LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Energy Systems
Degree Programme in Environmental Technology

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DEVELOPING THE WASTE MANAGEMENT SYSTEM TOWARDS LANDFILL FREE OPERATION AT UPM PAPER ENA OY IN RAUMA – CIRCULAR ECONOMY APPROACH

Examiners: Professor Mika Horttanainen
M. Sc. Eerik Ojala

ABSTRACT

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Developing the waste management system towards landfill free operation at UPM Paper ENA Oy in Rauma – Circular Economy approach

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Keywords: UPM, Circular Economy, Waste management, Waste, Landfill, Recycling

This study examines the waste management system at the paper mill owned by UPM Paper ENA Oy in Rauma. The intention of the research is to determine the preconditions for landfill free waste management system at the mill site through circular economy. The study is part of Zero Solid Waste project implemented by UPM. The goal of the project is to give up the landfills operated by UPM in Finland by the year 2018 and globally by the year 2030.

The theory part examines the concept of circular economy and clears its origins. Most important driver for circular economy in Finnish forest industry is the decreasing demand of paper products. By implementing the principles of circular economy, the annual saving potential in the forest industry sector is estimated to be 220-240 million euros. Finnish forest industry is already seen as a forerunner of adapting the principles of circular economy. There have been done a long-term work already past two decades to decrease the environmental impact caused by forest industry. In the year 2016 around 300 tonnes of waste were disposed to landfill by Rauma's paper mill. In addition, waste fractions were utilized in recycling, energy production and in earth construction projects. Landfill actions and waste transportation covers the largest share of the waste management costs.

As a result of this study it was noted that the Rauma's paper mill is close to achieve the goal of the Zero Solid Waste project. Landfill actions consist mainly of disposing unsorted mixed waste to the landfill from the production sites. Mixed wastes can be directed to municipal waste incineration for energy recovery. Incineration and recycling was noticed to be more cost efficient solution compared to landfill disposal. In addition to landfill disposal, saving potential were found also in the waste transportation system. Ash utilization were noticed to be critical for landfill free waste management system. Ash can be utilized in earth construction projects.

TIIVISTELMÄ

Lappeenrannan Teknillinen Yliopisto
LUT School of Energy Systems
Ympäristötekniikan koulutusohjelma

Mikael Kostamo

Jätehuoltojärjestelmän kehittäminen kaatopaikattomaksi toiminnaksi kiertotalouden keinoin UPM Paper ENA Oy:n paperitehtaalla Raumalla

Diplomityö

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Hakusanat: UPM, Kiertotalous, Jätehuolto, Jäte, Kaatopaikka, Kierrättäminen

Tämän tutkimuksen tarkoituksena on tarkastella UPM Paper ENA Oy:n paperitehtaan jätehuoltoa Raumalla. Tavoitteena on selvittää tehtaan edellytykset kaatopaikattoman jätehuoltojärjestelmän saavuttamiseksi kiertotalouden keinoin. Tutkimus on osa UPM:n Zero Solid Waste -projektia. Projektin päämääränä on luopua kaikista UPM:n operoimista kaatopaikoita Suomessa vuoteen 2018 mennessä ja maailmanlaajuisesti vuoteen 2030 mennessä.

Diplomityön teoriaosuudessa tarkastellaan käsitettä kiertotalous, kiertotalouden liikkeellepanevia voimia metsäteollisuudessa ja esteitä kiertotalouden toteuttamiselle. Kiertotalouden vauhdittajana metsäteollisuudessa on toiminut paperituotteiden kysynnän lasku. Suomen metsäteollisuuden vuotuiseksi säästöpotentiaaliksi on arvioitu 220-240 miljoonaa euroa, mikä on mahdollista saavuttaa kiertotalousajattelun avulla. Suomen metsäteollisuus yksi edelläkävijöistä kiertotaloudessa. Metsäteollisuuden ympäristövaikutusten pienentämiseksi on tehty pitkäjänteistä työtä jo kahden vuosikymmenen ajan. Vuonna 2016 Rauman paperitehtaalla tuotettiin noin 300 tonnia kaatopaikalle sijoitettua jätettä. Jätejakeita hyödynnettiin myös materiaalikierrätyksessä, energian tuotannossa ja maanrakennuksessa.

Työssä saatujen tulosten perusteella Rauman paperitehtaan jätehuoltojärjestelmä ei ole kaukana kaatopaikattomasta toiminnasta ja Zero Solid Waste -projektin tavoitteen saavuttamisesta. Kaatopaikkatoiminta koostui lähinnä tuotannossa syntyvästä sekalaisen prosessijätteen hävittämisestä, mikä voidaan ohjata energiahyötykäyttöön. Energiahyötykäyttö ja kierrätys huomattiin työssä kaatopaikkasijoitusta kustannustehokkaammaksi ratkaisuksi. Kaatopaikkatoiminnan lisäksi, myös jätteiden kuljetusjärjestelmästä löydettiin säästöpotentiaalia. Tuhkan hyötykäyttö huomattiin kriittiseksi kaatopaikattoman toiminnan kannalta. Tuhkaa voidaan hyödyntää maanrakennus projekteissa.

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In addition, I want to thank Lappeenranta University of Technology and professor Mika Horttanainen who was the supervisor of this study. During the five and a half years at the university I have met many lifetime friends and made a lot of unforgettable memories. Now it is time to move on.

In Rauma 4.12.2016

Mikael Kostamo

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

%	Percent
€	Euro
a	Year
CO_2	Carbon dioxide
d	Day
g	Gram
GWh	Gigawatt-hour
kg	Kilogram
km	Kilometre
km^2	Square kilometre
m^3	Cubic Meter
MJ	Mega Joule
MWh	Megawatt-hour
t	Tonne (metric)
η	Efficiency

Sub-indexes

Dry	Dry waste fraction
Wet	Wet waste fraction

Abbreviations

CE	Circular Economy
DM	Dry-Matter
ESIF	European Structural & Investment Funds
EU	European Union
EWC	European Waste Catalogue
GDP	Gross Domestic Product

KVVY	Kokemäenjoen Vesistön Vesiensuojeluyhdistys Ry
MSW	Municipal Solid Waste
OECD	Organization for Economic Co-operation and Development
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
REF	Recovered Fuel
TMP	Thermo-Mechanical Pulp
UPM	United Paper Mills Oy
UPM Paper ENA Oy	UPM Paper Europe and North-America Oy
WEEE	Waste Electrical and Electronical Equipment
WRAP	Waste and Resource Action Programme
ZSW	Zero Solid Waste

1 INTRODUCTION

Over the past few years' sustainable values have received more and more attention on many levels. Tightened regulations and changed values in consumers' behavior have forced companies to concentrate more to the sustainability aspects in manufacturing processes and products. The trend is approaching a situation where sustainability labels are not only as an added value but a necessity to compete in the markets. It seems that sustainable development has become a part of everyday life.

The rapid growth of world's consumption has followed by increased living standards and growing population. To fill everyone's needs the manufacturing processes have become unsustainable which have brought a concern about the increasing amount of waste and adequacy of resources. This have led to a point where traditional linear economy "take, make and dispose" -model is no longer seen sufficient since the Earth has only limited amount of resources. A concept of circular economy (CE) has gained a lot of attention worldwide as one of the possible solution for the problems caused by growing consuming culture. Some even say that implementing CE is inevitable to maintain economic prosperity and ecological balance. (Jawahir & Bradley 2016, 103-104.)

CE aims to increase resource efficiency to achieve better balance between economy, environment and society by promoting to close the loops in economic systems and receiving the materials back to cycle. The idea of the CE is to decouple environmental pressure from economic growth, which is often perceived as a reason for consuming culture. Implementation of CE is still generally in early stages and it is seen more as recycling rather than reusing. There are cases where team oriented companies have gained competitive advantage through CE, but on a larger scale the biggest results have been achieved in the waste management sector. This can be seen as increased recycling rates. All successful CE cases are based on capacity to link and capacity to create fitting liaisons and exchange patterns. Also, economic viability must be seen to motivate companies and investors. (Ghisellini et al. 2015, 11.)

Finland is one of the greatest pulp, paper and cardboard producers in the world. Forest industry employs directly and indirectly around 160 000 people. The sector affects extensively to Finnish society. Finland has a great potential to be a leading country in bio-economy because of large forest reserves, sustainable forest industry and topline professionality. (Metsäteollisuus 2016a.) United Paper Mills Oyj (UPM) has an important role in this opportunity. In UPM the corporate responsibility is important part of its all operations and seen as a source of competitive advantage. The company is strongly committed to develop its performance in the area of sustainability from economic, social and environmental point of view. UPM promotes its values through the whole value chain and strives to be active in innovating new and better solutions to improve its actions. Now one of the key focuses is to improve the waste management system in the company. UPM corporate launched recently a new project called Zero Solid Waste (ZSW) showing that sustainability is taken seriously in the company and the will to make a change is strong. The goal of the ZSW project is to quit the landfill actions in factory sites owned by UPM. (UPM 2015a, 9; UPM 2016a.). UPM corporate is among the first forestry companies to solve the challenge of landfill free operation and the key elements of CE are strived to put to account.

The paper mill at Rauma belongs to UPM Paper Europe and North-America Oy (UPM Paper ENA), which is a part of UPM Oyj. Main product in Rauma is coated and uncoated magazine paper, which are used in magazines and catalogues. The mill is the largest magazine paper producer in the world with a yearly wood consumption of over 1,3 million cubic meters, pulp consumption of 165 000 tonnes (t) and a production capacity of 955 000 t of paper. The mill site consists of three paper machines, two debarking lines, two grinderies, two thermomechanical pulp lines (TMP), wastewater treatment plant and water supply system. In addition, RaumaCell has a production line for fluff and Rauman Biovoima has a biopower plant, which produces process steam, electricity and heat. Both companies operate at the same mill site and are part of UPM Oyj.

UPM paper ENA Oy owns a landfill for industrial waste disposal in Suiklansuo, about ten kilometers from the mill site. The landfill is divided in three parts. One section is an already closed older landfill area where the last closure works were done in 2013. The paper mill uses the second part of the landfill and Metsä Fibre Oy uses the third part for green liquor sludge disposal. In addition, there is a pool for kaolin sludge disposal, which is not in active use anymore. Landfill costs are shared in relation to use with Metsä Fibre Oy. In 2015 around 300 t of waste were disposed to Suiklansuo's landfill by UPM Paper ENA's paper mill. (UPM 2015b; UPM 2016b)

1.1 Background of the study

UPM's have launched a new Biofore strategy, which challenges the old linear economy model. Biofore comes from the words bio and forest industry. UPM's vision is to be a front-runner of the new forest industry and lead the integration of bio and forest industries into sustainable and innovation-driven future. The slogan "More with Biofore" expresses the on-going pursuit to maximize the value while minimizing the environmental impacts. Goals in the Biofore strategy are to reduce landfill actions and increase recycling rates. In addition, UPM strives to reduce water and energy used in processes. The ZSW project is a part of a larger responsibility agenda and Biofore strategy. Goal of the ZSW is to stop landfill disposal of wastes and incineration without energy recovery. The project looks for alternative ways to get the excess materials to circulate and solves how to get the most out of the current waste management systems. The goal is intended to achieve in all UPM's mill sites in Finland by the year 2018 and globally by the year 2030. UPM and its subsidiaries own around 15 landfills in Finland that are all meant to give up by the deadline. Mill site in Austria and seven mills in Germany within the company have already achieved the ZSW goal. (UPM 2014; UPM 2016a; UPM 2016c.) Improving the excess material sustainable utilization strengthens UPM's status as a frontrunner in CE and gains competitive advantage in the business.

UPM is already a very advanced company when it comes to recycling. Globally UPM produces a total amount of 1 400 000 t of solid waste per year, from which only around 120 000 t is located to the landfills. This means that more than 90 percent of the waste is recycled, reused or utilized in energy production. Parts of the side streams are also used to create new innovative products such as UPM BioVerno diesel or ProFi composite. Basically, all the materials that are easily recyclable are already recycled. ZSW project is now focusing to waste fractions that are still generally disposed to landfills. Composite waste, sludge, dregs, ash and wood residues, which contain sand, are identified in UPM as most difficult fractions to recycle. (UPM 2016a.)

The challenge in the ZSW project is that the practices and the regulations, especially in Finland, are often incoherence. The generated materials in production are usually considered as a waste or a by-product in the legal point of view, which makes the utilization more complex. Legal definition sets restrictions for reusing and recycling of wastes. ZSW project will probably face some regional challenges in manufacturing processes and license practices because of variety in regulations. The same model that works in Germany might not work in Finland. (UPM 2016a.)

1.2 Objectives and research questions

This master's thesis is part of the UPM corporate's ZSW project. The objective of this study is to analyze UPM Paper ENA's current waste management system in Rauma and find a cost-effective solution to rearrange the waste management system so that the landfill operations could be ended. It prerequisites new innovative suggestions in waste recovery and making the most of the current waste management system cost effectively. Essential part of the study is that the suggested improvements are taken into the practice.

The research questions of this study are stated as follow:

- What are the preconditions to landfill free operation in UPM Paper ENA's mill site in Rauma?
- What are the best available solutions to achieve Zero Solid Waste goal locally when the economic and practicality is considered?
- Why the change is inevitable and what are the consequences if nothing is done?

1.3 Structure and boundaries

This master's thesis consists of two parts. First the literature review introduces theory related to CE, followed by the empirical part of the work. The literature part first describes the context of CE and then studies the driving forces behind CE. What does CE mean? What are the driving forces of CE? What is the role of CE in Finnish paper industry? These are the questions, which are discussed in the literature part.

The empirical part of the work first studies the current waste management system in UPM Paper ENA's mill in Rauma. The study explores how the system is organized and how different fractions are separated. Also, the quality of certain waste fractions will be examined in a laboratory research. After this the amount of produced wastes are described. The purpose is to create a clear idea of how much and what kind of waste fractions are produced in different processes in the paper production and how they are utilized. In the end the preconditions to landfill free operation and different possibilities to develop the waste management system are introduced. The economical aspect of the waste management system is important part of the research to achieve the goal in a most cost efficient way. This study focuses only developing the waste management system in Rauma's mill. Further studies can and must be done if the results are to be extended into other UPM's sites in Finland or abroad.

2 CIRCULAR ECONOMY – PRINCIPLES, DRIVING FORCES AND OPPORTUNITIES

Circular economy is not as new concept as many might think. Its origins are difficult to trace to a one particular person or date, but there are some important periods that can be identified on the timeline. The roots of CE trace back to different schools of thoughts to 1970's and 1980's. Some important schools of thoughts refining the concept were for example: regenerative design, performance economy, cradle to cradle, industrial ecology and biomimicry. (Ellen Macarthur foundation 2013a, 26-27; Ghisellini et al. 2015, 14.) One important person in the development of CE in the beginning was a Swiss architect Walter Stahel (Benton et al. 2014, 33). Stahel came up with the idea of loops in the economy where resources would be recycled into productive use rather than wasting them (Stahel & Geneviève 1981). According to Stahel this would create more jobs and help to solve problem of unemployment.

Another important turning point was in the late 1980's when environmental economists David Pearce and Kerry Turner introduced the concept of CE in their book "Economics of natural resource and the environment" (1989). Pearce and Kerry are many times considered as one of the first to raise up the concept of CE. Pearce and Kerry built their research on previous studies of ecological economists like Boulding (1966) and Georgescu-Roegen (1971). They explained the principles of CE and the change from linear to CE by the laws of thermodynamics. (Ghisellini et al. 2015, 14-15; Pearce and Turner 1989.)

The concept has slowly developed to its current form while becoming more and more popular in the past two decades. Nowadays there are already dozens of articles and researches about CE. The amount of charities and foundations related to CE have increased and governments are getting more interested in to the topic. Especially in China, where the pollutions are a complex problem, CE has gained a lot of attention and support from different parties. China's government and various enterprises are developing a society that saves resources and causes less impact to the environment by implementing eco-industrial networks and CE (Yuzhong & Chunyuan 2015, 65). In United Kingdom, again a good example of a new generation's policymaker on the field of environmental issues is Waste and Resource Action

Programme (WRAP). WRAP works in co-operation with governments businesses and communities. Its vision is a world where resources are used sustainably by implementing the principles of CE (WRAP 2016).

Another similar British example is Ellen Macarthur foundation, which was established in 2010. Ellen Macarthur foundation aims to accelerate the transition towards CE by providing education and consulting companies and governments. (Ellen Macarthur foundation 2016a.) Ellen Macarthur foundation has released a lot of material and theory for companies to help them over the transition phase. The foundations like Ellen Macarthur and WRAP seems to represent CE nowadays most prominently. The focus is to make a change now that the principles of the concept have rooted into awareness of a larger audience. These kinds of associations are important players when it comes to adopting the principles of CE on a company and governmental level.

2.1 The principles of circular economy

There is not one correct definition for the term CE. Since the concept is difficult to trace back to one person or to a certain time, the variety of definitions is also wide. It could be said that there are as many definitions as there are articles or researches about CE. Most of the definitions express the same ideas, but trough different ways. Some definitions are shown below to get the first impression of the concept.

"A circular economy is one that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles." (Ellen Macarthur foundation 2016b.)

"Maintaining the value of products, materials and resources in the economy for as long as possible while minimizing waste generation" (European Commission 2015, 2.)

"Circular economy is production and consumption of goods through closed loop material flows that internalize environmental externalities linked to virgin resource extraction and the generation of waste (including pollution)." (Sauvé et al. 2016, 49.)

The circular economy is based on sustainable use of materials and resources, which is a core characteristic of the concept. To be more exact this means minimizing raw materials and toxic chemicals in manufacturing, relying on renewable energy sources, monitoring waste streams and by-product flows and eliminating them by circulating. The concept aims to reach further than just manufacturing and consumption of goods or services to areas that it pursues to define again. (Ellen Macarthur foundation 2013a, 22; Sitra 2015a, 4.) Thinking outside of the box is an important part of CE.

Figure 1 pictures the main differences of linear - and circular economy simplistically. In both models the planet Earth plays an important role providing resources and absorbing wastes and pollutions. The system is working as long as the Earth's system boundaries are not exceeded. The linear economy model on the left side is based on a simple process, which includes resource extraction, producing goods, use and disposal, but it doesn't consider environmental impacts. The CE model on the right side takes into account the environmental impacts on every phase of the life cycle. This creates recycling opportunities and alternative closed loops to the model which eases the stress directed to the Earth and decreases the amount of pollutions. (Sauvé et. al 2016, 52-53.) The main differences between linear and circular economy are reductions in virgin raw materials, reductions in end of life wastes and substitution of manpower for materials and energy (Webster et al. 2013, 46).

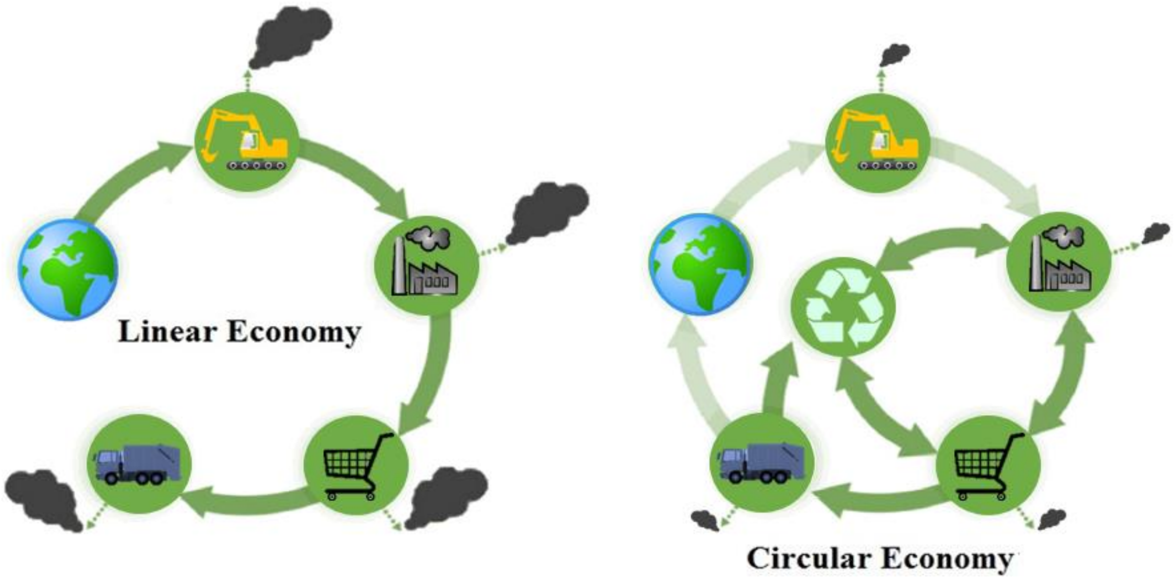

Figure 1. Simplified picture about the differences of linear and circular economy model (Sauvé et al. 2016, 52)

Economic systems in a business world are many times inclined to be linear "take, make and dispose" -production models, where the products or services are based only on the use phase of the product and recycling is separated from production (Sitra 2015a, 4). This linear model of economy has been more or less dominating the society from the beginning of industrialization (Sauvé et al. 2016, 53). In CE however, recycling and production are seen in the same big picture. The concept of CE bases on living world's circulation of nature where material or energy is never wasted. There are no landfills in the nature, but the materials and nutrients circulate through the whole system (Ellen Macarthur foundation 2016c). Another important insight from living systems is so called "designed to fit" –model, which means optimizing and managing systems rather than single components (Ellen Macarthur foundation 2013a, 22). It includes taking into account two type of flows or "nutrients", as they are described. These flows are biological nutrients, which are designed to recycle back to biosphere and technical nutrients, which are meant to circulate without releasing them back to biosphere (McDonough & Braungart 2002).

The core principle related to CE is so called "3Rs" principle, which CE has been relying heavily upon (Feng & Yan 2007; Ren 2007; Sakai et al. 2011; Wu et al. 2013; Jawahir & Bradley 2016). The term 3Rs come from *Reduce*, *Reuse* and *Recycle* (figure 2) which are quite easy to connect to the CE. Priority is to reduce the waste generation, then reuse the products and then to recycle the materials if previous alternatives are not possible. There is also a more complex 6Rs principle innovated, which comes from the words *Reduce*, *Reuse*, *Recycle*, *Recover*, *Redesign* and *Remanufacture* (Jawahir et al. 2006, 1-10). 6Rs methodology offers a closed loop solution for multiple lifecycle system for a process. According to Jawahir's report (2006) recovering refers to the process of collecting products in the end of the use phase, redesigning means products which are made by using recovered materials from previous life cycles and remanufacturing involves processing of used product for its restoration for original purposes or in a new form.

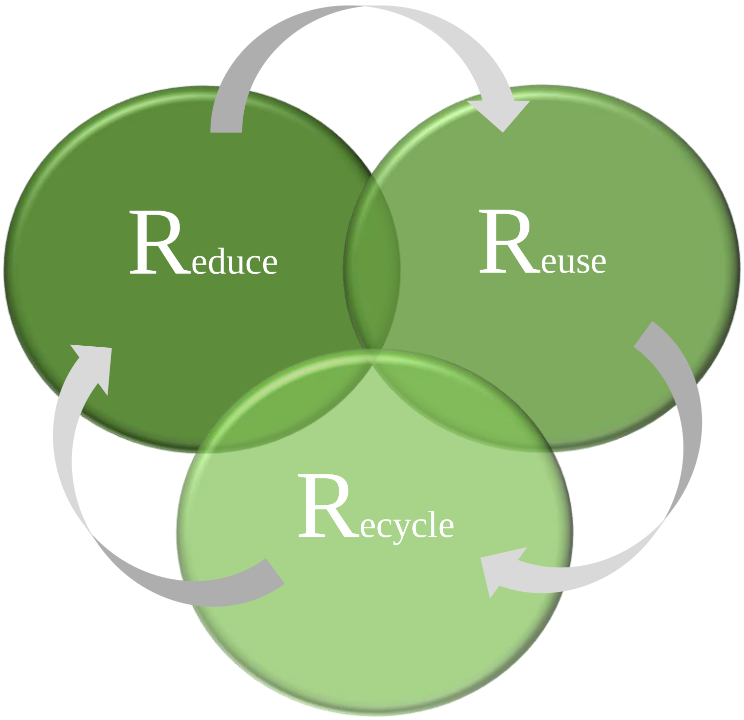

Figure 2. 3Rs principle of circular economy (Jawahir 2016, 106)

Ellen Macarthur foundation offers another point of view about the principles of CE. According to the report by Ellen Macarthur foundation (2013) a working CE business model requires following not three but five basic principles. These five principles are: design out waste, build resilience through diversity, rely on energy from renewable energy sources, think in "systems" and waste is food. Also in this approach, biological and technical components are separated. (Ellen Macarthur foundation 2013a, 22-23.)

Designing out waste means that waste doesn’t exist when the biological and technical parts of product and side streams from a process are intentionally designed to cycle. Biologically degradable components can be composted or digested and technical components, such as polymers and metals, can be designed to be utilized again.

Build resilience trough diversity. In a fast developing and uncertain world, where we are now living, features like modularity, versatility and adaptivity need to be prioritized to keep up with development. The more diverse the system is the more resilient it is for external factors.

Rely on renewable energy sources. Everything needs energy for running. Renewable energy sources are excellent way to support circular economy.

Thinking in systems comprises the ability to understand how different components affect to one another. To see the relationship of the whole to a single component is pivotal when building a CE model. This is usually one of the biggest differences between linear and circular systems. It also encourages to think flows and connections in a long-term rather than limiting the focus.

Waste is food is said to be at the hearth of the concept. This means the ability to recycle safely the nutrients back into the biosphere from products, services and processes. This is vital for the innermost idea of a circular economy.

While CE seeks a way to use resources and materials more efficiently and improve material recycling it naturally boosts energy efficiency and drives companies closer to carbon-neutrality. It saves a lot of energy through efficiency which makes implementing CE also profitable and through that attractive for companies. (Sitra 2013, 4-5.) The idea of CE for a single product is visualized in the figure 3. The left side visualizes the CE model for biological nutrients and right side for technical nutrients.

