

# Opportunities for increased heat recovery in the secondary heating system at an NBSK pulp mill

Master's thesis in MPSES-Sustainable Energy Systems

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DEPARTMENT OF Environmental and Energy Sciences, ENV

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2026

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Cover: Simple process flow diagram of the Secondary Energy System

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## Abstract

This thesis investigates the energy balance of a kraft pulp mill, with a particular focus on identifying and evaluating the potential for utilizing low-grade waste heat. The study is based on process data from SCA Östrand and examines how excess heat, primarily in the form of warm wastewater, can be recovered and used in external or integrated systems. An energy balance model was developed using averaged operational data over selected time periods. The total incoming and outgoing energy flows were quantified, including contributions from process streams, heat exchangers, and wastewater. The results indicate that a significant portion of energy leaves the system as low-temperature heat, representing an opportunity for improved energy efficiency.

Several utilization pathways for this excess heat were assessed, including vertical farming, aquaculture, and insect (larvae) production. These alternatives were evaluated from a technical and practical perspective, considering temperature levels, scalability, and integration with existing mill operations.

The findings show that while internal heat recovery is limited by process constraints, external applications of waste heat present viable opportunities. The total amount of waste heat available at temperatures exceeding 25 °C was approximately 55-110 MW, depending on season and year. Among the evaluated options, larvae production and aquaculture demonstrate the most promising balance between feasibility and energy utilization. However, economic and operational factors remain critical for successful implementation.

Overall, the study highlights the potential of industrial symbiosis as a means to increase resource efficiency and reduce energy losses in pulp and paper production.

Keywords: Secondary energy system, Energy balance, Energy, Heat, Process flow diagram, Waste heat, Secondary heating system



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I would like to thank everyone at SCA Östrand for making me feel supported and welcome. Special thanks to everyone who helped me with my calculations, held informative presentations and was my sounding blocks when needed. My deepest thanks go to Lovisa and Robin for being my supervisors and making sure I had everything I needed. I will miss my time at SCA Östrand and all the lovely people I met there. Also thank you to Simon Harvey for being my examiner and Daniel for agreeing to be my opponent.

MILLY LIEBACK, Gothenburg, February 2026



# Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order and with page references for when they are used:

**EB** Energy Balance. 5, 10, 12, 33, 35, 45, 50–52

**ECF** Elemental Chlorine Free. 10

**ISO** International Organization for Standardization. 10

**LP** Low Pressure. 21, 22

**NBSK** Northern Bleached Softwood Kraft. 1, 2, 4, 42

**PFD** Process Flow Diagram. xiii, xv, 2–4, 6, 12–18, 20, 21, 29, 38, 45, 49, 50, 52, I

**SAF** (Sustainable Aviation Fuel; jet-range hydrocarbons, C8–C16). 42

**SES** Secondary Energy System. xv, 4, 6, 53

**SHS** Secondary Heating System. xv, 1–7, 10–13, 15–17, 23, 29, 30, 32–35, 43, 45, 50, 52

**TCF** Totally Chlorine Free. 10



# Nomenclature

Below is the nomenclature of indices, parameters, variables and arrow colors that have been used throughout this thesis to calculate or illustrate energy entering and leaving the system.

## Indices

$i, j$	Indices meaning any stream
$in$	Indice for stream entering the system boundary
$out$	Indice for stream exiting the system boundary
$avg$	Average value







## Parameters

Symbol	Unit	Description
$Q$	MW	Thermal energy rate [Heat]
$\dot{m}$	kg/s	Mass flow rate of fluid
$H$	kJ/kg	Specific enthalpy
$\Delta H$	kJ/kg	Change in specific enthalpy
$c_{p,water}$	kJ/kgK	Specific heat capacity
$T_{in}, T_{out}$	°C	Inlet and outlet temperature
$\dot{V}$	m <sup>3</sup> /h	Volumetric flow of fluid
$\Delta T$	Temperature difference	K
$\rho_{water}$	Density of water	kg/m <sup>3</sup>

## Variables

$H_i$	Enthalpy for different streams $i$
$T_i$	Temperature for different streams $i$
$m_i$	Mass flow for different streams $i$

## Colors in figures

Arrow style	Type of stream	Color
	Fresh water	Blue
	49 °C warm water	Yellow
	65 °C medium warm water	Orange
	85 °C hot water	Red
	LP-steam	Purple
	Wastewater	Black

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# 1

## Introduction

### 1.1 Background

SCA is a company specializing in forest-based products, such as Northern Bleached Softwood Kraft (NBSK) pulp [5], containerboard [6] and wooden building materials [7]. SCA Östrand is a leading producer of NBSK sulphate pulp [5], but it was only after 2002 that SCA Östrand became solely focused on Softwood pulp. During the following years many new improvements were made, for example a new recovery boiler, a steam turbine and a mesa oven (lime kiln), which are of interest for the energy recovery system and the white liquor recovery (a cooking chemical used in the digester). In 2014 a new project called Helios was initiated to modernise the mill and increase the NBSK pulp production to the current capacity of 900 000 ton per year while increasing heat recovery. The improved plant started operations in 2018 [8]. The Helios project aimed to double the capacity of producing NBSK pulp from 430 000 to 900 000 ton per year, making it the largest mill of its kind [9][10][8]. Besides increasing production, the project also aimed to minimize emissions, increase resource efficiency and sell excess energy as district heating to the surrounding area[11]. This was achieved by building:

- An entirely new fiber handling line, consisting of new boiling and bleaching equipment [10][11]
- A new wood processing line [9][11]
- A new pulp drying system [9] and two new baling lines, where the NBSK pulp is dried into sheets which are packaged into bales for sale [10][11]
- A new larger recovery boiler [9] and equipment for concentration by evaporation for white liquor recovery[10][11]
- A new operations center [10][11]
- A new water cleaning plant [10][11]
- And the SHS (Secondary Heating System) for recovering heat from process streams were updated and expanded[10].

The project and the impact on the SHS will hereafter be referred to as "Project Helios". It is known that some chemical process unit operations require energy (endothermic) whereas other chemical operations release energy (exothermic)[12], meaning processes at the mill produce and consume energy. The SHS consist of heated water streams, available for use instead of using primary heat (steam) to heat parts of the process. This is done since steam has a high value, both in energy content and economical value, meaning it should not be wasted where it can be avoided. The SHS is separated into 45°C, 65°C and

## 1. Introduction

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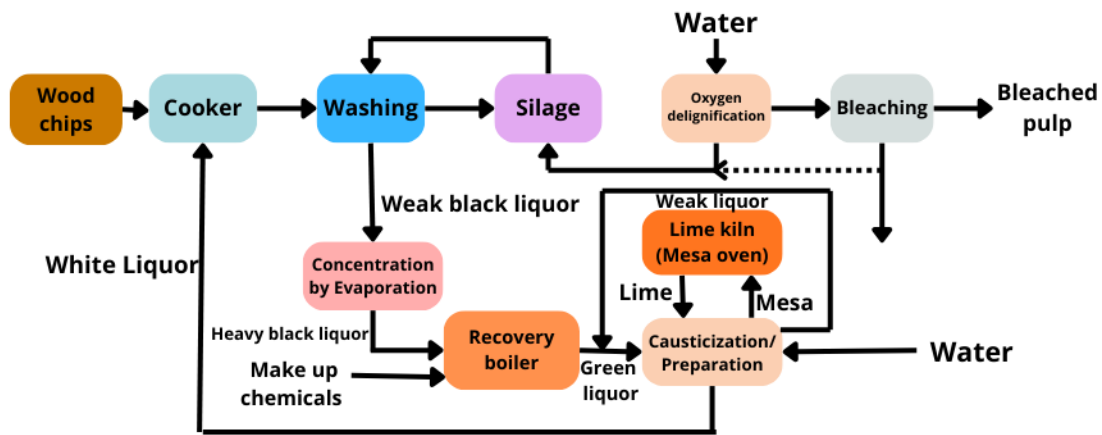
85°C utility water for the facility, where most of the 85°C water is sold as district heating (hereafter denoted SEAB for Sundsvall municipality and ADVEN for Timrå municipality), a simplified Process Flow Diagram (PFD) can be seen in Figure 1.3 below. The 65°C water is used for process steps, the ventilation, producing 85°C water and more. The 49°C water on the other hand is mostly used to produce higher energy process streams, like 65°C or 85°C, along with using it for some process steps. There is often more 49°C water in the system than can be used, so some of it goes to waste.

The SHS is the central part of this project. In figure 1.3 the *heavy black liquor from white liquor recovery* is fired in the recovery boiler, where white liquor is used as a cooking chemical to produce the NBSK pulp and after use the white liquor is called diluted black liquor or black liquor [13]. The diluted black liquor is then evaporated into heavy black liquor used as fuel in the recovery boiler [14].

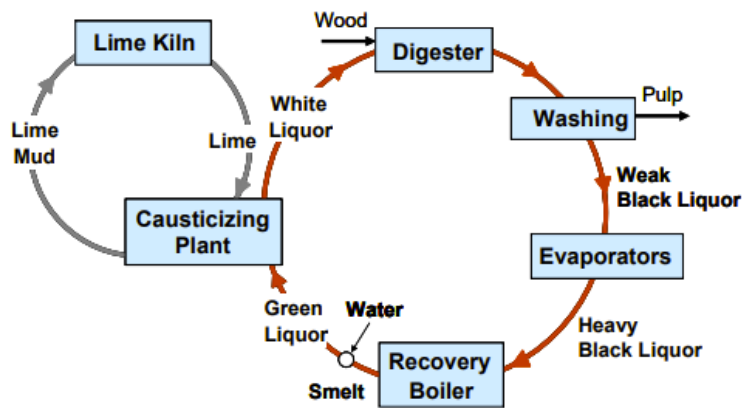
Through the recovery boiler and other recovery steps, the white liquor cooking chemical is regenerated. The white liquor recovery process from the black liquor is 98% effective and requires only 2% new white liquor [15]. For economical and energy recovery purposes, the white liquor recovery process is vital. For economic reasons, white liquor recovery is of particular interest, as the use of entirely fresh white liquor entails high costs. In addition, the recovery process provides opportunities for steam and electricity generation, thereby improving the overall economic performance of the process. White liquor is used in the digester and washed out from the sulphate mass in the washing as can be seen in pictures 1.1 and 1.2.

After the washing process, the spent white liquor is called weak black liquor. After being evaporated, the weak black liquor minimizes the water content and becomes heavy black liquor, before entering the recovery boiler[14]. In the recovery boiler the residual product, lignin and other dissolved residuals, in the black liquor are combusted. This results in a smelt, including the chemical components for the white liquor recovery. Only about 47% of the woodchips into the digester will actually become NBSK pulp, the other 53 % will be utilized in the recovery boiler for energy [16]. These 53 % consist of the lignin, hemicellulose and other parts of the feedstock which are not suited for sulphate pulp production. Green liquor is produced by mixing smelt with weak liquor, the latter consisting primarily of water. Mesa is a residual product or rather an intermediate product in the recovery cycle of the pulp mill, consisting of calcium carbonate burned in a mesa oven (lime kiln) to become lime, which can be mixed into the green liquor to yield the desired white liquor [1][2]. The recovery of white liquor is part of the general energy system, as heat and electricity are produced in the recovery boiler. The heat and electricity produced can be used in the mill or for district heating and electricity grid.

Figure 1.1 displays an overview of the NBSK pulp process, from wood chips to wet pulp, including the white liquor recovery [1] and Figure 1.2 displays more clearly the kraft recovery process (white liquor recovery) [2]. In Figure 1.1 a weak liquor is mentioned, not to confuse with weak black liquor. The weak liquor is a water heavy stream containing small amounts of white liquor chemicals and mesa.



**Figure 1.1:** PFD of pulp production including white liquor recovery, from source [1] translated to English



**Figure 1.2:** White liquor kraft recovery, from source [2]

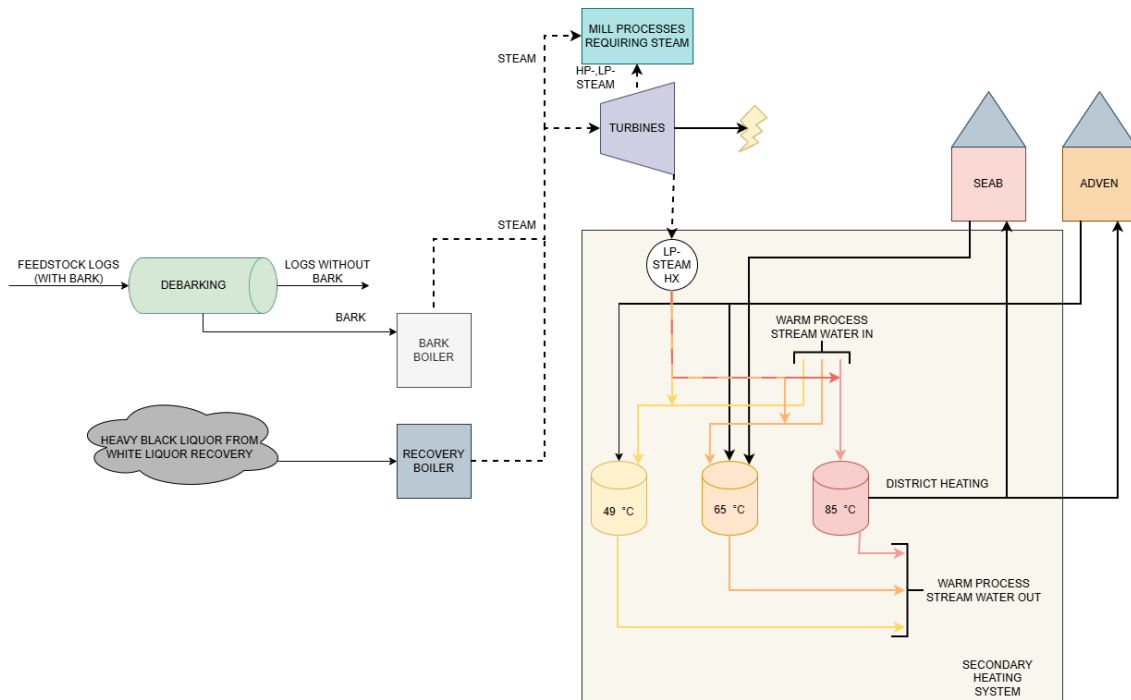
To reduce waste, the entire tree is utilized at the mill, therefore the bark boiler is used to incinerate bark to produce both heat and electricity for the process as well as district heating and electricity for sale. The NBSK pulp process utilizes the heat produced both in the boilers and during the process for heat consuming process steps, like drying the pulp. The amount of electricity and district heating produced in the mill and exported to the grid can be seen in Table 1.1, along with other key mill data.

The SHS has seasonal variations mainly in district heating, as during winter both Timrå (in which the mill is located) and Sundsvall (neighboring town) are in need of district heating. During summer months only Timrå is in need of district heating, since Sundsvall heat demand is satisfied by other sources. Therefore there is a cooling need for the excess 85 °c water in the summer months, which requires a lot of cooling water and the use of cooling towers. During the winter months the incoming process cooling water is colder and thus the streams will need more heating to reach the required temperatures and heat losses in pipes are higher. More heat will also be required for pre-heating the logs at the start of the process as they may be frozen.

# 1. Introduction

Key mill data	Value	Unit
Production capacity of the NBSK pulp	900 000	tonnes/year
Feedstock supply rate	4.5	Mm <sup>3</sup> wood/year
Electric power generation	1100	GWh/year
Electric power usage on-site	600	GWh/year
Electric power sales	500	GWh/year
Maximum export capacity of district heating	185	GWh/year
Export of district heating 2024 total	142	GWh/year
Excess process heat used for district heating 2024	72	GWh/year
Primary heat (steam) used for district heating through steam condensers 2024	70	GWh/year

**Table 1.1:** Key mill data for SCA Östrand [3][4]



**Figure 1.3:** Simplified PFD of the SES

In preparation for Project Helios, a detailed model of the SHS was developed and opportunities for increased heat recovery were identified. This PFD for project Helios was 10+ years old and thus in need of updating. In Figure 1.3 a simplified PFD of the current SES is displayed and later on the new PFD for the SHS will be presented. The difference between the SES (Secondary Energy System) and the SHS (Secondary Heating System) can be seen in Figure 1.3, where the SES includes all electricity and heat produced by the boilers, whereas the SHS consist only of the streams within the box in the figure. The SHS will be explained more later but generally it is a system designed to reuse energy in the form of heat to minimize energy losses.

The Energy Balance (EB) for the system is affected by how primary heat (steam) is utilized, whether for electricity production, process heat, or district heating. Utilizing excess heat within the process reduces the demand for steam in the mill. This decreases the need for primary heat production, which is beneficial from both an economic and environmental perspective.

In the turbine systems of this plant, steam can be extracted at different turbine pressures or even bypass the two turbines. Bypassing the turbines can be done to alleviate some specific mill operation problems. Forcing the steam to bypass the turbines can also be done to increase the pressure of the steam in the outlet header connected to the turbine. A reduction in process steam demand may allow a larger fraction of the steam to expand through turbines, thereby increasing electricity generation. However, this is dependent on the system configuration and operational constraints.

Depending on the turbine configuration, steam at different pressure levels is produced. When steam expands through all turbine stages, low-pressure steam is generated, which can be utilized in the secondary heating system. Saving low-pressure steam does not significantly increase electricity production, as most of the available energy has already been extracted during expansion through the turbines.

There are limits to how much steam can be diverted to electricity generation, as sufficient steam must remain available for essential processes and to meet district heating demands. Additionally, turbine capacity constrains the maximum amount of steam that can be used for power production.

The mill requires primary heat (steam) for certain endothermic processes, and there is also a contractual obligation to supply district heating to surrounding areas. Therefore, a minimum steam demand must always be met. While improvements to the SHS can reduce the need for primary heat by utilizing secondary heat sources, it is important that such changes do not negatively affect other parts of the process.

### 1.1.1 Previous Studies

Previous studies of similar pulp mills have identified significant energy-saving potential through the utilization of excess heat. In early investigations, the primary focus has been on reducing primary heat (steam) consumption. For example, a study conducted at Södra Cell Värö by a Chalmers master's student reported steam savings of 1.03–1.15 kg/s, depending on seasonal conditions [17]. In 2015 a pinch analysis for SCA Östrand was made by Chalmers students in preparation of project Helios. The Master thesis aimed to reduce steam usage and increase heat recovery resulting in two possible SHS solutions [18]. Research at the SCA Obbola mill, comparable to SCA Östrand, emphasized minimizing primary heat usage, particularly due to the absence of an implemented heat recovery system [19]. Another study from Lund University estimated a primary energy-saving potential of at least 6.8 MW [20].

Collectively, these studies highlight the substantial availability of excess heat in pulp mills and demonstrate that further efficiency improvements are consistently achievable. The study at Södra Cell Värö also accounted for seasonal variations, noting that reduced district heating demand during summer necessitates increased cooling to manage excess energy [17]. This seasonal dependency is likewise relevant to the present study, especially

given the considerable energy losses observed during summer operation.

Additional research includes a doctoral thesis from Lausanne (2018), which presents a comprehensive methodology for conducting detailed energy reviews [21]. While primarily methodological in nature, its existence underscores the broader need for systematic energy assessments. The practical importance of such reviews is further illustrated by an article by Jörgen Persson, which investigates seasonal variations in a SHS. The study identified savings potentials of 16.5 MW in primary energy and 24.2 MW in secondary energy, with seasonal variations reducing the total savings potential by 2.5–5 MW [22]. This highlights the importance of considering both seasonal effects and secondary energy utilization.

Finally, the revised EU Energy Efficiency Directive, which entered into force in 2023, requires energy-intensive industries to conduct energy audits or implement certified energy management systems [23]. SCA Östrand produces approximately 1.1 TWh of electricity and up to 185 GWh of district heating annually (see Figure 1.1). Given that Sweden's total electricity consumption in 2023 was 125.27 TWh [24], SCA Östrand accounts for roughly 0.88% of national consumption. This clearly indicates that the directive applies to SCA, reinforcing the need for a comprehensive energy mapping of the SHS and the mill as a whole [23].

## 1.2 Purpose

Since Project Helios started in 2014 [8], SCA Östrand has undergone several reconstructions. As a result, there is no accurate PFD of the SHS. An accurate PFD will facilitate understanding of the SHS in terms of energy efficiency. It will serve as a basis on which to rely for making choices regarding future changes to the SHS of the mill and provide information on previous changes made to the mill, 2014-2025. It will also be able to provide information about the size of the existing energy losses from the SHS in order to propose improvements to the SHS. It will also enable quantification of the energy losses associated with the SHS, in particular the unused thermal energy contained in wastewater streams.

## 1.3 Limitations

Including the whole mill in the study would be too extensive for the time frame given and would not provide enough beneficial information to the study of the SES. Therefore, the study is limited to that of the SES. The electricity produced at the mill is constant, therefore we limit the project further by only investigating the heat recycling in the SHS and also only for the temperatures  $49^{\circ}\text{C}$ ,  $65^{\circ}\text{C}$  and  $85^{\circ}\text{C}$  as those temperatures are used for the process. The years under investigation are 2023-2025 in order to get two summer and two winter cases to compare.

## 1.4 Objective

**The objective was to:**

- Produce two PFD's; recreating the PFD for Project Helios and creating a new PFD for the current mill configuration (2025).
- Compare the current SHS to that of Project Helios, including seasonal variations and energy savings, by creating heat balances of the systems.

- Identify heat losses and if possible propose changes: modifying, replacing or cleaning current equipment to improve energy efficiency.
- Propose uses for warm water energy losses.

**In order to reach the objectives the following research questions were asked:**

- How does the outcome of Project Helios compare to the original plans?
- Are there any possible further optimizations to the SHS?
- Are the optimizations economically viable and technologically feasible?

