Industrial Symbiosis in Enköping

This report is the result of a field study conducted within the course Industrial Symbiosis, TKMJ38, at Linköping University.

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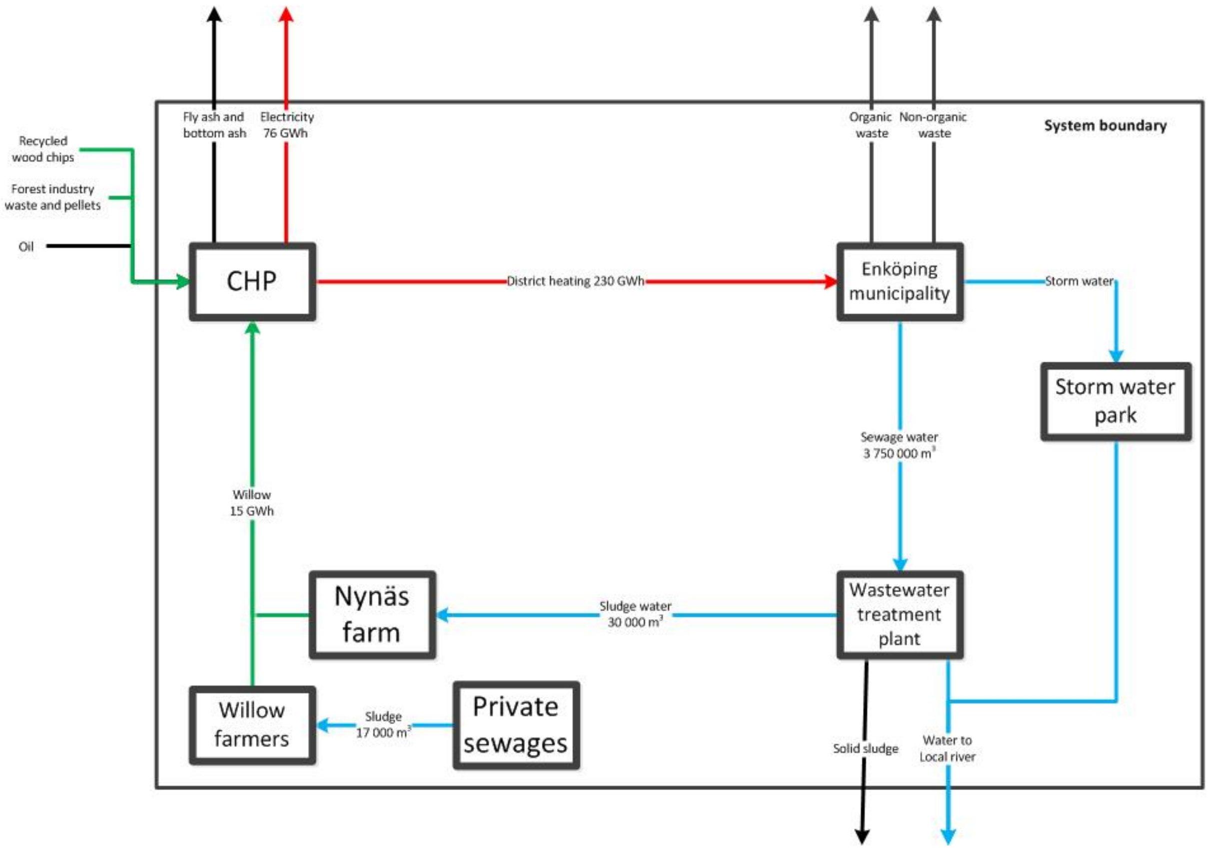
Overview

The city of Enköping is located in close proximity to Sweden's third largest lake, Mälaren. Enköping is described as "Sweden's Closest City" since more than 38 cities are located within a radius of 120 kilometers. This area houses a third of the total Swedish population. The slogan has been used since 1965 and is well known throughout Sweden. There are approximately 24 000 citizens living in Enköping and apart from Mälaren the city is mostly surrounded by open areas and farmland.

The industrial symbiosis in Enköping



Picture 1 - Flowchart of the symbiotic system in Enköping. The colors are representing different material types. Blue = Water, Green = Biobased fuels, Red = Energy and Black = Solids. The fly and bottom ash is landfilled, and the non-organic waste is incinerated in Västerås. Organic waste is sent to Uppsala for production of biogas.

