Opportunities for Industrial Symbiosis Between CHP and Waste Treatment Facilities (Case Study of Fortum and Ragn Sells, Brista)

Yevgeniya Arushanyan

Master of Science Thesis
Stockholm 2010
Opportunities for Industrial Symbiosis Between CHP and Waste Treatment Facilities
(Case Study of Fortum and Ragn Sells, Brista)

Supervisor: Graham Aid
Supervisor & Examiner: Nils Brandt

Royal Institute of Technology, Sweden,
Department of Industrial Ecology

Master of Science Thesis
STOCKHOLM 2010

PRESENTED AT

INDUSTRIAL ECOLOGY
ROYAL INSTITUTE OF TECHNOLOGY
Opportunities for Industrial Symbiosis Between CHP and Waste Treatment Facilities

(Case Study of Fortum and Ragn Sells, Brista)

Yevgeniya Arushanyan

Supervisors: Graham Aid, Nils Brandt

Examiner: Nils Brandt

Master of Science Thesis

Stockholm 2010
Abstract
Pursuing the possibilities of increasing efficiency, saving costs and improving environmental performance more and more companies today are looking into the possibilities of industrial synergies between companies and processes.

This study is considering the possibilities of industrial symbiosis between combined heat and power plant (Fortum) and a waste sorting facility (Ragn Sells). The paper shows possible scenarios of utilization heat from CHP for the various processes within the waste treatment facility. The work includes the overview of previous research done in this area as well as theoretical analysis and estimation of the probable economic and environmental effects from the application of industrial symbiosis.

The study covers several possibilities for the industrial symbiosis between CHP and waste treatment facility in form of heat application for the waste streams upgrading. The study proposes the heat application for the following processes: composting speed-up, anaerobic digestion, sludge drying, waste oil treatment and concrete upgrading.

In the result of the work the conclusions are made concerning the possibility and feasibility of application of the proposed scenarios and their environmental and economic effects.

Key words: industrial symbiosis, CHP, waste treatment, district heating, composting, anaerobic digestion, concrete upgrading, sludge drying, waste oil treatment
Acknowledgements

I would like to express my gratitude to those who made this Master Thesis possible. First of all to my supervisors at the Industrial Ecology department (KTH) Graham Aid and Nils Brandt for the professional guidance all through the project. Special thanks to Graham Aid for help with finding data and for providing me with great insights and feedback.

I would also like to thank Eva-Katrin Lindman (Fortum) for her assistance in finding necessary data and provision of fruitful and interesting basis for discussion.

I am also grateful for the help I have received from Paul Wurtzell (Ragn Sells), who provided me with useful and interesting information.

Thanks to my family and friends for their love and support.
# Table of Contents

Abstract ........................................................................................................................................... 2  
Acknowledgements .......................................................................................................................... 3  
List of tables and figures .................................................................................................................. 6  
List of Abbreviations ....................................................................................................................... 7  

I. Introduction ................................................................................................................................. 8  
  1.1. Background .......................................................................................................................... 8  
  1.2. Aims and objectives ............................................................................................................ 8  
  1.3. System boundaries ............................................................................................................. 9  
  1.4. Methodology .................................................................................................................... 9  

II. Overview of CHP and Waste Sorting facility. Synergy and heat sales market expansion ....... 9  
  2.1. Combined heat and power plant (Fortum) ......................................................................... 9  
  2.2. Waste treatment facility .................................................................................................... 10  
  2.3. Synergy ........................................................................................................................... 10  
  2.4. Why to consider the heat sales market expansion? .......................................................... 10  

III. Concept of industrial symbiosis ................................................................................................. 11  
  3.1. Overview of existing cases ............................................................................................... 12  

IV. Industrial symbiosis opportunities proposal and selection ..................................................... 13  
  4.1. Drying MSW ..................................................................................................................... 13  
  4.2. Composting speed-up ....................................................................................................... 13  
  4.3. Anaerobic digestion ......................................................................................................... 14  
  4.4. Torrefaction ...................................................................................................................... 14  
  4.5. Sludge drying ................................................................................................................... 14  
  4.6. PTP pellets production ...................................................................................................... 14  
  4.7. Concrete upgrading ......................................................................................................... 15  
  4.8. Elimination ....................................................................................................................... 15  

V. Case studies ............................................................................................................................... 15  
  5.1. Composting ....................................................................................................................... 15  
      5.1.1. Process description .................................................................................................... 15  
      5.1.2. Overview of previous research .............................................................................. 16  
      5.1.3. Case study analysis ................................................................................................. 16  
  5.2. Sludge drying .................................................................................................................... 20  
      5.2.1. Process description .................................................................................................. 20  
      5.2.2. Overview of previous research ............................................................................ 21  
      5.2.3. Case study analysis ............................................................................................... 23  
  5.3. Anaerobic digestion ......................................................................................................... 25  
      5.3.1. Process description .................................................................................................. 25  
      5.3.2. Overview of previous research ............................................................................ 27  
      5.3.3. Case study analysis ............................................................................................... 27  
  5.4. Waste oil treatment .......................................................................................................... 30  
      5.4.1. Process description .................................................................................................. 30  
      5.4.2. Case study analysis ............................................................................................... 30  
  5.5. Concrete upgrading ......................................................................................................... 33  
      5.5.1. Process description and previous research ............................................................. 33  
      5.5.2. Case study analysis ............................................................................................... 34  

VI. Discussion ............................................................................................................................... 37  

VII. Conclusions ............................................................................................................................ 40
References.......................................................................................................................... 42
Appendix I. Composting spread sheet ........................................................................... 45
Appendix II. Sludge drying spread sheet ..................................................................... 46
Appendix III. Anaerobic digestion spread sheet.......................................................... 47
Appendix IV. Waste oil treatment spread sheet ............................................................ 48
Appendix V. Concrete upgrading spread sheet.............................................................. 49
List of tables and figures
Figure 1.1. Location
Figure 2.1. District heating demand trend
Figure 3.1. Industrial ecosystem at Kalundborg, Denmark
Figure 5.1. Composting in Ag-Bags
Figure 5.2. Heat supply for the composting speed-up.
Figure 5.3. Amount of material composted during wintertime
Figure 5.4. Composting. Material and energy flows
Figure 5.5. Annual costs and benefits for the composting speed-up
Figure 5.6. Drum drying technology
Figure 5.7. Energy supply system for sludge drying
Figure 5.8. Sludge drying. Material and energy flows
Figure 5.9. Comparison of annual energy costs in case of using heat and electricity
Figure 5.10. Standard process of anaerobic digestion
Figure 5.11. Biogas upgrading through water scrubbing
Figure 5.12a. Return heat application
Figure 5.12b. Heat application.
Figure 5.13. Anaerobic digestion. Material and energy flows
Figure 5.14. Costs and Benefits of biogas production
Figure 5.15. Comparison of costs of using heat and biogas to run the anaerobic digester
Figure 5.16. Heat supply for the waste oil treatment
Figure 5.17. Material and energy flow
Figure 5.18. Comparison of energy costs in case of heat and electricity application
Figure 5.19. Flow scheme of thermal treatment of concrete rubble
Figure 5.20. Material flow (unit – tons, I – incoming flow, E – outgoing flow)
Figure 5.21. Material and energy flows for the concrete upgrading
Figure 5.22. Costs VS Benefits for the concrete upgrading
Figure 6.1. Industrial symbiosis
Table 5.1. Percentage composition of the composting material
Table 5.2. Various drying technologies energy demand. (Drying sludge from 30% d.s. to 90% d.s.)
Table 5.3. Rough market prices for the materials
Table 6.1. Relative evaluation of industrial symbiosis possibilities.

List of Abbreviations
CHP – combined heat and power plant
RS – Ragn Sells
MSW – municipal solid waste
EIP – eco-industrial park
PTP – plastic-wood (trä)-paper
d.s. – dry solid
MFA – material flow analysis
SEK – Swedish Crown
I. Introduction

1.1. Background

The ideas of symbiotic performance are of high interest as one of the ways for sustainable development. Various kinds of symbiosis give an opportunity to optimize the industrial performance with the lowest economic costs and the highest environmental benefits. The application of symbiosis concepts leads to the recycling of materials and energy, using waste as a resource instead of emitting it to the environment in a form of pollution, and therefore saving money.

In industrial ecology the idea of symbiosis developed into the concept of Eco-industrial parks. A lot of research has been done in this area and the numerous examples of Eco-industrial parks and simple industrial symbiosis are successfully performing today.

An Eco-industrial park or symbiosis can be based on the exchange of resources (including knowledge), waste or energy. The simplest examples of the synergy based on energy are cogeneration energy plants – producing electricity and utilizing the “waste” heat for district heating or cooling.

The idea of the present study was to go further than heat utilization for district heating and to investigate the other possible ways of the utilization of “waste” heat from electricity production as well as to study the possibilities of “double” use of the waste heat through utilization of return heat from district heating.

