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Energy optimization, Sobacken biogas plant

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Abstract

Energy optimization, Sobacken biogas plant

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In order to make the biogas plant at Sobacken located 8 km west of Borås more profitable you must become aware of flows at the plant. This not only concerning the incoming waste to the plant but also the use of energy. Since the rebuilding in 2005 of the plant there has been no follow up concerning the energy use. This thesis is meant to clarify the use of electricity and heat at the plant. The work determining the use of energy at Sobacken biogas plant has been done by collecting data from documentation from the builder Läckeby Water but also by obtaining information from the computer systems and frequency converters. The results of the study and its calculations shows that the plant uses approximately 3,2 GWh of electricity per year and 3,1 GWh of biogas, produced at the plant for heating per year. The production of biogas is corresponding to 17,7 Gwh per year of which 14,1 GWh reaches the distribution network. The biogas is used by the city buses but could also be used by private car owners in Borås refuelling at the newly built tank station at Åhaga. The study does not only show that the process consumes 6,3 Gwh per year to produce 14,1 Gwh per year, there is also a large amount of energy being released in secondary energy flows. These energy flows consists mostly by heat form the cooling system which could potentially be recovered by heat exchangers and used to heat the process.

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Populärvetenskaplig beskrivning

Rötning av organiskt avfall har pågått vid Sobackens avfallsanläggning utanför Borås sedan 1990-talet. 2005 stod en ombyggnad av anläggningen med en utveckling av biogas produktionen färdig. Ungefär samtidigt som ombyggnaden genomfördes även organisatoriska förändringar där anläggningen övergick i det kommunalägda bolaget Borås energi och miljö från att ha varit en del av Gatukontoret i Borås stad. I takt med organisationsförändringen har ambitionen förändrats från att vara en verksamhet som skall klara tilldelad budget till att ge avkastning på verksamheten. Ett led i att öka lönsamheten är att få kontroll över sina utgifter för verksamheten. En stor del av utgifterna förväntas vara användningen av energi vid produktionen. Tidigare har det betalats en årlig elkostnad utan att veta hur mycket energi som används vid biogasanläggningen detta eftersom ställverk där mätutrustning sitter delas med annan verksamhet. Uppgiften för detta examensarbete är främst att försöka kartlägga energi användningen för biogas produktionen vid Sobacken, en underordnad ambition har varit att föreslå möjliga effektiviseringar. Användningen av el vid biogasanläggningen är beräknad till 3,2 Gwh per år och 3,1 Gwh biogas vid processpannan som förser process och byggnader med värme. Undersökningen genomfördes genom att samla in data om effekter och driftstid för maskiners samt beräkning av energiåtgång för att värma rötkammaren och hygieniseringstankar. Slutsatsen för studien är framförallt att ett informationsinhämtande i realtid hade varit önskvärt för att undvika approximationer av energiförbrukningen. Intressanta fortsatta spår kan vara att djupare undersöka möjligheten till att utnyttja värmeåtervinning från gaskylningen genom att använda värmen till att värma spädvatten till rötkammaren.

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Introduction

Background

Biogas is today belived to be one of the most promising future solutions of biofuels for vehicles to reduce the emissions of carbondioxide to prevent the global warming. Biogas production is not a newly developed process to produce fuel. Already in the 1970:s started production at farms by digesting manure to use in a boiler producing heat and electricity. Producing biogas is also used in developing countries to produce fuel for stoves by digesting the households own waste, reducing the need for firewood. During the years has the methods of digesting been developed and grown in size. Today it is a interessting method not only for farmers but also for municipal waste handling. Instead of using distric heating or landfills to handle waste it is possible to produce methane of organic waste in an industrial process. The process has been improved and needs larger machinery which will use more energy than the small facilitys at the farms. Energy is used in different steps of the process, mechanical for transporting slury or mashing waste and heat to make the environment optimized to the process. The facility gets the mechanical energy from electical engines that consumes electricity from the electric mains, the thermal energy is processed by combustion of biogas in a boiler which provide the heating system by hot water.

Sobacken biogasplant was put into operation in 2005 after reconstruction of the existing plant. The former plant was built upon the ambition of developing the already existing method of degradation of organic waste by composting and making it become a resource. The major component of the waste handling was an automated sorting machinery called ”Optibag” which sorted the bags of waste depending on their color, white or black. The Optibag-system was considered to become a revolution of waste handling in the early 1990:s. Today the reception using “Optibag” manages waste from the city of Borås, Bollebygd municipality and Marks municipality and is still a part of the plant, since the start has several different receptions for organic waste been added. The production of biogas has increased a lot since the reconstruction and produces 2620 000 m^3 biogas between November 2008 and October 2009 or about 300 m^3/h in average. The amount of biogas produced correspond to 17,7 GWh or the total use of energy by 740 swedish standard houses (Energimyndigheten, 2010). Since the beginning the managing of the plant changed from being a part of the department at the city hall called “Gatukontoret” to becoming a division of the company Borås energi och miljö AB owned by the city of Borås. This had changed the ambitions of the business from being cost centre in the municipal to being commercial and making returns of investments in the business.

Since the reconstruction there has been no follow-up of the energy use of the plant. Today the cost of electricity is calculated by a way, which makes the bill not depending on the plants own use of electricity. The cause of this is that existing electricity meters are mounted at switchgear where also surrounding activities and are included. That makes it impossible to calculate the electricity use by using these meters. That makes this study to be in a deeper level to determine the use of different components of the plant. The study will be dealing with the use of electricity and use of hot water produced at the plants process boiler using biogas as fuel, used by the processes and surrounding activities.

Aim of study

The Aim of this thesis is to investigate and evaluate the use of energy at Sobacken biogas plant. By calculating the total use of electricity there is an ambition to find sources of efficiency potentials to reduce the use of electricity. Another target for the evaluation is to find possible points where it could be useful to invest in electricity meters to be able to follow-up the use of electricity in the future. There will also be an investigation of the internal produced energy, the use of it and if there is any potential of efficiency.

Limitations

In this study it will be a limited investigation of support systems. I have chosen to not make a complete study of the ventilation due to the limited time for this project, it is more important to clarify the energy use of the production related systems like receptions, digester, water supply and so on. The heating of the buildings is also an issue where more work need to be done after this study due to the limited time for the study. It would have very time consuming to calculate transmission losses of every building, time that has been used to the study of the production systems.

Other limitations for this work are the use the operational data such as the amount of hours the machines are being used. It has been approximated for a year by only knowing the use during three month for many machines. The limited time for the thesis and the lack of data for operational times makes this limitation necessary. Lack of performance data in some cases makes the data not exactly. But a difference of just a few percent makes the approximations valid enough this compared to the aspect of variations on time of use during a complete year.

Further on has this project by its focus on electricity use made the study of thermal energy limited. The project has been focused on determining the quantities of used heat in the process and released heat by chillers used in the process. There has been no greater or complex analysis like pinch analysis. It has been more of interest to determining the turnover of the energy use of the plant then a deeper analyse. But by intuition and design of the plant is it possible to understand that pinch analysis was a component of designing the plant. The heat exchangers are a result of pinch analysis. But it is obvious the pinch has not always been possible at the plant due to geographical matter or chemical matters when designing the plant. The complexity of large-scale biogas production also makes it more important to adjust to maintenance and flexibility than using every possibility for energy efficiency like pinch analysis.

Method and theory

The method used in this thesis is inspired by a methodology provided by the Swedish energy agency developed as a tool for energy intensive industry like paper mills and mining to analyse their use of energy. The method first describes the system and its subsystems by word and pictures to give an understanding of the process. Block diagrams are a good tool to analyse energy flows and production flows at the unit, to make it visual, which of the components that are the major consumers. After dividing into subsystems and making block diagrams you start the mapping of the plants consumption. This will be done for the currently, short time and approximated to use in the long run. (Energimyndigheten, 2009) The method gives me a possible disposition for this work. The time-scale of the method is about 10 years but will not be a large deal of this thesis because the plant is during development and it will be hard to forecast what will happen with in the next ten years. The last step of this method is to analyse if there are any potential for efficiencies. If you discover great potential you make a more detailed calculations, what would the cost be and what is the return of it.

This survey has been done during July until beginning of October 2009, that means that the result of the investigation depends on the circumstances during this period, such as weather, seasonality of waste etc. In a standard survey of energy flows you usually use a much longer time scale, usually a year. By collecting data during a full year are you able to include all variety's depending of season. Variation of weather is not the only thing that matters for the use of energy. It is also variation of the amount and kind of waste received at the plant depending on season but also if the company finds new partners. The consumption will be presented for each subsystem in the same order and way as the presentation of the plant.

Collecting information

The data about energy use will be collected from the managing computer system called PLC and from frequency converters used to control different components of the plant. Unfortunately the data from the PLC are only a measure of hours that the components have been operating, but together with information from the documentation such as dimensioned power and other performances of different machines it will be possible to calculate the use of energy. The calculation will be an approximated theoretical value, like a forecast of the use of energy. By using this data and theory it will be possible to make a statistical approximation this because of the lack of possibility's of making good measures of energy use at the plant. You could use different ways of making the forecast, using electricity meters and stored data or using documentation and solve it theoretical. Components like lightning are calculated by the theoretical method, but the operational time has to be assumed or approximated since there is no equipment for measuring the time they are running.

Calculations

When using the method of measuring you can use both energy meters, which could count the use during a period of time or measure the current momentously and calculate the power of a 3-phase engine by the formula (Alfredsson och Mårtensson, s. 41).

$P\ (W) = \sqrt{3} \times U_{Measured}\ (V) \times I_{Measured}\ (A) \times \cos \varphi$

P = Power

U = Voltage
I = Current

The method is useful when the current is documented like in most cases at the plant when not using frequency converters. Unfortunately the current has not been documented for all engines but in that few cases have I made the assumption in this study that the load will be of what it is dimensioned for in average in the long run. In these cases with no documentation of current will I use the documented power of the engine. So the basic formula in most cases will be the following.

$Q = P_{documented} \times T_{operationaltime}$ (2)
Q = energy consupmtion (kWh)

Energy consumption of heating has been calculated theoretically by calculating the cost of warming the slurry of waste to the demanded temperature at sanitation and the digester. The calculation for the digester involves both warming the waste but also the dilution water continuously added. The demand of heat is calculated by know asked temperature, incoming temperature, flows, density and heat capacity of the substrate. There are also transmission losses of heat caused by outdoor temperature and insulation of digester and sanitation tanks. The transmission losses are calculated in appendix 2-3. Transmission losses are the heat that is lost from inside to the outside through the walls, roofs and ground plate depending on the ability of its consisting materials. Different materials have different ability to transfer heat to its surroundings. Transmission losses could also be calculated for the different buildings but I have chosen only the digester and sanitation tanks because I think they are most important for my study and I would have caused me a lot more work doing the calculations for the buildings as well. The heating of the digester, the warm treatment of waste and the buildings will be calculated by simple thermodynamics. It will be calculated by knowing asked temperature, temperature before warming and the amount of waste. (Beckman et al. s. 162) Temperatures have been collected from the PLC-system, measuring and asking the operating staff about demanded temperatures in the process.

Q_{enter} = entering flow digester
p = density
C_p = heat capacity
ΔT = difference in temperature

$E_{enter} = Q_{enter} \times p \times C_p \times \Delta T$ (3)

Also losses of energy by transmission need to be theoretically calculated, done by knowing the insulation and the average outdoors temperature. (Petersson s. 352-363) The average outdoor temperature will be found as 6,1 ºC in the city of Borås (SMHI). The data for the calculation of heat transfer through wall etc have been found in the blue prints of the digester and sanitation tanks. On the blue prints data about dimensions and choice of materials are found.

U = heat transmission coefficient depending on the insulation,
$\Delta T = T_{inside} - T_{outside}$

$E_{transfer} = 8760$ (h/year) x Area (m^3) x U (W/m^2K) x (ΔT), (4) Other thermodynamic processes interesting to investigate are coolers that cool and dry the Gas. The release of energy from coolers at the plant will be calculated by the approximation of using the coolers electricity use and their COP-value to calculate the power of the cooling. This will be done to make a measure if it would be possible to recover heat from the gas-coolers at the plant. (Beckman et al. s. 222)

COP = cooling effect by cooling machine (kW)/energy consumption of cooling machine
(kW) (5)

The calculation of demanded heat at the ventilation will be calculated by the formula below (Beckman et al. s. 137). The average outdoor temperature needed for this is the same as used calculating heat transmissions before.

$E_{ventilation} = Q_{ventilation} \times p_{air} \times C_{p, air} \times \Delta T$ (6)

To calculating content of energy in the biogas the value of 9,97 kWh/normal cubic metre will be used, approximated with the content of methane in the biogas (Biogasportalen). Normal cubic metre is the standard unit used for biogas to describe the amount of it, so when cubic metre is used in the context of biogas it is corresponding to normal cubic metre. The approximations of the content of energy are using the following formulas.

$E_{NormalCubicMetre}$ = Content of energy per normal cubic metre methane
$P_{Methane}$ = Percent of methane in biogas
$B_{Quantity}$ = Quantity of biogas
E_{Biogas} = Energy content of biogas

$E_{Biogas} = E_{NormalCubicMetre} \times P_{Methane} \times B_{Quantity}$ (7)

The frequency converter

One of the most important components of creating modern and efficient automations in the industry is by using frequency converters to control engines. This is made by that the converter by changing frequency or voltage controlling the speed of the rounds of the engine. Tree steps of the converter make controlling the voltage and frequency where you first transform AC to DC and than back to AC to meet the demands of the engine to get the right speed. The frequency converter does not only make the engine go at a certain speed it also reduce or increase the use of electricity. A lower speed consumes less energy and the opposite. In modern frequency converter are functions to measure the consumed amount of electricity. A meter that by calculating the average consumption per hour can store the values and calculate the total use of electricity or for asked period makes this. (Alfredsson and Mårtensson s. 154)

The Sobacken Biogas plant

The structure of the plant is similar to a standard chemical industry or a waste water treatment plant. The main components are pumps, storage tanks, conveyor screws, conveyors, blowers and compressors. The plant is located in 5 buildings containing different functions. The receptions are depending on the properties of the received waste. A view of the plant in detail and in larger perspective are presented below in the following text, pictures of the subsystems are presented in appendix 1. The plant has been divided into 10 different subsystem during this study. This to make it easier to analyse the use of electricity. The description of the plant has been made by using information from blueprints, process charts, PLC-computers, operating staff and viewing the plant by my own eyes.

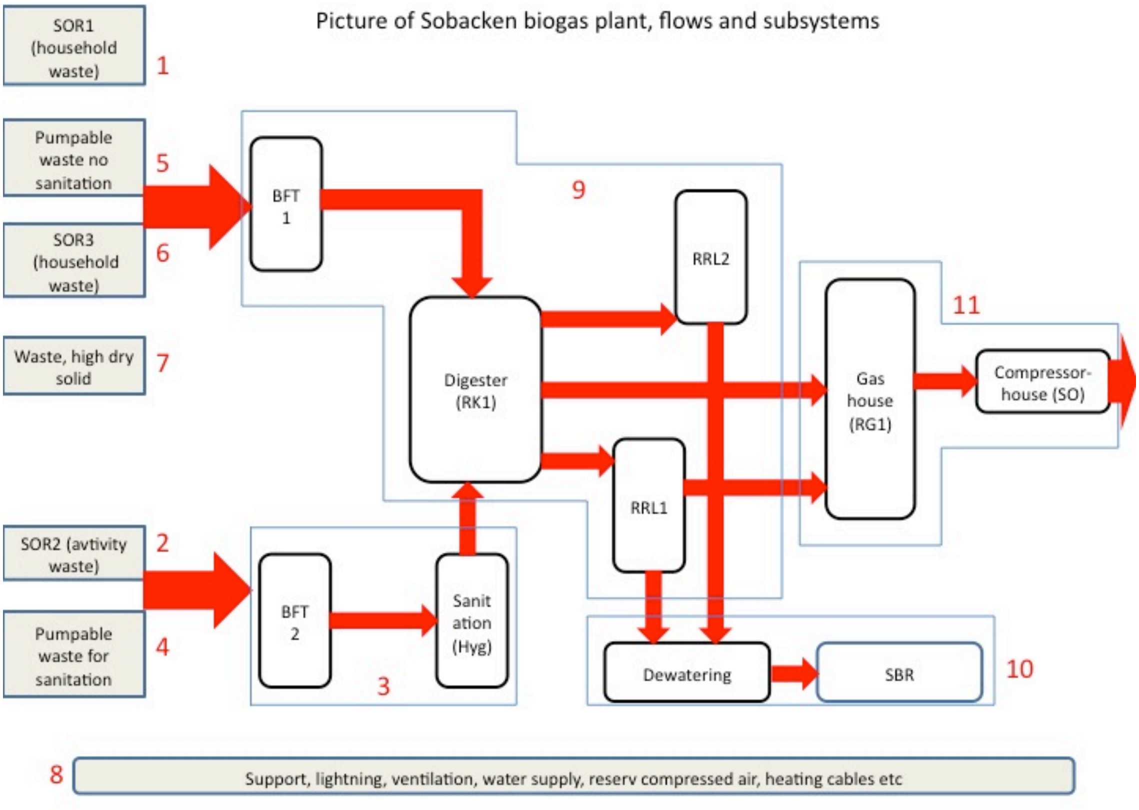


Figure 1. Picture of the biogas plant and its subsystems

The receptions 1, 2, 4-7 are possible to compare against each other in key figures by calculate the cost of energy to receive the waste. This must be compared to the amount of waste they receive to determine the cost to process the waste at the reception. The amount of reasons of making Buffer tank 2 (BFT2) and sanitation/heat treatment to one single subsystem is because it is only need for waste received at Sorting 2 (SOR2) and one of the lines at reception of liquid waste. This waste needs to be disinfected or heat-treated before entering the digester or being stored at the Buffer tank 1 (BFT1). The step of sanitation is not needed any more cause of a change of regulations that means that it is enough to disinfect at 53 ºC in the digester. The heating of waste is still used but for a shorter time and only to start the process specially needed for slaughterhouse waste. Subsystem 9 is the system for processing the waste to biogas and digestate at the digester and storing the digestate before reaching the dewatering. At subsystem 10 the sludge of digestate are being dewatered by separating water and solids. The solids goes to composting and the water to a nitrogen treating plant called Sequent batch reactor (SBR) to reduce the amount of nitrogen before returning to the process of being released in a pond. The last subsystem treats the biogas by pressurizing and dehydrating it before it can be transported to Gässlösa in the city of Borås to the upgrading plant. Subsystem 8 is a fusion of all support needed to run and maintain the machinery and buildings of the Biogas plant.