The chart above describes the symbiotic system in Enköping. The wastewater produced in the city is transported to the wastewater treatment plant. There, sludge water is separated and is directed to pools located adjacent to the plant and the nearby willow (salix) farms. This sludge water is then used to irrigate the fields during the growth season. In addition, sludge from private sewages is collected in pools adjacent to four different farms, which use the sludge in the same fashion. The willow is then harvested and used as fuel in the CHP plant. The CHP plant provides the city with district heating and electricity.

How did the symbiosis come about?

The idea behind the collaboration took form in a conference room at the office of the local waste water treatment facility. A local farmer, who owned land in connection with Enköping, had a vision of bringing his operation closer to the city. The waste water treatment facility faced a 30 - 35 MSEK investment in denitrification equipment, due to problems with fulfilling the requirements of maximum nitrogen content in their treated water.

When looking at an aerial photo hanging on the wall of the conference room, picturing the waste water facility and its surroundings, the representatives of the three actors saw the potential in taking advantage of the geographical proximity. The photo showed that the CHP plant was located just north of the waste water facility and the farmland south of it.

If the farmer would start to grow some sort of primary wood energy source, the waste water facility could spread its nitrogen rich sludge water over the fields to increase the growth capacity. The primary wood fuel would then be incinerated in the CHP plant to produce biomass based electricity and heat.

By implementing this arrangement, the waste water facility avoided the otherwise needed equipment investment. The farmer got the opportunity to grow a crop with low demand for attendance and have it fertilized ecologically free of charge. The farmer also received a steady income from selling it directly to the CHP plant. Furthermore, the CHP plant was able to further diversify its production mix and strengthen its relations to the surrounding area.

Key Actors and Exchanges

The symbiosis in Enköping primarily consists of three key actors.

ENA Energi

ENA Energi, that runs the local power plant in Enköping, is a company owned by the municipality. The power plant supplies electricity to the main grid as well as district heating to most of the residents and companies within the Enköping municipality. The main boiler of the plant has a capacity of 55 MW of heat and 24 MW of electricity, using mainly wood resources as fuel. The largest contribution comes from recycled wood chips (RT-flis) but forest industry wastes and pellets are often used as well. Some willow is also used as energy input, and during the colder season EO1 is used as a top load fuel. In 2010 the plant had an output of about 230 GWh of district heat and 76 GWh of electricity. Apart from the willow the other fuels are considered to be crossing the system boundary and are therefore not further discussed in this text.

ENA Energi is involved in the symbiotic network within Enköping as the main contributor of heat to the district heating system and as end-user of the willow produced at the farms. They have also started to receive raw biogas, which they incinerate, from a nearby recently covered landfill site. The size of this flow is not established since it's just starting up. Currently, the ash from the boilers ends up in dumpsites in Västerås and Sala. It used to be mixed with the sludge and utilized as fertilizer by the willow farmers.

Wastewater Treatment Plant

The Enköping municipality supplies the wastewater treatment plant (WWTP) with 3 750 000 m3 (2012) of wastewater every year. After the water has been treated it is released to the Enköping River. The sludge water is separated from its solids and then put through anaerobic digestion, creating flammable methane gas. The gas was previously transported to the CHP plant but is currently flamed on site. The reason for this is unclear but ENA Energi claims it's due to technical difficulties in the WWTP. The remaining sludge water, which is rich of nutrition and is fluid enough to be distributed through hoses, is used to water the local willow fields. The remaining solid sludge used to be sold to other willow farmers in the region, but nowadays it is deposited nearby the WWTP without usage because of too high concentrations of zink.

The Willow Farmers

There are five different plantations that are a part of the industrial symbiosis network. The plantations receive sludge as fertilizer that would otherwise be handled by the WWTP. One plantation is a bit different from the others, Nynäs Gård, as water is sent directly from the WWTP whereas the other plantations receive sludge from private septic tanks and does not take the rout via the WWTP. The sludge is hygienized in ponds for one year and, when ready, used for fertilizing the willow fields. The fertilizing sludge makes the willow to grow faster which allows it to be harvested sooner. This makes it possible to harvest the willow every third year instead of every fourth. The sludgewater used at Nynäs Gård has less concentration of solids than the sludge used on the others farms.