1.2. Aims and objectives

The aim of the study is to assess the possibilities for using heat and excessive heat from Fortum CHP for upgrading waste material streams to improve the economic viability of related technologies.

In order to reach the aim the following objectives are to be fulfilled:

- Identify and present the technologies of waste streams upgrading available (current and potential)
- Present the technologies to Fortum and Ragn Sells (to get indicators and priorities)
- Quantify the amounts of waste available for upgrading
- Estimate the potential environmental and economic effects of the highlighted projects
- Make rough cost-benefit analysis of the proposed projects
- Outline the findings in presentations to Fortum, Ragn Sells and KTH.
1.3. **System boundaries**

Area: Brista, Sigtuna (Figure 1.1)

![Map of Brista, Sigtuna](image)

Figure 1.1. Location of industries of interest

The study is focused on the analysis of possibilities for industrial symbiosis with rough analysis of environmental and economic costs and benefits obtained from their application. Cost-benefit analyses exclude maintenance costs.

The case study is limited to the use of heat and excessive heat from the Fortum’s CHP in Brista and waste materials treated within the Ragn Sells’ waste sorting facility.

The time frame of the study is restricted by 5 months.

1.4. **Methodology**

The study is of theoretical character based on literature review of the available and potential technologies, material and energy flow analysis and rough cost-benefit analysis. The life-cycle approach is applied while performing the study.

II. **Overview of CHP and Waste Sorting facility. Synergy and heat sales market expansion**

2.1. **Combined heat and power plant (Fortum)**

Fortum is currently constructing a new waste-fired combined heat and power plant that will be adjacent to an existing facility in Brista, Sigtuna. The plant is expected to start operation in 2013 and will be linked to the existing district heating network, supplying the north and west of Stockholm. (Fortum, 2008)
The plant’s planned capacity is 240,000 tons of waste per year. The plant will provide approximately 57 MW of heat and 20 MW of electricity that is equivalent to the needs of medium-sized Swedish town. (Fortum, 2007) The new plant is located next to the Ragn Sells waste treatment facility, which could be beneficial from the transportation point of view.

2.2. Waste treatment facility
Ragn Sells is one of the most competent and experienced companies in recycling and environmental business. The waste treatment facility deals with industrial and municipal waste from all over Stockholm and the Baltic. The company is always looking for the new ways of solving the waste problems as well as the ways of the processes improvements. (Ragn Sells, 2010) The facility in Brista is represented now by a landfill area only, but is permitted to be upgraded and to allocate other waste treatment processes. (Aid, 2010)

2.3. Synergy
The location of both facilities next to each other gives an opportunity to look into possible synergies between the companies that will be beneficial for their efficiency, economic viability and environmental performance. The synergies could be based on use of the excessive heat from CHP in the waste treatment facility for the support of various processes, such as composting, anaerobic digestion, waste oil treatment, etc. Another option is expansion of the heat sales market for Fortum and considering new customer lines other than district heating, such as for example waste concrete upgrading.

The ideal case of the industrial synergy is utilization of the waste heat from electricity production in the waste treatment facility. But Fortum’s CHP does not have any so called “waste” heat as is it utilized for district heating and all the energy production is thoroughly planned according to the district heating demand. In summer, when the demand is low, the energy production is reduced or even shut down. (Lindman, 2010) In this case utilization of heat for other purposes, such as supporting of waste treatment processes, would give an opportunity to run the plant all year round without breaks due to the low energy demand. This will give an opportunity for the company not to reduce energy sales in summer as well as eliminate the problem of waste storage or other utilization caused by reducing the incineration rates.

2.4. Why to consider the heat sales market expansion?
The new CHP is oriented on the district heating supply. According to the prognosis from the Swedish District Heating Association (Svensk Fjärvärme) the demand for district heating will continue growing up till 2015 and then is going to go down by the year 2025 by approximately 10% (Fig. 2.1) The forecast is based on the results of national studies, statistical data and interviews with district heating companies. The reasons for such a decrease could be as following: efficiency improvements, heat pumps application and warmer climate. In case of such scenario the extension of the market for the heat sales gives better economy and reliability for the company now as well as more opportunities in the future. (Trad, 2010)
III. Concept of industrial symbiosis

Industrial symbiosis is one of the main concepts of the industrial ecology science, which is focused on studying material and energy flows in a system prospective. The principle of industrial symbiosis is that companies, suppliers and consumers all act within a system that resembles a natural one. (Sokka et al., 2009) This means that participants are interconnected by the resources they use or waste they produce. In other words industrial symbiosis (simulating a biological symbiosis) is an association of two “species” for the benefit of one or both of them. (Graedel & Allenby, 2003).

Industrial symbiosis is a basic element for the construction of an eco-industrial park (EIP), which includes several players/participants hoping to benefit from their association. Marian Chertow of Yale University has classified eco-industrial parks into five groups (Graedel & Allenby, 2003):

1. EIP based on waste exchange, where the recovered waste is sold or donated to another company.

2. EIPs that are organized within a company or organization: materials and/or products are exchanged with the same facility but between various units, when for example the by-product from process is used as a feedstock for another one.

3. EIPs that are created between companies in one industrial area: the exchange of water, energy, materials could be involved.

4. EIPs that are connecting companies located close to each other but not in the same industrial area. The most famous example of this kind of industrial park is Kalundborg in Denmark, where several companies located in 3 km radius exchange steam, heat, fly ash, sulfur and some other resources.
5. EIPs that are organized among the companies within broader area. This kind of eco-industrial park could include all types mentioned above.

In case of the present study the industrial symbiosis can be based on energy and waste exchange. The waste treatment facility provides municipal solid waste for the incineration plant, which in turn provides the facility with energy for the waste treatment processes, which improves their own performance and may also result in providing extra resources for the energy company, such as sludge for the furnaces and biogas for trucks or furnaces.

### 3.1. Overview of existing cases

**Kalundborg, Denmark**

The most well known example of industrial symbiosis is eco-industrial park created in Kalundborg, Denmark (Figure 3.1). The industrial ecosystem embraces oil refinery, plasterboard plant, pharmaceutical firm, fish farm, soil remediation company, coal-fired electrical power station and the municipality of Kalundborg. In addition several other companies receive materials and energy from them. The steam, water and various raw materials, such as sulfur, fly ash and sludge are exchanged among the ecosystem. Participants benefit from reduction of waste disposal costs, better efficiencies of resources usage, etc. (Peck, 2004)

![Industrial Ecosystem at Kalundborg, Denmark](image)

**Figure 3.1. Industrial ecosystem at Kalundborg, Denmark (Peck, 2004)**
According to the latest data from Kalundborg the firms have saved US$160 Million in general up to date, which corresponds to $15 Million of annual savings as return on total investments, which constitutes $75 Million. (Liu, 2009)

**Yeosu, South Korea**
The effects of industrial symbiosis creation were also investigated by Song Hwa Chae et al (2009) on a case study of an existing petro-chemical complex in Yeosu, South Korea. The research covered the investigation of energy optimization through the waste heat utilization. For example, waste steam could be mixed with waste water and utilized by the other companies in form of low pressure steam or used for district heating. Several ways of waste heat usage were proposed and investigated. The results of the study indicated that the total energy cost and the amount of waste heat of the region can be reduced by more than 88% and 82% from the present values, respectively, applying the suggested waste heat utilization networks. (Song Hwa Chae et al, 2009)

**IV. Industrial symbiosis opportunities proposal and selection**
There are a variety of the industrial symbiosis opportunities between a CHP and a waste treatment facility. The initial proposal for the study included the following possibilities:

- Drying municipal solid waste (MSW) for the extraction of various fractions
- Composting speed-up
- Sludge drying
- Anaerobic digestion
- Torrefaction
- Waste oil treatment
- PTP pellets production
- Concrete upgrading

**4.1. Drying MSW**
Stockholm has a highly developed system of sorting and collecting of municipal solid waste. However, sorting is done not in all areas, so some of the municipal solid waste coming to the Ragn Sells’ sorting facility still requires sorting. Automatic sorting technologies give an opportunity to increase the recovery of the recyclable materials from waste, but the efficiency of these technologies is rather low if the waste is humid. (Tako et al., 2004) The humidity of MSW could be up to 40% (Khorasani et al., 2010), while the optimal conditions for good sorting are around 10% (Tako et al., 2004) Natural drying requires a lot of space and is not possible in wintertime. So, the application of low temperature heat would be helpful for the increasing efficiency of sorting and would be cheaper for the sorting facility in comparison with buying electricity for these purposes.

**4.2. Composting speed-up**
Composting process is slowed down during the wintertime in Swedish weather conditions. The option of heat application for the speeding-up of composting during wintertime is interesting to look into due to the fact, that the temperature required to keep the composing pile warm is not high, so the return heat from district heating could be applied. The investment costs are not expected to be high since the waste treatment facility is located just 100 m from the CHP and could be included in the district heating system. Operational costs (the costs of energy) should not
be high as well as it is the return heat that would be applied. As for benefits, the turnover of composting could be increased, saving space, bringing more income due to better processing and eliminating the problem of storage.

