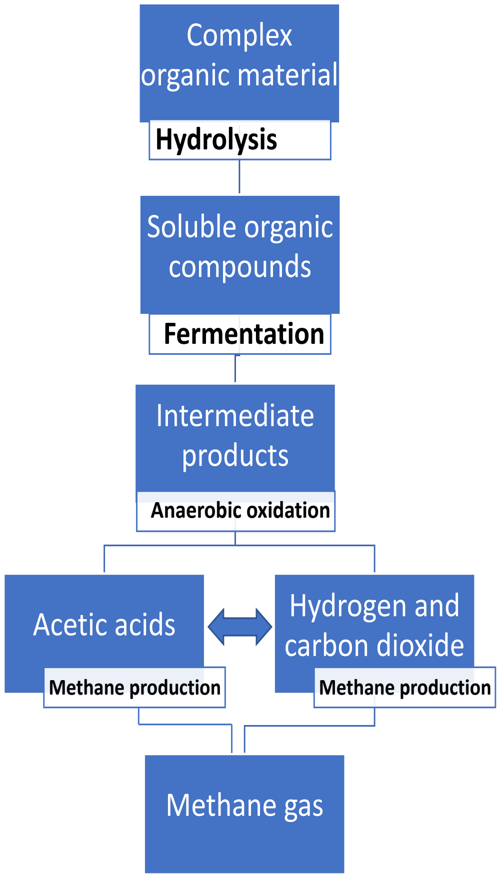

Figure 8. The main processes involved of biogas creation

For the second point, the trend among the participants was a desire for circular economy also referred to as circularity, which means that the production and wastewater treatment system would minimize the waste within its processes, and make the most out its resources. The main functions for circular economy is presented in figure 9.

A specific method mentioned for reuse within the process, was to reuse already heated water, which was mentioned by two participants. SCA Graphic Sundsvall AB mentioned MBR as a future technology for wastewater treatments, since it can achieve a level of purifying that would make it possible to reuse the wastewater in the processes, while creating biogas, without excessive use of energy.

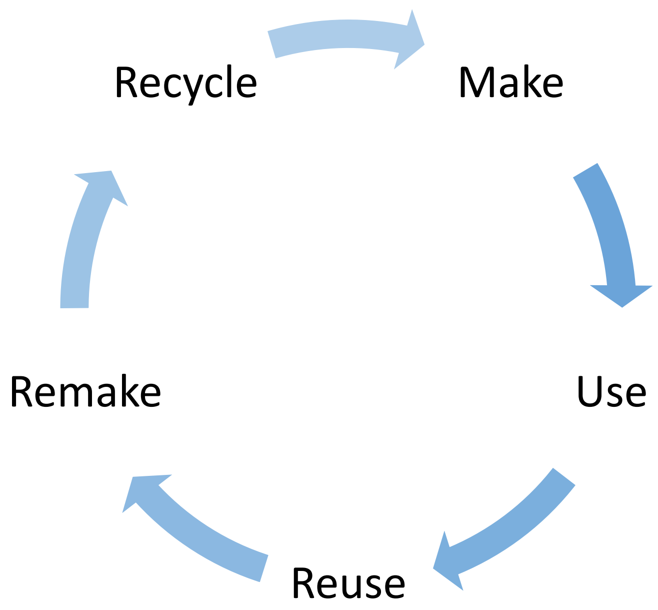

Figure 9. Main functions to achieve circular economy (modified from Weetman, 2016)

For the last point, most of the participants mentioned circular economy again, but the need for less or zero emissions was also mentioned. Most of the participants use wood as a raw material, which is a renewable source. However, within the processes emissions to air and water is released. CO_2 emissions was mentioned the most in regards to reduction priority.

Most of the participants had a plan for reduction of emissions especially to air, but there was no specific plan concerning reduction of emissions to water besides corresponding with government demands, that was described as consistently becoming stricter.

4.5 Expected Discharge Permit to water

Since the location and recipient is undecided, the recipient is assumed to be normal. The annual production is expected to between 20-25 000 ton, depending on the yield. However, for the discharge permit the annual production is set to 25 000 ton.

The information gathered from the case study on discharge permits and the literature available, are used as reference. The companies most relevant concerning discharge permits are located in Norway, and have wooden processed and normal recipient. Therefore, Norske Skog and Borregaard are compared and used to create a relevant discharge permit in combination with the Norwegian legislation.

The expected annual permit for COD and SS was calculated by the following methods:

First, find COD and SS/per ton produced using the formula:

$$\frac{AP\text{-}DC}{AN\text{-}DC} \qquad (4\text{-}2)$$

Where

AP-DC	Annual permitted discharge of compound
AN-DP	Annual production in discharge permit

Second, using the answer from (4-2), to find the expected permitted COD and SS for Elkem's annual production, using the following formula:

$$ElkemAN * Ans(4\text{-}2) \qquad (4\text{-}3)$$

Where

ElkemAN	Elkem annual production
Ans(4-2)	Answer from (4-2)

The formula was set to find the permitted discharge of COD and SS per ton of production in the discharge permits of Norske Skog and Borregaard. The amount that was allowed was basis for what Elkem can receive as a limit in the discharge permit. The calculations resulted in the expected discharge permit presented in the table 15.

Table 15. Expected Discharge Permit for integrated charcoal-silicon process (production of 25000 ton/year)

Component	**Low Annual discharge permit**	**High Annual discharge permit**
COD, ton	38 (daily) 141 (annual)	221 (daily) 809 (annual)
SS, ton	2,6 (daily) 9,7 (annual)	21(daily) 79 (annual)
BOD	Not measured	Not measured

The discharge permit have a low and high limit, but usually the discharge permits are given on the basis of daily and annual limits. However, since the difference between the discharge permits for Norske Skog and Borregaard were significant, it was created a lower and upper limit. It should be noted, that the lower limit is exceptionally strict and represent the possible future restrictions. Since neither Norske Skog or Borregaard had regulations for BOD, the regulation for BOD absent in the expected discharge permit.

5. Discussion

In this section, the criteria and the scenarios for potential wastewater treatment and carbon recovery is presented and explained. The scenarios are based on the findings previously presented. The scenarios are compared regarding risks and vulnerability, and potential biomass recovery and biogas.

5.1 Criteria for scenarios and calculations

In order to create scenarios, some criteria were set. The following four criteria are the basis for the scenarios.

1. The wastewater treatment scenario needs to comply with discharge permit and possible future restrictions
2. The wastewater treatment scenarios should be in accordance with circular economy
3. The scenario should involve anaerobe treatment with pH approximately 7, for optimized conditions.
4. The amount of carbon in the potential biomass and biogas is not calculated.

The following equations for calculations were used and are presented below: anaerobe fermentation (Henze, 2002) (5-1), potential COD after removal (5-2) and percentage of discharge permit (5-3) :

$$\frac{Y0.2 * gCOD(Biomass)}{gCOD*(Substrate(A)(M))} \qquad (5\text{-}1)$$

Where

Y: Yield 20%

Substrate(A) Acid: $C_6H_{12}O_6 + 0.24\ NH_4^+$
$= 0.24\ C_5H_7NO_2 + 2.40\ CH_3COO^- + 0.72\ H_2O + 2.64\ H^+$

Substrate(M) Methane: $CH_3COOH + 0.012\ NH_4^+ + 0.012\ OH^-$
$= 0.012\ C_5H_7NO_2 + 0.97\ CH_4 + 0.97\ CO_2 + 0.048\ H_2O$

$$(COD_{bf}) * (1-R_R) \qquad (5\text{-}2)$$

Where

COD_{bf} COD before Wastewater treatment

R_R: Removal Rate of wastewater treatment

$$\frac{(\underline{COD_{DC}}}{(DP)} * 100 \qquad (5\text{-}3)$$

Where

COD_{DC} COD for discharge to recipient

DP Discharge Permit

The first criteria is set since the Norwegian legislation demands that all companies that emits emission to air and water have a discharge permit. The discharge permit was presented in section 4.5 in table 15, with an low and high limit. Since the case study revealed that the participants experience increasing demands from the government on emissions to water, the scenarios should have COD and SS levels below the upper limit. The regulations are becoming stricter, and to avoid changing the wastewater treatments after short time, the wastewater treatments scenarios should be able to withstand stricter regulations.

The second criteria is set for the wastewater treatments to meet the increased interest for circular economy, of which the processes resources are recycled instead of replaced. The reuse of resources can help avoid unwanted costs and benefit the environment.

The third criteria is set to achieve possible savings or profit through circularity. A reward for implementing a anaerobic treatment into the wastewater treatment system is the production of biogas, that can either be transformed into liquid and sold as fuel (Norske Skog), or reused into the processes that causes savings in production costs (Borregaard).

The forth criteria was set in relation to calculating the potential biomass and biogas. Since the wastewater streams reaction to the different wastewater processes is unknown, as is the content of the wastewater, therefore the carbon remaining in the biomass and biogas cannot be calculated without potential significant margin of error . Therefore, the calculation is not attempted.

5.2 Anaerobe EGSB reactor: Norske Skog and Borregaard

The wastewater streams are in this scenario treated partly separated, but for sludge handling the streams are merged. The wastewater system is presented in figure 10, and the process is explained in detail below.

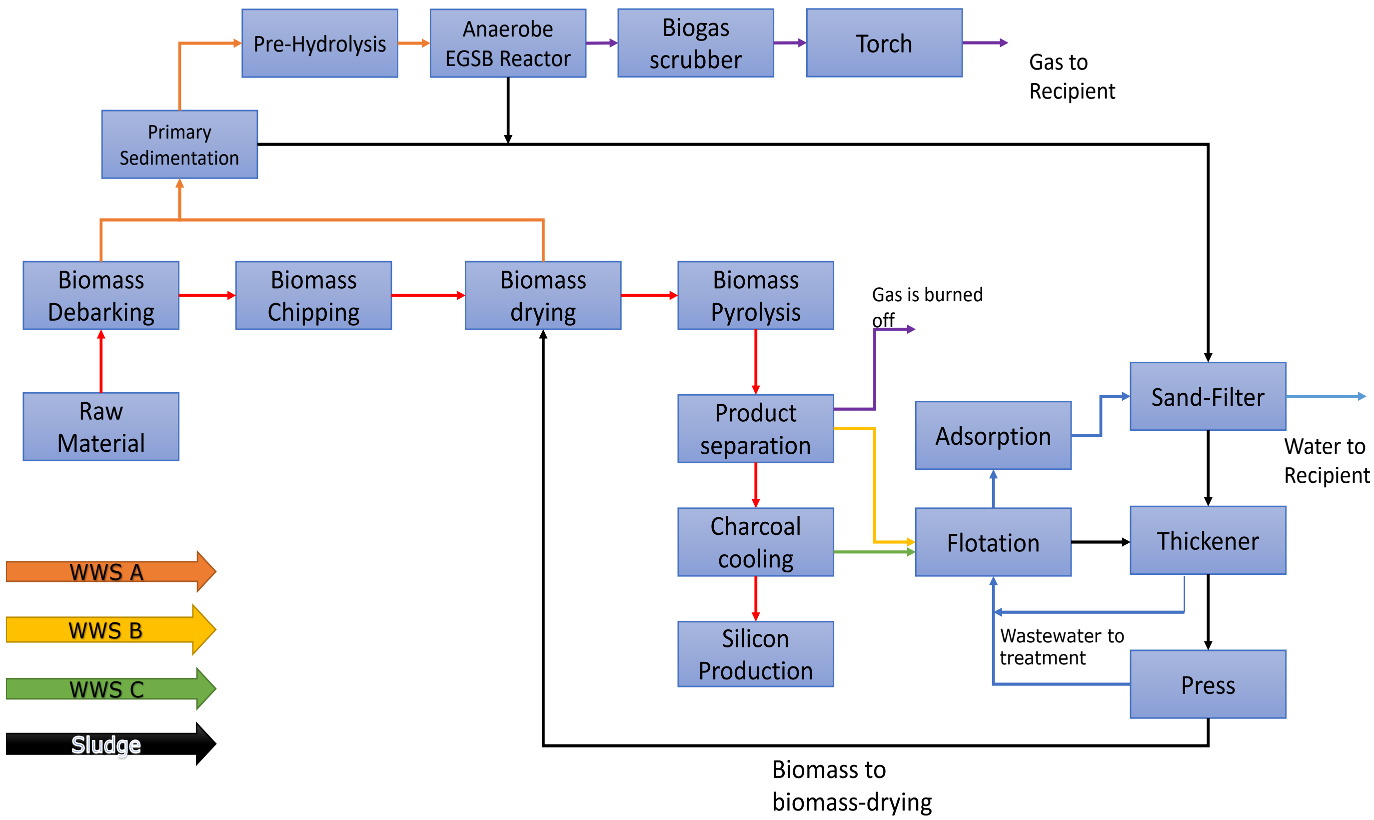

Figure 10. Wastewater treatment system with EGSB reactor inspired by Norske Skog and Borregaard

5.2.1 Wastewater system components and removal rates

The wastewater treatment system consist of primary, secondary and tertiary/ polishing treatments.

WWS A is the wastewater stream used to create bio-gas, since it contains high amounts of COD from the wood processes. The SS is separated from the water in a primary sedimentation, of which the primary sludge is forwarded to sand-filter, where it is joined with the biomass from WWS B and WWS C. While, the water and smaller particles remaining in the WWS A after sedimentation is forwarded to pre-hydrolysis as pre-treatment before it creates gas in the anaerobe EGSB reactor. The gas is scrubbed to remove Sulphite, and the surplus gas is burnet off in the torch, before the biogas is sent to recipient.