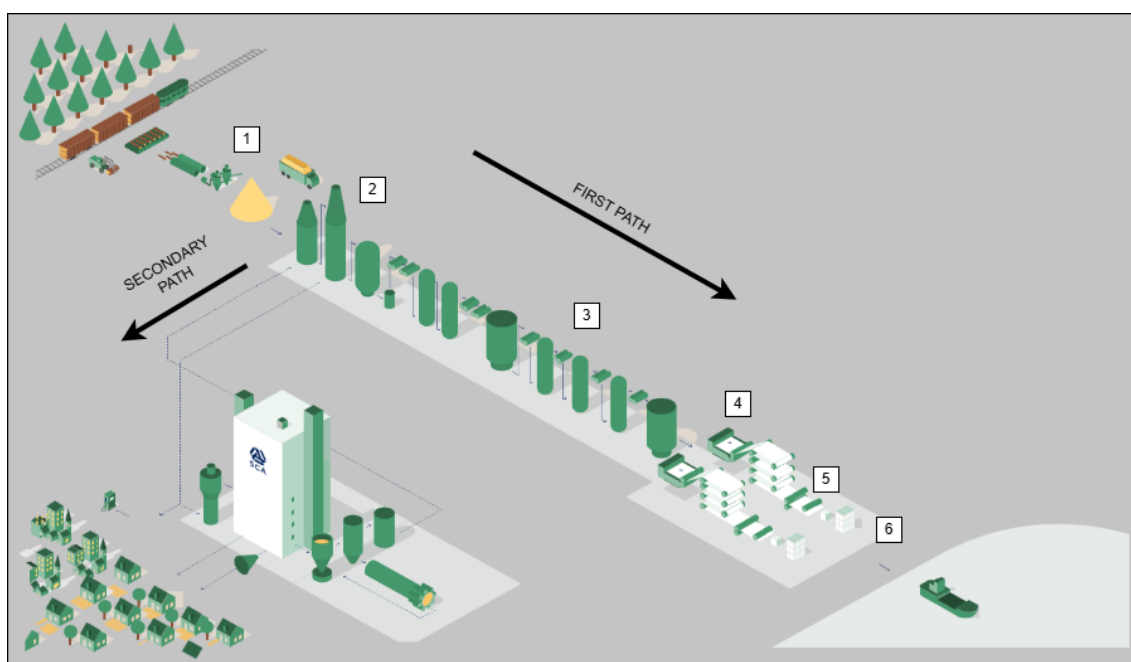


# 2

## Methods

### 2.1 Process description

The mill at SCA Östrand consists of a combination of process equipment designed for production of sulphate pulp (NBSK). Briefly, the process consists of several steps that convert the wood into the dried NBSK pulp shipped to clients. The process is contained by two paths, the first path is the fiber line, processing the wood fibre into pulp as can be seen in Figure 2.1 described below:



**Figure 2.1:** First and secondary process path with mill process illustrating picture from SCA Östrand

- 1. Wood preparation- The process of defrosting the wood, debarking and chipping it into wood chips.
- 2. Digester- The wood chips are steamed in order to remove the air in the fibers of the chips and warm them, the chemicals are then added. The air extraction is critical for the absorption of the chemicals. When the pressure is released the wood chips explode into fibres.

## 2. Methods

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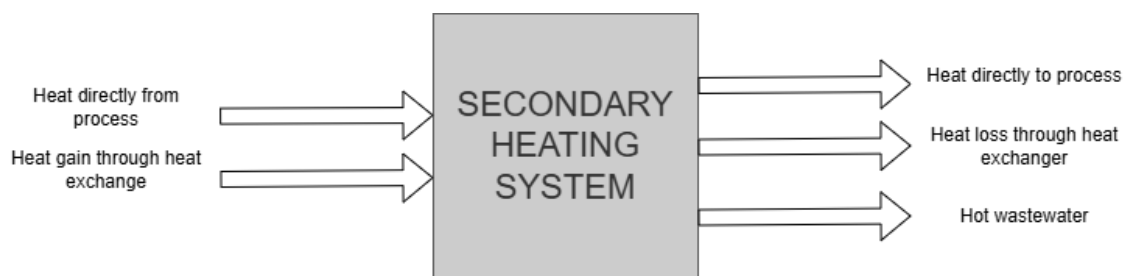
- 3. Bleaching- The pulp fibres are bleached to the required International Organization for Standardization (ISO) brightness using either the Totally Chlorine Free (TCF) or Elemental Chlorine Free (ECF) process, both of which are available on site.
- 4. Dewatering- Excess water is removed from the pulp through mechanical pressing.
- 5. Drying- The pulp is further dried using steam and heat to form sheets for delivery to clients.
- 6. Baling- The NBSK pulp sheets are cut to size and stacked into pulp bales, using pulp sheets as packaging to facilitate dissolution at the client's site.

The secondary path is the path of energy and chemical recovery, mainly the white liquor recovery. This process of the white liquor recovery was explained in Section 1.1.

The secondary path produces steam and electricity through the recovery boiler. The steam and electricity can be utilized within the mill or sold on the market. For the purpose of this report, both the primary and secondary paths are relevant to the SHS. The primary path is of main interest for the production of hot process streams requiring cooling, while the secondary path is responsible for the production of electricity and most of the district heating. The reuse of hot water streams from the primary path constitutes the basis of the SHS.

### 2.1.1 System boundary

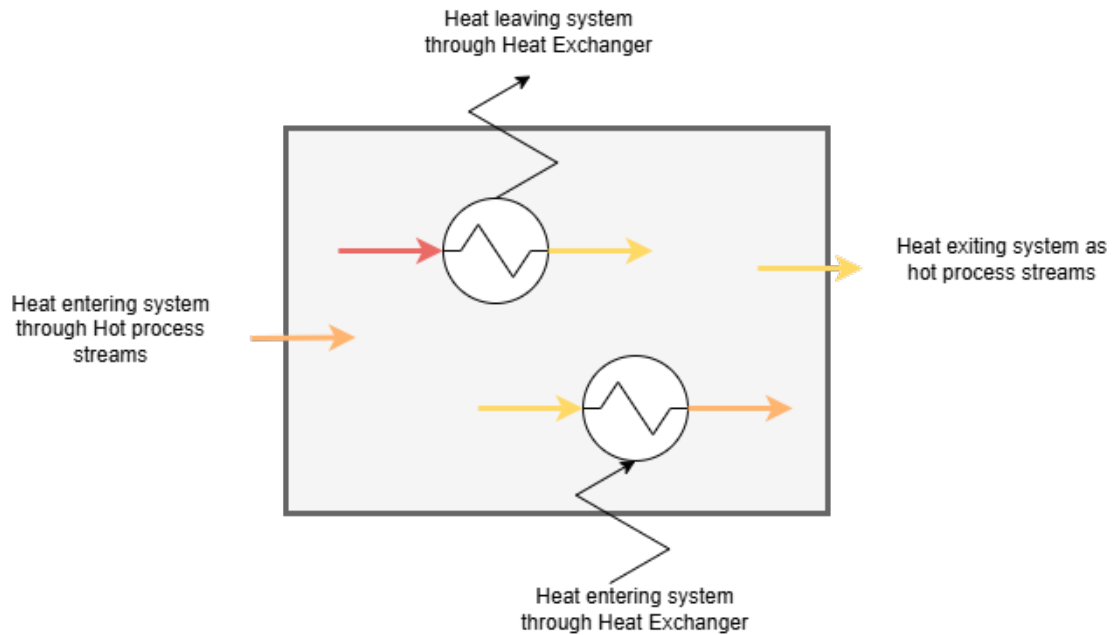
The system boundary is determined by the energy entering and exiting the SHS. For this case that means incoming heat originating from the process as well as heat recovered from hot process streams through a heat exchanger. It also means heat out is categorized as either heat directly entering the process, heat recovered through heat exchangers for use in the process or hot wastewater. The combined flows of heat entering or exiting the SHS are categorized and displayed in 2.2 and 2.5. The EB over the SHS should comply with *The law of conservation of energy*.



**Figure 2.2:** General energy balance description

In Figure 2.3, the heat flows crossing the system boundary are illustrated, including hot streams entering and exiting the system as well as heat exchangers transferring energy across the boundary. Only streams within the temperature range of 49–85 °C are considered. While such streams are typically represented by color-coded arrows as described in the nomenclature section, the arrows in this figure are used solely as schematic placeholders to visualize heat flows and heat transfer. As such, they may represent any of the defined color categories, provided that they follow the governing thermodynamic principles. In particular, for streams passing through heat exchangers, the temperature change

must be consistent with the direction of heat transfer: a stream that *loses* heat must have a *lower outlet* temperature than *inlet* temperature, whereas a stream that *gains* heat must have a *higher outlet* temperature than *inlet* temperature. Some of the streams crossing the system boundary may be connected to heat exchangers located outside the defined system. This is relevant for subsequent calculations, as unknown properties, such as mass flow rate or temperature, of these boundary streams may be determined using additional information from the associated heat exchangers.



**Figure 2.3:** System boundaries for heat exchangers visualized

## 2.2 Assumptions, simplifications and data handling

In this section all assumptions and simplifications are presented. Data handling is also treated here.

### 2.2.1 General assumptions

- There is a measuring error of around 1-2% for all measurements
- All flows lower than 30-40  $m^3/h$  are neglected. This is due to the fact that for streams with high flows, 30-40  $m^3/h$  is roughly equal to the measuring error.
- Streams with temperatures significantly below 49 °C are disregarded as they are outside the boundaries of the SHS.
- The timeline for the summer case is May to the Autumn plant shutdown, around October, for both the Helios energy balance and for the current 2023-2025 cases presented in this report. The timeline for the winter case is from the Autumn plant shutdown to May, for both Helios and current cases.

### 2.2.2 Assumptions for calculations

- All flows can be assumed to have the same properties as water for the energy flow calculations
- Steady state operation, the warm water tanks have equal levels before and after the set timelines (May-October (summer case) vs October-May (winter case)). In other words, no heat storage is assumed to be possible within the system as the tanks are small and only suitable for short time storage.
- No chemical reactions, the flows through the heat exchangers are assumed to be water, thereby they are clean enough to not have any chemical reactions.
- The specific heat capacity,  $c_{p_{water}}$  is assumed to be constant.
- Ideal mixing is assumed in water tanks, thereby the water temperature is constant at all levels inside the tank.
- There are heat losses throughout the SHS, from heat radiation, convection and conduction through the walls of the equipment, but then losses are assumed to be negligible.

### 2.2.3 Comments on the assumptions made

The timelines for the Helios case were based on the temperature of the feed water from Indalsälven. As feed water temperature data for 2014 was not available, measured data from 2024 was used as a proxy to define seasonal conditions. This approach is considered reasonable, as river temperatures are primarily governed by climatic conditions and are expected to follow similar seasonal patterns between years.

Seasonal cases were defined using thresholds to represent typical operating conditions. Temperatures at or below 10 °C were defined as winter conditions, while temperatures at or above 15 °C were defined as summer conditions. Temperatures between these thresholds were considered transitional and were not included in the analysis.

The 2024 feed water data show the following:

- **Winter:** Min 0.37 °C, Max 18.73 °C, Average 7.62 °C
- **Summer:** Min 4.47 °C, Max 23.65 °C, Average 18.36 °C

The wide ranges reflect natural temperature variations within each season as well as possible measurement errors which might affect the average temperatures for each season. Colder feed water requires more heat to reach the desired temperature for the process, while warmer water requires less. Using threshold-based definitions ensures that the seasonal cases focus on typical operating conditions rather than short-term fluctuations.

The seasonal variations are presented as the differences between the summer and winter cases, representing the extremes of operation. For the Helios energy balance, the winter case is characterized by increased demands for ventilation heating and wood thawing, as well as lower feed water temperatures. A notable difference between the Helios 2015 EB and PFD and the current EB and PFD is that the 2015 Helios cases were designed for the most extreme conditions to ensure that the heat exchangers could operate effectively in all seasons.

The measurement error of 1-2 % was stated by co-workers at SCA. The flow for the hotwater heater has an average flow of 1346 kg/s [5006  $m^3/h$ ] between the dates 2025-04-26 to 2025-09-22. This results in 50-100  $m^3/h$  for the 1-2 % measurement error for the average flow. In comparison, the 30-40  $m^3/h$  limit for the flow is reasonable as 50-100  $m^3/h > 30-40 m^3/h$ , meaning a stream with a flow of 30-40  $m^3/h$  can be smaller than the measurement error of a large stream.

## 2.3 Data sources

The data was imported from process data collection systems, as follows:

- **PI ProcessBook** 2015 R3, version 3.7.0.801 , for current mill data and smaller process diagrams.
- Excel extension **PI Datalink** to import historic data stored in PI ProcessBook
- **ABB** 800xA 6.1.1-3 for mill data and smaller process diagrams

PI Processbook is a program connected to ABB where both show the set up of the mill with process and measuring equipment. PI Processbook saves historical data as well as collects current data and with PI Datalink the information can be downloaded into excel and used for calculations from there. There are gaps in the data mainly during a shutdown of the mill or during shorter periods due to measurement or equipment complications. Errors in measurement data can either be ignored completely or assumed to be 'zero'. For this report any measurement data errors are assumed to be 'zero', in order to calculate the average for all streams and heat exchangers with the same amount of data points as the base. Choosing either to ignore errors or replace them with 'zero' is a judgement call, but due to the magnitude of measurement errors the second option was assumed to be the best choice. The data is also imported through PI Datalink as time-weighted averages, using 1h of measurements for each data point.

## 2.4 Producing the Process flow diagram (PFD)

A process flow diagram (PFD) displays the relevant equipment and streams within the boundary. Utilizing the existing small process diagrams in ABB and PI (PI Processbook) the current PFD was assembled for the entire SHS. Some flows were excluded according to the assumptions was made. At first the PFD included all heat exchangers and streams connected to the SHS. After some further investigation into flow rates and temperature criteria for entering the three tanks, small streams and streams not fulfilling temperature requirements were removed. The PFD made for project Helios was used as a reference when navigating ABB and PI and characterizing important streams. The PFD made in preparation for project Helios will later be compared to the PFD made for this master thesis.

### 2.4.1 Main components

The SHS includes three hot water tanks for 49 °C, 65 °C and 85 °C water, as well as the connecting streams of 49-85 °C hot water. Steam is excluded with a few exceptions. For the reheater heat exchangers for the 49 °C and 65 °C tanks steam is used for heat transfer

and the condensate goes into the tanks. The system includes streams entering and exiting the system as well as heat exchangers which either exchange heat with the mill in order to heat process streams or receive heat from the mill process streams in order to use it elsewhere.

### 2.4.2 Process flow diagram (PFD)

A detailed version of the PFD is presented in Figure 3.1. The simplified version of the PFD can be seen in Figure 2.4 below. This figure is less detailed for the purpose of understanding and overview, the detailed PFD is too large to view easily. By starting with a simplified PFD understanding is gained before getting lost in details. In the simplified picture (Figure 2.4) below we have  $49\text{ }^{\circ}\text{C}$  ,  $65\text{ }^{\circ}\text{C}$  and  $85\text{ }^{\circ}\text{C}$  streams leaving the systems going to consumers of hot water and streams entering the system carrying heat produced by producers in the process. The figure also shows streams changing energy content through heat exchangers located within the system and warm waste water exiting the system.

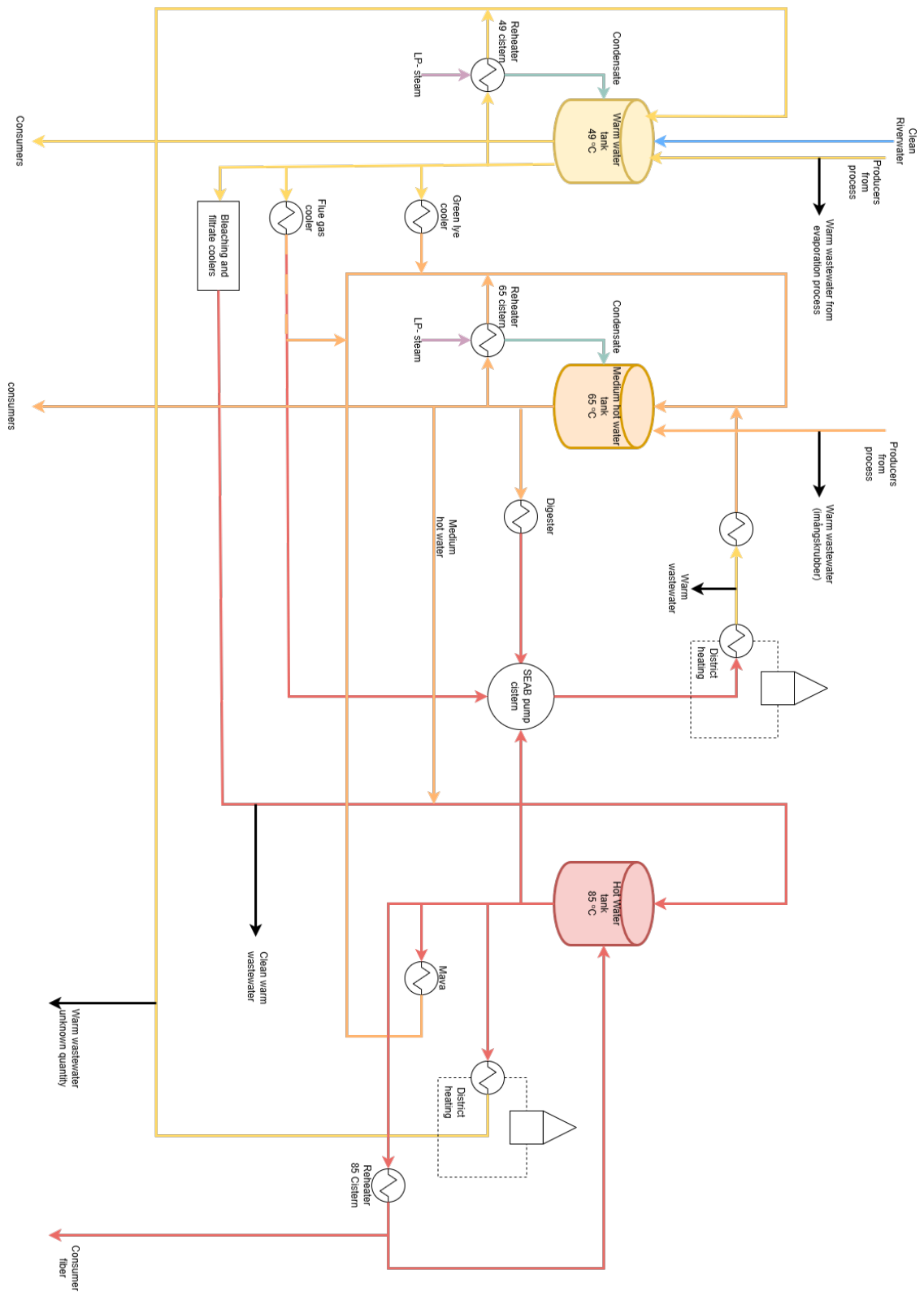


Figure 2.4: Simplified PFD for the SHS

## 2.5 Energy balance calculations

In this section, more detailed calculations are presented. The assumptions made in order to calculate the energy balance as well as the structure used for calculating were presented in Section 2.2. The heat exchangers and streams missing data for calculations will be handled in section 2.5.2.

### 2.5.1 Energy balance formulation

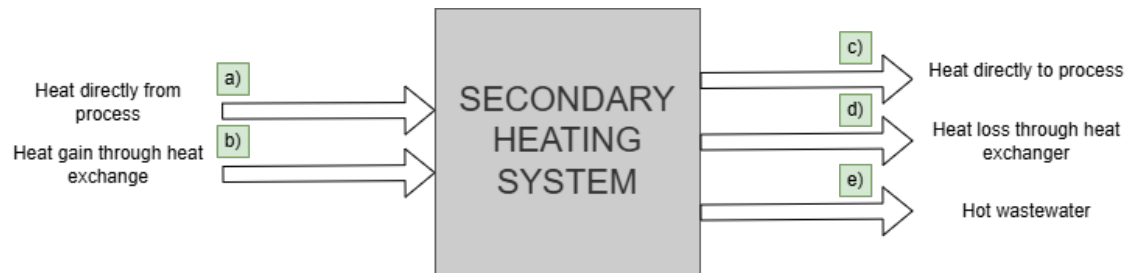
After producing the PFD for the SHS the calculations for the energy balance were made. Normal energy balance equations for heat exchangers were used to calculate  $T_{out}$  and  $\dot{m}$ , using known data for the two streams.

To decide the energy content from streams exiting the boundary of the energy balance or the energy gain from streams entering the boundary of the energy balance Equation 2.1 is used.

$$Q = \dot{m} * H_i \quad (2.1)$$

where i is for out or in, depending on whether the stream is entering or exiting the system.  $C_{p_{water}}$  is assumed to be constant at 4.18 [kJ/kgK], density is calculated through Excel add-on function XSteam [25]. The density calculation depends on temperature, here either temperature of one stream or an average temperature based on known incoming and outgoing temperatures is used. XSteam is also used for the enthalpy, based on temperature in or out respectively. Density and enthalpy vary throughout the set time-period due to varying temperatures.

After the total heat for each stream and total heat transferred through each heat exchanger in the system has been calculated, the compilation of these into the energy balance can be performed.



**Figure 2.5:** General energy balance description

Below is the order in which the calculations are performed (1–5). For steps a)–e), see Figure 2.2 for further information about where each calculation belongs.

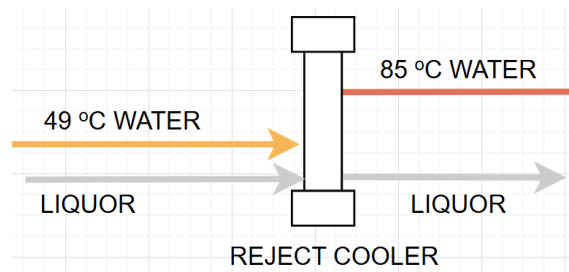
1. First every heat exchanger and stream is allocated an average value for the  $Q$ [MW] over the determined time interval. This is done in Excel files, together with all other calculations. See Tables 3.1, A.1, A.2 & A.3 for  $Q$ [MW] and other variables needed for calculations.
2. Thereafter  $Q_{in} = Q_{in_{stream}} + Q_{in_{HX}}$  is calculated as incoming hot streams and energy (heat) gained from heat exchangers.
  - a) The average values calculated for the entering streams are first summed,  $Q_{in_{stream}}$

- b) Next the heat exchangers where the entering stream gains energy in the form of heat from for example a process stream are summed,  $Q_{in_{HX}}$ .
3. After this  $Q_{out_{useful}} = Q_{out_{stream}} + Q_{out_{HX}}$  is calculated, where heat flows which serve a purpose for the mill are included.
  - c) Starting with summing the energy of streams exiting the system, excluding warm wastewater,  $Q_{out_{stream}}$ .
  - d) Next energy deliveries through heat exchangers are calculated, where energy from the secondary heating system is used to heat up a process stream of some sort,  $Q_{out_{HX}}$ .
4. e)  $Q_{wastewater}$  is the warm wastewater leaving the mill SHS, calculated by summing the energy for the warm wastewater.
5. Finally the energy balance can be calculated,  $\Delta Q = Q_{out_{useful}} + Q_{wastewater} - Q_{in}$ .