4.3. Anaerobic digestion
Anaerobic digestion is hoped to be implemented in more of Ragn Sells’ waste sorting facilities. (Aid, 2010) It is a good way of biological waste treatment that yields biogas, which could be utilized for the local or regional demands (such as trucks/bus fuel or as primary fuel for furnaces). Traditionally the energy required to run anaerobic digester is produced using the process’ own biogas. Since the temperature requirements are not very high (the digester should be kept warm - at temperature around 35°C (Held et al., 2008) it seems to be interesting to consider the possibility of using return heat from district heating to substitute process biogas, which instead could be sold or used for the company’s trucks.

4.4. Torrefaction
Another biochemical process for biological waste treatment of biomass performed at temperatures ranging between 200-320 °C. During torrefaction the biomass properties are changed to obtain a much better fuel quality for combustion and gasification applications. Torrefaction in combination with densification leads to the creation of a highly energy dense fuel carrier of 20-25 GJ/ton. (Bergman and Kiel, 2005)

Torrefied material is characterized by (Bergman and Kiel, 2005):
- High heating value
- Low moisture content
- Stability and resistance to fungal attack
- Not gaining humidity at storage (hydrophobic)
- Possibility to be used as fuel for combustion and gasification or for production of charcoal

The possibility of using heat as an energy source for the process was considered to be interesting to investigate.

4.5. Sludge drying
Sewage sludge is often used in furnaces in the incineration process to decrease the level of Cl compounds emissions. (Krause, 1985) But the sludge has to be dried before adding it to the furnace, which makes the process energy demanding and usually not economically feasible. It was supposed that application of heat instead of electricity would make a process cheaper.

This case is also beneficial for both of the sides in the industrial synergy as incineration plant will be able to reduce Cl emission and thereby reduce the maintenance costs of the plant. The sorting facility will have a disposal for the sewage sludge without spending much money for drying or looking for other ways of sludge utilisation.

4.6. PTP pellets production
PTP (plastic-wood (trä)-paper) pellets production is an option of waste to energy recycling. The waste plastic, wood and paper are formed in pellets becoming an easily transportable high grade fuel. The products could be used locally or easily shipped for sale. The process of pelletizing
requires pretreatment of waste – drying at temperatures of 60-110°C (Aid, 2010), for which the heat from CHP could be utilized.

4.7. Concrete upgrading
The researches show that the waste concrete from demolition could be upgraded till almost virgin condition and used again for construction. Recycling allows to save energy and to avoid greenhouse gasses emissions from the new material extraction and manufacturing. (PCA, 2010) But the amount of energy required for the recycling is still quite high that makes it very expensive in case of using electricity for these purposes. As an alternative an option of tapping off the steam and using it directly instead of electricity production could be considered. This option should be cheaper since the efficiency would be higher.

4.8. Elimination
After discussion with the companies’ representatives the options of drying MSW, PTP pellets production and torrefaction were excluded from the research as those of mere interest.

Drying of MSW doesn’t look reasonable in long-term prospective, since the waste sorting in Stockholm is at the high level and is constantly improving. As for increasing of heating value of waste for the future incineration, the new boilers are adapted to deal with humid waste, so pre-drying would not be necessary in future. This could be an interesting technique for developing countries with high moisture contents in their waste.

The PTP pellet manufacturing process creates its own heat that could be utilized for drying, which is more economically feasible than applying external heat.

Torrefaction requires higher quality of materials than the waste under study, so it was decided to be of higher interest for the energy companies as a fuel production process rather than a part of waste streams’ upgrading.

V. Case studies

5.1. Composting

5.1.1. Process description
Composting is the process of organic material decomposition under activity of insects, earthworms and microorganisms resulting in a formation of humus-like product called compost. The process requires anaerobic conditions and around 50% of moisture content. The process consists of three main stages, which imply activity of various microorganisms under different temperature conditions. Composting starts with a mesophilic phase that is characterized by high rate composting with an increase of temperatures up to 25-45°C and rapid break down of organic matter. It is followed by thermophilic phase, which is also known as stabilization stage, when weed seeds and pathogens are destructed at high temperatures, such as 45-70°C. The last stage - cooling or maturation - is characterized by the decrease of temperature and microbiological activity; material is stabilized and moisture content is reduced. (Componordic system, 2000; Williams, 2005)

The rate of the process and quality of compost depend on waste type, structural material added, aeration, homogeneity, moisture content, carbon-nitrogen ratio, temperature levels and time. (Componordic system, 2000)
Composting in Ragn Sells is represented by two types of composting – composting of food waste coming from supermarkets (such as ICA) and composting of industrial wastes such as waste oil. Composting of food waste as a basic composting material is considered in this study.

Organic waste is delivered to the composting area, where it is shredded, mixed with structure material and put into the plastic sacks, called Ag-Bags. The bags are placed close to each other in straight lines on the flat, slightly inclined ground. Each bag is equipped with a ventilation system, providing aeration, with a fan placed at the highest point and the leachate collector placed at the lowest point. (Figure 5.1) (Componordic system, 2000)

![Composting in Ag-Bags](image)

Figure 5.1. Composting in Ag-Bags. (Source: Componordic system, 2000)

The composting ground at the facility is able to place up of 15 Ag-Bags. Each bag is capable to contain from 80 to 300 tons of composting material. The process of compost production normally takes around 12 weeks. But Swedish weather conditions slow the process down to about 14 weeks in autumn and winter since the ambient temperature is not sufficient for the normal bacterial activity. (Wurtzell, 2010)

5.1.2. Overview of previous research

The rate of composting depends among other factors on the temperature. The temperature inside the windrow is increased in the result of the microbial activity. But in order for the process to start the sufficient ambient temperature (not lower than 10°C) is required. Otherwise the process takes a longer time. (ZWS, 2010)

No previous research was found concerning the energy application for the purpose of heating of compost windrow. The conventional solution for the winter composting is using proper insulation and accepting the low rates of composting.

5.1.3. Case study analysis

Technology

The process of composting in wintertime could be speed up by organizing a heat supply to the compost piles in order to provide sufficient initial temperature for the normal bacterial activity. The problem of winter composting is only upper layers of the windrow, where the process heat doesn’t reach because of the low temperature. The inner layers are able to keep their own temperature due to microbial activity. So the task of energy supply is just to create conditions similar to those in summer or spring. Keeping temperature of the upper layers around 10°C would be enough to start biological degradation of the material. To create such conditions the organizing of supply of warm air through the aeration system is proposed.

The return heat from district heating (temperature range 40-45°C) should be directed to the heat exchangers connected with the fans. Then, instead of cold ambient air the windrow would be
aerated with the warm air. In order to organize the system the composting site could be included in the district heating system, but supplied by the return heat. (Figure 5.2)

Figure 5.2. Heat supply for the composting speed-up.

The data used for the case study analysis is summarized in Appendix I.

**Material and energy flows**

The food waste (provision waste from the supermarkets – both packed and unpacked) is mixed with other compostable materials and also with structure material for the better processing. The composition of the composting windrow with annual shares of various materials is represented in Table 5.1.

<table>
<thead>
<tr>
<th>Name of material</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compostable sludge</td>
<td>0.03</td>
</tr>
<tr>
<td>Organic sludge</td>
<td>5.54</td>
</tr>
<tr>
<td>Park- and gardening waste*</td>
<td>10.48</td>
</tr>
<tr>
<td>Compostable material from households</td>
<td>8.16</td>
</tr>
<tr>
<td>Unpacked provision waste</td>
<td>19.69</td>
</tr>
<tr>
<td>Packed provision waste</td>
<td>26.93</td>
</tr>
<tr>
<td>Vegetable waste</td>
<td>8.76</td>
</tr>
<tr>
<td>Animal waste</td>
<td>0.30</td>
</tr>
<tr>
<td>Sawdust*</td>
<td>20.10</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

*Structure material

According to the data from Ragn Sells (Wurtzell, 2010), the total amount of waste composted in 2009 was around 9,525 tons, while the potential of such composting within the company is considered to constitute about 30,000 tons waste.
Since there was no previous research found concerning energy use for the composting speed-up it is unknown how much energy would be required in order to keep the windrow at temperature around 10°C. Thus the assumptions concerning energy consumption were made. As a reference point the energy consumption for anaerobic digestion was taken as the material involved is of similar composition.

It is known that anaerobic digestion process requires 70 kWh of energy per ton of material processed (Aid, 2010). The material there has to be heated from 10 to 70°C, so the temperature has to be increased on 60°C. In case of composting the temperature of material has to be increased in average on 20°C. Therefore it was decided to assume that 35 kWh/ton of energy would be maximum required to keep the temperature over 10°C.