WWS B needs to remove COD before release, and is first through adsorption, before sand-filter. WWS C consist of suspended solids from cooling the charcoal, and since the solids are expected to float well (density), its initial treatment is flotation. The spruce has density with 15 % of moisture giving 0,47 g/cm m3, indicating it will float well and easily be removed in the process. WWS C is merged with WWS B to remove potential COD before sand-filter as tertiary.

The solids collected from sand-filter continues to sludge handling. The biomass is thickened to reach 40% moisture, pressed to reduce the water content, before functioning as substitute for the wooden biomass. Since it probably needs to be dried before pyrolysis it enters at biomass drying process rather than directly in biomass pyrolysis.

To ensure that the system complies with the discharge permit, the wastewater streams are presented in tables below with the removal rate. The calculation for removal of COD and SS, is done on basis of the known removal rates presented in theory. The components in WWS A is presented in table 16, with the method, purpose and removal rates. The components for WWS B and WWS C before merging is presented in table 17, and the components of WWS B and WWS C after merging presented in table 18.

WWS A components

Table 16. Overview of wastewater treatment methods for WWS A, purpose and removal rate

Method	**Purpose**	**Removal of COD%**	**Removal of SS%**	**Reference**
Primary-Sedimentation	Separate the solids from water to redirect solids to sludge handling		80-90	(Pokhrel,D, 2004)
Pre-Hydrolysis	Proteins, fats and carbohydrates are solved and restructured into amino acids, fatty acids and sugar.			Case study (Norske Skog)
Anaerobe EGSB Reactor	Creation of biogas by turning ethanoic acid into methane and carbon dioxide. The tail gas is extracted and sends the water to flotation.	30-90		(Meyer&Edwards, 2014)
Biogas scrubber	The scrubber removes the Sulphite from the gas			Case study (Norske Skog and Borregaard)
Torch	The surplus gas is burnt off			Case study(Norske Skog and Borregaard)

WWS B and WWS C

Table 17.Components of WWS B and WWS C before merging

WWS B Method	**WWS C method**	**Purpose**	**Removal of COD%**	**Removal of SS %**	**Reference**
Adsorption		To remove COD and color in the wastewater	90		Pokhrel, D, 2004)
	Flotation	Separate the suspended solids and water		65-95	(Pokhrel, D, 2004)

Shared components of WWS C And WWS B

Table 18. Overview of wastewater treatment methods for WWS C, purpose and removal rate

Method	**Purpose**	**Removal of COD%**	**Removal of SS %**	**Reference**
Sand-filter	Removes suspended solids and COD.	99	95	(Hamonda et al.,2004).
Thickener (Sludge Handling)	The thickener process is to reach a 40% moisture level.			Case study
Press (sludge Handling)	The press is to remove the water content.			Case study

Using the methods presented, the wastewater treatment system is within the higher limits of the discharge permit presented in section 4.6, in table 15, if the system does not function at the lowest level found in literature with the highest potential COD. The expected annual discharge from the scenario and deviation from permit is presented in table 19.

Table 19. The expected annual discharge from the Wastewater System: EGSB reactor

	WWS A	**WWS B**	**WWS C**	**SUM**	**Percentage of discharge permit: low limit, %**	**Percentage of permit: high limit, %**
COD, low, ton	167,5[b]	0,15		167,65	118,7	20,74
COD high, ton	4690	4,5		4694	3,329	580
SS low, ton	0,18		0,75	0,93	10,33	1,18
SS high, ton	0,75		5,25	6	61,86	7,59

The high COD ton, is when the anaerobe EGSB is at 30% removal rate, and the expected level of COD is at maximum, meaning the level of COD in the stream is unlikely high. Therefore, the stream is not able to meet the lower or higher permit for COD.

[b]Assuming the Anaerobe EGSB reactor removal rate is 90%

5.3 Anaerobe Digester: Kristiansand Municipal Water and Sewage Department

The wastewater system with an anaerobic digester is inspired by Kristiansand Municipal Water and Sewage Department. The wastewater streams are treated separately for primary treatment, but all are merged in sedimentation to recover the most carbon. The system is presented in figure 11.

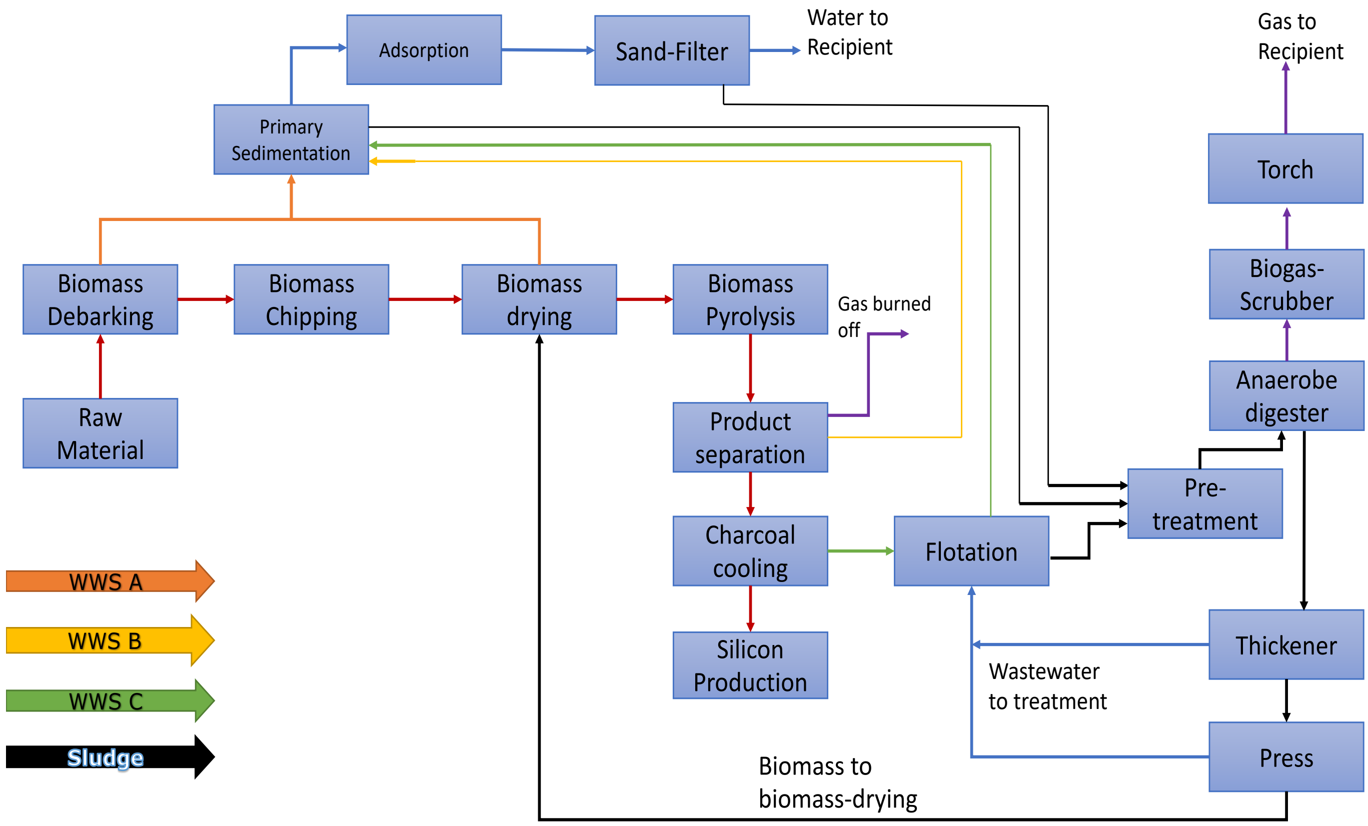

Figure 11. Wastewater treatment system with anaerobe digester: inspired by Kristiansand Municipal Water and Sewage Department

As presented in the figure, the system contains some of the same components as scenario 1, therefore the same components: *biogas scrubber, torch, thickener and press*, is not presented in the overview of components, purpose and removal rates.

5.3.1 Wastewater system components

The wastewater streams are combined in the sedimentation, where WWS C has it at secondary treatment, while WWS A and WWS B has it as primary. To ensure that the capacity for sedimentation is not exceeded, and discharge permit is met, parts of the solids from charcoal cooling water is removed by flotation, where the primary sludge is forwarded to pre-treatment before anaerobic digester, and the water to sedimentation with the two other wastewater streams.

The wastewater A, has high levels of COD and SS. Therefore, it requires treatments for COD and solids before release. The sedimentation can remove the particles and direct it as primary sludge to the pre-treatment before the anaerobic digester, while the adsorption and sand-filter remove the COD and remaining SS. The wastewater stream B is not expected to contain much SS, but it is expected to have a high COD level. Therefore, WWS B is directed to sedimentation for removal of possible particles, and adsorption and sand-filter for removal of COD and possible remaining particles before release. The biomass from sand-filter is forwarded to the pre-treatment, while the water is released to recipient.

The treatments method, purpose and removal rate for WWS B is presented in table 20, and for all wastewater streams in table 21.

WWS B: method and removal rate

Table 20. Overview of wastewater treatments for WWS B, purpose and removal rate

Method	**Purpose**	**Removal of COD**	**Removal of SS**	**Reference**
Flotation	See table 17.		65-95	(Pokhrel, D, 2004)
Pre-treatment	The biomass is pre-treated before the digester to maximize the utilization			Case Study
Anaerobe digester	Digest the biomass, which create biogas without producing significant amount of new biomass			Case Study

All wastewater streams: method and removal rate

Table 21. Overview of wastewater treatments for all wastewater streams , purpose and removal rate

Method	**Purpose**	**Removal of COD%**	**Removal of SS%**	**Reference**
Sedimentation	See table 17.	80-90		(Pokhrel, D, 2004)
Adsorption	See table 17.		90	(Pokhrel, D, 2004)
Sand filter	See table 18.	99	95	(Hamonda et al,. 2004)

The expected annual discharge from the wastewater system is calculated based on the removal rates previously presented, and are available in table 22.

Table 22. The expected annual discharge from Wastewater System: Anaerobe digester

	WWS A	**WWS B**	**WWS C**	**SUM**	**Percentage of discharge permit; low limit %**	**Percentage of discharge permit: high limit, %**
COD low, ton	167,5	0,15		167,65	118,97	20,74
COD high, ton	670	4,5		674,5	478,37	83,37
SS low, ton	0,18		3	3,18	32,78	4,03
SS high, ton	0,75		21	21,75	241	27,53

The higher limit of the discharge permit is met with good margin for all parameters, as is the lower limit for SS. However, the lower limit is not met for COD in either cases.

5.4 Anaerobic Membrane Bioreactor: SCA Graphic Sundsvall AB

The wastewater system is inspired by the interview with SCA Graphic Sundsvall AB, where the MBR was presented as a potential future investment. The wastewater streams are treated partly separated, but have joint sludge handling. The anaerobic membrane bioreactor combines the biodegradation with membrane filtration and ultrafiltration membrane processes. It provides a solid-liquid separation, while it produced biogas and have a low biomass yield resulting in low operation costs. The system is presented in figure 12.

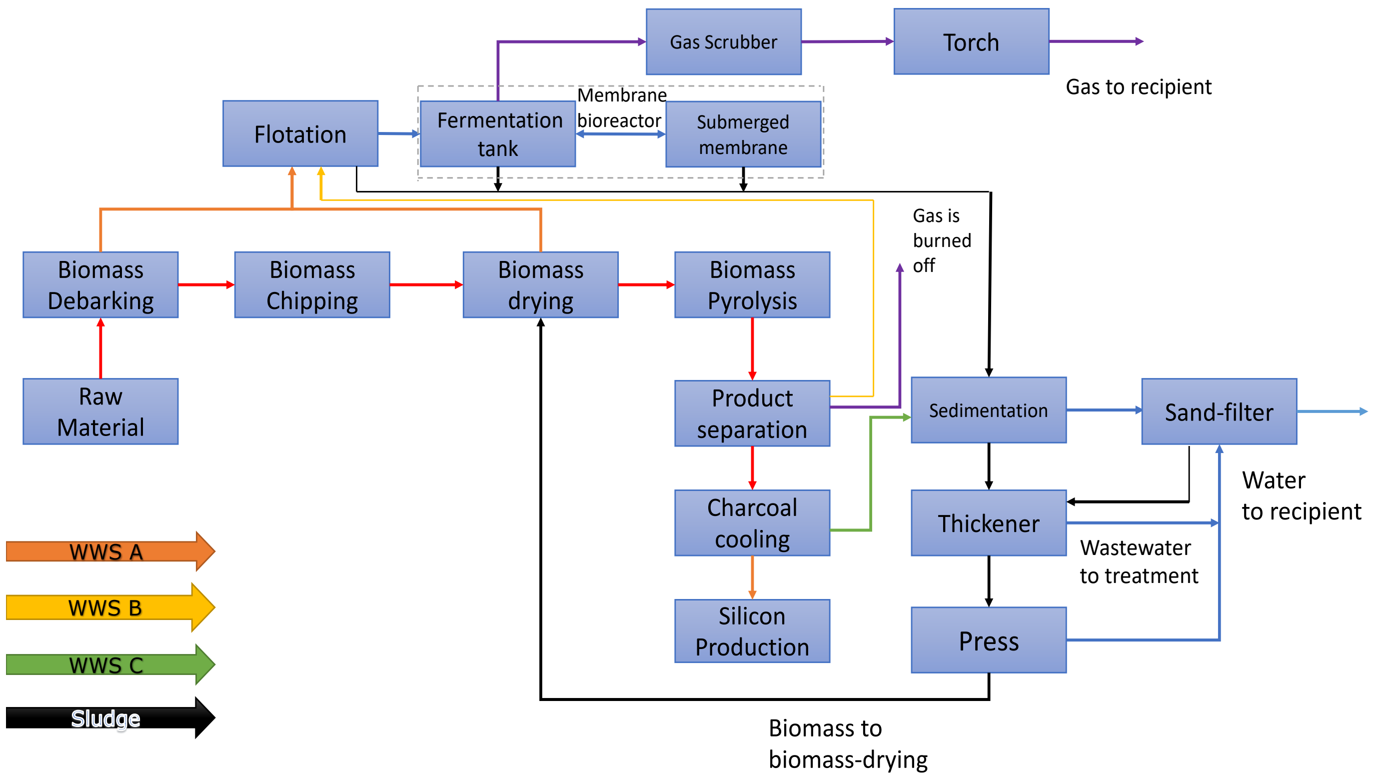

Figure 12. Wastewater treatment system with membrane bioreactor: inspired by SCA Graphic Sundsvall AB

As presented in the figure, the scenario contains some of the same components that have been previously presented. The components in relation to sludge handling (thickener and press), and for biogas creation (gas scrubber and torch), are not presented in the overview of components and removal rates.

