DEVELOPMENT OF FLUIDIZED BED BOILER COMMISSIONING PLANNING: A CASE STUDY

Lappeenranta–Lahti University of Technology LUT

Master's programme in Energy Conversion

Master's thesis

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Examiners: Adjunct Professor, D. Sc. (Tech.) Kari Myöhänen

Associate Professor, D. Sc. (Tech.) Jouni Ritvanen

Supervisor: M. Sc. (Tech.) Rita Marjeta

ABSTRACT

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86 pages, 23 figures, and 41 tables

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Keywords: Fluidized bed boiler, commissioning, COMOS, commissioning planning

The current situation in the energy production sector has influenced the future of investments. Carbon-neutral and carbon-negative solutions are now in focus. New technology innovations are under heavy development. Fluidized bed technology is one of the applications that can shape the future. This master's thesis examines Sumitomo Foster Wheeler Energia Oy's (SFWs) fluidized bed boiler commissioning planning.

This study analyzes SFW's commissioning planning for efficient project scheduling and cost control. A firm schedule and clear goals are necessary for a satisfactory supplier-customer relationship. The commissioning planning process of a fluidized bed boiler is presented and examined for similarities. The thesis includes a case study.

The research concentrates on enhancing commissioning planning documentation. During this work, a new tool will be developed and tested. The tool aims to streamline commissioning planning documentation, and a case study will serve as a testing environment.

This work found similarities in fluidized bed boiler commissioning projects. A new tool was created to streamline the commissioning documentation. The case study proved that the tool worked. Commissioning documentation was created, and the tool proved to be convenient. This thesis also provided information regarding process commissioning.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUTin energiajärjestelmien tiedekunta

Energiatekniikka

Valtteri Liimatainen

Leijukerroskattilan koekäyttösuunnitelun kehittäminen: case-tutkimus

Energiatekniikan diplomityö

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Energiantuotantosektorin nykytilanne on muuttanut tulevaisuudennäkymiä investointien kannattavuudesta. Tuotantosektori keskittyy yhä enemmän ja enemmän hiilineutraaleihin ja jopa hiilinegatiivisiin tuotantometodeihin. Uusia teknologisia innovaatioita kehitetään voimakkaasti. Leijukerrostekniikka on yksi sovellus jolla voidaan maalata tulevaisuutta. Tässä lopputyössä käsitellään Sumitomo Foster Wheeler Energia Oy:n (SFW) leijukerrostekniikkakattiloiden koekäyttösuunnittelua.

Työssä analysoidaan SFW:n koekäyttösuunnittelua projektiaikatauluttamisen ja kustannusten hallinnan näkökulmasta. Pitävä aikataulu ja selkeät tavoitteet ovat edellytys onnistuneelle asiakassuhteelle. Leijukerroskattiloiden koekäytön suunnitteluprosessi käydään läpi ja siitä etsitään toistuvuuksia. Työhön sisältyy case-tutkimus.

Tutkimusosa keskittyy parantamaan koekäyttösuunnittelun dokumentaatiota. Tämän työn aikana luodaan uusi työkalu jonka toiminta testataan. Työkalun tavoitteena on suoraviivaistaa koekäyttösuunnittelun dokumentaatiota, johon case-tutkimus antaa oivan testiympäristön.

Työssä löydettiin toistuvuuksia leijukerroskattiloiden koekäyttötoiminnassa. Uusi työkalu kehitettiin suoraviivaistamaan koekäyttösuunnittelun dokumentaatiota. Case-tutkimus osoitti että työkalu toimii. Työkalun avulla luotiin koekäyttödokumentaatio ja sen käyttö osoittautui käteväksi. Työssä myös tuotiin esille prosessien koekäyttämiseen liittyvää tietoa.

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My school journey was not the most ordinary one. Before graduating, I decided it was a good idea to supervise the energy production of Tampere and start up a circulating fluidized bed boiler in Helsinki. These decisions postponed my graduation for a couple of years, but now, looking back, it was precisely the right thing to do.

I want to thank Sumitomo SHI FW and my supervisor, Rita Marjeta, for organizing this learning opportunity and for providing excellent guidance while creating this thesis. With every discussion we had, I learned something new. Thanks to all my colleagues in SFW, for managing time to help me with the stumbling blocks of this thesis. An honourable thank you also belongs to the examiners of this thesis, Kari Myöhänen and Jouni Ritvanen.

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Finally, an incredibly big thank you to my family. Without your continuous support, I would not be who I am today.