## 2.5.2 Exceptions to normal flow and temperature calculations

In following sections the calculation of heat exchangers needing additional assumptions and special calculations are explained. These heat exchangers are missing either temperature meters, flow meters or both. For the overview of system, see PFD's in Figures A.1, A.2, A.3 and A.4.

### 2.5.2.1 Reject cooler



**Figure 2.6:** Reject cooler

The Reject cooler has an unknown flow of water through the heat exchanger, therefore the flow of liquor and the inlet and outlet temperatures of the liquor is used to calculate the flow of water. The inlet and outlet temperature of the water is also needed for the calculation. The Reject cooler can be seen in Figure 2.6. Using normal energy balance equations and known data,  $\dot{m}_{water}$  is calculated.

### 2.5.2.2 Bleaching plant effluent coolers

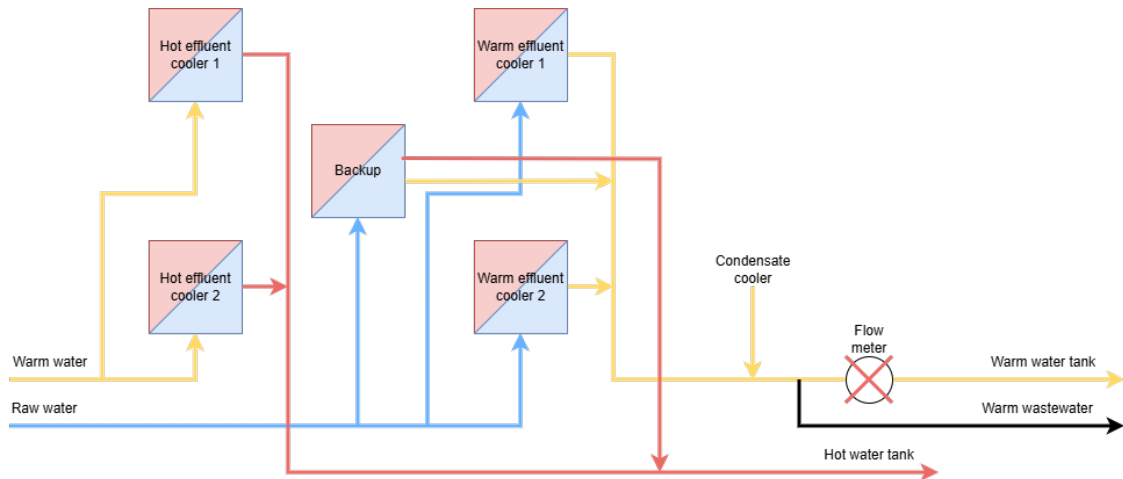
There are five bleaching plant effluent coolers, two producing 85 °C water, two producing 45 °C water and one backup. There is no certainty that 45 °C water into the tank can be reached, which is the minimum acceptable temperature into the 49 °C tank. Average temperature out of the warm bleaching plant effluent coolers is 39 °C during summer

## 2. Methods

2024 and  $46\text{ }^{\circ}\text{C}$  during winter 2024-2025. The warm bleaching plant effluent coolers use raw water (water from Indalsälven) and the hot bleaching plant effluent coolers use  $49\text{ }^{\circ}\text{C}$  water as cold streams. A backup effluent cooler is used when the original effluent coolers are in need of cleaning, which is quite frequently. The outlet of the backup cooler depends on the case, if used for *hot* then the backup cooler produces  $85\text{ }^{\circ}\text{C}$  water and it goes to the  $85\text{ }^{\circ}\text{C}$  tank, if the backup cooler is used for *warm* then it produces roughly  $45\text{ }^{\circ}\text{C}$  water entering the  $49\text{ }^{\circ}\text{C}$  tank.

What this means in terms of calculations is that first the  $Q$  [MW] is calculated for each of the four main bleaching effluent coolers excluding when they are shut off for maintenance and plugged into the backup heat exchanger. This is a normal calculation for both of the hot effluent coolers, but for the warm effluent coolers the calculations become a lot more difficult. A contributing factor of the more complicated calculations is a broken flow meter located at the *warm water tank* position in Figure 2.7.

The calculation for  $Q$  [MW] is done for the backup cooler when used in place of the warm effluent coolers. The warm backup cooler is combined with the warm bleaching plant effluent coolers for the calculation as it is based on total raw water into the three coolers and old values for total water outlet out of them. For the backup cooler when used in place of the hot effluent coolers it is more difficult to calculate the energy transferred. Figure 2.7 shows the effluent coolers as well as the broken flow meter positioned for better understanding. Clarification, There is only **one** backup effluent cooler but it can be used for two cases, in place of one of the hot effluent coolers or in place of one of the warm effluent coolers. These two cases are divided into what seems like two heat exchangers in the PFD as seen in Figure A.1, the cases are called hot backup effluent cooler and warm backup effluent cooler.



**Figure 2.7:** Visual description of the bleaching plant effluent coolers

**Calculation of warm effluent coolers** As shown in Figure 2.7 there is a broken flow meter at the inlet of the warm water tank, this makes calculations more complicated. Since the flow meter is broken and there are no flow meters into/out of the warm effluent coolers or to the waste water outlet, the flow is not known or easily calculated here. To determine the flow through the warm effluent coolers we assume first that the flow of raw

water through the warm effluent coolers can be roughly calculated by eliminating streams using raw water from the main line of raw water going to the bleaching plant of the mill. The raw water to the effluent coolers goes into the warm effluent coolers and the backup cooler for both warm and hot, meaning there is a risk of double counting for the hot backup effluent cooler. The hot backup effluent cooler flow can be calculated as the flow of the other stream and all temperatures are known. The flow of warm water out of the hot backup effluent cooler is the same as the flow of raw water in. The rough estimation of the raw water flow has to be further adjusted through known flows going through the now broken flow meter when it was working, around 2018-2020. The combined flow of the condensate cooler and the warm effluent coolers can be calculated when the valve to the waste water outlet is closed, meaning the whole flow goes to the warm water tank. The temperature also has to be in an acceptable range which is accounted for in the calculation. Comparing the flow of warm water through the flow meter in 2018-2020 and the raw water flow in the same years an adjustment factor was calculated, 75.3%. The adjustment factor is an average of the acceptable points of data when the valve was closed and the temperature was high enough. The adjustment factor was then applied to the raw water flow calculated for the time period researched by multiplying the raw water flow with the adjustment factor.

The calculation can now be made as the flow is estimated, the calculation itself is calculated as the rest of the heat exchangers in the system, as in Equation 2.1, if all warm coolers are assumed as one.

**Calculation of backup for hot effluent coolers** There are two assumptions specifically for this case;

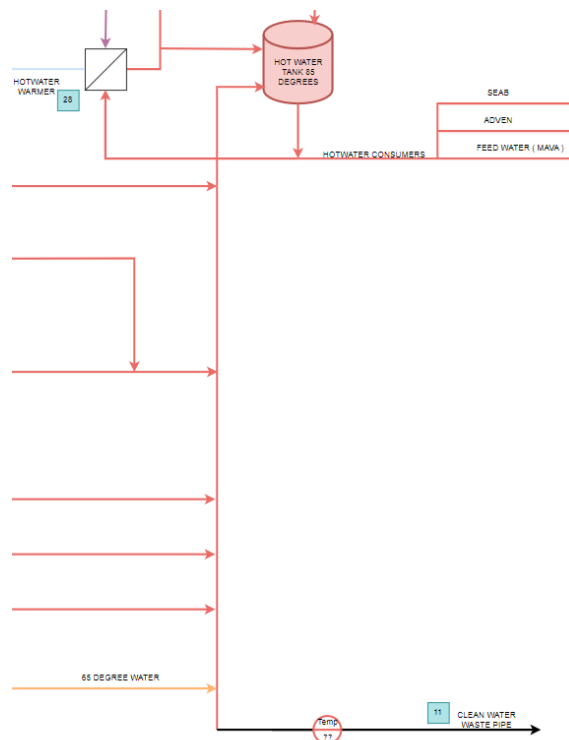
- First, when one of the two hot effluent coolers does not have any flow, the flow value is assigned to the hot backup cooler.
- Second, if both hot effluent coolers have no flows, then it is assumed that it is downtime at the mill.

The calculation itself has all the values it needs for the calculation of the backup for the hot effluent coolers, the problem here is that the backup is used for all four effluent coolers. The warm backup effluent cooler is included in the calculation for warm effluent coolers (and should be), but the hot backup effluent cooler should not be included (but is included). The operational hours for the hot backup effluent cooler therefore has to be determined in order to remove it. The operational hours for the hot backup effluent cooler is when one of the hot effluent coolers are shut down and thus replaced by the hot backup effluent cooler. This only happens when the temperature meter is at reasonable temperature ( $85\text{ }^{\circ}\text{C}$ ) and the flow meter for the hot effluent cooler shows a value lower than  $2\text{ m}^3/\text{h}$ . When the flow of warm water into the hot effluent cooler is higher than  $2\text{ m}^3/\text{h}$ , the hot effluent cooler is on and the backup hot effluent cooler is thus off, in alignment with the assumptions. According with assumptions made, if both of the hot backup coolers have a warm water flow lower than  $2\text{ m}^3/\text{h}$  entering them, then there is operational downtime at the mill or for this part of the process. The hot backup cooler has the same temperature and flow meters for the hot flow of filtrate through the hot effluent coolers. The temperature exiting the hot backup effluent cooler and the raw water temperature in are both known, thus leaving the flow of raw water as the only unknown. As the flow of raw water through the hot backup cooler is the only unknown, the flow is calculated through rearranging of normal heat exchanger equations for flow calculation, adjusted by operational hours and

shut down of the mill. In Excel calculations this was done by multiplying by 1 if the hot backup effluent cooler was used in place of the hot effluent cooler investigated and 0 if the mill was shut down at that point in time.

**Waste water from warm effluent coolers and condensate cooler** As previously mentioned, the output wastewater from the warm effluent coolers will either go into the warm water tank or to the warm wastewater output. The condensate cooler also has warm wastewater output, which mixes with the warm effluent wastewater before the branching. In order to determine the amount of wastewater exiting the energy balance system, some factors have to be determined. First, knowing when the valve determining the warm wastewater output is closed and when the flow is large enough will determine the amount of water entering the 65 °C tank. This is based on the assumption that the valve will have to be more than 5% open for any flow to go to warm wastewater output. After 5% all the flow will go to warm wastewater outlet. By determining at which points the valve is less than 5% open and the flow is more than 40 [m<sup>3</sup>/h], it is possible to determine a rough estimate of warm wastewater exiting the system. The average value of warm wastewater flow calculated when the valve is not open and the flow is high enough is also taken. Then both the flow to the warm water tank when the valve is open and when it is closed is known. Taking the averaged flow for when the valve is closed and subtracting the flow for when the valve is open, results in the average flow 220.24 [m<sup>3</sup>/h] to wastewater based on historical values when the valve is open. This flow is then used in Equation 2.1 on the condition that the valve is fully open, meaning more than 75% open.

### 2.5.2.3 Hotwater tank wastewater outlet



**Figure 2.8:** Hotwater tank wastewater outlet, part of PFD, Figure A.1

The flow to the clean water waste pipe is known, but the temperature is not. It was unclear from ABB and PI Processbook if the 85 °C water produced in the process would enter or exit the 85 °C tank. To clarify, the PFD part of interest can be seen in Figure 2.8. Most likely part of the joint stream enters the hot water tank and part of it leaves through the clean water waste pipe. To calculate the missing temperature of the clean water waste pipe, a mixing point calculation is used. The joint stream contains a mix of 7 streams. The assumption is therefore that the joint stream is an ideal mix, meaning the temperature was homogenous into the tank and out through the clean water waste pipe. The equation used to calculate the temperature out of the clean water waste pipe, with the assumption of ideal mixing, is shown in Equation 2.2.

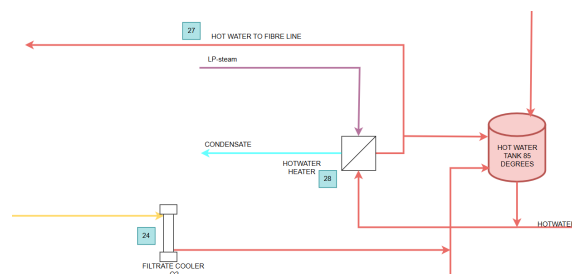
$$T_{\text{mix}} = \frac{\dot{m}_1 * T_1 + \dots + \dot{m}_7 * T_7}{\dot{m}_{\text{mix}}} = \frac{\sum \dot{m}_i T_i}{\sum \dot{m}_i} \quad (2.2)$$

Where  $i$  is a number from 1-7.

### Medium heat water into clean wastewater or 85 tank

The medium heat water (65 °C) entering the 85 tank and/or clean water waste pipe does not have a flow meter, but it can be calculated through the exclusion of streams from the total flow into that specific process. This is a stream included in the calculation of the mixing point above.

#### 2.5.2.4 Hotwater heater



**Figure 2.9:** Picture of the hotwater heater

The hotwater heater illustrated in Figure 2.9 reheats the 85 °C water for the hotwater tank, it also reheats 85 °C water for the use in later processing steps. Low Pressure (LP)-steam is utilized in the hotwater heater for this reheating purpose, the LP-steam exits the hotwater heater as condensate. For the calculation of this heat exchanger only the heat exchanged is of interest, meaning the LP-steam entering and the condensate exiting the heat exchanger is not in itself of interest, only the heat left behind in the heat exchange.

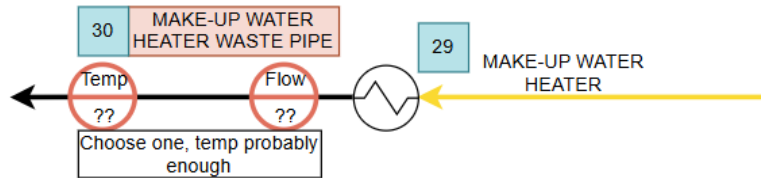
The heat absorbed from the steam can be calculated as follows:

- Calculate first the unknown flow of hot water, through the known flow and temperatures of the LP-steam and condensate. Also using the temperatures entering and exiting the hotwater heater in the other direction, meaning the warmwater reheated.
- After converting the flow from ton/h to kg/s, Equation 2.3 is used to calculate the heat transfer for the hotwater heater:

$$Q = \dot{m}_{steam \rightarrow condensate} * \Delta H_{LP-steam \rightarrow condensate} \quad (2.3)$$

Where  $\dot{m}_{steam \rightarrow condensate}$  is in [kg/s] and the phase change occurring in the heat exchanger is automatically accounted for when using enthalpy for the heat exchange calculations.

### 2.5.2.5 Make-up water heater



**Figure 2.10:** Make-up water heater with missing meters displayed

The make-up water heater has no flow meters for the entering hot stream, it also has no temperature meter for the wastewater, meaning it is not possible to calculate the flow. The illustration of the make-up water heater with missing flow and temperature meters can be seen in Figure 2.10. After investigation and discussion with experts a temporary temperature meter was placed on the pipe for one hour, in order to make a rough calculation and thereby an estimate of the flow through the heat exchanger. There is also the original scheme from when the heat exchanger was designed, including the flow values for the two incoming flows and the desired temperatures.

The design temperatures and flows are not close to the current values as can be seen in Table 2.1.

	Design	winter 2023-2024	summer 2024	Unit
Temp in	8	19.82	20.95	°C
Temp out	41.8	24.72	31.35	°C
Flow	330	296	276	m <sup>3</sup> /h
ΔT	33.8	4.9	10.4	°C

**Table 2.1:** Make-up water stream values for comparison

The large difference in heat transfer can be seen by the difference between the designed ΔT and the much lower current ΔT.

There is around 4.9-10.4 °C in heat transfer driving force (ΔT) between winter 2023-summer 2024, compared to design where ΔT = 33.8°C which is a large difference and a problem in itself. Using the design values for the flow calculations in themselves is not

advisable, some adjustments are needed. Due to the lack of information, the flows used for the design is 300 [ $m^3/h$ ] for the incoming hot stream and 330 [ $m^3/h$ ] for the cold stream is of interest. Utilizing this as a basis together with the temperature known for a single hour (40 °C) to calculate the flow. For the single hour measurement resulting in 40 °C water exiting the system, the flow was calculated. Using the design values the cold stream flow can be calculated through Equation 2.4:

$$\frac{300}{330} * \dot{m}_{cold} = 245[m^3/h] \quad (2.4)$$

$\dot{m}_{cold}$  is the flow for the cold stream when the waste water temperature is 40 °C, 245 [ $m^3/h$ ] is the estimate of the cold stream flow. The calculated flow for the hour when the waste water temperature was 40 °C is 203  $m^3/h$ . The correction factor of 0.83 is calculated through equation 2.5.2.5:

$$\frac{203}{245} = 0.83$$

Using the correction number to calculate the estimated flow of 49 °C water into the make-up water heater. The estimated flow is calculated through equation 2.5:

$$\dot{m}_{estimated} = \frac{\frac{300}{330} * \dot{m}_{cold_{current}}}{0.83} \quad (2.5)$$

Where  $\dot{m}_{cold_{current}}$  is the flow of the cold stream (make-up water) for the timespans relevant for this report.

Using flow Equation 2.5 the temperature can be used to calculate the temperature of the wastewater, now both the estimated temperature and the estimated flow is calculated and can be used to determine the heat leaving the system through the wastewater using Equation 2.1. It is important to note that only the entalpy for the calculated temperature is used. Note also that the warm stream entering the heat exchanger has already exited the SHS. This means that if the flow of the warm stream is known, the calculation around the heat exchanger would be redundant. As it stands both heat transferred through the heat exchanger and the warm stream going to wastewater is of interest for calculations. The division of calculations for the waste water heat and heat loss through the make-up water heater is due to being able to separate the heat out of the system boundary into useful and non-useful heat in order to get a measure of how much excess energy is available.

In order to verify this method a few data points was chosen in order to calculate the temperatures and flows using iterations. This is possible due to one known temperature (40 °C), which makes it possible to calculate a value for UA in Equation 2.6, using Equation 2.7.

$$Q = UA * \Delta T_{lm} \quad (2.6)$$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\frac{\Delta T_1}{\Delta T_2}} \quad (2.7)$$

Where  $\Delta T_1$  is calculated through Equation 2.8 and  $\Delta T_2$  is calculated through Equation 2.9.

$$\Delta T_1 = T_{in_{warm}} - T_{out_{cold}} \quad (2.8)$$

$$\Delta T_2 = T_{out_{warm}} - T_{in_{cold}} \quad (2.9)$$

Q here is for the cold stream and UA is unknown, the hot stream temperature out is known for this data point making it possible to extract the UA-value. For the purpose of calculationg the UA-value the values in Table 2.2 are used.

Make-up water (cold stream)	
$T_{in}$	23.591
$T_{out}$	28.944
$m$ [kg/s]	74.755
Warm stream	
$T_{in}$	47.146
$T_{out}$	40
$m_{Estimated}$ [kg/s]	56.024
$m_{UA}$	55.990
$Q_{cold}$	1673287
$UA_{iterated}$	42030
$\Delta T_{lm_{Q_{cold}}}$	39.812
$\Delta T_1$	18.202
$\Delta T_2$	16.409
$\Delta T_{lm}$	39.812
Difference $\Delta T_{lm}$	0.000113

**Table 2.2:** Values used to produce the UA-value for  $T_{out_{warm}} = 40^\circ C$

In Table 2.2,  $m_{UA}$  is the flow calculated using the  $UA_{iterated}$ . The  $UA_{iterated}$  is a guessed values in the beginning of the iteration and until the  $\Delta T_{lm} \approx \Delta T_{lm_{Q_{cold}}}$ , in this case the difference is only 0.000113. Since this is such a close iteration the  $UA$ -value is 42030 for this heat exchanger, assuming no fouling.

Assuming that the UA value is constant it is therefore possible to calculate Q values dependant on temperature but not flow. This makes iteration possible which is done as follows:

- For the make-up heater, guess an outlet temperature for the warm stream.
- Calculate a Q-value using the guessed temperature and the UA value constant.
- Compare Q-value for the guessed temperature with the Q value for the cold stream.
- When the Q-values are only roughly 5 W apart, they are close enough. If they have a larger difference a reiteration was done by guessing a new temperature.
- When the Q-values are close enough a flow can be calculated ( $m_{calc}$ ) which will be compared with the flow calculated based on assumption previously ( $m_{estimated}$ ).

The results of the iteration and the compared values are displayed in Table 2.3.

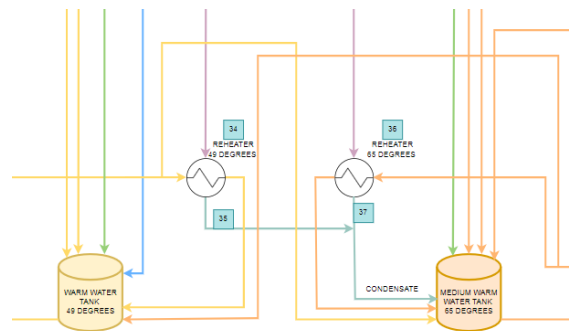
As shown in Table 2.3, the flow calculated through iteration ( $m_{calc}$ ) was up to 4.6 times higher than the flow estimated from design dimensions and known data points ( $m_{estimated}$ ). For the selected sample data points, the calculated flow ranged from 1.035 to 4.606 times the estimated values, confirming that the initial estimation was highly approximate and lacked accuracy. Although the estimated approach is more efficient when handling large amounts of data points, it does not provide the most reliable results. Performing these types of iterations for the amount of data handled would not be feasible. However, it is important to note that while the estimations provide an indication of the order of magnitude, they cannot be assumed to accurately represent real conditions. Table 2.3

	Case 1	Case 2	Case 3	Case 4	Case 5
Make-up water (cold stream)					
$T_{in}$	24.115	23.431	23.466	22.946	22.907
$T_{out}$	31.085	28.113	29.412	26.526	34.171
$m$ [kg/s]	64.280	103.434	75.098	142.373	37.194
Warm stream					
$T_{in}$	48.240	48.140	47.738	48.361	48.145
$T_{out_{estimated}}$	41.878	43.890	42.322	45.129	37.819
$m_{estimated}$ [kg/s]	69.574	111.902	81.276	153.974	40.270
$Q_{cold}$	1873881	2025319	1867471	2131536	1752086
$T_{guess}(T_{out_{warm}})$	45.868	45.286	43.766	45.163	45.886
$\Delta T_1$	17.154	20.027	18.327	21.835	13.973
$\Delta T_2$	21.753	21.885	20.300	22.217	22.979
$\Delta T_{lm}$	44.585	48.188	44.432	50.715	41.687
$Q_{Iterative}$	1873882	2025321	1867471	2131534	1752086
$\Delta Q$	-0.634	-1.360	0.102	1.316	0.122
$m_{calc}$ [kg/s]	188.926	169.718	112.406	159.392	185.478
$\Delta m(m_{calc} - m_{estimated})$	119.351	57.816	31.130	5.418	145.208
$X = m_{calc}/m_{estimated}$	2.715	1.517	1.383	1.035	4.606

**Table 2.3:** Data and results for iterative calculations

also indicates that the flow calculated from estimations ( $m_{estimated}$ ) was more accurate for flows above 81 kg/s compared to lower flows such as in Case 1 and Case 5. However, it is unclear whether this represents a coincidence or a systematic trend. Either way, the clear difference between the estimated and the calculated flow indicates that the flow used for the energy balance is not very accurate. The energy balance would therefore benefit from measurements here instead of using estimated values.