5.4.1 Wastewater system components and removal rates

In this scenario, the wastewater stream A and B are used as feed for the anaerobic membrane bioreactor, since these streams are expected to have the highest amount of COD. The sand-filter removes the larger particles that are not suitable for the AnMBR, and forward the it to sedimentation.

The wastewater stream C is directed to sedimentation as primary treatment, due to the expectance of solids. The biomass from sedimentation and sand-filter is used as substitute for biomass, after thickener and press. Since the biomass might require further drying before use, it is directed to biomass drying before the fast pyrolysis process. The water separated from the solids in sedimentation, has sand-filter as tertiary treatment to remove COD before release to recipient, ensuring that the discharge permit is reached with good margin.

The wastewater systems components and removal rates are presented in table 23 and 24. The wastewater streams A and B are presented together.

WWS A and WWS B

Table 23. Overview of wastewater treatments for wastewater stream A and B, purpose and removal rate.

Method	**Purpose**	**Removal of COD**	**Removal of SS**	**Reference**
Sand filter	See table 18.	99	95	(Hamonda et al,. 2004)
Membrane bioreactor[c]	Fermentation to create biogas	99,4	99	(S.A. Deowan, et al., 2015)

WWS C

Table 24. Overview of wastewater treatments for wastewater stream C, purpose and removal rate.

[c] Assuming operating temperature 33 °C and pH is 6,9.

Method	Purpose	Removal of COD	Removal of SS	Reference
Sedimentation	See table 16.		80	(Pokhrel, D, 2004)
Adsorption	See table. 17	90		(Pokhrel, D, 2004)

The excepted annual discharge from the scenario, and the percentage of discharge permit used is presented in table 25.

Table 25. The expected Annual discharge from Wastewater System: membrane bioreactor

	WWS A	WWS B	WWS C	SUM	Percentage of discharge permit: low limit %	Percentage of discharge permit: high limit %
COD low, ton	10,4	0,009		10,409	7,38	1,29
COD high, ton	40,2	27		67,2	47,66	8,31
SS low, ton	0,009		60	60,009	666	75,96
SS high, ton	0,037		60	60,0037	666	75,95

The discharge permit is met with very good margin expect for the lower limit of SS, probably since the limit is exceptionally strict. The higher limit of SS is met with relatively good margin.

5.5 Comparison of scenarios: Risks and vulnerability

The anaerobe system is well known, and has evolved in the last decade to be able to treat several types of wastewater. One major advantages with the system is the recovery of carbon through production of biogas, that can provide profit or savings. While, the substitution of biomass, provide a circularity of the system.

Scenario 1, have no new and untested components in the treatment process, and each of the treatment processes was chosen to fit the integrated charcoal-silicon/ferrosilicon process. For adsorption charcoal have had good effect, and can provide a removal rate of 90% COD. Since the system create charcoal the product perhaps some of the less quality-produced goods or ash can be a adsorbent, as part of the circular economy perspective. The scenario was able to meet the higher levels of the discharge permit for all parameters. However, the scenario was not able to meet the strictest level of the discharge permit, meaning the scenario needs further researching for the removal rates, when a discharge permit is given, before start-up.

There are a few limitations for the system concerning technology readiness level, in relation to lack of testing or simulations, and might require some adjustments. Therefore, some initialization problems may occur.

Scenario 2, use a anaerobic digestor to create biogas, while reducing the biomass. The digester require a flow of biomass that is pre-treated to decompose it. However, the anaerobe digester studied in the collective case study was in relation to treatment of sewage. The sludge sources from the integrated charcoal-silicon/ferrosilicon process, can be quite different considering the difference in emitted wastewater. Therefore, the risks for this scenario involve the difference in biomass in the anaerobic digestor. The anaerobe digester was not in accordance with the lower set of discharge permit, but was within the higher levels with good margin.

Scenario 3, the AnMBR show the greatest removal rate of COD, but there are notable risks and vulnerabilities linked to AnMBR. The filters involved in the process can become clogged, meaning regular maintenance and cleaning is required to remove remaining solids. Therefore, the wastewater treatment scenario require trained operators, and framework for check-ups. This have costs linked to it, but considering the removal rates, the system has the potential to reach very strict discharge permits, even for vulnerable recipients. The AnMBR had the best results concerning the discharge permit, besides the lower level of SS. In comparison to the other scenarios, it was able to meet the discharge permits strictest regulation for COD.

All the scenarios require a framework for testing the wastewater, to be in accordance to the demands for analysis, guidelines concerning maintenance, and operators. For anaerobe systems, there can be a need for start-up biomass for the system, that applies for all scenarios.

5.6 Potential carbon recovery: biogas and biomass

To determine the potential carbon recovery in biogas and biomass, table 6 that was presented in section 4.1, was used with the equation (5-1). However, since the equation (5-1) uses the COD for calculation, the wastewater stream C was not included, due to the COD level was not found in literature or provided by Elkem and SINTEF.

Using (5-1), the expected yield of biomass is 20%, meaning the remaining yield of 80% is biogas in anaerobic digestion treatments. However, in the wastewater treatment scenarios the processes provide reduction in the amount of COD, meaning a reduction in the available carbon for biomass and biogas. Therefore, to get an overview of the available potential biomass and gas before treatments, the first calculation was done before entering wastewater treatment system.

The actual percentage of carbon cannot be calculated without more information on the wastewater. The relationship between COD and BOD found in literature regarding pulp and paper wastewater indicate that there may be compounds that are not easily biodegradable in the wood processing wastewater stream A. The results of the calculation is available in table 26.

Table 26. Potential carbon for recovery before wastewater treatments

	WWS A	**WWS B**	**Reference**
COD ton	167,500 -670,000	150-4500 (*10-50% carbon*)	
Biomass ton ,*with 20 % yield*	33,400-134,000	30-900	(Henze, 2000)
Biogas ton, *with 80 % yield*	133,600-536,000	120-3600	(Henze, 2000)

In the different scenarios, the reduction of COD varies. Since there is little knowledge as to how the wastewater would react to the different treatments, it is difficult to calculate the amount of biogas and biomass, that can be recovered in the scenarios. As an attempt to give a potential biogas and biomass, the original amount of COD ton (table 26), is reduced by the removal rate presented in the previous scenarios.

EGSB Bioreactor
The calculation for available COD for biomass and biogas was calculated using (5-1), (5-2) and (5-3). The results is presented in table 27, and explained below.

Table 27. Scenario 1: Potential biomass and biogas after reduction processes in wastewater treatment system

	WWS A	**WWS B**
COD ton/year	167,500-670,000	150-4500
COD reduction, %	EGSB:30-90	Adsorption: 90
	Sand-filter: 99	Sand-filter: 99
Potential COD, ton/year	1172,5-4690	0,15-4,5
Potential biomass, ton/year: *yield 20%*	234-938	0,03-0,9, (*where 10-50 wt% carbon*)
Potential Biogas, ton/year: *yield 80%*	938-3752	0,12-3,6

In scenario 1, the wastewater stream A is the stream as input to create gas, after primary sedimentation to remove larger particles. The anaerobic EGSB removes 30-90% of the COD in the process, since it is a bioreactor it can transform some of the COD to biogas as it is decomposed, and the primary sludge created in the process is forwarded to sand-filter, and merged with WWS B. The biomass from WWS A and WWS B is merged with the primary sludge from WWS C in thickener, where the water is removed and biomass is forwarded to press, and can probably be used as substitute.

Anaerobe digestor
In the second scenario, the main component is the anaerobe digester that digests biomass and create biogas. The main wastewater source to the digester is the wastewater stream C due its high expected content of SS, that can be used to create gas through digestion. Since the COD level for this wastewater stream is unknown, the amount of biogas and biomass is not calculated.

Wastewater A and B are also directed to the digester after primary sedimentation, and the particles from the streams remaining in the wastewater at tertiary. The calculation for available COD for biomass and biogas was calculated using (5-1), (5-2) and (5-3). The results is presented in table 28.

Table 28. Scenario 2: Potential biomass and biogas after reduction processes in wastewater treatment system

	WWS A	**WWS B**
COD ton/year	167,500-670,000	150-4500
COD reduction %	Adsorption: 90	Adsorption: 90
	Sand-filter: 99	Sand-filter: 99
Potential COD, ton/year	167,5-670	0,15-4,5
Potential Biomass, ton/year: 20 % yield	33,5-134	0,03-0,9
Potential Biogas, ton/year: 80% yield	134-536	0,12-3,6

AnMBR Technology
The anaerobic membrane reactor have a high removal of COD and suspended solids. The wastewater streams involved in creation of gas is WWS A and WWS B, while WWS C is filtered to use as biomass, and the water is released to recipient.
The calculation for available COD for biomass and biogas was calculated using (5-1), (5-2) and (5-3). The results is presented in table 29.

Table 29. Scenario 3: Potential biomass and biogas after reduction processes in wastewater treatment system

	WWS A	**WWS B**
COD, ton	167,500-670,000	150-4500
COD reduction, %	Sand filter: 99	Sand filter: 99
	AnMBR: 99,4	AnMBR: 99,4
Potential COD, ton/year	100,5-402	0,9-27
Potential Biomass, ton, yield 20%	20,1-80,4	0,18-5,4
Potential Biogas ton, yield 80%	80,4-321,6	0,72-4,32

With the high removal rate associated with AnMBR, this scenario naturally provide the least amount of biogas and biomass. However, this may not be the case if the calculations were done with more information on the wastewater and the response of treatments. A comparisons of the scenarios potential biogas and biomass is presented in the subsequent section.

5.7 Comparison of the potential biogas and biomass in the scenarios

All scenarios provide a wastewater system that can recover carbon as biomass and biogas, using an anaerobe digestion or bioreactors. The carbon recovery though biomass, can create sustainability in processes, since the potential substitution reduce the need for raw material, in this case wood (spruce). Therefore, the substitution have the potential to contribute to an improved sustainable production. The comparison of potential biomass in the scenarios is available in figure 13.

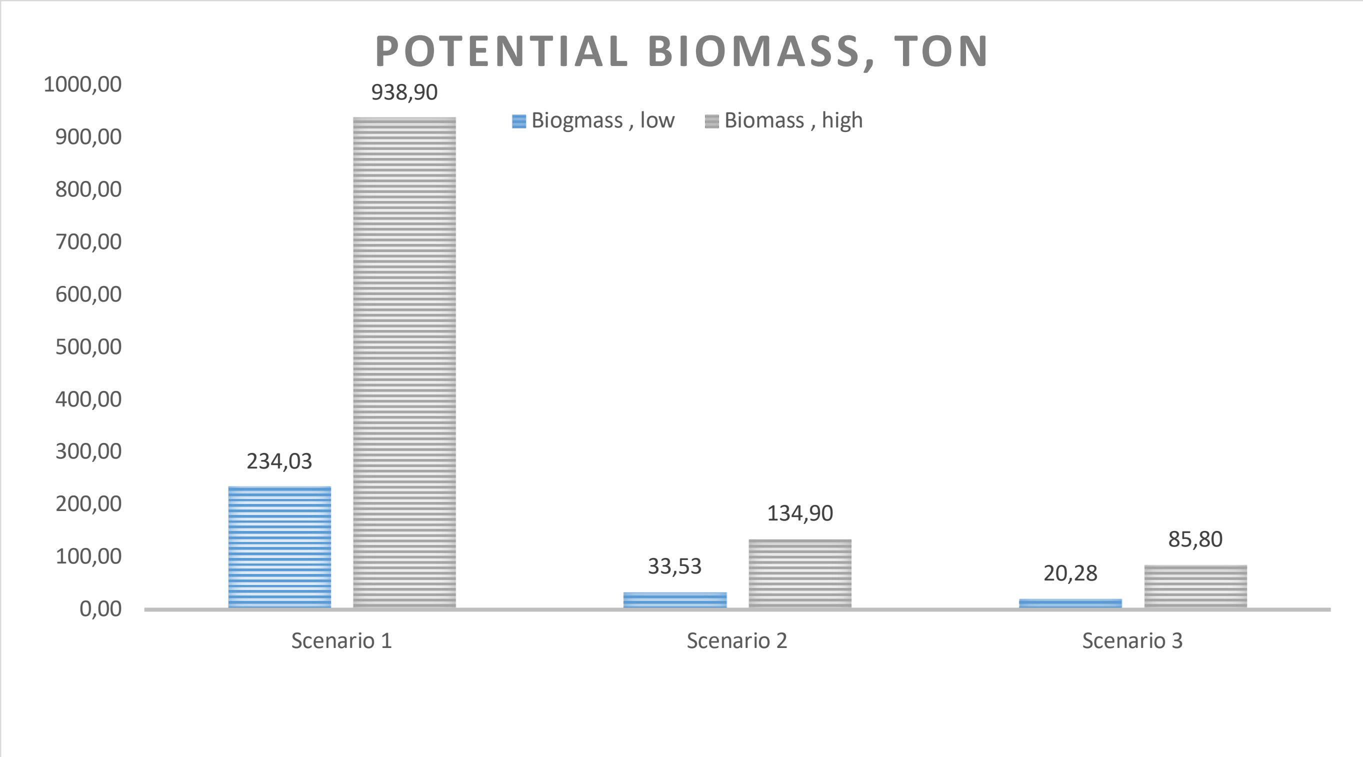

Figure 13. Comparison of potential biomass in the scenarios

The biogas can be part of savings or possible profit. The biogas can either be sold to costumers or used within the process to save energy costs. It can also be transformed to fuel in order to reach out to a new market. A comparisons of the potential biogas is available in figure 14.