Lappeenranta, 5.4.2024

Valtteri Liimatainen

ABBREVIATIONS

BFB	Bubbling Fluidized Bed
CBD	Continuous BlowDown
CCW	Closed Cooling Water
CFB	Circulating Fluidized Bed
CHP	Combined Heat and Power
COMOS	Component Object Server
DCS	Distributed Control System
ESP	ElectroStatic Precipitator
FAT	Factory Acceptance Test
HVAC	Heating, Ventilation, and Air Conditioning
KKS	Kraftwerk-KennzeichenSystem (Power Plant Identification System)
KPI	Key Performance Indicator
MT	Magnetic-particle Testing
NDT	Non-Destructive Testing
NOx	Nitrogen Oxides
P&ID	Piping and Instrumentation Diagram
PT	Penetrant Testing
RO	Reverse Osmosis
RT	Radiographic Testing
SAT	Site Acceptance Test
SCAH	Steam Coil Air Heater
SCR	Selective Catalytic Reduction
SFW	Sumitomo SHI FW

SHI	Sumitomo Heavy Industries Ltd.
SNCR	Selective Non-Catalytic Reduction
SRF	Solid Recovered Fuel
UF	Ultra-Filter
UPS	Uninterruptible Power Supply
UT	Ultrasonic Testing
VFD	Variable-Frequency Drive
VT	Visual Testing
WCAH	Water Coil Air Heater

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1 Introduction

This master's thesis investigates the commissioning planning of Sumitomo SHI FW Energia Oy (SFW). SFW is an international energy solution provider and a part of Sumitomo Heavy Industries Ltd. (SHI). Its portfolio includes circular carbon solutions, energy storage systems, and fluidized bed applications.

A steam boiler is much more than just a water steam circuit. Many auxiliary subsystems must be available before the steam generation can begin. This work will examine fluidized bed boilers, project planning, process commissioning, and the thoughts behind commissioning planning. In the research section, the system commissioning process of SFW is analysed, with an interest in commissioning planning. The research aims to create documentation groups related to commissioning via a new method developed during this study. The new method is accomplished via a data link in the Siemens-COMOS environment. The writer has worked for SFW as a power boiler commissioning engineer. This experience brings new insights into the research, and some information regarding steam boiler commissioning comes from the work site.

1.1 Background

The energy sector is developing quickly, and products based on new technology applications are being released. Traditionally, the quarter of the energy production sector has been thought to last 25 years, affecting the decision-making on new investments. The last couple of years have proved this is not the case anymore. Restriction of emission levels has started to gain popularity, environmentally friendly energy production is sponsored, and the pressure to eliminate the usage of fossil fuels has increased. Every country has its understanding of what its energy production spectrum must be. Political agreements on emission prices, such as CO2-tons, encourage even more conservative views to examine the problem in a new light. Some fuel resources are gathered from other countries, so international relations also affect fuel prices. Europe was taught a lesson in 2022 when the natural gas from Russia suddenly stopped flowing. The lesson contained an interesting point, never be too dependent on one external fuel source.

This, among many other reasons, has been directing energy production toward renewable energy sources such as biomass, solar, and wind. Solar and wind power are great ways of producing green energy, but they need a way to store the excess energy in some form efficiently. These energy storage technologies are evolving rapidly, and reasonable variations are starting to appear on the market. For example, SFW is developing a liquid air energy storage system to solve the storage problem, and the results seem promising. Along with an option for energy storage, it is a good idea to have stable energy sources to balance the production variation spikes. Small and midsize biomass boilers are one solution to this problem and a good choice in the energy portfolio for a stable base load when the other renewables fluctuate.

Biomass is also a viable option since many countries have some sort of biomass production on their territory. This means that the fuel source is not so dependent on other countries. Small and midsize biomass boilers are currently being sold all around the world for this exact reason. They bring reliable and relatively cheap energy production to the table with reasonable emissions. In the figure below are three different scenarios of the history and future of global electricity production according to International Energy Agency.