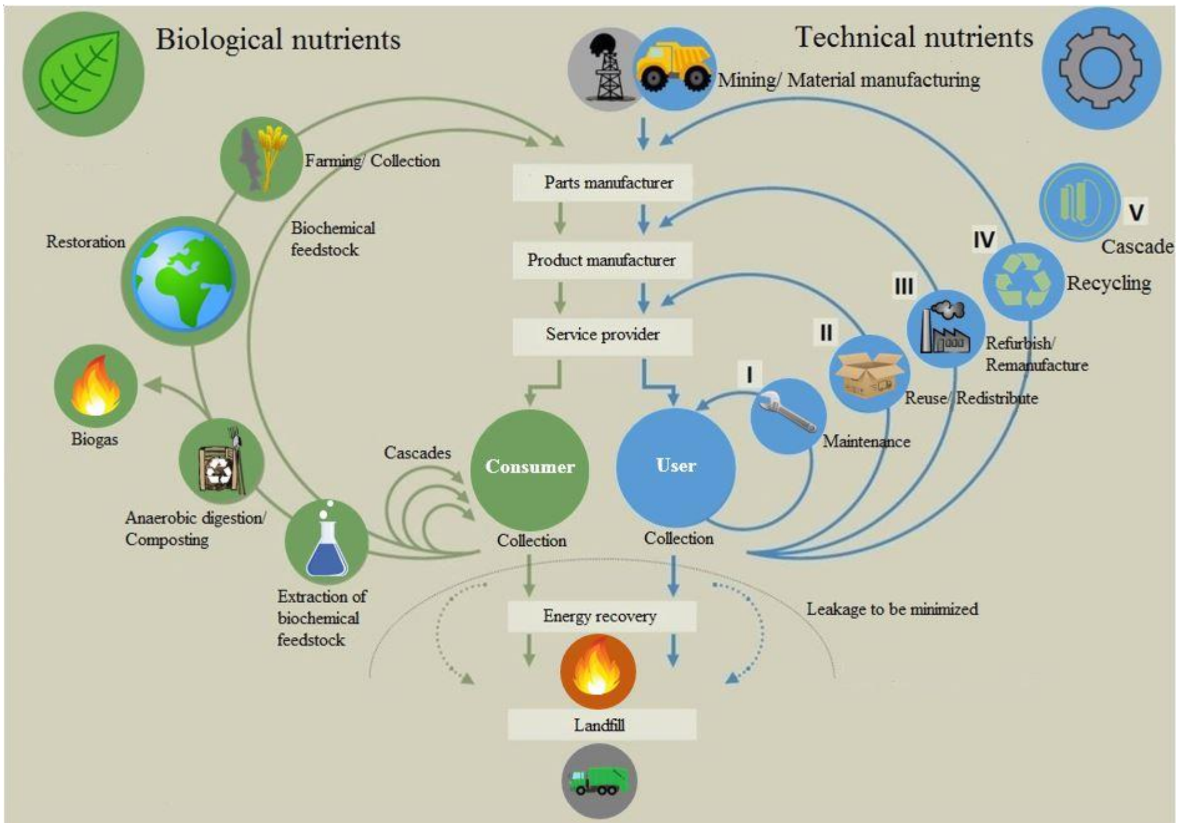

Figure 3. Loops for biological and technical nutrients in circular economy (Ellen Macarthur foundation 2013a, 24)

Because of different kind of qualities of technical and biological components the cycles look different. Biological nutrients decompose naturally and thus the circulation is simpler. Biological nutrients are supposed to cycle back to the biosphere when technological nutrients are designed to stay in the cycle. In the figure, collection in biological nutrient cycle means hunting and fishing. Unfortunately, still a large share of biological nutrients ends up into municipal waste because of neglectful sorting. Technical nutrients have more specific order in the CE model and the loops can be formed back into every phase of the life cycle. Products can be cycled in five ways as shown in the figure 3. (Ellen Macarthur foundation 2013a, 3, 24.)

1. *Maintain*: Build products to last longer and offer maintenance service to extend products' lifetime. Thus, the same user can take advantage from goods longer time.

2. *Reuse/Redistribute*: Reusing the product for the same purpose for example through resale.

3. *Remanufacture/Refurbish*: Plan several life cycles for the product and resell it after remanufacturing.

4. *Recycle*: Plan the product so that it can be easily recycled again as a material and that the materials are easy to sort. Think also how to ensure safe return for nutrients to enter back to nutrient cycle.

5. *Cascade:* Use the material or parts again in a different value chain, if it can't be reused in the original sector.

Even though, CE is many times related to environment protection and sustainability it is more about economics and profit maximization. It is not completely wrong way of thinking since it decreases environmental impacts and it corresponds to the objectives of a "green economy". When managing the CE, there are four important notions that must be considered. First is to be aware that the smaller the loop activity-wise and geographically is the more resource efficient and profitable the system is. Also, the speed of the circular flows is pivotal. When the flow speed decreases in the CE the efficiency of managing stock increases. The next important notion is that the loop doesn't have a starting point or an end, which means that the value maintained in the circulation replaces the value added. Third notion is that the longer the ownership is the more cost efficient it is. Reusing, repairing and remanufacturing without changing the ownership can save double in the transaction costs. And finally, maybe the most important notion is that a working model of CE needs functioning markets. (Webster et al. 2013, 46-49.)

CE is characterized by number of principles which linear economy model doesn't have. Thus, there is a problem that economic actors of the process industry don't know them or their impact to the economy and therefore adapting CE into everyday business life struggles. Because of the complex nature of CE, it never reaches the optimum level in many companies. (Webster et al. 2013, 46-49)

2.2 Driving forces of circular economy

The pressure on material efficiency and environment protection is reaching a breaking point and the CE is slowly getting stronger foothold. But if the CE and the need for a change have been recognized for more than four decades, why the time to act is now? Report by Ellen Macarthur foundation (2014) suggests that attractiveness to CE rises when the resource prices increase or remain high, and if the cost of creating a return cycle decreases. According to the report these two conditions should be now in place. (Ellen Macarthur foundation 2014, 26.) In this part, it is discussed what are the driving forces accelerating the transition towards a society where the principles of CE are implemented in everyday life.

2.2.1 Limits of linear consuming

Companies extract raw materials, manufacture a product and sell it to the consumer who in the end disposes it. Systems based consumption causes major losses in the value chain, even though there have been great improvements in resource efficiency. (Ellen Macarthur foundation 2013a, 14.) The physical limits of linear consumption have been noticed already decades ago. First time the concern was brought out in the book Limits to Growth in 1972 (Meadows et al. 1972). The research showed that if the trend in growing does not change, the physical limits of the Earth will be overshot in 100 years. Later in early 1990's the same group of authors continued with the topic presenting evidences in their new book how the world has already exceeded some of the limits of which they were earlier discussing (Meadows et al. 1992). Meadows was one of the first who brought up the concern about the state of the environment and resource scarcity. Sir David Attenborough, who is a host of famous BBC's nature documents, commented well about the resource depletion in an interview 2013:

> *"We have a finite environment – the planet. Anyone who thinks that you can have infinite growth in a finite environment is either a madman or an economist"* (The Guardian 2013).

From 1850's to 2000 resource prices, especially price of fossil fuels, were declining which was working as an engine for economic growth. Reusing seemed to be unnecessary since it was easier to produce products from primary resources and cheaper to dispose them after use. Major part of economic efficiency benefits came from using more resources, especially energy, to reduce labor costs. Now the big picture has changed mainly for two reasons: permanent rises in resource prices and unprecedented volatility. Commodity prices increased overall nearly 150 per cent only in a less than a decade from 2002 to 2010 (McKinsey 2011, 8). This made meaningless the whole last century's real price declines. Many companies are now struggling to find a way to protect their business from sudden shocks. This have created joint ventures between manufacturers and waste management companies. The joint ventures have created access for manufactures into secondary material streams. Through the joint ventures companies can reduce virgin raw material intakes and at the same time benefit economically. (Ellen Macarthur foundation 2014, 26.) Increasing resource prices naturally boosts CE implementation.

Price volatility for metals, food and non-food agricultural products in the beginning of 21st century were higher than in any decade in 20th century. Instability of the prices will probably remain high in the future as well while population grow and urbanize. This weakens the economic growth by increasing uncertainty, decreases willingness to invest and innovate and increase costs from the operations against resource-related risks. Resource extraction will also slowly move to locations where the materials are harder to reach. This affects to the prices and at the same time raises environmental costs. On competitive market, many companies are looking for a business model that could lower the material costs and this is where CE stands up. Adapting CE can gain competitive advantage and differentiation to perform better than the competitors on the markets. (Ellen Macarthur foundation 2013a, 14; Benton et al. 2014, 24-25. Ellen Macarthur foundation 2014, 26-28.)

According to report of Ellen Macarthur foundation both of these effects, increasing prices and incomparable volatility, are likely to continue in the future too. This means that adopting CE based business model offers a possibility to achieve substantial value creation. The drivers of these changes in price increasing and volatility can be divided to demand and supply side trends. Demand side trends, which are shown in the figure 4, includes for example growing population and increasing living standards. There have been estimated that world's population will grow by more than a billion people by the year 2025 and from the whole population more than 3 billion are expected to reach the rank of a middle-class consumer (McKinsey 2011, 8). The change would take a place mainly in third world countries and it would be the fastest increase in disposable incomes ever seen before. On the other hand, there will be significantly more wealthy customers in Organization for Economic Co-operation and Development (OECD) countries, whose resource footprint is multiple compared to a middle-class consumer. The coming increase in consumer demand is described as a "potential time bomb". Food spending is predicted to rise almost 60 % and end of life materials 41 %. (Ellen Macarthur foundation 2014, 27.) These are difficult challenges, which are still looking for the best possible solution.

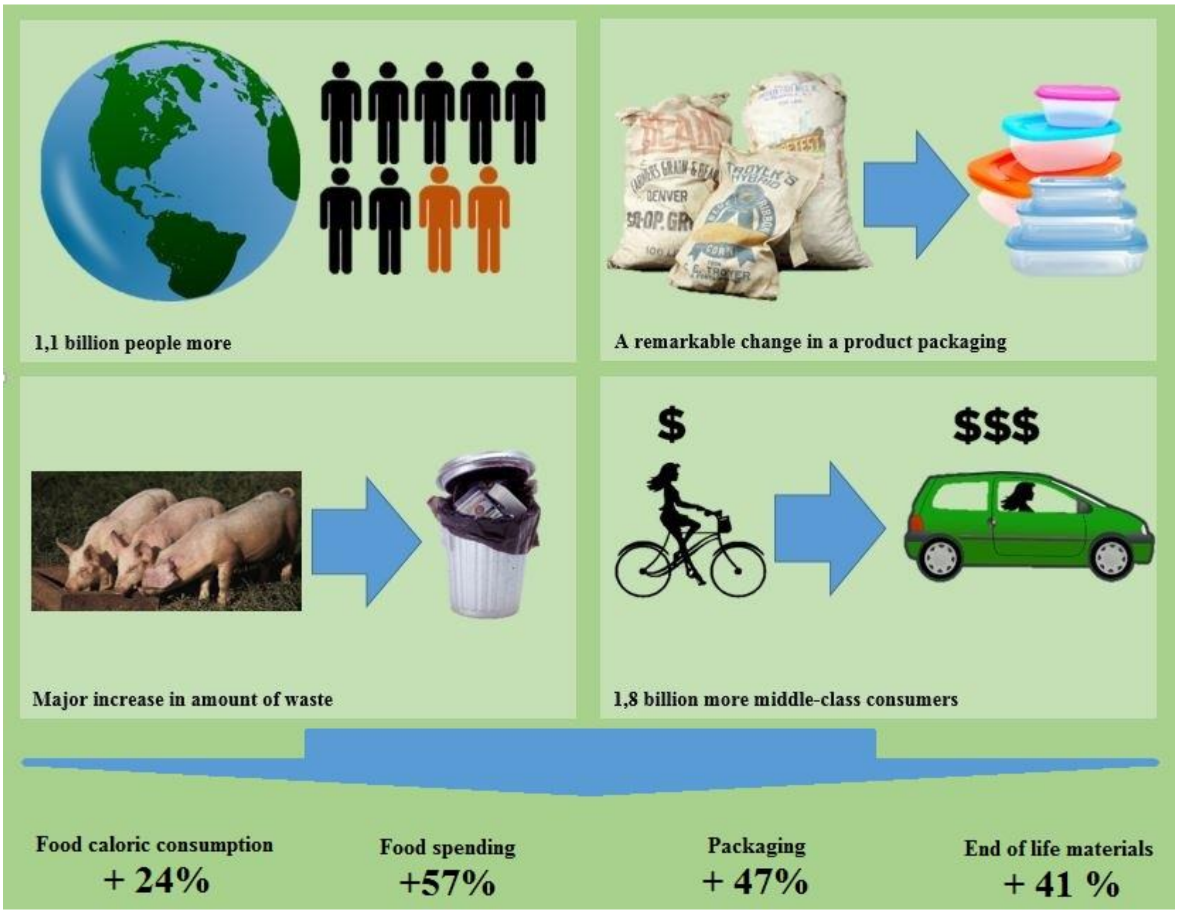

Figure 4. Possible changes in a structure of the society globally. Numbers describe an estimate on a time period of 2010-2025. (Ellen Macarthur foundation 2014, 26)

Supply-side trends include for example pressure on limited resource reserves. Professor James Clark from University of York has done a research about current recycling rates on various elements of the periodic table. Professor Clark estimates that the pressure on limited resources will remain high because we are not able to keep the existing stock of materials in use due to leakage in recycling. Materials like gold, indium, silver, tungsten and iridium, which are vital for industry, may be depleted. (Hunt et al 2013.) Figure 5 represents an estimate how long the metal reserves are going to last if consumption and extraction level remain the same. From the periodic table, can be seen that not only oil and natural gas reserves are shrinking, but also surprisingly many metals have very limited reserves.

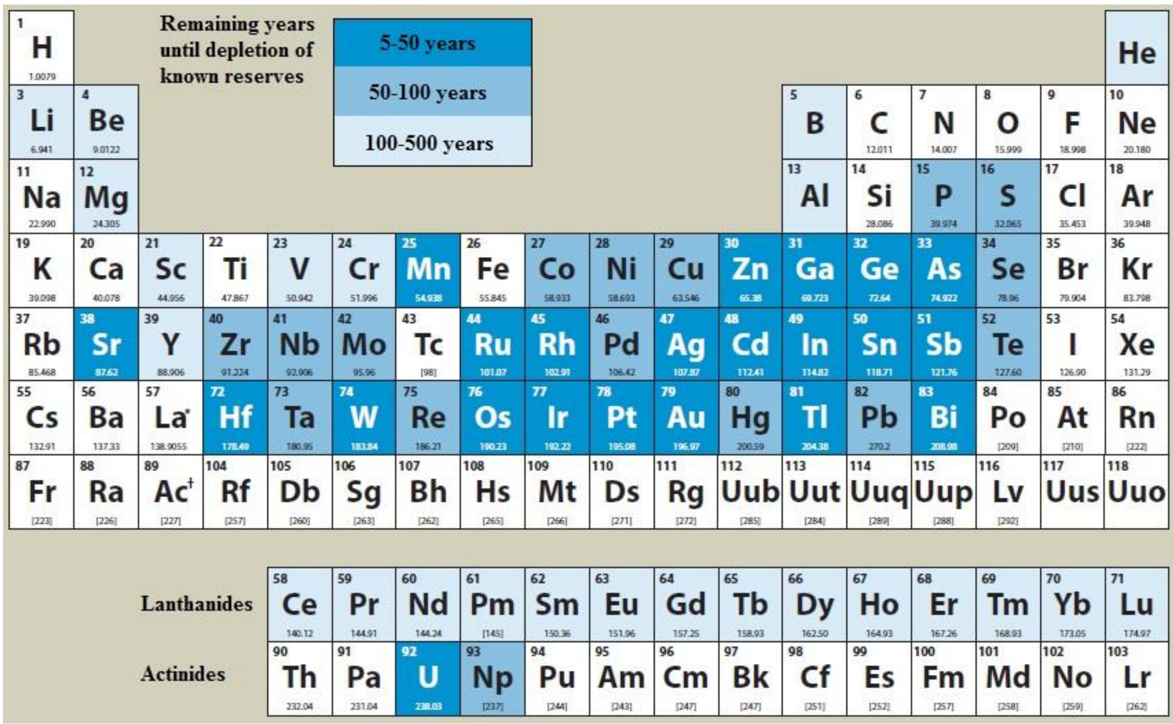

Figure 5. Years remaining of rare and precious metal reserves if consumption and extraction levels remain the same (Rhodes 2008, 21-23)

Figure 6 again reflects the recycling rates for most of the valuable metals. When comparing the figure 5 and 6, it can be seen how unbalanced they are. Only few of the valuable metals that are estimated to last only 5-50 years have a recycling rate 25 % or better, which is alarming. Metals that have very limited reserves are marked with red outlines in figure 6. Extracting virgin raw materials is more expensive and consumes a lot more energy compared when using secondary raw materials.

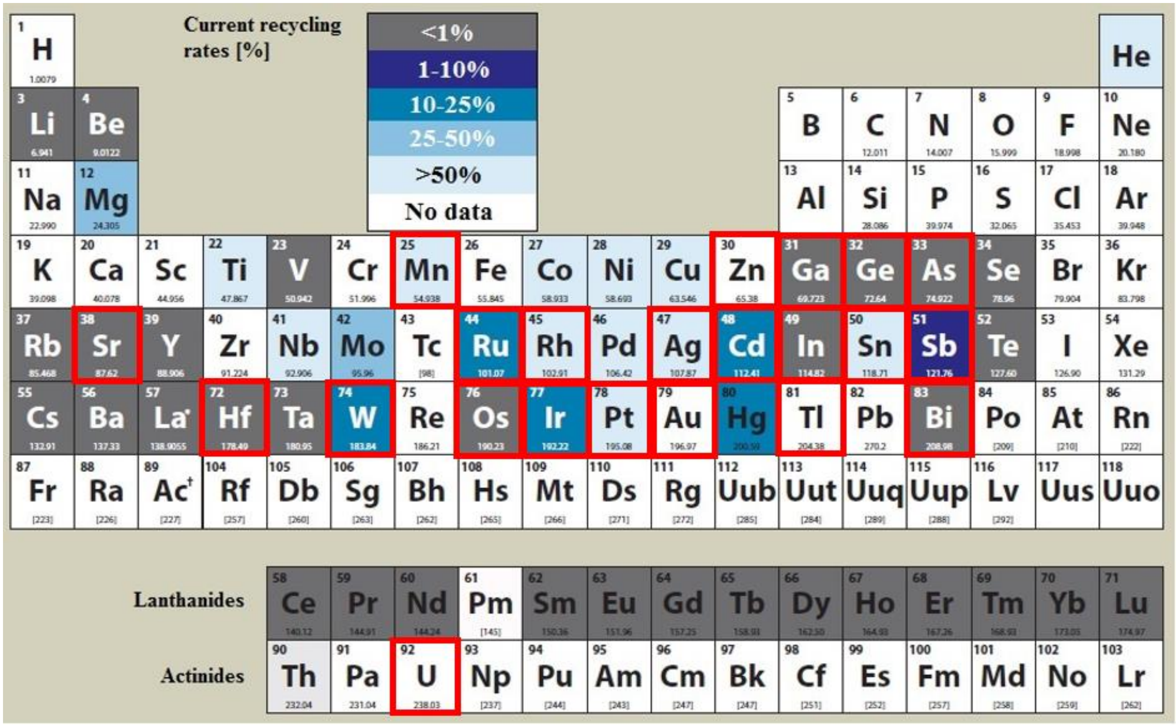

Figure 6. Recycling rates for rare and precious metal reserves (Rhodes 2008, 21-23)

At the same time, it is expected that average resource is facing increasing production costs in the future. This is because of mining industry is moving to new areas where the raw materials are harder to reach and requires heavy investments. Many areas that interest mining industry are in areas with high political risk. This has a potential to affect to continuity of supply and to volatility of resource prices. Not only the mining industry is facing this problem but also this holds true for food and farming industry such as maize, wheat or beef. Environmental concerns such as erosion, fresh water depletion and deforestation have also a potential to increase the resource prices in the future. (Ellen Macarthur foundation 2013b, 18-21.) Implementing the principles of CE can reduce pressure on limited resource reserves, reduce price volatility and prevent noxious effects on the economy on a larger scale.

Raw material reserves in forest and paper industry in Finland are not facing a radical depletion any time soon. Finnish forest industry consumed during the years 2011-2013 around 60 million cubic meter of wood per year, while the yearly growth rate of forest in total in Finland is a bit more than 100 million cubic meters. From used wood materials 90 % were domestic. The rest 10 percent which was imported consisted mainly of birch. (Metla 2015, 33.) Also, the price volatility in wood price is generally low. Figure 7 shows the price development of pulpwood in Finland. The figure pictures the pulpwood price in a situation where the buyer organizes cutting hand harvesting of the wood material. This is called a stumpage price. This refers to the raw material what is used in UPM Paper ENA's mill in Rauma. Logwood is more expensive.

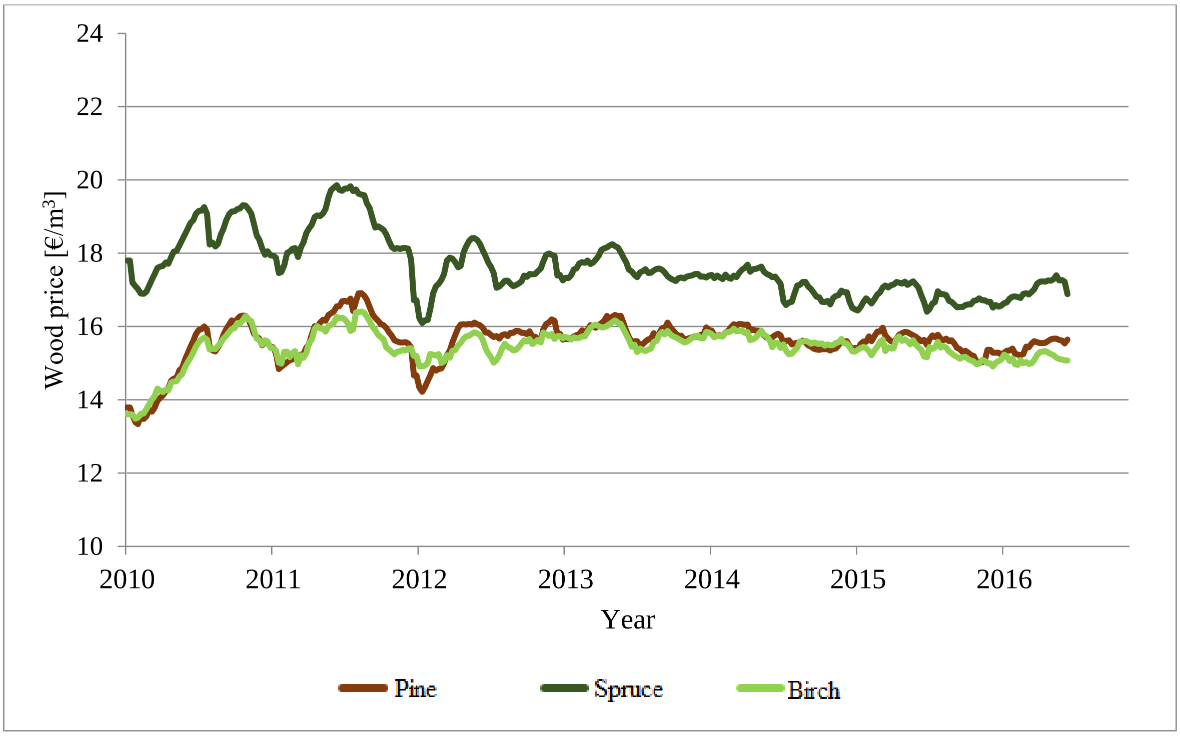

Figure 7. Price development of pulpwood in Finland (Metsäteollisuus 2016b)

Pulp, which is another important raw material in paper industry, has had much more volatility in its price development compared to pulpwood. Pulp's price development is presented in figure 8. Although the price development has had high peaks and drops, the trend has been steadily increasing which makes it easier to predict on a longer time period. This can be seen from the black trend line in the figure 8. Against these facts, it could be said that resource scarcity or price volatility which are generally main reasons accelerating CE globally, are not the main driving forces in Finnish paper industry.

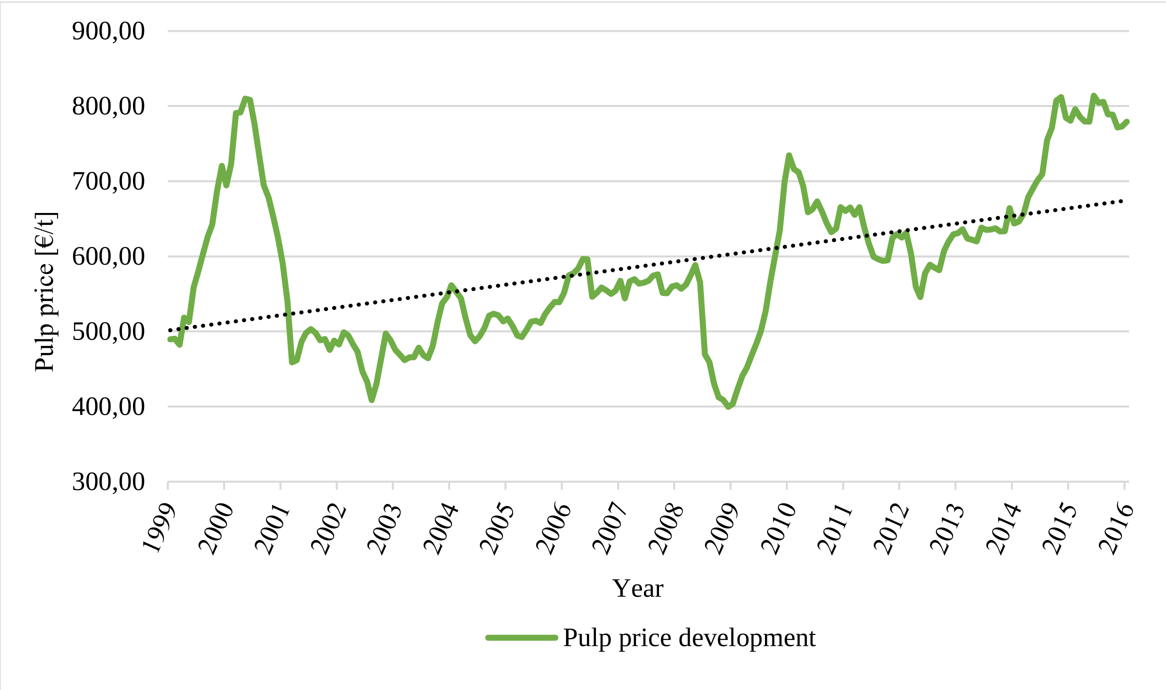

Figure 8. Pulp price development from 1999 to 2016 (Indexmundi 2016)

Printing and writing paper demand again have dropped remarkably in recent years. Printing and writing paper demand have crashed almost 40% from almost 10 million tonnes close to 6 million tonnes only in few years. This is mainly because of digital media, which have reduced the need of traditional paper (Metsäteollisuus 2015a). Decreasing demand have led to reduction of production capacity in Europe and North-America which is predicted to stabilize the drop in the price. (Metla 2015, 20.) Also in Rauma, the production capacity was contracted from four paper machines to three in 2013 (UPM 2016e). Demand rates for printing and writing paper, cardboard and other paper products from 1960-2015 are shown in figure 9. Decreasing demand in paper industry can be seen much stronger driving force to implement principles of CE than resource scarcity. Producing quality paper cost effectively is a necessity to be able to compete in the narrowing markets and CE offers an attractive solution for that.