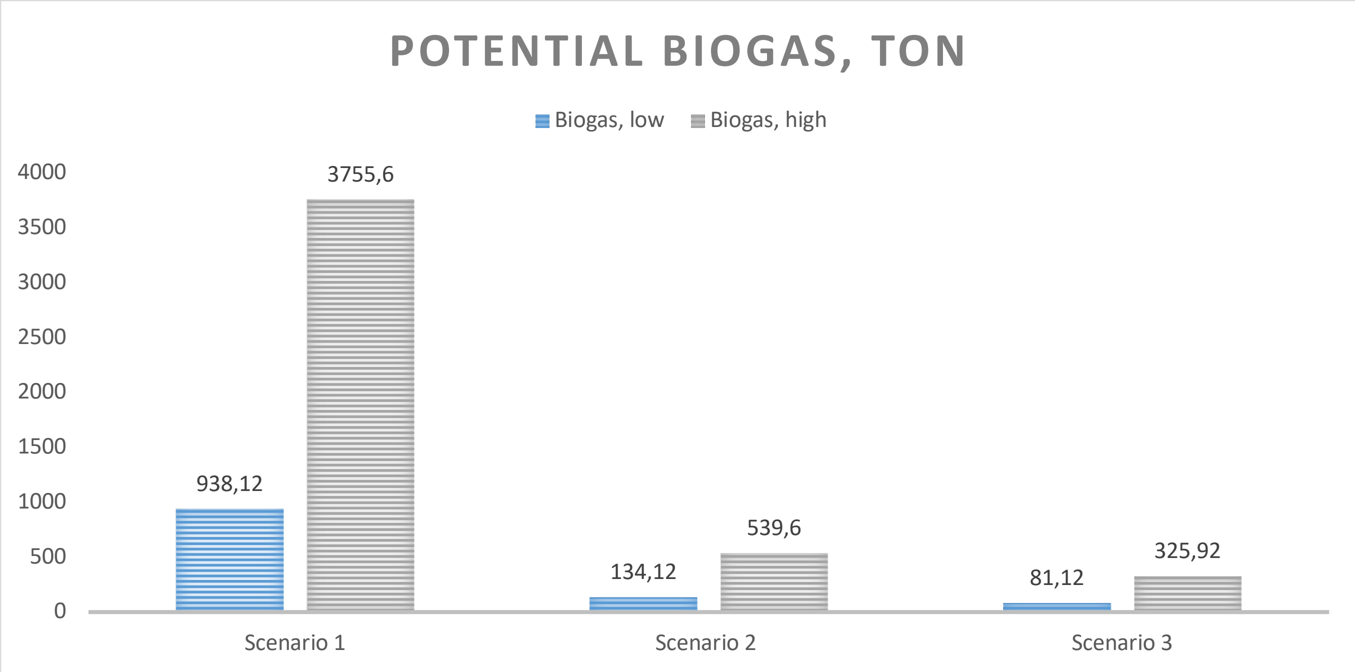

Figure 14. Comparison of the potential biogas in the scenarios

The scenarios provide potential biomass as substitute for raw material, and biogas, with scenario 1 having the highest potential. However, the scenarios that had the best results concerning the discharge permit was scenario 3. The scenarios do not take into consideration if the wastewater treatments have overloads of wastewater or some parts in the production mail-function, leading to changes in wastewater characteristics and need for disposal of excess primary sludge or biomass. However, should it be need for disposal for various reasons a possible solution is to burn it and research possible reuse of ash.

6. Limitations of scenarios

There are limitations in relation to the scenarios and the calculation of potential carbon for recovery, that is discussed in this section.

The main limitations of the model are in relation of the following

- Lack of actual data of the wastewater from the process
- Little study in the field on the specific production and reuse of carbon to use as material
- Time limitation

The main limitation for the creation of potential wastewater treatments scenarios that recover carbon, was the limited data of wastewater from the production, and its response to treatments. The data of amounts of COD, BOD and SS in the wastewater can differ significantly from the wastewater produced in the integrated charcoal-silicon process. Therefore, the potential recovery of carbon can be different than what was calculated.

The study on field was limited and divided into either research on pyrolysis of biomass to produce charcoal and wastewater treatments of pulp and paper wastewater. The time limitations of 20 weeks set a limit for time spent searching for literature, and time spent visiting and interviewing participants for the collective case study. Therefore, there might be aspects and issues that has not been taken into consideration.

7. Conclusion

The integrated charcoal-silicon process is part of the project pyrOPT, that is a joint project between Elkem and SINTEF. PyrOPT is part of the vision to reduce the use of fossil coal during Elkem's production of silicon and ferro-silicon, of which the integrated charcoal-silicon/ferrosilicon process produces tailor-made biocarbon that can replace the use of fossil coal. The goal is to have 40% renewable carbon in mix of reduction material by 2030 in Norwegian alloys.

The integrated charcoal-silicon/ferrosilicon process have several processes that leads to emissions to water, and that require treatment before release to recipient. Therefore, the aim of master thesis was to investigate potential wastewater treatments and methods for carbon recovery.

The method chosen for the master thesis was a collective case study, since it allows for multiple sources of data. The participants of the case study was Norske Skog, SCA Örtviken, SCA Graphic Sundsvall AB, Kristiansand Water and Sewage Department and Borregaard. It was conducted one company visit to Norske Skog, SCA Örtviken and Borregaard. While, two visits were done to Kristiansand Municipal Water and Sewage Department. The visits were done in the period of February – March, 2019.

The literature used in the master thesis was found in two ways: provided by SINTEF and Elkem, and through searches in the following databases: Oria, ScieneDirect and GoogleScholar. Due to the wastewater from the integrated charcoal-silicon/ferrosilicon process was unknown, literature in combination with expected amounts of wastewater provided by SINTEF, was the basis for expected characteristics of the wastewater used in the master thesis.

At the company visits, an interview was conducted and recorded, and it was taken notes and made observations. The interviews questions were divided into general and in-dept questions to cover the methods of wastewater treatments, the discharge permits, what the representatives considered as key factors for sustainable production, and a beneficial wastewater treatment system. It was emphasized the importance of circular economy for sustainable production and anaerobic treatments for a beneficial wastewater treatment system, due to the creation of biogas for savings in production and potential profit if sold.

A discharge permit was made on the basis of the collected discharge permits of participants, and the Norwegian legislation. There were also made certain criteria for scenarios and calculations, to create scenarios that could recover carbon, while treating the wastewater to an acceptable level before discharge. The criteria involved the use of anaerobe reactor or digestor, being in accordance with circular economy, and that the amount of carbon in the potential biomass and biogas would not be calculated, but it was attempted to make calculations on the amount of biomass and biogas expected from the scenarios.

The results of the case study gave the foundation for creating scenarios for wastewater treatment systems and carbon recovery. The following scenarios were made: anaerobic EGSB inspired by Norske Skog and Borregaard, anaerobic digestor that was inspired by Kristiansand Municipal Water and Sewage Department, and anaerobic membrane reactor inspired by the interview with SCA Graphic Sundsvall AB.

The scenarios recover carbon in the wastewater treatment systems through biogas, and biomass that can be potentially be a replacement for raw material. The biogas can be sold or reused in the processes as a method to save energy. If the biomass function as substitute for raw material, it can contribute to circularity on the process. However, the response of the compounds may differ since the expected wastewater is based on literature form pulp and paper, and the changes in wastewater besides removal rate during processes, was not taken into account.

8. Further research

The master thesis mapped potential wastewater treatments, created a discharge permit, and created scenarios for wastewater systems and carbon recovery for the integrated charcoal-silicon/ferrosilicon process using data on wastewater amounts and characteristics provided from SINTEF and Elkem, and from literature. Therefore, the following recommendations are given for further research, when the integrated charcoal-silicon/ferrosilicon process have available wastewater and discharge permit.

- Review the wastewater treatments data used in the master thesis and make adjustments to wastewater treatments system to fit the actual wastewater characteristic and amounts.
- Find actual wastewater permit to ensure wastewater treatments are in accordance with it.
- Test or simulate the wastewater treatment system to find the expected annual biomass and biogas.
- Develop framework for wastewater testing to fulfil the demands for analysis.
- Create default-system for possible unexpected need for disposals of excess primary sludge or biomass through boiler-house and reuse of ash.
- Review possibility to use possible excess or biomass as soil improver.
- Review possibility for ash or produced goods of less quality as adsorbent

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Appendix I. Interview Questions (Norwegian)

DEL 1. Generelle

a. Hva er deres (hoved) produksjonsprosesser?
   Flytskjema over produksjonen (hvis mulig råvarer (inkludert vann) og energi inn, prosesser som inngår, produkter ut, avfall (biprodukter) og avløpsstrømmer ut
b. Mengder i de ulike strømmene i flytskjemaet (i utgangspunktet per år, men kortere tidsperiode(r) kan være aktuelt)

2. Hva er gjeldende krav knyttet til utslipp (både vann og luft) for din bedrift?

3. Hva er deres vannrensnings metoder?
   Flytskjema som viser hvilke vannstrømmer som behandles og hvilken del av produksjonen som inngår (kan allerede inngå i flytskjema for produksjonen)
   a. Hvilke(n) vannbehandlingsmetode(r) benyttes?
   b. Hva er bakgrunnen for valget av denne/disse metoden(e)?
      i. Hvor lenge har de benyttet metoden(e)? Hva er grunnen til at de evt. byttet metode?
      ii. Knyttet til sparing av energi/materialer/kjemikalier?
      iii. Knyttet til mulighet for gjenvinning og gjenbruk (f.eks. vann/organisk stoff/metaller/næringssalter)
   c. Noen typiske driftsutfordringer?
   d. Driftskostnader (kjemikalier; hvilke og mengder, energi; f.eks. til lufting og pumping)
   e. Hva gjør dere med det rensede avløpsvannet (utslippssted og dybde)?
4. Hvor mye avløpsvann renser dere?
   a. Hvor store vannmengder og hvordan varierer disse over døgnet, uka og sesong?
   b. Hvordan varierer stoffbelastningen på innløpet til renseanlegget; hvilke parametere måler de på innløpet (f.eks. suspendert stoff, KOF, BOF, TOC, metaller?
   c. Flere avløpsstrømmer som samles og behandles samlet?
   d. Hvilke strømmer behandles ikke (f.eks. kjølevann)?

5. Hva er gjenværende i avløpsvannet etter behandlingene?
   a. Hvilke parametere måler de? Hva er styrende parameter?
   b. Noen utslippsgrenser som (periodevis) ikke overholdes eller man er veldig nær?

6. Hvordan er deres slamhåndtering?
   a. Hva slags slamtyper har dere?
   b. Hvordan behandler dere de ulike slamtypene?
   c. Varierer kvaliteten på slammet mye?

7. Hva gjør dere med slammet etterpå?
   a. Er det noe i slammet det er verdt å ta vare på?

    b. Hvor mye kommer til nytte internt og hvor mye eksternt – hvor og til hva?
    c. Hvor mye blir deponert og /eller brent?

8. Hvordan kvalitetssikres vannrensningen og slammet – daglige rutiner/ukes/måned?

DEL 2. Utdypende

1. Hva er deres nåværende verdiskapning innen slam og avløpsvann – ved tanke på gjenbruk?
    a. Hvor mye rent vann eller andre innsatsfaktorer (råvarer) sparer dere på å gjenbruke renset vann og «slam»?
    b. Lønner det seg økonomisk (i kroner og øre)?
    c. Har dere sett på hva dette har å si for CO2-utslippet deres?

2. Har dere planlagt å adoptere gjenbruk inn i deres verdikjede/ produksjon?
3. Om ja; hvordan? →
    a. hvorfor (akkurat) dette ble gjort?
    b. hvor dette passer inn i flytskjemaet
    c. hvilke ekstra innsatsfaktorer som trengs?
    d. evt. Hvilke utfordringer har dere møtt?
4. Om nei; Hvorfor ikke?
5. Dersom du kunne endre noe av prosessene for å oppnå en mer miljøvennlig produksjon, hva ville du endret?
6. Hva anser du er den viktigste faktor for å oppnå en bærekraftig produksjon, og gjør din bedrift dette?

Appendix II. Transcription of interview with Norske Skog

Transkript – Norske Skog intervju 4.februar
Lengde: 1t 24 min

DEL 1. Generelle

Prosess ingeniør

a. Hva er deres (hoved) produksjonsprosesser?
   Magasinpapir av tømmer
   Tømmerrenseri – kappa, barka, hogga til flis, raffinere flisen så de skal få frigjort og binde seg bra, fibret blir bleket, papir maskin – blandet ut med vann, fiber kjørt ut på virer – avvanna, kjørt inn for å få rett farge, press filter for å få ut vannet,
   Bi produkt: bio gass og biorest, flis til brensel
b. Mengder i de ulike strømmene i flytskjemaet (i utgangspunktet per år, men kortere tidsperiode(r) kan være aktuelt)

9. Hva er gjeldende krav knyttet til utslipp (både vann og luft) for din bedrift?
   a. (Be om å få (tilsendt) gjeldende utslippstillatelse → KOF, SS, Forsor totalt, nitrogen

10. Hva er deres vannrensnings metoder?

   a. Hvilke(n) vannbehandlingsmetode(r) benyttes?