The energy supply would be necessary only for 28 weeks a year (winter time). The amount of waste composted during this period of time in case of heat application is estimated at 5,080 tons in case of the same waste amount as in 2009. And about 16,000 tons in case of realizing the full potential of 30,000 tons per year. The difference between the amount composted in ordinary conditions and with heat supply is presented on Figure 5.3.

![Material composted in winter time](image)

**Figure 5.3.** Amount of material composted during wintertime.

The amount of heat required for each of the cases equals 178 MWh/year and 560 MWh/year correspondingly. The material and energy flows in both cases are represented on the Figure 5.4.
CBA

Speeding up composting in winter would give a possibility to increase the turnover of the waste and as a result get higher profit and avoid the problem of organic waste storage.

The heat supply to the composting area would give a possibility to treat about 726 tons more food waste per year in case of amounts of 2009 or up to 2,285 tons more in case of full potential. Which is about 642,000 SEK/year and 2,000,000 SEK/year of income in the form of payment for the waste treatment respectively.

On the other hand the heat supply requires investment as well as some expenditure for operation. The investment cost would consist out of costs of district heating pipe construction, which is 2,500 SEK/m (Svensk Fjärrvärme, 2007). So for the construction of 100 meters of pipes the investment cost would constitute 250,000 SEK.

Annual energy costs would be 80,000 and 252,000 SEK in case of capacity of 2009 and full capacity correspondingly. The real energy costs could be lower in the final end, since the return heat is used, which should be cheaper than the normal heat. For the calculations the price of normal heat was taken (0.45 SEK/kWh (Fortum, 2010) as there is no market price for return heat, because it was never sold before. Operation costs include only energy costs, as additional human power would not be required and maintenance costs were not taken into account due to lack of data. Figure 5.5 represents the annual costs and benefits.
Apart from economic benefits there are also environmental benefits, such as avoiding greenhouse gases emissions from the storage of the food waste that is waiting to be composted. Estimated saved emissions from the two cases is 1,000 and 3,000 tons CO₂-eq correspondingly.

**Discussion**

The possibility of the turn over increase could give various opportunities for the waste treatment facility. Having such a system of heat supply the option of increasing composting share could be considered. The amount of waste composted in Högbytorp facility is 9,500 tons, while the potential amount of waste to be composted for the whole company is about 30,000 tons. So, the full potential could be realized without using more space for this purpose.

On the other hand, in case there is no interest in increasing composting turn over, the space could be saved and used for the other purposes.

For the Fortum this kind of symbiosis could give an opportunity for the double use of heat and therefore getting higher income without extra expenditures and resources.

From the environmental point of view the increase of composting rates would reduce the amount of waste stored at the facility and therefore eliminate sanitary problems as well as emissions’ problem.

### 5.2. Sludge drying

#### 5.2.1. Process description

Sewage sludge is also often used in furnaces in the incineration process to neutralize Cl compounds emissions. The research (Krause, 1985) shows that co-incineration of sewage sludge together with solid municipal waste reduces the corrosion of heat recovery surfaces caused by presence of Cl in the refuse. Adding 5% of sewage sludge to the incineration is enough to get the positive effect (Gyllenhammar, 2010).

However an obstacle for this way of sludge utilization is high moisture content. Thus material requires pre-drying before adding it to furnace. Drying actually is a part of the sludge utilization process. But the process is highly energy demanding and therefore expensive. An option of
utilizing excessive heat from the electricity production was considered to be interesting to look into as it might reduce the costs of sludge drying.

This kind of synergy would be beneficial for both sides (CHP and waste treatment facility) making the process of sludge utilization cheaper and producing a good additive for the furnaces reducing corrosion and thereby maintenance costs.

5.2.2. Overview of previous research
The most common method of sludge drying applied today is drum drying technology. (Figure 5.6). Sludge comes to the drying stage with 15-20% d.s. (dry solid) and mixed with the sludge that is already dried. Then the mixture is lead to the drum where it stays for 20 minutes reaching the temperatures 80-85°C until it reaches 95% d.s. The main disadvantage of the method is high-energy consumption that makes it expensive in case of using electricity. (Krebs et al.)

![Figure 5.6. Drum drying technology.](Source: Krebs et al.)

There is a number of drying techniques that were investigated by Stockholm Vatten. They could be classified into two groups: direct and indirect drying methods. Direct drying methods include fluidized bed technology, drum and band dryers. Indirect drying methods are drum (skiv) drying, thin film drying, tubular, multicoil, step and stream drying. (SV, 1998)

In a fluidized bed dryer is drying in a closed system. Wet sludge is mixed with the already dried one and sent to the fluidized bed dryer that constitutes vertical chamber with perforated bottom. Hot air or superheated steam (230-270°C) is used both for the fluidized bed and drying. The gas is heated indirectly with hot oil circulating in a pipe system in the bed. The gas is blown through the mixture of fluid, which gives a high degree of interference and heat transfer distribution between the solid phase and gas phase and provides an even drying. The bed temperature not exceeding 85°C controls the process. (SV, 1998)

The drum dryer (Trumtork) is the most common direct drying method for sewage sludge. The dryer consists of a slow rotating horizontal cylinder, which is slightly tilted. Before entering the dryer the sludge is mixed with already dried sludge (60% d.s). Warm air (260 – 450°C, depending on drying type) is led into the downstream dryer and mixed with the sludge during transport to the outlet. (SV, 1998)
In a *band-drying* the dewatered sludge is transported through the kiln in the form of an even layer on a perforated band. Drying occurs through convection. Hot air or overheated steam is blown into the drying zone and passes through the sludge. Some of the drying air is recirculated. The temperature in the dryer is usually around 400°C. (SV, 1998)

*Disc dryers* are a widely used method of indirect drying for sewage sludge. The dryer consists of a hollow rotor enclosed in a fixed horizontal container, a stator. A number of persistence discs are mounted on the rotor. Steam or thermal oil is used as heat transfer medium and is fed into the rotor. The sludge to be dried can have various dry solids content, depending on the final dry solids content desired. Dewatered sludge is mixed with already dried sludge with dry solid content of about 70%. The sludge is continuously fed into the top of the dryer and drying occurs via heat transfer from the rotor. The vapor pressure is approximately 10 bar at 180°C (saturated steam) and outgoing sludge is heated to a temperature of approximately 100°C. (SV, 1998)

In a *thin film drying* system drying is carried out in two steps. The first step consists of very thin film dryer and is a partial drying of the sludge. The sludge is then dried to the desired dry solid content in a subsequent plate dryer of so-called segment type. Thin film dryer consists of a horizontal enclosure surrounded by a heating jacket. The inside of the casing is the heating surface on which the sludge is dried. The sludge is fed continuously at high speed at one end of the dryer. The thin layer results in a fast drying. Sludge residence time in the dryer is about 10 minutes. The sludge does not need to be returned to the inlet and mixed with dewatered sludge before it is fed into the dryer. After the thin film dryer where the sludge is dried till the dry solid content of about 60%, it falls down to a subsequent plate dryer for final drying up to 90-95% d.s. at 100-110 °C for about 45 minutes. (SV, 1998)

*The tubular dryer* consists of a cylindrical, horizontal rotors which are towed by a number of longitudinal tube. The rotor is surrounded by a stationary housing. Drying gas is sucked into the tubes with mild depression and the sludge is fed into the rotor center. The drying gas may be air or exhaust gases up to 800°C. The sludge is dried both via convection and by the contact with the heat transfer surface in the result of rotation. The driving force of the output is sludge own weight and it exits at the same rate as it entered. Incoming sludge mixed with the recirculated one and transferred to a sieve where fine particles are separated and returned to the feed. The system of the tubular dryer includes a boiler, where the hot drying gases are produced. Fans supply the combustion air. Combustion gases of about 1,100°C are mixed with cooled recirculated combustion gases from the kiln to a temperature of about 400°C before the mixture is fed into the tubes. (SV, 1998)

*Multicoil dryers* consist of a hollow rotor surrounded by a housing. A number of parallel annular tubes are connected to the rotor central tube. Central tube functions as a single container for both the steam condensate for all the connected pipes. Steam of 15 bar and 200 °C is led into one end of the dryer using shovels. The rotation condenses the vapor in the part of the tubes in contact with the sludge. Condensate formed is returned to the boiler the same way as the steam enters through a rotary cup interconnect. Slam intensity and the residence time regulate content on the dry finished product. The temperature of the outgoing slurry is about 100 °C. (SV, 1998)

All the above-described technologies have rather high energy demand (Table 5.2) and require high temperatures, which make it difficult to apply heat as an energy source for the process.
Table 5.2. Various drying technologies energy demand. (Drying sludge from 30% d.s to 90% d.s.)
(Source: SV, 1998)

<table>
<thead>
<tr>
<th>Technique</th>
<th>Energy consumption kWh/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multicoil</td>
<td>908</td>
</tr>
<tr>
<td>Fluidized bed dryer</td>
<td>757</td>
</tr>
<tr>
<td>Drum dryer (Trumtork)</td>
<td>683</td>
</tr>
<tr>
<td>Band dryer</td>
<td>664</td>
</tr>
<tr>
<td>Tubular dryer</td>
<td>646</td>
</tr>
<tr>
<td>Thin film dryer</td>
<td>619</td>
</tr>
<tr>
<td>Step dryer</td>
<td>638</td>
</tr>
<tr>
<td>Drum dryer (Skivtork)</td>
<td>568</td>
</tr>
<tr>
<td>Stream dryer</td>
<td>555</td>
</tr>
</tbody>
</table>

Another technology for sludge drying is Exergy Steam Drying developed in Chalmers University of Technology (Gothenburg, Sweden). The sludge is dried by the superheated steam, which originates from the wet material itself in the result of indirect heating transferred through the tubular heat exchanger from the heat source. The sludge is fed to the circuit and dried in the process of transport through the drying loop, then led to a cyclone for separation. The technology allows to reach up to 99.9% of dry solid. (Exergy E&C, 2009)

5.2.3. Case study analysis

Technology
As the Exergy Steam drying technology seems to be one of the less energy consuming technologies and is quite easy in implementation and operation it was suggested for the case study. In order to organize energy supply the process of sludge drying should be included in the system of district heating (Figure 5.7)
Figure 5.7. Energy supply system for sludge drying.