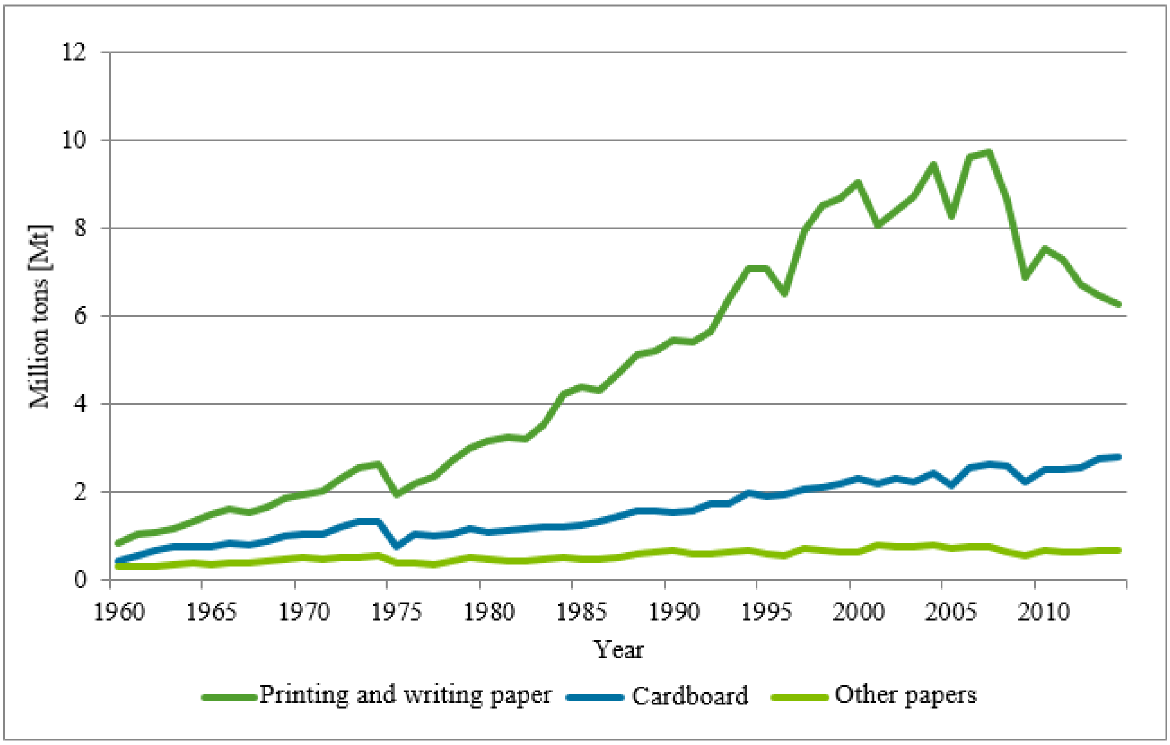

Figure 9. Export rates for different paper products from Finland 1960-2015 (Metsäteollisuus 2016c)

2.2.2 Regional and political drivers

Governments have an important role when it comes to adapting principles of CE. The concept has drawn attention especially in Asian countries like China and Japan, but also in Europe. Japan has been enduring resource scarcity since 1990's because of its geographical location and geological limits. Domestic resource extraction in Japan faced difficulties with too expensive extraction costs, which lead the energy sector depended on oil imports. After the 1970's oil crisis broke out and the government had to think again their resource policy. The disadvantage of lacking natural resources forced Japan to develop CE based economic model to keep up with the western countries. Japan's route to develop its CE model consists of three stages. First step was to adjust the structure by reducing dependency on oil by improving the efficiency and increasing the amount of renewable energy in energy production. Second phase included setting up a comprehensive legal system to support sustainability, environmental policies and waste management. Finally, the third step was to increase education and awareness about CE and through that raise societal participation. (Ji et al. 2012, 725-730.) Japan's progress in building a legislation to support CE has been prominent especially after 1990's. Some of the laws related to CE and environmental issues in Japan are shown in the table 1.

Table 1. Laws set by the Japanese government to promote circular economy model (Ji et al. 2012, 728; Davis & Hall 2006; Ministry of environment 2016)

Classification of law	Name of the law	Year
Fundamental law	The basic environmental Law	1993
	Promoting the formation of a recycling society Law	2000
Comprehensive law	Waste disposal Law	1970
	Law for promotion of effective utilization of recyclables	1991
Special laws	The law of separate collection and recycling of container and packaging	1995
	Specified home appliance recycling law	1998
	Construction material recycling law	2000
	Polychlorinated biphenyl (PCB) special measures law	2001
	End-of-life vehicle law	2002

The successfulness of the CE program driven by the government in Japan divides opinions. When looking at some of the numbers, the program has been a great success. Rate of recycling for metal increased up to 98 % and it is high for other materials too. This at the same time decreased the amount of waste going to landfill to only 5 %. Also from electronic appliances 89% of the materials are now recycled and as a rule the materials recovered are used to produce similar kind of products, which creates an actual closed-loop example. (Ellen Macarthur foundation 2014, 35). On the other hand, the program has got critics for high implementation costs and some of the laws have created unintended consequences like illegal waste disposal (Davis & Hall 2006, 2-3).

China again has a total opposite situation compared to Japan. The country has large land area and massive resource reserves. This can also be seen from consumption levels which are reaching a crisis level. China consumed more raw materials than all 34 OECD countries together. (Mathews & Tan 2016, 440-442.) According to national statistics, CO_2 emissions in China have been growing 7,5% per year from over 3000 Mt in 1997 to almost 8000 Mt in 2010 (Guan et al. 2012). One of the challenge in China is the largest population in the world which is closer to 1,4 billion (Worldometers 2016). This represents almost 19 % of the whole world's population.

Chinese government has chosen CE as a national development strategy to improve material efficiency, energy consumption and to lower emission levels. There are three major forces accelerating the implementation of CE in China. First reason is daunting environmental challenges such as land degradation, desertification, deforestation, loss of biodiversity, air pollutions and water depletion. Secondly there is starting to be a severe shortage on resources because of growing demand (Li et al. 2010). China holds 9 % of the farmed land on Earth, 6 % of World's water reserves and 4 % of forests, which should meet the need of almost one fifth of the Earth's population (Vermander 2008, 85; Worldometer 2016). The third force accelerating the change is tightened regulations regarding environmental issues in international trade markets that can cause so-called green barriers and have influence to export. (Su et al. 2013, 216.) China's government has released many of laws related to CE similar to Japan to accelerate the implementation of CE. In 2003 the government of China released the Cleaner Production Promotion Law, then the amended Law on Pollution Prevention and Control of Solid Waste in 2005 and the Circular Economy Promotion Law was approved in 2009. (Su et al. 2013, 217-218.)

China have also committed to invest 1,2 billion US dollars in science and technology for sustainable development. One important part of the plan, where a large share of the money is directed, is to develop an industrial park network. A good example is Suzhou New District near Shanghai which is a 52 km^2 area designed for industrial and technological enterprises. There is in total around 4000 manufacturing companies in the area that creates a lot of opportunities for symbiotic relationships and material recycling cost efficiently. On a general, level China's resource efficiency has improved almost 35 % and pollution treatment rate increased almost by 74 %. This included sewage, pollutant reduction and decontamination of residential waste. The statistics have been created by comparing levels of 2005 to levels of 2013. (Ellen Macarthur foundation 2014, 34; Mathews & Tan 2016, 440-442.) The pilot projects have been a good support in adopting principles of CE in Chinese industry. Other practices related to CE in china are shown in the table 2. It is divided in four focus areas on a micro, meso and macro level.

Table 2. Practices of CE in China (Su et al. 2013,217)

Focus area	**Micro (Single object)**	**Meso (Symbiosis association)**	**Macro (City, province, state)**
Production	Cleaner production and eco-design	Eco-industrial parks and eco-agricultural system	Regional eco-industrial network
Consumption	Green purchase	Environmentally friendly parks	Renting service
Waste management	Product recycle system	Waste trade market and venous industrial park	Urban symbiosis
Other support	Policies and laws, Information platform, Capacity-building, NGOs		

Even though, there have been some great achievements in China from an environmental point of view the oversized resource consumption is still a serious problem. OECD statistics reveal that resource intensity in China fell from 4,3 kilograms (kg) of materials per unit of gross domestic product (GDP) in 1990 to 2,5 kg in 2011, which means that in China 2,5 kg of material is required to generate US$1 of GDP. For a comparison in OECD countries the average resource intensity in 2005 was closer to 0,5 kg. At the same time China's resource consumption five folded from 5 to 25 billion tonnes. Although the direction towards a sustainable economic model is right, there is still a lot of work to do. (Mathews & Tan 2016, 440-442.)

It is also recognized in European Union (EU) that the linear economic model and unlimited resource consumption is not sustainable and the transition to a more circular economic model is indispensable. CE priorities are seen very much similar to EU's priorities and therefore there is a strong willingness to support the transition. In EU, local and regional authorities, such as governments, have an important role in the development of CE and EU has been made to carry its responsibility so that the necessary regulatory framework will take place.

EU have underlined that the transition to CE strengthens international competitiveness, promotes economic growth, creates job opportunities and lowers greenhouse gas emissions. European commission released an action plan for the CE development in December 2015 where ambitious goals are set further than ever before. The common EU-level target is to increase the recycling rate for municipal waste up to 65 % and for packaging materials up to 75 % by the year 2030 and at the same time decrease the amount of waste going to landfills to only 10 %. In addition, the commission proposed directives concerning waste management, packaging waste and waste electrical and electronical equipments (WEEE). (European Commission 2015, 2-3; Seppälä et al. 2016, 72.)

The ambitious plan strives to "close the loop" of product life cycles through recycling and reusing. The transition is supported by European Structural & Investment Funds (ESIF). ESIF is committed to invest 5,5 billion euros for development of waste management infrastructure. Besides that, the EU's funding program for research and innovation, EU Horizon 2020, will provide 650 million euros to CE related innovations at national level. (European Commission 2015, 2-3; European commission 2016.)

In EU, there are two directives that control waste management: directive on waste 98/2008 and directive on the landfill of waste 31/1999. In addition, every member country has their own regulatory policy, which must follow the guidelines set by EU. Also Finland is committed to move towards circular model and support EU's goals. The waste management law 646/2011 and council directive about wastes 179/2012 generally controls waste management in Finland. Environment protection law 527/2014 and environment protection act 713/2014 guides organizing the waste management in Finland. The waste management regulatory aims to prevent risks on health and environment, reduce the amount and noxiousness of wastes, promote sustainable use of resources and to ensure a working waste management system. (Seppälä et al. 2016, 6; Ministry of environment 2016). Figure 10 pictures the priority order in waste management set by EU, which can be also found from Finnish waste law 646/2011.

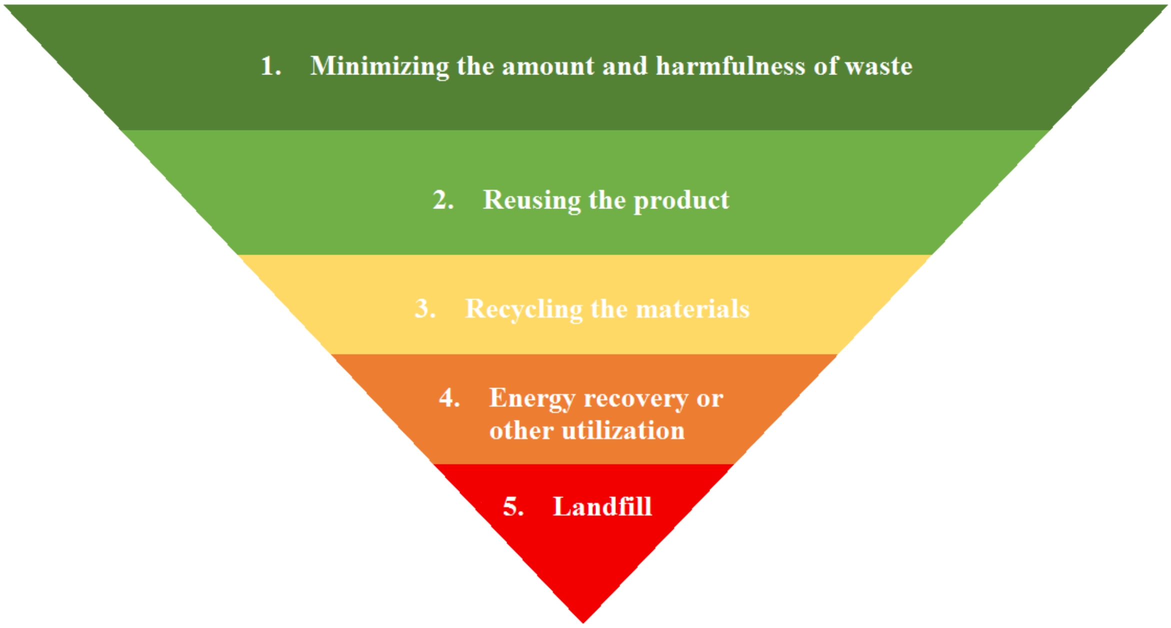

Figure 10. Priority order in waste management (Directive on waste 2008/98/EC, 4§)

One important act supporting CE in Finland is the council act of wastes 331/2013, which prohibits placing organic wastes to landfills. More precisely this means that wastes containing organic materials 10% or more are not allowed to be located to landfills. The goal of the decree is to improve material recovery and energy recovery from wastes while reducing the environmental impacts of the landfills (Ympäristöministeriö 2013). The act was released 2nd of June in 2013 and the landfill prohibit came into effect 1st of January in 2016. Mixed MSW is directed now to energy recovery, after separate collection of recyclables. The act was important step in the development of CE in Finland.

Also in forest and paper industry the waste management have to be organized by the Finnish legislation. Landfill prohibition for organic waste causes substantial arrangements in waste management systems in the sector. Most of the waste flows are exceeding the 10 % organic material limit and thus considered as an organic waste by the law. Most common waste fractions that have been disposed to landfill by forest industry are ash and green liquor sludge. By the new act forestry companies need to find new innovative ways to utilize also the difficult waste flows. UPM Paper ENA’s landfill in Rauma has worked also as an intermediate storage for some of the wastes such as ashes and kaolin sludge. The materials are retrieved back for utilization.

Another important political driver is taxation. In Finland, new waste tax law 1126/2010 came into effect from the beginning of 2011. Waste tax must be paid from fractions disposed to landfill that are technically possible to utilize in some other way. The taxation concerns public and private landfills such as UPM Paper ENA's landfill in Rauma. The new updated waste tax law aims to increase the recycling and utilization rate. In pulp and paper industry all waste produced in the process is taxable by the new law except the green liquor sludge, which is at the moment exempted from taxation due to its difficult utilization (1126/2010). Also, storing wastes to landfill for less than three years is tax free. (Ympäristö 2016.)

Taxation and new laws concerning waste management have been trying to steer forest and paper industry to reduce the amount of wastes and increase utilization rates, even so a lot of improvements were done already before economic controlling measures such as waste tax. There has been some complaining that the taxation hasn't been the best way to force forest industry to improve the waste management. One of the biggest reasons is that landfill costs basically defines the cost of the utilization when it is outsourced, which means that also the cost of the utilization is now higher for the forestry companies. It is seen that waste tax weakens the position of Finnish forest industry in the international markets by increasing the overall waste management costs, when for example in Sweden waste produced by forest industry is still tax free. (Metsäteollisuus 2015b.)

2.3 Circular economy in Finnish forest industry now and prospects

Another driving force behind CE in the forest industry is economic benefit. There are dozens of researches about the saving potentials when implementing the principles of CE. Sitra's research (2015a) estimates annual saving opportunities through CE in Finland to be 1,5-2,5 billion euros. The same research evaluates that pulp and paper industry's potential would be 220-240 million euros, even there are already many principles of CE implemented in the sector. The estimates vary depending what sectors and perspectives are taken into account in the research (Sitra 2015; Seppälä et al. 2015). However, the potential only in paper industry is millions of euros. Figure 11 presents the overview of the value chain of wood in Finland. End use of wood in Finland is mainly construction and paper production. In the figure inputs are determined as intermediate consumption to the sector excluding labor costs where only the largest inputs are considered. Therefore, inputs will not add up to 100%.

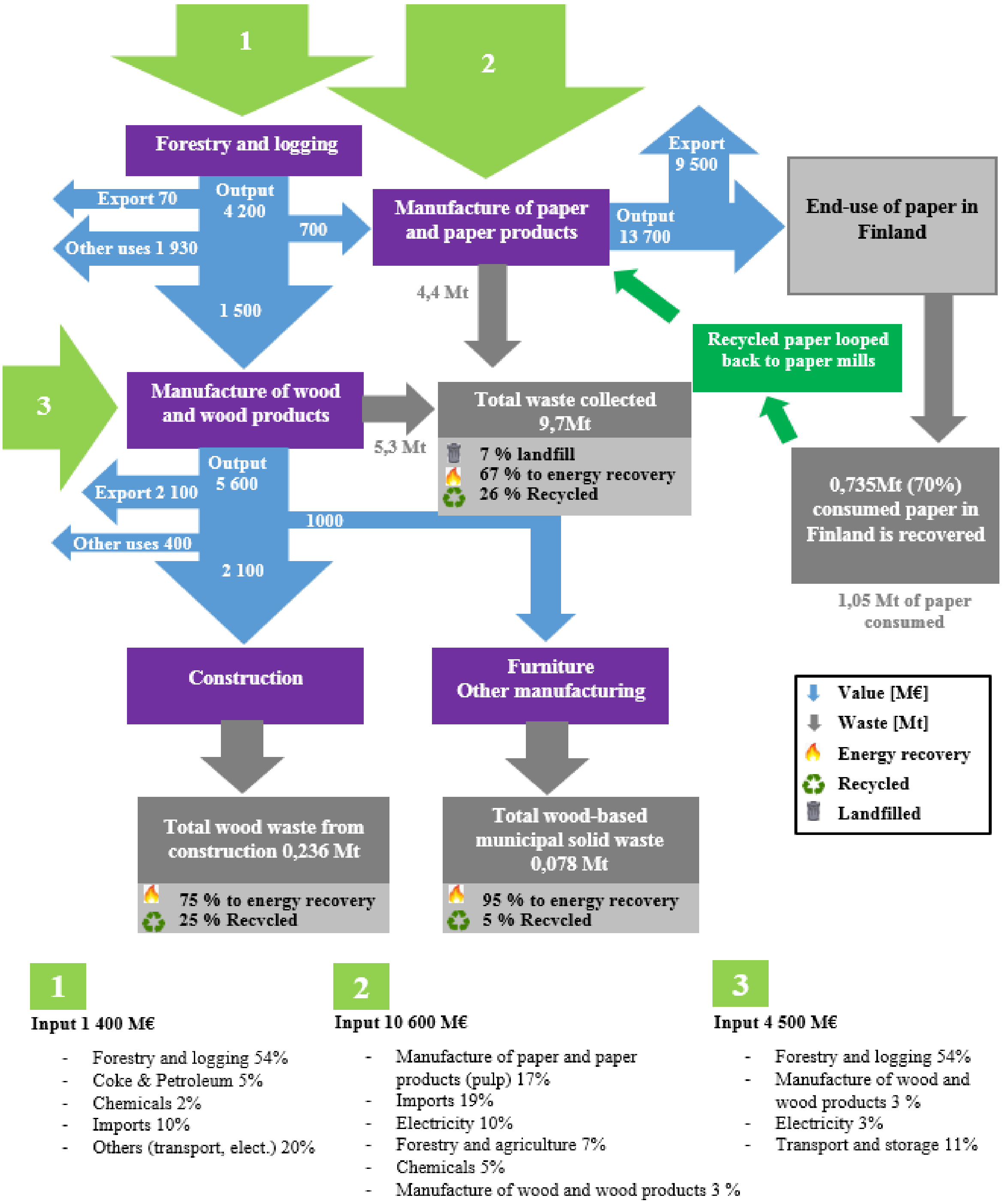

Figure 11. Overview of the value chain of wood in 2011 in Finland (Sitra 2015a, 29)

The figure reveals two main areas of CE at the moment in the forest industry sector. First is recycling of paper fibers which covers remarkable share of the total flow of the materials.

Overall 70 % of domestically used paper in Finland is recycled back to the loop. It is important to notice that a large share of the produced paper is exported and therefore paper producers don't have control over the recycling chain. This creates challenge from a CE point of view. Therefore, Sitra's study suggests that paper industry should focus more to the by-products from the means of CE. (Sitra 2015a, 10, 28.)

The second area is energy recovery at incineration plants. Wood based fractions and even a share of recyclable paper end up many times to incineration. Energy recovery is the easiest way in many cases to utilize wood based waste fractions, when many of the factory sites have their own incineration plant, like in Rauma. Energy recovery locally decreases impacts caused by the landfill and transportation, but it is still important to consider if it is the most efficient way from CE or economic point of view to utilize the materials. (Sitra 2015a, 28.) In the waste management law order of priority emphasizes reusing and recycling of the materials before energy recovery. Other generally implemented principles of CE in pulp and paper industry from each production phase are shown in the table 3.

Table 3. Examples of circular economy principles implemented in pulp and paper industry in Finland (Sitra 2015a, 30)

Process	**Principles of CE implemented in forest industry**
Barking and wood processing	- Energy recovery from bark and wood waste
Fiber processing and pulping	- Black liquor processing: Recovery boiler and lime kiln - Refining by-products (Tall oil) - Sludge to energy recovery and ash landscaping and fertilizers
Paper production	- Mill broke is recycled back to the fiber processing - Maintenance for paper machines - Products are designed to ease recycling
End-use by consumers	- Recycling paper recovery

Finnish forest industry has done long-term work to decrease its environmental impact already the past two decades. Recovery rates are clearly higher and pollutions to water and air have decreased. When looking at the statistics the amount of waste produced by forest industry in Finland have decreased 90 per cent from the beginning of the 1990's, even the production capacity has increased. (Metsäteollisuus 2015b.) Also in the year 2015 there were 16 percent less waste disposed to landfills compared to the year 2014. By-product flows were utilized mainly in energy production and in fertilizing business. More than 100 000 t of wastes were used in fertilizing business in 2015. (Metsäteollisuus 2016a.)

The potential of 220-240 million annual savings through CE in paper industry are suggested to hide in by-product flows. This is due to a fact that only one third of the wood is fibers which are used in paper production. The rest two-thirds consist of glucose and lignin, which are not yet utilized with full potential. Especially lignin is said to have a good potential to create even higher added value than it is estimated in the research. Lignin is generally incinerated with black liquor, but it could be further processed to various raw materials for other industries. Sitra's research estimates that 25 % of lignin could be extracted without disturbing mill's energy balance, even it is an important part of black liquors burning process. (Sitra 2015a, 30-32.)

The side streams of forest industry offer also other opportunities, not only lignin. Paper industry has a potential to raise the amount of renewable materials used in Finnish economy by further processing the side streams for other industries. Functional products such as lignin, nanocellulose, specialty fibers, biochemical and other innovations are estimated to cover 210-220 million euros from the total saving potential and the rest 10-20 million euros are estimated to be covered by utilization of sludges, ashes and other industrial wastes. It is important to notice that the study excludes so called drop-in products, which could increase the added value even higher. Drop-in product category includes for example bioethanol and biofuels, which have a very high economic potential. The reason why this category was outlined from the study is that the estimates about the added value of these products varies a lot and could give a distorted result. (Sitra 2015a, 30-32.)

To achieve the benefit in forest industry companies are suggested to expand to product development with a greater volume and to learn to understand the possible markets. Creating new product-related co-operative relationships are said to be vital for taking the next step. This means expanding the partnerships from negotiation table in to production and research and development (R&D). (Sitra 2015a, 37.) The concentration leans too much to outer loops of the CE when the interest should be more in material use and research and development to reach the full potential of CE. (Seppälä et al. 2015, 67.)

2.4 Barriers to adapt circular economy

Even though, the concept has a lot of advantages from environmental, economic and social point of view and at its best it offers savings of millions of euros, there still are some barriers for implementation. Generally, challenges like lack of reliable information, poor management, shortage in advanced technology, financial issues, deficiency of effective legislation and regional barriers have been identified as challenges that may slow down the implementation (Wernick & Ausubel 1997; Peng et al. 2005, El-Haggar 2007, 90-92; 10; Su et al. 2013, 222; Heshmati 2015, 18-20; Rizos et al. 2015, 2-6).

One of the main barriers recognized when implementing the principles of CE are shortage of advanced technology and high investment costs. Development of CE business model and following the principles of CE requires updated facilities, infrastructure and advanced equipment, especially in industrial sector. Overcoming the technological issue to recover by-products and waste materials from the process is an indispensable step, but alone insufficient. For stimulating greater use of waste the recovery must also be cheap, easy and the quality of side streams needs to be assured. Investing in new technology and infrastructure requires a lot of capital and with long and uncertain payback time and low reward this can cause a lack of interest for many companies. Finding financing for implementing CE model is many times the most difficult barrier also in developing countries where the government funds are often used in targets that are seen more important. It is also possible that the necessary technology is not yet available or the scale is not large enough. (Wernick & Ausubuel 1997; El-Haggar 2007; Su et al. 2013, 222; Ellen Macarthur foundation 2016e.)

Another problem related to economics arises from the way how CE is introduced to possible investors. Among the investors, the concept might not be that familiar and when CE is often related to sustainability it is translated to the investors as a financially less attractive target. (The Guardian 2014.) The recovered material needs also present markets. Volatility in quality of material and in price can create a barrier for finding markets for recovered material. One of the options for finding markets is direct waste exchange within different industries, but even then, the possibilities can be very narrow. Side streams can be also relatively small.

Even if the products would be good, the commercialization wouldn't be profitable enough for larger companies. (Wernick & Ausubuel 1997; El-Haggar 2007, 88-89; Sitra 2015a, 35.)

Second remarkable barrier is legislation. Regulatory that concern wastes are estimated to lower their market potential compared to virgin raw materials. This unfair competition leads to a situation where competing by utilizing recovered raw material is not a profitable business. (Seppälä et al. 2016, 43.) Legislative limits play an important part also in Finnish paper industry's operation. A good example from a legislative barrier in Finnish paper industry is sludge which is seen as an interesting opportunity in the sector. However, in many cases the problem in utilizing the material lies on the regulatory that increases costs and suppresses the development of innovations. Certain bio-sludges which contain hardly any harmful bacteria, are bound by some of the same legislation than wastes directed to sewers which makes the utilization more difficult. Recovery of ash faces similar problems. Difficult regulatory many times causes lack of interest to utilize the material. Applying environmental permits for utilization of wastes can be a very long and complex process. In addition, limit values restrict ash utilization even it is not known whether exceeding the limits of heavy metal concentrations causes danger for example in forest fertilization. (Sitra 2015a, 35.)