Other relevant actors
Other main actors include the city of Enköping and the local water park run by the municipality. The storm water that is collected in the city of Enköping used to be led through pipes and Krokängsdiket to Enköpingsån from which it was sent directly into Mälaren. This was done without any treatment of the water. Pollutions such as heavy metals, phosphorous and nitrogen were therefore transferred to Mälaren where it caused problems for the ecosystem as well as eutrofication. To decrease the negative effects on Mälaren the municipality of Enköping created a natural treatment system for storm water. The treatment system consists of a canal across a field with depths varying between 0.2- 1.5 meters. Different processes occur naturally in the different sections of the canal and the circulation time for one drop of water is between 5-10 days. The canal has created a beautiful area that is suitable for recreational purposes and has a diverse bird population. The symbiotic exchange between the municipality and the water park might not be an example of classic industrial symbiosis. It can be argued the local community benefits from this, since the park provides a recreational area as well as a diverse habitat for animals. Furthermore, the authors still find it a great example of an environmental initiative that ought to be highlighted.

Environmental Benefits

Phosphor recovery
Phosphorus is a limited resource but every year large amounts leak out into the water system and are lost for future utilization. The leakage also causes big environmental impacts such as eutrophication and eco-system damage. By using sewage water as fertilizer more than 1 ton of phosphorus is recovered back into the cultivated system, which reduces the amount artificial fertilizer needed.

Absorption of Cadmium
Cadmium is one of the most hazardous heavy metals and the guideline values are strongly regulated. The special kind of willow crops used at the plantations absorbs cadmium well and therefore purifies the soil. This can lead to that contaminated land, after a longer time of growing willow, might be suitable for growing eatable crop.

Nitrogen
Nitrogen is an element with a high nutritional value, and like phosphorus it can cause eutrophication. The burning of willow in the CHP plant means that the cycle of nitrogen within the municipality is partially closed. Using the sewage water as irrigation on the nearby willow crops has reduced the sewage treatment plant's emissions of nitrogen by 30 tons a year, which is 25 % of their yearly emissions. The nitrogen is then bound to the willow and can be obtained in the CHP purification process. After the purification process the nitrogen ends up in the bottom ash, which in turn is securely deposited in Västerås and Sala. This ash cannot be utilized as fertilizer because of the high concentration of heavy metals. The concentration has risen due to the CHP plant's increased amount of recycled wood chips in its fuel mix.

Emissions of carbon dioxide

The willow burned in the CHP is locally replacing other bio mass fuels. This means that from a local point of view the gains in terms of reduced carbon dioxide emissions are not significant. In a broader system view however, the willow added to the system will increase the total amount of biomass within the production mix, assuming that the symbiosis is driving the willow production itself. In this perspective the willow is replacing fossil fuels somewhere in the system leading to reductions of carbon dioxide emissions.

Economic benefits

The annual production of 500 tonnes sewage sludge (dry content) has a potential to generate a significant income for the WWTP. This has a two-stage benefit, firstly the WWTP avoids costs related to landfilling and secondly it generates income from sales. Previously, the sludge was primarily bought and used as a fertilizer by other willow farmers in. Due to the symbiosis, the wastewater treatment plant was able to postpone an investment of 30-35 MSEK intended for the extension of the plant capacity. The alternative investment also averted a projected increase in operational costs. What they did instead was to construct three ponds and invest in equipment for the spreading of sludge water on the willow farms as well as diverting wastewater from private sewages to local farmers. This, in comparison, led to a total investment cost of 15 MSEK. In addition, the costs related to transportation of sewage sludge from private sewages could be cut down because of the redirection to the regional farms.

Growing willow is often as profitable as growing grains if not more. The largest cost of growing willow is to set the willow plant but in Sweden there are programs that offer financial aid for up to half of the investment cost. Another aspect which makes willow profitable is the fact that each farmer does not need his or her own harvest machinery. Instead there are organisations where farmers own the machinery together, which could be considered a form of symbiosis, as well as companies that buy the willow unharvested.

In relation to ENA Energi, the size of the economic benefits depends on what assumptions that are made regarding which type of fuel the willow is replacing. However, assuming that the willow burnt in the CHP plant is offsetting pellets, ENA Energi reduces its cost for fuels by 2,5 MSEK/year.