The data used for the case study analysis is summarized in the Appendix II.

**Material and energy flows**

The potential amount of sludge to be treated at the Waste Treatment facility constitutes 100 000 tons per year. The mechanically treated sludge normally contains 20-30% of dry solid. So, in order to obtain a good product approximately 60% of moisture has to be evaporated. The material and energy flows of the process are represented on Figure 5.8.

![Sludge drying. Material and energy flows.](image)

**CBA**

Utilizing heat as an energy source for sludge drying is much more economically feasible than using electricity (Figure 5.9), which is obvious from the difference of prices: 0.45 SEK/kWh for heat versus 1.02 SEK/kWh for electricity (Fortum, 2010).
Figure 5.9. Comparison of annual energy costs in case of using heat and electricity.

The energy costs for the sludge drying would constitute around 8,100,000 SEK/year. Operational costs would also include human power (which is roughly estimated as 454,000 SEK/year) and maintenance costs that were not included in analysis due to lack of data.

The investment costs consist of district heating pipes construction, which is the same as in case of composting (250,000 SEK) and also the cost of an Exergy Heat Dryer.

In case of considering dried sludge as a valuable additive to furnaces it could be considered as a product and potentially sold at the price of about 50 SEK/ton, which would give an income of 2,000,000 SEK/year in our case.

**Discussion**

Sewage sludge drying is an important step of the sewage sludge utilization, which usually causes problems due to the high energy demand and therefore high operational costs. Application of heat would give an opportunity for the costs reduction in comparison with electricity use for these purposes.

The project doesn’t look very profitable in case of its application from the very beginning because of rather high investment and operational costs. But in case of symbiosis, when the CHP provides heat and the waste treatment facility gives the dried sludge for the furnaces it could still be interesting for both of the sides.

### 5.3. Anaerobic digestion

#### 5.3.1. Process description

Anaerobic digestion – is biological degradation of organic waste without oxygen access in an enclosed, controlled reactor with production of biogas reach with methane and carbon dioxide. (Williams, 2005) The residues from anaerobic digestion can also be used as fertilizer after some treatment. The effectiveness of gas production depends on the composition of organic waste digested. The rate of decomposition depends on the microorganisms and temperature. The standard process of anaerobic digestion is represented on Figure 5.10.
Biogas produced could be utilized as a primary fuel for furnaces in Fortum’s CHP or as a vehicle fuel for the company’s trucks or sold on market.

There are two types of anaerobic digestion: mesophilic and thermophilic. Mesophilic anaerobic digestion requires the digester heating up to 30-35°C and retention time of 15-30 days. Thermophilic digestion requires temperature of 55°C and retention time of 12-14 days. Thermophilic digestion provides higher methane production, but also requires better operation and monitoring, more expensive technologies and has higher energy consumption. Mesophilic process despite of lower methane yields is more reliable and easier in operation and therefore is more common to use. (Gunaseelan, 1997)

The gas produced in the result of anaerobic digestion is not ready for use yet. It contains about 50-60% of methane, while the rest is carbon dioxide and trace elements of hydrogen sulfide. In order to get better methane concentration as well as remove corrosive elements such as hydrogen sulfide the post-treatment of biogas is required. There is a number of methods used for the biogas purification, such water scrubbing, polyethylene glycol scrubbing, membranes technologies, high pressure gas separation, biological desulfurization, activated carbon, etc. The most common method is water scrubbing, which allows removing both carbon dioxide and hydrogen sulfide. (IEA bioenergy, 2010)

Water scrubbing (Figure 5.11) is based on a physical process of absorption, which occurs counter-currently since the gas is fed to the bottom of a packed column, while water comes from the top. The water can be regenerated and recirculated back to the absorption column. The outgoing biogas contains 90% of methane. (IEA bioenergy, 2010)
5.3.2. Overview of previous research

Usually the anaerobic digester is operated using its own produced biogas in order to keep necessary temperature. In the study it was proposed to use return heat from district heating instead, since the necessary temperature is about the same and then extra biogas could be used as trucks’ fuel or sold. It was assumed that finally it would be more beneficial to use return heat rather than biogas to run the digester. But there was no previous research found concerning application of heat for anaerobic digestion.

5.3.3. Case study analysis

Technology

Anaerobic digestion is the technology that is planned to be started by Ragn Sells. Traditionally, the process is self-supportive in terms of energy supply – biogas produced is used to run the digester. As an alternative, the application of heat and return heat was considered in the study.

Since there are two possible temperature regimes (35 °C and 55 °C) the two scenarios of heat supply are available. In case of mesophilic digestion the return heat from district heating could be applied (Figure 5.12a). In case of thermophilic digestion with higher temperature requirements the process could be included into the system of district heating (Figure 5.12b).

Figure 5.11. Biogas upgrading through water scrubbing (Source: IEA bioenergy, 2010)

Figure 5.12a. Return heat application

Figure 5.12b. Heat application.
The data used for the case study analysis is summarized in Appendix III.

**Material and energy flows**

The estimated potential amount of waste that could be treated in an anaerobic digester at Ragn Sells’ site is around 50,000 tons per year (Aid, 2010). Basing on the experience of operating digester the estimated energy demand to run the digester is 70 kWh/ton (Aid, 2010) that results in 3,500 MWh/year for this specific facility in case of utilization of full potential.

The products of anaerobic digestion are biogas and sludge. The biogas yield from anaerobic digestion depends on number of factors such as waste composition, type of digester and temperature regime and therefore varies from 70 m$^3$ to 330 m$^3$ of biogas per ton of waste (Hogg, 2010). Which may result in 3.5 Mm$^3$ up to 16.5 Mm$^3$ of biogas production in this specific case study.

Since the type of digester and exact composition of the waste treated is unknown, the average value for the biogas yield 190 m$^3$/ton was taken for the case study. In this case the potential biogas production was estimated as 9.5 Mm$^3$ per year. The pure biogas yields (after purification) would constitute around 6.65 Mm$^3$ per year. Approximately 38,000 tons of liquid digestate would be obtained in this case annually according to MFA performed in STAN program.

Material and energy flows of the process are represented on Figure 5.13.

![Diagram](image)

**Figure 5.13. Anaerobic digestion. Material and energy flows.**

**CBA**

The cost-benefit analysis of the application should take into account the following costs:

- Capital investment
  - Digester
  - Heating system construction
- Upgrading facility
  - Operation of the digester
    - Energy consumption
    - Human power
  - Income from
    - Biogas sale
    - Compost sale

Capital investment for the district heating pipes construction constitutes 250,000 SEK. Costs of the anaerobic digester could vary from 3,500,000 SEK up to 16,000,000 SEK depending on its type and characteristics (Barker, 2001). Upgrading facility (scrubber) could cost up to 10,000,000 SEK.

Concerning operational costs, energy costs to operate digester (using heat or return heat) is estimated as 1,575,000 SEK/year, while energy costs to run the scrubber (using electricity) would be about 2,624,000 SEK/year.

Benefits from the biogas production could be estimated in two ways: as an income from selling biogas, which would constitute about 58,400,000 SEK/year or as saved costs from buying biogas for trucks in case of using own biogas, which would be about 77,870,000 SEK/year. The benefit of each case in comparison with energy costs is presented on Figure 5.14.

![Costs and Benefits](image)

**Figure 5.14. Costs and Benefits of biogas production**

Apart from economic benefits there are environmental benefits to be considered but not possible to be evaluated in monetary terms.
**Discussion**

Despite high investment costs for the anaerobic digestion application, biogas production seems to be profitable in both cases – selling biogas or using it as fuel for the company’s trucks. The process also has environmental benefits, providing a good way of organic waste utilization and at the same time giving renewable energy to substitute fossil fuels.