Also, organization of the corporate can be a barrier for implementing CE principles. Private firms are important units when it comes to innovating new ideas to improve environmental quality. Corporations have a variety of approaches to environmental matters. Some firms commit exclusively to regulatory compliance and in other firms the environmental issues play more of a strategic role. This determines a lot whether the company is prone to adopt new technologies or practices that concerns their environmental performance or not. This affects also to willingness to invest into cleaner technology and to the ability to make short- and long-term decision related to environment. (Wernick & Ausubuel 1997; El-Haggar 2007, 88-89.) More internal and external barriers that are likely to come up when implementing principles of CE are shown in table 4. In the research by Benton et al. (2014) it is suggested that possibly the quickest route to overcome most of the internal barriers is to hold a workshop within the company where the meaning of the CE and the corporate strategy are opened.

Table 4. Other barriers that a likely to come across when implementing principles of CE (El-Haggar 1997, 24, 88; Benton et al. 2014, 67-68)

Internal barriers	- Lack of commitment of senior management - Lack of time and effort to consider the possibilities - Lack of understanding the principles of CE - Attitude problems - Lack of technical expertise on new process options - Perceived uncertainty about future policy leading to inertia - Not being prepared to accept a long enough return on investment
External barriers	- Poor design of products in the supply chain - Lack of leadership from the government or another important player from the sector - Encountering resistance - Not having enough control over supply chain - Not finding appropriate partners - Lack of recovery and reprocessing infrastructure - Lack of public awareness - Geographical location

3 WASTE MANAGEMENT SYSTEM AT UPM PAPER ENA'S PAPER MILL IN RAUMA

The environmental and safety manager Eerik Ojala has published a waste management guide, which can be found from the company's intranet. The guide imparts people who are responsible for waste management at the mill and what are their tasks. It describes how the waste management is organized and indicates that the company is committed to follow the Finnish waste law 646/2011 and the waste management's priority order. (Ojala 2016, 3-5.) The responsibility hierarchy of the waste management system is shown in the figure 12. It pictures the administrative background of the waste management system at the paper factory. (Ojala 2016, 20-21).

Figure 12. Responsibility hierarchy of the waste management in Rauma's paper factory (Ojala 2016, 20)

As described in the figure, mill board of directors is responsible for mill's environmental impacts and the waste management system. After the mill board comes the environmental and safety manager who responds to the mill board. When it comes to waste management, the responsibility of environmental and safety manager is to organize a system, which meets legal requirements, organize effective implementation and to keep the system up to date. Environmental manager is also obliged to assist different units in problems related to environmental issues and to response to the waste management targets set by the concern such as ZSW project. Next in the hierarchy is the facility maintenance. Facility maintenance sector has more practical approach to the waste management system. Its responsibilities include for example arranging waste containers to the production site, keeping the equipment in a decent condition and to manage the agreements with subcontractors. (Ojala 2016, 3, 21.)

After the facility maintenance comes unit managers who are responsible for different operative areas. Each unit has a worker named in responsible for the operation. Usually the people in response are day supervisors or maintenance superiors. Their responsibility is to intervene to possible shortages in the waste management system in the area and to communicate with environmental manager. Area responsible ensures that everyone working in the area knows how to recycle correctly and they know how the waste management system works in their area. Last and the most important step in the responsibility hierarchy is a common responsibility. Common responsibility means that everyone is obligated to recycle, mention about irresponsible action and to ask help if necessary. (Ojala 2016, 3, 21.)

3.1 Waste management service description

The mill's waste management system works in co-operation with UPM Paper ENA's own employees and subcontractors. The waste collection system in the mill site consists of tipping skips and demountable waste container transportation. Despite of the scrap metal containers that are owned by Kuusakoski Oy, all the skips and containers are owned by UPM Paper ENA Oy. Tipping skips are located around the mill site for source separation of the wastes. Common fractions that are collected at the site are factory waste, recyclable plastics and fibers, combustible material, domestic waste, metals and WEEE. Skips are color coded and labeled for each fraction. The instruction labels explain what can be placed in the tipping skip. (Ojala 2016, 6-7.) A tipping skip and a demountable waste container are shown in the figure 13. There are also 140 liters (l) and 240 l wastebaskets in some locations where it is seen more suitable because of use of space. Wastebaskets are emptied to the tipping skips or directly to the demountable containers by employees.

Figure 13. Tipping skip (left side) for source separation and demountable container (right side) for waste transportation (Langtons 2016; DJE 2016)

Tipping skips are emptied to demountable waste containers by forklifts. The emptying is handled together by mill workers and a logistic company Järvelän Siirtokuljetus Oy. There are around 110 tipping skips at the factory site for source separation, of which 85 is emptied by UPM Paper ENA’s own employees and 25 by Järvelän Siirtokuljetus Oy. Transportation distance from tipping skips to demountable containers at the factory site varies between 100 and 300 meters.

Demountable containers are used for waste transportations. In the mill area there are in total around 30 actively used demountable waste containers. Demountable container traffic can be divided into external and internal transportations. Internal container transportation is arranged by another local logistic company P. Peltomaa Tmi. Internal transportation contains of combustible material transportations to the biopower plant, packaging material transportations to the loading station and some bottom ash and sand transportations. External waste transportation consists of transporting wastes that can’t be handled at the site. This means landfill transportations and recyclable waste transportations to external partners. P. Peltomaa manages all the logistics to industrial waste landfill to Suiklansuo and to domestic waste landfill to Hevossuo. Recyclable material container transportations and hazardous waste transportations for further processing are handled by the recipients.

All waste fractions produced and collected at the mill site are shown in the table 5. Some of the fractions are called differently at the site than generally. Therefore, there are examples what each fraction contains according to the recycling instructions. There is also a column where it is explained who is in responsible for the transportation, where the waste fractions are transported and for what purposes. Later these same names of the waste fractions are used in the study. Waste flows and processes are presented in the text more precisely after the table.

Table 5. Collected waste fractions, contents and current transportation (Ojala 2016, 22)

Waste fraction	Contents	Transportation and location
Combustible material	-Dirty paper and cardboard -Felts and screens in pieces -Pieces of wood -Plastics (Excluding PVC) -Styrofoam -Ropes and rubber belts	Transported to energy recovery to Rauman Biovoima's biopower plant by P. Peltomaa Tmi.
Factory waste (Mixed waste)	-PVC -plastics -Braided sealants -Glass and mineral wool -Ceramics and porcelain -Carbon fiber scrappers -Abrasive discs	Transported to industrial waste landfill to Suiklansuo for waste disposal by P. Peltomaa Tmi.
Domestic waste (Municipal solid waste)	-Disposable cutleries -Paper cups, plates and tissues -Food wrappings -Office waste -Waste from break rooms	Transported to municipal waste landfill to Hevossuo by P. Peltomaa Tmi. Wastes are transported from there to energy recovery to Vaasa by the City of Rauma.
Metal scrap	-Black metal scrap -Stainless steel -Aluminium -Empty aerosols -Turning chips	Transported to material recycling by Kuusakoski Oy.
Bio waste	-Leftovers -Fruit peelings -Coffee grounds and tea bags	Transported by the city of Rauma to digestion plant of Biolinja Oy for biogas production.
Recyclable fibers	-Paper roll sockets -Packaging card board -Paper roll wrappings	Transported to packaging material recycling station by P. Peltomaa Tmi. Paperinkeräys Oy empties the containers later for material recycling.
Recyclable plastics	-Bright packaging plastics -High/Low-density polyethylene (LPDE/HPDE) -Polypropylene (PP)	Transported to packaging material recycling station by P. Peltomaa Tmi. Paperinkeräys Oy empties the containers later for material recycling.
WEEE	-Computers and screens -Other electronical devices -Electric tools -Cables	Transported to material recycling by Kuusakoski Oy.
Hazardous waste	-Oils and oil filters -Process chemicals -Fluorescents and batteries	Transported to the central warehouse by factory workers to a locked storage room. Ekokem Oy empties the storage room when necessary.
Ash	-Bottom ash -Fly ash	Transported to Suiklansuo's construction project by Rantanen Osku Tmi and P. Peltomaa Tmi.
Kaolin sludge	-Kaolin sludge	Circulated back to the process. Also utilized as a raw material in the brick industry.
Sludge from the waste water treatment plant	-Primary sludge -Bio sludge	Transported to energy recovery to Rauman Biovoima's biopower plant by conveyor.
Wood chips and barks	-Wood chips -Barks	Transported to energy recovery to Rauman Biovoima's biopower plant by conveyor.

Combustible material collected at the mill site and from offices is used for energy production. Energy recovery takes place in the biopower plant, which is owned by Pohjolan Voima Oy. The company operates at the same site with the paper production. Combustible material collected from the mill site consists of pieces of felts and screens, styrofoam, oily fibers, dirty papers, cardboard and belts (Ojala 2016, 24). Collected paper from the offices is incinerated at the biopower plant instead of recycling due to confidential reasons. (Ojala 2016, 15). Excess paper from the production is re-pulped and used in the paper production as a raw material. Combustible materials are collected also externally from private and public sector. In the beginning of 2016 the city of Rauma started collecting waste for energy recovery. Collected material contains of combustible non-hazardous waste fractions like cardboards, plastics, stryrofoam and textiles (Rauma 2016a; Rauma 2016b). Collected waste for energy production from mill site and externally goes through mechanical treatment process which includes crushing and screening before it is utilized as a recovered fuel (REF) at the incineration plant.

The biopower plant is combined energy and heat production plant. The power plant consists of two actively used boilers: circulating fluidized bed boiler (180MW) and a bubbling fluidized bed boiler (120MW). Besides, there is a smaller back up boiler, which is run by heavy fuel oil. (52/2011/ESAVI.) In the year 2014 energy production at the biopowerplant was 474,7 GWh (Energiateollisuus 2014). The fuel used in the biopower plant consists of biofuels, peat and REF. Biofuels, which covers the largest share of the fuels, consist of forest fuels, wood residues from factory site and sludge from the waste water treatment plant. In addition, there is a permission to incinerate wooden railroad sleepers. Recyclable oil from the paper factory is used to lubricate the conveyor lines. Fuel distribution at the biopower plant in 2014 is shown in the figure 14. Non-renewable energy sources that are used in the ramp-up situations consisted of coal and heavy fuel oil.

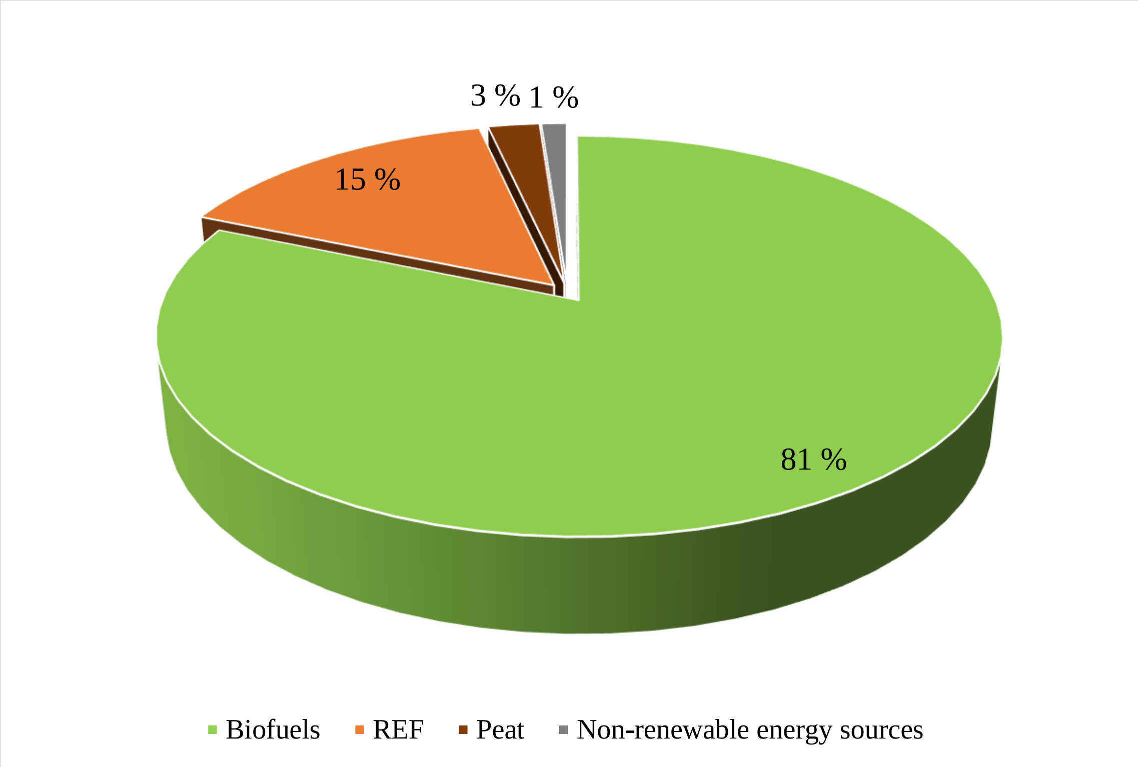

Figure 14. Fuels used in heat production at Rauman Biovoima's biopower plant in the year 2014 (Energiateollisuus 2014)

Landfilled waste consists of waste fractions which doesn't have yet a utilization purpose or which can't be utilized by legal means at the mill. At the mill, these fractions are called factory waste and domestic waste. Factory waste represents a mixed waste fraction which is collected at the production sites and it covers clearly the biggest share of landfilled wastes. The fraction is transported to industrial waste landfill to Suiklansuo, owned by UPM paper ENA. Factory waste consists of PVC -plastics, carbon fiber scrapers, abrasive discs, ceramics and mineral wool. Also a lot of combustible and recyclable materials end up to the landfill due to deficiencies in source separation. (Ojala 2016, 10-11; 15-17; 26.) A small share of landfilled waste is covered by construction waste. Construction waste collection is mostly project related action.

Domestic waste, which is at the moment transported to the Hevossuo's municipal landfill, consists basically of combustible material such as paper cups, paper plates, food wrappings and napkins. The waste fraction is comparable to municipal solid waste. Domestic waste is still collected from controlling rooms, break rooms and offices. From Hevossuo the wastes are transported to Vaasa to waste incineration plant owned by West Energy. The transportation is handled by the city of Rauma with other collected municipal waste (Rauma 2016; Yle 2014). Current operation model at the mill has been already noted to be outdated. The intention is to remove the domestic waste baskets, change them to the combustible material baskets and incinerate the wastes at the biopower plant. To assure that there wouldn't end up any harmful residues to combustion glass and metals are collected separately at the break rooms. This practice was already partly adapted during the study.

Bio waste collection started at the factory site in the summer 2016. It is mainly collected from the factory canteen, but also three office floors have baskets to separate bio waste as a pilot experiment. Bio waste is gathered into a deep collection container from the offices and the canteen by cleaning stuff. Collected bio waste is transported to biogas production to Uusimaa to Biolinja Oy. Transportation to the bio gas plant is handled by the city of Rauma. Currently left overs, coffee grounds and fruit peelings produced at the mill site are directed to incineration. According to the conversation the volume of produced biowaste in the production site is so small that the separation would cause unreasonable amount of work compared to the benefits. It will be discussed later if the bio waste separation should be started on a larger scale at the mill.

Collected recyclables such as metals and packaging materials and also bio waste are handled by external partners. Kuusakoski Oy is responsible for recovering and transporting metal scrap and WEEE. Collected metal scrap at the mill site is mainly a mixture of different metal qualities and sold as a black scrap metal to Kuusakoski. There are also few containers for stainless steel but the separation of black scrap metal and stainless steel is more project related action. In addition, there is an aluminum separation at the biopower plant. Collected scrap metal is used as a secondary raw material in a metal production by Kuusakoski Oy. Produced metal scrap is strongly related to demolition projects at the mill site and the annual amount can vary a lot. Separated packaging materials, plastics and recyclable fibers, are recovered by Paperinkeräys Oy. Paperinkeräys Oy have invested to a packaging material recycling station, which is located at the mill site. The recycling station consists of sheltered containers for recycled fiber and plastics. P. Peltomaa transports the material from the production site to the station from where Paperinkeräys Oy takes care of the recyclable fractions.

Ekokem Oy handles hazardous wastes produced at the mill site. The company is specialized in hazardous waste material treatment. Their technique generally bases on a high temperature incineration, which allows them to burn materials on a wider scope than a normal waste incineration or co-incineration plant. (Ekokem 2016.) Hazardous waste collected from Rauma's paper mill consists mainly of oily filters, batteries, process chemicals, fluorescent lamps and oils. Mill's own employees centrally collect these fractions to a locked warehouse where Ekokem Oy collects them when necessary. The hazardous waste production varies a lot annually. (Ojala 2016, 15-16.) On the average the warehouse is emptied two or three times per year.

In addition to regular waste fractions, which are collected at the mill site, there are production related waste fractions. The nature of these residues is different because of the large annual volumes. These fractions at Rauma's mill site are for example: fly and bottom ash, wood chips, barks, kaolin sludge and sludge from the waste water treatment plant. At the moment, the situation in Rauma is very good due to a large landscaping project. UPM Paper ENA's mill in Rauma has received an environmental permit to fill Sampaanala's gulf with certain waste materials. The Sampaanala's gulf is an elongated inner gulf of the Bothnian Sea and located to vicinity of the paper mill. In addition to the paper mill, there are a pulp mill, biopower plant and wastewater treatment plant located around the gulf. Objective in the project is to use as much materials that would be otherwise classified as a waste from the local industry as possible to replace natural resources as a filling material. Waste flows such as demolition material, fly ash, bottom ash, sludge from the waste water treatment plant, green liquor sludge, kaolin sludge and tire crumbs are allowed to use as a filling and stabilizing material. (21/2010/ESAVI) Because of the project Rauma's mill site have reached the recycling rate of 100 % for ash and kaolin sludge.

After the project at the gulf of Samaanala started in 2012, all of the ash and kaolin sludge produced at UPM Paper ENA's mill site have been located to the gulf and also reserves stored to Suiklansuo's landfill have been transported to the project. In addition, a large amount of rocks, cement and bricks from demolition sites have been used in the project. The filled area is meant to use after the project as a storage field for wood. The permit for the project came in to effect at 28th of March in 2011 and it allows the project continue ten years after its beginning. It is estimated that the project will still last 5-7 years. The project won an award from a Finnish Geotechnical Association from an advanced and effective excess material utilization in 2013. (21/2010/ESAVI; UPM 2016d.)

The waste water treatment plant is managed by UPM Paper ENA Oy. It processes both industrial and municipal waste waters. The industrial waste waters are directed to the primary clarifier and the municipal waste water straight to the aeration pool. Processed sludge contains high percentage of clay and other rock materials from the paper industry. Mixed sludge is incinerated at the incineration plant, but the environmental permit also allows using it in the Sampaanala's construction project. The mixed sludge is defined as a slightly biodegradable but it is not seen as a problem in the construction work. (21/2010/ESAVI.) The calorific value of the sludge is relatively low or in some cases even negative depending on the dry-content of the sludge.

Kaolin is used in a pigmentation material in paper production. For the most part kaolin residue is recycled back to the process. (21/2010/ESAVI.) Remaining kaolin sludge were earlier disposed into a kaolin pool to Suiklansuo, but authorities prohibited this action in 2012 and ordered to rebuild the base structure of the pool. The pool was not completely renovated for the disposal and therefore it can't be used for the kaolin sludge disposal at the moment. A ramp for unloading was built in 2014, but the ground works weren't seen necessary to start since the sludge is allowed to use in the gulf filling project. Currently the kaolin sludge is circulated back into the process. Kaolin sludge has also been used as a raw material in brick industry, but the problem is a low dry-matter content, which increases the transportation costs. The year 2014 was the best, when 1819,72 t of kaolin was transported to Kemiö for Tiileri Oy. This included the kaolin sludge transportations from the intermediate storage from Suiklansuo. The sludge was mainly collected from Suiklansuo where the stored sludge was already thickened and therefore easier to transport. Main waste flows at the site are summarized in a waste diagram in figure 15. In the figure, collected wastes at the factory site are divided into three categories: recycling, energy recovery and waste disposal.

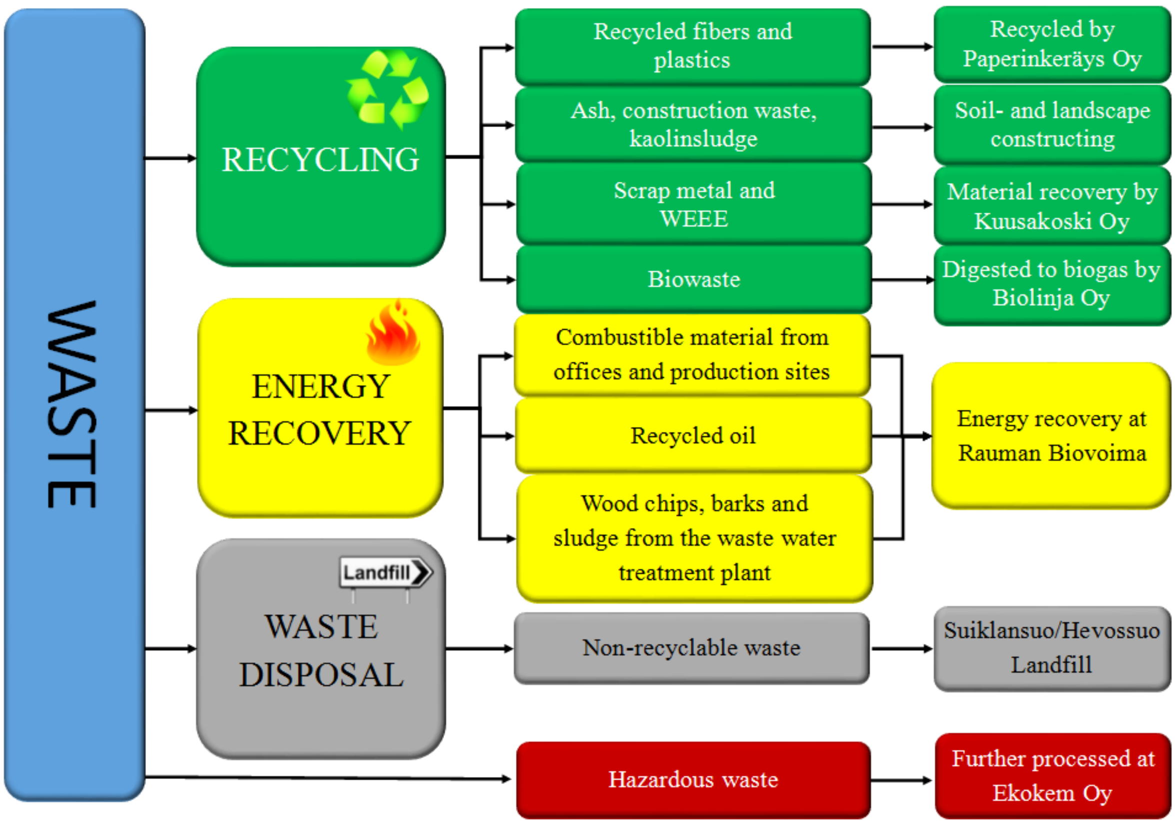

Figure 15. Waste diagram from Rauma's factory site (Ojala 2016, 4)

All waste fractions, except the waste water sludge and wood chips, are weighted at the weighting station which is located at the factory area. Weighting service is out sourced to Mitta-Asema, which is owned by Metsä Fibre Oy. Beside the paper mill, the weighting station is also used by the pulp mill owned by Metsä Fibre Oy and external parties who transport material in and out from the factory site. Driver informs at the scale the transported waste fraction, its origin and where it is going to be located. The information is downloaded to a Rapu-database where the waste amounts are reported regularly. The information is used to report waste amounts and to track the waste generation.

Each waste container is also coded according to the location which enables to track the origin of the produced wastes. The intention of the system is to enable to develop waste management and to follow the waste management costs unit specifically. The tracking system bases on demountable container coding system. Besides that, all waste fractions are coded due to the European Waste Catalogue (EWC) coding system. In addition to EWC codes, local additional codes are used to individualize the fractions more accurately.

3.2 The quantities of produced wastes

Next the produced waste amounts at the mill are viewed more accurately. First the study examines the landfilled waste amounts to find out the utilization rate of Suiklansuo. Later also other produced waste residues are researched. Amount of landfilled waste at Rauma's paper mill have dropped remarkably in the past decade. This is mainly because of ash recovery for the gulf construction project but also due to technological improvements like kaolin circulation technology in the paper production. In figure 16 is shown the waste amounts located to the industrial waste landfill in Rauma during the years 1997-2015.

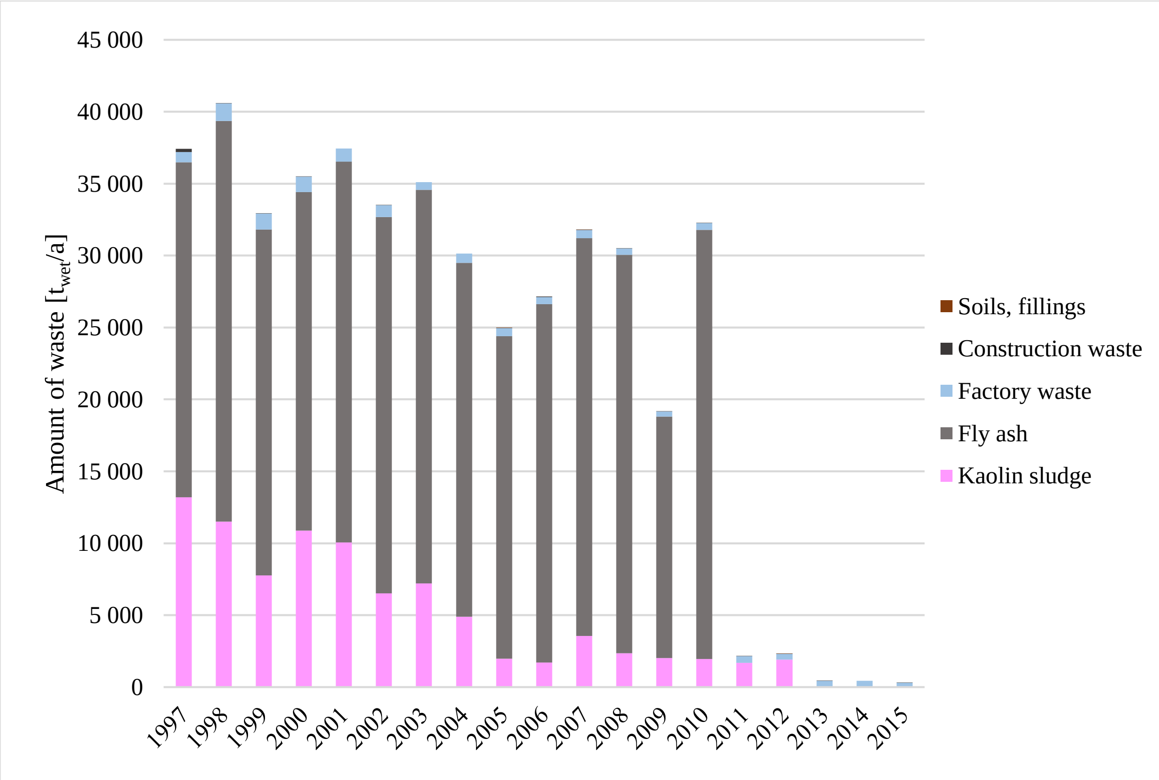

Figure 16. Amount of waste disposed to Suiklansuo's landfill during the years 1997-2015

The impact of the Sampaanala's construction project can be clearly seen from the figure. After the project started in 2012, it cut the amount of disposed waste located to Suiklansuo's landfill. Disposed waste decreased from more than 30 000 t in 2010 to 300 t in 2015. Ash produced in 2011 was recorded for intermediate storing purposes for the construction project even it was located to the landfill. The distribution of landfilled material can be well seen from the figure. Factory waste and construction waste represents only a small share of landfilled wastes compared to ash or kaolin. At the moment, the side of UPM Paper ENA of the landfill is almost out of action. A corner which is in an active use for the factory waste and construction waste disposal, represents 5 % from the total volume of the planned landfill. Metsä Fibre uses a half of the landfill for green liquor sludge disposal. In this work the share of the landfill actions caused by Metsä Fibre are not taken into account.