Sorting 1

Sorting 1 (SOR1) is the reception for non-sorted municipal waste from Borås and some surrounding municipality's and its process chart is shown in appendix 1. The waste arriving to Sobacken is packed in white and black. The black bags contain of organic waste and the white bags contain combustible waste, the bags are then separated by automation at Sobacken. Sorting is made by a system of conveyors where the waste is transported through. The lorries dump the waste at a reception unit consisting of a bin, a segmented conveyor and a rising conveyor. The next step of conveyors are the optic sorting system, where the white bags are knocked of to another conveyor for transportation to containers for combustible waste. The black bags continue on in the conveyor-system to a machine that rips the bags apart. Following step on the conveyor-system is a drum sieve that separates large things like the plastic bags to the conveyor for combustible waste and the remains falls through the sieve to another conveyor. The conveyor does a last separation of metal by a magnetic conveyor running above the waste conveyor before reaching a machine called MEVA. The machine is a screw conveyor where the organics are washed apart from plastic and other non-organics by adding water and squeezing out a slurry consisting water and organics from the waste. The MEVA is originally made for washing away faeces from waste collected by cleaning grids at wastewater treatment plants. From the MEVA the organic waste slurry is pumped to BFT 1. Conveyors for combustible waste transport the remaining washed non-organic waste. The combustible waste is at the end of its conveyors loaded into containers by two compactors depending of which one in service. The combustible waste is then transported to a crush before becoming fuel at the municipal heat and power plant. Large components of SOR1 are all its conveyor, pumps and machines which make it possible to store the waste at BFT1 in the end.

Sorting 2

Reception at SOR2 consists of a reception bin where 4 screws are located at the floor that mashes the waste. No matter how the waste is packed before it is put into the reception unit, the unit has capacity to crush metal and plastic cans. Often the waste consists of metal cans from a dog food manufacturer but also organic waste from restaurants etc. By a screw conveyor and passing through a mill is the waste transported to a machine called bioseparator. In the bioseparator is the waste suspended and becomes slurry. Non-organic waste is separated from organic waste by a process where plastics will remain floating, gravel will sink and the organics will float in between. The gravel sinks because of air blown in the water by a fan that makes heavy things like gravel and metal to sink. A machine called “rotamat” collects the non-organics like plastics and transports it away by a screw conveyor. The “rotamat” looks like a waterwheel at a mill but instead of transforming the energy of a waterfall into energy to the mill it collects the non-organic waste and deliver it at the conveyor. The non-organic waste are put to a container and goes to the crushing unit before ending at the heat and power plant located in the city. The slurry of organic waste is pumped to Buffer tank 2. Using a fan for airing and a circulation pump to circulate the water of the bioseparator the slurry will settle and for that reason there is a screw conveyor mounted in the bottom to transport metal fraction from the bioseparator. At the units is also a pump pit located to collect water from the surroundings of the bioseparator like when being cleaned or if the units are flooding.

Sorting 3

The waste at SOR3 is received in a hall where it is dumped on the floor by lorries transporting the waste to Sobacken. The waste received in SOR3 is mainly from external municipal costumers where the customer already sorts the waste, so there is no need for optic sorting before treatment. The unit for treatment of this waste is the mixing bin, a rebuild machine originally used in farming for mixing bales of silage. To the mixing bin is the waste loaded by a wheeled loader from the floor. In the vehicle the waste is mashed to a viscous mud to fit next process step and water is also used to dilute the mixture of waste. The mixer is automated and controlled by a frequency transformer to control the speed of its rotating components. After mixing the waste is put to a screw press, Doppstadt DSP 20-5, where the organic parts of the substrate are squeezed out of the mud and reject water consisting of organics is received in a tank located below the press. At top of the press where the dehydrated waste drops out is a conveyor mounted, which transporting the non-organic waste to a container for combustible waste. To the tank of reject water is a pump mounted to push the waste slurry to buffer tank 1. The screw press is driven by hydraulic pressure and has the possibility to change settings like the pressure between the screw and the cone that is crucial for the amount organics you might be able to wash out of the waste. A pump located close to the screw press makes the hydraulic pressure.

Reception liquid waste

Liquid waste is received at two different lines presented in appendix 1, one used to be only for waste needed to be disinfected and one for waste with no such regulations. Today there is no need to separate them because of regulations but some waste need to be treated by heat before entering the digester. Slaughterhouse waste has a need for being treated by heat to establish hydrolysis, the first step in degradation for more complex carbon chains, before entering the digester. If hydrolysis or any degradation already is established the process at the digester will go faster.

Reception of waste consisting high amount of solids

Located in the same building as the reception of sorted organic waste (SOR3) are a reception for waste consisting high amount of solids like dry dog food and orange-peel. The waste is received in a reception unit, loaded by wheeled loader, and is mixed by a screw in the bin and water is added. At the unit are then paddles mounted to mash the substrate even more. Connected to the paddle bin is the pump that pushes the slurry to buffer tank 1. Except from the engines of the screw, paddles and pump there is also a small pump to higher the pressure for the dilution at the screw. The pump and the screw are both managed by frequency converters.

Buffer tank 2 and sanitation/heat treatment

Sanitation is today used as heat treatment to warm the waste but also start the degradation process before the waste entering the digester. In the buffer tank is a stirrer working for homogenizes the substrate. Attached to the tank is also as pump to circulate the contents of the tank which also contribute to the homogenization, a mill reduces lumps in the slurry. Connected to the pipes after the mill is another pump, which pumps the substrate to the sanitation tanks. At the sanitation are two different tanks built where it is possible to alternately disinfect the waste from Buffer tank 2. Mixing equipment homogenizes the material and makes it getting an equal temperature in the tank. Connected to the tanks is a heat exchanger that heats the contents to a demanded temperature by circulating the slurry by it. The hot water used by the heat exchanger is heated at the process boiler that also heats the digester and the buildings. In the bottom of the tank is a pump built that pumps the heated slurry to Buffer tank 1 or the digester. As added equipment is compressed air to clean the tanks by blowing compressed air into them when they are empty.

Buffert tank 1, Digester, digestate storage 1 and 2

In buffer tank 1 is the slurry stored until it is pumped in to the digester. A stirrer and a circulation pump makes the substrate homogenized and two parallel pumps that takes it in turns to pump the substrate to the digester managed by a recipe. The recipe decides when the pump should be running and for how long, this to manage the execution of the calculated demand of slurry to the digester. Two pumps are to get redundancy, so it still will be possible to pump substrate to the digester if one pump is broken. With out redundancy a major failure could occur if a pump gets broken, causing a close down of the biogas production for months. Without food the gas producing methanogenes would starve to death. The digester has like the other tanks and a stirrer and circulation pumps. By having two circulation pumps to circulate substrate by a heat exchanger to maintain the desired temperature to reach the optimized biogas production, are redundancy is archived. At the circulation pipeline is a mill attached to disperse the substrate from the digester. At the top of the digester are two blowers mounted to pressurize the gas and push it to the gashouse. Digestate storage consists of two tanks where the digestate is being stored. In the tanks are stirrers for homogenizing the digestate and releasing the remaining methane from the sludge that is still producing methane. At the top of the storage are fittings to the gashouse mounted to take care of gas that is still produced at the digestate storage. There is also a circulation pump at the storage to help the stirrers to in their work. The pump allows circulating with in one tank, as between the two tanks, this is managed by valves. Connected to the outflow in the bottom is a pump that pushes the digestate to the centrifuge at the dewatering. Before the dewatering is the digestate put over a heat excharger to recycle heat back to the process water used by the water supply system.

Dewatering and Sequenced batch reactor (SBR)

Dewatering or decanting means that solid particles are separated from liquid material by using centrifuges. Digestate are pumped from the storing to one of the two centrifuges depending which one in service this is also to have redundancy of dewatering. To make the process working you need to add polymer solution, the solution makes the solid material to form flocks. By forming flocks it becomes possible to separate the solids from the liquid in the centrifuged. The polymer solution is made in a polymer mixer by solving solid polymer in to water. Critical components in the polymer-mixing tank are the stirrer, a fan and a dosage unit. The solution is added to the centrifuged by one of the two pumps, only one in service, depending on which centrifuge that is used. When using the pump it is possible to adjust the flow rate by changing settings of its frequency converter. The remains from the dewatering are reject water and sludge. The sludge is transported by several conveyors to a storage for sludge. The reject water is collected in a small tank a floor down, to make the flow even to the pump before being pumped to the reject buffer. From the buffer is it possible to pump the reject to the SBR.

The reactor is function as nitrogen treatment to reduce the amount of nitrogen in the reject water. By changing the environment between anaerobic and aerobic environment could nitrogen reduction be achieved, the process is possible by the bacteria that transform nitrogen compounds to gas. The process consists of bioremediation and sedimentation, decanting, reaction phase, filling phase, sedimentation phase and reaction phase with aeration and stirring. The main process is to reduce the amount of nitrogen but as a biprocess does also degradation of organic material occur. Nitrogen removal process must go through several steps to achieve the results you want, that ammonium release for nitrogen. Steps are nitrification and denitrification. The nitrification of ammonium is using bacteriological processes to convert it into nitrite in step one and in a further step to nitrate, which is the final product of nitrification. The processes are alkalinity consuming which requires that water is a strong buffer, therefore, adding of lye to water as required. This happens with either of the two lye pumps located at the reception station. You need to bring an non-organic carbon source to the process where bacteria that are involved cause the process does not use organic carbon instead it uses carbon dioxide. This carries a risk of bacteria being eliminated by bacteria that use organic carbon. During denitrification the process instead uses heterotrophic bacteria in a phase with out aeration. An oxygen-free environment force the bacteria to instead use oxygen of the nitrate which makes the nitrogen to converted to nitrogen gas. The denitrification process is dependent on the added carbon source that in our case is the ethanol that can be put into the process by ethanol pumps at the ethanol tank. In addition to the pumps for the lye and ethanol are the blowers for aeration. These blowers are constructed in such a way that they have a major fan but also a small extractor fan for cooling. A frequency converter at one of them and a soft landing at the other, not to tear too much on the engines at start up, manage these blowers. Furthermore, there is a pump that serves as agitators and aerators by SBR. Finally, there is a pump for sludge removal to digestate storage or buffer tank 1.

Gas-house and compressor-house

In the Gashouse is the first of dehumidifying step for the biogas located, when the gas arrives from the digester it passes by a condensing vessel. Gas must be cooled to condensate the large amount of steam contained in the biogas from the process at the digester. A blower increases the gas pressure that comes from the digestate storage that enters in the same direction as the gas from the digester. The next step will be the gas cooler before it passes over a filter to move on to the compressor building. After the filter is a direction to a gas torch and pipeline continuing to two gas boilers. The process-boiler is heating the buildings and the process of the biogas plant and the second boiler heat other buildings at Sobacken than the biogas plant. At the pump pit under the gashouse is the condensing water collected and pumped away when needed.

At the compressor building two blowers push the gas to the gasholders at Gässlösa. Before the gas is transported to the upgrading plant, the biogas is first cooled down to 20 ºC from 40 ºC in the gas cooler and then goes by the refrigeration dryer where the gas is cooled to -10 ºC. The reason of the cooling is to condensate the steam within the biogas and cooling the gas does it. Condenser and refrigeration dryer is made up of different parts where gas coolers are cooled by liquid coolers. Condensers consist mostly of fans while the compressor that is large energy consumer mainly operates the liquid cooling. A large component of the cooler is their compressors, which cools the fluid that cools the gas in the gas coolers. Refrigeration dryer is made up of condenser containers and heat exchangers in general. A compressor acts as the hub of refrigeration dryer, which is providing the three gas coolers where the water is condensed. The compressor obtains access to cold from a condenser outdoors, refrigeration dryer is not alone in exploiting the condenser. The high-pressure compressor pressurizing the gas at the tank station at Sobacken also uses the condeser.

Support

To make the plant running and create an environment friendly for both people and process, there are some support systems to accomplish this. The most important systems will be mentioned bellow. In common for the support systems are also that they are being mutually used by the different subsystems. Water is needed in all systems and also heating and ventilation, that make it logic to put them together as a single subsystem.

Water supply

Water supply is crucial for the process of producing biogas and a process chart is shown in appendix 1. At the receptions the way of using water to dilute and make the substrate easier to pump and to handle in the future processing is important. The core of the water supply is the three storages of flushing water tank (MS1.C3), decant well and process-water tank (MS1.C6) that supply the plant of water. The storage's are connected to each other in a certain order. All water first arrives to the plant at MS1.C3, where it is stored until there is a need of it. The need could be water for the polymer preparation that occurs 2 times every day for approximately 40 minutes in total or dilution at the digester. MS1.C1 is connected to a net of hydrants for cleaning and also to some machines for cleaning valves and other components. The supply is made possible by a pump (MS1.P8) and a pressure tank to higher the pressure of the water. The flushing water is also a large supplier to MS1.C6 together with the decanter well. The water at the decanter-well is supplied by the release from the SBR. By being pumped to MS1.C6 or being released to a leachate pond, decantate could return the water of the decantate well to the process. Before entering the MS1.C6 the water from MS1.C3 and decantate water are circulated by a heat exchanger to restore heat from digestate storing before dewatering. From MS1.C6 the process water is pumped to different parts of the plant where process water is used. The difference between process water and freshwater is that freshwater is added from the city's water net of fresh water and process water consists of some parts of reused water from the SBR.

Heating cables

The heat cables are operated when the outdoor temperature is below 5,0 ºC this is to prevent pipes from be broken by freezing. If the water or sludge with in the pipes would freeze to ice, the ice would work as a plug and it would also crack the pipes so that they would not be able to use any more. The heating cables installed have together a power of 20 kW.

Ventilation and heating

The ventilation system of the biogas plant is very important for the comfort of the employees and but also to please the environmental authorities and the public. Wrong temperatures indoor and bad smell makes the plant an unpleasant place to work at. Pleased employees are more productive than workers that have to stay in bad smell or to cold/warm workplace. (Svensk ventilation) To prevent this a sophisticated system for ventilation is installed. By having lower pressure at production areas it is possible to avoid bad smell outdoor of this buildings where waste is being handled. To hold a lower pressure than in the surrounding areas fans are installed. The fans blow the air from the spaces through systems of pipes and by a high-pressure fan SOR2.FF to a filter, which prevent the smell. In the buildings where SOR1 and SOR2 are located are also areas for personnel located. There is a laboratory with office area and lunchroom located in close connection to SOR1. Between SOR1 and SOR2 are an operating room and a room for managing equipment that control the processes. Both of these rooms have the air supply in common. The principles of these two different ventilation areas are that they both must have a higher pressure compared to the areas where the waste is handled. This is solved by that they have separate air supply that makes the pressure in the personnel areas being higher than the surrounding areas to prevent bad smell penetrate from polluted areas.