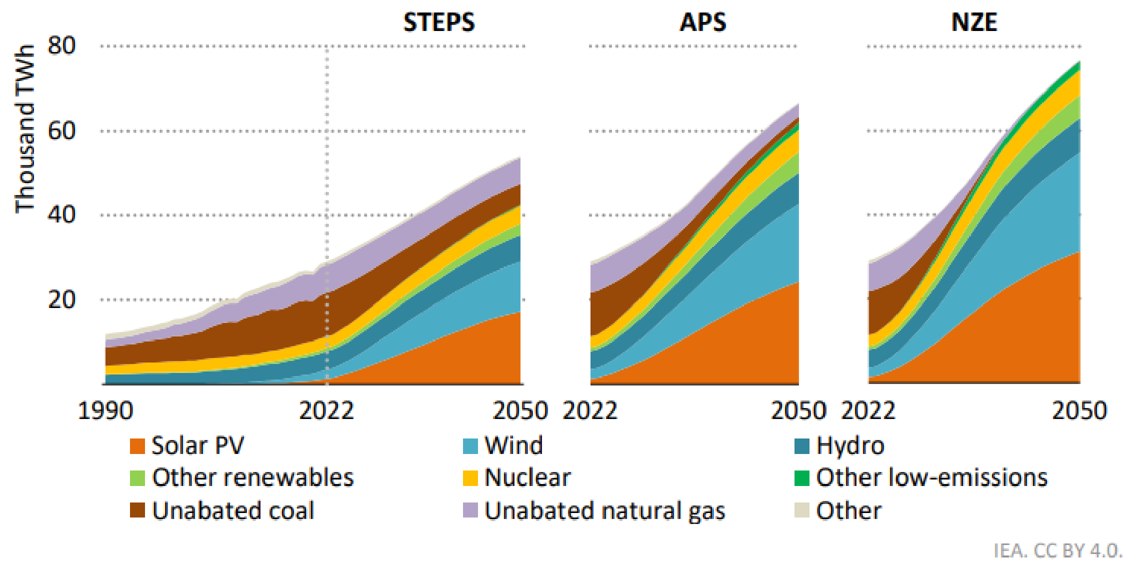


Figure 1. Global electricity production history and future scenarios (IEA 2023, 126).

Notable is that these graphics made by the International Energy Agency (2023, 126) are scenarios made with different parameters, not predictions. Biomass is included in the other renewables colored light green. All three scenarios see the possibility of renewable energy production rising. Noteworthy is that these scenarios only consider electricity production.

Biomass is a great factor also in the whole energy sector, including household heating and process steam generation. Biomass also has a growing purpose in the production of different more advanced fuels, such as bioethanol (Betiku & Ishola 2023).

Energy storage technologies and biomass boilers have similar features in the project stage. Both need offering, engineering, design, construction, and commissioning. This master's thesis will go through the development of the commissioning planning process regarding SFW's fluidized bed products in the energy production field. As discussed, the trend is leading to burning only sustainable fuels soon, and further away, the focus is moving onwards to other solutions not using combustion. This work will concentrate on improving the commissioning planning process of conventional power plants, but the possible solutions found in this work can be easily applied to other energy solutions.

1.2 Research problem

SFW's product portfolio is increasing as the transition to cleaner energy continues. This creates an excellent opportunity to standardize the commissioning planning process just before the new products enter the market.

The commissioning planning process in SFW has room for improvement in the data management section. In the current process, there is a missing datalink between the construction and commissioning data packages. This means that while creating a data package for commissioning, the planner needs to manually link the data package to the mechanical installations' tracking system. The lack of this datalink also makes tracking the commissioning process on the site more difficult. Filling this gap by hand is time-consuming, and it is estimated that adding a new data relation between these two different planning sections can save a lot of time not only in the offering and planning phase of the project but also in the execution phase when the progress needs to be tracked. This gap is aimed to be filled with an entirely new set of data named the commissioning group.

1.3 Research methods

In the theory section, the base layer for the research problem is made by a literature survey. The survey focuses on project planning, steam boiler commissioning planning, and the commissioning phase of a project.

In the commissioning planning chapter, the research transforms from literature to past projects of SFW. Past projects are used as a baseline, for instance, on the lengths of different phases of boiler commissioning. This information is merged with the writer’s experience in the field. These two create a good structure for general commissioning planning.

In the COMOS section, research on the new function is done via trial and error. The functionalities of the created add-in are tested carefully from every aspect to ensure the correct behaviour. Adding new features to running project management software is cautious and time-consuming, as the publisher must be sure that the function works before publishing it.

In the case study section, the presented information will be utilized to form the commissioning groups via the newly created tool in COMOS. The newly formed commissioning groups will be prioritized, and the choices behind them will be revealed.

1.4 Expected results

This thesis has three concrete main goals:

1. Develop a COMOS-datalink to streamline commissioning planning in SFW.
2. Create turnover packages for the case study power plant.
3. Provide literature material for anyone interested in process commissioning.

The thesis is expected to develop a better and more efficient way to execute the commissioning planning phase of a project. This will improve the bidding phase, as making a commissioning plan for a new project is time-consuming. After the bidding is won, the same tool can then be used to create a more specific plan for commissioning. The aim is to simplify the project processes related to commissioning. This means commissioning planning, progress reporting, and scheduling. This is done by streamlining the data usage and getting more out of the data we already have. Adding a commissioning-related datalink allows the data to be processed more quickly in the project.