Figure 17 represents amount of wastes disposed to Suiklansuo's landfill in years 2011-2015. The figure gives a better understanding about the landfill actions in Suiklansuo by the paper mill in recent years. Intermediate storing of ash or kaolin during this time is not taken into account in the figure, since the reserves were unloaded for the Sampaanala's construction project. Figure shows that in each year more than 95% of landfilled waste consisted of factory waste. A positive observation is that amount of landfilled waste has dropped almost 150 t within the same time period. It is estimated that in 2016 the amount of produced factory waste will be less than 200 t. During the time 1st of January to 30th of September there were 143,2 t of factory waste produced. The reduction can be due to more efficient source separation and higher interest about environment. Any larger changes weren't made in the waste management system before September, but during this study the waste management system at the mill site raised a lot of conversation. To reach the ZSW goal, the focus must be in factory waste and finding an alternative solution for the landfill disposal. Rauma close to achieve the ZSW goal.

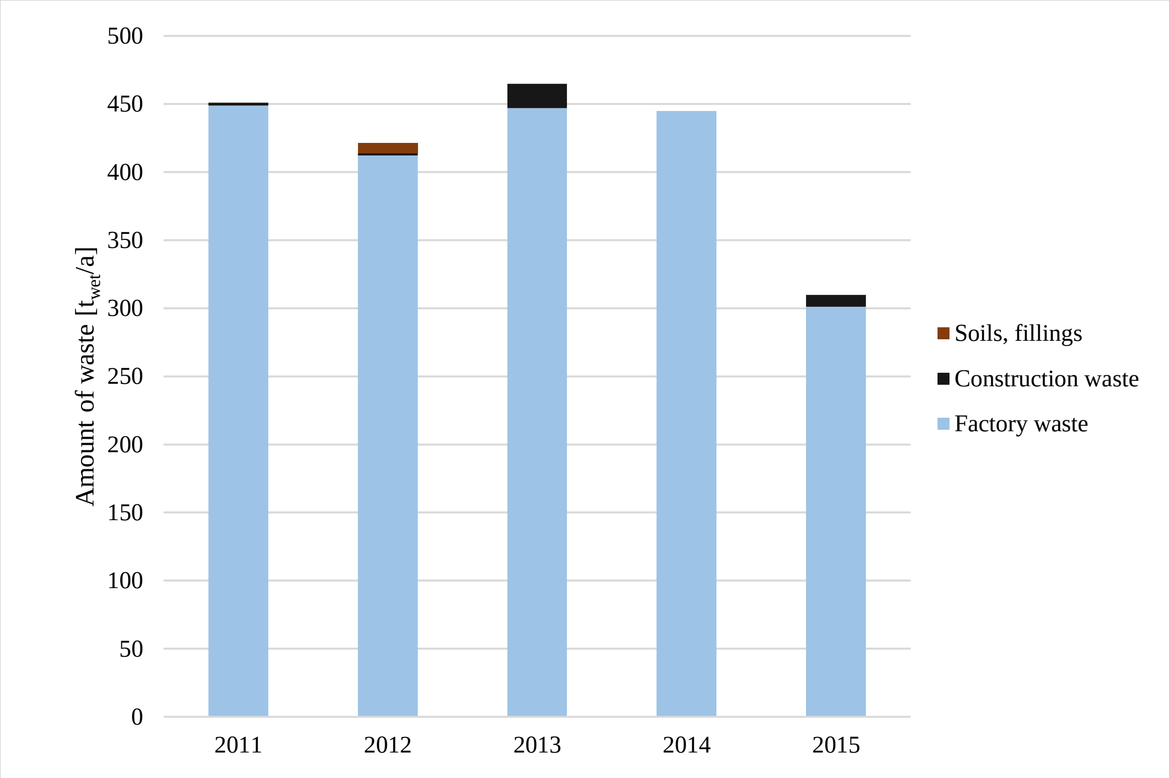

Figure 17. Amount of waste disposed to Suiklansuo's landfill during the years 2011-2015. Intermediate storing of kaolin sludge and ash are not included.

Produced waste fractions during the year 2015 are shown in the table 6. A more detailed version of the table can be found from the attachment one. The table also shows the distribution of the waste production between different sections. This is based to the tracking system of the demountable waste containers. Waste containers are allocated into eight different sections. Different sections are: paper machines 1-4 (PM 1-4), thermo-mechanical pulp line (TMP), Common, Rauma Cell (RC) and Rauman Biovoima. Paper machine 3 is still an individual section even the actual machine was demolished in 2013. There is an actively used winder in the old production hall, but the rest of the area is mainly used in storage purposes. Waste water treatment plant is not considered in the allocation, but the sludge from the waste water treatment plant handled later in this section.

Table 6. Waste amounts in 2015 from different operative units [t_{wet}/a]. PM = Paper Machine, TMP = Thermo-mechanical pulp line, Com. = Common, RC = Rauma Cell, RB = Rauman Biovoima.

Waste fraction	**PM 1**	**PM 2**	**PM 3**	**PM 4**	**TMP**	**Com.**	**RC**	**RB**	**Total**
Kaolin sludge	353,5	0,0	0,0	0,0	0,0	29,2	0,0	0,0	**382,7**
Waste to Suiklansuo's landfill	64,1	25,2	0,6	16,2	16,8	132,4	12,2	42,4	**309,8**
Waste to Hevossuo's landfill	0,0	1,7	0,0	0,0	0,0	28,3	0,0	0,0	**30,0**
Incinerated waste	393,0	54,1	25,8	911,8	59,8	793,7	96,4	18,0	**2 352,5**
Metals	0,0	0,0	22,2	0,0	29,6	302,0	0,0	529,5	**883,2**
Soils, Cement and Bricks	0,0	2,0	4,4	0,0	0,0	482,5	0,0	11,3	**500,3**
Recyclables	52,8	38,8	18,8	46,0	0,0	9,5	0,0	0,0	**165,8**
WEEE and cables	0,0	0,0	55,3	0,0	0,0	123,0	0,0	0,0	**178,2**
Ash	0,0	0,0	0,0	0,0	0,0	0,0	0,0	37 918,5	**37 918,5**
Total	**863,3**	**121,8**	**127,0**	**974,0**	**106,2**	**1 900,5**	**108,6**	**38 519,6**	**42 721,0**

The table shows that the amount of produced wastes varies a lot between the sections. There are clear fraction specific differences between some sections even the operations are quite similar for example in paper machine 1, 2 and 4. Common sector covers a large share of the produced fractions in many cases. The same results are shown in figure 18 to visualize the situation better. Ash is excluded from the figure 18 since it would change the scale and make the figure harder to read. All of the produced ash comes from the biopower plant.

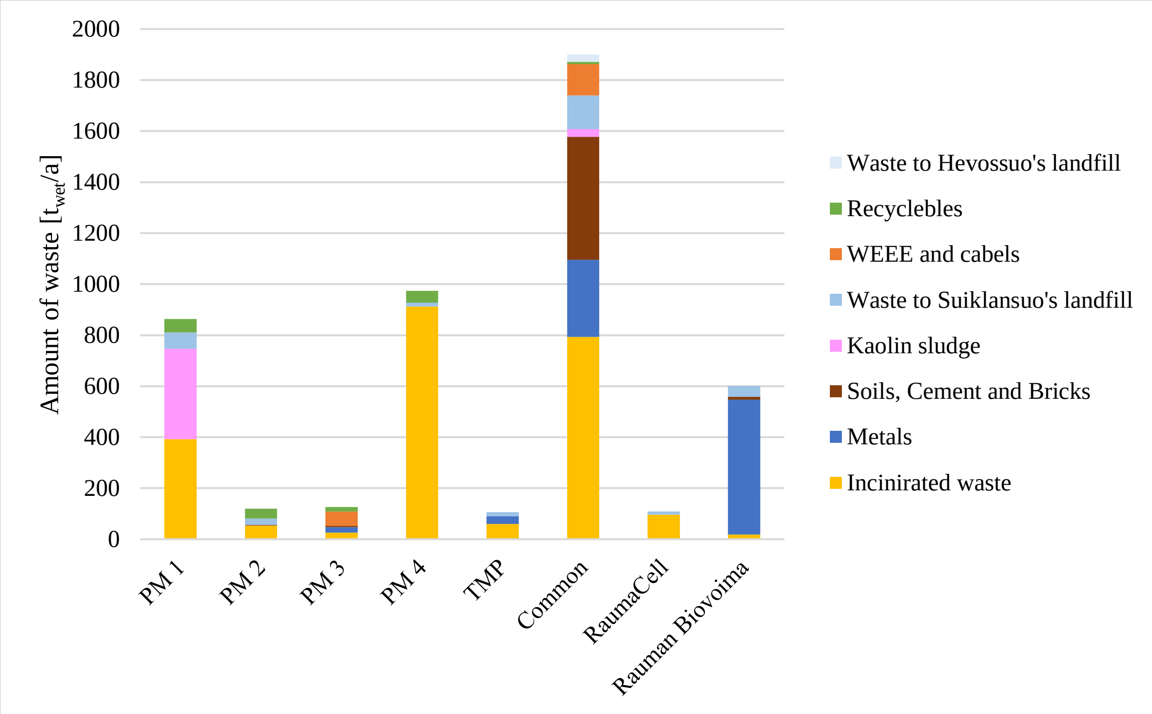

Figure 18. Waste produced in each section in 2015 [t_{wet}/a]. PM = Paper Machine, TMP = Thermo-mechanical pulp line

Sastistically paper machines one and four and the common section covers clearly a larger part of produced waste than the rest of the units. According to the conversations this doesn't respond to the real- situation. The waste management system and the reporting system have been evolving with and without purpose over the years making the tracking system outdated. Typical reasons could be for example: containers have changed a location and therefore have wrong code, containers are coded to one operative unit, but are used also actively by another section, or tipping skip from one section is emptied to a waste container which is coded to another section. For this kind of reasons statistics aren't telling the exact truth and therefore don't serve the original purpose anymore.

Some of the differences can be also explained by geographical reasons. Paper machine four and the biopower plant are geographically isolated from other sections in the mill area making the coding of the waste containers easier. This also assures that wastes produced in the area end up in a correctly coded container. Paper machines one, two and three, TMP -line and production line of Rauma Cell are physically connected to each other which makes tracking the waste flows accurately more difficult. The volume of produced waste amounts of paper machine one and two should be statistically closer to the presented statics of paper machine four. Apparently, lot of wastes end up to the containers that are coded to common use. It seems that the more rear waste fractions such as WEEE and soils are generally coded to common use. Variation between the sections in metal and kaolin sludge separation can be also explained because of technological solutions.

The tracking system is an interesting idea but it is difficult to implement. To get best out of the system and to get it represent the real situation better every demountable waste container should be marked again and employees should be trained. Some of the workers might not even know that these kinds of statistics are followed. It should be also revalued if the code for common use is even needed anymore since it doesn't give any valuable information. From the total amount of produced waste 40% of the wastes were recorded to come from common activities. Containers that are used by two or more operative units should be coded so that the produced amount of wastes would be divided equally for each section. There were conversations during this study if the tracking system will be discontinued because of its complexity.

The total waste amounts were researched during the years 2011 – 2015. The results from the time period are presented in a table 7 in wet tonnes. More detailed version of the table can be found from the attachment two. Under the review period there have been some variation in the produced waste amounts. Kaolin sludge generation almost doubled during the years 2011-2014, but then dropped more than 2500 t in the year 2015. Decreased amount of produced kaolin sludge is because of technical problems with the collecting equipment.

Table 7. Produced amount of wastes during the years 2011-2015 [t_{wet}/a]

Waste fraction	**2011**	**2012**	**2013**	**2014**	**2015**
Kaolin sludge	1 696,04	1 904,44	2 384,72	2 927,42	382,66
Waste to Suiklansuo's landfill	383,92	375,14	407,10	394,46	309,82
Waste to Hevossuo's landfill	71,58	62,66	102,42	45,64	30,00
Combustible material	3 105,60	2 919,90	2 163,62	2 212,04	2 352,52
Metals	390,92	603,08	945,90	508,36	883,18
Soils, Cement and Bricks	15,64	828,87	2 799,40	841,46	500,26
Recyclables	428,10	499,98	486,38	231,84	165,76
WEEE	27,80	11,92	19,86	58,36	178,24
Hazardous waste	58,78	21,59	40,64	445,67	37,00
Ash	37 603,10	36 395,00	36 342,04	37 849,49	37 918,54
Total	43 781,48	43 622,58	45 692,08	45 514,74	42 757,98

Amount of wastes disposed to Suiklansuo and Hevossuo waste have decreased by around 150 t in total during the review period. This could be because of more efficient source separation or decreased amount of produced waste. The share of combustible material has increased in the last two years by almost 200 t, which could refer to a fact that a share from landfilled waste would have ended to incineration. This is still just speculation. Also, the amount of recyclables has decreased notably. A larger drop in combustible material from the 2011-2012 level is because of decreased amount of wood based waste produced at the site. Amount of produced metals, WEEE, hazardous waste, soils, cement and bricks varies a lot due to different projects which can be seen also from the table 7. The demolition of the paper machine three in 2013 increased the amount of produced metal scrap, cement and bricks notably in the same year.

In the year 2014 amount of produced hazardous waste was clearly higher than on average year. This was because of a Rauman Biovoima’s cleaning project on contaminated soils. The results in the table 7 are also presented in a bar chart in figure 19. The purpose of the chart is to visualize the changes in the produced waste amounts more clearly. Produced ash is excluded from this figure to adjust the scale more informative. As seen from the table 7 the amount of produced ash has been quite stable under the review period.

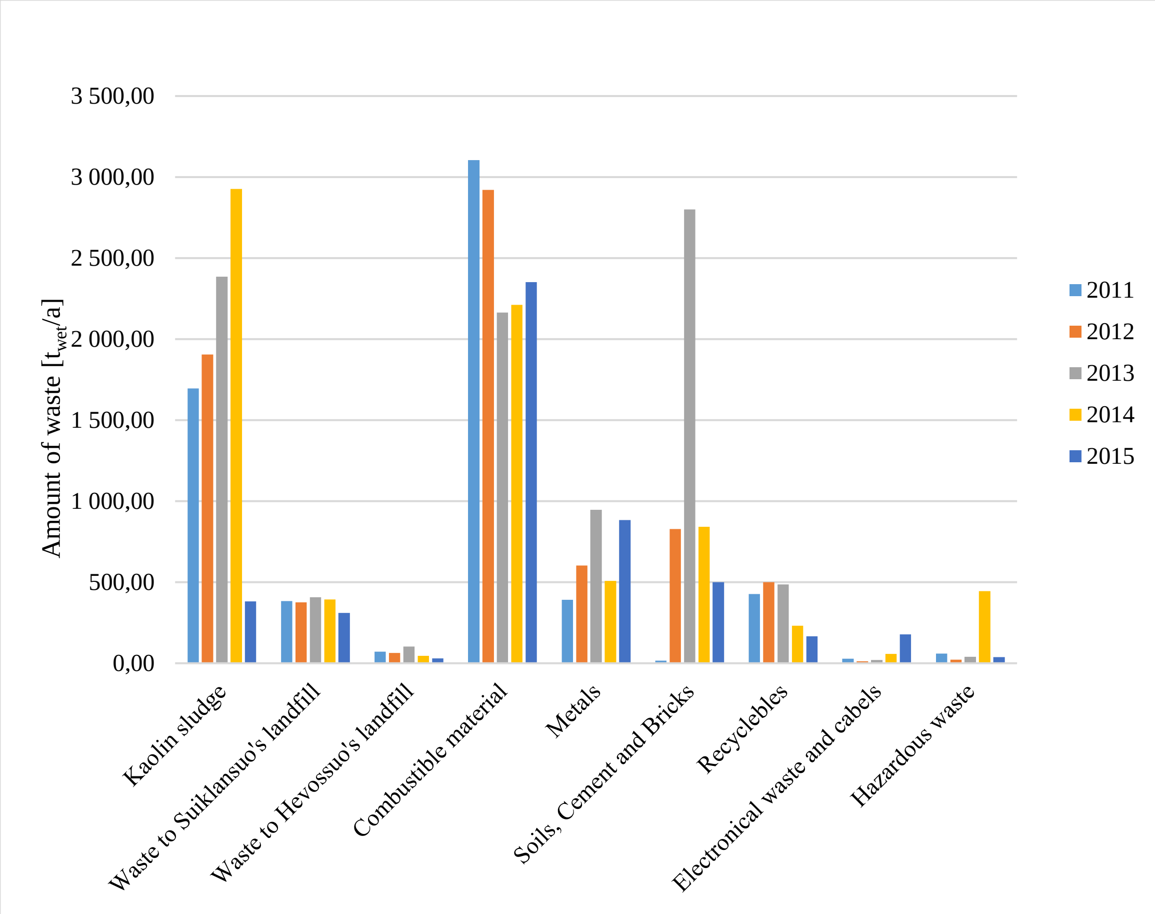

Figure 19. Produced amount of wastes during the years 2011-2015 [t/a]

Annually produced bio sludge share from the waste water treatment plant had to be estimated since it is not weighted. The calculations for annual amount of sewage sludge are shown in the equation 1. It was estimated from the statistics that the waste water treatment plant produces daily on average of 30 t of bio sludge and 70 t of primary sludge in a dry weight. The dry-matter content of the mixed sewage sludge in Rauma is approximately 35 %.

$$Sewage\ sludge\ \left[{}^{t_{wet}}/_{a}\right] = \frac{Mixed\ sludge\ [t_{dry/d}]*365}{DM\ content\ [\%]} \tag{1}$$

$$Sewage\ sludge\ \left[{}^{t_{wet}}/_{a}\right] = \frac{100\ t_{dry/d} * 365}{0{,}35} \approx 104\ 000\ t_{wet}/a$$

Reported waste amounts in official papers like in Eco-Management and Audit Scheme (EMAS) report are informed in dry weights. Used dry-matter contents are tested for the waste fractions in Rauma's paper factory. Dry weight for kaolin sludge is calculated as an example in the equation 2. In the table 8 is listed total amount of all waste fractions produced in 2015 in wet weights, their dry-matter content and dry weights. In hazardous waste dry-matter content is not taken into account. The reporting from hazardous waste is received directly from Ekokem Oy.

$$t_{dry} = t_{wet} * DM\ content\ [\%] \tag{2}$$

$$t_{dry,kaolin\ sludge} = 382{,}7\ t\ * 0{,}37 = 141{,}58\ t$$

Table 8. Amount of waste produced [t/a] in 2015 and Dry-Matter (DM) content of different fractions [%]

Waste fraction	**Weight [$t_{wet/a}$]**	**DM content [%]**	**Weigh [$t_{dry/a}$]**
Kaolin sludge	382,7	37	141,6
Landfill waste to Suiklansuo's landfill	309,8	90	278,8
Landfill waste to Hevossuo's landfill	30,0	60	18,0
Combustible material	2352,5	66,7	1569,1
Metals	883,2	-	883,2
Soils, Cement, Bricks	500,3	90,4	452,2
Recyclables	165,8	90	149,2
WEEE	178,2	-	178,2
Hazardous-waste	37,0	-	37
Ash	37918,5	85,7	32496,2
Sewage sludge	104285,7	35	36500, 0
Total	**147006,7**	**-**	**72703,6**

3.3 Landfill and earth construction eligibility research

Most interesting waste fractions for the company were sent to further laboratory tests. Ash, sludge from the waste water treatment plant, sludge from the balancing reservoir and factory waste were chosen for the tests. The primary purpose of the laboratory research is to find out what is the share of organic matter in the factory waste and if the source separation works correctly. This will give an answer if disposing the factory waste to the landfill is even legal and offers a clear message for the factory's management if waste management system needs a rapid transformation. The secondary object is to find out possible recovery purposes for tested waste fractions through the results. Ordered laboratory tests package varies between the samples. Different tests are landfill eligibility for non-hazardous and inert waste, earth-work eligibility and acid neutralization capacity with 9 different pH -values.

A sample of sludge from the waste water treatment plant and a sample from balancing reservoir sludge were sent to Eurofins Oy's laboratory for further analyses. In addition, a sample from screens felts and most common factory waste fractions were sent to the laboratory tests. Factory waste fractions were selected so that the whole would represent the factory waste collected at the production sites. The share of each fraction from the total amount of the factory waste was based on estimation. Ordered laboratory tests and the samples are shown in the table 9. Composition of fly ash was recently tested by Kokemäen vesistön vesisensuojeluyhdistys Ry (KVVY) and bottom ash was tested for the Sampaanala's construction project. Therefore, ash samples were not send to the laboratory tests in this context, but the results from earlier laboratory tests are used in the research. Pictures from the factory waste fractions and screens and felts are added in the attachment 3-10. Exact laboratory results are not presented in this work.

Table 9. Samples sent to the laboratory and ordered tests. * = Earlier results were used in this study

Fraction	Non-hazardous waste research	Inert waste research	Earthwork eligibility research	Acid neutralization capacity
Ash*	X	X	X	X
Sewage sludge	X	X	X	X
Sludge from balancing reservoir	X	X	X	X
Screens and felts	X	X	-	X
Fabrics including metal	X	X	-	X
Hoses and plastics	X	X	-	X
Abrasive discs and sanding strips	X	X	-	X
Braided sealants	X	X	-	X
Glass and mineral wool	X	X	-	X
Ceramics and Porcelain	X	X	-	X
Carbon fiber scraper	X	X	-	X

3.3.1 Fly and bottom ash

Ash's laboratory tests included landfill eligibility and earth construction eligibility tests. The results are based on KVVY's statement. Laboratory test were done for fly ash from both boilers separately, boiler five and six. There was some variability in the results between the boilers even the fuel distribution at the time was basically the same. Utilization eligibility research for landscaping were based on a council act 591/2006 and 403/2009 which are concerning about waste utilization in earth construction works. Landfill eligibility research was based on council act 331/2013. The research defined the total organic carbon (TOC) content and total concentrations for certain elements. Solubility of harmful substances was tested by two-staged batch leaching test based on a standard SFS-EN 12457-3. The ash samples taken from both boilers represent an aggregate sample taken between 1st of November in 2016 and 29th of February in 2016. An average fuel distribution in the review period for boiler 5 was peat 2,6 %, coal 0,3 %, forest residue 8,6 %, industrial wood residue 69,8 % and other fuels, such as REF, 18,8 %. In boiler 6 the fuel distribution was the same except there were no coal incinerated at all and industrial wood residue was 70%.

For the boiler five the fly ash's TOC concentration was less than 5 g/kg and the loss on ignition was less than 0,2 % meaning that the limits for landfill waste in the council act 331/2013 are not exceeded. In addition, polycyclic aromatic hydrocarbon (PAH) and PCB compounds were under the limits of the council act 403/2009 for covered structure earth construction eligibility. Metal concentration limits for earth construction eligibility in the fly ash in council act 403/2009 were exceeded in the case of copper, zinc and lead. Exceeds can't be explained by measurement uncertainty. In two-staged batch leaching test the solubility of chrome, lead, chloride and sulfate exceeded the limits for earth construction eligibility in the council act 403/2009. Landfill eligibility limits in the council act 331/2013 were not exceeded. Filtrate's pH was 13 in the leaching test and the acid neutralization capacity (ANC) was 3,4 mol/kg. The buffer capacity of the ash is good against an acid deposition. The conductivity of the filtrate was 1000 mS/m, which is quite high.

The fly ash's TOC concentration from boiler six was 7 g/kg and the loss on ignition was 0,2 %. The limits for different elements in landfill waste in the council act 331/2013 weren't exceeding. In addition, PAH and PCB compounds research gave the same result with the boiler five's fly ash. Concentration limits for earth construction eligibility in council act 403/2009 were exceeded in the case of arsenic, copper and lead. Lead concentration was so high that it can't be explained by measurement uncertainty. In two-staged batch leaking test the solubility of chrome, lead, chloride and sulfate was exceeded. In the case of boiler six the lead concentration of the filtrate exceeded the solubility limits of non-hazardous waste's landfill eligibility in the council act 331/2013. Solubility of the lead was 12 ± 3,1 mg/kg when the limit for the non-hazardous waste is in the council act 331/2013 is 10 mg/kg. If the measurement uncertainty is considered at the lower limit the exceeding can't be verified with certainty. The pH for the filtrate was in the case of boiler six 13 and ANC was 3,6 mol/kg. The buffer capacity of the ash from boiler six was good against acid deposition. The conductivity of the filtrate was 1200 mS/m, which is quite high.

The critical components for fly ash are the total concentrations of copper and lead from both boilers. In addition, the total concentration of arsenic from boiler six and zinc from boiler five exceeded the limits for utilization in earth construction. Also, concentrations of chrome, lead, chloride and sulfate in the two-staged leaching test are too high compared to the limits set in the council act 403/2009. According to the results direct utilization of ash is not possible in earth construction projects but it is still possible to obtain project related permit for ash utilization from environmental authorities corresponding to Sampaanala's project. Non-hazardous waste's landfill eligibility limits are not exceeded in the case of boiler five and the ash can be classified as a non-hazardous waste by the council act 331/2013. Fly ash's lead concentration for non-hazardous waste's landfill eligibility from boiler six is exceeded, if the measurement uncertainty is not considered. The fly ash from boiler six can be classified as a non-hazardous waste if the environmental authorities take into account the measurement uncertainty.

Contents of harmful elements were generally lower in the bottom ash compared to the results of fly ash's laboratory tests (21/2010/ESAVI, 11-12). Results were lower than the limits set in the landfill eligibility act and in the earth construction eligibility act. According to the tests, bottom ash utilization in earth construction projects would be possible through notification procedure. Bottom ash utilization in earth construction projects is easier than fly ash.