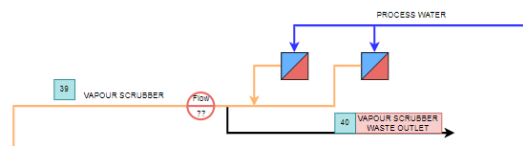
### 2.5.2.6 Reheater 49 and 65



**Figure 2.11:** Reheaters for 49 ° C and 65 ° C water tanks

For the reheaters, see Figure 2.11, there is a flow of steam reheating the 49 °C and 65 °C streams from the tanks, respectively. After the steam reheats the recirculating tank water, the condensate enters the respective tanks. The heat absorbed through heat exchange between the recirculating water and the steam can be calculated using the usual heat exchange calculations for  $Q$ , when applied to the water side. Equation 2.1 can be used for calculating the energy (heat) in the condensate entering the tanks.

### 2.5.2.7 Vapour scrubber



**Figure 2.12:** Vapour scrubbers

The vapour scrubbers, see Figure 2.12, have known flows out. The problem is due to unknown division of flow between *vapour scrubber waste outlet* and flow going to the 65 °C tank, after the vapour scrubber. The wastewater outlet has no flow meter and as such the amount of warm wastewater is unknown. According to SCA plant operators, the vapour scrubber has some problems with the temperature of the warm water outlet. As such it has been suggested that most if not all of the warm water out of the vapour scrubber go to the *vapour scrubber waste outlet*. The approximated flow of wastewater is determined by the valve opening percentage. In this case it is assumed that if the valve is more than 80 % open all of the warm water from the vapour scrubbers exits through the wastewater outlet. This is conservative due to the warm water waste pipe being large enough to handle 100% of the flow from the vapour scrubbers at maximum capacity. It is more likely that even when the valve is only 70-75 % open all of the wastewater would go out the wastewater outlet due to the large waste pipe.

There is a large difference between an 80% open valve for a large vs small pipe as can be seen in Figure 2.13. For the vapour scrubber case there is a rather large pipe, closing the valve to 80% might not constrict the flow of water by 80 %. For an example, if the vapour scrubber has an outlet pipe the size of the smallest pipe in Figure 2.13 and the waste



**Figure 2.13:** Visualizing the difference between an 80% open valve for a large pipe and an 80% open valve for a small pipe.

water outlet is the size of the larger pipe in the figure, then constricting the outlet pipe to 80% would still let all of the water go to the waste water outlet. This due to the large pipe constricted to 80% being the same size as the smaller pipe at 100%, according to the referred figure. If both pipes where the same size the valve openness might diminish the flow going to waste water outlet by 20%, if it is assumed to be max flow. For a flow lower than max and the valve being set to 80%, the whole or most of the flow would still go to waste water outlet for this case. The valve openness can therefore be assumed to be untrustworthy, but assumptions can be made to make it useful in some cases.



# 3

## Results

### 3.1 PFD

The SHS consists of three tanks with three different temperatures,  $49^{\circ}\text{C}$  warm water,  $65^{\circ}\text{C}$  medium warm water and  $85^{\circ}\text{C}$  hot water. Water with different temperatures flows enter the tanks; streams heated from process streams, streams cooled by process streams, streams between tanks and pure process streams. From these tanks streams are headed for different uses; used for heating up process streams, used for processes, used for district heating or used in another tank. There is also wastewater leaving the SHS. In figure 3.1 the detailed flowchart for the SHS is displayed.

The PFD is a diagram used as a tool for the calculating the energy balance. For the calculation of the energy balance it is essential to know which streams and heat exchangers are of interest. Note, for zoom-ins of the PFD, see Figures A.2,A.3 and A.4.

### 3. Results

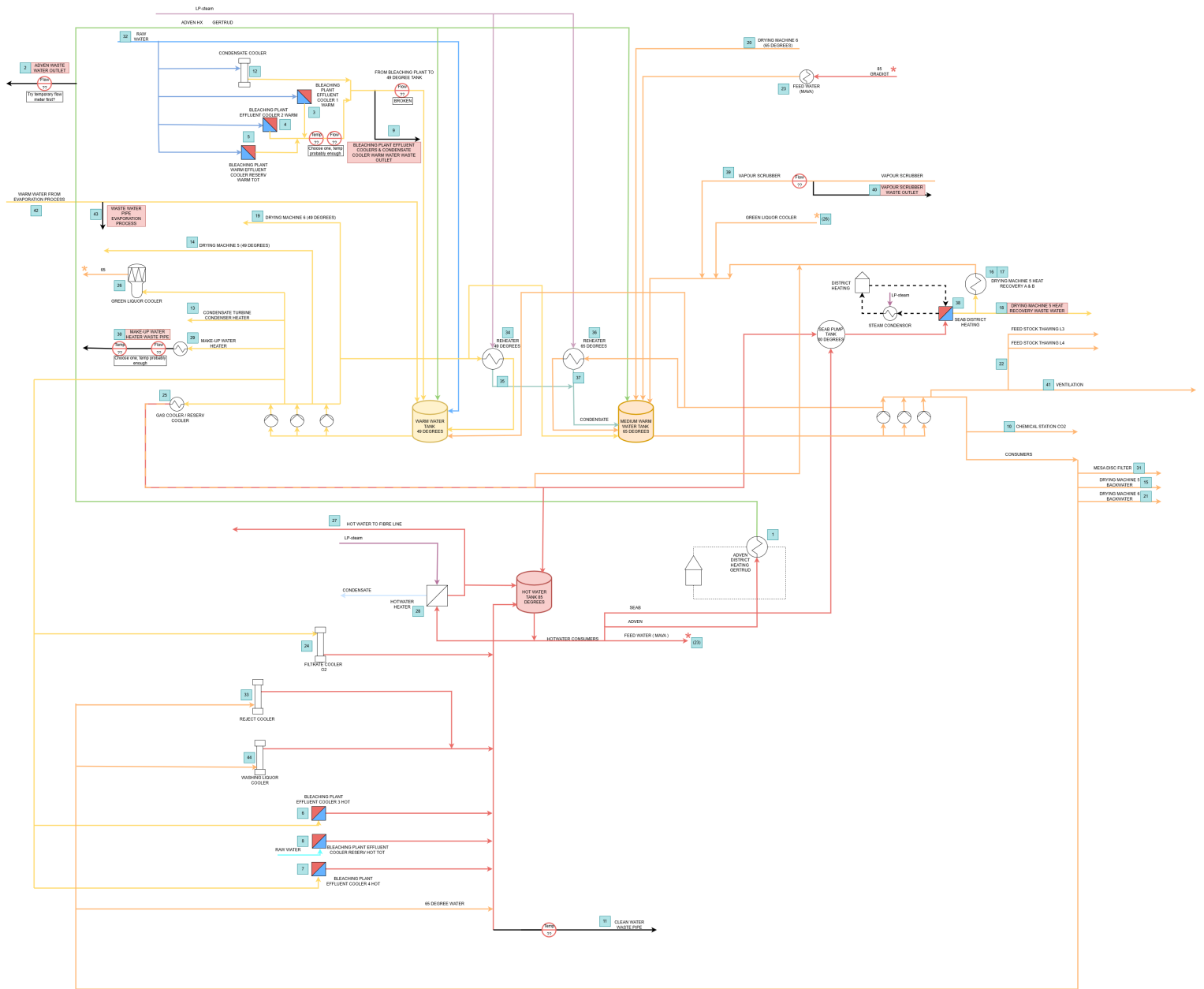


Figure 3.1: Detailed PFD of SHS

### 3. Results

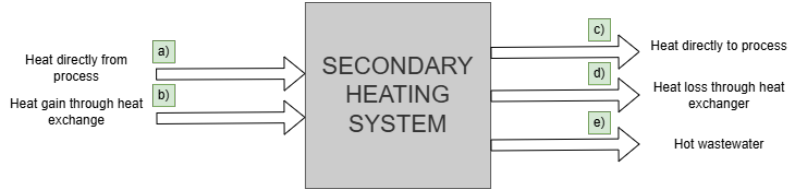
No	Name	HX	Stream	Tin [°C]	Tout [°C]	Flow [m <sup>3</sup> /h]	Q [MW]	EB	No unk	1 unk	Mult unk	Comments
1	ADVEN District Heating (Gertrud)	HX		83.22	56.84	356.27	10.70	OUT	X			
2	ADVEN Waste Stream		Stream	-	56.84	UNKNOWN	-	OUT		X		Flow cannot be calculated.
3	Bleaching Plant Effluent Cooler 1 Warm	Cooler										
4	Bleaching Plant Effluent Cooler 2 Warm	Cooler		13.17	46.45	628.24	24.12	IN			X	Flow calculated from historical data and raw water balance.
5	Bleaching Plant Effluent Cooler Reserv Warm Tot	Cooler										
6	Bleaching Plant Effluent Cooler 3 Hot	Cooler		48.21	82.67	358.76	14.10	IN	X			
7	Bleaching Plant Effluent Cooler 4 Hot	Cooler		48.26	80.09	285.56	10.37	IN	X			
8	Bleaching Plant Effluent Cooler Reserv Hot Tot	Cooler		1:12.77, 2:15.15	1:79.74, 2:28.82	1:1.82 kg/s, 2:-0.01 kg/s	1:0.51, 2:-0.0006, Tot:0.57	IN		X		Rarely used but important, therefore an exception to the rules.
9	Bleaching Plant Effluent Cooler & Condensate Cooler Waste Outlet		Stream		44.96	172.08	8.91	OUT			X	A mixing-point calculation based on the temperature of the vapour scrubber and the calculated outgoing temperature of the warm effluent coolers. The flow was calculated using old values from 2018-2020 when the flow meter was in working order. The calculation also uses valve openness of the waste water outlet.
10	Chemical Station CO <sub>2</sub>		Stream	-	62.83	153.80	11.03	OUT	X			
11	Clean Water Waste Pipe		Stream	-	80.18	378.30	34.28	OUT		X		
12	Condensate Cooler	Cooler		14.04	32.65	95.73	2.07	IN		X		Temp out calculated from values over cooler.
13	Condensate Turbine Condenser Heater		Stream	-	48.13	50.12	2.77	OUT	X			
14	Drying Machine 5 (49 C)		Stream	-	47.50	216.30	11.82	OUT	X			
15	Drying Machine 5 Backwater		Stream	-	62.28	18.60	1.32	OUT	X			
16	Drying Machine 5 Heat Recovery A	HX		61.48	63.93	168.60	0.472	IN	X			
17	Drying Machine 5 Heat Recovery B	HX		61.47	63.56	163.59	0.39	IN	X			
18	Drying Machine 5 Heat Recovery Waste Water		Stream	-	60.53	184.56	12.77	OUT	X			
19	Drying Machine 6 (49 C)		Stream	-	47.85	358.90	19.75	OUT	X			
20	Drying Machine 6 (65 C)		Stream	60.07	-	314.17	21.58	IN	X			
21	Drying Machine 6 Backwater		Stream	-	62.75	187.44	13.43	OUT	X			
22	Feed Stock Thawing		Stream	-	62.83	153.80	11.03	OUT	X			
23	Feed Water (MAVA)	HX		83.71	58.85	295.62	8.36	OUT	X			
24	Filtrate Cooler O <sub>2</sub>	Cooler		48.35	82.42	180.34	7.01	IN	X			
25	Gas Cooler / Reserv Cooler	Cooler		47.93	84.88	165.73	6.98	IN	X			
26	Green Liquor Cooler	Cooler		48.30	73.49	221.99	6.39	IN	X			
27	Hot Water To Fibre Line		Stream	-	89.84	71.77	7.24	OUT	X			
28	Hotwater heater	HX		83.29	88.74	1265.84 kg/s	30.38	IN		X		Flow unknown
29	Make-Up Water Heater	Heater		47.61	39.68	321.27	2.92	IN			X	
30	Make-Up Water Heater Waste Pipe		Stream	-	39.68	321.27	14.67	OUT			X	
31	Mesa Disc Filter		Stream	-	63.30	46.23	3.34	OUT		X		Flow calculated.
32	Raw Water		Stream	4.02	-	18.62	0.09	IN	X			This has too low temperature, but shows that even low temperature streams carry some heat energy.
33	Reject Cooler	Cooler		63.46	77.80	56.14 kg/s	3.37	IN		X		
34	Reheater 49 C HX	HX		47.65	50.23	766.04	2.27	IN	X			
35	Reheater 49 C Stream		Stream	46.84	-	17.23	0.94	IN	X			
36	Reheater 65 C HX	HX		61.94	66.44	426.67	2.19	IN	X			
37	Reheater 65 C Stream		Stream	60.68	-	14.63	1.03	IN	X			
38	SEAB District Heating HX	HX		83.26	61.15	533.63	13.42	OUT	X			
39	Vapour Scrubber		Stream	50.99	-	603.86	35.36	IN	X			
40	Vapour Scrubber Waste Outlet		Stream	-	50.99	519.49	30.42	OUT		X		Flow is estimated from the openness of the valve to waste water outlet.
41	Ventilation		Stream	-	61.94	322.90	22.84	OUT	X			Flow and temperature are derived from multiple ventilation streams.
42	Warm Water from Evaporation Process		Stream	48.62	-	2299.83	128.56	IN	X			
43	Waste Water Pipe Evaporation Process		Stream	-	43.73	614.66	30.98	OUT	X			
44	Washing Liquor Cooler	Cooler		63.27	84.46	260.78	6.28	IN	X			

**Table 3.1:** Calculated average data for winter 2024-2025

Notes:

- It is normal for a stream to only have one temperature, whereas heat exchangers should have two temperatures.
- Red values in Table 3.1 are calculated values and if a unit is specified in a table cell, then the unit specified at the top of the table no longer applies.
- The flow values and Q-values are average values over the winter 2024-2025 season.
- The temperature values are calculated a bit different, an average gives unreasonable values for the temperatures. Weighing the temperature with the flow for each data point through a mixing point calculation results in the presented temperatures in the table.

## 3.2 Energy Balance



**Figure 3.2:** Secondary Heating System boundaries

In figure 3.2 the SHS is repeated, for ease of understanding. The letters a)-e) in Figure 3.2 correlate to Table 3.2 as follows:

- *Energy in* is a)-b)
- *Energy out* is c)-e)
- *Waste water heat* is e)

The data used to achieve the calculated values in table 3.2 are displayed in table 3.1 for the winter 2024-2025 case, and in appendix for the other three cases, Table A.1, A.2 and A.3. In table 3.2 the error is calculated by:

$$Error[\%] = \frac{Energy\ balance\ inequality}{Total\ energy\ in} \quad (3.1)$$

The *Waste water heat* in table 3.2 refers to the heat not used for processes, but rather leaving the mill. Due to some unknown flows and temperatures, some of the *Waste water heat* actually consist of both waste water heat and heat used for a process step (useful heat). This should only be a very small part though.

	winter 2023-2024	summer 2024	winter 2024-2025	summer 2025
Energy in [MW]	290.47	278.91	303.07	283.40
Energy out [MW]	264.85	261.35	269.76	289.86
Energy balance [MW]	25.62	17.56	33.31	-6.47
Error [%]	8.82	6.30	10.99	-2.28
Waste water heat [MW]	98.90	179.88	131.87	204.50
Waste water heat ( $T > 25^{\circ}C$ ) [MW]	55.06	97.21	69.12	110.26

**Table 3.2:** Energy balance summary in [MW]

Note that *Waste water heat* (hot wastewater) is a part of *Energy out*. *Energy Balance* is the same as  $\Delta Q = Q_{in} - Q_{out}$ .

The maximum energy savings are calculated using equation 3.2, which gives an energy saving in %, while the waste water heat in 3.2 is the actual maximum amount of energy savings. Out of all the *Waste water heat* only heat above around  $25^{\circ}C$  is usable heat for heat exchange in reality, giving us the *Waste water heat* ( $25^{\circ}C - > T_{avg}$ ). The results are available in table 3.3.

$$Max\ energy\ savings[\%] = \frac{waste\ water\ heat}{total\ energy\ out} \quad (3.2)$$

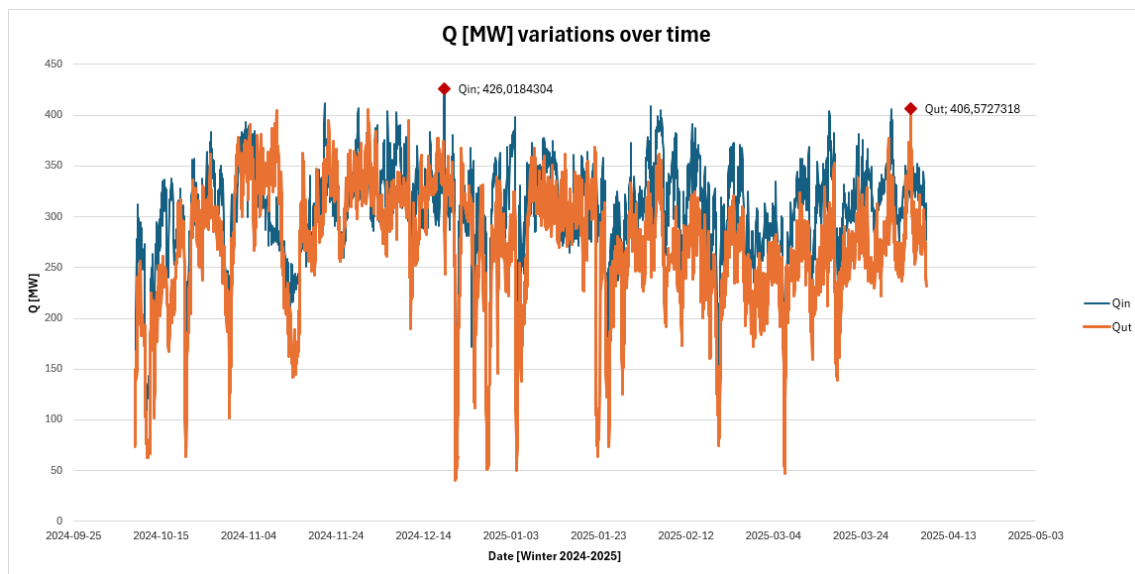
	winter 2023-2024	summer 2024	winter 2024-2025	summer 2025
Max energy savings [%]	42.59	68.83	53.41	71.24
Actual energy savings [%] ( $T > 25^{\circ}C$ )	23.71	37.19	28.00	38.41

**Table 3.3:** Energy savings [%]

The possible uses for these energy savings are presented in section 3.5 below and could also yield an increased economic gain for the company.

### 3.2.1 Helios

The EB SCA made in preparation of the Helios project was created to use as a tool for testing and possibly redesigning the heat exchangers in the system in preparation for the increased production of NBSK pulp. Therefore the energy balance tested the limits of the system, making sure it could handle all the peaks in incoming and outgoing heat. This makes a comparison between Helios and current status difficult. The Helios balance made sure any peaks could be handled by the system, therefore we compare the maximum values for the energy entering and exiting the system, obtained during the winter of 2024-2025 and summer 2025 for fair comparisons.

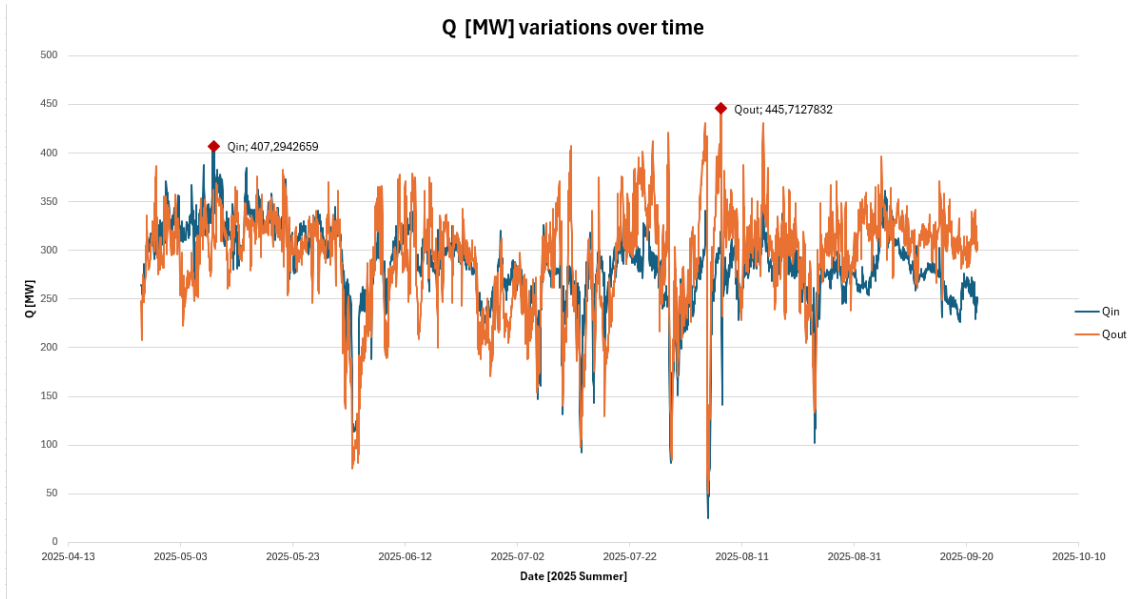


**Figure 3.3:** Data points for the winter 2024-2025 case, also indicating the max values for both ingoing heat and outgoing heat

	Max energy entering SHS	Max energy exiting SHS	Max energy entering & exiting SHS
Energy in [MW]	426.02	325.43	426.02
Energy out [MW]	301.35	406.57	406.57
Energy balance [MW]	124.66	-81.15	19.45
Error [%]	29.26	-24.94	4.56
Waste water heat	92.58	273.94	273.94

**Table 3.4:** Energy balance summary 2024-2025 winter max

### 3. Results



**Figure 3.4:** Data points for the summer 2025 case, also indicating the max values for both ingoing heat and outgoing heat

	Max energy entering SHS	Max energy exiting SHS	Max energy entering & exiting SHS
Energy in [MW]	407.29	305.56	407.29
Energy out [MW]	314.80	445.71	445.71
Energy balance [MW]	92.50	-140.15	-38.42
Error [%]	22.71	-45.87	-9.43
Waste water heat	167.09	126.41	126.41

**Table 3.5:** Energy balance summary 2025 summer max

Note that what is meant by *Max energy entering/exiting SHS* are the maximum values achieved over the time-period, meaning the two data points where either energy entering the system or energy exiting the system is maximized. *Max energy entering SHS* and *Max energy exiting SHS* does not occur at the same time as can be seen in figures 3.3 and 3.4, the figure also contains the maximum values used in tables 3.4 and 3.5.

	winter case	summer case
Energy in [MW]	437.2	481.2
Energy out [MW]	415.1	480.1
Energy balance [MW]	22.1	1
Error [%]	5.056	0.212

**Table 3.6:** Energy balance summary Helios in [MW]

Comparing instead the *Max energy entering and exiting SHS* case for winter 2024-2025 and the winter case for project Helios. Where both of the largest data points are used in order to compare to the Helios case. As can be seen, the max energy in and max energy out for winter 2024-2025 is very close to the Helios winter values, resulting in a similar Error [%]. Comparing the Helios summer case to the maximum values for summer 2025 resulted in a larger difference. The model seems to be accurate when comparing maximum values for the winter case, the summer case however differed in maximum values quite a lot. The maximum values for Helios (2014-2015) was compared to the maximum values for the current situation (2025), a comparison 10 years in the making. The situation for the summer case might have changed more than the winter case during these years. The summer case also brings more waste water as a general rule, not accurately depicted due to only the current data point being used in tables 3.4 and 3.5 but rather clearly shown in table 3.2 for the average values. The unknown waste water flows calculated using assumptions may be more accurate for the winter case but inadequate for the summer case. The energy out might therefore be larger than depicted in table 3.4. As for the energy entering the system, it is unclear where more energy could be introduced.