Lighting

The use of lighting outdoors are controlled by a relay which turns on the lights if it is dark between some certain point of the day. That makes the time using lights outdoor differ but limited depending on time a year. Lights indoors are more or less just estimated and variations are probably not even useful to do. The way that windows are located at the buildings make you always need to use the lights being inside the building, so estimation and assuming will be that there is no larger variation on the use of lights indoors depending on time a year.

Reception of waste

Between the month of July and September the amount of received waste where in all 6250 ton. This numbers is to give the reader of this report a view of in what size the different receptions receive waste. The plant is dimensioned to be able to receive 30 000 tons of waste per year. An estimation made by using the received amount of waste during July to September 2009 was made and shows that altogether 25000 tons of waste arrived to Sobacken. The amount of the waste that was possible to process to biogas was 16800 tons or 2/3. A summary of the received waste is shown in a table in appendix 8. The values of the reception will be used to make key figures later in this reports presentation of results to visualize the efficiencies of different receptions.

Results

The results in the study of energy consumption will be presented by the process charts that earlier visualised the function of the different subsystems in appendix 1. This time calculated energy flows has been added to the chats and are shown in the figures 2-13. There will also be some small comments about the result, important issues for the calculations and measuring that might effect the result.

Sorting 1

The total amount of used energy at SOR1 is 144700 kWh/year and is mainly electricity. As the figure show the largest single consumer of this subsystem is the Bag opener. This is not a surprise since it costs a lot of energy to rip the bags apart to release the waste from the plastic bags. The surprise are on the other hand the drum sieve, operated by two 15 kW motors but by using a frequency converter to control them their use is reduced to only 4760 kwh/year. The conveyors do consume a lot of energy but there are all together about 30 conveyors that make them consuming approximately 3000 kWh/year in average.

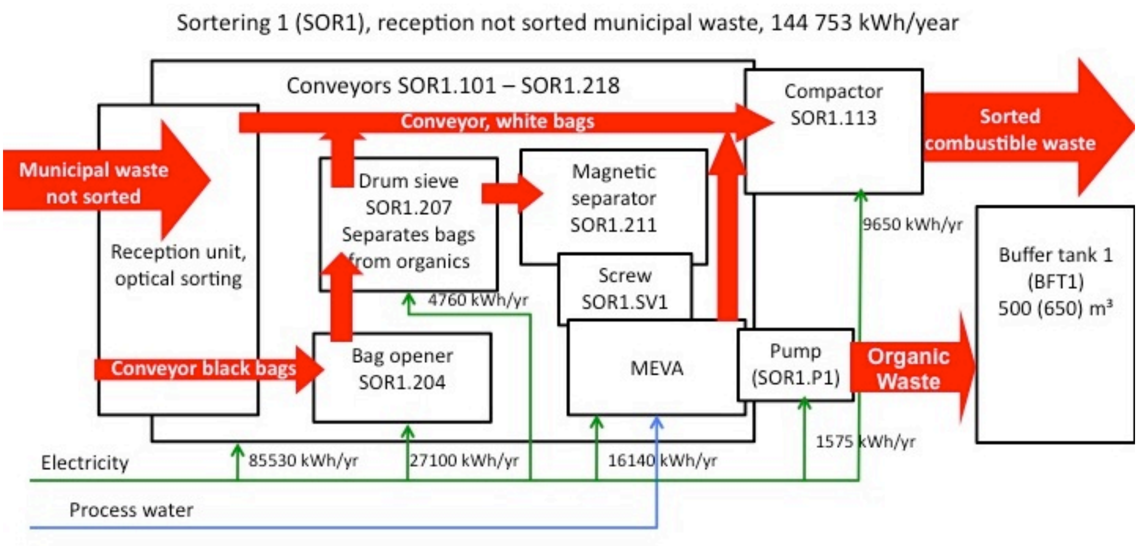


Figure 2: Energy use at SOR1

Sorting 2

The results of SOR2 show us that the total use of electricity at SOR2 has been calculated to 122000 kWh/year. SOR2 does not sort waste but it still need to treat it to assimilate the organic material, the difference in method matters for the energy use. The largest use is the reception bin, to tear cans and similar things apart, a method that logically consumes great amount of energy, 74932 kWh/year. The bioseparator does not consume a large amount of energy comparing to what a complex equipment it is. It has several components operated by motors that will consume electricity.

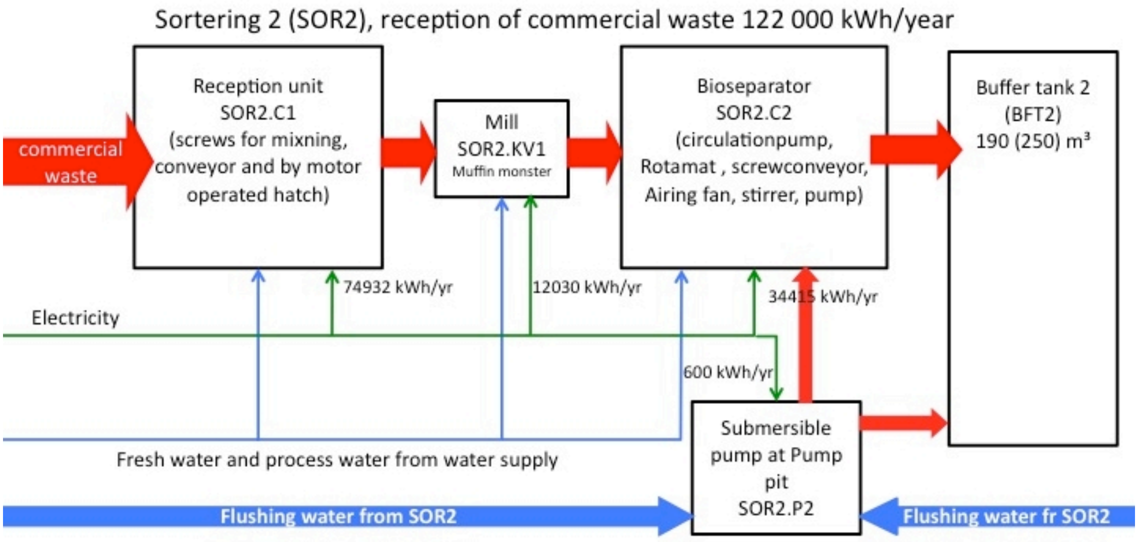


Figure 3: Energy use at SOR2

Sorting 3

SOR3 is the newest reception at the plant but the simplest principle and most efficient to process the received waste. It uses 108700 kWh/year and its largest consumers are two very critical components, the mixer 40200 kWh/year and the Doppstadt biopress 62920 kWh/year.

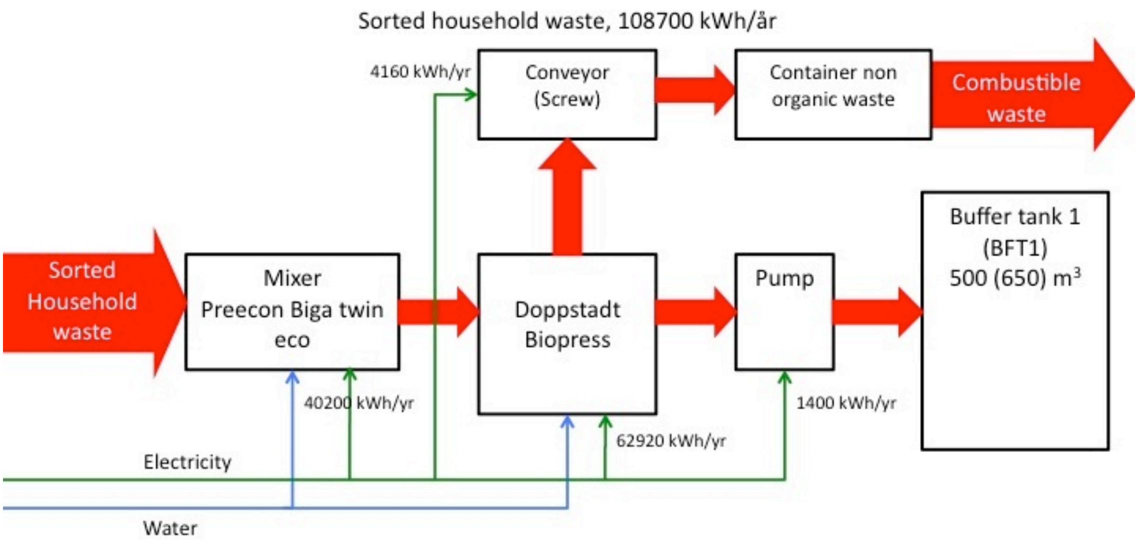


Figure 4: Energy use at SOR3

Comparing the biopress to the MEVA solution is not really suitable when their capacities and efficiencies are different. The data of SOR3 are approximated by calculating the average time of use per day to 4 hours for the components not using frequency converters. The data from the mixer was found from the frequency converter at the cabinet located at the machine. The consumption is correct but the time it has been running, which is the foundation for the estimations of the other components are not exactly correct. The subsystem could probably be running more but it is estimated to 4 hours/day but production stops has decreased the use of the reception at SOR3 during the time for the study. Another issue about the data is that the time for collecting data about the use has been limited due the installation of electricity at SOR3 during the summer which has made the use of frequency converter limited.

Reception of waste consisting high amount of solids

The use of energy at this subsystem is 4100 kWh/year that is the smallest energy using subsystem and the use is of electricity. The data for the reception of high dry solid waste has been collected from the frequency converters of the conveyor and the pump at the reception unit. Except from achieving data about the amount of energy used it has also been possible to use their operation hour counter to calculate the operational time for the paddles and the booster pump. This because the booster pump always is running when the pump at unit is running.

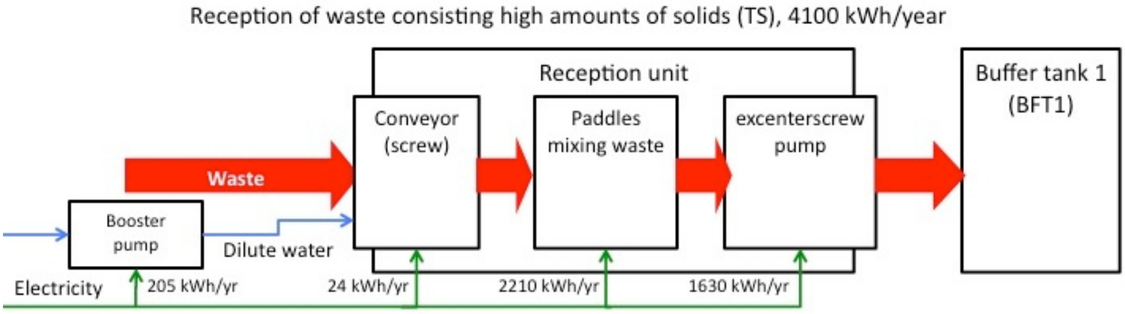


Figure 5: Energy use at Reception of waste consisting high amount of solids.

Reception of liquid waste

The receptions of liquid waste are the second smallest consuming subsystem at the plant, using 6500 kWh/year. The waste is already slurry, not in any need of sorting, crushing, mashing or separating of non-organic parts. The data has been collected from PLC-system, the time they has been running (MS1.P1 and MS1.P3), and the amount of used electricity by the frequency converter (MS1.P2). By including data from the documentation has it been possible to forecast the use of electricity for the equipment. The Pump in the pump pit has been estimated together with staff to be running 4 hours a week because there is no information at the PLC about its operational times.

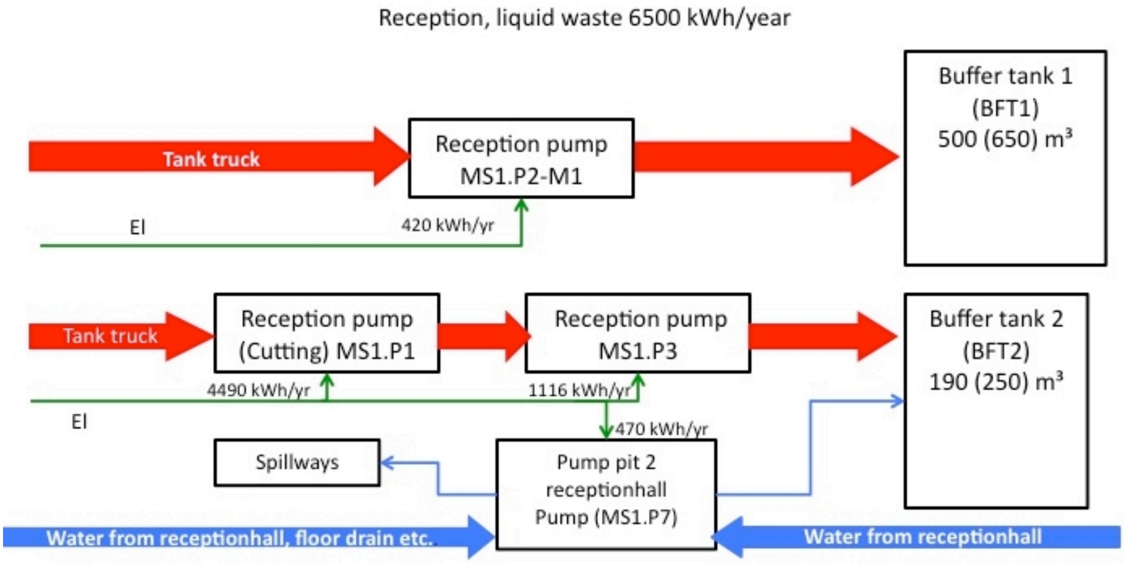


Figure 6: Energy use at reception of liquid waste.

Buffer Tank 2 and sanitation/heat treatment

The total energy use at the BFT2 and the sanitation is 130900 kWh/year of electricity and 972000 kWh/year to heat the sanitation tanks during their heat treatment. The data about MS1.P6 and BFT2.P2 was collected from frequency converters. The operational data about the stirrers was collected from the PLC and made it possible to calculate the use of electricity.

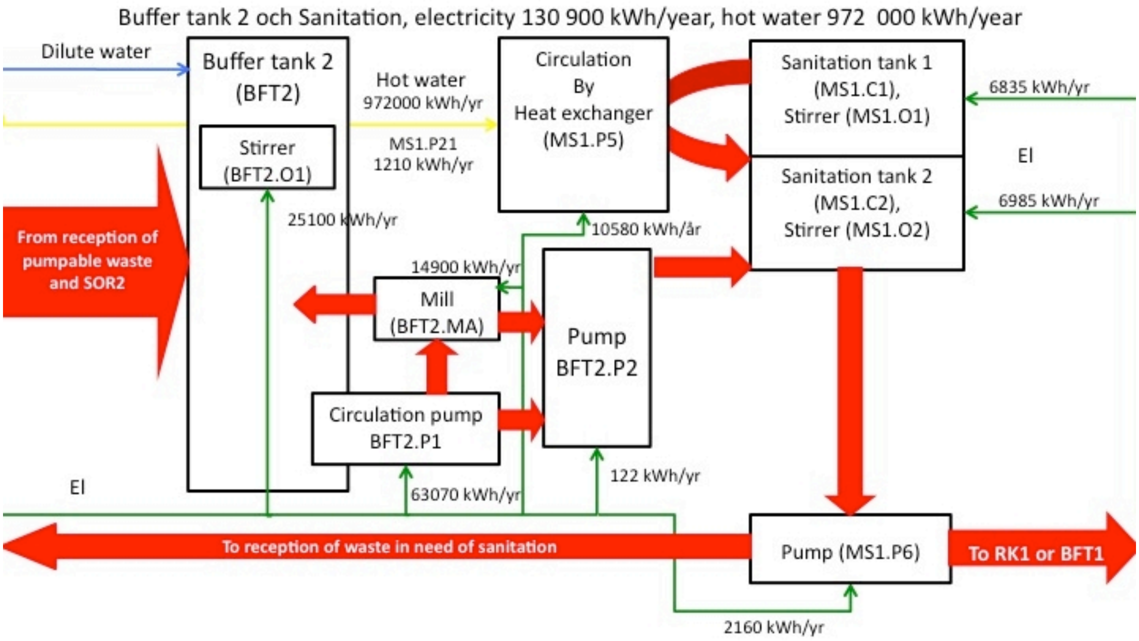


Figure 7: Energy use at BFT2 and sanitation/heat treatment.

The mill and the circulation pump did not need information from counters of the PLC-system when they are running 24 hour 7 day a week, so a forecast of them was easy to calculate. Important to be aware of is that the use of disinfection is reduced only to work as heat treatment that affects the amount of time the sanitation tanks are being used. That could make the forecast to differ from how it has been working out before. The large energy cost is the pure heating while the transmission losses are about 23 % of the energy cost of heating the tanks. An aspect of this is that the hatches make the major transmission losses where the stirrers are mounted to the tank.