Traditionally the process of anaerobic digestion is self-supportive as part of the biogas produced is utilized to run the digester. Why then to consider the use of heat instead of biogas? In the result of the study the operational costs (energy costs) in case of heat application appeared to be lower than those in case of biogas return to the process (Figure 5.15). The cost of biogas was estimated as the lost profit from its sale.

![Cost of using heat instead of biogas](image)

Figure 5.15. Comparison of costs of using heat and biogas to run the anaerobic digester.

The amount of biogas required for the digester operation equals to approximately 360,000 m³, which corresponds to 360,000 liters of petrol.

5.4. Waste oil treatment

5.4.1. Process description

The waste treatment facility deals with the waste oil coming from the car services and petrol station sectors mainly after car washing and servicing. The process of waste oil treatment constitutes heating the waste oil to 70°C in order to separate oil and water into layers. Normally electricity is used for the process. The amount of waste oil to RS in the region is confidential. Here we will use a fictitious number of 26,000 tons for illustrative purposes.’’

5.4.2. Case study analysis

Technology

In order to make the process of waste oil treatment cheaper the heat from CHP could be used instead of electricity or other energy sources. For this the site for waste oil treatment should be included into the system of district heating. (Figure 5.16)
The data used in the case study analysis is summarized in Appendix IV.

**Material and energy flows**
The illustrative amount of waste oil that is coming to the waste treatment facility is 26,000 tons/year. In order to estimate how much energy would be required to heat this amount of waste oil to 70 °C for the layers separation, the simple formula for the energy calculation was applied: \( E = c \cdot m \cdot \Delta T \), where \( c \) – specific heat, \( m \) – mass, \( \Delta T \) – temperature difference. Since this waste oil contains certain amount of water (around 10%), the total energy demand was calculated as a sum of energy required to heat water and energy required to heat oil. It is known that that the waste oil comes to the facility mainly from car washing, but the data about its exact composition was not available. So, the specific heat for the waste oil was taken as a mean value of specific heat of assumed components (2.04 kJ/kg*K). According to the calculations about 976 MWh of heat per year would be required to treat the waste oil coming to the waste treatment facility. Material and energy flow for the process is presented on Figure 5.17.
The cost-benefit analysis for the waste oil treatment with application of heat is rather simple. The investment costs would consist of the district heating pipes’ construction and would be the same as in described above case studies (250,000 SEK). Concerning operational and maintenance costs, the maintenance costs were not taken in to account due to lack of data; additional human power would not be required since the process is not new, just the way of performance will be changed. So the operational costs would consist from the energy costs, which in this case would constitute 439,043 SEK/year.

The only benefit defined could be the lower costs of energy in comparison with use of electricity for this purpose. Figure 5.18 shows that heat application would give a possibility to reduce the energy costs more than twice.

Figure 5.18. Comparison of energy costs in case of heat and electricity application.

Discussion
The case of heat application for the waste oil treatment is not exactly a case of industrial symbiosis, since it does not give any benefits for the energy company. But for the waste treatment facility it is a profitable application, since it will allow reducing the energy costs for the process.

It seems to be not worthy to apply this technology separately, but in case of other cases application it would be a good complement for the system.
5.5. **Concrete upgrading**

5.5.1. Process description and previous research
Research shows that the waste concrete from demolition could be upgraded to almost virgin condition and used again for construction (PCA, 2010). The problem is that the amount of energy required for the material recovery is nearly the same as the amount of energy used to produce new concrete and that makes it economically unfeasible. Here it was supposed in the case study that the problem could be solved with waste heat use that costs much less than conventional energy.

One of the technologies of waste concrete recycling was investigated and tested in the Netherlands by Mulder et al. To obtain good quality material the concrete rubble should be treated in a thermal process represented on Figure 5.19.

![Figure 5.19. Flow scheme of thermal treatment of concrete rubble (Mulder et al, 2007)](image)

The process occurs in several steps (Mulder et al, 2007):

- Concrete rubble comes to a jaw crusher that is aimed to reduce the size of concrete pieces to below 10 cm
- A magnet removes any steel that is present in the rubble
- The mass comes to the rotary kiln, where it is heated and prepared for further release of different components
- Coarse aggregates are extracted in a vibrating screen
- Fine aggregates and cement stone are detached after treatment in air separator.
To obtain good results and get clean fractions the process should be carried out at the minimal temperature of $700^\circ C$. The dehydrated cement rubble is capable of replacing newly produced cement and that saves a considerable amount of energy and raw materials. (Mulder et al, 2007)

5.5.2. Case study analysis

For the technology described above the waste was used as a fuel to heat the kiln. For the case study first it was proposed to use the heat from CHP, but after preliminary analysis it was found out that the current district heat was not enough for such a process, since it requires much higher temperatures. As an option it was decided to consider tapping off the steam and using it directly in the process instead of producing electricity and applying it. It was supposed that such a way of energy use would be more beneficial, due to the better efficiency.

The data used for the case study analysis is summarized in Appendix V.

Material and energy flows

Material flow analysis for the process was based on the Mulder et al research and model and performed with the help of STAN program. (Figure 5.20)

![Material flow diagram](image-url)

Figure 5.20. Material flow (unit – tons, I – incoming flow (Import), E – outgoing flow (Export))

The potential amount of waste concrete for this waste treatment facility is estimated at 70,000 tons/year. The technology implies that all waste concrete goes to the jaw crusher and then through the magnet. According to the Mulder’s research about 1.2% of the material, which is 840
ton in our case, is iron and is removed by a magnet. The rest (about 98.8 %) goes to the sift. The sift removes large aggregates (>10 mm), which constitutes around 34.6% of the initial material. The rest goes to the rotary kiln, where the waste concrete is dried and then sent to the vibrating screen. About 4.4% of the weight is lost after drying due to water evaporation. Vibrating screen allows separating the coarse aggregates, which constitute almost 31% of the total mass. After that the rest of the materials go to the air separator, which separates fine aggregates and cement stone which constitute 21.5 % and 9 % of the initial mass correspondingly.

A rotary kiln is equipped with a heater and an exhaust filter. This is the key element of the case study, where steam an energy source for the concrete drying should be applied. But for the material flow analysis the case of the original research was taken, since it gave a possibility to calculate the mass flows of the fuel and exhaust. The secondary fuel mentioned in the material flow scheme is the amount of waste used as an energy source in the original research.

In the result of concrete upgrading several types of the good quality products are obtained and could be used as substitutes to the corresponding raw materials. The types of materials and their amount obtained in this specific case study are represented on Figure 5.21.

The amount of energy required to perform concrete upgrading was calculated based on the original research and constitutes about 21.3 GWh/year for the given amount of waste concrete. The summary of the material and energy flows of the case study is represented on Figure 5.21.

![Figure 5.21. Material and energy flows for the concrete upgrading.](image)

**CBA**

Cost-benefit analysis for the case study should include the following costs and benefits:

- Investment costs
  - Tap off system construction
- Steam transportation pipes construction
- System of concrete upgrading

- Operational costs:
  - Energy costs (heat)
  - Energy costs (electricity for other equipment)
  - Human power

- Economic benefits
  - Sales of the materials

- Environmental benefits in comparison with new cement production
  - Saving of raw materials
  - CO₂ emissions saving
  - Saving energy

It was not possible to estimate the investment costs due to the lack of data, because the system is not implemented yet and the costs of its construction and maintenance are unknown.

Energy costs to upgrade 70,000 tons of waste concrete per year would constitute 13,841,360 SEK/year. While human power costs would be 907,000 SEK/year in case if one worker is required for the process operation.

Economic benefit of the process consists from the sales of the materials obtained. The rough prices for the materials are summarized in the table 5.3.

<table>
<thead>
<tr>
<th>Material</th>
<th>Price, SEK/ton</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement stone</td>
<td>1,000</td>
<td>Jehander, 2009</td>
</tr>
<tr>
<td>Large aggregates</td>
<td>100</td>
<td>Miliutenko, 2009</td>
</tr>
<tr>
<td>Gravel</td>
<td>50</td>
<td>Miliutenko, 2009</td>
</tr>
<tr>
<td>Sand</td>
<td>50</td>
<td>Miliutenko, 2009</td>
</tr>
<tr>
<td>Steel</td>
<td>6,000</td>
<td>MEPS, 2010</td>
</tr>
</tbody>
</table>

The total sales price of the materials recycled from concrete upgrading could constitute up to 15,000,000 SEK/year. The correspondence between operational costs and sales profit is represented on Figure 5.22.
In the result of concrete upgrading many valuable materials are obtained, such as cement stone, gravel, large aggregates and steel. It gives an opportunity to save the raw materials or those for the production of cement or steel. Moreover, materials recycling will give an opportunity to avoid or reduce the environmental problems caused by the raw materials’ extraction.