3.3.2 Sludge from the waste water treatment plant

The sample from waste water treatment plant's sludge was taken from the screw press where the mixed primary and bio sludge is directed to incineration. The sludge sample was taken into a sealed bucket and sent to Eurofins Oy to Tampere for further researches. The ordered sampling package was a combined landfill - and earth construction eligibility research. Batch leaching test was carried out in one stage. First intention was to use two-staged batch leaching test, but the dry-matter content of the sample was too low for the method. Leaching test was performed in liquid/solid (L/S) ratio 10. Dissolved organic coal (DOC), total concentration of dissolved solids and (TDS) and the concentration of dissolved elements and ions mentioned in the council act 331/2013 were determined from the filtrate. Also the concentration of hydro carbon oils (>C10-C40), PAH (16), PCB (7) and benzene, toluene, ethylbenzene and xylene (BTEX) contents were researched. Total contents of different elements were researched by aqua regia extraction and also pH –value, ANC and TOC were determined.

Based on the tests carried out the TOC content and DOC concentration exceeded the limit values presented in the council act 331/2013 of non-hazardous waste and inert waste landfill eligibility. The council act 591/2006 about waste recovery in earth construction defines limit values only for ash and concrete crush utilization in coated and covered constructions. If the results are compared to the limits set for ash utilization, DOC value for the sludge from the waste water treatment plant is clearly higher than the limits in the council act for earth constructions. Sulfate, fluoride and lead content exceed the solubility limits for covered construction for ash in the council act 591/2006 and the inert waste landfill eligibility limits in 331/2013. PH of the sludge was close to 6,9.

Certain landfill eligibility limits and earth construction eligibility limits for ash were exceeded according to the results. The possibility to utilize the sludge from the waste water treatment plant with a mixture of ash in landfill structure constructions or sound barrier constructions could still be possible. The sludge is allowed to be utilized in the Sampaanala’s project according to the environmental permit (21/2010/ESAVI) even the founding were similar in the permit. This refers that comparable earth construction utilization could be possible also in the future. However, it requires further research and approval from environmental authorities. Concentrations of different elements were generally lower in the sludge compared to the fly ash’s results. In the environmental permit of Sampaanala’s construction project the earth construction eligibility limits were also compared to ash. If the results are compared to the act 24/11 by ministry of agriculture and forestry about fertilizing products, the total concentration of harmful metals in field or forest fertilizer products are not exceeded. However, the sludge would still need pre-treatment for sanitizing the product. There is no certainty if the nutrient content is high enough for fertilizing purposes. Fertilize utilization needs more research and laboratory tests. In the environmental permit of Sampaanala’s gulf filling project the sludge was considered only slightly biodegradable which creates uncertainty if it is suitable for composting and digestion purposes. Thus, digestion and composting requires more research.

3.3.3 Sludge from the balancing reservoir

Waste waters can be directed to a balancing reservoir to adjust the waste water supply to the waste water treatment plant. This can occur for example because of technical failure in pulp or paper mill which increases the content of harmful compounds in the waster waters. A large amount of strong waste waters could affect to the bacterial strain in the aeration pool and have an influence to the performance of the plant. The balancing reservoir is emptied little by little to the waste water treatment plant. A sample from the balancing reservoir was taken after the sludge was settled on the bottom of the reservoir and it was fully emptied from the water. The sludge layer in the reservoir needs to be emptied in the near future. The intention for the laboratory tests for the sludge from the balancing reservation is to find possible utilization targets. The test for the sludge from the balancing reservoir was the same than for the sludge from the waste water treatment plant.

The results indicated as expected that the TOC content and DOC concentration exceeded the limit values presented in the council act 331/2013 for non-hazardous waste and inert waste landfill eligibility. Also the concentration of hydro carbons (>C10-C40) exceeds the limits of landfill eligibility of inert waste. PH of the sludge was 10,3, which is much higher than the sludge from the waste water treatment plant. If the results are again compared to the limits set for ash in the council act 591/2006 about waste recovery in earth construction, it can be noticed that selenium concentration exceeds the possibility to utilize the sludge from the balancing reservoir for example with a mixture of ash in landfill structure constructions or sound barrier constructions requires further research and discussions with environmental authorities. The sludge from the reservoir could obtain a permit to be utilized also in the Sampaanala’s construction project similar than the sludge from the waste water treatment plant. The content of elements was higher in the sludge from balancing reservoir compared to the sludge from the waste water treatment plant but the limits are not exceeded. Biodegradability of the sludge is unknown and might be a barrier for the utilization in the gulf filling project.

3.3.4 Factory waste

Factory waste fraction testing failed because of problems in a sample pretreatment. Some of the materials were too hard to crush into sufficiently small particles for the tests. Especially challenging residues were the fabrics including metal and carbon fiber scrappers (Attachment IV and X). This led to a decision that the factory waste residues weren't tested at all. A short analyze wouldn't have given enough information about the landfill eligibility of the factory waste which was the priority to explore. Eurofins Oy wrote a statement about the challenges what they faced in the laboratory tests.

3.4 Waste management costs

In this section the economical side of the current waste management system is researched. The costs are mostly shown in percentages due to confidential reasons. Intention is to find out how much does the waste management system cost overall, where does overall cost consist of and where are the biggest saving opportunities. Waste management costs analysis takes into account landfill costs, taxes, transportation costs, waste treatment costs and other variable costs. In addition, waste management incomes from scrap metal sales and recyclables are examined. Waste management costs and incomes during the years 2013-2015 are shown in the table 10. All costs presented in this section exclude value-added tax. A longer time period wasn't taken into account since the structure of the waste management system have changed due to Sampaanala's construction project that affected remarkably to the waste management's costs. In the table 10 waste transportation, landfill costs, kaolin pool, hazardous waste, waste taxes, sewage lorry and other costs represents the share of the cost from each year's total waste management cost in percentage. The row "total" compares 2013 and 2014 years' total costs to 2015 year's total costs. Therefore 2015 total costs represent 100 %. Incomes from metal scrap and recyclable material sales represent a share from each year's total waste management cost.

Table 10. Waste management costs and incomes in 2013-2015 presented in percentages [%]. Waste management cost categories represent a share from each year's total costs. Total costs in the year 2013 and 2014 are compared to the total costs of the year 2015. Waste management incomes represent a share from each year's total waste management costs.

Waste management Costs	**2013 [%]**	**2014 [%]**	**2015 [%]**
Waste transportation	52,5	46,1	60,5
Landfill costs	26,8	15,1	23,3
Kaolin pool	0,5	15,3	3,0
Hazardous waste	3,6	9,0	2,0
Waste taxes	8,3	7,4	6,7
Sewage lorry service	3,2	3,5	2,3
Other	5,3	3,6	2,2
Tot.	181,1	135,5	100,0
Waste management Incomes			
Scrap metal sales	32,3	90,6	122,5
Recyclables (plastic, fiber)	0,44	0,28	0,27

A trend in total waste management costs has been decreasing in a past three years. Waste management costs in 2015 were only 55 % compared to the total costs in the year 2013. Based on a conversation with environmental manager any remarkable changes in the factory's waste management haven't been done during this time, but the total costs are difficult to compare because there have been a lot of project related actions every year. This can cause variation in the cost structure between different years. To get better idea about the costs the numbers must be opened more.

Waste transportation costs consist of tipping skip transportations, demountable waste container transportations and waste basket emptying service in other properties owned by UPM. Biggest share of the transportation costs consists of demountable container transportation which is handled by the logistics company P. Peltoma Tmi. Annual costs from the demountable container transportations have been stable in the review period. Contract of employment of P. Peltomaa bases on eight hour long working days five days per week. Other logistic companies sharing the waste transportation costs are Reunanen Aaro Tmi who manages the waste management in other properties owned by UPM in Rauma and Järvelän Siirtokuljetus Oy who manages a part of the tipping skip emptying. Their share from the waste transportation costs is relatively smaller. In 2013 transportation costs were higher compared to other years because of kaolin sludge transportations from Suiklansuo's kaolin pool to the Sampaanala's construction project. There were more than 16 000 t of kaolin sludge transported from Suiklansuo to Sampaanala's construction project. Other remarkable changes haven't happened in the transportation cost structure. The waste transportation costs don’t include ash transportation costs from the biopower plant or from intermediate storage to the Sampaanala’s construction project. The ash storage was unloaded from Suiklansuo during the years 2013 and 2014. Also, the tipping skip transportation that is handled by UPM Paper ENA’s own employees is not taken into account in the statistics.

Landfill costs include landfill treatment costs, labor costs, leachate water treatment costs, sampling costs and equipment maintenance costs. Landfill costs have been also quite stable under the review period. Landfill maintenance costs are shared between Metsä Fibre Oy and UPM Paper ENA Oy. The division of the landfill costs between the companies during the reviewed period is shown in a table 11.

Table 11. The division of the landfill costs between Metsä Fibre Oy and UPM Paper ENA Oy during the years 2013-2015

Year	Metsä Fibre Oy	UPM Paper ENA Oy
2013	38,7 %	61,3 %
2014	49,6 %	50,4 %
2015	41,0 %	59,0 %

The largest part, around 60 % annually, of the landfill costs consists of landfill treatment works. There is some variety in annual sampling costs and equipment maintenance costs, but this doesn’t make any remarkable difference in total landfill costs. The higher costs in 2013 are due to a closure project of an old part of the landfill, which almost doubled the landfill costs compared to the other years under the review period. The cost from the closure project was shared between Metsä Fibre and UPM.

The kaolin pool, which has been used for kaolin sludge disposal, is located to the Suiklansuo’s industrial waste landfill. Costs from the kaolin pool are basically due to the kaolin pool restoration in 2014. In the restoration a new ramp was built for unloading the sludge. Largest share of the costs are building costs, but also emptying the pool completely covers a notable amount of the costs. The pool has been out of use since the authorities have demanded to rebuild the base structure of the pool. There haven’t been done any decisions yet to renovate the pool completely.

Waste tax in Finland must be paid from all waste fractions disposed to landfill, if the waste fraction is possible to utilize in some other reasonable way. An exact list what fractions are under the waste tax can be found from the attachements of the waste tax law's 1126/2010. The waste tax is 70 € per a ton of waste (Tulli 2016). The waste tax costs basically follow the amount of factory waste disposed to Suiklansuo which has decreased during the period reviewed by 100 t. UPM Paper ENA also received a massive tax refund from the government in 2013 because of the ash and kaolin reserve dismantling for the Sampaanala's project.

Costs from the *sewage lorry services* consist mainly of kaolin sludge tank emptying service from the paper machine one. This service is managed by Rauman Tankkihuolto Oy. Sewage lorry service is also needed occasionally at the grindery, Rauma Cell, the biopower plant and at the waste water treatment plant. The need for the service has been decreasing under the review period. *Other costs* consist of random variable costs from smaller equipment acquisition and maintenance works. A large part of the costs registered in this part can't be predicted. Other costs play only a minor part in the waste management's total costs. Costs from the *hazardous-waste* treatment is difficult to predict since the amount of produced hazardous-waste can vary a lot depending on the year. This can already be seen from the costs in years 2013-2015. In 2014 the costs from hazardous waste disposal were clearly higher due to the cleaning project of the contaminated soils.

Incomes from the waste management basically consist of scrap metal sales. Produced metal scrap also varies a lot depending on the year. Produced scrap metal is strongly related to demolition projects at the site. For example, the demolition of paper machine three increased the amount of sold scrap metal remarkably increasing the incomes in 2014 and also in 2015. More stable scrap metal flows come from the biopower plant and workshops. In 2015 the waste management costs were covered by scrap metal sales. Incomes from selling other recyclables such as recyclable fiber and plastics don't play a big role in a larger picture, but is still positive income and implements the priority order from the waste law. Annual incomes from recyclable fiber sales have been less than a percent from the total costs.

The waste management costs in 2015 is shown in a pie chart in the figure 20. The chart clarifies what are the most significant costs related to the waste management. In the figure the costs from the kaolin pool renovation are not taken into account because it was only one-time project and affected mainly to the costs in 2014. Therefore the pie chart doesn't fully respond to the relations in table 10. Waste transportation costs, landfill treatment costs and waste taxes covered more than 90 % of the total costs related to waste management in the year 2015. At the same time, this means that these sections cover the largest saving potential. The year 2015 was taken as a reference year because there was no large project related actions like in 2013 and 2014. The project like the landfill closure project and the kaolin sludge pool renovation project can affect to the relations, but keeping still the relations almost the same.

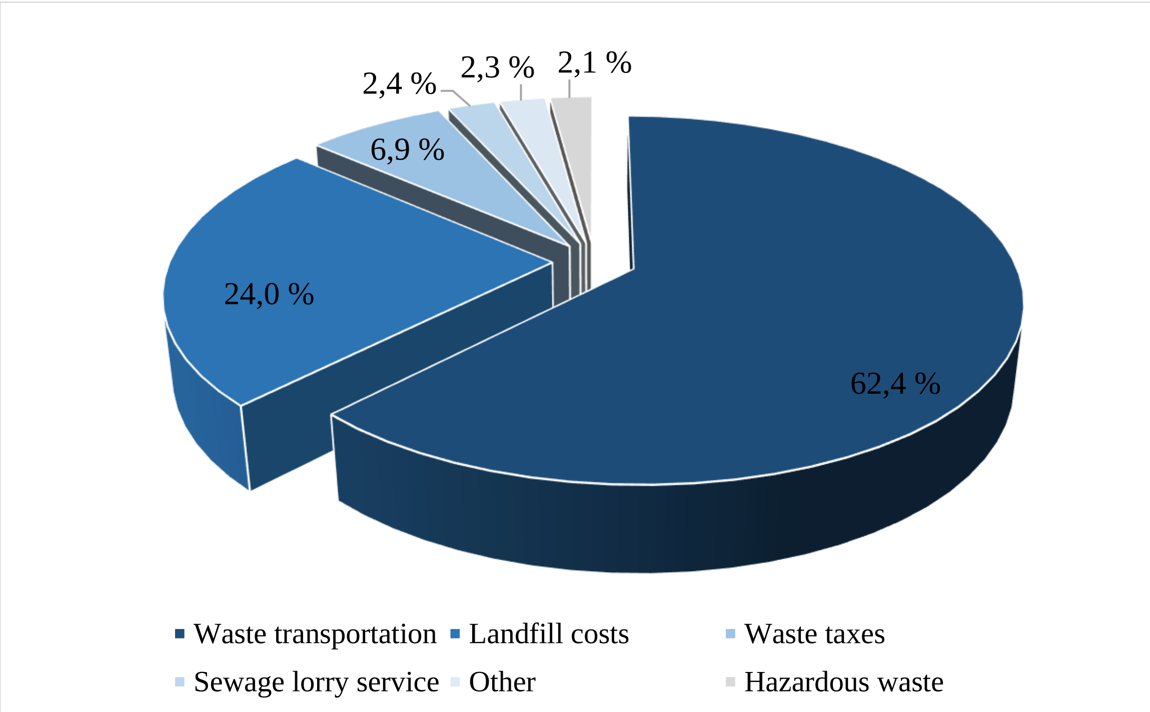

Figure 20. Waste management cost structure in 2015 [%]

If the legislative limits of organic waste disposal and ZSW project goal are wanted to achieve the landfill action requires to be changed. Directing the factory waste to utilization will decrease the landfill treatment costs and reduce waste taxation costs. Even though, it should be considered, that the overall cost won't just disappear. If the factory waste is not transported and disposed to the landfill, it still must be transported to some third party who will charge a fee from taking care of the waste fraction. However, landfill maintenance alone is already expensive and when taxation and transportation is taken into account the cost is even higher. In the current waste management system landfill actions are strongly related to the factory waste disposal, but even factory waste would be directed somewhere else, landfill maintenance would still cause costs for UPM Paper ENA. For example, annual samples that need to be taken for the authorities and leachate water treatment causes costs even there wouldn’t be any action. Landfill costs and taxes covered more than 30 percent from the total waste management costs in 2015.

Based on a conversation with Peltomaa, there are some problematics in the factory’s waste management system that causes extra working hours in waste transportation. In 2015 Peltomaa did almost 10-12 hours extra every week. With small investments to larger demountable containers or compressive containers in certain locations and by optimizing the system the extra hours could be avoided. If all of the extra hours in 2015 could have been avoided, annual costs saving would have been 5-10 percent from the total waste management costs.

Also, decreasing the amount of produced factory waste would lead to cost saving. Based on own observation and conversations with Peltomaa and employees the wastes sorted to factory waste consist of 50-80 % of recyclable or combustible material. If the source separation system would work properly the share of factory waste would decrease notably. Cutting the annual amount of factory waste into a half would also cut the disposal costs into a half. To cut the annual factory waste production to half is seen possible by optimizing the source separation system at the factory site and making the separation easier. This could be done through re-organizing the waste baskets, education and better sorting instructions. During the study, it was noticed in many locations at the factory site the tipping skips were located individually which doesn’t offer a possibility to separate different fractions easily. The result is that everything is located to the same skip.

Possibility of using E-learning web tool for education was discussed and it gained popularity. The web course could include information about the waste management system at the factory site and activating tasks in the end where the user needs to sort correctly the common waste fractions that are created in production site and offices.

Increase the incomes of the waste management system with small arrangement could be also possible. Sold metal scrap, recyclable fiber and plastics covered the whole waste management costs in 2015. Higher value could be obtained through stainless steel separation system. According to the conversation with employees a large share of the produced stainless steel is now sold as a black scrap metal, which represent the lowest price category for metal scrap. Low separation rate for stainless steel is because of deficiencies in the infrastructure. There are only few tipping skips and one or two demountable containers for stainless steel scrap at the factory site. This leads to a situation that most of the stainless steel is disposed with other metal qualities or, even if there is a tipping skip for stainless steel there isn't demountable container for stainless steel nearby and the skips are emptied to the same container with other metals. In demolition projects the separation works better.

In 2015 from the total amount of sold scrap metals 77 % were sold as black scrap metal. This means 678,27 t. The price for stainless steel is ten times compared to black scrap metal (Aurek 2016). It is hard to predict precisely how much stainless steel or other valuable metals are sold as a black scrap metal at the moment. According to conversations with the employees 20-30 % from the amount of black scrap metal would consists of stainless steel. If it is estimated that 20 % from the black scrap metal is stainless steel and could be sold with a correct price, incomes from total metal scrap sales would be more than 40 % higher. Estimation depends on the scrap metal prices.

Another source of income for waste management is recyclable fibers and plastics. Incomes from selling the recyclable fibers and plastics have been less than a percent from the total costs of the waste management under the review period. This is very marginal from economical point of view, but it is still a positive income and recycling the materials is in accordance with waste management's priority order. Material recycling also creates added value for UPM's image. The contract with Paperinkeräys Oy is from 2002 and hasn't been updated after that. Contract prices are already below the current price level. The revenue consists of the recyclable fiber sales since the recyclable plastic price in the contract is defined as zero. A simple way to increase the income from recyclable plastic and fiber sales is to update the contract to respond the current price level. A phone conversation with a purchase and sales manager of Paperinkeräys Oy revealed that almost half of the material received from Rauman paper factory can’t be utilized in recycling process due to a bad quality.

Currently a lot of recyclable material such as paper, cardboard and plastics, end up to incineration. This is mainly since the combustible material disposal is easy and economical at the biopower plant. In addition, Rauman Biovoima receives fuel for the biopower plant and creates revenues from districts heating and electricity sales. This creates a dilemma between the two options: incineration and recycling. There has been discussion if there should be more recyclable material directed from energy recovery to Paperinkeräys Oy for material recycling. Recycling would be better option according to priority order of the waste law, but viewing the situation from economic side creates a conflict. Calorific value for REF is estimated to vary between 13 and 35 MJ/kg and price for district heat in Rauma is 40,76€/MWh (VTT 2000, 153; Rauman Energia 2015). Because the calorific value for the combustible material at the factory site hasn’t been tested, the lower limit from the literature value is used. Produced energy is assumed to be used to district heat production. Heat production efficiency is estimated to be 90% (Motiva 2016). Income from district heat sales by incinerating one ton of combustible material is calculated in equations 3 and 4.

$$Produced\ energy\ \left[\frac{MWh}{t}\right] = \frac{\left(Incinirated\ waste[kg] * Calorific\ value\ \left[\frac{MJ}{Kg}\right]\right) * \eta}{3600} \tag{3}$$

$$Produced\ energy\ \left[\frac{MWh}{t}\right] = \frac{1000\ Kg * 13\ \frac{MJ}{Kg} * 0{,}9}{3600} = 3{,}25\ \frac{MWh}{t}$$

$$Income\ [€] = Produced\ energy\ \left[\frac{MWh}{t}\right] * District\ heat\ price\ \left[\frac{€}{MWh}\right] \tag{4}$$

$$Income\ [€] = 3{,}25\ MWh * 40{,}76\frac{€}{MWh} = 132{,}47\ €/t$$

This means that incinerating a ton of combustible material creates 132,47 € incomes by district heat sales. When the price for a ton of recyclable fiber is only 10-30 €, it can be noticed that incineration of recyclable fiber would be more profitable for UPM Paper ENA Oy. Even the calorific value for the combustible material or the price for district heat would be clearly lower, the incineration would still be five to ten times more profitable option. High price from incineration doesn't contribute to recycle but the opposite. If half of the material sent to Paperinkeräys Oy is rejected and the rejected material is probably used in energy production, recycling seems to be useless. However, even the incineration in this case would be economically justified option, it shouldn't be the only perspective considered. Reuse and material recycling should be prioritized before incineration according to priority order of waste management. In addition, recycling creates added value through a sustainable corporate image. Volatility in energy prices and increasing price of recyclable material can equalize the different in the future. Besides, it is assumed that waste incineration tax will be put into service in the future on a larger scale which increases incineration costs.

The waste management costs at UPM Paper ENA's paper mill at Rauma stand well comparing with other UPM's paper mills in Finland. Important reason for cost efficiency is the Sampaanala's construction project where especially ash can be utilized. The project enables tax-free ash and kaolin sludge utilization in the factory area. It creates savings in transportation, landfill treatment and taxes. If 30 000 t of ash that is approximately produced every year, would be located to the landfill, only the tax costs would be more than two million euros. In addition, transportation and landfill treatment costs would increase the total ash disposal costs even higher. Costs from the kaolin sludge disposal to Suiklansuo would also cause annually remarkable costs. The estimate varies depending how much kaolin sludge is produced. The amount of collected kaolin sludge dropped 2500 t in the year 2015, which is supposed to be because of an equipment failure. In addition to taxes and transportation, kaolin pool renovation works would cause extra expenses. It is important to realize how large is the economic impact of ash and kaolin sludge utilization. A continuous work to search alternative options must be done. Sampaanala's project is predicted to last from five to seven years.

The waste management costs were researched also fraction specifically. This offers information about how much does the waste disposal cost per a ton of waste, where does the cost consist of and what fractions should be taken under surveillance. The research included demountable waste container transportations, taxes and waste handling costs. For some fractions the total cost consisted only of transportation costs. Tipping skip transportations and weighting costs from the weighing station were excluded from the study. Contract with the weighing station is a part of a larger service contract and the pricing is not directly cargo based.

The year under review for the calculations was 2015. Direct costs are not shown in this research due to confidential reasons. Examined waste fractions were: combustible material, factory waste, recyclable fiber, recyclable plastic, domestic waste, construction waste, bottom ash, kaolin sludge and others. Category “other” included occasional waste transportations during the year which occurred only few times per year. Transported fractions were for example twines, metal scrap and soils. All other fractions were transported by P. Peltomaa Tmi except the kaolin sludge which was transported by Rauman Tankkihuolto Oy. Waste water sludge, wood chips and barks were not included because the transportation is handled by conveyors and there are no money exchange from the combustion. Also, metal scrap and hazardous waste transportations were excluded because of divergent pricing technique in the contracts. Only bottom ash transportation costs were researched. Fly ash transportation costs are on the same range.

Waste transportation costs for transported fractions were estimated through average hourly wage of P. Peltomaa. Since Peltomaa’s contract is hour-based also the transportation costs estimation was based on how much time emptying a waste container takes. The variation for emptying times between different fractions is due to different transportation distances, loading and unloading times. Estimations for emptying times used in the calculation are based on conversations with Peltomaa. A transportation cost per cargo was calculated based on the time estimations and Peltomaa’s average hourly wage. With the annual cargoes for each fraction transported by Peltomaa from the Rapu -data base and the amount of transported waste, it was possible to calculate the transportation costs for each fraction in a unit €/t. Kaolin sludge’s transportation costs were handled separately because the transportation were managed by Rauman Tankkihuolto Oy. The transportation cost was calculated through the company’s billing information and transported amount of kaolin sludge also in a unit €/t.

Results from the transportation cost research are shown in a table 12. Transportation costs are presented in a relation to the most expensive waste fraction's transportation costs.

Table 12. Estimated emptying times, annual transportations, annual transported waste amounts and transportation costs in relation to most expensive waste fraction to transport when examined in a unit €/t. * = Occasional waste transportations during the year.

Waste fraction	Emptying [h/cargo]	Transportations [cargo/a]	Amount of waste transported [t/a]	Proportioned transportation cost [%]
Recyclable plastics	1,00	25	9,58	100,0
Municipal waste	1,33	30	30,00	51,1
Construction waste	1,33	8	9,06	45,1
Kaolin sludge	1,00	31	382,66	36,7
Factory waste	1,33	139	300,76	23,6
Recyclable fibers	1,00	69	156,18	16,9
Combustible material	0,67	1371	2352,50	14,9
Other*	0,67	16	33,78	12,1
Bottom ash	0,67	691	3710,54	4,8

Two most important factors in the transportation cost calculations were emptying time and a weight of the cargo. Emptying time was related to the transportation distance and loading/unloading times. Recyclable plastic transportations were estimated to be most expensive. The transportation distance to one way is only around 1,5 km but the weight per cargo for plastics was very low. The cargoes for recyclable plastic varied between 200 kg and 600 kg. According to Peltomaa unloading of a recyclable plastic and - fiber cargo is slow and includes a lot of handwork that increases the emptying time and therefore costs more. Bottom ash cargoes were regularly over five tonnes and when the transportation time was considered also low it was the cheapest waste fraction to transport. Municipal waste, factory waste and construction waste transportation costs were higher because of the longer transportation distance. Municipal waste is transported to Hevossuo's landfill and factory waste and construction waste to Suiklansuo's landfill more than 10 km away from the factory site.

In addition, tax costs and possible waste treatment costs were taken into account to the total costs. Tax costs consisted of waste tax, which is paid form residues disposed to landfill. The waste taxes were paid in 2015 only from factory waste and construction waste which were disposed to Suiklansuo's landfill. The amount of waste tax was 70€/t. Since there is no direct money exchange related to the waste treatment internally at the site, waste treatment costs concerned only municipal waste, factory waste and construction waste. Factory waste and construction waste treatment costs were estimated trough landfill treatment costs. In 2015, landfilled waste consisted of 97 % factory waste and the rest were construction waste. The landfill treatment costs were shared between the waste fractions in the same relation and divided per ton of waste. Landfill treatment costs were around 60% of costs related to the landfill in 2015. Municipal waste's treatment costs consist of a gate fee, which is paid to City of Rauma. In addition, there is a small weighing fee paid to city of Rauma from each municipal waste cargo transported to Hevossuo's landfill.