### 3.3 Energy discrepancy

As mentioned earlier, there is a discrepancy for the EB, this due to many variables, like unknown flows, temperatures or both. There is also the forementioned measurement errors and the following exclusion of flows less than  $30\text{-}40\text{ m}^3/h$ . Wastewater pipes have been low on the priority list for the company to investigate and improve and therefore many of the flows and temperatures for such streams are unknown. Assumptions for calculations based on valve openness are very uncertain as valve openness says nothing about the flow through the pipe or the size of the pipe. Other unknown streams are streams going into processes which have no measurements, some may be included in combined flows going into a part of the process but there is a risk of including a stream multiple times or not including it at all. There is also the energy loss in the form of heat escaping due to lack of insulation (especially during the winter months).

### 3.4 Ineffective heat exchangers

#### 3.4.1 Make-up water heater

The make-up water heater has a setpoint of  $40\text{ }^\circ\text{C}$  for the clean water out during summer, currently the temperature of the clean water out is around  $30\text{ }^\circ\text{C}$ , meaning the heat exchanger is not working as it should, is too small or dirty. When the heat exchanger works as it should, it produces clean water at  $40\text{ }^\circ\text{C}$ , when this is the case, the mill uses less steam in the end.

#### 3.4.2 Vapour scrubber

The vapour scrubber operates at a lower temperature than expected. The average outlet temperature is  $51.4\text{ }^\circ\text{C}$  during the winter of 2024–2025, meaning that the design setpoint of  $74.82\text{ }^\circ\text{C}$  has not been reached. This could be due to fouling or a fundamental error during planning and construction.

The heat exchanger does not reach a sufficiently high temperature for the water to enter the 65 °C tank. It is therefore likely that a larger fraction of the flow is discharged to wastewater rather than directed to the tank. As a result, the initial assumption may overestimate the amount of water entering the 65 °C tank. The impact of the vapour scrubber on the energy balance is significant. Any warm water not entering the 65 °C tank is lost to wastewater, resulting in less hot water retained within the system. Consequently, even small changes in this distribution can have a large effect.

The temperatures around the heat exchangers appear to align with design specifications. However, the process water has a setpoint of 25 °C, while the measured average temperature is only 10–15 °C. It therefore follows that the outlet temperature is also lower than expected. The heat exchanger may be undersized or inefficient, making the low temperature understandable, though not desirable. Increasing the inlet temperature of the process water, for example by mixing with warmer water or recirculating outgoing water while reducing the total process water flow, could improve the situation. This would improve the energy balance and reduce the amount of warm wastewater.

#### 3.4.3 Ventilation

The heating of the ventilation air currently uses 65 °C water which is limited during the winter. During the winter is when the ventilation heating is the most used. Currently some old buildings on site are disconnected from the heating at times when there is a shortage of 65 °C water. This saves the 65 °C water for the process but the consequence is that steam is used to heat the ventilation air instead. This due to the ventilation setup, which uses 65 °C water as the main heating and steam as the secondary heating option for all building ventilation. Using 49 °C water for the ventilation requires piping modifications and extra plates for the current ventilation heat exchangers. The plate heat exchangers used for the ventilation are built with the possibility to add more plates, but space is limited.

There is not a lot of data available for the ventilation system. For comparing the current case for the ventilation with 65 °C to the new possibility of 49 °C warm water, a  $\Delta T = 10^\circ C$  for the air flowing through the heat exchanger was assumed. Through  $\Delta T = 10^\circ C$  and assuming a temperature for the room at large,  $T_{in} = T_{room} = 20^\circ C$ , a flow can be iterated by calculating the temperature  $T_{out_{warm}}$  and comparing it to the temperature calculated using equation 3.3. With the assumption of  $\varepsilon = 0.7$  which is the heat exchanger effectiveness used in equation 3.3.

$$T_{calc_{out}} = T_{w_{in}} - \varepsilon * (T_{w_{in}} - T_{air_{in}}) \quad (3.3)$$

Where  $T_{air_{in}}$  is assumed to be roughly 20 °C, which is close to the bulk preferred temperature of 22 °C for a room.

Without knowing the U-Value, the exact area increase can not be calculated. Using Equation 3.4, the area difference  $\Delta A$  can only be calculated if U is constant and known. Then Equation 3.5 can be used to find the difference in area. Typical U-values for liquid to air systems are limited by the air side, so around 50-400  $W/m^2 * K$  is reasonable according to *Perry's Chemical Engineering Handbook* (chapter 11) [26], when converting

	49 °C	65 °C
Air (cold stream)		
$T_{in\_cold}$	20	20
$T_{out\_cold}$	30	30
$\Delta T$	10	10
$C_{p\_air}$ [J/(kg*K)]	1005	1005
$m_{iterated}$ [kg/s]	16.17	25.1
Warm water		
$T_{in\_warm}$	49	65
$T_{out\_warm\_iterated}$	28.713	33.509
$m_{warm}$ [kg/s]	1.915	1.915
$Q_{warm}$ [W]	162508.5	252255
$\Delta T_1$	19	35
$\Delta T_2$	8.713	13.509
$\Delta T_{lm}$	30.382	51.981
UA [W/K]	5348.782	4852.825

**Table 3.7:** Values used to calculate the UA-value with incoming warm water (65 or 49 °C)

the british unit system to the SI units. Choosing that U-value span,  $\Delta A$  (the additional area needed) is equal to around 9.919-1.240  $m^2$ , which is relatively small and likely feasible to accommodate within the existing heat exchangers. This indicates that a transition to 49 °C water is technically feasible without major modifications to the existing system.

$$UA_{49} - UA_{65} = U * \Delta A \quad (3.4)$$

$$\Delta A = \frac{UA_{49} - UA_{65}}{U} \quad (3.5)$$

### 3.4.4 Technical improvements

In order to sell warm wastewater and thereby create an additional revenue stream, there is a need for more information regarding the amount of warm wastewater. There are several waste water pipes with no measurements or with damaged measuring equipment. In order to collect enough information about these streams there is a need for the following new measuring equipment at the following locations.

- a) A flow meter for the wastewater outlet between the heat exchanger called ADVEN and the water entering the 49 °C tank, positioning in figure 3.5a.
- b) A temperature or flow meter for the wastewater outlet for the make-up water heater can be positioned as in figure 3.5b.

### 3. Results

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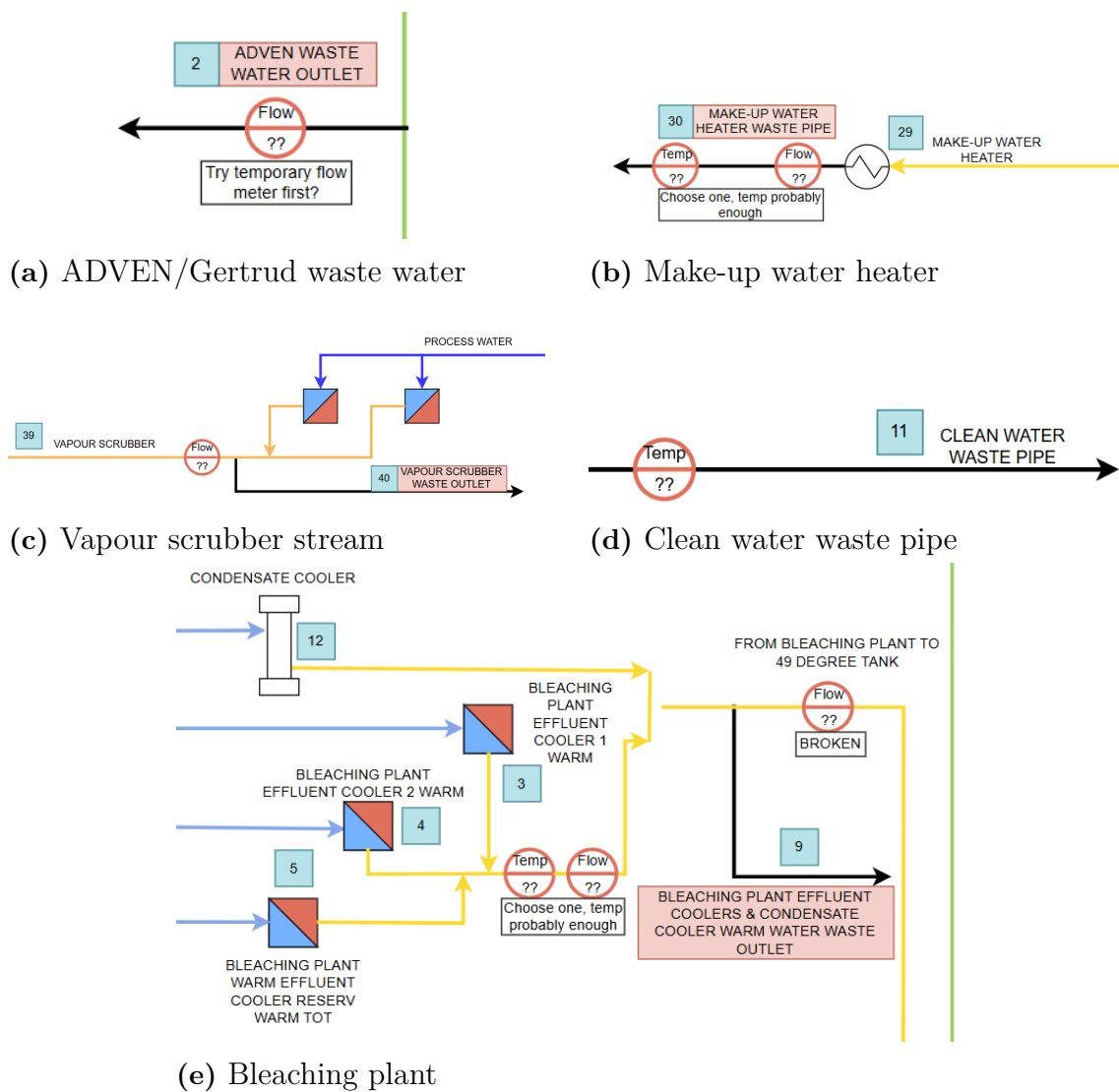
- c) A flow meter needed for the vapour scrubber, specifically measuring the flow going into the 65 °C tank [39]. That way the flow of the warm wastewater is also known. Positioning of the flow meter can be seen in figure 3.5c
- d) A temperature meter for the clean water waste pipe as this is currently calculated using mixing point calculation and several assumptions. Correct positioning can be seen in figure 3.5d
  - i. Flow meter or temperature meter needed at the bleaching plant warm effluent coolers outlet for water. Put it after the mixing point for the outlet water from the effluent coolers, see figure 3.5e.
  - ii. Fix or replace the flow meter measuring the flow into the warm water tank from the warm effluent coolers, see positioning of the flow meter in figure 3.5e.

Since flow and temperature meters are expensive, this list is compiled with that in mind. For the choice between flow or temperature meters, temperature meters should be chosen if possible, due to being much cheaper for both equipment and installment costs. If only a flow meter will suffice, then that is the only option mentioned in the list. For the cases described in the list above and visualized in figure 3.5 [a)-e)] the following apply as to why the measuring equipment is needed.

- a) There is no given flow, meaning there is no data concerning the amount of waste water flowing, therefore a temporary flow meter could be advised at first to ascertain the need for a permanent one.
- b) Choose between temperature or flow meter as both measuring equipment for temperature and flow are missing. It is possible to use the temperature to calculate the flow and vice versa, meaning only one is required. Choosing temperature meter is the economically better choice.
- c) One flow meter at the assigned position has the function of two, knowing the flow going into the 65 °C tank at this point will easily determine the flow going to the vapour scrubber waste outlet.
- d) The temperature here is unknown, but can be estimated through a mixing point calculation of multiple streams out of which some are calculated with estimations. Also it has not been verified whether it is reasonable to do this mixing point calculation to determine the temperature we seek.
- e) There are three suggested pieces of measuring equipment suggested in this picture, the one after the 'bleaching plant effluent coolers and condensate cooler warm water waste outlet' is broken and was missed during the last autumn plant shutdown. The other two are both missing and either of them would positively impact calculations, maybe even both if that is in the budget. As it is the flow is very complicated to calculate and the temperature is calculated using the flow.

When these are installed the energy balance can be revised and the exact amount of waste heat can be determined.

Note that the numbers refer to heat exchangers or streams in the PFD in figure 3.1 and to table A.1.



**Figure 3.5:** Locations of proposed measuring equipment for different process streams.

## 3.5 Possible uses for warm wastewater

There are multiple uses for warm wastewater from industry, most significantly for the food industry which requires large amount of energy. Most significantly for agricultural and aquacultural uses, as these are productive uses for waste heat[27]. A symbiosis between industries with warm wastewater and the food industry is reasonable. The food industry requires heat for growing for instance tomatoes, exotic fruit and cucumber in greenhouses, or fish and larvae for the fish industry.

### 3.5.1 Vertical farming

As is common knowledge, photosynthesis [28] requires sunlight, water and CO<sub>2</sub> to produce glucose and thus grow plants. The building blocks for photosynthesis are all available at the mill: carbon dioxide from various processes, heat, and electricity. LED lighting can replace the need for sunlight for growing plants [29], and both heat and electricity are available on site. If more electricity is needed solar cells could be installed on any of the multiple rooftops on site. Additionally, hot water can provide heating for the greenhouse and subsequently be used for irrigation.

Vertical farming is a suitable option for on-site food production, as floor space may be limited. There are multiple empty or nearly empty buildings on site that could be utilized, many of which already have ventilation systems in place. Vertical farming on rooftops of skyscrapers have been proven to work, this concept should be applicable on lower buildings as well [30]. Furthermore, other companies have demonstrated that vertical farming using waste heat is viable even in subzero climates [31].

The combination of excess heat, vertical farming, and greenhouse cultivation, either indoors or on rooftops, may therefore be an attractive option. Vertical farming in a greenhouse environment utilizing excess heat enables year-round production of various crops. Leafy greens are particularly well suited for vertical farming, although strawberries and tomatoes may also be viable options. Producing food on-site at SCA could provide financial benefits while simultaneously reducing the need for cooling. Additionally, industrial wastewater that is cooled in ventilation heat exchangers could potentially be reused for irrigation, reducing the demand for fresh water.

Further investigation is required before any investment in vertical farming can be justified. Several technical, economic, and logistical factors must be evaluated, including crop selection, production capacity, market prices, transportation, energy demand, water supply, and greenhouse design.

Crop yield is a key parameter and varies depending on the type of plant. Reported yields include approximately 20 *kg/m<sup>2</sup>/year* for strawberries [32][33], 50-75 *kg/m<sup>2</sup>/year* for lettuce [34], up to 115 *kg/m<sup>2</sup>/year* for leafy greens [33] and 30-116 *kg/m<sup>2</sup>/year* for tomatoes [35]. Herb production, such as basil, is often reported in volumetric terms, with yields of 35-50 *kg/m<sup>3</sup>/year* [36]. These variations highlight the importance of selecting crops that match the environmental conditions and spatial constraints of the site.

In addition to yield, plant-specific requirements such as temperature, humidity, light intensity, and CO<sub>2</sub> concentration must be considered, as these directly affect productivity

and system design. Economic feasibility is also influenced by fluctuating market prices, which vary depending on supply, demand, and seasonal factors.

Energy demand is another important factor. A study conducted at Uppsala University proposed a greenhouse design powered by waste heat, consisting of four vertical levels. This resulted in an estimated annual energy use of 790 652 kWh [37]. Such estimates are important for evaluating integration with the mill's energy system. In a normal greenhouse the energy need would be around 1.06 MJ/kg tomatoes and would require 24 574 MJ/hectare [38]. A company called WA3RM reuses 35 GWH waste heat/year, producing 8000 tonnes of tomatoes/year in a normal greenhouse, meaning more land area used, 100 000  $m^2$  [39]. These numbers can be used to estimate the possible energy use and yield for a vertical hydroponics tower instead of horizontal. If there are 4 extra plants per  $m^2$ , then both the yield and waste heat needed should be multiplied by 4. That would result in 140 GWH waste heat/year for a site of the same land area to produce 32000 tonnes of tomatoes in a year. Per 1  $m^2$  land area that would be 320 kg of tomatoes and 1.4 MWH waste heat/year.

Environmental performance should also be considered. A life cycle assessment comparing vertical farming with conventional agriculture is presented in [34], showing that emissions depend strongly on system design and energy sources. This is particularly relevant when utilizing industrial excess heat, as it may improve overall sustainability.

Finally, the technological complexity of vertical farming systems should not be underestimated. Climate control, irrigation, lighting, and automation systems require careful design and integration. Therefore, collaboration with experienced technology providers is recommended. Examples include WA3RM [40], which develops systems for tomato cultivation using industrial waste heat, and Systemair [31], which has demonstrated greenhouse operation in cold climates such as Boden, with outdoor temperatures reaching as low as -20 to -30 °C.

### 3.5.2 Fish farming

Another use for excess heat is in fish farming, using heat for fish farming or growing larvae for feeding the fish. There was a pond fish farm for trout nearby SCA Östrand called Vivstavarv, it is currently closed but farming larvae for fish food would have been an intriguing possibility. There is an ongoing project at Vattenfall (a company in Sweden) where they grow fly larvae for fish food from waste heat [41], which is also of possible interest fish farming. A few small project for fish farming for more tropical fish and shrimp based of waste heat of 30 – 40 °C exists already. Professor Anders Kiessling at Uppsala University expresses that he believes that this will be increasingly common in the future[42]. Using the heat directly for heating at a fish farm is promising, especially when a lot of the 49 °C water is not used and can go almost directly toward this venture. Fish farming typically requires a water temperature in the range of 18–20 °C. The total energy consumption associated with water circulation, heating and cooling, oxygenation, filtration, and removal of unwanted compounds is reported to be approximately 2.9–81.48 kWh per kg of produced fish. This wide range depends on factors such as production volume, geographic location, growth stage, and system design. The implementation of heat recovery from drainage water and exhaust air has been shown to reduce the heat demand by approximately 50%. The study in question was for a fish farm with a total

floor area of 782  $m^2$  [43].

Fish farming technology for waste heat recycling is provided by companies like Big Akwa, where the cooled water is reused in the industrial process, which reduces the need for cooling and new water [44], according to an article from RISE [45] summarizing findings from a project conducted in collaboration with SCA. A fish-farm for rainbow salmon will start building in Ånge (Alby) in 2026, set to finish in 2029 by Big Akwa. The fish-farm will use oxygen and waste heat from the industry nearby to grow the rainbow trout on land and minimize environmental impact [46]. There is also the possibility of fish being grown at pulp mills due to the process water being good for algae production which the fish can eat, proposed by a woman named Åsa Strand in collaboration with the company ÅF (currently called AFRY) [47]. The fish farming venture requires plenty of space, which might not be available adjacent to the mill, but since SCA owns plenty of forest and land area, there might be space close by. Farming fish in the ocean is an option, but there is the risk of eutrophication due to the waste (consisting of waste produced by the fish and excess feed) produced by the fish [48] and the project would require multiple permits [49]. Releasing waste heat into the ocean also contradicts the purpose of using waste heat. More investigation into the possibility of fish farming or larvae farming is needed in order to reduce waste heat and possibly produce products for economical gain.

#### 3.5.3 Larvae farming

As mentioned in section 3.5.2, growing larvae for fish food is a possibility [41], but larvae farming has more uses. Fly larvae could possibly be used to feed pigs, hens [41] and ducks. Larvae is good for food waste treatment by decomposing it into high value bio-oils and proteins, the flies themselves can be used for animal feed or biofuels [50]. During fly larvae farming something called frass is collected, consisting of dead skin and excrements from the fly, resulting in an end product possibility of fertilizer [51]. The black soldier fly has a very specific temperature range, 27-30  $^{\circ}C$ , for the optimal growing conditions, where more than a few degrees change in temperature can result in slower growing or death of the larvae [52]. Production of 1 ton of larvae meal requires 9329 MJ of energy [53], thereby since the mill produces 55 MW=198 000 MJ/h waste heat with a temperature over 25  $^{\circ}C$ , roughly 21 ton larvae meal could be produced per hour. This is if space allows, but since trays of larvae can be stacked tall there should be enough space to produce many tonnes of larvae meal per month, due to the 38 day lifespan of the black soldier fly [54].