   Mekanisk rensning på inntaksvannet; roterende filter – tistren får de vann fra Sandfilter på kjelevannet

   Vannet går direkte i prosessen og til kjøling, kjølevannet er bare sendt rett ut i elven om det ikke er innom prosessen.

   Vannet tas inn via hovedrør-

   Vannet blir varmet og tas tilbake til prosessene; siden det er allerede varmet opp og renset. Gjenvinner fiber og vannet i prosessen.

   Prosessvannet – inntaksvannet renses ikke veldig – det burde bli renset bedre

   Gjenvinnes slik; Skive filter – kjørt inn først påleggsmasse i filteret så suger til seg fiberen og tar ut for-filtrat; bygget filterkake. Bygger seg opp. Neste sone tar man ut *klarfiltrat*, nærmer seg slutten så tar man *superklarfiltrat*; setter vannet tilbake i prosessen fra de to siste prosessene.

   Prosess-vannet: sedimenterings basseng – fast material skal sedimentere og presses også brennes det slammet

Vannet som går videre som inneholder til kof – går til firetrinns biologisk renseanlegg og noe skal til metan reaktor

Det som skal til metan reaktor går til to basseng for å slippe/frigjøre VFA, og klargjøre kof'en så det skal kunne produseres biogass fra næringen i vannet. Etterpå pumpes det inn i reaktoren – produserer gass – gassen renses- og komprimeres til 250 bar – får to typer FLAK som de henter

Avløpsvannet fra biogass reaktoren går sammen med det andre vannet og inn til to luftrør og til ettersedmienteringsbasseng. En del av det blir sirkulørt tilbake til luftrørene og vannet fra ettersediterningsbasseng til tertiær for å ta ut som ikke ble fjernet før med flotasjonsbasseng.

Vannet inneholder; fyllstoff, fine små partikler, det skal være rent

b. Hva er bakgrunnen for valget av denne/disse metoden(e)?
   For å fjerne Kof og det er dårlig med alternativene
   i. Hvor lenge har de benyttet metoden(e)? Hva er grunnen til at de evt. byttet metode?
      Det ble bygget i 93 – ny metode med biogass reaktor som er større
   ii. Knyttet til sparing av energi/materialer/kjemikalier?
      Inntekt på gassen de selger
   iii. Knyttet til mulighet for gjenvinning og gjenbruk (f.eks. vann/organisk stoff/metaller/næringssalter)
      Gjenbruker ikke mer vann, men selger gass og trailere som skal begynne med biogass.
c. Noen typiske driftsutfordringer?
   Sedimenteringsbassenget – grove partikler bygger seg opp og får material som skal synke til å flyte. Biorest, bioslam – bli kvitt det. Tidligere blitt brent, dårlig brennverdi,
d. Driftskostnader (kjemikalier; hvilke og mengder, energi; f.eks. til lufting og pumping)
   Mye kostnader knyttet til dette. Kjemikaler koster. Næringsstoffer. Energi til rund pumping og luft i anlegget.
e. Hva gjør dere med det rensede avløpsvannet (utslippssted og dyp)? Se også del 2.
   Sluppet til Tista – vet ikke om dybde

11. Hvor mye avløpsvann renser dere?
   a. Hvor store vannmengder og hvordan varierer disse over døgnet, uka og sesong?
      200-300-350 liter per sekund, varierer ikke mye på døgnet, men om det er stopp vil det variere. Sesong variasjon grunnet sommeren blir det brukt mer kjølevann, kjølevannet går rett tilbake til elven
   b. Hvordan varierer stoffbelastningen på innløpet til renseanlegget; hvilke parametere måler de på innløpet (f.eks. suspendert stoff, KOF, BOF, TOC, metaller?

Måler: SS, og det varierer veldig: 500 mg/L – 2000 mg/L
Vann til renseanlegget: 20 000 kubikkmeter i døgnet varierer fra 15-25

Kof måles fra sendimenter til bio til 1500 mg/l – 3000 mg/l
Fosfor, nitrogen – døgnmiddel verdier

c. Flere avløpsstrømmer som samles og behandles samlet?
   Ja, alle fabrikkavsnitt
d. Hvilke strømmer behandles ikke (f.eks. kjølevann)?
   Kjølevannet,

12. Hva er gjenværende i avløpsvannet etter behandlingene?
    a. Hvilke parametere måler de? Hva er styrende parameter?
    SS, KOF, ufiltrert: 150-300 og filtrert: 140-200, fosfor; 0,04- 3 mg/l, total nitrogen: 4-11 mg/L
    b. Noen utslippsgrenser som (periodevis) ikke overholdes eller man er veldig nær?
       Døgnverdier er over inni mellom, problemer med biogass reaktor som har ført til man er over på det meste

13. Hvordan er deres slamhåndtering?
    a. Hva slags slamtyper har dere?

Sedimenteringsslammet blir presset sammen med noe av det fra aktiv – biobrensel kjelen – får igjen noe energi, men er mye fukt
Prorest - biorensen: avpresse på aktiv (der bakterier er aktive) delen – det blir kjørt ut til bøndene

    b. Hvordan behandler dere de ulike slamtypene?

Utfordring med behandle slamtyper -

    c. Varierer kvaliteten på slammet mye?

stabil

14. Hva gjør dere med slammet etterpå?
    a. Er det noe i slammet det er verdt å ta vare på?
       Nei – noe sirukuleres i prosessen, men da er det ikke tatt ut som slam
    b. Hvor mye kommer til nytte internt og hvor mye eksternt – hvor og til hva?
    Gir vekk noe av slammet til bønder – bruker ikke noe internt som slam
    c. Hvor mye blir deponert og /eller brent?
       ikke noe deponert – restavfall kun og sand . Alt brennbart brennet 1500 kubikkmeter i døgnet før presset
15. Hvordan kvalitetssikres vannrensningen og slammet – daglige rutiner/ukes/måned?
    Daglige prøver – eget laboratoriet som tar prøver – tørr stoff tas en gang i uken,

DEL 2. Utdypende

7. Hva er deres nåværende verdiskapning innen slam og avløpsvann – ved tanke på gjenbruk?
   a. Hvor mye rent vann eller andre innsatsfaktorer (råvarer) sparer dere på å gjenbruke renset vann og «slam»?
      Gjenvinner vannet og råstoff og fiber med at det fileteres
   b. Lønner det seg økonomisk (i kroner og øre)?
      Energisparing. Bruker 30% av energien for hele østfold – blitt noe mer effektivt etter da. 1% av strømforbruket og energi til Norge
   c. Har dere sett på hva dette har å si for CO_2-utslippet deres?

Slipper varme så mye vann – direkte og indirekte pga strømforbruk

8. Har dere planlagt å adoptere gjenbruk inn i deres verdikjede/ produksjon?
   Om ja; hvordan? →
   a. hvorfor (akkurat) dette ble gjort?
   b. hvor dette passer inn i flytskjemaet → gjenbruk av vann passer inn ved hele produksjonen
   c. hvilke ekstra innsatsfaktorer som trengs?
   d. evt. Hvilke utfordringer har dere møtt?

Jobbes med kontinuerlig – blitt mer bevisst

Mye med å kjøre vannvekslere for å gjenbruke varmen og overføre fra ett fabrikk til et annet.

Møtt utfordringer med vann som er lavenergi – ikke høy temperatur og kan derfor ikke gjenvinne mye energi av det

9. Om nei; Hvorfor ikke?
10. Dersom du kunne endre noe av prosessene for å oppnå en mer miljøvennlig produksjon, hva ville du endret?

    Bruke mer av avløpsvannet til å varme opp vannet som tar inn - men de har bare ett vanninntak til fabrikken som går til kjølevann og prosessvann. Han ville endret dette og delt det slik at man kunne varmet alt prosessvannet med avløpsvannet
11. Hva anser du er den viktigste faktor for å oppnå en bærekraftig produksjon, og gjør din bedrift dette?

Ta vare på energi og bruke den best mulig og unytte de ande råstoffene. Blir sluppet mye flis og fiber som kanskje kunne ha blitt brukt , men grunnet ikke alle avdelinger virker optimalt så får man ikke utnyttet dette.

Driftssikkerhet: spart inn på personell som kan gå utover driftssikkerheten.

Årsproduksjon: 500 000 – 485 000 tonn

Appendix III. Transcription of interview with SCA

Transkripsjon SCA møte 15.02-19

NORSK VERSJON av spørsmål til bedrifter

DEL 1. Generelle

Hvem er med: Bent Westin; Miljøteknikker med ansvar for vannrensing fra start til slutt.
Hannah – prosess ingeniør vann
Kjersti Andersson – Prosess ingeniør

a. Hva er deres (hoved) produksjonsprosesser?

SCA örtviken	SCA Sundvall/ ØSTRAND
Produserer papir, ulike papir typer. En maskin gjør forbedret papir til Ikea kataloger osv. 5% tradisjonelt papir, resten er forbedret papir. Koker ikke massen. Raffinerer som sliper massen, også bleker den med kjemikaler. Ingen klor, men lut. I denne prosessen gjør man massen så faller det mye ut – fra veden, som de skal ta rede på – mye kullhydrater, ligningen, fett , aske(?)	Sulfat:Papirmasse, men ikke papir – gir til ortviken og gir til hygieneartikler. Koker massen – og går mot 900 000 tonn per år. Bleker massen: ECH- elementær klorfritt – bleker med: Klodioksid TCF – helt klorfritt: bleker med vaterperoksid? CTNP- lite kjemikaler og maler massen ned til papirmassen – annet kvalitet til sulfatmassen – blekes med vaterperoksid

b. Mengder i de ulike strømmene i flytskjemaet (i utgangspunktet per år, men kortere tidsperiode(r) kan være aktuelt)

Ortviken	Sundvall
95% av vannet som kommer inn blir papir eller energi Tar inn mye vann: kjølevann helst som ikke renses. Ca 30-35000 kubikk per døgn er prosessberørt	Ca 45 000 kubikk per døgn, som må renses.

16. Hva er gjeldende krav knyttet til utslipp (både vann og luft) for din bedrift?

Ortviken	Sundvall
To typer krav: regions krav og EU krav Reg: Hvor mye: Forsor, Nitrogen, COD, SS X antall kilo per produserte tonn enhet (EU)	Alle utslipp til vann er kg per masse. Så det kommer an på hvor bra fabrikken går. Svenske myndigheten har satt det til:

13 ton COD pr døgn, 9-10 tonn cod pr døgn Fosfor: 15 kg per døgn – 6-7 kg i snittet Nitrogen: 320 kg ; ligger på 220- 280 kg pr døgn SS = 2,1 tonn er lov døgnet, men ligger på 0,3 tonn per døgn	COD: 16 kg per masse Fosfor:0,030 kg per tonn masse Nitro: 0,30 pr kg tonn masse SS: 2,2 kg pr tonn masse

17. Hva er deres vannrensnings metoder?
    a. Hvilke(n) vannbehandlingsmetode(r) benyttes?

Ortviken	Sundvall
Mekanisk metoder, biologisk metode hvor de løse partiklene løses opp, har mulighet til kjemisk rensing, men de flokkerer / felning. Men dette anvendes ikke	Mekanisk og biologisk. Sendimenterer det første innkommende vannet, også biologisk, så sedminterer de før det slippes ut

    b. Hva er bakgrunnen for valget av denne/disse metoden(e)?

Ortviken	Sundvall
Det er valgt grunnet myndighets krav – første var bare at det skulle ta bort SS for å unngå fiberoppsamling til vanns. Fjerning av COD, det er kravene som styrer – de gjør kun det som kreves.	Samme gjelder her – man ønsker så bra rensning som mulig, men for så lite man kan. Og fordi de ønsker så fin masse som mulig å selge

        i. Hvor lenge har de benyttet metoden(e)? Hva er grunnen til at de evt. byttet metode?

Ortviken	Sundvall
Utviklet metodene etter kravene som ble satt. Første; 1966 – sedimenteringsbassenget, biologisk 1978, utviklet etterpå – cod reduksjon på 50%, og nå på 90%. begynte med lagunen , men den er veldig energikrevende . 2005 og 2012 at man bygget ut, pga produksjonen ble større og for å klare	Første sedimentering rundt 67, senere har de gjort antall forsøk med biologisk rensing 80-90 tallet. 2003 bygges prinsippet den rensning de har i dag med sedimentering før og etter som også er bygget ut i år 2019 – for å doble kapasitet

        ii. Knyttet til sparing av energi/materialer/kjemikalier?

Ortviken	Sundvall
Ikke opplevd sparing, heller motsatt – koster energi dermed koster det mer og mer. Selv om man forsøker å spare inn og trykke ned kostnadene på energi og kjemikaler	Blir ikke store effekt om de sparer mye EL

        iii. Knyttet til mulighet for gjenvinning og gjenbruk (f.eks. vann/organisk stoff/metaller/næringssalter)

Ortviken	Sundvall
Ingen gjenbruk – bruker kun fiber eller bioslam som anvendes på nytt. Tar bort vannet og brenner for energi, men har aldri	Nei

sett på å ta tilbake metaller i vannet eller ta tilbake forsfor. De har flokkasjon anlegget hvor man tar tilbake fiber. Der de bleker sin masse, så spiller de fint material i form av fiber- der forsøker de å sende tilbake til papirmaskinen som biomasse	

c. Noen typiske driftsutfordringer?