Turnover packages are SFW's data packages used in the transition from installation to commissioning. Turnover package creation is assumed to take the biggest effort in this work.

Process commissioning is required at the beginning of every plant but is rarely discussed. This thesis aims to break this barrier and provide some pointers on how the commissioning process is planned and carried out. The focus will be on steam boiler commissioning and more precisely on fluidized bed boiler technology.

1.5 Limitations of research

Research is limited to considering only steam boilers using fluidized bed technology. Fluidized bed technology is an own form of art in commissioning's perspective and requires special expertise. This limitation is done to narrow the theory section to a reasonable spectrum. Steam boiler commissioning is an interesting part of process technology. It has not been extensively studied in previous thesis works.

2 Power plant theory

This chapter explains the basic background theory for the research problem. Understanding the functionality of a fluidized bed boiler is important, as it is within the scope of this research. Another essential piece of knowledge is the main principle of the KKS-coding system, which will be used in the system planning section.

2.1 Fluidized bed boiler

Fluidized bed technology in the energy sector means a combustion method in which the fuel burns within the bed material in the furnace. The fluidized bed is a common technology in biomass combustion. It has stable burning quality even with varying fuels and power levels. The bed has multiple functions in the combustion process; it dries the fuel inserted, balances heat transfer, and works as a fluidization substance for the fuel. The fluidized bed has a huge mass, allowing the boiler to have a stable response to quality changes in the fuel used. This is achieved via the thermal mass of the bed; there are tens of tons of material flowing in temperatures of 750-950 ℃ constantly mixing in the furnace (Raiko et al. 490).

The operation of a fluidized bed boiler utilizes the thermal mass of the bed; in normal operation conditions, the fuel power changes take time to affect the steam values. Typical guaranteed changing speed can be, for instance, 5 MW of steam power per minute. This can be seen both as an advantage and disadvantage. In urgent situations, the boiler output cannot be changed very quickly due to the bed’s thermal mass. On the other hand, the boiler can handle variations in fuel quality with little effect on the steam values. This feature makes fluidized bed technology a great option for biomass boilers. A fluidized bed technology allows multiple fuel sources to be used simultaneously (Vakkilainen 2017, 212). According to Vakkilainen, these are why the fluidized bed is managing so well in biomass combustion. A fluidized bed boiler allows the combustion of wet and varying fuel quality.

While examining fluidized bed boilers, it is reasonable to divide them into bubbling and circulating fluidized beds. The main differences between them are the furnace's fluidization velocity and the bed material's grain size (Raiko et al. 2000, 159; Vakkilainen 2017, 213). With a bubbling fluidized bed (BFB) the bed is targeted to stay in the bottom of the boiler.

Air or fluidization gas is then forced through the grate, and this causes the bed material to form gas bubbles that go through the bed material layer. The fluidization of the bed causes the bed material to enter a state that looks like boiling water to the naked eye.

With circulating fluidized bed (CFB), the fluidization gas is pushed to the grate more aggressively compared to BFB. The particle size distribution is also smaller, allowing it to elutriate more easily. During operation, combusting fuel and bed material are purposedly pushed upwards the furnace and then gathered back from the combustion gases later and returned to the furnace. Below is a simplified image demonstrating BFB and CFB material flows.

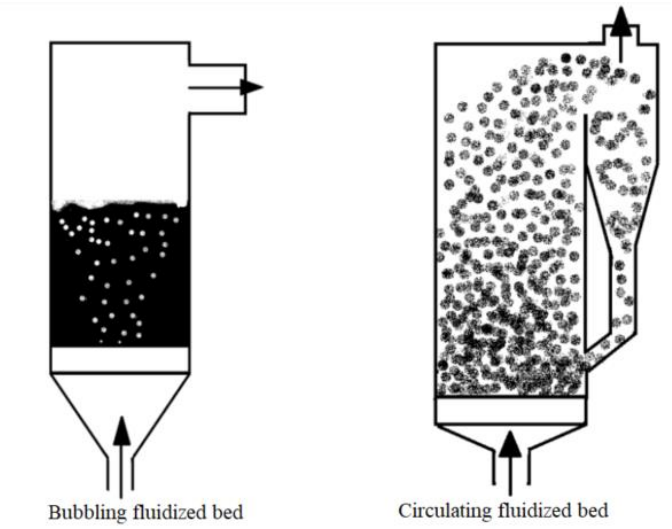


Figure 2. Bubbling and fluidized bed technologies. (Adapted from Huhtinen et al. 2000, 154.)