### 3.6 Biorefinery-Warm wastewater production increase

On site at SCA Östrand a new co-owned development between ST1 and SCA Östrand is in its early stages. The proposed new development is a biorefinery [55], which was investigated for this project as an intriguing possibility for a receiver of waste heat. In an interview with Lars Gustavsson [56] a key person in the development of said biorefinery, the possible opportunity for a symbiotic relationship between the NBSK mill and the planned adjoining biorefinery was investigated. The biorefinery aims to utilize bark currently used in the bark boiler and sawdust which will be transported from sawmills to make 80% (Sustainable Aviation Fuel; jet-range hydrocarbons, C8–C16) (SAF) and 20% naphtha. The estimated avoidance of around 1,000,000 tonnes of  $CO_2$  equivalent per year

is based on replacing a procentual part of the conventional aviation fuel with SAF [57]. The biorefinery will produce around 185 000 tonnes of SAF and 50 000 tonnes of naphta per year[58].

The refinery production will result in the Bark boiler becoming redundant in time and possibly being replaced by an electric boiler. The refinery itself will not require additional heat, but rather produce an excess amount, pumped into the SHS at the mill. The SHS will receive an unknown flow with 65 °C and/or 85 °C hot water from the refinery as the wastewater is too hot to release into the ocean. The mill will not have a proportional increase in energy use or outside energy demand, therefore the majority of this new heat will go to waste. Lars also proposed use of excess heat in fish farming, at saw mills or in greenhouses, which confirmed earlier research on the subject. For fish farming and greenhouses, there is a demand for space, which is not always available. For saw mills there are a few places nearby which could be suitable as customers of excess energy. There was also a discussion about the amount of jobs which would be provided by the new refinery, due to the possibility that if the residential area expanded the demand for district heating would increase as well.



# 4

## Discussion

### 4.1 Interpretation of the energy balance

Regarding the EB in tables 3.1 and 3.2 and the PFD in figure A.1, there are a few parts to discuss. First, the 'feedstock thawing' (nr 22) and 'chemical station  $CO_2$ ' (nr 10) have the same exact values, but with different flow meters. This could indicate that the streams are the same or that the similarity is coincidental. Excluding one of these streams would make the EB more unbalanced as less heat would leave the boundary of the system. Comparing the Helios EB in table 3.4 and the 2025 EB in table 3.6 it suggests that the created EB tool is reasonable, as explained in section 3.2.1. Therefore, removing one of the streams without further justification would be unwise.

Secondly, in table 3.2 the highest error [%] was 11%, and the lowest was -2.28%. Both of the lowest errors [%] were for the summer cases and the higher errors [%] were for the winter cases. This is reasonable as during winter there are sometimes temporary streams which are not always clearly displayed in process schemes and may also lack flow meters, like freeze-protection circulation of warm water. There is also the case of lost heat due to poor insulation that is more significant during winter when the temperature difference is much larger. An error of approximately  $\pm 10 - 15\%$  is reasonable for the EB of a SHS of this size. Next, the wastewater heat in table 3.2 had to be adjusted in order to identify the amount of heat that is actually usable for in particular heat exchangers as the usual temperature for cold wastewater is around  $25\text{ }^\circ\text{C}$  or less. The energy savings in table 3.3 are also adjusted for that same issue.

The waste heat for winter 2023-2024 in figure 3.2 can be expressed as energy (total energy transferred over time)[MWh] rather than power (rate of energy transfer)[MW=MJ/s], taking the winter 2023-2024 case as an example:

- POWER: 55 MW=55 MJ/s=198,000 MJ/h
- ENERGY: 55 MWh for one hour or 241 560 MWh for the entire winter 2023-2024 period

The largest heat sinks are warm wastewater out of the system, some of these have both unknown flows and temperatures. The assumptions made regarding these waste heat flows are relatively rough due to limited available data, which may contribute significantly to the observed imbalance in the EB.

Table 3.2 displays the wastewater heat available, between 99-204 MW, which is rather a lot. But since water can be released into the sea at around  $25\text{ }^\circ\text{C}$  (rough estimate) not much more can be gained from waste heat below  $25\text{ }^\circ\text{C}$  in a heat exchanger. Therefore the wastewater heat above  $25\text{ }^\circ\text{C}$  was investigated which resulted in between 55-110 MW useable waste heat, which is still quite a lot.

The waste heat left presented in table 3.2 is still a large amount, for the summer 2025 case the wastewater heat ( $T > 25\text{ }^{\circ}\text{C}$ ) [110 MW] was calculated to be around a third of the total energy in [283 MW], for winter 2023-2024 the comparison resulted in the wastewater heat ( $T > 25\text{ }^{\circ}\text{C}$ ) was calculated to be around 1/6:th of the energy in.

### 4.2 Sources of error and uncertainty

Even though the error is reasonable within  $\pm 10 - 15\%$  it is of interest to understand where the imbalance stems from. The energy imbalance may be attributed to several factors, including unknown heat sinks or sources, simplifying assumptions in the energy balance, measurement uncertainties, and heat losses from poorly insulated equipment. There are many unknown heat sinks and sources which are not accounted for in the energy balance due to the flows being too low, the temperature being too low or there being no information about the temperatures and flows for the streams.

**Table 4.1:** Sources of uncertainty in the energy balance and their potential impact

Source of Uncertainty	Potential Impact on Energy Balance	Notes / Examples
Missing flow meters	Underestimation of heat flows	Some streams (e.g., wood impregnation heater, small condensate streams) are not measured.
Rough assumptions	Over- or underestimation of heat flows	Assumptions about wastewater temperature and flow are often very approximate.
Seasonal variations	Higher errors in winter	Temporary streams, freeze-protection circulation, and increased heat losses due to larger temperature differences.
Low temperature streams	Reduced usable heat	Wastewater below 25°C cannot be efficiently used in heat exchangers.
Unknown heat sinks / sources	Imbalance in energy accounting	Heat losses or gains in minor equipment, low-flow streams, or unmonitored parts of the mill.
Measurement errors	Minor inaccuracies in EB	Temperature and flow meters have finite precision; errors propagate through calculations.
Insufficient insulation	Increased heat loss	Especially significant in winter due to larger temperature differences between process streams and ambient.
Integration with future biorefinery	Potential increase in wastewater heat	Additional heat from future refinery may increase flows beyond current system capacity.



# 5

## Conclusion

### 5.1 Comparison with Helios project

To address the research questions, the final design of Project Helios is compared with the original project plans developed approximately ten years ago. Differences between the corresponding process flow diagrams (PFDs), shown in Figures A.1 and A.5, are identified and summarized below:

- The A-condensate was included in Helios but was phased out around 1-2 years ago (around 2024). A-condensate is A-grade, meaning good quality condensate (water) from steam with high temperature. There is also B-condensate and C-condensate in the mill, where C-condensate is a low quality condensate. Neither of these condensate qualities are of interest for the current design (2025) PFD and as such have not been discussed previously.
- The vapour scrubber in the Helios case utilized water at approximately 49 °C, whereas the current system uses process water at a significantly lower temperature of approximately 12 °C. This difference may contribute to the reduced performance of the vapour scrubber.  
For the Helios case, the higher inlet water temperature meant that less heating was required to reach the desired operating temperature. In contrast, in the current system, a larger portion of the available heat must first be used to raise the process water temperature from approximately 12 °C to around 50 °C. As a result, less energy is available to achieve and maintain the target temperature of 65 °C after the scrubber, which may negatively affect its performance.
- The gas cooler only produced 85 °C water in Helios, compared to the possibility of producing either 65 °C or 85 °C water depending on the need currently.
- The reheater for 65 °C water did exist for Helios but was not shown in the Helios PFD. The condensate for the reheaters for 49 °C and 65 °C was also not shown to enter the tanks in the Helios PFD.
- Backwater drying machine 5 was not mentioned in Helios but is currently used in the mill.
- The wood impregnation heater was investigated in the preparation of the current PFD, but was determined to have a very low flow. There is no flow meter attached and as such the flow was calculated and found to be much lower than the acceptable range.

- The condenser O2 and OP2 in Helios is not in the current PFD due to low flow. Multiple SCA employees were adamant that these flows were very low and as there were no flow meters, these heat exchangers were not included.
- Some streams may have different names, be too small for the 2025 PFD in figure A.1 or be included in larger combined streams. Streams such as *weak liquor* and *preheating carbon dioxide water* may be included in any of the possible combined streams, as they are not depicted in the 2025 PFD.

It is of interest to note that the investigation only investigated changes to the PFD, if some equipment was exchanged but kept the same name it will not have been possible to determine that a change has occurred. In regards to the EB it was difficult to compare the 'worst case scenario' for project Helios to the 'average case' for the current one. To be able to compare Helios to that of the current EB, the max values for a current case in winter 2024-2025 was found in figure 3.3. The comparison of table 3.4 and table 3.6 shows that they are very similar indicating very little change. This mainly shows that the energy balance tool is working, having similar max values for heat entering and exiting the system. Comparing the EB for the *Helios* vs the *2025* does not really give any more information. For a more complete picture of the EB differences more detailed information about the different heat exchangers and data for them from before Helios would be needed.

## 5.2 Further optimization/ Future work

Further optimizations of the SHS are now addressed. The make-up water heater does not fulfill its purpose, heating the make-up water to around 27 °C instead of 41.8 °C as mentioned in section 2.5.2.5, due to insufficient temperature of the inlet make-up water. This insufficient temperature leads to using more steam later in the process. Whether the installation of a new heat exchanger or modifications of the current one is economically and technologically sound is outside the scope of this report as it does not actually affect the energy balance directly. After adjustments it may affect the SHS, but as it stands there is no easy fix and investigating the Make-up water heater that is located outside the SHS would be too much work and is not included in the boundaries of this report.

The heat exchangers, known as Vapour Scrubbers, may require additional heating, potentially from steam or another higher-temperature source, to reach the desired outlet temperature of 65°C. However, much of this heat ends up in the wastewater, representing a loss of energy. Recirculating some of the outgoing water might also be a possibility. The problem of too low heat originates from the warm stream of process fluid assumed to have a higher temperature in the construction of the Vapour scrubbers.

Using steam to help top up the water temperature from the Vapour scrubber might also be a possible solution. However, this approach would require additional equipment and a continuous supply of steam, which would increase operational costs. Despite this, introducing steam at this stage of the process might reduce the need for heating further downstream in the system (like for the ventilation). By increasing the temperature earlier in the process, it may be possible to decrease the overall steam demand later in the heating stages. Consequently, although this solution requires additional investment and operational costs, it could potentially result in a net reduction in steam consumption and improved overall energy efficiency. Further investigation would be required to determine whether such a modification would be economically and technically viable.

Some measuring equipment is needed to get a more thorough insight into the actual amount of warm wastewater needed for any given venture, especially after the proposed refinery is built and connected to the mill. The measuring equipment is listed in 3.4.4 and some flow and temperature meters for the flow and temperature of warm wastewater from the proposed refinery is also needed. These should ideally be installed prior to or during the planning of the venture, in order to gather data on the total flow and temperature of the warm wastewater.

In regards to the possible ventures using wastewater heat, a viable investment requires that the venture is located nearby to enable efficient heat delivery, there should be a stable market for the product, and the amount of available heat should be well defined. The available heat has to be a known entity because the customer must have some guarantee of delivery of heat to make proper economical decisions regarding the possible venture. As the amount of excess heat is unknown at this time it is difficult to do proper calculations regarding the amount of excess heat available for sale. There are a few streams where there are no flow meters and/or temperature measurements, making it difficult to calculate the total amount of excess heat which can be supplied at a certain temperature and flow. There might also be an issue of how to collect the different sources of excess heat into one in practice, as the exit points are located at different parts of the mill. The cost of pipes to connect these warm wastewater streams and the equipment to start for example the vertical greenhouse might be expensive but the products that can be sold at the end might justify the expenses. The exact amount of heat available is only an estimate and the investment costs of this venture are too extensive to calculate within the scope of this report. More information and calculations are needed, therefore this might be a good idea for the next master thesis if SCA are interested in this venture.

As to the economical viability of vertical farming, the heat and water is essentially free and as they could use some existing infrastructure it could be very economically viable. There is the investment cost of pipes and other farming and heat exchanger equipment which can be expensive. The vertical farming venture do produce products not specifically made for a certain process, but rather a product available in all supermarkets, which should be profitable. The technology is also widely studied currently and many companies provide complete setups with adjustments to suit each companies need. With the technological expertise of the greenhouse setup, greenhouse growing in general and technical expertise of the equipment there should be no trouble.

### 5.3 Summary of key findings

The maximum available waste heat with a temperature above 25 °C is 110 MW for summer and 68 MW for winter according to table 3.2. This is only between 23-38 % of the total waste water heat produced.

The comparison of the EB between the Helios project and the current 2025 case resulted in an unfair comparison initially. With adjustments to accommodate for Maximum data points for the 2025 case and keeping the use of maximum values for dimensioning of the equipment for the Helios case, a comparison could be made. This resulted in simply confirming that the current EB tool was adequate but nothing else, due to similar max values for both energy (heat) entering and exiting the system. Investigating the EB for 2025 in terms of 'The law of conservation of energy', table 3.2 presented that IN was not

equal to OUT. The Error [%] was between -2.28 and 10.99 %, it was assumed that if the inequality was between  $\pm 10 - 15\%$  the EB was reasonable and therefore the EB was accepted.

Comparing the PFDs did introduce a few differences between the design case (Helios) and the current situation (2025). Mostly some minor changes were located, but a few changes made an impact. A-condensate for example had a large flow, but is now closed. Changing the cooling stream for the vapour scrubber from 49 °C to process water (lower temp) affected the temperature of the cooling stream out, resulting in too low temperature often. The other changes while of interest does not impact the EB significantly in the end.

### 5.4 Answers to research questions

- How does implementation of project Helios compare to the project plans?
  - The comparison showed that most of the system is similar, with some minor changes, for example in A-condensate handling and the vapour scrubber cooling stream.
- Are there any possible further optimizations to the SHS?
  - Modifications to the vapour scrubber and a redesign of the make-up water heater could increase the temperature level of the recovered heat while reducing the amount of excess waste heat. This improves the overall thermal efficiency of the system, but also decreases the availability of waste heat for other potential uses.
  - Further improvement to the mill includes decreasing the amount of wasted heat by utilizing it in a side venture such as vertical vegetable farming or larvae farming.
- Are the proposed modifications economically viable and technologically feasible?
  - While the proposed SHS modifications appear technically feasible, their economic viability would require further calculations and investigation. Steam saved does not automatically translate into financial gain. Often the cost of additional equipment exceeds the money gained from the steam saved.
  - Additional measuring equipment would provide more accurate data regarding the amount of waste heat available, after which economic evaluations could be performed. The proposed ventures proposed to utilize waste water heat are technologically viable according to available sources, but a decision must be made regarding which venture to pursue. At present, no credible calculations could be produced within the scope of this thesis.

### 5.5 Potential utilization of wastewater heat

Since there is a relatively large amount of waste energy available for use and the possibility of more wastewater heat from the proposed biorefinery the suggestions of using the wastewater for another purpose could be a good solution to minimize energy losses. Possible uses investigated in this work include using it for fish farming, larvae farming for fish feeding or farming fruit and vegetables in a warm wastewater heated vertical greenhouse. The possible refinery will not be available to receive wastewater heat but will rather add to

the wastewater amount. The possible refinery would actually provide a challenge for the SES as the amount of warm wastewater would increase, which the system is not designed for. This makes it even more important to find a solution for how to handle the warm wastewater. Therefore, three options remain, starting with the larvae farming. The larvae farming is a very viable option as the larvae can be used for fish feed in fish farming, but the larvae can also be used for other animal feed, like chicken, ducks, pigs and in some cases for pet food. The residual products from larvae farming, like skin and excrements can be used in fertilizer and the fly itself if not used for feed could possibly be used in bio-fuel production, therefore it is possible that the refinery could reuse the wastewater heat through fly larvae farming for economical gain. Further research is required to evaluate the technical feasibility and economic viability of these potential applications.

The fish farming might be a good additional venture in addition to larvae farming if not for the space issue. The space would have to be close by for the cost of pipes for the warm wastewater transport to be worth it. Fish farming in the ocean next to SCA is also not an option due to eutrophication being a problem. The remaining option is vertical farming, which could be an onsite project in and on available unused buildings. Using wastewater for watering and warm wastewater for heating the greenhouses as well as electricity for the lamps. A possibility is to demolish the unused buildings to make room, but that might be too much of a commitment at this point. The heated ventilation in the buildings could possibly be used for the heat transfer to the greenhouse air or be adjusted to use wastewater. After the biorefinery has been built and the amount of warm wastewater increases some additional heat will be provided. A combination of fly farming and vertical farming might be beneficial at that point to handle the extra heat, due to the possibility of using the fertilizer for the plants and of using the flies in the biorefinery or sell it, the larvae farming might be of interest. It is also possible to use food waste, farming waste and plant parts from a vertical greenhouse to feed the larvae, making it beneficial for the environment on multiple stages. Diversification is generally advantageous, but not guaranteed. Maintaining both ventures might appear beneficial theoretically, yet prove challenging in reality. The final decision is at SCA's discretion. There are probably both challenges and further possibilities with this vertical greenhouse venture and the larvae farming, but vertical farming seems to be the most viable option at this point.

## 5.6 Practical implications

Warm wastewater is essentially an untapped potential, although not the best for heat exchange it still holds significant heat. The heat can be utilized for other ventures like fish farming, larvae farming or vertical farming of vegetables. Due to the large amount of waste heat available and the possibility of using old structures on site as well as possibly reusing old ventilation heat exchangers for the older buildings, vertical farming is an interesting option. This is particularly true if the wastewater can be used for watering as well. Larvae farming is also an attractive option due to being easy to start, space efficient and it has a few products and byproducts which can be sold. The fish farming requires more free space and is thus not a very attractive option for this mill. The economical gain for the vertical farming depends on the produce grown, if some of it is premium produce, such as locally grown strawberries during winter, it will sell for more money.

Whichever venture is chosen new pipes to gather the waste heat will be needed and pos-

sibly a tank. For vertical farming the starting cost is quite high due to new equipment, fertilizer, soil, seeds, monitoring equipment and more. For the larvae farming there is lower starting cost due to only needing trays, heat and feed, where the feed can possibly be mill waste or organic waste. The waste heat will also require ventilation heat exchangers due to incoming heat existing in water and the larvae need warm air. Depending on the temperature of the waste heat, this might not be enough for the larvae, they need temperatures of around 27-32 °C for black soldier fly larvae and are very specific, variations from optimal temperature can result in slower growth or death of the larvae. Deciding on a venture requires more research and calculations, therefore a decision will not be made here.

### 5.7 Recommendations/Future work

The measuring equipment mentioned in the report need to be installed in order to further investigate which venture, vertical or larvae farming, is most reasonable on site. Starting small pilot projects of larvae farming and vertical farming might be of interest to further investigate which venture is the most reasonable for SCA.

Improving the Vapour scrubber through recirculation or by using some LP-steam to improve the ingoing/outgoing temperature would in theory decrease the amount of waste heat and increase the amount of 65 °C water entering the tank.

Economical viability for the vapour scrubber can be hard to determine, a reduction in steam consumption might save enough money to warrant a rebuild, but it also might be too costly to rebuild despite the saved money and energy from steam saving. The Vapour scrubber being modified to get higher temperature into the heat exchanger by recirculating some of the water out might improve the temperature into the 65 °C tank and thus decrease the warm water waste. A recirculation should in theory be profitable as it would require less equipment, less pipes and the heat exchangers would not need major modification, leading to lower cost than the alternatives.

Another piece of equipment in need of change is the Make-up water heater. By redesigning this heat exchanger, steam would be saved down the line and also less heat exiting the system through warm wastewater. There is a possibility that the Make-up water heater is fouled. This would indicate a need for more frequent and structured cleaning routines.

### 5.8 Limitations

Due to a few pieces of measuring equipment missing, more exact calculations regarding waste heat flows and temperatures can not be made. The wastewater heat amounts are based on assumptions and estimations. This also includes measuring data errors of 1-2% and the assumption that all flows below 40 m<sup>3</sup>/h can be disregarded. Any calculations which could be made based on these numbers would be rough estimates. Using these numbers for estimating the cost and execution of one of the proposed ventures should be seen as just that, an estimate. If the biorefinery is built, it would also impact the amount of wastewater heat and the size of the venture. It is important to keep this in mind for the sake of accuracy and success of venture. Despite these limitations, the results

indicate that a significant amount of waste heat is available and that further investigation into potential utilization strategies are needed in order to assess the environmental and economic benefits.



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# A

## Appendix 1

The full and zoomed in pictures of the PFD's for the Helios and current case are all displayed here. Three out of four tables displaying the calculation data for the four cases; winter 2023-2024, summer 2024, winter 2024-2025 and summer 2025 are displayed here as well. The winter 2024-2025 case is displayed in *Results*. Notice also that the arrow colors and meaning of the arrows are displayed in and that Low pressure steam is included in the PFD's as it is of economical interest to know where steam is used.