Buffer 1, Digester and digestate storage

The digester is the largest single user of heating with 1610 000 kWh/year to keep the temperature in the digester at 53 ºC. If the heating fails the methane production will fail. Among the other components there are stirrers and circulation pumps that are large consumers but not surprising. Comparing to its size is the transmission loss for the digester rather small, about 6 % of used heating of the digester, but it is dimensioned for this and there are certain demands of a digester running a thermophilic process. The heat exchanger MS1.E2 is through its daytime operation recovering 270000 kWh/year back to the process water from the digestate. The use of electricity is 500800 kWh/year and the largest users are stirrers and circulation pumps of BFT1 and the digester.

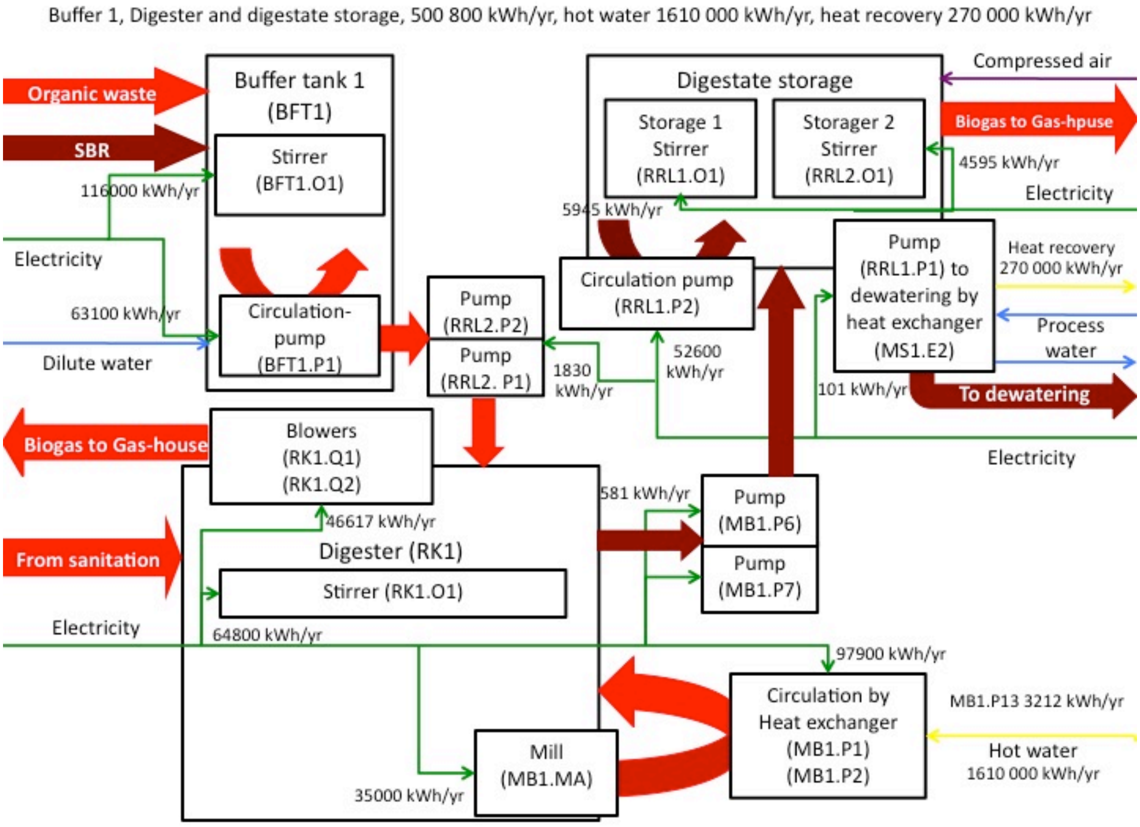


Figure 8: Energy use at BFT1, digester and digestate storage.

Dewatering and SBR

Dewatering and SBR are the two most electricity consuming systems of the plant, they stands for more than 2/5 of the electricity use, 1270400 kWh/year in total. Dewatering is a energy consuming process, running a centrifuge needs a lot of energy to separate the solids and water, the centrifuge uses 336520 kWh/year of electricity to dewater about 55000 m^3 sludge per year.

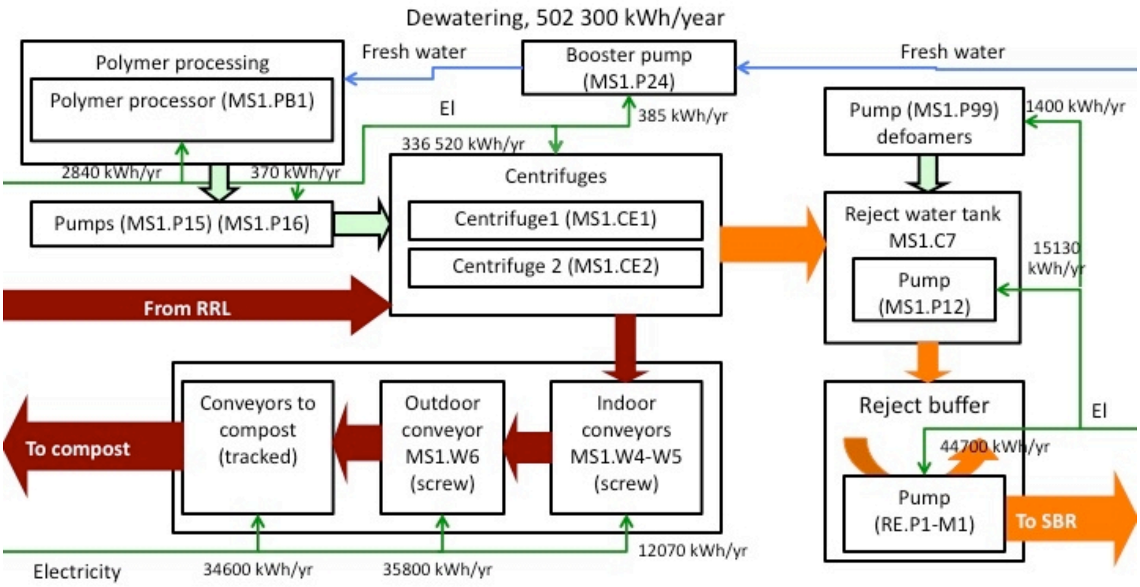


Figure 9: Energy use at dewatering.

The nitrogen reduction is very energy demanding and uses almost 1/3 of the total amount of electricity at the plant. These two processes are hard to make less energy consuming. The methods of dewatering and nitrogen reduction need to be of a certain quality which makes it energy consuming. The same problem is of the SBR-process, to be able to airing 2600 m^3 of water it needs a lot of energy to supply the SBR plant with its demand of oxygen to be working correct. The blowers that are airing the SBR-plant uses 553900 kWh/year and the circulation pump 213280 kWh/year.

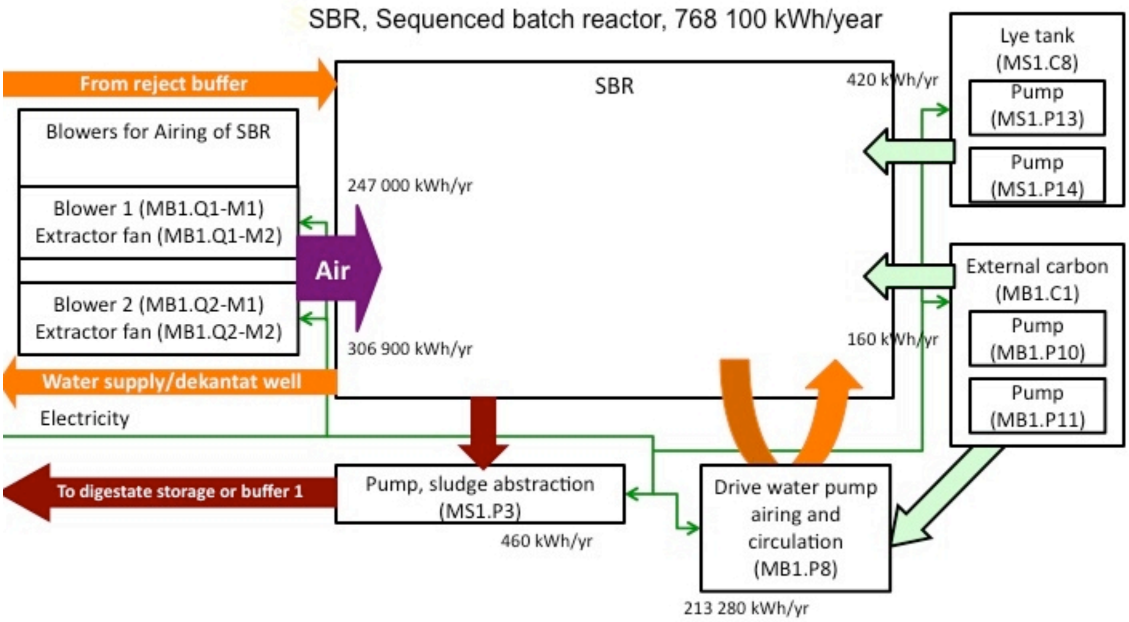


Figure 10: Energy use at SBR-plant.

Gashouse and compressor building

The Gas-house and compressor-building share the same pattern of energy use, the need of using blowers and coolers. The use of electricity at the Gas-house is 86600 kWh/year and the use at the Compressor-building is approximately 224200 kWh/year. The largest single user is the compressor of the dryer at the Compressor-building, 86600 kWh/year. The Cooler at the Gas-house had to be calculated by measure the use of the compressors, which was made by hand by measure the time intervals of when the compressors was operating and when not operating. The Gas-cooler at the compressor-building was measured by determining the data from the operating display at the cooler. The use of cooling will vary depending on outdoor temperature that is fluctuating during the year. The consumption of energy when cooling is not only depending on the outdoor but also the humidity of the biogas. The coolers work as a fridge and its compressors will be running when needed and circulation pump circulating a media is always running to supply the gas cooler where the gas is cooled down to the demanded temperature. The compressors of the gas cooling system uses a lot of energy but it also recover a lot of energy from the gas. The large exchange of heat is released by the coolers in the surrounding air. Other systems of gas-house and compressor house is the always running blowers that gives the gas a pressure, only a few bars pressure, enough going through the cooling and drying phase but also to bee transported to Gässlösa by the pipeline system. The release of gas at the gas torch was an amount of 420 000 kWh burned, which is not very much less than the cost of the heating of the buildings. The use of the torch is depending on over production when the production at Sobacken is higher than what is possible to receive at Gässlösa.

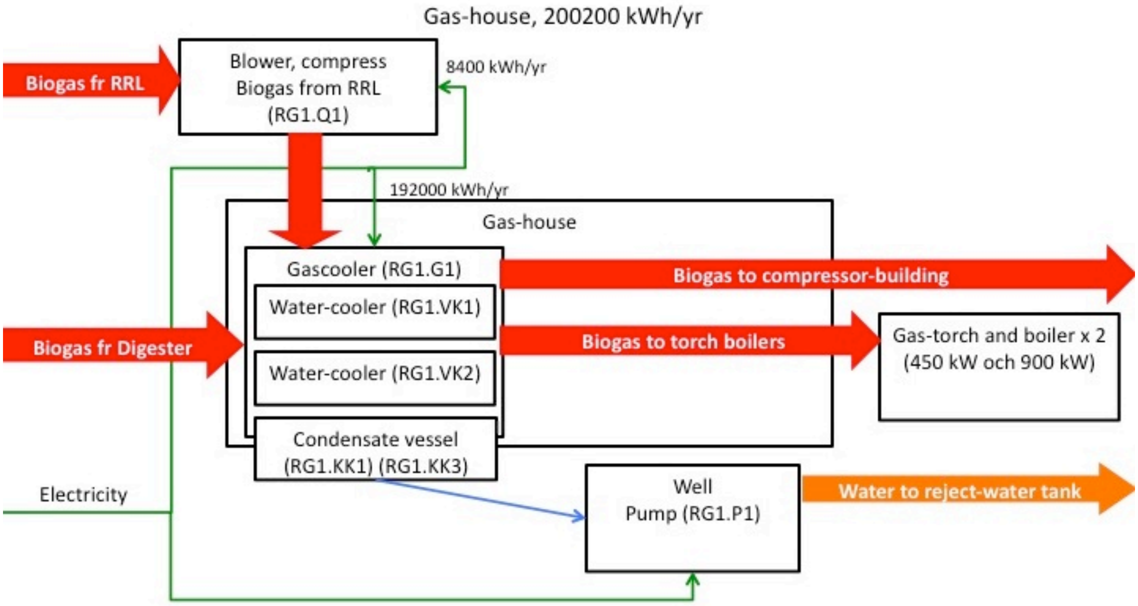


Figure 11: Energy use at the Gas-house.

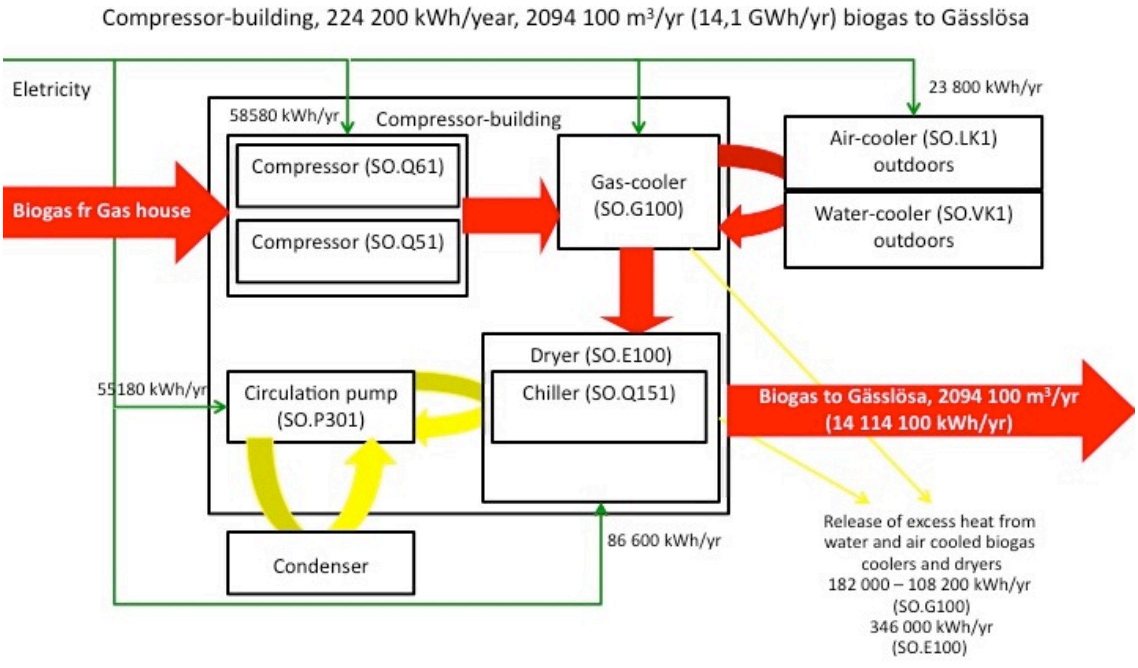


Figure 12: Energy use at the Compressor-building.

Support systems

Water supply

The water supply runs all time and the minimum flow is by night when only the dilution of the digester is done with is 2,5 m^3/h. The question mark at the water supply is the pump MS1.P8 that has a hour-meter that not work in a proper way. During a period when a collected the data it was running 37 hours per day, which is not possible. This made me use data from just one month for this pump. The two other pumps work normal and I find their data reliable.