As one can see, the difference between the two is quite remarkable. The BFB applies greatly to smaller applications as it is simpler to construct but can have lower burning efficiency. The possible lower efficiency is caused by finer carbon particles escaping out of the combustion zone which Basu states to be usually 0,5-1,5m deep (Basu 2015, 9). These escaping particles can be gathered back from flue gases, for example, from the first back pass and driven back to the furnace, this can improve the burning efficiency. Different boiler makers have different options to overcome this issue to a level where it is not a problem.

The bed material of the furnace varies depending on the state of the boiler. In a cold start of the boiler, the bed is filled with starting material which can be for example sand. During normal operation, the composition of the bed will transfer to sorbent materials and ash of the fuel burned. If the boiler uses limestone for sulphur removal, most of the bed will consist of calcium compounds during combustion. Notable is that alkali and chloride compounds found in ash have lower melting temperatures. Melting of bed material is called agglomeration (Raiko et al. 2000, 287). Raiko states that in agglomeration, the melting point of the bed is met, and the particles start to stick together. Agglomeration can develop into a snowball effect and thus lead to problems. In bad cases, agglomeration creates big solid sinter blocks that require the boiler to be shut down. This creates a need for constant bottom ash sampling and analysing to react to agglomeration in time. It is typical to find some small agglomerates with a radius of 1mm or under. Bottom ash removal and fresh bed material input must be increased immediately if the samples look bad. Fresh bed material is inserted into the furnace to lower the risk of melting. In a mid-size CFB boiler, a good guess for fresh material input for biomass combustion is around 10 tons daily.

2.2 KKS-coding system

Kraftwerk-Kennzeichensystem, or KKS, is a coding system standard widely used in process technology to identify systems and parts of systems. Especially power plant industry has embraced this system. KKS was created for nuclear power plants to answer to their strict code on safety and preciseness. There are other similar ways of naming the process equipment, but this work will concentrate on the KKS standard by VGB since it is adapted in SFW's systems engineering. VGB-S-811-01-2018-01-EN, from now on VGB 2018, KKS-coding system has three different types of codes:

Table 1. Types of code and breakdown levels. (Adapted from VGB 2018, 11).

Type	Users
Process-related code	Process-related identification of items and systems according to their functions.
Point of installation code	Identification of installation points for electrical units, for instance, cabinets, panels, and consoles.
Location code	Identification of locations in rooms, floors, and structures. Also, fire zones and topographical stipulations.

In this work, the focus is on the process-related code. The process-related KKS code creates a standard basis on how the equipment can be named so that they can be easily identified even when there are multiple similar devices in a row. Companies' KKS-coding systems have differences in their internal coding based on what has been learned to be a good convention. VGB sets the code's basis, but companies can adapt the free parts of the standard to meet their needs. On upper levels, the standard is strict and does not leave room for negotiation. In lower levels, for example, in the numbering section, the naming is freer. In one company, a control valve can be called AA210, and in another, AA151. AA states that the equipment in question is a valve, but the numbering can be chosen according to the corporation's interest. In the VGB standard, the process-related KKS structure is broken down into four levels:

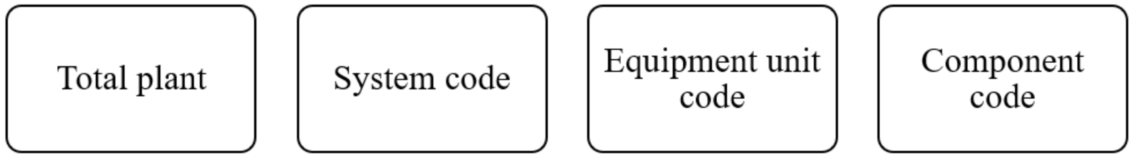


Figure 3. Process-related KKS-structure. (Adapted from VGB 2018).

Total plant code indicates in which plant the device belongs, system code states the designated system, equipment code indicates the equipment in question and component code the possible additional information of for instance the motor attached to the equipment. The image below interprets of the KKS base structure using Huhtinen et al. (2013) as a reference.