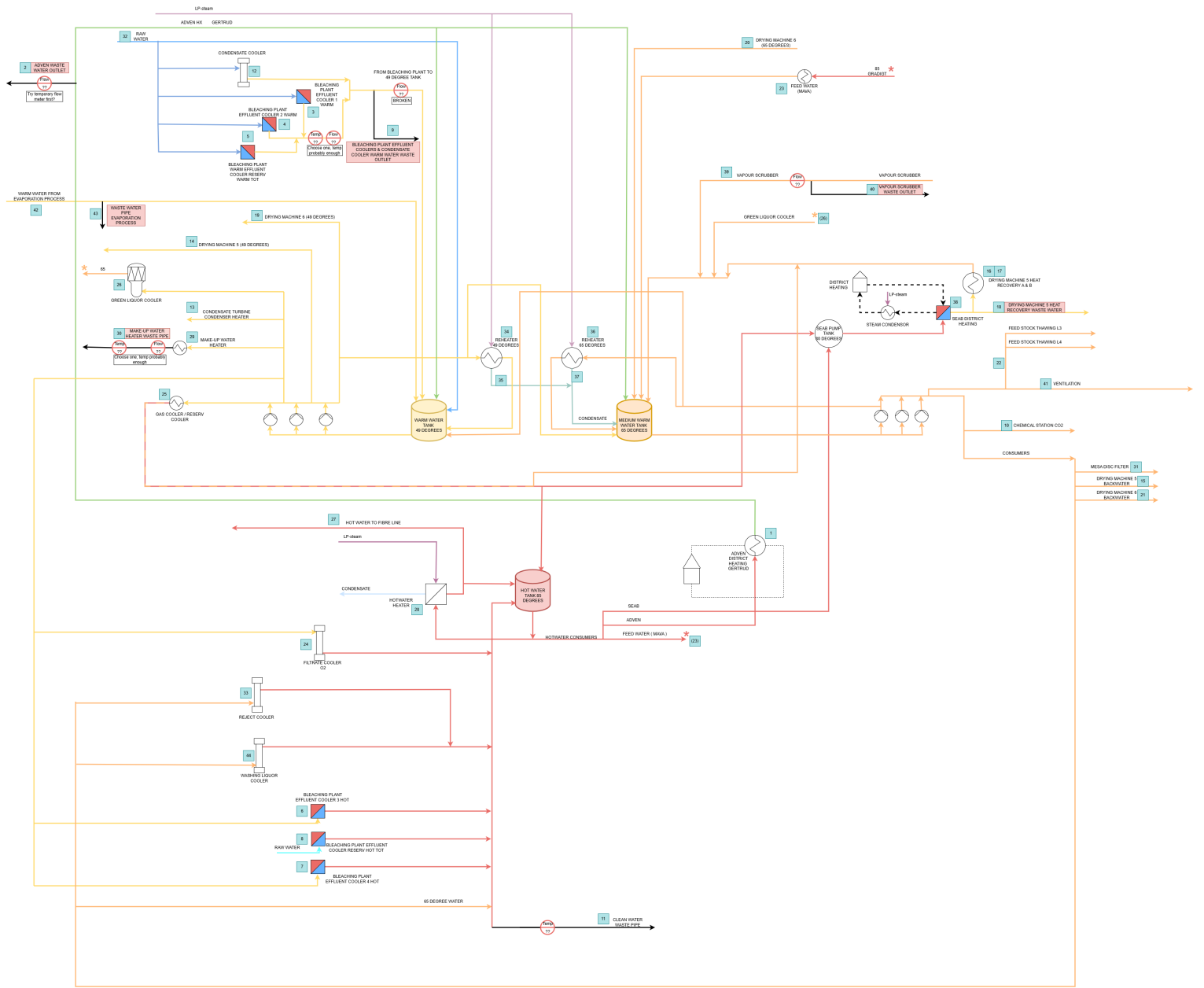
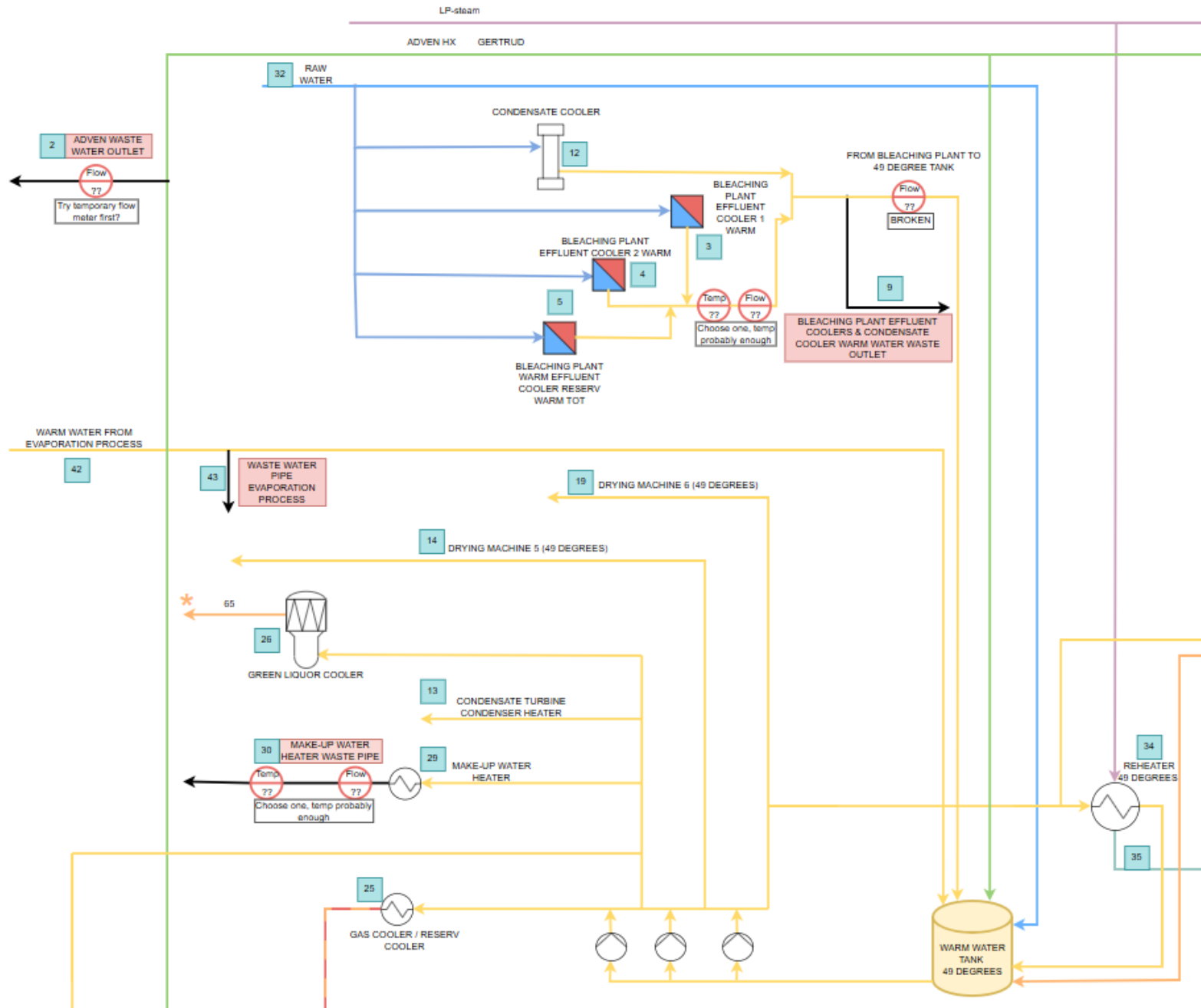
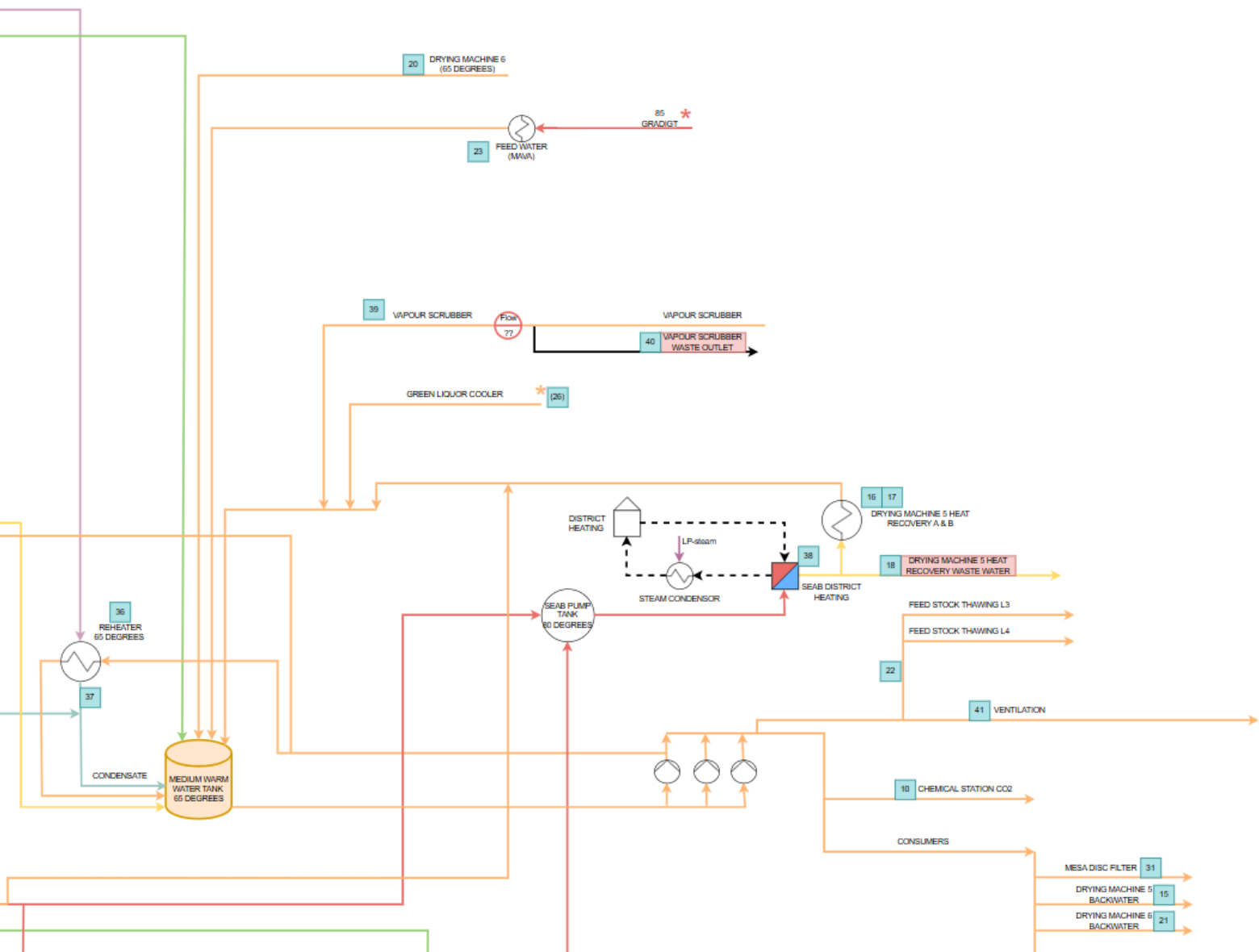


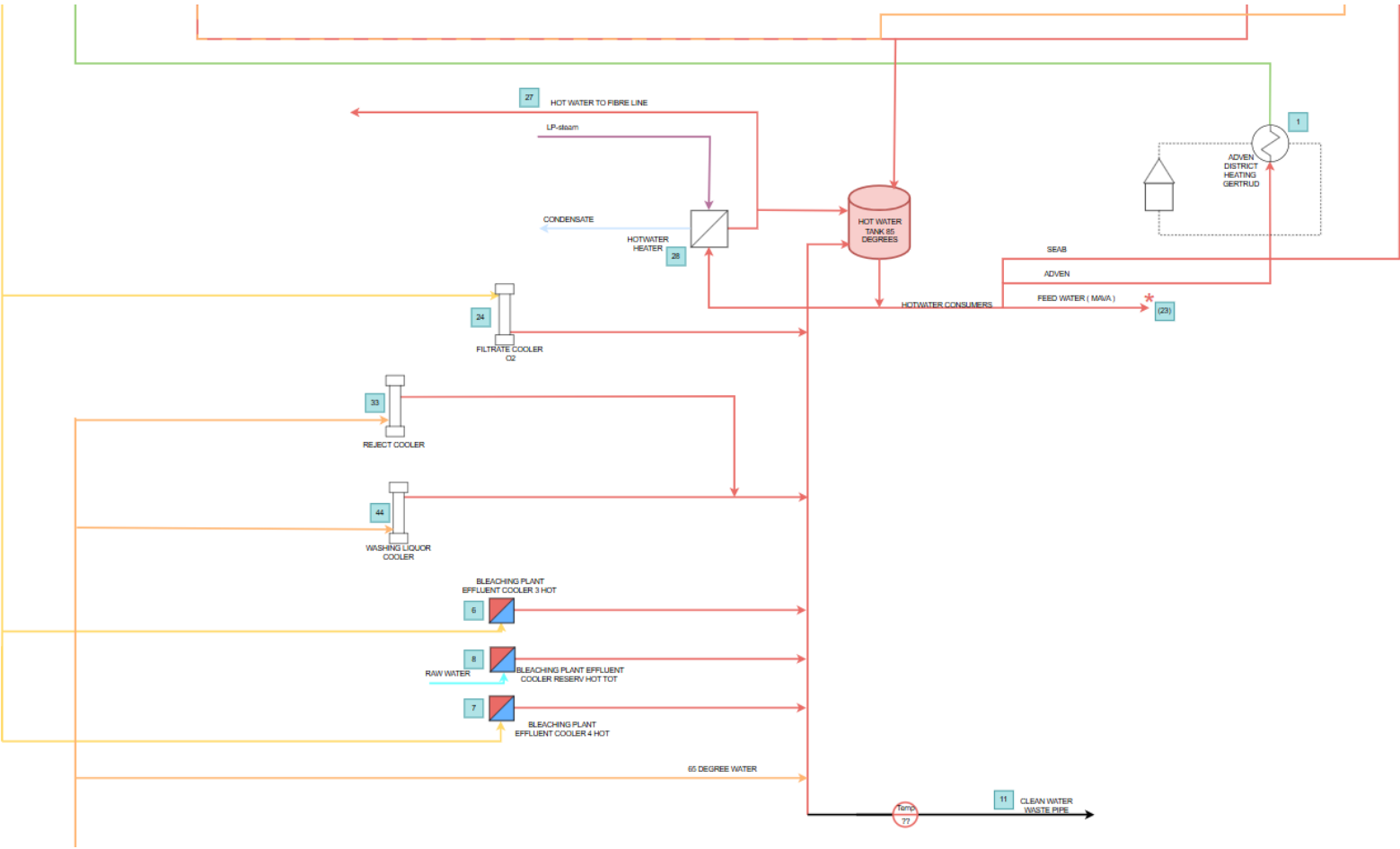
Figure A.1: The entire detailed 2025 PFD



**Figure A.2:** The 49 degree cistern and surrounding streams in the detailed 2025 PFD



**Figure A.3:** The 65 degree cistern and surrounding streams in the detailed 2025 PFD



**Figure A.4:** The 85 degree cistern and surrounding streams in the detailed 2025 PFD

No	Name	HX	Stream	Tin	Tout	Flow	Q [MW]	EB	No unk	1 unk	Mult unk	Comments
1	ADVEN District Heating (Gertrud)	HX		81.88	60.05	380.39	9.45	OUT	X			
2	ADVEN Waste Water Outlet		Stream		60.05	UNKNOWN	-	OUT		X		Flow cannot be calculated.
3	Bleaching Plant Effluent Cooler 1 Warm	Cooler										
4	Bleaching Plant Effluent Cooler 2 Warm	Cooler		7.92	41.49	168.08 kg/s	23.61	IN			X	Flow calculated from historical data and raw water balance.
5	Bleaching Plant Effluent Cooler Reserv Warm Tot	Cooler										
6	Bleaching Plant Effluent Cooler 3 Hot	Cooler		47.23	80.36	350.83	13.26	IN	X			
7	Bleaching Plant Effluent Cooler 4 Hot	Cooler		47.26	79.15	210.02	7.64	IN	X			
8	Bleaching Plant Effluent Cooler Reserv Hot Tot	Cooler		1:7.78, 2:8.37	1:78.86 , 2:32.86	1:2.78 kg/s, 2:-0.01 kg/s	1:0.83 2:-0.001 , Tot:0.83	IN		X		Flow determined through assumptions and calculations. Rarely used but important, therefore an exception to the minimum flow rule.
9	Bleaching Plant Effluent Cooler & Condensate Cooler Waste Outlet		Stream		38.97	114.81	5.17	OUT			X	A mixing-point calculation based on the temperature of the condensate cooler and the calculated outgoing temperature of the warm effluent coolers.
10	Chemical Station CO <sub>2</sub>		Stream		61.89	170.85	12.08	OUT	X			
11	Clean Water Waste Pipe		Stream		74.57	323.43	27.35	OUT		X		Temperature calculated using mixing-point calculation.
12	Condensate Cooler	Cooler		8.51	25.26	102.30	1.99	IN		X		Temp out calculated from values over cooler.
13	Condensate Turbine Condenser Heater		Stream	-	47.04	298.84	16.17	OUT	X			
14	Drying Machine 5 (49 C)		Stream	-	46.41	245.80	13.13	OUT	X			
15	Drying Machine 5 Backwater		Stream		61.15	39.41	2.75	OUT	X			
16	Drying Machine 5 Heat Recovery A	HX		63.32	64.29	279.13	0.31	IN	X			
17	Drying Machine 5 Heat Recovery B	HX		63.31	64.06	270.30	0.23	IN	X			
18	Drying Machine 5 Heat Recovery Waste Water		Stream		64.16	241.64	17.68	OUT	X			
19	Drying Machine 6 (49 C)		Stream	-	46.75	438.47	23.59	OUT	X			
20	Drying Machine 6 (65 C)		Stream	60.29	-	383.63	26.44	IN	X			
21	Drying Machine 6 Backwater		Stream		61.58	232.72	16.37	OUT	X			
22	Feed Stock Thawing		Stream		61.89	170.85	12.08	OUT	X			
23	Feed Water (MAVA)	HX		81.93	58.10	169.01	4.58	OUT	X			
24	Filtrate Cooler O <sub>2</sub>	Cooler		47.35	82.28	119.70	4.90	IN	X			
25	Gas Cooler / Reserv Cooler	Cooler		46.59	86.88	111.17	5.11	IN	X			
26	Green Liquor Cooler	Cooler		46.98	73.25	210.07	6.31	IN	X			
27	Hot Water To Fibre Line		Stream	-	82.97	1.63	0.15	OUT	X			
28	Hotwater heater	HX		81.65	87.19	1201.39 kg/s	29.40	IN	X			
29	Make-Up Water Heater	Heater		46.35	41.90	323.21	1.65	IN			X	flow calculated based on measured temperature out at 1 time-point, used to make rough assumptions to calculate the flow and thereby allowing the temperature to be determined.
30	Make-Up Water Heater Waste Pipe		Stream		41.90	323.21	15.59	OUT			X	flow calculated based on measured temperature out at 1 time-point, used to make rough assumptions to calculate the flow and thereby allowing the temperature to be determined.
31	Mesa Disc Filter		Stream		61.17	56.97	4.04	OUT		X		Flow calculated.
32	Raw Water		Stream	3.97		39.39	0.18	IN	X			
33	Reject Cooler	Cooler		62.61	75.55	53.64 kg/s	2.91	IN		X		
34	Reheater 49 C HX	HX		46.41	49.31	743.58	2.48	IN	X			
35	Reheater 49 C Stream		Stream	44.34	-	7.29	0.37	IN	X			
36	Reheater 65 C HX	HX		61.02	61.80	536.04	0.48	IN	X			
37	Reheater 65 C Stream		Stream	58.82	-	4.43	0.30	IN	X			
38	SEAB District Heating	HX		83.07	63.56	817.74	18.13	OUT				
39	Vapour Scrubber		Stream	59.26	-	444.602	30.52	IN	X			
40	Vapour Scrubber Waste Outlet		Stream	-	60.05	324.09	22.25	OUT		X		flow calculated through valve openness, with flow of the vapour scrubber as basis
41	Ventilation		Stream		61.67	463.36	32.64	OUT	X			all flows and temperatures known, but since a combined stream for the purpose of the PFD, Flow-weighted mixing temperature is calculated.
42	Warm Water from Evaporation Process		Stream	48.39	-	2364.93	131.61	IN	X			
43	Waste Water Pipe Evaporation Process		Stream		43.86	232.28	11.74	OUT	X			
44	Washing Liquor Cooler	Cooler		62.40	86.56	110.65	3.04	IN	X			

Table A.1: Calculation data for winter 2023-2024

No	Name	HX	Stream	Tin	Tout	Flow	Q [MW]	EB	No unk	1 unk	Mult unk	Comments
1	ADVEN District Heating (Gertrud)	HX		83.71	62.38	101.88	2.47	OUT	X			Flow cannot be calculated
2	ADVEN Waste Stream		Stream		62.38	UNKNOWN	-	OUT		X		
3	Bleaching Plant Effluent Cooler 1 Warm	Cooler										
4	Bleaching Plant Effluent Cooler 2 Warm	Cooler		18.98	39.01	240.14 kg/s	20.12	IN			X	Flow calculated from historical data and raw water balance.
5	Bleaching Plant Effluent Cooler Reserv Warm Tot	Cooler										
6	Bleaching Plant Effluent Cooler 3 Hot	Cooler		47.80	81.44	352.30	13.52	IN	X			
7	Bleaching Plant Effluent Cooler 4 Hot	Cooler		47.80	79.53	260.75	9.45	IN	X			
8	Bleaching Plant Effluent Cooler Reserv Hot Tot	Cooler		1:19.02 ;2:19.21	1:79.52 ;2:33.94	1:4.63 kg/s ;2:-0.003 kg/s	1:1.17 ;2:-0.0002 ;Tot:1.17	IN		X		Flow determined through assumptions and calculations. Rarely used but important, therefore an exception to the minimum flow rule
9	Bleaching Plant Effluent Cooler & Condensate Cooler Waste Outlet		Stream	-	0	0	0	OUT			X	A mixing-point calculation based on the temperature of the condensate cooler and the calculated outgoing temperature of the warm effluent coolers
10	Chemical Station CO <sub>2</sub>		Stream	-	63.56	115.12	8.35	OUT	X			
11	Clean Water Waste Pipe		Stream	-	79.39	707.51	63.50	OUT		X		Temperature calculated using mixing-point calculation
12	Condensate Cooler	Cooler		19.09	23.96	293.25	1.66	IN		X		Temp out calculated from values over cooler.
13	Condensate Turbine Condenser Heater		Stream	-	48.05	132.87	7.34	OUT	X			
14	Drying Machine 5 (49 C)		Stream	-	44.94	137.89	7.14	OUT	X			
15	Drying Machine 5 Backwater		Stream	-	64.62	34.93	2.57	OUT	X			
16	Drying Machine 5 Heat Recovery A	HX		69.90	70.30	51.45	0.024	IN	X			
17	Drying Machine 5 Heat Recovery B	HX		69.96	69.78	49.56	-0.01	IN	X			
18	Drying Machine 5 Heat Recovery Waste Water		Stream	-	67.78	77.09	5.95	OUT	X			
19	Drying Machine 6 (49 C)		Stream	-	46.34	209.69	11.18	OUT	X			
20	Drying Machine 6 (65 C)		Stream	-	60.82	167.13	11.62	IN	X			
21	Drying Machine 6 Backwater		Stream	-	64.03	181.32	13.24	OUT	X			
22	Feed Stock Thawing		Stream	-	63.56	115.12	8.35	OUT	X			Noticed identical values to chemical station despite different meter IDs.
23	Feed Water (MAVA)	HX		83.74	67.22	350.78	6.58	OUT	X			
24	Filtrate Cooler O <sub>2</sub>	Cooler		47.79	81.19	429.76	16.37	IN	X			
25	Gas Cooler / Reserv Cooler	Cooler		46.27	79.47	116.09	4.40	IN	X			
26	Green Liquor Cooler	Cooler		47.77	73.26	215.24	6.27	IN	X			
27	Hot Water To Fibre Line		Stream	-	89.39	25.01	2.51	OUT	X			
28	Hotwater heater	HX		83.76	88.03	1136.88 kg/s	20.42	IN	X			
29	Make-Up Water Heater	Heater		45.93	36.40	301.06	3.30	OUT			X	flow calculated based on measured temperature out at 1 time-point, used to make rough assumptions to calculate the flow and thereby allowing the temperature to be determined.
30	Make-Up Water Heater Waste Pipe		Stream	-	36.40	301.06	12.62	OUT			X	flow calculated based on measured temperature out at 1 time-point, used to make rough assumptions to calculate the flow and thereby allowing the temperature to be determined.
31	Mesa Disc Filter		Stream	-	65.04	49.52	3.67	OUT		X		Flow calculated.
32	Raw Water		Stream	7.88	-	5.58	0.05	IN	X			Low temperature but still carries heat energy.
33	Reject Cooler	Cooler		65.32	77.36	64.53 kg/s	3.26	IN		X		
34	Reheater 49 C HX	HX		45.40	46.30	653.02	0.68	IN	X			
35	Reheater 49 C Stream		Stream	40.37	-	2.08	0.10	IN	X			
36	Reheater 65 C HX	HX		59.78	62.83	210.68	0.73	IN	X			
37	Reheater 65 C Stream		Stream	62.71	-	7.37	2.57	IN	X			
38	SEAB District Heating	HX		82.66	69.96	178.60	0.57	OUT	X			
39	Vapour Scrubber		Stream	52.35	-	647.56	40.53	IN		X		
40	Vapour Scrubber Waste Outlet		Stream	-	54.61	606.29	37.96	OUT			X	Flow estimated from valve openness, based on flow exiting the vapour scrubber.
41	Ventilation		Stream	-	57.21	43.38	2.84	OUT	X			all flows and temperatures known, but since a combined stream for the purpose of the PFD, Flow-weighted mixing temperature is calculated.
42	Warm Water from Evaporation Process		Stream	-	48.16	2216.95	122.80	OUT	X			
43	Waste Water Pipe Evaporation Process		Stream	-	43.49	1190.70	59.69	OUT	X			Flow calculated through valve openness estimates.
44	Washing Liquor Cooler	Cooler		65.38	86.14	195.88	4.62	IN	X			