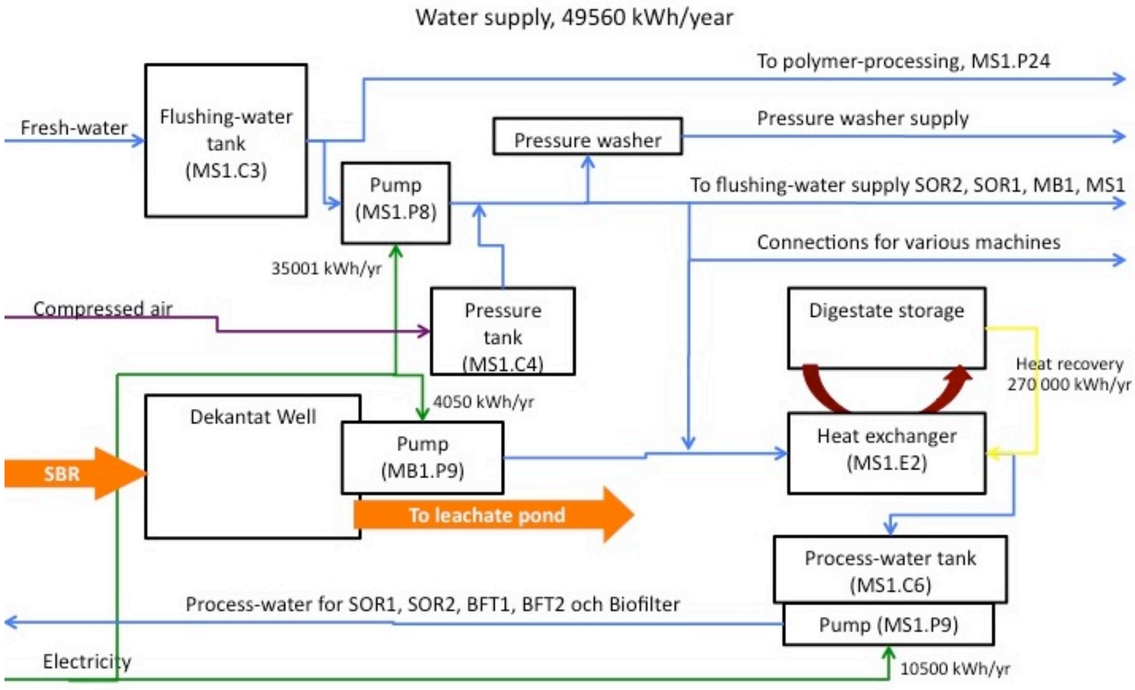


Figure 13: Energy use at the water supply

Remaing support systems

The heat cables are operated when the outdoor temperature is below 5,0 ºC this is to prevent pipes from be broken by freezing. If the water or sludge within the pipes would freeze to ice, the ice would work as a plug and it would also crack the pipes so that they would not be able to use any more. The use of heating cables has been estimated to 2400 hours per year that in electricity use is according to 48000 kWh/year. Calculating all days when the average temperature is 5 ºC or below based on the average day temperatures of the neighbouring city of Gothenburg has approximated the time of use (SMHI).

The lightning indoors is more or less only running when there are people operating the plant. Which means that the lights is only running during day time even if it happens that someone forget to switch them of sometimes. The most lights indoors has been estimated to be used about 10 hours per day.

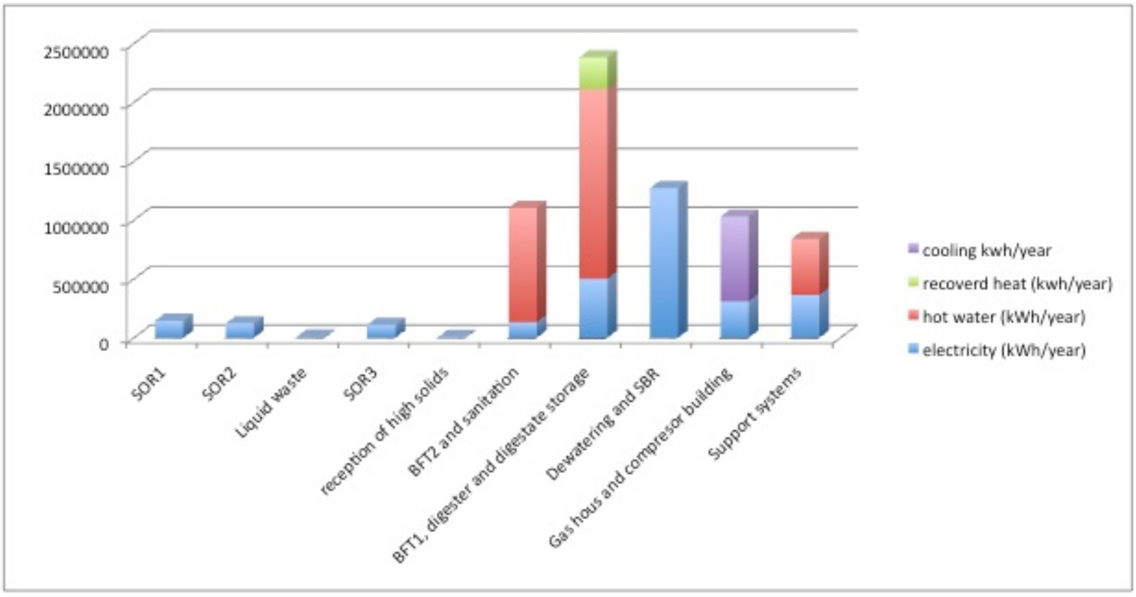
The outdoor lightings are controlled by time and twilight relay. The settings of the relay make the outdoor light run about 5 and a half hour per day in average during the year.

The lights are mostly set to be running when there are people at the plant. The twilight relay makes the lights not running if it is still sun on the afternoon or if the sun is up early like during the summer. The only variation of using light that is that they are mainly being used at daytime. Together does the indoor and outdoor lighting use 81274 kWh/year, this is shown in appendix 5.

Ventilation is used continuously no mater time a day, week or month. This is because of the environment, which would cause odour problems if you close down the ventilation both indoors and outdoors. The total amount of energy use of the ventilation is 195291 kWh/year. There is only one heating battery using electricity and that one has been estimated to use about 47 000 kWh/year. The estimation is based on the flow the ventilation unit is designed for, 1000 m^3/hour, so the use of electricity could be less or more. The temperatures that the calculation is based on is the average outdoor temperature of Borås, 6,1 ºC. The largest consumer is the fan at the biofilter that correspond to half of the ventilations energy use. A compilation of the ventilation is done in appendix 5.

Turnover energy

One of the interesting aspects of this survey is comparing the different energy flows. The total use of energy at Sobacken biogas plant is 3,0 GWh of electricity and 3,1 GWh of heating per year. Of the 3,1 GWh for heating 2,58 GWh are used by the digester and the heat treatment/sanitation, the remaining 0,48 are assumed to be used as heating for the buildings of the biogas plant when no calculation of its use has been possible during this study. The production of biogas is corresponding to 17,7 GWh per year and is shown in appendix 7. There is an amount of 14,1 GWh per year that reaches Gässlösa for upgrading and distribution. Another not visual loss of energy is the release of energy from the coolers that is corresponding to approximately 0,72 GWh per year. The net use of energy, bought external and use of internal produced energy minus sold energy is about 6,6 GWh that is the amount of energy used by the plant per year. 0,1 GWh is used to heat the surrounding buildings at Sobacken and 0,4 GWh goes of to the flare.



Picture 14, turnover of energy at Sobacken biogas plant

Key figures

To make the numbers of the energy use more substantial using key figures are a good way to visualise the cost or efficiencies of the use. This is done for the receptions because that is the only subsystems that are interesting to compare to each other. The possible of comparing them are by divide the use to the amount of received waste shown in table in appendix 8. The key figures for SOR1 is 26,9 kWh/ton compared to the waste that is received and 495,6 kWh/ton for waste extracted reaching the BFT1 for further digestion. SOR2 is less efficient, 50,2 kWh/ton, comparing the actual received waste but has a better value in 63,2 kWh/ton for the waste extracted to the BFT2. SOR3 is the most efficient of the reception of waste needing processing to reach the buffer tanks. SOR3 has a key figure of 16,7 kWh/ton and 28,5 kWh/ton of reaching the buffer. The two lasting receptions are much different from the three first and much more efficient. The liquid waste need 0,7 kWh/ton the reach the buffer tanks and is the most efficient reception at the plant, logical when there is no need for any preparation to be pumped to the buffer. The reception of waste consisting high amount of solids needs 4,7 kWh/ton to reach its buffer tank.

Comments on major variations in energy use

The major variations will be between day time-night time, depending on weekday and month during the year. The receptions are only running on weekdays, during the weekend occurs no reception activities. That means that no substrate are being pumped into the buffer tanks on Saturday and Sunday. SOR 1-3, reception for liquid waste etc. are not running then, which means that their energy use occurs weekdays at day time between 6.30-16.00. That makes their use of energy limited to a certain period where the total use will be larger than the rest of the time. The other subsystems are running every day 24 hours per day, these subsystems running all days are the core of the production plant like the buffer tanks, digester and gas treatment.

Heat treatment/sanitation is running about 10 hours per day all week. Which means that its consumption of electricity and heating but also its transmission losses occur during this 10 hours. Buffer tank, BFT1 is running 24 hour a day caused by its size and because of substrate from the heat treatment is pumped to the tank after first being stored in BFT2. Only the pumps pumping to digester has a limited use, approximately 8 hours a day. BFT2 is running 24 hour but not all of its components. The stirrer has a limited time of use because how it is managed, like when the quantity of material reaches a lower limit the stirrer will be stopped. Also the pump to digester or BFT1 has a limited use about 3 hours a day. Other components such as circulation pump has a continuously operation.

Variations at the digester are pumps controlling out flow of digestate that only consume small amounts of energy every day. Circulation pumps for the shunt valve is also not running continuously but around 20 hours a day. The remaining components of the digester run continuously but variation do occur at the frequency converter controlled blower that pressurize the gas from the digester. The energy use depends on the amount of produced biogas, more gas means more work to pressurize the gas.

The storage for digestate has variation during day, there are variations of when stirrers are running but circulation operates continuously. The level of storing in the storages causes the variations, the stirrers are only running at a certain level. The out flow pump is only running at the same time as the centrifuge at the dewatering. The process of dewatering occurs during daytime and is running approximately 10 hours every day. Dewatering is a large energy consuming process that increases the energy consumption a lot when it is used. Mostly all equipment at the dewatering are operation the 10 hours except from a dehumidifiers and the reject water pump which are operating 24 hours a day. The reject water pump is not only pumping reject water to the SBR but also circulate water in the reject buffer tank.

Variation of the SBR depends of in which sequence that is running. The aerobic sequence is the large consumer of energy caused by the use of aerators. A cycle starts with a sub-cycle where of filling reject water, stirring and airing three times before the last sequences of sedimentation, decanting and sludge withdrawal. The algorithm permit one cycle a day when working correct without any problems. After a cycle an amount of water is released from the SBR, adding it to the process water or releasing it to the pond depending on the need of process water.

At the remaining subsystems Gashouse and Compressor-building no variations depending on time a day or week occurs. The huge variation is depending on the outdoor temperature. If it is cold outdoors like during the winter the gas will have a lower temperature when it reaches the gas coolers that will make de demand of cooling decrease. It is not only the lower biogas temperature that is affecting the coolers, the low outdoor temperature will also make the chillers work more easy because of the lower surrounding temperature. Both the compressor of the cooler and its condensers need to work less hard.

Water support systems use of energy depends on the use of water. If the use of fresh water increases then will the amount of energy use also increase, the freshwater will be used 24 hour/day cause of the dilution of the digester.

Identification of possible optimization

As one of the ambitions of this thesis has been to analyse it there could be any method of making the energy use more efficient at the biogas blant. During the work there has been several tracks investigated in the analyse. Four of them was taken to a more deeper analyse, assuming the cost of rebuilding e.t.c. to be able to analyse the efficiency of the different solutions.

Dewatering

When analysing the use of energy finding solutions of saving energy without large rebuildings of the plant was of interest. One interesting solution of becoming more efficient was about the work of changing centrifuges at a wastewater treatment plant in Falkenberg where a new more efficient solution of centrifuges was tried out. By not only using one frequency converter but two they made it possible to recycle the energy from the motor reversing the screw conveyor of the centrifuge. The solution made the centrifuge more energy efficient by reusing energy and did also lower the costs by terminate the cost of brake components. (Emotron). How does the centrifuge work at Sobacken biogas plant? The main centrifuge is a SD1530 from Westfalia Separator AB using two motors a primary and a secondary. The primary motor function is to make the drum and shell running, the secondary motor function is to control the difference between the drum and the screw conveyor with in the centrifuge.

The ambitions of rebuilding the centrifuged fell on its plausibility, both technically and economically. To be possible to do you had to build a new centrifuge, which would cost a lot of money. A cheaper way could have been to rebuild the existing one but that was not possible according to a company manufacturing centrifuges. When being in contact with people of Noxon AB a Swedish centrifuge manufacture they meant that it was more important to make the dewatering in a proper way than to start changing the centrifuge and making it reduce its ability to separate solids and water. The conclusion of was that it is impossible to rebuild the existing centrifuge to a reasonable cost compared of buying a new centrifuge. Also the amount of saved energy could be discussed, there where no numbers of how much it would be possible to cut the energy use. (Gustafsson) When not knowing the possible saving it would be hard to make a valid approximation of the changed cost for energy and compare it to the cost of making the investment.

Energy meters

Installing meters is one of many solutions of becoming more aware of you use of energy. By being more aware of how you use energy it is easy to save energy just trough small changes in behaviour. These small changes could in the long run be important in the work of becoming more energy efficient. There are several solutions of energy meters the simplest is a meter for 3-phase electricity that costs from 1800 to 3100. The final cost will depend on additional equipments like transformer and modules (Elfa). This kind of meters has to be connected to a computer system or could be read by hand. There is also a possibility of installing a complete information system for the assignment of continuously determining the use of electricity. Megacon AB provides a complete system for this. The system called MultiLog consists of meters connected to a system that could be reached by Internet to see the use of energy at the plant. Multilogs also have the capacity of measuring flows of water, hot water, gas, etc. Maybe there is no need of installing a new information system when it should be possible to integrate the information of energy use with in the PLC-system. (Megacon AB)

Heat exchangers

A reconstruction of the gas-cooler of the gashouse has a great potential of saving energy by using the heat of the biogas to warm the process water to the digester. The calculation gave us that there release of heat from the coolers could be 270 000 kwh/year. If it is possible to extract 70 % of this to the water added at the digester that would be 190 000 kWh/year. The problem is that the solution probably needs to install new coolers a investment of several 100 000 sek (Kylclimat). The investment of a heat exchanger and the pipelines would be a lower than the cost for new coolers. The cost of a standard plate heat exchanger of 30-60 kW would be between 15000 to 35000 sek depending on the number of plates used in the model (Ahlsells). But to work together the chiller, heat exchangers and pipes has to be installed a cost of several 100 000 sek.

Insulation

Insulation could be a cheap solution of reducing the heat transmission losses of the sanitation tanks. Just a few square meters of insulation could save more energy than the cost of the insulation would correspond to. Insulation of mineral wool has a cost from 23 sek/m^2 depending on the quality (Byggmax). Problems could be that the insulation could prevent future efficient maintenance work.

Discussion

The search for energy efficiency

The possibilities of finding potentials of optimization were not very easily done at the Sobacken biogas plant. The plant had a major reconstruction as late as 2005 and some further at 2006-2007 that makes its design very modern. In a modern design is it included to be energy efficient. It could be the design of new pumps or blowers but also the way of recover heat by heat exchanger which is done not always, but when the heat exchanger works in a proper way. Other things that you think is not optimized like the absence of heat exchangers at the ventilation units are so because the environment is not friendly to things like heat exchanger. And reusing used air it is not an option to think of, because the air becomes polluted and would cause bad environment for the workers working at the plant so there is no potential of reusing air to be more energy efficient. The reuse of water is another way of being efficient or sustainable which already exists at the plant. One of my first thought of where to find potential of optimization was the centrifuge. This was after reading about the solution at Falkenberg wastewater treatment plant to reuse energy from one of its engine and put it over to the other one by connecting the two frequency converters. A possible solution but a very large investment. Another possible option could be to investigate the possibilities of recover the heat from the coolers to heat the dilution water of the digester.

Discussion on major variations in energy use

Variations in energy use are mainly due to the disruption in production caused by need of maintenance or microbiological matters. During normal operation, the use more or less remains constant because all the machines in the process are operated according to estimations and assumptions. The variations of use is the what will be the largest influence on the energy use, but included in the variation of use of the machines will also be a variation of production. A larger use will result in a greater production of biogas. A heavier use of the plant closer to its capacity limit will increase the energy use but probably also increase its energy efficiency. The equipment will be used in the way it is designed for.

Except for the amount of using the machinery processes that will affect the consumption is the outdoor temperature, which will affect the use of heating cables and heating systems for ventilation and radiators. It is then essentially variations due to heating of buildings and processes. Circulation pumps for the heating system will be more heavily burdened and also the boilers. The need of biogas for heating will lower the output of biogas from the plant when the plant needs more heating. A conclusion of this is that a warmer surroundings makes the production more efficient.

Recomendations

Implementation of energy meters is a good investment of getting more valid data. It does not change the use it self but it helps to visualise the use and help to change pattern in the use. By being aware of the consumption you could lower the consumption even if it is not an action in it self. The cost of implement meters is very small compared to the investments made initially at the plant. If you install a new Doppstadt biopress for 500 000 sek, installing a meter to measure its energy is a small cost compared to the big investment. The cost should also be compared to the use of energy that in the case of the Doppstadt biopress is about 110 MWh/year for both biopress and mixer bin. The cost for the energy meter will also depend on the quality of the meter. A more accurate meter will be more expensive. But it depends on what you want to display, if it is a single machine you might not need to be as accurate as if you measure the use of electricity to bill a customer.