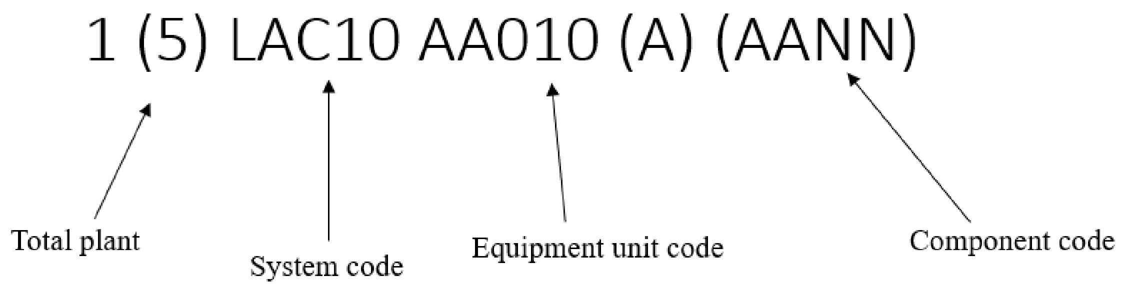


Figure 4. KKS-base structure. (Adapted from Huhtinen et al. 2013, 338.)

This work concentrates on the system codes. System code is a five symbols long code, in which three first symbols are letters and the last two numbers. VGB discusses the first three letters as alpha code elements; they work as a classifying function of the code (VGB 2018, 14). For example, the LAC means the system classifies as a feedwater pump system. VGB KKS standard has the meanings of the letter combinations listed in the standard book. The two numbers in the system code are called numbering code elements and their function is to state the part of the system where the code refers to. The numbering logic is freer and VGB does not strictly state on how the numbering should be used. The system code is in the centre of COMOS and case study sections. The aim is to categorize the commissioning packages using only the system code, preferably only the alpha code elements.

Total plant code indicates the plant this device is in, for example, 1 can be boiler one and 2 boiler two. The equipment unit code dictates the device this code refers to, AA is in this case marking a valve and 010 specifies the valve type. Component code marks the device linked to the previous, for example, a pump needs an electric motor to rotate. The motor specification would be these four symbols.

3 Project planning

According to Worsley & Worsley (2018), a project is a temporary organization built to overcome a momentary client need that must be fulfilled. Another definition is from Pelin (2020), who states that a project is a certain amount of work that is done to achieve a predefined one-time goal. According to SFS-ISO 10006:2018, the definition of a project is simple: a project "is a unique process undertaken to achieve an objective". All references have a different way of describing what a project is, but the message behind the explanation remains the same. All agree that the project is happening only once, and it has a specific goal.

This thesis aims to find similarities between different project processes to save effort. Similarities can be expected to arise in the commissioning planning section. Even though the scope and equipment are changing, standardization will help with the planning process, as everything does not need to be made from scratch.

A project is a temporary organization that involves many experts from different fields working together. While many people are working on different things simultaneously, it is crucial to have a good plan so that they are working on the correct thing at the correct time. This is the basic need for project planning: to allocate the resources to be used as efficiently as possible. While resource allocation is the focus, other things must be considered while planning: realizing risks, cost planning, and creating a strategy. Project planning can be done using various strategies, and it is dependent on the project which strategy will bring the best results.

3.1 Project plan

Project planning starts by stating what the objectives and scope of the project are (Kerzner 2022, 384). Kerzner states that in object determination, the different objects are also prioritized over each other. Scope means the area of responsibility in the project. In commissioning planning the object is to plan the commissioning of predetermined systems. The problem comes when the different systems need to be prioritized so that the commissioning progress is as efficient as possible.

After the objectives are clear the planning continues by finding the best way to achieve these objectives. In general, the project plan is the basis of the project's surveillance. It describes that objectives are being done on schedule (Pelin 2020, 74). Project planning is the most crucial step of the project, a good plan can recover from different kinds of issues, poor plan might not perform even in almost perfect conditions. Project planning is done in various sites, this chapter concentrates on making a project plan for an energy industry project. The general structure of a project plan according to Pelin (2020, 76) is following:

1. General description
2. Project organization
3. Executing plan
4. Project budget
5. Documentation
6. Meetings
7. Instructions.

The project plan for commissioning is part of the big plan, considering the whole plant from foundations to handover. Handover means the system testing and tuning are ready, and the plant can start commercial operation according to the customer's needs. This work's research analyzes the documentation part more deeply, as the documentation between mechanical erection and commissioning is discussed.

3.2 Personnel

Human resources planning is an essential part of the project plan, and it must be handled at an early stage of the project as it will affect the project's costs. The cost estimation of the workforce used must be ready for the offering phase of the project. When the deal is done and the execution begins, staffing gathering must begin immediately. With projects comes often temporary project personnel called subcontractors. Subcontractor means that the personnel are hired for a certain period or process. With every subcontractor, a contract is made on how the work will be paid. For example, the cable contractor can be paid for every meter of cable pulled and the erection contractor for every kilogram of piping installed. This easily leads to subcontractors prioritizing the systems where the money can be gathered more easily. To prevent this from happening there must be strict supervision that the subcontractors prioritize the systems that are planned to be ready first for commissioning. It is also important to consider this factor while making the contracts with subcontractors on how they will be paid. In this way, the commissioning plan also determines the progress of the earlier parts of the project.