Ortviken	Sundvall
Hele dagen er det utfordringer, og prøve å klare de nye kravene . TOC analysator som skal tilpasse seg slik at det ikke får for mye nitrogen eller COD. Nå tar de prøver per dag, og tilpasser da, men da kan det tilpasses og styre hver 10ende minutt ved sensor	De bruker TOC sensor siden 2009. De har for lite nitrogen og forsor i anlegget fordi de har for lite på innløpet – men det er reguleringen på hvor mye som kan slippe ut. Derfor må de tilsette for at bakteriene skal kose seg, også må det tas bort – balanse gang

d. Driftskostnader (kjemikalier; hvilke og mengder, energi; f.eks. til lufting og pumping)

Ortviken	Sundvall
Mye kostnader – ingen tall. Tilsetter mye kjemikaler – nitrogen og fosfor. Kjøper også fluksjon kjemikaler så SS skal skilles bort Skumdempere – lut fra prosessen. Mikro organismer som produserer skum som må dempes eller fjernes. Prøver hele tiden forminske kostnader Få inn syre og lufting, stor kostnader. Finne best mulig løsning og har fiberslammet som er bra brensel, men bio slammet er ikke. Energikrevende. Kjemikalene er knyttet til slammet for å få bort vannet Normalt tilsettes luft i biodammene så det skal godgjøres til syre – dette må tilsette som flytende syregass i lufte for berike opp luften. Utmaning – minske syregassen	Store utmaning: veldig varierende hva de får til med rengjøring – kan mikro organismene kan forsvinne fordi det er for lite, og noen ganger er det for mye. Varierende mengde inn med cod.

e. Hva gjør dere med det rensede avløpsvannet (utslippssted og dybde)?

Ortviken	Sundvall
Slippes ut i sundvannsfjæren – lang tube slik at det slippes ut der det er mest strøm Ser tidligere synder – fiberbanker – myndighetene som har sett på de om det kan tas bort	Slippes ut i viken skjønviken går en elv som tar det med seg Indalsälven – mye strøm så trenger ikke tuben. Har gamle synder utenfor

18. Hvor mye avløpsvann renser dere?

Ortviken	Sundvall
35 000 kubikk per døgn	45 000 kubikk per døgn

a. Hvor store vannmengder og hvordan varierer disse over døgnet, uka og sesong?

Litt mindre på vinteren og litt mer på sommeren. Temperaturen er et problem – fordi det ferskvannet kommer fra Indalsälven Har kjøletårn, men for lave	Kjøletårn. Vinteren er det enkelt å kjølevannet, mens på sommeren er det vanskelig fordi temperaturen er for høy Bruker mindre vann på vinteren

b. Hvordan varierer stoffbelastningen på innløpet til renseanlegget; hvilke parametere måler de på innløpet (f.eks. suspendert stoff, KOF, BOF, TOC, metaller?

Ortviken	Sundvall
Varierer veldig mye. Skiller veldig mellom bra dager med 40-50 per døgn med andre dager 140-150 tonn per døgn SS. Avhenger av produksjon på COD andelen. BRA produksjon = mye. Lite produksjon= lav	Varierer veldig mellom 3 tonn – 25 tonn SS Normalt 5-12 tonn Om noe stopper så stopper alt. Ingenting inn til rensning og da blir det fra bunn til topp ved slike stopper.

c. Flere avløpsstrømmer som samles og behandles samlet?

Ortviken	Sundvall
Det meste behandler samlet, men filtrat som separat behandler pga er vanskelig vann Vannet behandles i 5 dager	Samlet, men deler opp det fra blekeriet : går inn til før sedimentering og fiberfilter og varmevekslere som tar det resterende vannet (42.02 på opptak)

d. Hvilke strømmer behandles ikke (f.eks. kjølevann)?

Ortviken	Sundvall
Behandler ikke kjølevannet, men all vann som er prosessberørt som behandler	Behandler ikke kjølevannet, og en liten strøm kondensat som ikke tas og inneholder 3 tonn cod, men mesteparten av dette vannet går tilbake til blekeriet, men en andel av dette går ut. Om det blir havari – kan en pumpe vann gå rett ut? For om det hadde gått inn, ville det stoppet opp alt

19. Hva er gjenværende i avløpsvannet etter behandlingene?

a. Hvilke parametere måler de? Hva er styrende parameter?

Ortviken	Sundvall
En del overskuddet av fosforet og cod (i form av ligninger som er den mest komplekse molekyler). SS i form av 300 kg mikro	En del metaller, kadium, klorat, aox,

organismer – ingen krav på metaller , men skal rapporteres og ha orden på det	

b. Noen utslippsgrenser som (periodevis) ikke overholdes eller man er veldig nær?

Ortviken	Sundvall
Strenge krav – men max en eller to går de over grense, men på mnd målingene	Vanskelig å holde i fjor, og hadde seks ganger over på mnd målingene. Det var ikke et normalt år, og forventer overholde fremover.

20. Hvordan er deres slamhåndtering?

a. Hva slags slamtyper har dere?

Ortviken	sundvall
Fiberslam fra ved – 78 tonn fiber per døgn Bioslam 25-30 tonn per døgn Prosess slam 15 tonn per døgn = 110 TONN PER DØGN fra alle strømmer	10 tonn fiber slam per døgn – rent fiberslam som tas ut seperat 35-40 tonn bioslam per døgn når de er oppi full produksjon

b. Hvordan behandler dere de ulike slamtypene?

Ortviken	
Flokkasjon fra blekeriet – små bobler med luft som gjør at det flyter – tilsetter også polymer så de skal trekke seg sammen slik at boblene treffer de Bioslam: gravitasjon – centrifuger, 18-19% tørrhet Fiberslammet: går til silbrandspressen; valspresse som tar bort mer vann – 50% tørr slam	Fiber: sendimenterer i før sendimetering, også skrupresser så det avvannes – tilsettes kjemikaler og avvannet også brennes det med barken i barkpann Bio: 07-08% - sendes i centrifuger som avvannes, så blandes det inn med lut, også brennes det i sodapanna. Inneholder mye nitrogen, så det kan ikke blandes med fiber pga blir for mye NOX.

c. Varierer kvaliteten på slammet mye?

Ortviken	Sundvall
Varierer ikke veldig mye	Varierer ganske mye, men klarer avvanne til den grad de trenger polymer kostnader øker når det vanskelig

21. Hva gjør dere med slammet etterpå?

Ortviken	Sundvall
Panner – brenner opp med bark En panne som brenner slam – boblene bed – så får god innblanding fordi slammet er for bløtt.	Brenner fiberslammet i boblene bed med barken Kan ikke ta ut bioslammet om det ikke blandet med luten og man må ha konstant flyt med lut for at det skal gå.

a. Er det noe i slammet det er verdt å ta vare på?

Ortviken	Sundvall
Slammet fra blekeri tas tilbake og lager papir. Asken – ser på hva denne kan brukes til Prosjekter på det – veier i skogen med asken. fiberslammet – er godt å brenne prøver heller produsere minst mulig slam – ikke finne noe bruksområdet Barken: inneholder mange kjemiske goder som kan brukes i jordbruket eller medisin, men dette har jobbet med å presse ut vannet fra barken. Garvesyre av bark vannet – ulike prosjekter med bark vannet. Vanskelig å rense inneholder 70 000 ml COD	Vurdert å selge fiberslammet. Men har ikke noen nære å selge til så det lønner seg pga transport kostnader Bioslam: Har god anvendig, men mange gode muligheter som biorafferi – så det kan omgjøres til gas Litt for bløtt

b. Hvor mye kommer til nytte internt og hvor mye eksternt – hvor og til hva?

Ortviken	Sundvall

c. Hvor mye blir deponert og /eller brent?

Ortviken	Sundvall
Deponerer ingenting – kun i så fall aske	Ingenting deponeres

22. Hvordan kvalitetssikres vannrensningen og slammet – daglige rutiner/ukes/måned?

Ortviken	Sundvall
Døgnprøver og egen lab og analyserer både sine og Sundsvall sine. Tar prøver hver dag av slammet	Analyserer prøver – og hverandres prøver . prøver hvert 10 minutt – vannet. Tar tester av slammet

DEL 2. Utdypende

12. Hva er deres nåværende verdiskapning innen slam og avløpsvann – ved tanke på gjenbruk?

Ortviken	Sundvall
Energi av bioslammet får ut mer energi som er verdiskapende. Sparer ikke noe råvarer.	Sparer inn i inndustingen -

a. Hvor mye rent vann eller andre innsatsfaktorer (råvarer) sparer dere på å gjenbruke renset vann og «slam»?

Ortviken	Sundvall
Sparer ikke	Sparer ikke

b. Lønner det seg økonomisk (i kroner og øre)?

Ortviken	Sundvall
Slammet er biprodukt de ønsker kvitte seg med og få minst mulig av	Bioslammet ønsker de minst mulig av. anarobe gir minst mulig bioslam. Men det er ikke nok teknologi på dette

c. Har dere sett på hva dette har å si for CO2-utslippet deres?

Ortviken	Sundvall
-	-

13. Har dere planlagt å adoptere gjenbruk inn i deres verdikjede/ produksjon?

Ortviken	Sundvall
Nei. Må ha en ren prosess og derfor blir det vanskelig å gjenbruke slammet. Pågikk en del forskning at man kunne bioslammet – noe byggmateirale , bioboards. Ikke blitt noe av dette	Begynt med å gjenbruke prosessvannet inndunstingen → går til blekeriet isteden for fersk vannet og kastosering Mindre vann brukes Vannet er allerede varmet – gjenbrukes

14. Dersom du kunne endre noe av prosessene for å oppnå en mer miljøvennlig produksjon, hva ville du endret?

Ortviken	Sundvall
Anaerobe- – bruker nå så mye penger på lufting. Men dette kan oppnå flere problemer	Ønsker seg et ekstra steg i renseprosessen, en type sluttsteg. Så man kan være sikrere om det oppstår problemer. MBR: setter ned en membranfiltrering så det trenges ikke noen sedimenteringsbassenger som gir rent vann, men krever mye energi. Null SS. Gir også muligheter for å etteranvende vannet

15. Hva anser du er den viktigste faktor for å oppnå en bærekraftig produksjon, og gjør din bedrift dette?

Ortviken	Sundvall
Har en bærekraftig produksjon, de er en stor skogeier – de skal da forvalte denne skogen på best mulig måte og minimerer sin påvirking på det ytre. Kan avende mindre kjemikaler, og vann. Få biogas. Metallet gjør at det ikke kan anvendes	Bli mer sirkulære – etterbruke bioslam og aske. Men det finnes regelverk som hindrer de å gjøre dette. Teoretisk burde det kunne etterbrukes

Ortviken	Sundvall
PH: inn: 7 Ut: 7,2-7,3	PH inn: 4-12 (5,5-7-8, snitt 6.5) UT: 7,5 – 7,8

Appendix IV. SCA Örtviken Discharge Permit

Vår referens
Charlotta Lindberg
SCA Ortviken/Yttre miljö
060-19 40 63
charlotta.lindberg@sca.com

MÅNADSRAPPORT

2018-08-22

Reg nr
Dnr -555-3548-18

Informationsklassificering
OFFENTLIG

Utsläpp till recipient

Enl verksamhetstillståndet

		Oktober	Riktvärde månad
Flöde	m³/min	22,9	
Susp	g/l	0,002	
Susp	t/dygn	0,08	2,8
COD	mg/l	312	
COD	t/dygn	10,3	13/16
COD-reduktion	%	88,3	
Kväve	mg/l	5,2	
Kväve	kg/dygn	171	320
Fosfor	mg/l	0,08	
Fosfor	kg/dygn	2,6	15

Enl BAT-AEL (tabell 16 och 20)

BAT-AEL		Oktober	Ack 2018	Gränsvärde* År
Susp	ton	2	2	26
COD	ton	319	319	366
Kväve	kg	5 288	5 288	6 011
Fosfor	kg	82	82	616

*Gäller från 1 okt 2018

*Gränsvärdet från COD beräknas viktat utifrån förhållandet oblekt/blekt massa.

Appendix V. Transcription of interview with Kristiansand Municipal Water and Sewage Department

Transkripsjon Kristiansand Kommune

Per Borø – driftsleder på odderøya renseanlegg
Tore Magnussen – biolog og saksbehandler innen utslipp, seksjonsleder avløp

DEL 1. Generelle

a. Hva er deres (hoved) produksjonsprosesser?
   Flytskjema over produksjonen (hvis mulig råvarer (inkludert vann) og energi inn, prosesser som inngår, produkter ut, avfall (biprodukter) og avløpsstrømmer ut

   Renser avløpsvann – mekanisk og kjemiskrensning og produserer slam

b. Mengder i de ulike strømmene i flytskjemaet (i utgangspunktet per år, men kortere tidsperiode(r) kan være aktuelt)

23. Hva er gjeldende krav knyttet til utslipp (både vann og luft) for din bedrift?

Ikke krav til luft – rense 90% på fosfor – fikk nytt rensekrav og dermed var dette det mest brukte
Sekundær rensekrav; som ikke har trådd i kraft enda
Kravene står listet i rapporten -

24. Hva er deres vannrensnings metoder?
    Flytskjema som viser hvilke vannstrømmer som behandles og hvilken del av produksjonen som inngår (kan allerede inngå i flytskjema for produksjonen)

   a. Hvilke(n) vannbehandlingsmetode(r) benyttes?

Mekanisk rensning og kjemisk rensing – MMBR
Mekanisk: kommer inn ekstra filter- grovrist – største søpla – spaltåpning 5mm, sand og fett fjernes,-HER KOMMER BIO- kjemisk rensning og det tilsettes jernklorid og feller ut fosfor

   b. Hva er bakgrunnen for valget av denne/disse metoden(e)?

Nye krav og dermed måtte det legges til ekstra ledd

      i. Hvor lenge har de benyttet metoden(e)? Hva er grunnen til at de evt. byttet metode?