Key drivers

The main driver from the WWTPs point of view was the stricter regulations regarding nitrogen emissions to the Baltic Sea that was issued by the EU[1] in 1991 and implemented in Swedish law[2] in 1994. The estimated cost for complying with regulations solely by implementing additional nitrogen extraction was deemed too high. The WWTP therefore went about examining the flow of nitrogen in the municipality. They found that large quantities of nitrogen emerged from wastewater coming from private sewages. These quantities, transported by tanker from the more rural areas of the municipality, also contributed to more intermittent operational conditions in the WWTP. This intermittency lowered the plant efficiency, contributed to a rise in operational costs and added extra transportation.

Another driver might have been the open communication and relaxed discussion-climate that the actors had during the process. Another driver is related to the fact that both the WWTP and ENA

[1] The Urban Waste Water Treatment Directive (91/271/EEC) of 21 May 1991
[2] Naturvårdsverkets föreskrift SNFS 1994:7 med ändring 1998:7

Energi are owned by the municipality. This means that they both share the same environmental visions and organizational goals.

Key challenges

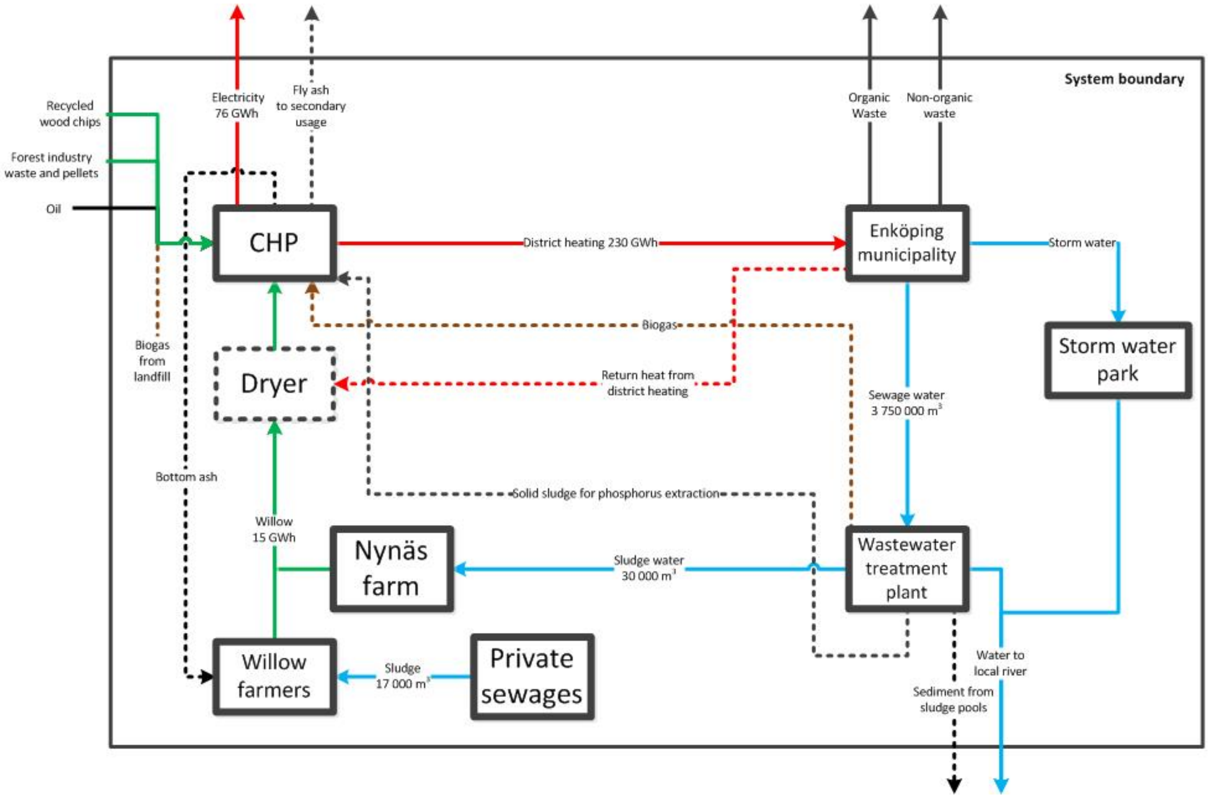
One main challenge in the cooperation with the farmer at Nynäs Gård was the question of how to divide investment and operational costs. Through a high level of responsiveness from both parts, an agreement was made that satisfied both parties. This agreement stated that the WWTP was to bear the chunk of the investment costs while the farmer would give up some of his land for the sludge water dams and to manage the operation of the irrigation system. They also signed a contract, spanning over 15 years, ensuring that the farmer was obliged to receive the sludge water and ENA Energi had to purchase the willow, thus removing many uncertainties for the actors regarding this matter. The farmer owns the land and the municipality has the economic capability.