3.3 Project metrics

While creating a project plan, the metrics for progress must be determined. Metrics are a way to track the progress of ongoing work. Therefore, there needs to be some thought behind the things being followed. The most important metrics are called key performance indicators (KPIs) (Kerzner 2022, 583). KPIs give an early warning sign if the project is slipping from its target, and possible actions can be applied. In an investment project for a customer, the KPIs are assessed weekly to ensure a sufficient pace.

A characteristic approach in an industrial project erection phase can be, for example, by the weight of the piping installed. It is a harsh way of estimation since small piping weighs a lot less so the progress might seem uneven. In steam boiler commissioning the KPIs are traditionally kept relatively simple and similar between the projects. Below is an example of a steam boiler commissioning KPIs.

1. Start of cold commissioning
2. First fire, with fluidized bed on secondary fuel
3. Acid cleaning
4. Steam blowout process complete
5. First fire with primary fuel
6. Start of hot commissioning
7. Steam to end user, for example, to a steam turbine
8. Trial run
9. Handover.

These steps are analyzed more deeply in the commissioning section of this work.

3.4 Project phasing

Project phasing means that the separate work orders are combined into different phases to follow and plan the project easily. This allows the costs to be allocated for different phases efficiently. Below is an example of project phasing of an industrial plant project:

Table 2. Project phasing. (Adapted from Pelin 2020, 87).

1.	Feasibility study
2.	Pre-engineering
3.	Basic engineering
4.	Detail design
5.	Procurement
6.	Construction
7.	Commissioning and startup
8.	Guarantee period

As can be seen, the commissioning is right at the end of a project before the guarantee period. While commissioning is one of the last specific stages of the project, it also determines the progress of earlier stages. This is why precise commissioning planning is so important. Commissioning can be found to affect all the other project stages. This can be easily understood as it requires all the previous stages to succeed.

4 Commissioning

Commissioning is one of the final stages of the project before the final product or service is provided to the customer. The term commissioning means that the device or system is in the testing phase, and various site acceptance tests (SAT) will be performed to ensure safe operation of the device or system. The results are then compared with the factory acceptance tests (FAT). This procedure is done for every device arriving at the site to ensure that they are working properly.

Usually, the installation and commissioning are carried out by different people with different specialties, and there are a lot of places where knowledge can get lost or miscommunication can happen. These things, among others, can be avoided with good commissioning planning. Before the system can go through commissioning, the system must achieve a state called mechanical completion. Mechanical completion indicates that the piping is welded, supports are put in place, instruments have been preliminarily installed and the components are mechanically ready for live testing. After mechanical completion, the system is ready to be transferred to commissioning. In SFW, this is called a turnover phase. In the turnover phase, the transfer of documentation and responsibility between installation and commissioning happens. SFW calls this the transfer of turnover packages. In the case study, the turnover package creation is shown. Below is a simplified example of a process system going through the turnover phase.

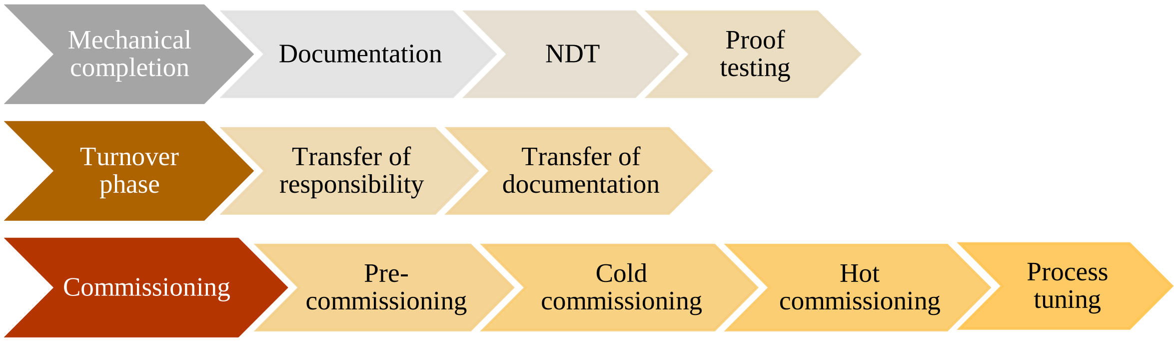


Figure 5. Phases of system going to commissioning.