Jernklorid brukes fordi det funker godt i tanken – det er fjerner også fosfor.
Aluminiumen funker ikke godt i renseanlegg fordi det vanskelig å spre utover fordi det er hardt

Kalk tetter rørene

ii. Knyttet til sparing av energi/materialer/kjemikalier?
Nei – knyttet til rensekrav

iii. Knyttet til mulighet for gjenvinning og gjenbruk (f.eks. vann/organisk stoff/metaller/næringssalter)

JERNKLORID: BINDER seg sterkt til fosfor og dermed kan hjelpe bryte det ned. Fjerner også Kof og bof, men det det ville vært mer naturlig med en biologisk prosess fordi der spiser bakteriene alt.

c. Noen typiske driftsutfordringer?

Mye fiber – mye rart i avløpsvannet –

d. Driftskostnader (kjemikalier; hvilke og mengder, energi; f.eks. til lufting og pumping)

Driftsbudsjett er 18 millioner i året

Tonn fellings kjemikaler i uka

e. Hva gjør dere med det rensede avløpsvannet (utslippssted og dybde)?

Byfjorden på ca. 50 meters dyp og følger elvestrømmen

25. Hvor mye avløpsvann renser dere?
    a. Hvor store vannmengder og hvordan varierer disse over døgnet, uka og sesong?

1000 kubikk i timen

b. Hvordan varierer stoffbelastningen på innløpet til renseanlegget; hvilke parametere måler de på innløpet (f.eks. suspendert stoff, KOF, BOF, TOC, metaller

Måler SS, kof, bof, tung metaller. Slammet måles også for tung metaller.
Varierer veldig i forhold til været
Total fosfor ml/ kubikk – mye regn er det tynt og når det er tørt er opp til ti

c. Flere avløpsstrømmer som samles og behandles samlet?

Får inn overvann, spillvann, industrielt

Alle avløpsstrømmer samles og behandles dermed samlet . to linjer, men blandes

d. Hvilke strømmer behandles ikke (f.eks. kjølevann)?

Benytter kun kjølevann i varmevekslere – ikke operativt

26. Hva er gjenværende i avløpsvannet etter behandlingene?

    a. Hvilke parametere måler de? Hva er styrende parameter?
       Fosfor – viktigste for dem, kof, bof, SS

b. Noen utslippsgrenser som (periodevis) ikke overholdes eller man er veldig nær?

Om vannet er for tynt inn fordi det må renses 90% av det

27. Hvordan er deres slamhåndtering?

Kjemisk felt slam – fjerner fiber, skal inn i råtneanlegg og produsere metangass

a. Hvordan behandler dere de ulike slamtypene?

Sier det står regninger for fiber slam også . dermed har de bio og fiber slam

b. Varierer kvaliteten på slammet mye?

Stabil kvalitet

28. Hva gjør dere med slammet etterpå?

Sentrifugeres også til støleheia

a. Er det noe i slammet det er verdt å ta vare på?
   Nei – det gjøres ikke. Er vanskelig å løse ut fosforet
b. Hvor mye kommer til nytte internt og hvor mye eksternt – hvor og til hva?

Sendes til støleheia og kan eventuelt brukes til jordforbedring

c. Hvor mye blir deponert og /eller brent?
   ristegods deponeres – 30 tonn i uka – brennes ikke

29. Hvordan kvalitetssikres vannrensningen og slammet – daglige rutiner/ukes/måned?

Leverer vannprøver til lab – annenhver uke – 0,5 L sendes inn. Auto prøvetakere – tar inn prøvene inn ei bøtte også tas det ut en prøve av det dermed blir det

DEL 2. Utdypende

16. Hva er deres nåværende verdiskapning innen slam og avløpsvann – ved tanke på gjenbruk?

    Får gass til å drive anlegget fordi det er gir strømmen de trenger til drifte råtneanlegget og med overskudd resten av anlegget

    a. Hvor mye rent vann eller andre innsatsfaktorer (råvarer) sparer dere på å gjenbruke renset vann og «slam»?

    b. Lønner det seg økonomisk (i kroner og øre)?

    c. Har dere sett på hva dette har å si for CO_2-utslippet deres?

17. Har dere planlagt å adoptere gjenbruk inn i deres verdikjede/ produksjon?
    Et ønske, men er ikke gjort nå
18. Om ja; hvordan? →
    a. hvorfor (akkurat) dette ble gjort?

Termisk hydrolyse hadde vært bra grunnet de allerede har råtnetanken, og prosessene kan tilpasses. Da kan det behandles mer slam – og man kunne sette på reduksjon av kjemikaler for å få benyttet noe av innholdet.

b. hvor dette passer inn i flytskjemaet

c. hvilke ekstra innsatsfaktorer som trengs?

Nei – passiv prosess

d. evt. Hvilke utfordringer har dere møtt?

Har ikke blitt gjennomført enda

19. Om nei; Hvorfor ikke?

20. Dersom du kunne endre noe av prosessene for å oppnå en mer miljøvennlig produksjon, hva ville du endret?

Ville endret fellingen så man ikke bandt opp fosforet – fordi det binder seg til jernklorid. Fosforet kunne benyttes til andre ting, om det hadde kunne blitt tatt ut av prosessene.

Kalk kan blandes inn i slammet og få øket slammet til ca 12,5 og da dør bakteriene og det blir hygenisert og kalk sammen med vann vil starte en oppvarming prosess. Den kan stige til over 60 grader – og da dreper du de andre bakteriene. Samtidig som fosforet fremdeles er tilgjengelig for plantene – og det vil lages mye slam. Kalk vil stoppe til alle rør – dette må det tas høyde for. Derfor burde det drives med kalk på en økonomisk måte

21. Hva anser du er den viktigste faktor for å oppnå en bærekraftig produksjon, og gjør din bedrift dette?

→ Få tilbake fosfor og utnytte slammet bedre; sirkulær økonomi

Termisk hydrolyse – kan redusere mengde og gir mer gass – stabilisert slam. Ingen HMS risiko . Tar mye plass
Når man råtner ut slam vil det bli oppkonsentrert av tung metaller

Benyttes Jernklorid

Ph inn: 7 – 7,5 ut: 6-6,5

Appendix VI – Transcription of interview with Borregaard

Transkripsjon Borregaard 4.3 . 19

DEL 1. Generelle

Simon Simonsen: Forsker på Borregaard fra 2011. For å jobbe med renseanlegg. Biorenseanlegg.

Morten Lislerud: Prosesseier for renseanlegg. Jobbet med anlegget siden 2013. ansvarsområde: prosessene

a. Hva er deres (hoved) produksjonsprosesser?

Henter ut cellulose fra treverket å lager produkter – liten aktør; 150 000 tonn i året -
Tar også ut alle sidestrømmer – etanol fra sukkeret –
inndampes så den er 50% tørr stoff – så til ligning fabrikk hvor det lages nye produkter. – verdensledende. Spray tørkes til slutt – pulver; 150 000 tonn.
Vanillin fra treflis; 1500 tonn

b. Mengder i de ulike strømmene i flytskjemaet (i utgangspunktet per år, men kortere tidsperiode(r) kan være aktuelt)

30. Hva er gjeldende krav knyttet til utslipp (både vann og luft) for din bedrift?
Norske utslipp. KOF grense på 69 m/l – krav fra miljødir. Forhandles hvert 5 år.

31. Hva er deres vannrensnings metoder?
Kondensat fra prosessene som renses – det er en liten andel som går til andre prosessene eller Glomma

a. Hva er bakgrunnen for valget av denne/disse metoden(e)?
Anaerob bio mesofilt system 36 grader og filter. Atom-mikro filter

i. Hvor lenge har de benyttet metoden(e)? Hva er grunnen til at de evt. byttet metode?

Anaerob er valgt fordi det er en legionella sikker metode + gir biogass
Hadde legionella problemer pga spraytørkere og igjen 2008 – men det var problem med det gamle biologiske renseanlegg grunnet legionella i lufte bassengene. Dermed var det behov for nytt anlegg.
Kapasitet til 100 tonn KOF i døgnet

ii. Knyttet til sparing av energi/materialer/kjemikalier?

iii. Knyttet til mulighet for gjenvinning og gjenbruk (f.eks. vann/organisk stoff/metaller/næringssalter)
→ Ikke knyttet til dette; det var om legge ned eller bytte rensemetode

b. Noen typiske driftsutfordringer?
For øyeblikket; er det kun utfordringer knyttet til ligning

Har to snille kondensat – har filter som hjelper mot overraskelser derfor er det svært lite utfordringer

c. Driftskostnader (kjemikalier; hvilke og mengder, energi; f.eks. til lufting og pumping)
   → vedlikeholdsbudjsett på ca 1 million
   Kjemikalene kostnadene er høye pga natrion lut til pH justering – 10 mill når prisen var 2250 kr tonnet

d. Hva gjør dere med det rensede avløpsvannet (utslippssted og dybde)?
   Til Glomma – dykket ned ca 2 meter under overflaten avhengig av årstiden. Den er alltid under, men ikke kjørt 10 meter ned.

32. Hvor mye avløpsvann renser dere?
    8-9 000 kubikk meter i døgnet

    a. Hvor store vannmengder og hvordan varierer disse over døgnet, uka og sesong?
       Kun varierer med produksjonens som tilsier at det kan være mindre
    b. Hvordan varierer stoffbelastningen på innløpet til renseanlegget; hvilke parametere måler de på innløpet (f.eks. suspendert stoff, KOF, BOF, TOC, metaller?
    Varierer en del i forhold til kvaliteten mellom asitat (KOF:5-6 000 ml/L) og ikke-asitat – tilnærmet null TSS VSS, sulfat innhold 100-200 ml/l og kalsium 90-100 ml/l → kan variere

    Ph inn = 2-3 snitt

    c. Flere avløpsstrømmer som samles og behandles samlet?
    To inn som blandes i buffertank også splittes og fordeles

    d. Hvilke strømmer behandles ikke (f.eks. kjølevann)?
Kjølevann – indirekte brukes. Jobber med å skille vekk kjølevann og spill vannet

33. Hva er gjenværende i avløpsvannet etter behandlingene?
    Vet aldri 100% - de har sine mistanker, men ønsker ikke oppgi
    a. Hvilke parametere måler de? Hva er styrende parameter?
    KOF og BOF måler på utslippet – men internt tss, vss, kof, bof, fosfor , nitrogen , kobber
    Det som ikke renses er ligning – det er for sterkt til å brytes opp
       Alle parameterer som er på utslipps tillatelser undersøkes
       Ligning skulle ikke vært i kondensatet fordi det er tapte penger
    b. Noen utslippsgrenser som (periodevis) ikke overholdes eller man er veldig nær?
    Godt innenfor innen rensegrad – men har problemer med andre prosesser til Glomma

34. Hvordan er deres slamhåndtering?

    a. Hva slags slamtyper har dere? Hvordan behandler dere de ulike slamtypene?

Biomassen – løsrevet fra trestammer – avvanner og transportere vekk
Bakterier i reaktoren: PH 7, 36 grader – stamme fra norske skog – så er samme bakterier som kan utvikler seg
Biomassen er den som holdes i bioreaktor – granulært slam – som kun skal være i reaktoren – der noe selges til andre fordi de har mye nok

Det som river seg løs fra granulene – fortykkes , presses og forbrennes og deponeres. Det er ikke god nok kvalitet for å bruke den til jordbruk i Norge, men muligens i utlandet. For mye sink til å brukes i Norge – sinken kommer nok fra trestokken og er der dermed naturlig

b. Varierer kvaliteten på slammet mye?

Det er ikke god nok kvalitet for å bruke den til jordbruk i Norge, men muligens i utlandet. For mye sink til å brukes i Norge – sinken kommer nok fra trestokken og er der dermed naturlig – norsk gran inneholder for mye sink

35. Hva gjør dere med slammet etterpå?
    Noe deponeres og noe brennes
    a. Er det noe i slammet det er verdt å ta vare på?
       Det er for dårlig kvalitet – det som er i bioreaktor er noe annet
    b. Hvor mye kommer til nytte internt og hvor mye eksternt – hvor og til hva?
       Ikke noe internt – men kunne blitt brukt til energi, men er for mye vann i slammet.
    c. Hvor mye blir deponert og /eller brent?
       100 tonn tørt i året
36. Hvordan kvalitetssikres vannrensningen og slammet – daglige rutiner/ukes/måned?

Daglige analyser av KOF inn og ut – tas prøver hver dag og 24 t – tar samleprøver for å vise driften alle dagene i uken. 5 bolker per uke da fre-lør-søn er en.
Automatiske prøver – mengde proporsjonale prøver for å få rett et bilde
Ingen slam prøver

DEL 2. Utdypende

22. Hva er deres nåværende verdiskapning innen slam og avløpsvann – ved tanke på gjenbruk?

Det er ikke rent nok til å brukes i prosessene – vannet har ingen verdi som fysisk substans, men det varme gjenvinnes før det sendes til Glomma – via Østfold Energi

Laget veldig lite slam – det er veldig annerledes anlegg –

12-18 timer er slammet inn i bio reaktoren fordi det er vannløsning derfor er konsentrasjonen i slammet mye lavere –

a. Hvor mye rent vann eller andre innsatsfaktorer (råvarer) sparer dere på å gjenbruke renset vann og «slam»?

b. Lønner det seg økonomisk (i kroner og øre)?