The total costs for each waste fraction are shown in the table 13. The results are presented in a relation to the most expensive waste fraction which was the construction waste. In the original research the costs were researched in euro per produced waste ton. The share of transportation costs, taxes and treatment costs are also presented in percentage in the table 13. Figure 21 visualizes the results presented in the table 13 graphically. Construction waste, factory waste and municipal waste had clearly the highest disposal costs per produced waste ton. Total costs were higher not only because of waste tax and waste treatment costs.

Table 13. Cost distribution for different residues presented in a relation to the most expensive waste fraction. In the original research the costs were researched in euro per produced waste ton. * = Occasional waste transportations during the year

Waste fraction	Transportation	Tax	Treatment	Total
Construction waste	14,5	21,5	64,0	100
Factory waste	8,3	23,6	68,1	91,4
Municipal waste	23,9	0,0	76,1	68,8
Recyclable plastics	100,0	0,0	0,0	32,1
Kaolin sludge	100,0	0,0	0,0	11,8
Recyclable fibers	100,0	0,0	0,0	5,4
Combustible material	100,0	0,0	0,0	4,8
Other*	100,0	0,0	0,0	3,9
Bottom ash	100,0	0,0	0,0	1,5

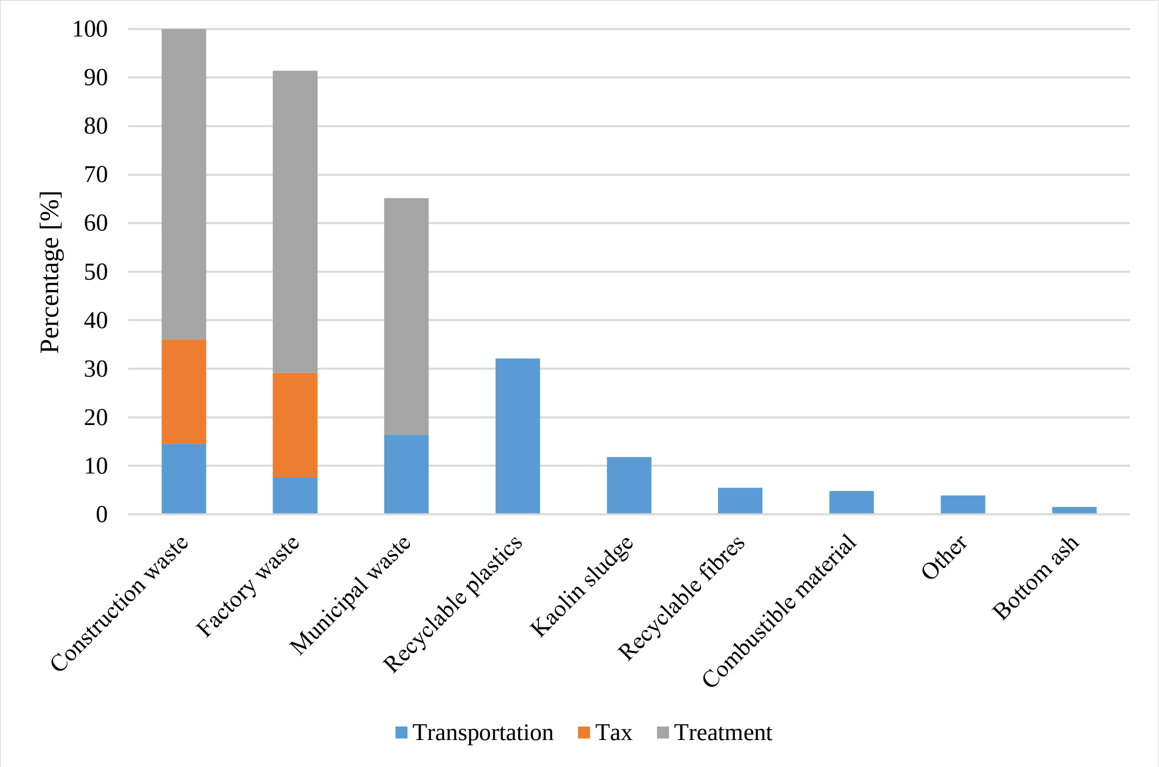

Figure 21. Fraction specific costs for different residues presented in a relation to the most expensive waste fraction when the results were examined in a unit €/t

From the results, it can be seen that the most expensive waste fractions to dispose per produced ton are construction waste, municipal waste, factory waste and recyclable plastics. However, it has to keep on mind that construction waste and recyclable plastics are produced less than 10 ton per year and municipal waste 30 ton per year. If the costs and the produced annual waste amounts are multiplied together, disposal of all recyclable plastics, construction waste and municipal waste is only 6,2 % from the overall costs. Factory waste disposal again covers 51,7 % of the costs and combustible material, bottom ash and kaolin sludge disposal together 40,3 % because of larger volumes. Figure 22 pictures the distribution of the overall fraction specific costs when the produced annual waste amount and the cost per produced waste ton are multiplied. The pie chart is based on the year 2015 data.

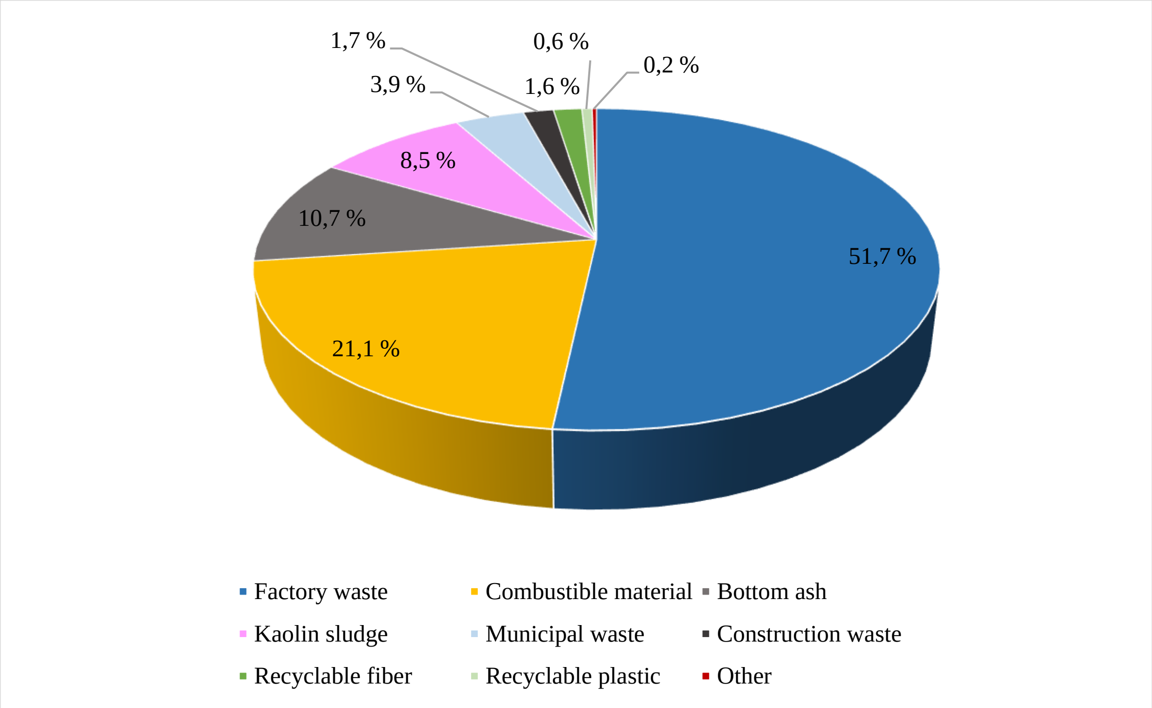

Figure 22. Waste disposal cost distribution when produced annual waste amounts in 2015 and fraction specific costs are multiplied [%]

Costs savings could be achieved through logistical improvements and changes in waste management structure. Logistical improvements could mean renting or investing in compressive demountable containers, which would increase the weight of each cargo transported. Also a system where the emptying would be handled by a compressive garbage truck could be cost effective for some lighter waste fractions like combustible material, recyclable plastics and recyclable fibers. Especially recyclable plastic and fiber transportations take a lot of resources compared to the economic advantage that is achieved through recycling. Recyclable fiber transportation cost is 50 % from the refund price and when plastic price is determined as zero recycling causes only expenses. If the plastics would be separated to combustible material, it would be easier to transport and unload. It would also create incomes through district heating or electricity sales. Another reason for expensive transportation costs for recyclables is the long emptying time even the transportation distance is short. Demountable containers in the recyclable plastic collection are not very effective. Prices for compressive container depend on the volume of the container. Used compressive containers are approximately from 5000 euros to 15 000 euros and non-compressive container from 500 to 5000 euros (Mascus 2016; Nettikone 2016). Renting prices are contractual.

Cost saving through waste management structure changes could be achieved by transporting the factory waste and construction waste to some entrepreneur from a waste sector who could re-sort the valuable items from it and utilize the rest in energy production or in other ways. These kinds of entrepreneurs can be found also from Rauma. For example, Lassila & Tikanoja Oy, Renonorden Oy, Suez Environmenr and Veikko Lehti Oy operates in the area. This would decrease the landfill treatment costs and costs from waste taxes. Municipal waste is already intended to be incinerated at Rauman Biovoima’s biopower plant and that will cut the municipal waste costs around to the same level with combustible material. It could also be considered if the weighing system could be arranged differently. Now every cargo needs to go via weighing station which causes additional driving. An integrated weighing system in the vehicles could cut the emptying times and transportation distance.

4 BENCHMARKING THE BEST PRACTISES

All UPM's factories in Germany have already reached the ZSW project goal. The goal is to find out what are the processes that could be implemented also at Rauma's paper mill. The researched waste fractions are ash, waste water sludge and factory waste. Ash and sludge from the waste water treatment plant are the largest waste fractions generated at the site. Utilization of these fractions are wanted to ensure also in the future. Factory waste utilization enables the mill site to reach the ZSW goal.

4.1 Ash

Ash is produced at Rauman Biovoima's biopower plant at the mill site. As it was noticed ash production have been quite stable during the review period 2011-2015. During this period the average amount of annually produced ash was 37 221 t. From the average total amount, 4177 t was bottom ash and the rest 33 044 t was fly ash. Ash production per month has a relation to seasons and incinerated mixed sludge from the waste water treatment plant. In colder months, such as January and February, when the heat and electricity demand reach the peak also ash production is at the highest. Also, the more mixed sludge is incinerated the more ash is generated. A recycling rate for ash produced in Finnish pulp and paper industry varied between 64-87 % during the years 2010-2013. Most of the produced ash was used utilized in earth construction after the year 2011. In the year 2010 around third of the produced ash was landfilled but the amount has decreased clearly after the year 2011 when the new waste act was introduced. Another important utilization purpose has been utilization on soil improvement. (Deviatkin et al. 2016, 22.)

Ash utilization has been recognized at UPM as an important factor when it comes to reaching the goal of ZSW -project. The volume of produced ash within the UPM is 150 000 t per each year (UPM 2016f). Especially in Germany UPM is relying heavily to the waste incineration and then concentrating to productizing the ash. Currently around 65 % of the ash produced in UPM's power plants in Germany is used in the cement industry, 30 % is used in earth construction and the rest 5 % is used in bleaching lines of recyclable fibers. Earth construction works consists mostly of road works but also soil stabilization and other landscaping works. Possibility of alkaline and lime replacements have been researched as well. (Heberle 2016, Ståhlberg 2016.)

In Finland UPM has been utilizing ash in addition to earth construction works also in a land improvement purposes. Ash from UPM's Jämsä's power plant has been productized to a so-called field ash. The product includes of calcium, phosphorus, potassium and trace elements and thus it is suitable for fertilizing and liming purposes. The field ash is also competent in a landscaping works and forest fertilizing. It is estimated that compared to a traditional fertilizers and lime, utilization of field ash can be 30-40 % cheaper. (Peltotuhka 2016.) Fuel in Kaipola's power plant consists 69% of biomaterials, 28% of peat and 3% of oil (96/2010/LSAVI). There is no REF incineration permit. Jämsä's power plant's ash is also used to build base structure for public and forestry roads. The ash have good strength endurance which improves the carrying capacity of the road and it has better thermal insulation compared to aggregates which decreases frost problems (Ramboll 2016).

Environmental engineer from UPM's Jämsä's factory site Pekka Rantala says that the share of ash utilized in construction works is too high. In ideal situation, a larger share of the ash could be used as a fertilizer, which would improve nutrient circulation and CE. According to Rantala this is partly due to strict legal requirements for origin and composition of the ash. Rantala also highlights the cost savings that could be achieved by using ash in fertilizing purposes. (UPM 2016f.)

Rauman Biovoima has researched ash utilization as a binder material in co-operation with Ramboll. The research is still on early stages. Productized binder would be meant to use in soil stabilization, road works, brick and concrete industry. (Pitkänen 2016.) Results from landfill and earth construction eligibility tests can make Rauman Biovoima's ash utilization more complicated. According to the results the limits for earth construction eligibility were exceeded. Exceeding the limits can be because of incinerating peat, waste water treatment sludge and REF which may affect to the heavy metal concentration. It could be considered if the changes in a fuel distribution between different months could lead to a result where the limits wouldn't be exceeded during some certain time periods. This would still need further laboratory tests and confirmation from the authorities to be possible.

Generally multiple utilization purposes for ash have been researched. Some of them are also used also within UPM. Ash utilization purposes vary depending on the composition of the ash, which are determined by the fuel. There is not one universal method that would be suitable for all ashes generated. For example coal ash and biomass ash have generally different utilization purposes. Biomass ash is widely used in fertilizing but only rarely in cement or brick industry. Coal ash again is suitable to utilize in cement industry. The reason for low utilization rate of biomass ash in cement industry is high potassium and chlorine contents that leads to problems in the manufacturing process. Ash from municipal solid waste (MSW) incineration has even more limited utilization purposes. MSW ash has been mostly tried to be utilized in road works, embankments and landfill constructions. Bottom ash again is widely used as an aggregate to replace gravel, sand or rock material. (Deviatkin et al. 2016.)

Rauman Biovoima's ash consists mainly from biomass and REF incineration. Incinerated REF includes also traces of regular municipal wastes due to lack of source separation. An overview of the ash utilization methods and possibilities for biomass and MSW ash is shown in the table 14. The table is part of the study about ash utilization in South-East Finland (Deviatkin et al. 2016). It can be seen from the table 14 that MSW ash has clearly more narrow utilization potential compared to biomass or peat ash.

Table 14. Researched and implemented utilization targets for biomass/peat and MSW ash (Deviatkin et al. 2016)

Already applied methods	Ash from biomass or peat	MSW ash
Forest fertilizing [1,2,3)]	x	
Liming [1)]	x	
Additive in composting [1)]	x	
Cement and brick industry [1)]	x	
Mine tailing cover [3)]	x	
Mine backfilling [1,2)]	x	x
Concrete filler [1,2)]	x	
Landfill construction [1,3)]	x	x
Soil stabilization [1,2)]	x	
Road construction [3)]	x	x
Possible methods	**Ash from biomass or peat**	**MSW ash**
Alternative binders [1,2)]	x	
Synthetic aggregates by cold bonding or sintering [1,2)]	x	
Stabilizing dredged material [1,2)]	x	
Production of adsorbents [2)]	x	
Neutralization of waste acids [2)]	x	
Impermeable layer [2,3)]	x	
Vitrification [2)]	x	
Stone wool fiber production [2)]	x	
Metal and glass and recovery [1,4)]		x
Phosphorus recovery [1)]	x	

1) KEMA 2012; Supancic and Obernberger 2009
2) Pels and Sarabèr 2011; Pels 2012
3) Ribbing 2007
4) Crillesen and Skaarup 2006

Ash utilization in Finland is regulated by multiple laws and decrees. Landfilling of ash is determined by the Finnish Government Decree on Landfills 331/2013. The decree 331/2013 determines limit values for leaching of salts and toxic substances from the landfilled material. Earth construction is regulated by the government decree concerning the recovery of certain wastes in earth construction 591/2006. The use of ash for fertilizing purposes is controlled by fertilizer product act 539/2006 and the regulation on fertilizer products 24/11 which is issued by ministry of agriculture and forestry. Ash utilization must be also in accordance with environmental protection law, waste law and European union's regulations. As it can be noticed, ash utilization requires a lot of preparing and research before implementation phase. Ramboll Oy have released a handbook for ash constructing in 2012 to foster the utilization of ash (Ramboll 2012). Even there are multiple options for ash utilization for biomass ash and MSW ash, the utilization need always to be reviewed a case by case. Utilizing the ash in earth construction projects could be a success for ash created in the biopower plant in Rauma. There are several road building and renovating projects planned in the South-West area of Finland (ELY 2015). If the co-operation with Ramboll is successful it could open more doors for ash utilization.

4.2 Sludge from the waste water treatment plant

Waste water treatment plant in Rauma handles industrial waste water and municipal waste waters. Waste water sludge consists of primary sludge and bio sludge. Primary sludge is from industrial waste waters and separated directly form primary clarifier. Bio sludge is separated from aeration pool. Municipal waste waters are directed straight to the aeration. Produced primary and bio sludge are mixed and dried with a steam heated screw press. Mixed sludge going to incineration is in 30-35 percent dry matter content. Sludge is transported with conveyors to the biopower plant. Sludge can be stored also to a field where it is transported to the incineration by loaders. Sludge incineration is the most common way to dispose bio sludge within UPM (Ståhlber 2016, Heberle 2016). To increase the heating value, improvements in drying process and possibility to pelletize the sludge have been researched, but not yet utilized on a larger scale.

Utilizing of sludge from the waste water treatment plants varies a lot depending of the content of the sludge. According to Sitra’s study (2007) most common way to handle waste water sludge from municipal waste water treatment plants in Finland are tunnel composting, rotating drum composting and digestion. Dried residue is usually further processed by windrow composting and later used for urban landscaping, fertilizer in agriculture or prepared as mold. Industrial waste water sludge in Finland, especially in forest industry are generally incinerated or located to landfills. More efficient recycling methods for fibers in the forest industry have decreased the amount of primary sludge and increased ash content which have made the drying process more difficult. In the 1990’s a possibility to compost and spread the sludge from forest industry's waste water treatment plants to the forest with ash was researched, but the methods didn't become more common. (Sitra 2007, 5-8.) There are also researches about phosphorous recovery from waste water sludge but commercialization of the technology still need more time (Adam 2009; European Commission 2015). Phosphorus recovery could be performed for example from the ashes after incineration by chemical treatment (Advantage environment 2015).

Rauma's waste water treatment plant's sludge has features from industrial and municipal waste waters. Forest industry's waste waters increases the content of ash and harmful elements in the sludge. Ash content varies approximately between 25-30 percent. High ash content is problem especially in incineration by decreasing the calorific value and causing surface contamination in the boiler. Forest industry's waste waters also increases the clay and rock material content in the primary sludge, which doesn't create added value neither in incineration nor in biological processes.

Municipal waste waters affect to the hygiene of the sludge. Fertilizer use of sludge from municipal waste water treatment plant is strictly regulated by fertilizer product law 539/2006, act of ministry of agriculture and forestry 24/11 and its changes 12/12 and 7/13. For example, Escherichia coli and salmonella are critical pathogens in the sludge. Also, trash content must not be more than 0,5 percent from the fresh weight and content of heavy metals are limited. Only processed sludge can be utilized in fertilizing purposes in food production and even then it requires approval from environmental authorities. Processing can be done biologically, physically or chemically. The purpose is to sanitize and stabilize the product. Processing doesn't have impact to the heavy metal content. (Vesilaitosyhdistys 2013, 16-17, 30.) In table 15 is shown different treatment possibilities for waste water sludge.

Table 15. Biological, physical and chemical treatment possibilities for sludge from waste water treatment plant (Vesilaitosyhdistys 2013, 30)

Treatment	Possibilities
Biological	-Composting -Digesting
Physical	-Thermal drying -Thermal hydrolysis
Chemical	-Lime stabilization -Oxidizing low pH

Advantage in fertilizer use compared to incineration is nutrient recycle that is one of the key priorities of CE. Fertilizer use still needs a lot of research and might have high investment costs which causes in many cases a lack of interest for further research. Pathogens, heavy metals and organic contaminants can prevent the fertilizing utilization in field. Also, the large volume of produced sludge can be a challenge. Since the fertilizing occurs mainly at the summer time, the sludge storing at the wintertime could be a problem. Fertilizing utilization requires also more research about the nutrient contents of the sludge.

Another possible way to utilize the sludge could be digesting. Helsingin seudun ympäristöpalvelut offers a waste water treatment service for the Helsinki metropolitan area. The waste water treatment plant is biggest in the Scandinavia and handles more than 800 000 people’s municipal waste waters and industrial waste waters. Annual sludge production is 60 000 t of dried sludge which is twice as much as in Rauma. The sludge is digested to biogas and the sludge residues are composted in windrows. The compost is further processed as a mold product and used in an urban landscaping. (HSY 2016.) A comparable process could be possible to arrange also in Rauma. There would be plenty of biomass at the area for digestion plant. In addition to sludge from the waste water treatment plant HK Scan Oyj invested in to a poultry production facility to Rauma (HK Scan 2015). The construction works are already started and the schedule is to start the operation by the end of the year 2017. The new poultry factory increases the produced biomass notably and improves the potential for production in Rauma’s area. However, a digestion plant requires an high investment costs and the suitability of the sludge from the waste water treatment plant for digestion should be researched.

In the table 16 are presented Sitra's (2007) research's results about unit costs for different sludge handling processes. The unit costs were viewed for waste water treatment plant where the annual wet sludge production was either 5000t/a, 25 000 t/a, 50 000 t/a or 75 000 t/a and the total solid content were estimated to be 20 %. The cost efficiency research included also the investment costs for the facilities. As result the digesting with post composting and thermal drying with steam were estimated to be the cheapest options. Incineration and digesting with thermal drying were clearly more expensive options. The Results can't directly be compared into Rauma's case. In Rauma incineration is at the moment cheapest way to utilize the sludge since the infrastructure already exists. The incineration still is not the best available technique. Research for alternative techniques is important part of the waste management system development.

Table 16. Comparison of the cost for different sludge handling processes (Sitra 2007). * = Steam is purchased from external partner and the product is further processed to a biofuel or fertilizer. ** = Assumed that the only fuel of the power plant is sludge.

Process	Cost [€/t]
Composting	71-80
Digesting + Post-composting	44-94
Digesting + Thermal drying	63-163
Thermal drying (Steam)*	44-95
Incineration **	70-123

It also have to be taken into account that if some waste fractions that are incinerated are directed to alternative utilization purposes, the amount of fuel needs to be replaced somehow. The district heat and electricity production is dependent from the fuel. If the sludge from the waste water treatment plant is directed somewhere else, it leaves a gap in received amount of fuel for Rauman Biovoima.

4.3 Factory waste

A non-recyclable mixed waste, which is called at Rauma's mill site as a factory waste, have been disposed to the Suiklansuo's landfill. A common habit to handle comparable waste fractions than Rauma's factory waste within UPM and generally is waste incineration (Pöyry 2014; Ståhlberg 2016; Heberle 2016; Eurostat 2016). A waste incineration capacity in Finland have increased after 2006 from less than 100 000 t of waste per year to 1,3 million tonnes, excluding co-incineration plants, such as Rauman Biovoima, which usually have permit to incinerate REF, but not MSW. By the year 2018, the capacity is estimated to increase up to 1,8 million tonnes. MSW incineration in Finland is generally based on grate combustion. (Pöyry 2015.)

At the moment, waste incineration would be the easiest way to get rid off the landfilled factory waste fraction also the UPM Paper ENA's Rauma's paper mill. There are entrepreneurs in the waste sector also at Rauma's area who receive un-sorted waste, recycles valuable materials from it and send the remaining residue to the waste incineration plants for energy recovery. Alienating the waste to a third party was considered also more economical option compared to landfilling in the section 3.4. A continuous improvement in the source separation system to decrease the amount of factory waste at Rauma's mill site needs to be done. The lower the amount of annually produced non-recyclable waste is, the lower the costs are.

Lower amount of produced factory waste produces also the risks caused by external factors, such as changes in regulations and political controlling means. Even the waste incineration would be at the moment the best option for factory waste disposal, the situation needs regular monitoring since waste incineration have raised a lot of discussion. Many people think that the waste incineration is not a sustainable solution and it is against the principles of CE. Increasing capacity for waste incineration causes a conflict with EU's goals of waste's priority order where the recycling and reusing should be prioritized over the waste incineration. When a common goal in EU is to improve the circulation of natural resources and the recyclability of the products, increasing the waste incineration capacity brings wrong kind of message. (Sitra 2014a; SLL 2009)

Waste incineration is many times justified as the best option because it is said to be economical. However, a research by Gaia Consulting and Sitra proves that material recycling in nowadays could be economically even better choice compared to waste incineration, especially when employment, tax receipts and current account is taken into account. The research studied two different cases. In the first case the waste management relied on a waste incineration that required an investment to the incineration plant and it was based on poor source separation system. The second case again relied on a material recycling and to efficient source separation system. As a result the second case, which relied on the recycling was estimated to create 60 new jobs more than the first case and would also effect positively to the current account. Tax receipts were also estimated to be more than one million euros higher in the recycling based option. (Sitra 2014b) However, with the current system waste incineration was estimated to be more economical for the paper mill.

Even the waste incineration has its disadvantages, there are also good sides. First of all waste incineration have rapidly decreased a notable amount of landfilled waste. Landfilling is considered even worse option compared to incineration in the waste management's priority order in the waste law. It is also estimated that waste incineration will replace 4,2 TWh non-recyclable energy sources in 2020 that decreases the greenhouse gas emissions by 0,4 million tonnes per year in energy production. Especially in Germany, the waste incineration is not seen as a barrier to material recycling. The incinerated waste is already source separated and thus most of the valuable materials are utilized in material recycling. (Pöyry 2015, 11, 35.)

To achieve EU's recycling goals, it is possible that waste utilization is directed by new controlling means in the future. Two possible controlling means that are likely to be implemented also in Finland are waste incineration tax and to place the MSW incineration under the emission trading scheme. Waste incineration tax is already implemented in Denmark and Belgium. Emission trading for waste incineration is implemented in Sweden and Denmark and for co-incineration also in Finland. In the research by Pöyry (2015) it is estimated that any remarkable changes in Finland's waste management structure won't take place before 2020, but the pressure to increase the recycling rate might trigger some measurements later. There is a risk that if the waste incineration becomes too expensive in Finland, waste exports become more common. MSW incineration companies should support to achieve the recycling rates so that waste incineration is not seen as a threat for CE but a part of it. (Pöyry 2015.) It is likely, that a role of MSW incineration in the future decreases.