As the symbiosis currently stands, with ENA Energi purchasing the willow from the farmers as input to the boilers, there isn't much economic or environmental gain for ENA Energi themselves – most of the benefits arise when viewing the symbiosis as a broader system. The willow is a more expensive fuel than the recycled wood chips, and come with many operational difficulties, such as increased soot, acidification in the boilers, and increased ash yields. Indeed, this is and has been a challenge for the symbiosis. If ENA Energi can be more beneficially included in the exchanges, they might be more inclined to evolve and expand the symbiosis. For instance, if they can resume the exchange of biogas with the WWTP, or if they can manage to use their ashes on the willow fields, ENA Energi might see the potential of the symbiosis more clearly. Over the years, ENA Energi has decreased its input of willow in favor of the cheaper RT-flis, which has an overall negative effect on the symbiosis. This can partly be explained by change of corporate management, since the executives involved in the initial planning no longer remains in the company.

Another challenge that the actors had to face was the risk of generating bad press from discontent citizens in the process of spreading sludge water on farmlands. This was thwarted by being transparent towards the public, emphasizing the environmental benefits of the project and avoiding watering the area closest to the municipality with sludge water.

Future improvements of the system

Even though the current system is beneficial for both the environment and for the actors economically, there is always room for improvement. Below are some ideas for how the symbiosis could be expanded by further leveraging the waste products generated within the system.



Picture 2 - Flowchart of the symbiotic system in Enköping with future improvements depicted with dashed lines and rectangles. The colors are representing different material types.
Blue = Water, Green = Biobased fuels, Red = Heat and electricity, Black = Solids and Brown = Gases

Deliveries of biogas to the CHP

Currently, the WWTP aren't delivering their biogas to ENA Energi. The reason stated for this is that there are difficulties with the equipment. However, the WWTP is planning to expand their biogas production, by increasing their fermentation capabilities. If this expansion is realised, the biogas deliveries to ENA Energi will most likely resume.

Utilization of fly ash

There are many secondary uses for fly ashes, for instance it can be used as a filler in construction sites, as road subbases, as a mineral filler in asphalt, and as the matrix within conglomerate construction materials. This would be of interest to ENA Energi, as they are currently paying 800 SEK/ton to have the ashes disposed of in landfills.

Bottom ash

The bottom ash was originally intended to be used as a fertiliser, by mixing it into the fermented dewatered sludge. Due to pollutants in the ashes, this hasn't been realised. However, if the problem with the pollutants could be resolved, perhaps by altering the fuel mix, they could start utilizing the high levels of nutrients in the ashes once again.

Pre-heating of Willow

As it currently stands the willow which is burned in the CHP plant has a much higher water content than many of the other fuels that enters the boilers, which reduces the efficiency of the plant when burning willow. By drying the willow before burning, the efficiency of the plant could be increased slightly. Furthermore, if the drying is done by using the low-grade heat of the district heating return water, the efficiency of the whole CHP cycle could be increased from two directions.

Extraction of phosphorus

ENA Energi is currently investigating the possibility to burn the leftover waste sludge and retrieve the phosphorus from the ashes. This would be a good way to benefit from the phosphorus in the sludge that has too high Zink content to be distributed on the willow fields. The technology to retrieve the phosphorus from the ashes might also make it possible to reduce the amount of bottom ashes that gets sent to the landfill.

Improved extraction of biogas

Today the CHP plant receives some raw biogas from a nearby landfill, this could be extended to include all of the methane that is produced there and the extraction could also be monitored more closely. This would reduce methane emissions from the landfill and reduce the amount of recycled wood chips to be used in the CHP plant.

Utilization of sediment in sludge pools

The amount of sediment in the bottom of the sludge pools is increasing every year. This sediment has high potential since it should have high nutrition content. But it needs to be tested for heavy metals to make it clear if it's an economical feasible solution which is allowed to be used as fertilizer.