In the result of concrete upgrading about 6,500 tons of cement stone is obtained. In order to understand the value of this recycling one should consider the production of the same amount of new cement. The amount of energy required for the cement production in average equals 1,300 kWh/ton (Sripple, 2001), which results in 8.5 GWh required for the production of 6,500 tons of cement. Carbon dioxide emissions from the cement production constitute about 0.9 tons/ton (Mahasenan, 2002), which results in about 5,800 tons in case of production of 6,500 tons of cement.

**Discussion**

The process of concrete upgrading requires big investment into the technology development as well as upgrading system construction, but it gives an opportunity to get benefits from sales of the raw materials, which are rather high. At the same time it has high environmental benefits providing the possibility to save energy, to reduce CO₂ emissions from the substituted cement industry, to save raw materials as well as to reduce the environmental damage from the raw materials extraction.

The project might not look extremely beneficial from the economic point of view, but it is definitely winning from the environmental prospective. In case of technology development or discovering the new ways of application the project could be worth implementation.

**VI. Discussion**

The proposed industrial symbiosis might conflict a little bit with the original idea of symbiosis, where it is based on the raw materials and/or waste exchange between the companies with the mutual benefit. But at the same time this scenario provides benefits for the both of sides, so can be considered as symbiosis.
The benefits for the waste treatment facility (Ragn Sells) would be as follows:

- Cheaper energy due to lower prices for heat in comparison with electricity
- Better efficiency due to possibility for improvements
- Performance improvement

On the other hand benefits for the CHP and Fortum in general are:

- Heat market expansion due to new “customers”
- Better efficiency due to the elimination of necessity to reduce the productivity in summer time and also due to the double use of heat
- Green image

The industrial symbiosis between CHP and waste treatment facility seems to have many various possibilities and options due to their close location. The scenarios could include implementation of all the process, so the scheme of the symbiosis would look like is presented on Figure 6.1.
In case of such a scenario some of the process could be connected between each other in order to optimize the system. It will allow using the return heat from the internal processes, which seems to be more efficient. Also it will reduce the general length of the district heating pipes to construct, which in turn reduces the capital costs.

In case of implementation of only one or few of the technologies it would be useful to compare the worthiness of the proposed possibilities. For this purpose the technologies were evaluated on scale from 1 to 5 (1 – the best, 5 – the worst) in comparison with each other for three parameters: ease of implementation, economic feasibility and environmental profitability. (Table 6.1.)

Table 6.1. Relative evaluation of industrial symbiosis possibilities.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Ease of Implementation</th>
<th>Economic feasibility</th>
<th>Environmental profitability</th>
<th>Total (Non Weighted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composting</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Anaerobic digestion</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Sludge drying</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Waste oil treatment</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Concrete upgrading</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>11</td>
</tr>
</tbody>
</table>

The composting and waste oil treatment were considered to be the easiest in implementation, since those processes do not require expensive equipment or extra human power. They are followed by anaerobic digestion and sludge drying, which would be new processes requiring new human sources, planning, management and equipment. Concrete upgrading is the most complicated in implementation due to new technology and equipment and more research necessary in the area.

Economic feasibility was estimated approximately according to the investment and operational costs and probable profit. Anaerobic digestion was considered to be the leader in this category, because of the better future prospective and higher profit potential.

Concrete upgrading has the highest environmental benefits, since concrete recycling would result in energy savings for cement production, reduction of carbon dioxide emissions from cement production, resources savings and reduction of the environmental effects from the raw materials’ extraction. Anaerobic digestion comes next due to its potential for renewable energy production (to replace fossil fuels). Composting and sludge drying were estimated with moderate points because those processes result in the reduction of the air emissions. Waste oil treatment got the lowest score in this category because the application of heat in this case does not make large changes for the environment.

In the result of such evaluation composting and anaerobic digestions seems to be the most attractive possibilities for industrial symbiosis due to the easy implementation of the former and high economic and environmental potential of the latter. However, it is of course up to the companies on how they “weight” the different categories when making implementation or further research decisions.
Since the aim of the study was just to make an analysis of opportunities for the industrial symbiosis, all possible combinations of the options were not analyzed and described. Therefore, there is a wide field for the future research and investigation of the scenarios, such as:

- Using waste heat from concrete upgrading for all the other processes
- Using waste heat from oil heating for the other processes
- Digesting sludge in the anaerobic digestion and then drying it

All those options require further analysis and comparison of their costs and benefits.

This study has many uncertainties due to the lack of data and time. The work done is to be taken as a “screening analysis” of what could be investigated further, rather than a ready source for the future reference in case of industrial symbiosis creation. Due to the fact that the field of investigation was very wide, it was not possible to go deep into details of each process, and therefore the study has much rough data and assumptions.

Moreover, the economic section of the analysis was challenging, given that it was not always possible to find the prices for certain equipment and it was impossible to get the prices for some services, such as for example the prices for return heat or dried sludge. Return heat has never been sold before, so it does not have a market price. This is approximately the same situation with dried sludge. Incineration plants used to get paid for the sludge utilization, but not to consider sludge as a product. But in case of using dried sludge as an additive for the furnaces in order to reduce corrosion the dried sludge would be bought from the waste treatment facility for the CHP. So, in case of the intention of the companies to make such kind of symbiosis all the prices (for heat, return heat and sludge) should be discussed and then the proper cost-benefit analysis made.

The study also did not consider the side products from the processes such as for example compost from anaerobic digestion, which could be also a part of the economic benefit.

**VII. Conclusions**

In the result of the study various possibilities for the industrial symbiosis between CHP and waste treatment facility were defined and analyzed. After the preliminary investigation, presentation and discussed with the stakeholders, the following technologies for the industrial symbiosis were considered to be interesting:

- Composting speed-up
- Anaerobic digestion
- Waste oil treatment
- Sludge drying
- Concrete upgrading

In the result of the performed investigation in form of literature review, material and energy flow analysis and rough cost-benefit analysis it was concluded that in general technologies look economically feasible and beneficial for both sides.
Some of the process, such as composting or waste oil treatment seem to be very easy to implement and could be considered as small-scale projects. Others, such as anaerobic digestion and sludge drying require more investment. Concrete upgrading stands apart from the other processes since the technology is not perfect for the immediate implementation and requires large investments as well and looks to be a big project with higher risks in case of application.

The current study has a screening character and gives a general picture of the possible scenarios of industrial symbiosis with their economic and environmental effects. In case of the companies’ interest in implementation - further research of the following issues is necessary:

- Deeper analysis of energy required for the support of waste treatment processes and energy available at the CHP
- Precise cost-benefit analysis on each technology, taking into account all investment, operational and maintenance costs
- Design of optimum network of heat distribution in order to minimize the costs of the network construction as well as avoid losses because of heat transportation
- Prices for heat, steam and sludge should be revised and discussed between the companies.
References


Miliutenko S. (2009) Aggregate provision and sustainability issues in selected European cities around the Baltic Sea, Degree Project SoM EX 2009-26, KTH, Department of Urban Planning and Environment


Stockholm Vatten (1998) Utredning angående slamtorkning vid Stockholm Vatten, Vai Va – PROJEKT AB.


## Appendix I. Composting spread sheet

<table>
<thead>
<tr>
<th>Composting</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer process duration</td>
<td>12 weeks</td>
</tr>
<tr>
<td>Winter process duration</td>
<td>14 weeks</td>
</tr>
<tr>
<td>Cost of utilization</td>
<td>885 SEK/ton</td>
</tr>
<tr>
<td>Annual amount composted (2009)</td>
<td>9,525 ton</td>
</tr>
<tr>
<td>Annual potential of waste to be composted</td>
<td>30,000 ton</td>
</tr>
<tr>
<td>Volume composted at once (capacity of 2009)</td>
<td>2,177 ton</td>
</tr>
<tr>
<td>Volume of 1 AG bag (capacity of 2009)</td>
<td>145 ton</td>
</tr>
<tr>
<td>Volume composted at once (full capacity)</td>
<td>6,855 ton</td>
</tr>
<tr>
<td>Volume of 1 AG bag (full capacity)</td>
<td>457 ton</td>
</tr>
<tr>
<td>Number of AG bags</td>
<td>15</td>
</tr>
<tr>
<td>Winter time</td>
<td>28 weeks</td>
</tr>
<tr>
<td>Energy demand</td>
<td>35 kWh/ton</td>
</tr>
<tr>
<td>Amount composted during winter time (capacity 2009)</td>
<td>4,354 ton</td>
</tr>
<tr>
<td>Amount composted during winter time+heat (capacity 2009)</td>
<td>5,080 ton</td>
</tr>
<tr>
<td>Difference b/w amounts composted (capacity 2009)</td>
<td>726 ton</td>
</tr>
<tr>
<td>Amount composted during winter time (full capacity)</td>
<td>13,710 ton</td>
</tr>
<tr>
<td>Amount composted during winter time+heat (full capacity)</td>
<td>15,995 ton</td>
</tr>
<tr>
<td>Difference b/w amounts composted (full capacity)</td>
<td>2,285 ton</td>
</tr>
<tr>
<td>Annual energy demand (capacity 2009)</td>
<td>178,000 kWh/year</td>
</tr>
<tr>
<td>Annual energy demand (full capacity)</td>
<td>560,000 kWh/year</td>
</tr>
<tr>
<td>GHG emissions from storage</td>
<td>1.29 ton CO₂-eq/ton</td>
</tr>
<tr>
<td>Avoided methane emissions (capacity 2009)</td>
<td>936 ton CO₂-eq</td>
</tr>
<tr>
<td>Avoided methane emissions (full capacity)</td>
<td>2,950 ton CO₂-eq</td>
</tr>
<tr>
<td>Benefit obtained from speeding-up (capacity 2009)</td>
<td>642,257 SEK</td>
</tr>
<tr>
<td>Benefit obtained from speeding-up (capacity 2009)</td>
<td>642,257 SEK</td>
</tr>
<tr>
<td>Length of district heating pipes</td>
<td>100 m</td>
</tr>
<tr>
<td>Cost of DH pipes construction</td>
<td>2,500 SEK/meter</td>
</tr>
<tr>
<td>Investment costs</td>
<td>250,000 SEK</td>
</tr>
<tr>
<td>Heat price</td>
<td>0.45 SEK/kWh</td>
</tr>
<tr>
<td>Energy costs (capacity 2009)</td>
<td>80,000 SEK/year</td>
</tr>
<tr>
<td>Energy costs (full capacity)</td>
<td>252,000 SEK/year</td>
</tr>
</tbody>
</table>
## Appendix II. Sludge drying spread sheet