The solution of integrating it into the PLC-system is probably a more expensive solution than using a web based information system with out needs of integration or tailoring of the system. Using the system with added functions of not only the electricity use but also the use of heating could be helpful of determining a more efficient use. You would get a complete picture of the energy flows that would affect the possibilities of managing the energy systems of the plant.

I have not been able to determining the cost for other meters then the one found at Elfa, meters which have the capacity to be installed just by one or for every subsystem. Deciding the need of installation should consider the usefulness of using electricity meters. Subsystems where the use is considered to be more or less equal no matter time at year or month are not the places of greatest interest of determine the use of electricity. Determining variations of use should be more important to find out than if the use is constant. The system of greatest need of electricity meters is considered by me to be the cooler. The use of the coolers will change depending on production flow and outdoor temperature. Higher temperature means more use of the coolers and this variation could be interesting to find out in a more statistical way than done in this study.

I think the action of investing in a energy managing system for the plant is necessary. Without valid information it is not easy to make good decisions. This study is not enough to make good decisions about the energy use and possible ways of becoming more energy efficient. A map is just a calculated static picture of the reality, but if you are able to see the reality instead it will be more easy to make the correct decisions for the dynamic changes that happens in the reality. A complete system which can extract values about electricity use, heating, etc. should be considered as a future investment, especially if the flows and us of the plant changes during the future. Else it would be going hiking in the mountains with a map from the medieval, easy to get lost. There will still be a meaning of this study, the start have to be somewhere. Everything has a start so even the awareness of energy use at Sobacken biogas plant

Another of options discussed in thesis of ”saving” energy could be to install more insulation at the tanks of sanitation. If my approximations are correct there should be huge potential of lower the heat consumption of the heat treatment by just adding 0,4 m^2 of insulation of 0,1 m thickness of mineral wool. This would reduce theoretical U-value from 2000 to 0,36 and reduce the heat transmission by 190447 kwh/year. If my approximation is valid then it has a great potential of improvements, investing in insulation is not a cost compared to the potential of saving energy.

Also a solution of decreasing the use of heat could be to recover more heat by heat changers. This could be done by extracting energy from the coolers as suggested earlier in this thesis. Suitable for this could be the coolers located at the Gashouse and use the heat to heat the water added as dilution at the digester. If not having very unusual demands depending on the environment it is operated in. Another solution could be to install a cooling step using water-gas heat exchanger instead of a complete rebuilding. That kind of solution would probably, if possible, be a lot cheaper when there is no need to invest in new cooling machines. The investment would be in a heat exchanger and a further water-cooled step at the gas cooling at the gashouse.

Future work

A suggestion of further studies if possible is to do more accurate studies of the coolers and also the ventilation and building heating system. It will consume some time to work out transmission losses of the buildings but also the heat consumption of the ventilation system. The main aim of this thesis was to recover the electricity use and so has been done. A suggestion of improvements was hard to consider when the plant already had a high grade of optimization of energy use from the design. A better determining of the use of electricity by the coolers would be useful not only for knowing the use but also to approximate the secondary flow and possibility of recovering the heat released by the coolers. Added to the study could be to calculate the amount of diesel used by the wheeled loader at SOR3 to make the compilation more complete.

Conclusions

Improving efficiency is not always easy and could fail if you have a kind of local perspective. If you make changes at one subsystem it could have negative effects at other subsystem, when analysing use of energy at a biogas plant is it important to have a holistic view. Energy use is probably not the greatest issue when you judge the technique of the biogas plant. Issues like maintenance and efficiency about how much organic material you get from the waste are likely to be much more important for the plant to work as good as possible. But I suggest that their should I possible done a deeper study of the costs of installing a information system of energy use.

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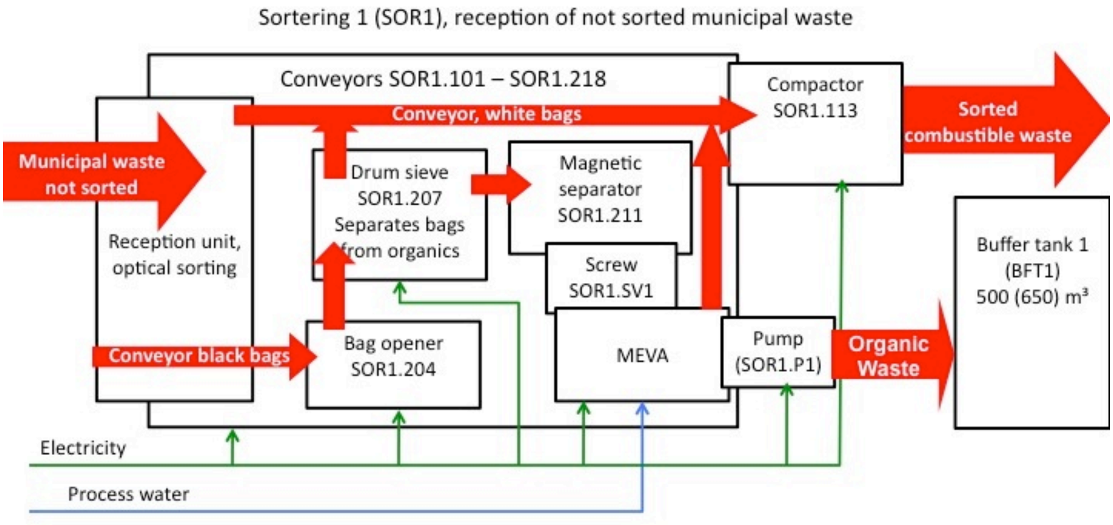
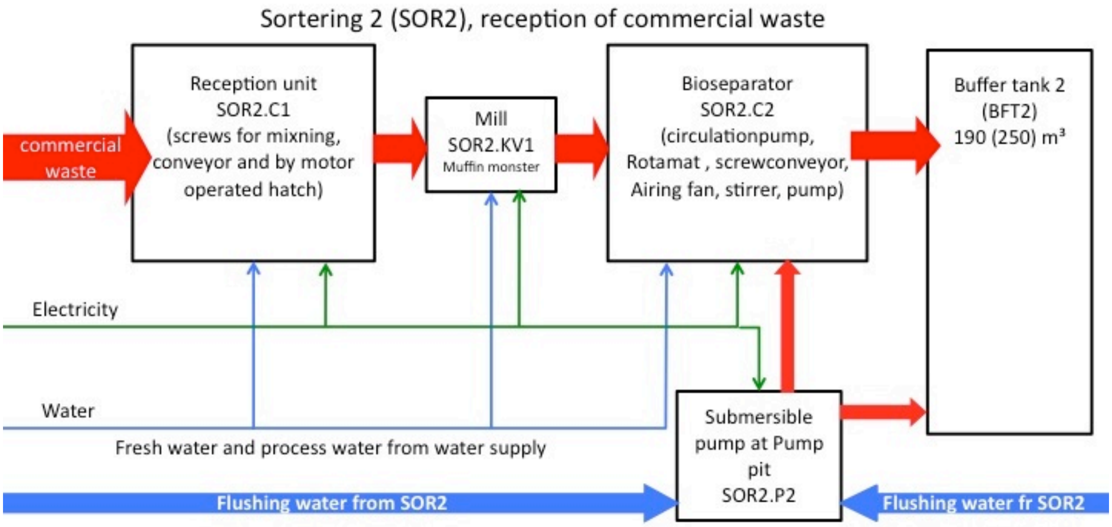
Appendix 1. Process charts the plants of Subsystems

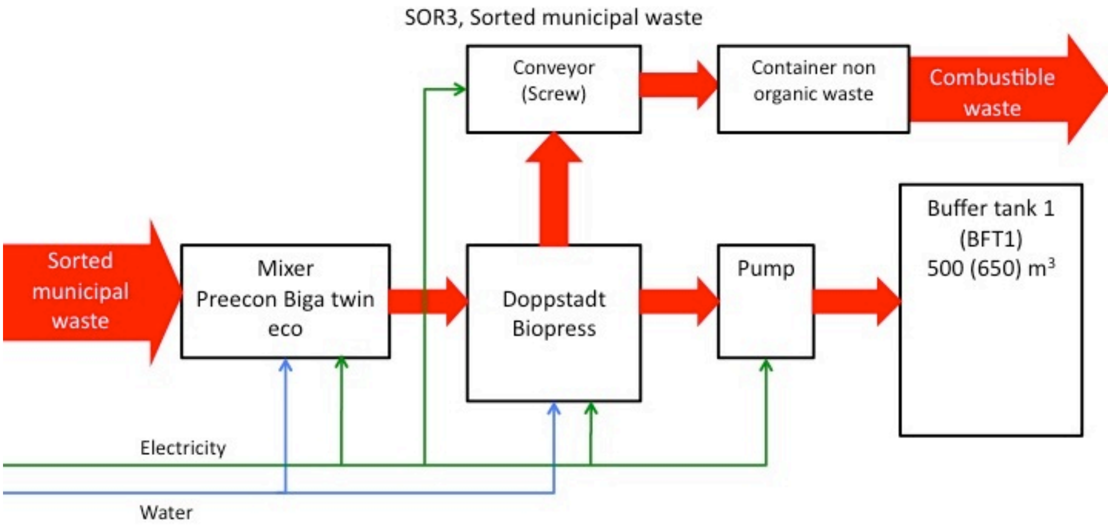
SOR1



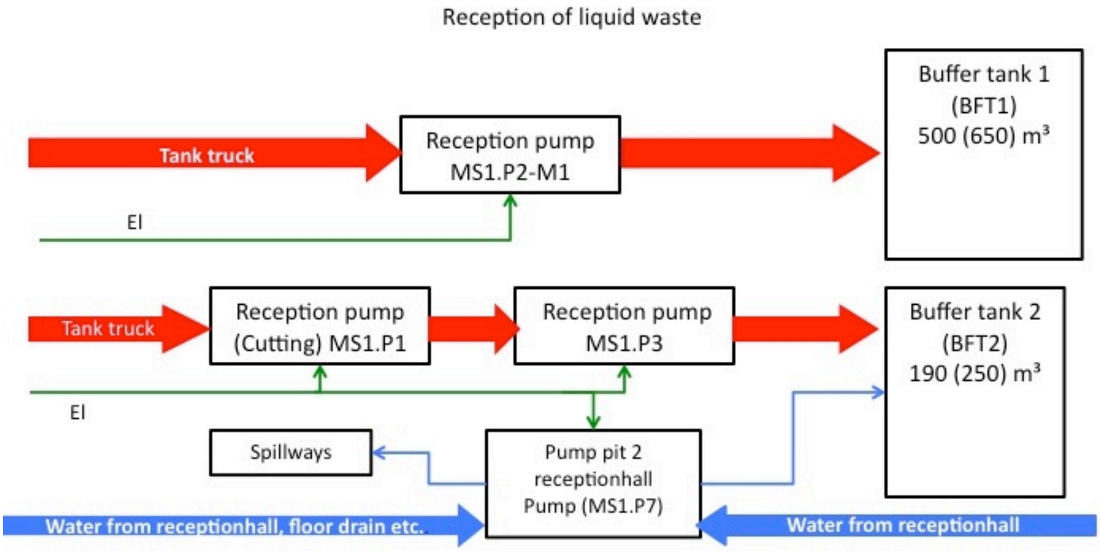
SOR2



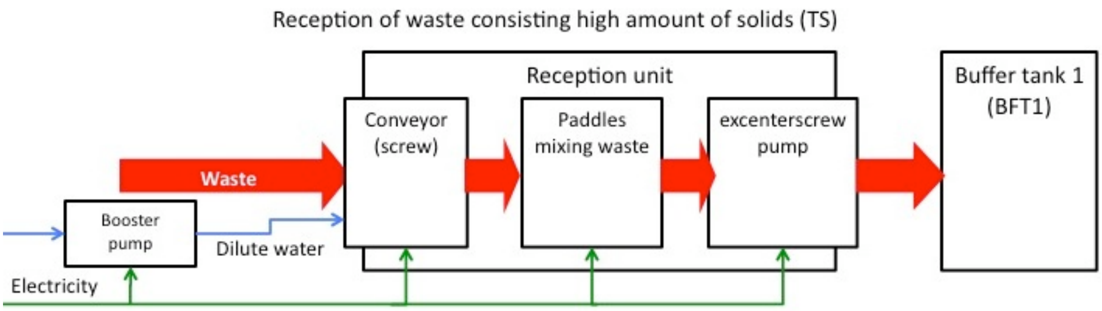
SOR3



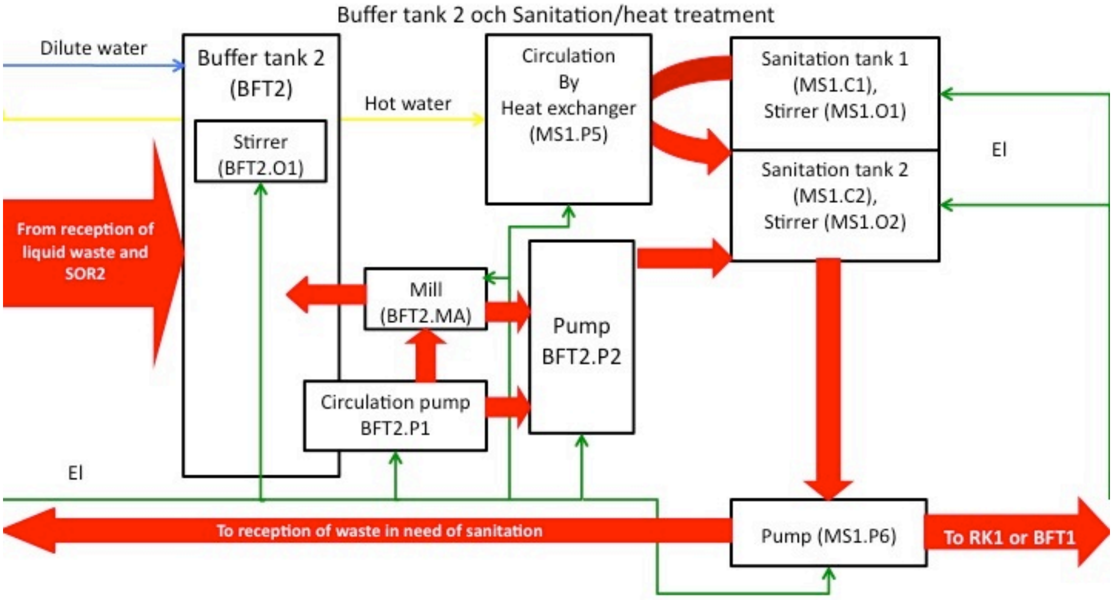
Reception of liquid waste



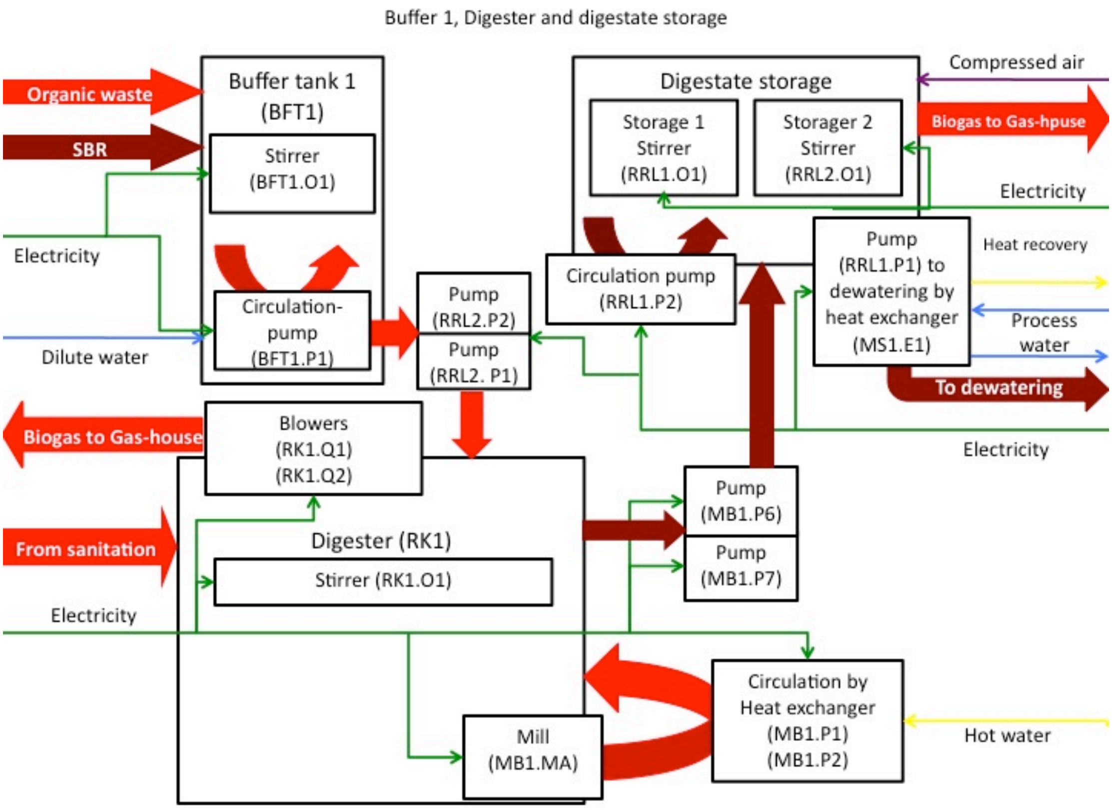
Reception of waste consisting high amounts of solids