5 COCNCLUSIONS

The paper mill of UPM Paper ENA Oy in Rauma is close to reach the ZSW -project goal, to end landfill disposal of wastes before 2018. In past five years, annually only 300-400 t of waste have been disposed to the landfill and the amount is expected to decrease below 200 t in the year 2016. More than 95 % of the wastes disposed to landfill during the review period consisted of a so-called factory waste which represents mixed waste collected at production site. It consists of waste fractions such as glass wool, carbon fiber scrappers, porcelain, PVC-plastics and abrasive discs, which don't have a utilization purpose. There is also a notable amount of combustible material in the factory waste because of problems in source separation. Factory waste can't be incinerated at the biopower plant since Rauman Biovoima has an environmental permit only for REF incineration, but not for MSW incineration. Beside factory waste a small amount of construction waste and soils were disposed to the landfill in recent years. Construction waste represents annually less than five percent from the waste disposed to Suiklansuo. To achieve the ZSW goal the focus should be in the factory waste utilization. The possibilities to develop the waste management system at the paper mill and saving potentials are summarized next fraction specifically. The largest saving potential in the waste management costs were noticed to be in transportation costs and landfill costs.

Factory waste and *construction waste* have been so far disposed to Suiklansuo's landfill more than 10 km from the factory site. In the economic research these fractions were estimated to be clearly most expensive waste fractions to dispose for UPM Paper ENA when the disposal costs were studied per produced waste tonne. In the cost estimation transportation costs, waste handling costs and taxes were taken into account. Especially waste tax and landfill treatment costs increased the overall waste disposal costs notably. Directing the landfilled waste fractions to MSW incineration were seen a cost-efficient solution to achieve the ZSW goal. Some offers from possible partners were already interviewed during the research. According to the conversations the cost per produced waste ton after handling and transportation could be less than two thirds from the current waste disposal costs for the landfilled waste fractions. From the overall waste management costs the saving potential would be 5-10 % depending on the contract. Alienating the unsorted mixed waste to a partner wouldn't be only economically smart but it would also enable to achieve the ZSW goal. Directing the waste from landfill to recycling and energy recovery would be in accordance with the priority order of the waste management in the waste law 646/2011 and by discontinuing the landfill disposal, the paper mill could also improve the brand image. Landfill maintenance costs would drop because of lower utilization rate. The landfill use affects directly to the waste management's tax costs which were 6,9 % from the total costs in 2015.

Factory waste includes a lot of combustible material due to deficiencies in source separation which makes the landfill disposal illegal due to the landfill prohibition of organic wastes. The share of organic compounds in correctly separated factory waste was intended to determine in laboratory tests. However, testing certain waste fractions turned out to be impossible. The aim of the factory waste's laboratory testing was to clarify if the current waste management system is even legal and through that send a clear message that the system requires a rapid change. The share of organic compounds even in correctly separated factory waste was suspected to be too high for landfill disposal. Decreasing the amount of produced factory waste and increasing recycling rate were seen possible through better source separation which could be achieved through education, better separation instructions and developing the collection system. Education and visible improvements in the source separation system could affect positively to people's attitudes towards recycling and reduce the amount of produced factory waste.

Municipal waste, which represents MSW was the third expensive waste fraction to dispose after factory and construction waste. The waste fraction consists mainly of paper cups, napkins and food wrappings which are produced in break and control rooms. Municipal waste has been so far transported to Hevossuo's municipal waste landfill, which is owned by City of Rauma from where it has been directed to MSW incineration. The disposal cost for the municipal waste was high because of the long transportation distance and the gate fee. The municipal waste collection is due to old practices that are already noticed to be out dated. Since the wastes sorted to the municipal waste can be comparable to combustible material, it was discussed to be separated to combustible material collection. This was partly adapted already during the research. Glass and metal scrap separations were discussed to adapt at the same time in the break rooms to avoid any harmful residues ending up to incineration. Bio waste separation was started at the mill site during the study. It will be discussed on later how large scale it will be implemented. Previously mentioned actions would cut the costs for disposing a ton of municipal waste to less than ten percent from current costs. However, the amount of annually collected municipal waste is so low that it won't affect notably to the overall costs of the waste management.

Recyclable plastics, recyclable fibers, kaolin sludge, combustible material and *bottom ash* disposal costs consisted only of the transportation costs and therefore the fractions are cheaper to dispose. Since the transportation distance for the fractions is short the factors that affected to the overall costs were average weight of the cargo and the emptying time. Recyclable plastic transportation was noticed to be the most expensive because of low weight of the cargoes and inconvenient and slow emptying process. On the other hand, annually produced recyclable plastic is so low that it doesn't play a large role in the big picture. It was noticed that directing the recyclable plastic and fiber to incineration to Rauman Biovoima, would be economically more profitable option compared to recyclable material sales. However, the economical side in this case can't be the only aspect since the waste law prioritizes recycling before incineration. The cost difference can also narrow in the future if the governments establish new controlling means such as waste incineration tax or places the waste incineration under the emission trading program. The results still strive to think how much time and effort should be seen into recyclable plastic and fiber separation.

Amount of collected *hazardous-wastes* varied a lot under the review period. Hazardous wastes collected on the factory consist mainly of oil filters, process chemicals, oils, fluorescent lamps and batteries. Any remarkable saving potential weren't seen in hazardous waste collection.

Metal scrap collection generates notable incomes annually. In 2015, the waste management costs were covered totally with metal scrap sales. The amount of produced metal scrap is strongly related into a demolition projects and therefore also the incomes from the sales varies. Based on the discussions, it became clear that a lot of stainless steel has been sold with the current separation system as a black metal scrap which represents the lowest price category of mixed metal scrap qualities. This action is mainly because of deficiencies in the separation instructions and in separation system. The price difference between the black metal scrap and stainless steel is almost ten times depending on a scrap metal prices. It was hard to estimate how much stainless steel scrap were actually sold as a black metal scrap, but the calculations pointed that stainless steel separation is profitable even with a smaller volumes.

An important reason for high utilization rate of *ash* is the Sampaanala's construction project which enables a cost-efficient waste utilization in earth construction project at the mill area. Ash produced in the biopower plant can be directed to the construction project. The project cuts the ash disposal costs remarkably. It is estimated to be finished in five to seven years. Finding a utilization purpose for also in the future is important. Landfill disposal of ash would be extremely expensive, because of the waste tax and transportation costs.

Fly ash from the bio power plant of Rauman Biovoima was recently tested by KVVY. The results revealed that copper, lead zinc and arsenic content of the ash exceeded the limits set in the council act 403/2009 about earth construction eligibility. Certain element concentrations exceeded the limits also in the leaching test. The most critical components in the leaching test were chrome, lead, chloride and sulfate. There was some variety in the results between different boilers at the biopower plant. The results complicate the utilization of the fly ash in earth construction projects. If the measurement uncertainty is not taken into account the lead content in the fly ash from boiler six exceeded the limits also in the council act 331/2013 for non-hazardous waste landfill eligibility. The research with Ramboll could improve the ash quality through additives fed to the combustion process and increase the utilization potential. Earth construction projects, soil stabilization and even a brick or cement industry could be possible utilization targets if the experiments turn out to be successful. Road constructions, concrete industry and other earth construction projects were discovered in general to be most common utilization target for ash. Content of harmful elements in the bottom ash was generally lower compared to fly ash and thus the utilization of bottom ash is easier.

Kaolin sludge circulation in the paper making process has improved notably in the last years which has decreased the amount of produced kaolin sludge. This can be also seen from the waste statistics during the years 1997-2015. Through the kaolin sludge circulation, the need for landfill disposal has decreased. Kaolin sludge have been also utilized as a raw material in a brick industry.

Production of *sludge at the waste water treatment plant* is another large waste flow at the mill site. Annually 30 000 - 40 000 t of dried sludge is produced at the waste water treatment plant. The sludge is transported by conveyors and incinerated at the biopower plant. Because of the low heating value and contamination effect in the boilers, incineration is not seen the best possible technique for sludge disposal. Composting and digesting of the sludge could be considered, but requires more research. Produced sludge at the waste water treatment plant of Helsingin seudun ympäristöpalvelut is digested and used in landscaping projects. A similar process could be possible to arrange in Rauma's area too since there is a lot of biomass available in the area, especially after the poultry factory starts running. According to the laboratory results landfill disposal of the sludge from the balancing reservoir and waste water treatment plant were not seen possible due to high TOC and DOC values. More research and discussions with the environmental authorities must be done, if the sludge could be utilized for example in landfill or in sound barrier structure constructions with ash. Also, composting or digestion utilization requires more study. The sludge is already approved to be used in the Sampaanala's gulf filling project, which refers that comparable utilization could be possible also in the future.

Table 17. Summary of waste management development possibilities

Waste fraction	
Factory waste/ Construction waste	Directing waste fraction to energy recovery possibly through a partner. Could lead to 5-10 % cost savings from the total waste management costs.
Municipal waste	Energy recovery at the biopower plant. Small (less than 1%) cost savings through cheaper transportation and handling costs.
Combustible material	Compressive containers in certain locations. Cost saving potential through more efficient logistics. Saving potential requires more research about investment and renting prices.
Recyclables	Compressive containers would lower the transportation costs. Should be considered how much effort to put in recyclables since incineration were seen more profitable.
Metals	Separate collection of stainless steal. Could lead more that 40 % higher incomes from total metal scrap sales.
Fly ash and bottom ash	Co-operation with Ramboll Oy to improve the ash quality in earth construction. Larger containers for bottom ash collection to improve the transportation system.
Sludge from the waste water treatment plant	Possibility to compost or digest the sludge should be researched more carefully. Also earth construction possibilities should be examine.

Rationalizing the waste management system in certain points could lead to cost savings. The logistic company P. Peltomaa Tmi who arranges most of the waste transportations reported overtime almost every week during the year 2015. According to the conversations especially some of the combustible material containers and the bottom ash container require emptying also at the evenings and on the weekends in addition to normal working days. The amount of containers that need to be emptied on the average per day is less than ten. This means that emptying of the containers should be possible during a regular eight-hour working day. The problem is that the containers irregular fill up irregularly. Costs which are caused by the extra hours done on the weekends and evening could be avoided by developing certain problematic locations. Most of the containers don't need emptying during the weekends. With two or three bottom ash containers and a possibility to fill each container separately could help to avoid the hours done on weekends and evening. Investing or renting compressive containers in certain locations would help to avoid the unnecessary emptying for other fractions. Compressive containers would increase also the average weight of the cargo for lighter waste residues such as recyclable, fibers, recyclable plastics and combustible material. Used compressive containers cost 5000-15000 euros and non-compressive containers cost from 500-5000 euros. Renting prices are contractual.

Weighing of the waste containers causes extra driving in waste transportation. Each container needs to be transported through the weighing station, which in a worst case can double the emptying distance. A possibility to weigh the containers in a truck while emptying was discussed. Even the distances are not long inside the factory area it would shorten the emptying time and ease the traffic at the weighing station. It wouldn't create notable cost savings in a short time period but it would rationalize the system. If the waste management system faces larger changes this could still be considered. A waste container tracking system was noticed to be out dated. The intention of the tracking system is to enable to develop and monitor the waste management in each operative unit separately. There is no certainty if properly working system could lead to cost savings or does it make the system just more complex. There are currently a lot of unnecessary codes for different waste fractions in the Rapu-database where the produced waste amounts are reported. Variety of different categories has been created over time that can easily lead to misunderstandings. Deleting and combining the unnecessary codes could prevent mistakes and save time.

CE is seen predicted to be connected even stronger into forest industry in the future especially through further processing of by-product flows. The focus is slowly shifting from paper recycling and energy recovery to inner loops of CE. Sitra's study estimated that cost savings of 220-240 million euros in Finnish forest industry could be achieved through CE by more efficient use of by-product flows even the Finnish forest industry is already seen as a forerunner in adapting principles of CE. In the future, there are expected to see a lot of CE related innovations in the forest industry. Catalytic bleaching of pulp, adaptations for nanocellulose, lignin-based innovations and the synthetic biology solutions have been predicted to be some of the commercial future innovation in the sector. (Sitra 2015a; Sitra 2015b.)

It could be said that a breakthrough in the fertilizing sector has already been made (Maaseudun tulevaisuus 2016). In the year 2015 more than 100 000 t of ash, sludge and lime mud were used in fertilizing purposes. Most of this consisted of sludge from the industrial waste water treatment plants. Also, nutrient circulation has taken a step forward. Complex legislative system has been slowing down the development especially in the sludge utilization for the fertilization purposes and ash utilization for the earth construction projects. A desire to success and invest in the future can also be seen in a 2025 vision of Metsäteollisuus Ry (Registered association of Forest Industry) “Renewable forest industry – success from the bio-economy” (Metsäteollisuus 2016d; Sitra 2015c). The vision highlights sustainability of the products and efficient use of resources.

6 SUMMARY

This master's thesis is part of the Zero Solid Waste project of UPM. The aim of the project is to give up all of the landfill operations that are caused by UPM in Finland by the year 2018 and globally by the year 2030. The premise for this study was to determine the preconditions to landfill free operation at the mill site and to increase the recycling rates through circular economy. In the study only the situation in Rauma was examined. The results can't be compared directly to other UPM owned factories. In addition to landfill operations other development targets of the waste management system, economics and future trends were researched in the study. The industrial waste landfill of Suiklansuo is used together by Metsä Fibre Oy and UPM Paper ENA Oy. Only the landfill actions caused by UPM Paper ENA Oy were researched.

As a result, it was noticed that the mill site of UPM Paper ENA Oy in Rauma is close to reach the goal of the Zero Solid Waste project. Annually there were 300-400 t of wastes disposed to the landfill during the review period and the trend was descending. More than 95 % of the wastes disposed to landfill consisted of unsorted mixed waste collected from the production sites. Waste disposed to the landfill could be directed to waste incineration for energy recovery, which would help to achieve the ZSW goal. In the research incineration was also estimated to be more cost-efficient solution than landfilling.

Largest saving potentials in the waste management system were estimated to be in the landfill operations and in the waste transportation system. Landfill costs covered 24 % and waste transportation costs more than 60 % of the total waste management costs in 2015. Landfill costs would decrease notably if the landfill disposal of the wastes is ended. Landfilling is directly related to the waste tax costs that must be paid from each ton of waste disposed to the landfill. Waste taxes covered 6,9% from the total waste management costs in 2015. Unnecessary costs in waste transportation are caused by evening and weekend transportations and transportation of light cargoes. These could be avoided through technological improvements and better planning.

Ash, kaolin sludge and sludge from the waste water treatment plant are produced clearly more than other waste fractions at the mill site, more than 30 000 t per year. Utilization of these fractions has a significant importance economically. The fractions have a utilization target at the moment, but continuous research for the utilization is recommended to be done. Currently ash is utilized in an earth construction project in the gulf of Sampaanala and the sludge is incinerated. Sampaanala's construction project is estimated to continue for five to seven years. Research of the eligibility of ash utilization in road construction, cement industry or other landscaping projects is already started. Kaolin sludge is currently circulated back to the process and it is also allowed to be utilized in the Sampaanala's construction project. Landfill disposal of ash and kaolin sludge is not recommended. The possibility of composting and digesting of the sludge from the waste water treatment plant, or utilizing the sludge as a fertilizer or in earth construction project was discussed, but all of them require more research and require investment. There is a lot of biomass produced at the area that creates a great potential for digestion business. Incinerating the sludge was not seen as the best possible solution for disposing the sludge. Political control means are estimated to tighten in the future. Waste incineration tax and placing the waste incineration under the emission trading scheme is already implemented in few European countries.

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Attachment I. Produced amount of wastes in different units in 2015 [t_{wet}/a]

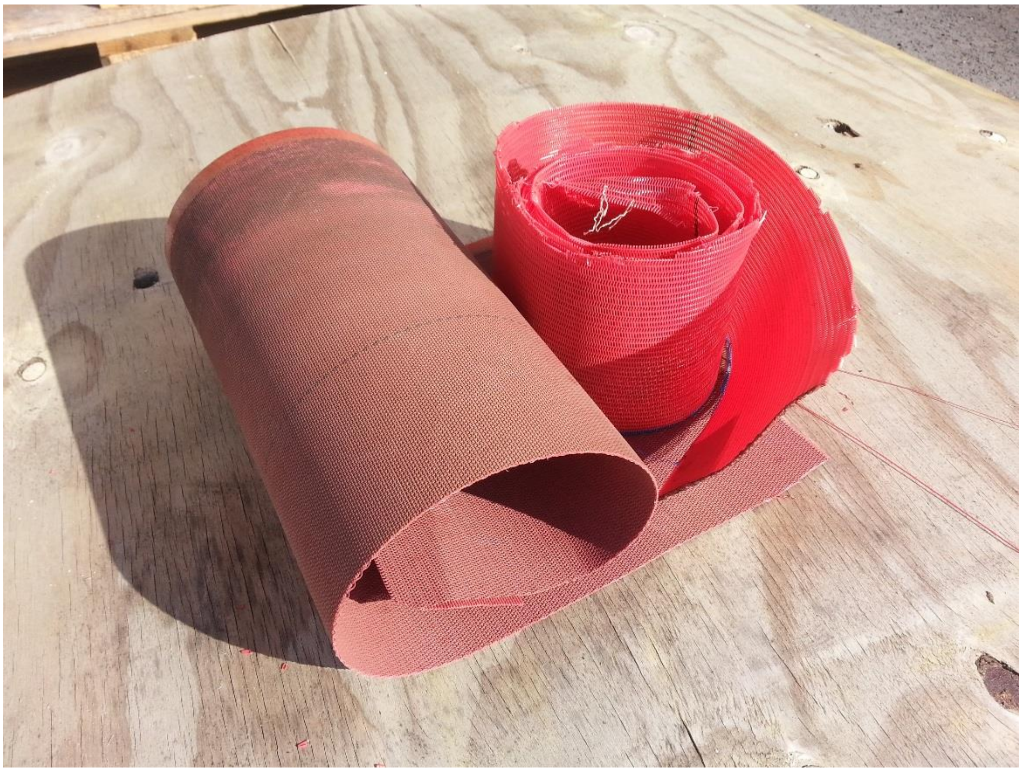
PM = Paper machine, TMP = Thermo-mechanical pulp line

Waste fraction	**PM 1**	**PM 2**	**PM 3**	**PM 4**	**TMP**	**Common**	**Rauma Cell**	**Rauman Biovoima**	**Total**
Kaolin sludge to Sampaanala’s gulf	353,48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**353,48**
Kaolin Sludge to Kemiö, Tiileri Oy	0,00	0,00	0,00	0,00	0,00	29,18	0,00	0,00	**29,18**
Fly ash	0,00	0,00	0,00	0,00	0,00	0,00	0,00	34208,00	**34 208,00**
Factory waste, Suiklansuo	64,06	20,32	0,64	16,16	16,82	128,58	12,20	41,98	**300,76**
Construction waste, Suiklansuo	0,00	4,86	0,00	0,00	0,00	3,82	0,00	0,38	**9,06**
Wood based combustible waste	0,00	0,00	0,00	0,00	13,60	75,96	0,00	0,00	**89,56**
Incinerated paper and cardboard	0,00	0,34	0,00	0,00	0,24	1,76	0,00	0,00	**2,34**
Combustible process waste	0,00	0,00	0,00	0,78	0,00	63,82	0,00	0,00	**64,60**
Other combustible waste	392,98	53,74	25,78	911,06	45,96	652,16	96,38	17,96	**2 196,02**
Waste to Hevossuos's landfil	0,00	1,74	0,00	0,00	0,00	28,26	0,00	0,00	**30,00**
Stainless steel	0,00	0,00	7,92	0,00	4,64	22,54	0,00	0,00	**35,10**
Steel scrap	0,00	0,00	0,00	0,00	3,90	13,90	0,00	0,00	**17,80**
Black scrap metal	0,00	0,00	14,24	0,00	21,06	261,34	0,00	381,60	**678,24**
Aluminium	0,00	0,00	0,00	0,00	0,00	4,18	0,00	86,50	**90,68**
Other metals	0,00	0,00	0,00	0,00	0,00	0,00	0,00	61,36	**61,36**
Bottom ash	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3710,54	**3 710,54**
Cement and bricks	0,00	2,04	4,40	0,00	0,00	52,24	0,00	11,28	**69,96**
Soils	0,00	0,00	0,00	0,00	0,00	430,30	0,00	0,00	**430,30**
Recycled fibers and shells	52,76	38,80	18,76	43,26	0,00	2,60	0,00	0,00	**156,18**
Recycled plastic/cardboard	0,00	0,00	0,00	2,72	0,00	6,86	0,00	0,00	**9,58**
Cables	0,00	0,00	0,00	0,00	0,00	74,46	0,00	0,00	**74,46**
WEEE	0,00	0,00	55,26	0,00	0,00	48,52	0,00	0,00	**103,78**
Total	**863,28**	**121,84**	**127,00**	**973,98**	**106,22**	**1900,48**	**108,58**	**38519,60**	**42 720,98**

Attachment II. Produced total amount of wastes during the years 2011 – 2015 [t_{wet}/a] *=Intermediate storing purposes

Waste fraction	**2011**	**2012**	**2013**	**2014**	**2015**
Kaolin sludge to Suiklansuo	1 696,04*	1 904,44*	443,12*	1 061,62*	-
Kaolin sludge to Sampaanala's gulf	-	-	1 464,70	46,08	353,48
Kaolin Sludge to Kemiö, Tiileri Oy	-	-	476,90	1 819,72	29,18
Fly ash	33 755,96	32 274,00	31 613,08	33 370,01	34 208,00
Factory waste, Suiklansuo	382,78	358,84	389,46	394,46	300,76
Construction waste, Suiklansuo	1,14	16,30	17,64	0,00	9,06
Wood based combustible waste	837,10	437,66	302,06	61,90	89,56
Incinerated paper and cardboard	6,36	4,10	9,34	8,98	2,34
Combustible process waste	72,80	105,14	68,42	60,56	64,60
Other combustible waste	2 189,34	2 373,00	1 783,80	2 080,60	2 196,02
Domestic waste, Hevossuo	71,58	62,66	102,42	45,64	30,00
Stainless steel	16,00	12,28	12,48	11,24	30,46
Steel scrap	0,00	36,56	2,62	0,00	22,44
Black scrap metal	321,22	528,72	869,50	408,22	678,24
Aluminium	0,00	2,62	0,00	5,84	90,68
Other metals	53,70	22,90	61,30	83,06	61,36
Bottom ash	3 847,14	4 121,00	4 728,96	4 479,48	3 710,54
Cement and bricks	12,92	632,20	929,48	146,84	69,96
Soils	2,72	196,67	1 869,92	694,62	430,30
Recycled fibers and shells	381,14	484,68	462,20	221,08	156,18
Recycled plastic/cardboard	46,96	15,30	24,18	10,76	9,58
Cables	1,90	0,00	1,18	40,00	74,46
Electronical waste	25,90	11,92	18,68	18,36	103,78
Hazardouz waste	58,78	21,59	40,64	445,67	37,00
Total	**43 781,48**	**43 622,58**	**45 692,08**	**45 514,74**	**42 720,98**

Attachment III. Screens and felts -sample



Attachment IV. Fabrics including metal -sample

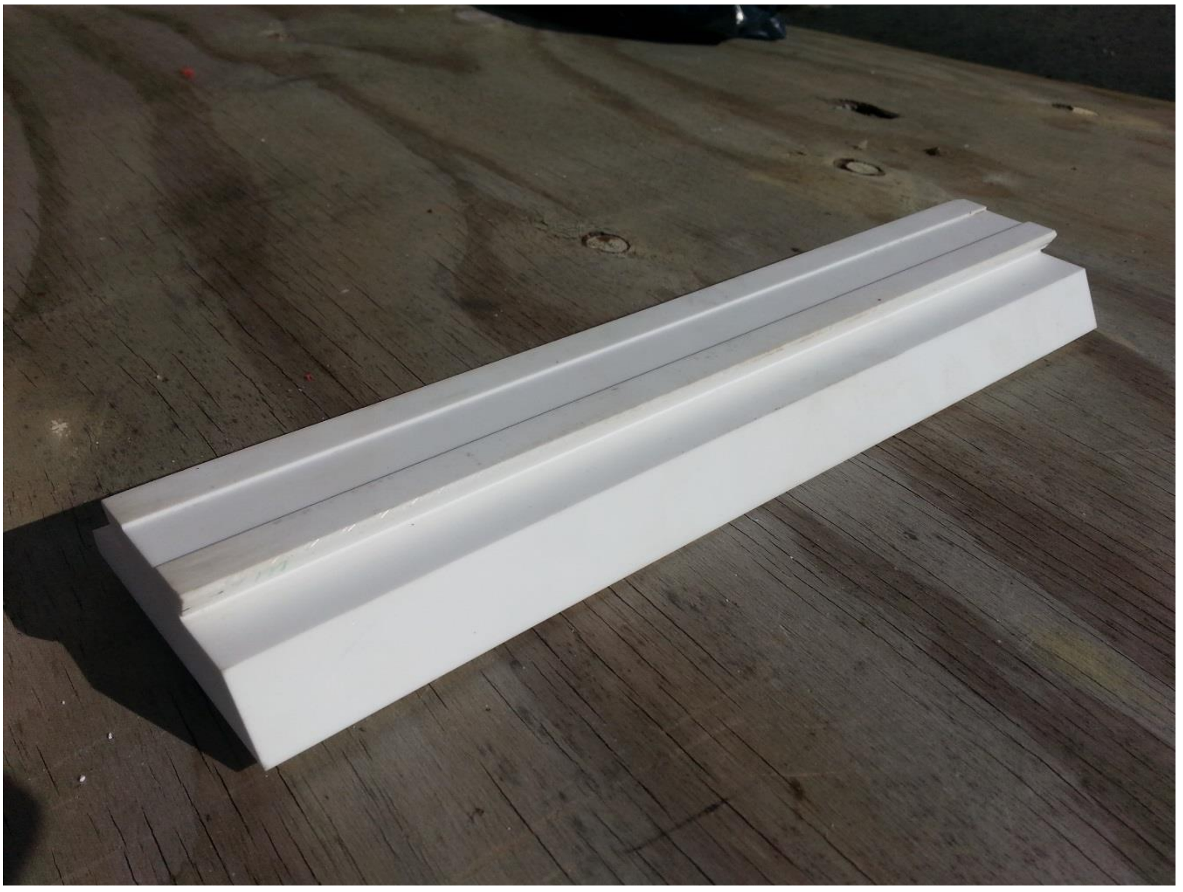
Attachment V. Hoses and plastics -sample

Attachment VI. Abrasive discs and sanding strips -sample

Attachment VII. Braided sealants -sample

Attachment VIII. Glass and mineral wool -sample

Attachment IX. Ceramics and porcelain -sample



Attachment X. Carbon fiber scrapers -sample