<table>
<thead>
<tr>
<th>Sludge drying</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual amount sludge</td>
<td>100,000 ton/year</td>
</tr>
<tr>
<td>Temperature requirements</td>
<td>100 °C</td>
</tr>
<tr>
<td>Energy demand</td>
<td>300 kWh/ton of evaporated water</td>
</tr>
<tr>
<td>Annual energy demand</td>
<td>18,000,000 kWh/year</td>
</tr>
<tr>
<td>Heat price</td>
<td>0.45 SEK/kWh</td>
</tr>
<tr>
<td>Annual energy cost (heat)</td>
<td>8,100,000 SEK/year</td>
</tr>
<tr>
<td>Electricity price</td>
<td>1.02 SEK/kWh</td>
</tr>
<tr>
<td>Annual energy cost (electricity)</td>
<td>18,338,400 SEK/year</td>
</tr>
<tr>
<td>Price for dried sludge</td>
<td>50 SEK/ton</td>
</tr>
<tr>
<td>Human power required</td>
<td>0.5</td>
</tr>
<tr>
<td>Cost of DH pipes construction</td>
<td>2,500 SEK/meter</td>
</tr>
<tr>
<td>Investment costs</td>
<td>250,000 SEK</td>
</tr>
<tr>
<td>Human power cost</td>
<td>453,600 SEK/year</td>
</tr>
</tbody>
</table>
## Appendix III. Anaerobic digestion spread sheet

<table>
<thead>
<tr>
<th>Anaerobic digestion</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual amount of waste</td>
<td>50,000 ton/year</td>
</tr>
<tr>
<td>Energy demand</td>
<td>70 kWh/ton</td>
</tr>
<tr>
<td>Annual energy demand</td>
<td>3,500,000 kWh/year</td>
</tr>
<tr>
<td>Annual biogas yield</td>
<td>9,500,000 m³/year</td>
</tr>
<tr>
<td>Biogas yield after upgrading</td>
<td>6,650,000 m³</td>
</tr>
<tr>
<td>Biogas price</td>
<td>8.78 SEK/m³</td>
</tr>
<tr>
<td>Biogas price with tax</td>
<td>11.71 SEK/m³</td>
</tr>
<tr>
<td>Biogas sales</td>
<td>58,400,000 SEK/year</td>
</tr>
<tr>
<td>Savings (biogas use in own trucks)</td>
<td>77,870,000 SEK/year</td>
</tr>
<tr>
<td>Heat price</td>
<td>0.45 SEK/kWh</td>
</tr>
<tr>
<td>Annual energy cost (heat)</td>
<td>1,575,000 SEK/year</td>
</tr>
<tr>
<td>Annual energy cost (biogas)=lost of sales</td>
<td>3,178,775 SEK/year</td>
</tr>
<tr>
<td>Biogas energy content</td>
<td>9.67 kWh/m³</td>
</tr>
<tr>
<td>Annual energy demand (biogas)</td>
<td>361,944 m³</td>
</tr>
<tr>
<td>Biogas equivalent to petrol</td>
<td>1</td>
</tr>
<tr>
<td>Cost of DH pipes construction</td>
<td>2,500 SEK/meter</td>
</tr>
<tr>
<td>Investment costs</td>
<td>250,000 SEK</td>
</tr>
<tr>
<td>Density of biogas (50%)</td>
<td>1.23 kg/m³</td>
</tr>
</tbody>
</table>
## Appendix IV. Waste oil treatment spread sheet

<table>
<thead>
<tr>
<th>Waste oil treatment</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual waste amount</td>
<td>26,000 ton/year</td>
</tr>
<tr>
<td>Initial temperature</td>
<td>10 °C</td>
</tr>
<tr>
<td>Final temperature</td>
<td>70 °C</td>
</tr>
<tr>
<td>Energy cost (heat)</td>
<td>439,043 SEK/year</td>
</tr>
<tr>
<td>Energy cost (electricity)</td>
<td>995,163 SEK/year</td>
</tr>
<tr>
<td>Heat price</td>
<td>0.45 SEK/kWh</td>
</tr>
<tr>
<td>Electricity price</td>
<td>1.02 SEK/kWh</td>
</tr>
<tr>
<td>Oil products specific heat (mean)</td>
<td>2.04 kJ/kg*K</td>
</tr>
<tr>
<td>Specific heat of water</td>
<td>4.20 kJ/kg*K</td>
</tr>
<tr>
<td>Energy demand to heat waste oil</td>
<td>975,650 kWh/year</td>
</tr>
<tr>
<td>Cost of DH pipes construction</td>
<td>2,500 SEK/meter</td>
</tr>
<tr>
<td>Investment costs</td>
<td>250,000 SEK</td>
</tr>
</tbody>
</table>

1 Illustrative Number
Appendix V. Concrete upgrading spread sheet

<table>
<thead>
<tr>
<th>Concrete upgrading</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of waste</td>
<td>70,000 ton/year</td>
</tr>
<tr>
<td>Energy demand</td>
<td>304 kWh/ton</td>
</tr>
<tr>
<td>Annual energy demand</td>
<td>21,294,400 kWh/ton</td>
</tr>
<tr>
<td>Product output</td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>840 ton/year</td>
</tr>
<tr>
<td>Gravel</td>
<td>21,448 ton/year</td>
</tr>
<tr>
<td>Cement stone</td>
<td>6,446 ton/year</td>
</tr>
<tr>
<td>Large aggregates (&gt;10mm)</td>
<td>24,206 ton/year</td>
</tr>
<tr>
<td>Sand</td>
<td>15,042 ton/year</td>
</tr>
<tr>
<td>Product prices</td>
<td></td>
</tr>
<tr>
<td>Large aggregates</td>
<td>100 SEK/ton</td>
</tr>
<tr>
<td>Cement stone</td>
<td>1,054 SEK/ton</td>
</tr>
<tr>
<td>Gravel</td>
<td>50 SEK/ton</td>
</tr>
<tr>
<td>Sand</td>
<td>50 SEK/ton</td>
</tr>
<tr>
<td>Concrete</td>
<td>1,125 SEK/ton</td>
</tr>
<tr>
<td>Steel</td>
<td>6,000 SEK/ton</td>
</tr>
<tr>
<td>Product sales</td>
<td></td>
</tr>
<tr>
<td>Large aggregates</td>
<td>2,178,540 SEK</td>
</tr>
<tr>
<td>Gravel</td>
<td>965,160 SEK</td>
</tr>
<tr>
<td>Sand</td>
<td>676,890 SEK</td>
</tr>
<tr>
<td>Cement stone</td>
<td>6,794,084 SEK</td>
</tr>
<tr>
<td>Steel</td>
<td>4,319,000 SEK</td>
</tr>
<tr>
<td>TOTAL sales</td>
<td>10,614,674 SEK</td>
</tr>
<tr>
<td>CO₂ emissions for cement production</td>
<td>0.9 ton/ton of cement</td>
</tr>
<tr>
<td>Energy saved</td>
<td>8,057,500 kWh/year</td>
</tr>
<tr>
<td>CO₂ saved</td>
<td>5,801 ton/year</td>
</tr>
<tr>
<td>Concrete utilization cost</td>
<td>600 SEK/ton</td>
</tr>
<tr>
<td>Energy consumption for cement prod</td>
<td>4.78 GJ/ton</td>
</tr>
</tbody>
</table>