Table A.2: Calculation data for summer 2024

No	Name	HX	Stream	Tin	Tout	Flow	Q [MW]	EB	No unk	1 unk	Mult unk	Comments
1	ADVEN District Heating (Gertrud)	HX		83.91	62.23	157.28	3.87	OUT	X			
2	ADVEN Waste Stream		Stream		62.23	UNKNOWN	-	OUT		X		
3	Bleaching Plant Effluent Cooler 1 Warm	Cooler										
4	Bleaching Plant Effluent Cooler 2 Warm	Cooler		18.85	41.72	261.61 kg/s	25.02	IN			X	Flow calculated from historical data and raw water balance.
5	Bleaching Plant Effluent Cooler Reserv Warm Tot	Cooler										
6	Bleaching Plant Effluent Cooler 3 Hot	Cooler		47.99	81.89	365.00	14.11	IN	X			
7	Bleaching Plant Effluent Cooler 4 Hot	Cooler		47.90	78.52	285.48	9.98	IN	X			Flow and temperature calculated.
8	Bleaching Plant Effluent Cooler Reserv Hot Tot	Cooler		1:18.60 ,2:18.98	1:78.66 ,2:32.18	1:4.13 kg/s, 2:0	1:1.04 2:0	IN		X		
9	Bleaching Plant Effluent Cooler & Condensate Cooler Waste Outlet		Stream	-	41.24	216.43	10.30	OUT			X	
10	Chemical Station CO <sub>2</sub>		Stream		65.20	111.21	8.26	OUT	X			
11	Clean Water Waste Pipe		Stream		79.89	849.89	76.75	OUT		X		
12	Condensate Cooler	Cooler		19.14	31.80	140.89	2.07	IN		X		Temp out calculated.
13	Condensate Turbine Condenser Heater		Stream		47.83	228.20	12.55	OUT	X			
14	Drying Machine 5 (49 C)		Stream		48.03	153.44	8.48	OUT	X			
15	Drying Machine 5 Backwater		Stream		65.37	18.58	1.38	OUT	X			
16	Drying Machine 5 Heat Recovery A	HX		48.30	62.04	1.27	0.02	IN	X			
17	Drying Machine 5 Heat Recovery B	HX		52.76	63.14	1.89	0.02	IN	X			
18	Drying Machine 5 Heat Recovery Waste Water		Stream		44.72	11.86	0.61	OUT	X			
19	Drying Machine 6 (49 C)		Stream		47.95	143.65	7.92	OUT	X			
20	Drying Machine 6 (65 C)		Stream	63.16		107.23	7.73	IN	X			
21	Drying Machine 6 Backwater		Stream		65.16	133.71	9.93	OUT	X			
22	Feed Stock Thawing		Stream		65.20	111.21	8.26	OUT	X			Noticed identical values to the chemical station despite different meter IDs.
23	Feed Water (MAVA)	HX		84.19	65.43	372.86	7.94	OUT	X			
24	Filtrate Cooler O <sub>2</sub>	Cooler		47.92	81.63	209.26	8.05	IN	X			
25	Gas Cooler / Reserv Cooler	Cooler		47.00	84.99	161.27	6.80	IN	X			
26	Green Liquor Cooler	Cooler		47.98	73.09	234.54	6.73	IN	X			
27	Hot Water To Fibre Line		Stream		89.00	79.48	7.95	OUT	X			
28	Hotwater heater	HX		84.17	87.85	1346.01 kg/s	20.81	IN	X			
29	Make-Up Water Heater	Heater		47.87	42.03	297.49	2.00	OUT			X	
30	Make-Up Water Heater Waste Pipe		Stream	-	42.03	297.49	14.40	OUT			X	
31	Mesa Disc Filter		Stream		65.39	53.82	4.01	OUT		X		Flow calculated.
32	Raw Water		Stream	18.12		24.84	0.52	IN	X			Low temperature but still carries heat energy.
33	Reject Cooler	Cooler		65.30	78.13	67.48 kg/s	3.63	IN		X		
34	Reheater 49 C HX	HX		47.92	51.11	722.59	2.65	IN	X			
35	Reheater 49 C Stream		Stream	7.06	-	7.25	0.06	IN	X			
36	Reheater 65 C HX	HX		64.36	65.37	107.03	0.12	IN	X			
37	Reheater 65 C Stream		Stream	62.97	-	3.00	0.22	IN	X			
38	SEAB District Heating	HX		82.02	54.15	10.08	0.32	OUT	X			
39	Vapour Scrubber		stream	54.26		694.04	43.18	IN		X		Flow estimated from valve openness.
40	Vapour Scrubber Waste Outlet		Stream		54.26	592.09	36.84	OUT			X	
41	Ventilation		Stream		59.93	61.05	4.18	OUT	X			Flow and temperature derived from multiple inlet streams.
42	Warm Water from Evaporation Process		Stream	-	48.91	2213.99	124.48	IN	X			
43	Waste Water Pipe Evaporation Process		Stream		43.50	1317.82	66.07	OUT	X			Flow calculated through valve openness estimates.
44	Washing Liquor Cooler	Cooler		65.48	85.85	270.30	6.25	IN	X			

Table A.3: Calculation data for summer 2025

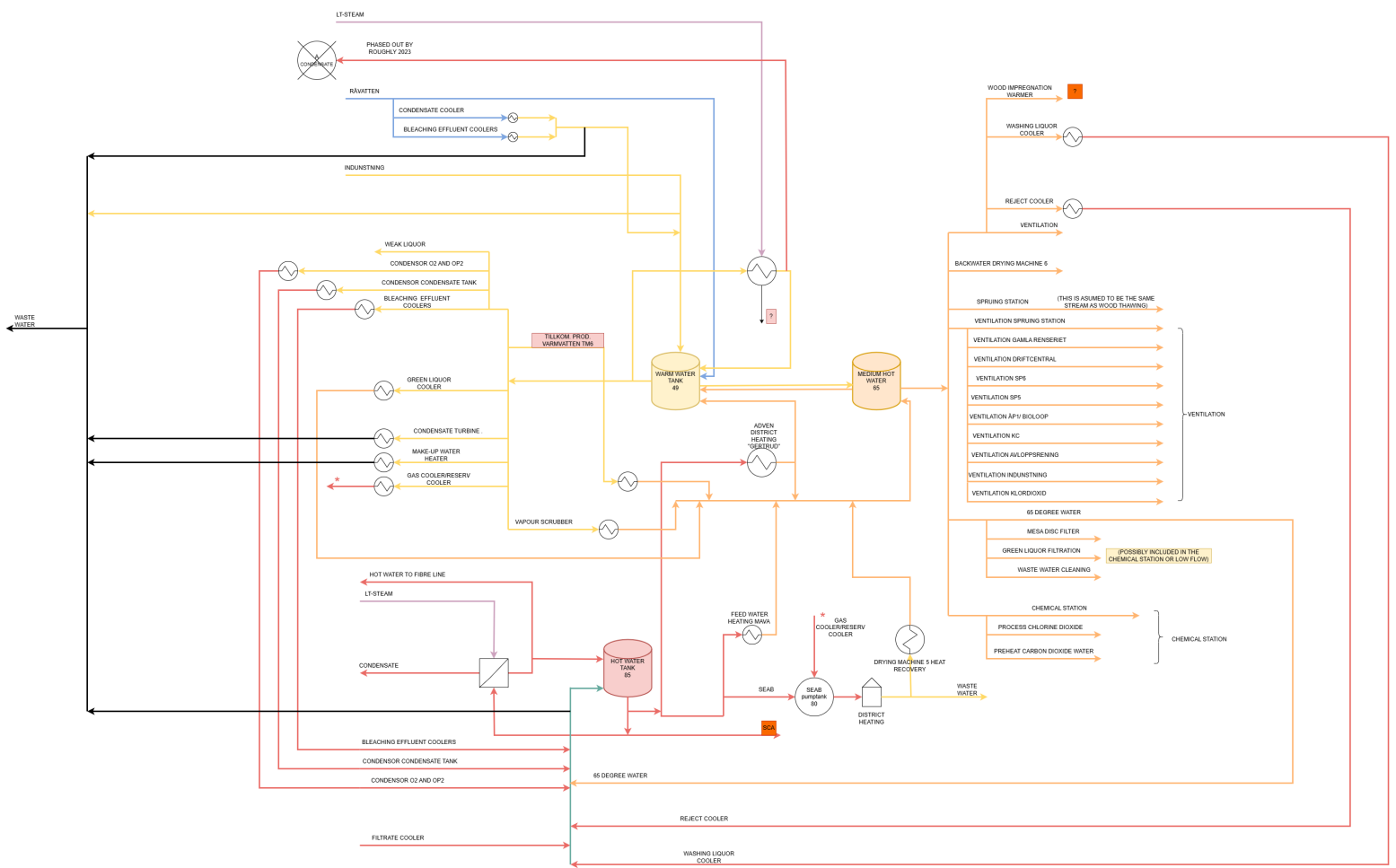
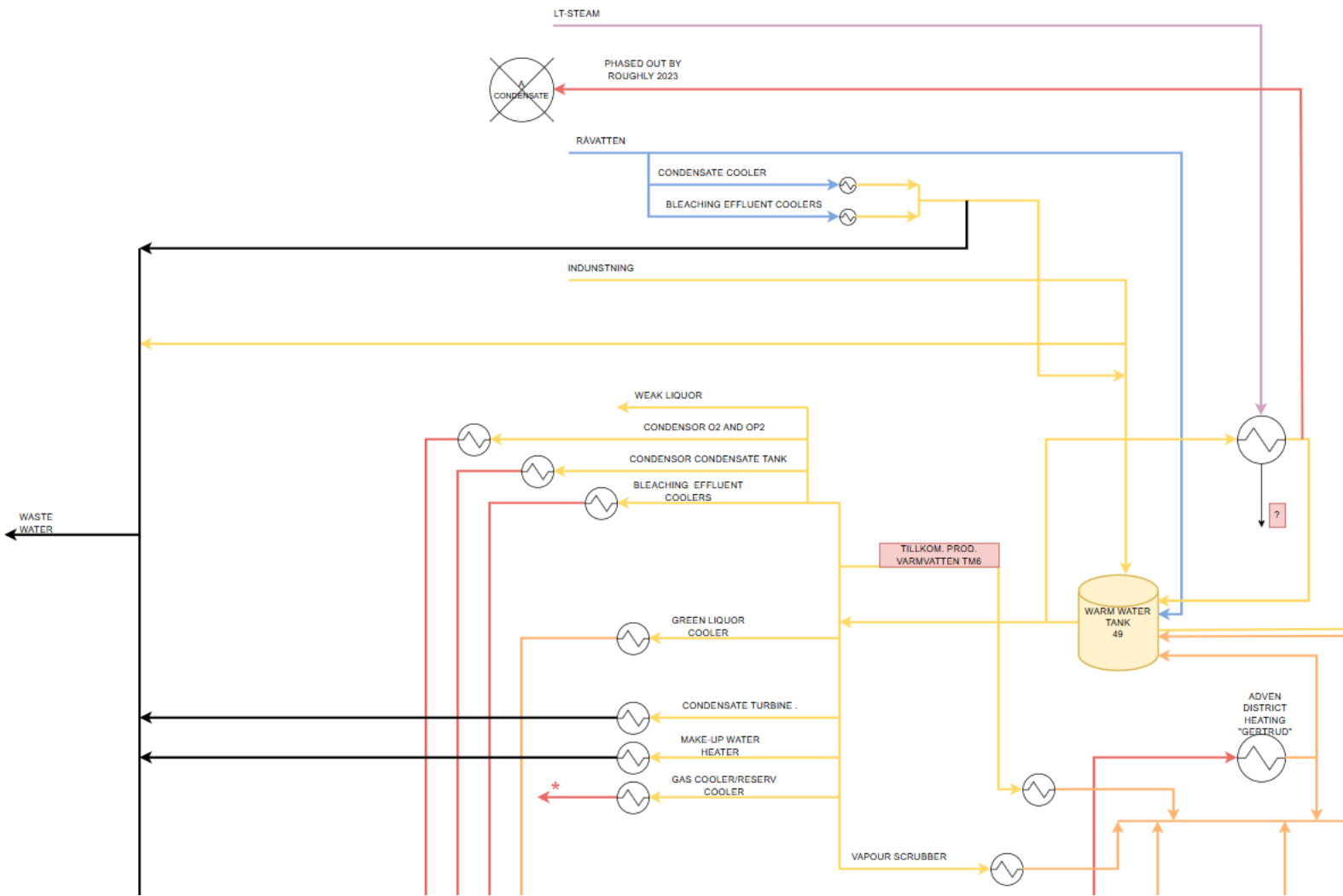


Figure A.5: The entire detailed Helios PFD



**Figure A.6:** The 49 degree cistern and surrounding streams in the detailed Helios PFD

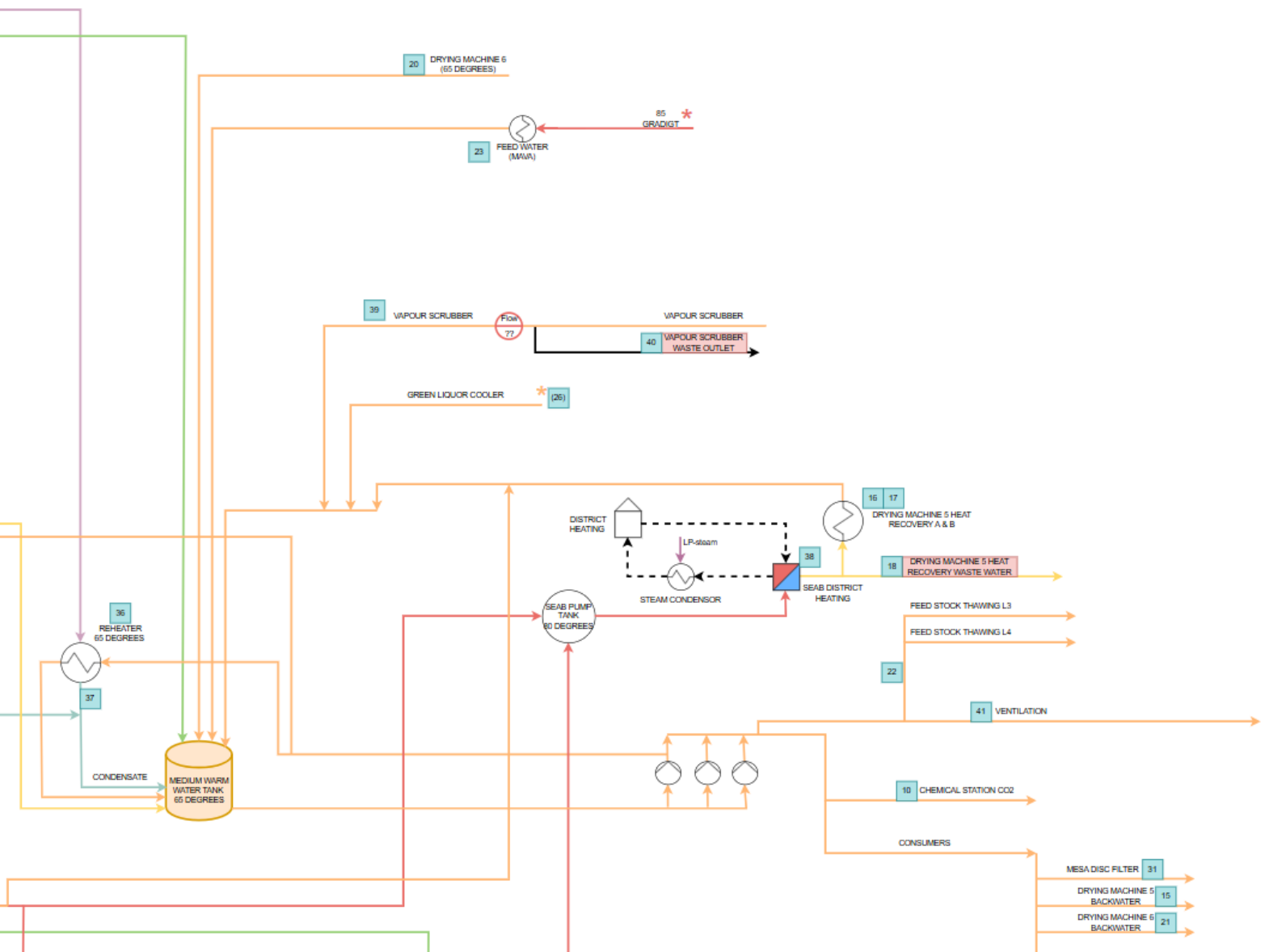
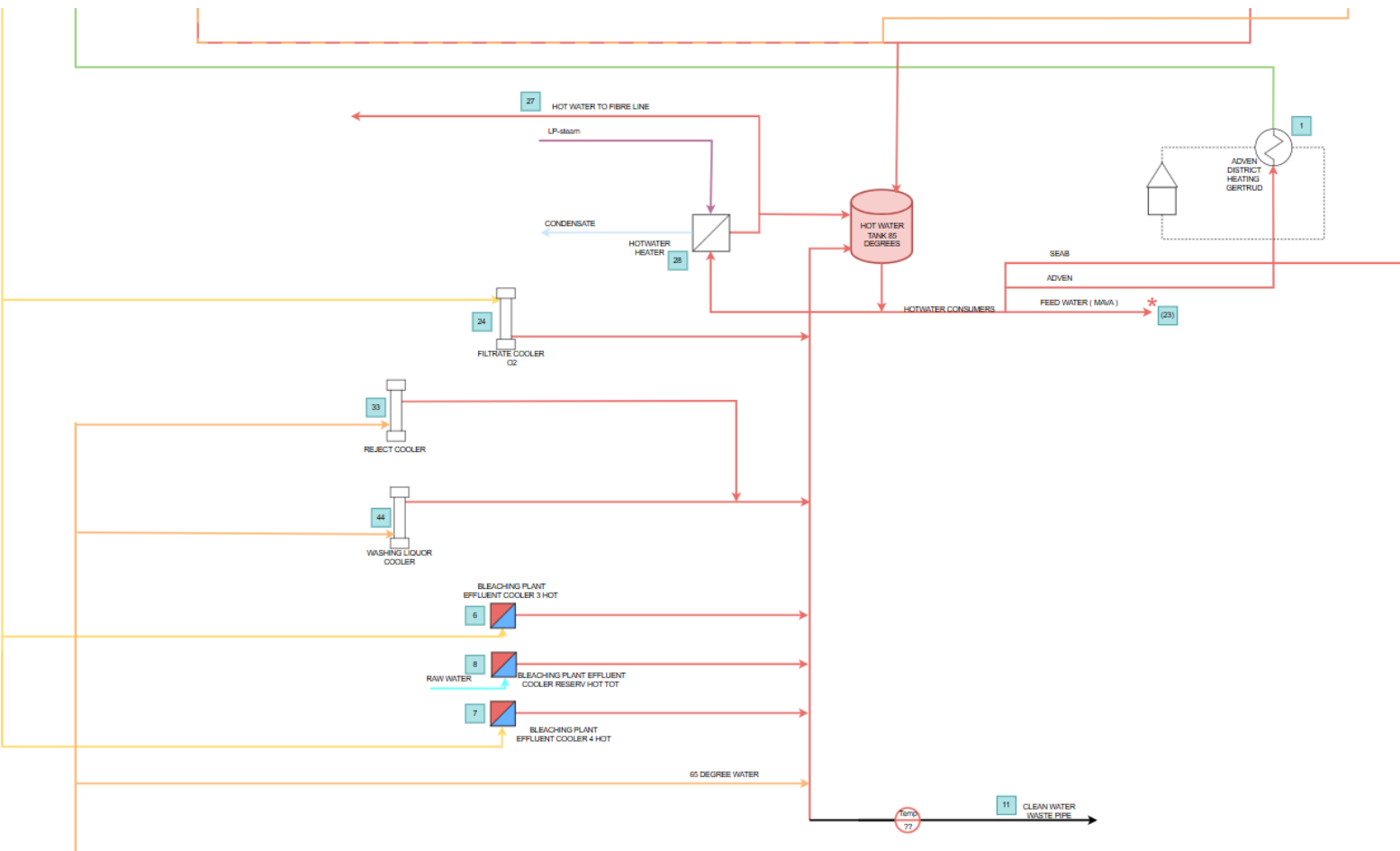


Figure A.7: The 65 degree cistern and surrounding streams in the detailed Helios PFD



**Figure A.8:** The 85 degree cistern and surrounding streams in the detailed Helios PFD



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