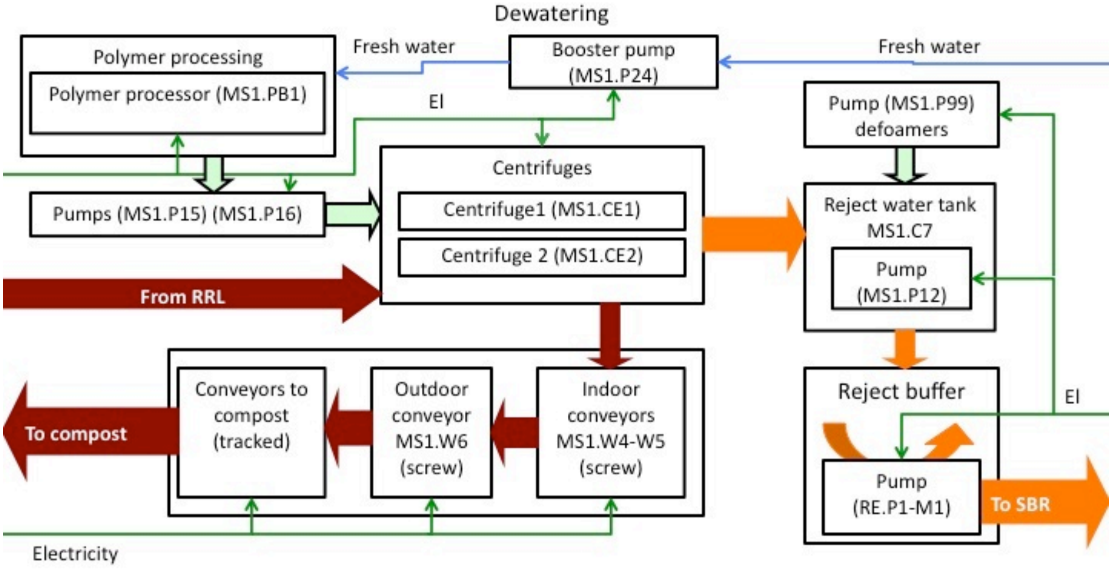
BFT2 and sanitation



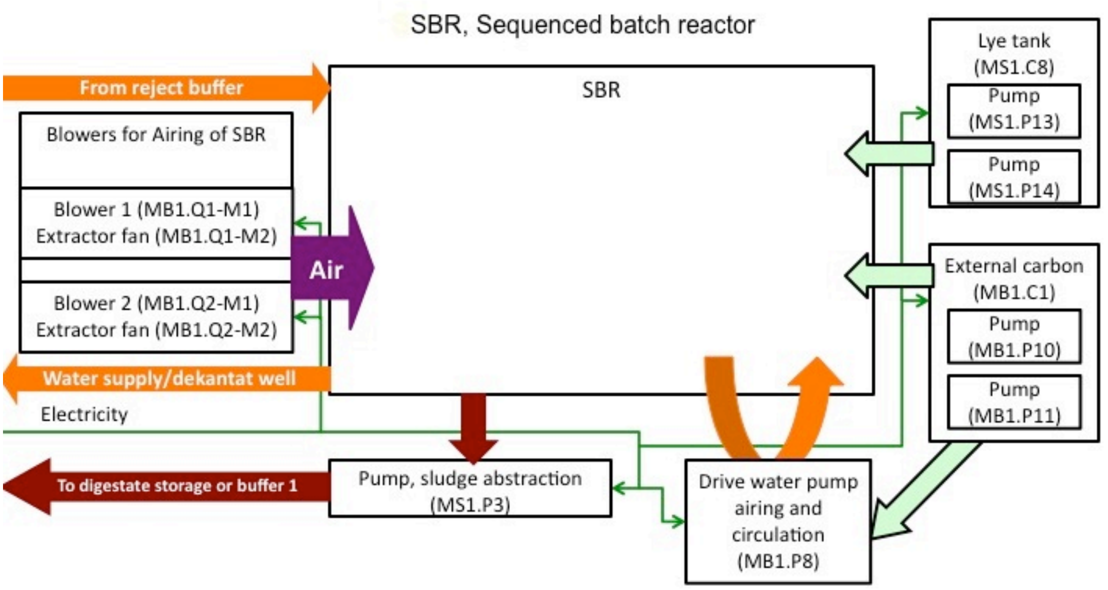
BFT1, digester and digestate storage



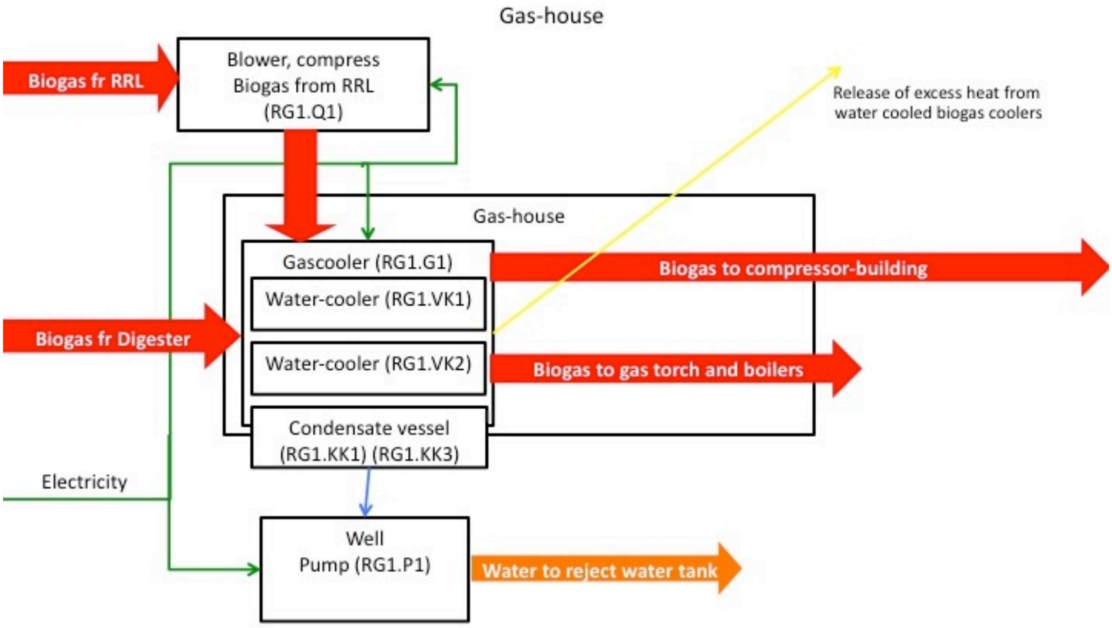
Dewatering



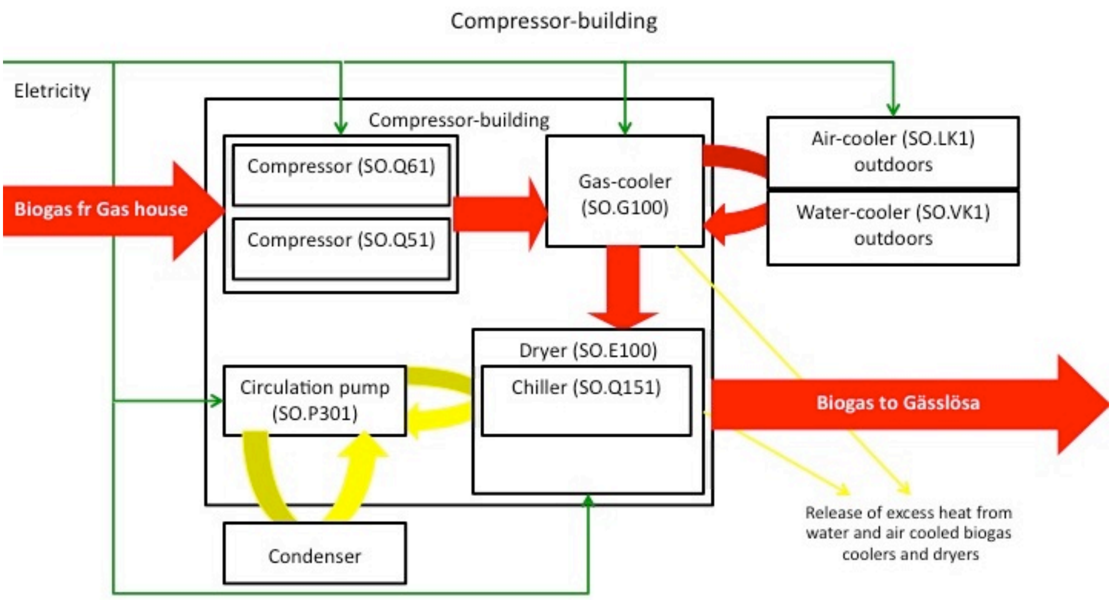
SBR-plant



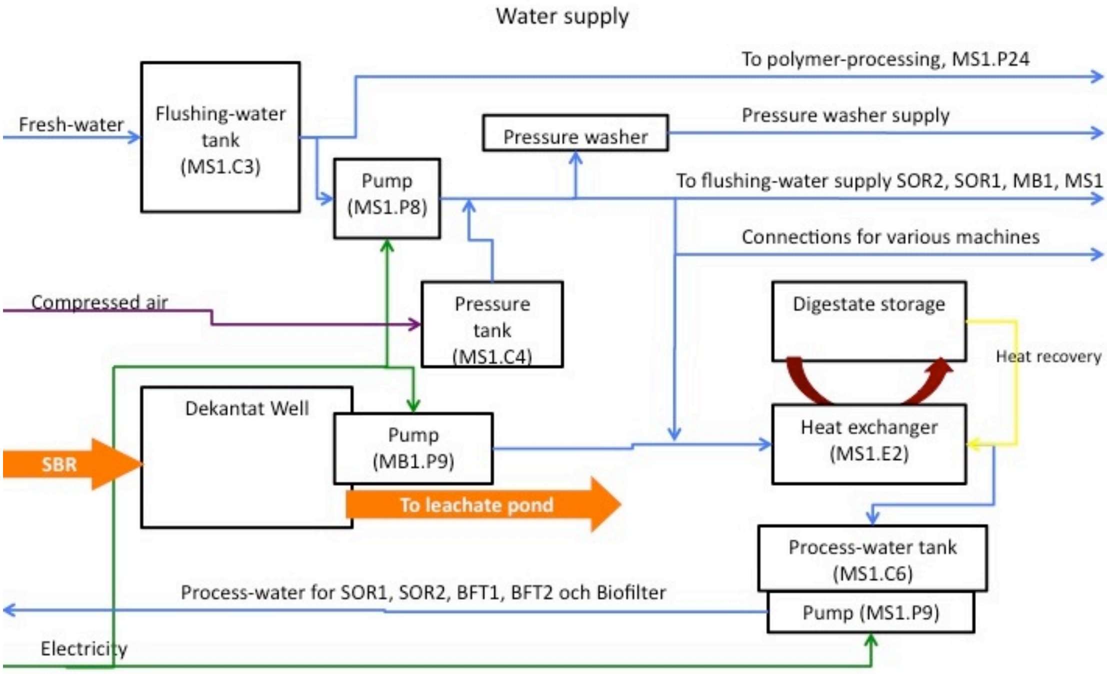
Gas-house



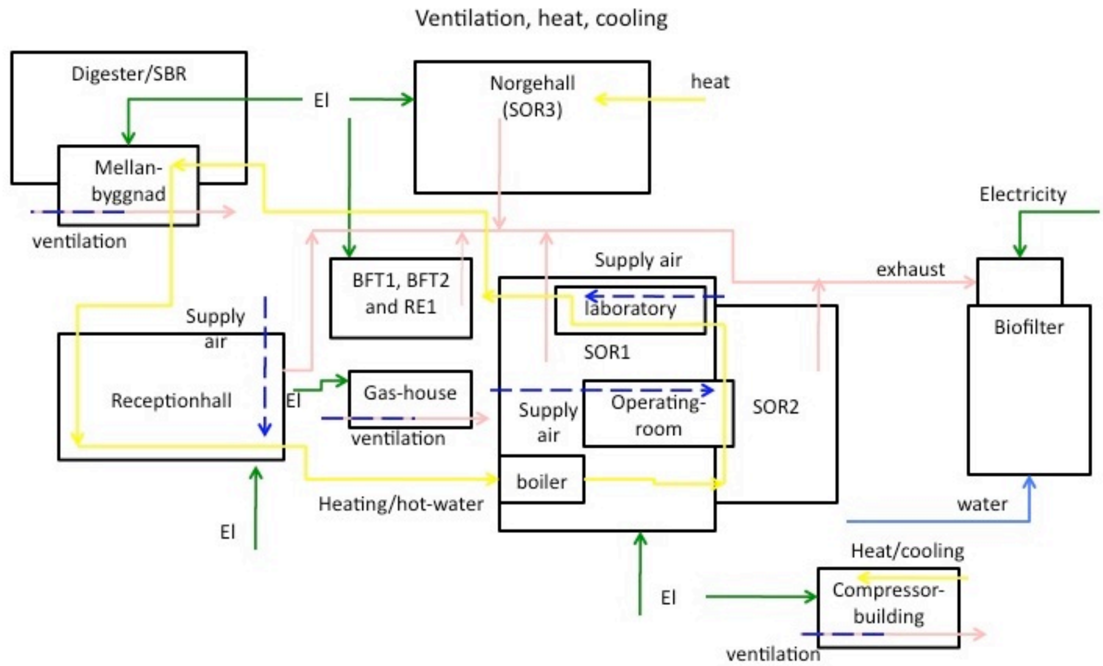
Compressor-building



Water supply



Ventilation



Appendix 2. Calculations of heat consumptions of digester

Heat through asset coefficient

$E_{transfer}$ = 8760 (h/year) x A (m^3) x U (W/m^2K) x (ΔT) = kWh/year

$\Delta T = T_{digester} - T_{outdoor}$, $T_{digester}$ = 53 ºC, $T_{outdoor}$ = 6,1 ºC

Digester thickness lamda-value U-value
Wall 0,465 m
concrete 0,255 m 1,7 1,7/0,255=6,67
insulation 0,2 m 0,033 0,033/0,2=0,165
gypsum 0,01 m 0,22 0,22/0,01=22
profiled sheet 0,052 m

U-value wall 1/(1/6,67 + 1/0,165 + 1/22) = 0,16
Ucorr = U + ΔUf + ΔUg = 0,16 + 0,01 + 0,02 = 0,19

Roof thickness lamda U
Concrete 0,36 1,7 1,7/0,36 = 4,72
Insulation 0,170 0,033 0,033/0,17 = 0,19
roof board 0,02 0,033 0,033/0,02 = 1,65
cardboard

U-value roof (1) = 1 / (1 / 4,72 + 1 / 0,21 + 1 / 1,65) = 0,164
Concrete + air + concrete = 0,08 + 0,2 + 0,08 gives U-value roof (2)
U-value roof (2) = 1 / (1 / 21,25 + 1 / 0,13 + 1 / 21,25 + 1 / 0,19 + 1 / 1,65) = 0,073
($U_{roof\ (1)}$ + $U_{roof\ (2)}$) = $U_{roof\ (average)}$ = (0,164 + 0,073) / 2 = 0,1185

$U_{corr} = U + \Delta U_f + \Delta U_g$ = 0,1185 + 0,01 + 0,02 = 0,1485

Ground plane (Pertersson s. 364-367)
U-value = 0,27 K_{insul} = 0,05 m
U = K_{floor} / Area Λ_{ground} = 2,0
B = A / (0,5 x P) = 227,47 / (0,5 x 53,25) = 8,463 a_{si} = 5,88
dt = W + Λ_{ground} x (1 / a_{si} + A / K_{insul} + 1 / a_{se}) a_{si} = 25
dt = 0,52 + 2,0 x (1 / 5,88 + 227,47 / 150,13 + 1 / 25) = 3,97
If dt < B then is K_{floor} = A x (2 x Λ_{ground}) / (μ x B + dt) x ln (μ x B / dt + 1)
K_{floor} = 227,47 x (2 x 2) / (μ x 8,51 + 3,97) x ln (μ x 8,51 / 3,97 +1) = 60,62
U = 60,62 / 227,47 = 0,27