Hadde i teorien ikke lønnet seg – fordi det måtte investeres inn i mer renseteknikk og ha mer filetering og enda et steg eller renseanlegg

Frebar – Fredrikstad kommunale renseanlegg – produserer gassen til bussene
Halvparten av bioslammet sendes der → ikke sikkert hva de gjør med de. Kan hende de bytter ut bakteriekulturen og dermed danner gassen til bussen

23. Har dere planlagt å adoptere gjenbruk inn i deres verdikjede/ produksjon?
24. Om ja; hvordan? →
    Biogassen som dannes – er en form for gjenbruk inn i kjeden – denne danner metan ca 7 million kubikkmeter som brukes internt for spray-tørking

    Erstatter innkjøpt av flytende naturgass – som er sparsommelig
    85% metan innhold – 7 millioner
    a. hvorfor (akkurat) dette ble gjort?
       Erstatte LNG og dermed spare inn penger og gjøre det mer miljøvennlig
    b. hvor dette passer inn i flytskjemaet
       Brukes til å tørke ligning
    c. hvilke ekstra innsatsfaktorer som trengs?
       Ekstra bakterie og kjemikaler for å få opp PH
    d. evt. Hvilke utfordringer har dere møtt?

25. Om nei; Hvorfor ikke?

26. Dersom du kunne endre noe av prosessene for å oppnå en mer miljøvennlig produksjon, hva ville du endret?
    anaerobes anlegg – dersom det kunne vært mulig å gitt et aerobisk trinn ville vært en enorm forbedring. Rensegraden er nå 85% - vil alltid finnes KOF som er nedbrytbar på annet måte og dermed om det hadde vørt mulig med et ekstra trinn som tok vekk mer. Målet er null utslipp.

27. Hva anser du er den viktigste faktor for å oppnå en bærekraftig produksjon, og gjør din bedrift dette?

Bruke penger på å bli bedre og bedre.
Tre er utgangspunktet – som er bra for bærekraftighet og vann energi, men mål er å bruke så mye energi som mulig fra fossil frie kilder. C02 utslipp må bedres. Hva brukes produktene til – stort potensial og fokus på hva man forsker på.

PH: 2-3 justeres til 7 og er da 7 når den går ut.

Appendix VII. Complete list of components for bio-oil

Compounds	*Bio oil wt% low*	*Bio oil wt% high*	*Formula*	*Nedbrytbarhet*	Weight g/mo	Antall C	Ant. H	Ant. O	Ant. N	Ant. S		Carbon Low	Carbon High
Guaiacols													
2-Methoxy phenol	0,1	1,1	C7H8O2		124,139	7	8	2	0	0		0,056388403	0,620272437
4-Methyl guaiacol	0,1	1,9	C8H10O2		138,166	8	10	2	0	0		0,057901365	1,100125935
Ethyl guaiacol	0,1	0,6	C9H12O2		152,193	9	12	2	0	0		0,05913544	0,354812639
Eugenol	0,1	2,3	C10H12O2		164,204	10	12	2	0	0		0,060899856	1,400696694
Isoeugenol	0,1	7,2	C10H12O2		164,204	10	12	2	0	0		0,060899856	4,384789652
4-Propylguaiacol	0,1	0,4	C10H14O2		166,22	10	14	2	0	0		0,060161232	0,240644928
Acetoguiacone	0,8	0,8	C9H10O3		166,176	9	10	3	0	0		0,433275563	0,433
Propioguiacone	0,8	0,8	C10H12O3		180,203	10	12	3	0	0		0,443943775	0,44
Syringols											**SUM**	**1,232605491**	**8,974342286**
2,6 DiOMe phenol	0,7	4,8											
Methyl syringol	0,1	0,3	C9H12O3		168,192	9	12	3	0	0		0,053510274	0,160530822
4-Ethyl syringol	0,2	0,2	C10H14O3		182,219	10	14	3	0	0		0,109758038	0,109758038
Propyl Syringol	0,1	1,5	C11H16O3		196,246	11	16	3	0	0		0,056052098	0,840781468
Syringaldehyde	0,1	1,5	C9H10O4		182,175	9	10	4	0	0		0,049403047	0,741045698
4-Propenylsyringol	0,1	0,3	C11H14O3		194,23	11	14	3	0	0		0,056633888	0,169901663
4-OH-3,5-diOMe phenyl ethanone	0,1	0,3									**SUM**	**0,325357344**	**2,022017689**
Sugars													
Levoglucosan	0,4	1,3	C6H10O5		162,141	6	10	5				0,148019317	0,481062779
Glucose	0,4	1,4	C6H12O6	readily biodegrad	180,156	6	12	6	0	0		0,133217878	0,466262572
Fructose	0,7	2,9	C6H12O6		180,156	6	12	6				0,233131286	0,965829614
D-xylose	0,1	1,4	C5H10O5		150,13	5	10	5				0,033304469	0,466262572
D-Arabinose	0,1	0,1	C5H10O5		150,13	5	10	5				0,033304469	0,033304469
Cellobiosan	0,6	3,2	C12H20O10		324,282	12	20	10				0,222028975	1,184154532
1,6 Anhydroglucofuranose	3,1	3,1	C6H10O5		162,141	6	10	5				1,147149703	1,14
Furans											**SUM**	**1,950156097**	**4,73687654**
Furan	0,1	0,3	C4H4O	degradable	68, 075	4	40					0,0587	0,176
2-Methyl furan	0,1	0,2	C5H6O		82,102	5	60					0,060899856	0,121799713
2-Furanone	0,1	1,1	C4H4O2		84,074	4	4	2				0,047577134	0,523348479
Furfural	0,1	1,1	C5H4O2		96,085							0,047577134	0,523348479
3-Methyl-2(3h) furanone	0,1	0,1											
Furfural alcohol	0,1	5,2	C5H6O2		98,101	5	6	2				0,05096788	2,650329762
Furoic acid	0,4	0,4	C5H4O3		112,084	5	4	3				0,1784376	0,17
Methyl furoate	-	-											
5- Methylfurfural	0,1	0,6	C6H6O2		110,112	6	6	2				0,054489974	0,326939843
5- OH-methyl-2-furfural	0,3	2,2											
Dimethyl furan	-	-											
Misc. Oxygenates											**SUM**	**0,498649579**	**4,491766275**
Hydroxyacetaldehyde	0,9	13	C2H4O2		60,052	2	4	2				0,299740225	4,32958103
Acetol (hydroxyacetone)	0,7	7,4	C3H6O2		74,079	3	6	2				0,283481149	2,996800713
Methylal	-	-											
Dimethyl acetak	-	-											
Acetal	0,1	0,2	C6H14O2		118,176	6	14	2				0,05077173	0,101543461
Acetyloxy-2-propanone	0,8	0,8	C5H8O3		116,116	5	8	3				0,344483103	0,344
2-OH-3-Me-2-cyclopentene-1- one	0,1	0,5											
Methyl cyclopentenolone	0,1	1,9	C6H8O2		112,128	6	8	2				0,053510274	1,016695205
1-Acetyloxy-2-propanone	0,1	0,1	C5H8O3		116,116	5	8	3				0,043060388	0,043
2-Methyl-3-hydroxy-2-pyrone	0,2	0,4	C6H10O3		130,143	6	10	3				0,092206265	0,184412531
2-Methoxy-4-methylanisole	0,1	0,4											
4-OH-3-methoxybenzaldehyde	0,1	1,1											
Maltol	-	-											
Alkenes											**SUM**	**1,167253134**	**9,016032939**
2-Methyl propene		-											
Dimethylcyclopentene	0,7	0,7	C7H12		96,173	7	12					0,509498508	0,5
Alpha-pinene		-											
Dipentene		-											
Aromatics											**SUM**	**0,509498508**	**0,5**
Benzene		-											
Toulene		-											
Xylenes		-											
Naphthalene		-											
Penanthrene		-											
Fluroranthene		-											
Chysene		-											
Nitrogen													
Ammonia		-											
Methyl amine		-											
Peyridine		-											
Methyl pyridine		-											

Compounds	Bio oil Wt % low	Bio oil wt% high	Formula	Nedbrytbarhet	Weight g/mol	Antall C	Ant. H	Ant. O	Ar	An	Carbon Cont.low	Carbon Cont. High
Acids												
Formic (methanoic)	0,3	9,1	CH2O2	biodegradable	46,025	1	2	2			0,065181966	1,977186312
Acetic (ethanoic)	0,5	12	C2H4O2	available to biodegradation	60,052	2	4	2			0,166522347	3,996536335
Propanoic	0,1	1,8	C3H6O2	readily biodegradable	74,079	3	6	2			0,040497307	0,728951525
Hydroxyacetic	0,1	0,9	C2H4O3	biodegradable polymers	76,051	2	4	3			0,026298142	0,236683278
2-Butenic (crotonic)	-	-	-	-								
Butanoic	0,1	0,5	C4H8O2		88,106	4	8	2				
Pentanoic (valeric)	0,1	0,8	C5H10O2	readily biodegradable	102,133	5	10	2			0,045399859	0,226999296
2-Me butenoic	-	-	-	-							0,048955773	0,391646187
4-Oxypentanioc	0,1	0,4	C5H8O3		116,116	5	8	3			0,043060388	0,172241552
4-Hydroxypentanoic	-	-	-	-								
Hexanoic (caproic)	0,1	0,3	C6H12O2		116,16	6	12	2			0,051652893	0,154958678
Benzoic	0,2	0,3	C7H6O2	readily degradable, aerobic	122,123	7	6	2			0,11463852	0,17195778
Heptanoic	0,3	0,3	C7H14O2		130,187	7	14	2			0,161306428	0,161306428
Esters											**0,763513624**	**8,218467371**
Methyl formate	0,1	0,9	C2H4O2		60,052	2	4	2				
Methyl acetate	-	-	-	-								
Methyl propionate	-	-	-	-								
Butyrolactone	0,1	0,9	C4H6O2		86,09	4	6	2			0,046463004	0,418167034
Methyl Crotonate	-	-	-	-								
Methyl n-butyrate	-	-	-	-								
Valerolactone	0,2	0,2	C5H8O2		100,117	5	8	2			0,099883137	0,099
Angelicalactone	0,1	1,2	C5H6O2		98,101	5	6	2			0,05096788	0,611614561
Methyl valerate	-	-	-	-								
Alcohols										SU	**0,197314021**	**1,128781595**
Methanol	0,4	2,4	CH4O		32,042	1	4	1			0,124836153	0,749016915
Ethanol	0,6	1,4	C2H6O		46,069	2	6	1			0,260478847	0,607783976
2-propene -1-ol	-	-	-	-								
Isobutanol	-	-	-	-								
3-Methyl-1-butanol	-	-	-	-								
Ethylene glycol	0,7	2	C2H6O2		62,068	2	6	2			0,225559064	0,644454469
Ketones										SU	**0,610874064**	**2,001255361**
Acetone	2,8	2,8	C3H6O	readily biodegradable	58,08	3	6	1			1,446280992	1,44
2-Butenone	-	-										
2-Butanone (MEK)	0,3	0,9	C4H7ClO		106,549	4	7				0,112624239	0,337872716
2,3 Butandione	-	-										
Cyclo pentanone	-	-										
2-Pentanone	-	-										
3-Pentanone	-	-										
2-Cyclopentenone	-	-										
2,3 Pentenedione	0,2	0,4	C5H6O2		98,101	5	6	2			0,10193576	0,20387152
2Me2cyclopenten20110ne	0,1	0,6										
Me-cyclopentanone	-	-										
2-Hexanone	-	-										
Cyclo hexanone	-	-										
Methylcyclohexanone	-	-										
2-Et-cyclopentanone	0,2	0,3										
Dimethylcyclopentanone	0,3	0,3	C7H12O		112,172	7	12	1			0,12480833	0,124
Trimethylcyclopentenone	0,1	0,5	C8H12O		124,183	8	12	1			0,064421056	0,32210528
Trimethylcyclopentanone	0,2	0,4	C8H14O		126,199	8	14	1			0,126783889	0,253567778
Aldehydes										SU	**1,976854265**	**2,681417294**
Formaldehyde	0,1	3,3	CH2O		30,026							
Acetaldehyde	0,1	8,5	C2H4O	readily biodegradable	44,053							
2-Propenal (acrolein)	0,6	0,9	C7H6O2		122,123	7	6	2			0,343915561	0,515873341
2-Butenal	-	-										
2-Methyl-2-butenal	0,1	0,5	C5H8O		84,118	5	8	1			0,05944031	0,29720155
Pentanal	0,5	0,5	C5H10O	readily biodegradable	86,134							
Ethanedial	0,9	4,6	C2H2O2		58,036							
Phenols										SU	**0,403355871**	**0,813074891**
Phenol	0,1	3,8	C6H6O		94,113	6	6	1			0,063753148	2,422619617
2-Methyl phenol	0,1	0,6	C7H8O		108,14	7					0,064730904	0,388385426
3-Methyl phenol	0,1	0,4	C7H8O		108,14	7					0,064730904	0,258923618
4-Methyl phenol	0,1	0,5	C7H8O		108,14	7					0,064730904	0,323654522
2,3 Dimethyl phenol	0,1	0,5	C8H10O	well-biodegradable	122,167	8					0,065484132	0,327420662
2,4 Dimethyl phenol	0,1	0,3	C8H10O	well-biodegradable	122,167	8					0,065484132	0,196452397
2,5 Dimethyl phenol	0,2	0,4	C8H10O	well-biodegradable	122,167	8	10	1			0,130968265	0,26193653
2,6 Dimethyl phenol	0,1	0,4	C8H10O	well-biodegradable	122,167	8	10	1			0,065484132	0,26193653
3,5 Dimethyl phenol	-	-		well-biodegradable								
2-Ethylphenol	0,1	1,3	C8H10O		122,167	8	10	1			0,065484132	0,851293721
2,4,6 TriMe phenol	0,3	0,3										
1,2 DiOH benzene	0,1	0,7										
1,3 DiOH benzene	0,1	0,3										
1,4 DiOH benzene	0,1	1,9										
4-Methoxy catechol	0,6	0,6	C7H8O3		140,138	7	8	3			0,299704577	0,2997
1,2,3 Tri-OH benzene	0,6	0,6								SU	**0,950555232**	**5,592323022**