E_{roof} = 8760 (h/year) x 227,47 (m^3) x 0,1485 (W/m^2K) x (73-6,1) = 13 878 kWh/year

E_{wall} = 8760 (h/year) x 734,33 (m^3) x 0,19 (W/m^2K) x (73-6,1) = 57 322 kWh/year

$E_{ground\ plate}$ = 8760 (h/year) x 227,47 (m^3) x 0,27 (W/m^2K) x (73-6,1) = 25 232 kWh/year

Heating of digester

$E_{enter} = Q_{enter}$ x p x C_p x ΔT
E_{enter} = added heat (kWh/day)
Q_{enter} = flow to unit (m^3/day)
p = density of sludge/water (kg/m^3)
C_p = specific heat capacity (kWh/kg x K)
ΔT = differences in temperature between entering sludge and asked digester temperature

Q_{enter} = 80 m^3/day, p = 998 kg/m^3 (Sludge), C_p = 0,00116 kWh/kg x K (Water/sludge), ΔT = 53 ºC (digester) – 42 ºC (entering substrate) = 11 K
$E_{enter} = Q_{enter}$ x p x C_p x ΔT = 80 (m^3/day) x 1000 (kg/m^3) x 0,00116 (kWh/kg x K) x (53-42 (K)) x 365 days = 372592 kWh/year

Dilution by adding 2,5 m^3 of water continiusly
Q_{enter} = 60 m^3/day, p = 998 kg/m^3 (Water), C_p = 0,00116 kWh/kg x K (Water), ΔT = 53 ºC (digester) – 8 ºC (Water supply) = 45 K
$E_{enter} = Q_{enter}$ x p x C_p x ΔT = 80 (m^3/day) x 998 (kg/m^3) x 0,00116 (kWh/kg x K) x (53-8 (K)) x 365 days = 1 140 894 kWh/year

Appendix 3. Calculations of heat consumptions of sanitation

Heat through asset coefficient

$E_{transfer}$ = 8760 (h/year) x A (m^3) x U (W/m^2K) x (ΔT) = kWh/year

$\Delta T = T_{sanitation} - T_{outdoor}$, $T_{sanitation\ treatment}$ = 73 ºC, $T_{sanitation\ warming}$ = 54 ºC, $T_{outdoor}$ = 20 ºC

Sanitation tanks thickness ʎ-value U-value
Wall 0,11 m
steele 0,01 m 20 20/0,01 = 2000
insulation 0,1 0,033 0,033/0,1 = 0,33
profiled sheet

compensation of man´s door and stirrer
steele 0,01 20 20/0,01 = 2000
Steele 0,05 20 20/0,05 = 400

U-value tank = 1/(1/2000 + 1/0,33) = 0,33
Ucorr = U + ΔUf + ΔUg = 0,33 + 0,01 + 0,02 = 0,36 = U_{tank}
U-value man`s $door_1$ = 2000
Ucorr = U + ΔUf + ΔUg = 2000 + 0,01 + 0,02 = 2000,03 = $U_{man`s\ door1}$
U-value man`s $door_2$ = 400
Ucorr = U + ΔUf + ΔUg = 400 + 0,01 + 0,02 = 400,03 = $U_{man`s\ door2}$

Mantle area = bottom cone + walls + roof – man`s door =
2,39 m^3 + 1,89 m^3 + 19,97 m^3 – 0,28 m^3 = 23,96
Area of man`s hatch1 = 0,38 $m^3$ , Area of man`s hatch = 0,28 m^3

$E_{sanitation\ warming}$ = 2 () x 7,5 (h) x 365 (h/year) x 23,96 (m^3) x 0,36 (W/m^2K) x 34 (K) = 1605,7 kWh/year

$E_{man`s\ hatch12}$ = 2 () x 7,5 (h) x 365 (h/year) x 0,38 (m^3) x 2000 (W/m^2K) x 34 (K) + 2 (st) x 7,5 (h) x 365 (h/year) x 0,28 (m^3) x 400 (W/m^2K) x 34 (K)= 162322,8 kWh/year

$E_{sanitation\ treatment}$ = 2 (st) x 5/3 (h) x 365 (h/year) x 23,96 (m^3) x 0,36 (W/m^2K) x 53 (K) = 556,2 kWh/year

$E_{man`s\ hatch12}$ = 2 (st) x 5/3 (h) x 365 (h/year) x 0,38 (m^3) x 2000 (W/m^2K) x 53 (K) + 2 (st) x 5/3 (h) x 365 (h/year) x 0,28 (m^3) x 400 (W/m^2K) x 53 (K) = 56229,5 kWh/year

Heating of sanitation/heat treatment tanks

$E_{heatsanitation} = Q_{entersanitation}$ x p x C_p x ΔT
$E_{heatsanitation}$ = added heat (kWh/day)
$Q_{entersanitation}$ = flow to unit (m^3/day)

p = density of sludge (kg/m^3)
C_p = specific heat capacity (kWh/kg x K)
ΔT = differences in temperature between entering sludge and asked sanitation/treament temperature

$Q_{entersanitation}$ = 260 m^3/week, p = 1000 kg/m^3 (Sludge), C_p = 0,00116 kWh/kg x K (Water/sludge), ΔT = 73 ºC (digester) – 25 ºC (entering substrate) = 48 K

$E_{heatsanitation} = Q_{entersanitation}$ x p x C_p x ΔT = 260 (m^3/week) x 1000 (kg/m^3) x 0,00116 (kWh/kg x K) x (48 (K)) x 52 weeks = 751288 kWh/year

Appendix 4. Heat recovery at heat exchanger MS1.E2

$E_{heatrecovery} = Q_{sludge}$ x p x C_p x ΔT
$E_{heatrecovery}$ = recovered heat (kWh/day)
Q_{sludge} = flow to unit (m^3/day)
p = density of sludge (kg/m^3)
C_p = specific heat capacity (kWh/kg x K)
ΔT = differences in temperature between entering sludge and outgoing sludge

Q_{sludge} = 140 m^3/week, p =1000 kg/m^3 (Sludge), C_p = 0,00116 kWh/kgxK (Water/sludge), ΔT = 4,5 K

$E_{heatrecovery} = Q_{sludge}$ x p x C_p x ΔT = 140 (m^3/week) x 1000 (kg/m^3) x 0,00116 (kWh/kg x K) x 4,5 (K) x 365 days = 266742 kWh/year

Appendix 5. Calculations of electricity use

The most machines will be calculated by using $P = \sqrt{3} \times U_{Measured} \times I_{Measured} \times \cos \phi$.

this because the current is set to be much higher than it is dimensioned to be in the documentation. The current is important to set the resistance between the drum and the screw of the centrifuge. A higher current makes a higher grade of dewatering which could be seen as a more efficient dewatering. The power used by the centrifuge will be.

$P = \sqrt{3} \times U_{Measured} \times I_{Measured} \times \cos \phi = \sqrt{3} \times 400 \times 205 \times \cos 0{,}89 = 89$ kW

SOR1

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Conveyors	46,8		7	81,6
Bag opener, SOR1.204	15		7	27,1
MEVA/magnetic tape	12,25		7,2	16
Compactor (SOR1.113)	5,5 (2x5,5)		6,75	9,65
Summary				134,35

Unit/component	Installed power (kW)	kWh/h	Kwh/day	kWh/year
Conveyor (SOR1.101)	2,2	0,74	2,1	408,44
Conveyor (SOR1.102)	2,2	1,64	6,6	2793,82
Conveyor (SOR1.115)	2,2	0,37	7,2	694,91
Drum sieve (SOR1.207)	30	2,62	7	4760,36
Weighing-conveyor (SOR1.SV1)	2,2	0,06	7,8	123,38
Pump (SOR1.P1)	3	0,83	7,3	1575,29
Summary				10356,2

SOR2

Units/compnents	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Reciving unit	44	46,8	6,14	74720
Muffin Monster (SOR2.KV1)	7,5		6,17	12030
Fan bioseparator (SOR2.TF1)	2,2	3,3	24	28908
Pump pit (SOR2.P2)	2,4	2,3	1	598
Summary				116256

Units using frequency converter	Installed power (kW)	kWh/h	kWh/day	kWh/year
Conveyor (SOR2.W5)	11		0,81	212
Pump (SOR2.P3)	2,2		14,1	3664
Rotomat (SOR2.RO1)	4		3,86	1003

Conveyor (SOR2.W6)	0,55		0,72	186
Pump (SOR2.P1)	4		2,51	654
Summary				5719

SOR3

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Doppstadt biopress	60,5			62920
Conveyor	4			4160
Summary				67080

Units using frequency converter	Installed power (kW)	kWh/h	kWh/day	kWh/year
Precoon Bga twin eco	75			40193
Pump	4			1390
Summary				41583

Reception high dry solids

Unit/components	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Booster pump	0,37		2,13	205
Paddles	4		2,13	2214
Summary				2419

Units using frequency converter	Installed power (kW)	kWh/h	kWh/day	kWh/year
Reception conveyor			0,08	23,8
Pump	4		6,2	1628
Summary				1652

Reception liquid waste

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Pump (MS1.P1)	18,5	16,5	1,05	4491
Pump (MS1.P3)	4	4,1	1,05	1116
Pump (MS1.P7)	2,4	2,25	0,8	468
Summary				6075

Units using frequency converter	Installed power (kW)	kWh/h	kWh/day	kWh/year
Pump MS1.P2	30		1,62	421
Summary				421

BFT2 and sanitation/heat treatment

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Stirrer (BFT2.O1)	5,5		12,5	25071
Mixer (BFT2.MA)	1,5	1,7	24	14892
Circulation pump (BFT2.P1)	7,5	7,2	24	63072
Stirrer (MS1.O1)	2,2	2,5	7,5	6834
Stirrer (MS1.O2)	2,2	2,5	7,7	6986

Circulation pump (MS1.P5)	4	3,9	7,4	10581
Pump heating (MS1.P22)	0,44		7,5	1212
Summary				128648

Units using frequency converter	Installed power (kW)	kWh/h	kWh/day	kWh/year
Pump (BFT2.P2)	3		0,33	122
Pump (MS1.P6)	2,2		5,9	2164
Summary				2286

Digester, BFT1 and digestate buffer

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Stirrer (BFT1.O1)	15	13,8	23	116022
Circulation pump (BFT1.P1)	9,2	7,2	24	63071
Stirrer (RK1.O1)	6,8	7,5	23,7	64757
Mill (MB1.MA)	4		24	35008
Circulation pump (MB1.P1)	15	13,8	5,7	28543
Circulation pump (MB1.P2)	11	10,8	17,6	69335
Heating pump (MB1.P13)	0,44		24	3854
Stirrer (RRL1.O1)	1,5	1,8	9,1	5943
Stirrer (RRL2.O1)	2,2	2,5	5,0	4594
Pump (RRL1.P2)	5,5	6	24	52560
Summary				443687

Units using frequency converter	Installed power (kW)	kWh/h	kWh/day	kWh/year
Pump (RRL2.P1)	4		5,0	1829
Pump (RRL2.P2)	4			
Pump (MB1.P6)	4		1,6	581
Pump (MB1.P7)	4			
Blower (RK1.Q1)	11		67,5	24652
Blower (RK1.Q2)	11		62,9	22967
Pump (RRL1.P1)	7,5		3,27	101
Summary				50130

Dewatering and SBR-plant

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Booster pump (MS1.P24)	1,5			383
Humidifier	2,1			18396
Polymer mixer (MS1.PB)	2,3		5,7	2215
Centrifuge (MS1.CE1-M1)	35	89	10	325560
Centrifuge (MS1.CE2)	22		0,12	1015

Conveyors (MS1.W4-W6)	11,8	12,2	10,8	47870
Conveyors tracked	9		10,6	34600
Pump defoamers (MS1.P99)	0,39		10	1400
Blower (MB1.Q1-M1)	90	65	10,3	245158
Blower (MB1.Q1-M2)	0,75	0,45	11,2	1833
Blower (MB1.Q2-M2)	0,75	0,45	11,2	1835
Pump circulation (MB1.P8)	45	35,7	16,4	212280
Lye pumps (MB1.P13-P14)	0,18 (2 x 0,18)		6,43	420
Carbon source pumps (MB1.P10-P11)	0,18 (2 x 0,18)		0,11	160
Summary				893125

Units using frequency converter	Installed power (kW)	kWh/h	kWh/day	kWh/year
Pump (MS1.P15)	0,75		1,0	366
Pump (MS1.P16)	0,75		0,01	4,4
Pump (MS1.P12)	5,5		41,44	15128
Centrifuge (MS1.CE1-M2)	15		27,2	9942
Pump (RE.P1)	5,5		122,5	44727
Blower (MB1.Q2-M1)	90		822,9	305036
Pump sludge abstraction (MB1.P3)	5,5		0,25	53,5
Summary				375257

Gas-house and compressorbuilding

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Water cooler (RG1.VK1)	8,2 (1,1 + 5,8)		24	47391
Water cooler (RG1.VK2)	13,7 (1,1 + 8,6)		24	30842
Pump (RG1.P1)				
Biogas cooler	26,5 (1,1 + 8 + 9,2 + 0,9 + 1,9)		24	23800
Dryer	10,62		24	86615
Pump and condensor	6,3			55188
Summary				243836

Units using frequency converter	Installed power (kW)	kWh/h	kWh/day	kWh/year
Blower (RG1.Q1)	3		23	8400
Blower (SO.Q51)	18,5		76,6	27969
Blower (SO.Q61)	18,5		83,9	30607
Summary				66976

Water supply

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Pump fresh water (MS1.P8)	7,5			35001
Dekantat well (MB1.P9)	11	10,5	1,1	4053
				39054

Units using frequency converter	Installed power (kW)	kWh/h	kWh/day	kWh/year
Process water pump (MS1.P9)	5,5		28,8	10506
				10506

Heat cables

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
Heating cables	20,08		10,9	79517

Lightning

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
SOR1/SOR2	14,78		10	38428
Outdoor	5,08		5,5	10198
MS1	6,52		10	16952
SOR3	2,78		10	7228
SOR3	6,96			
BFT1, BFT2, RE, RLL	0,72		10	1872
MB1, RK1, SBR, indoor	0,94		10	2444
MB1, RK1, SBR, outdoor	3		1	156
Gas-house, indoor	0,23		0,5	42
Compressor-building, indoor	2,11		0,5	275
Compressor-building, outdoor	0,42		24	3679
Summary				129466

Ventilation

Unit/component	Installed power (kW)	Calculated power (kW)	Hours/day	kWh/year
SOR1	1,08		24	7113
SOR1-heating/cooling			24	47000/3700
BFT1, BFT2	0,54		24	4730
MB1	0,98		24	8585
RRL	0,37		24	3241
RG1	0,1		24	876
Compressor-building	0,13		24	1139

Units using frequency converter	Installed power (kW)	kWh/h	kWh/day	kWh/year
SOR1.FF	3,5			8586
MS1.TF1	4		16,7	6088
MS1.FF1	4		13,1	4767
SOR2.FF1	3		29,3	10702
SOR2.FF2	30		264,3	96464
Summary				195291

Appendix 6. Calculations of possible heat recovery coolers/chillers

Unit	Electricity use (Kwh/yr)	COP-value	Cooling (kWh/yr)
Compressor (RG1.VK1)	25185	4,19 (3,6)	105525 (90666)
Compressor (RG1.VK2)	48618	4,96 (3,46)	241145 (168218)
Compressor (SO.VK1)	8605	3 (4)	25815 (34420)
Dryer (SO.Q151)	86615	4	346400
Summary			718885 (639704)

Appendix 7. Flows of biogas

Biogas production	m^3/h	081101-091031 (m^3)	081101-091031 (kWh) at 67,4 % methane
To process boiler	51,8	453496	3056586
To building boiler	1,3	11292	76107
To flare	7,1	62429	420777
To Gässlösa	239	2094062	14114080
Summary	299,2	2621279	17667550

Appendix 8. Turnover waste reception.

Reception	Received waste (To Buffer), July, tons	Received waste (To Buffer), August, tons	Received waste (To Buffer), September, tons	Approximated for 2009, tons
SOR1	362 (-13)	468 (90)	516 (-4)	5384 (292)
SOR2	155 (115)	168 (149)	214 (163)	2148 (1708)
SOR3	431 (279)	418 (137)	779 (531)	6512 (3788)
High amounts of solids	55 (55)	86 (86)	64 (64)	820 (820)
Liquid to BFT1	16 (16)	262 (262)	289 (289)	2268 (2268)
Liguid to BFT2	633 (633)	726 (726)	610 (640)	7876 (7876)
summary	1652 (1098)	2146 (1450)	2472 (1687)	25008 (16752)