In the figure the location of the turnover phase can be seen, it works as an interface between mechanical installation and commissioning operation. The turnover phase includes checks, walk-downs, punch lists, and filling reports. Walk-down means a walking check of the system or pipeline with necessary documents and representatives. A punch list is a term used in a project environment; according to Levy (2009), it means a list of possible flaws that need to be fixed later. The work can be unfinished or do not meet the requirements and must be later corrected (Levy 2009, 323). Punch lists are used both inside the project company and between the project company and the client.

4.1 Requirements for commissioning, mechanical completion

Legal requirements for commissioning to begin are different according to where in the world the project is located. In this work, the focus is on European standards and laws. Some specific laws and standards need to be followed when operating steam boilers or other equipment handling pressurized industrial liquids or gases. These laws and standards not only ensure the safe use of the equipment but also point out very specifically what needs to be done for efficient equipment commissioning. When commissioning a new power plant in the European Union, PED must be followed. PED or pressure equipment directive (2014/68/EU) harmonizes the laws of the European Union Member States on the market of pressure equipment.

PED must be followed in the EU, but usage of standards is a contractual factor, if it is approved by both supplier and client, the standard can be bypassed. The usage of standards is favoured since they set a clear set of rules that then can be followed by both parties: supplier, and client. One very common standard used in energy industry supply contracts is EN 13480, Metallic industrial piping.

EN 13480 states important factors that must be considered in the pre-commissioning part of the system before the mechanical completion and handover. Part 5 of the standard series, EN 13480-5 states the requirements for the inspection of the piping; this is essential knowledge that must be known by the mechanical contractors for successful turnover. As it is usual for process plants to use a lot of welded metal piping, the requirements for the final acceptance of a welded metal pipe must be understood. The requirements go onto a quite specific level that is not sufficient to analyse in this thesis. The basics are shown using standard SFS-EN 13480 as a reference.

There are different classifications for piping depending on its material and wall thickness. The inspection scope for the piping is then done according to this classification. There are three classification levels: I, II, and III (SFS-EN 13480-5:2017, 41-44). After categorizing the pipe, the pipeline is inspected using non-destructive testing (NDT) methods. NDT includes visual testing (VT), magnetic-particle testing (MT), penetrant testing (PT), radiographic testing (RT), and ultrasonic testing (UT). The classification implies what percentage of the welds must be checked with each method. For example, a pipeline can require 100% VT and 10% RT.

After the NDT inspection process, a final inspection of the piping system is done. The final inspection process includes a visual inspection, a proof test, another visual inspection after the proof test, and a review of the manufacturing documents (SFS-EN 13480-5:2017, 47-50). A proof test shall be done on all piping constructed under EN 13480 to demonstrate the integrity of the finished product. Proof testing is usually done by a hydrostatic pressure test with some exceptions: the piping can suffer damage from the weight, or it is unacceptable to have water residuals in the piping, so the hydrostatic testing cannot be performed. In this case, a pneumatic pressure test shall be performed instead.

After the piping system has been tested, there needs to be a final documentation package including for example the piping and instrumentation diagram (P&ID), welding documents, and operation instructions of the piping (SFS-EN 13480-5:2017, 52).

The transfer of documentation occurs when the responsibility transfers from installation to commissioning. In SFW, this phase is called a turnover. Turnover is when the system comes alive; it is no longer understood as a piece of piping but as a system. Improving the creation of these data packets will be part of the research problem of this master's thesis and will be considered in the COMOS and case sections.

4.2 Pre-commissioning

In the pre-commissioning phase, the system will be prepared for the cold commissioning phase. This includes inspecting and testing the piping and equipment after installation. It is important to check everything thoroughly at the turnover, mistakes can happen in the mechanical installation which can lead to dangerous situations later if not found in time. The cost of fixing the possible deficiencies also increases considerably in later project phases.

Pipelines should be blown with pressurised air and possibly also flushed with water depending on the system. This will ensure that once the system is up and running, debris left inside the piping during installation will not cause extra problems. This might seem simple, but it also takes some effort to plan for every system separately. The commissioning planning section will consider planning commissioning on a system-level basis.

It is critical to leave enough time for the pre-commissioning phase of the system; cutting corners in this phase will most definitely lead to problems later when the hot commissioning starts. These problems can be for example leaking valves due to debris in the valve chamber or a partial or complete blockage of the system. To solve these kinds of problems it is almost guaranteed that the hot commissioning must be stopped, and the pipe opened to see what is wrong with it. This will easily lead to the project being behind schedule and creating significant additional expenses.

4.3 Cold commissioning

Cold commissioning consists of starting up the devices, instruments, and electrical equipment. The first start is only to test that the equipment starts up and is working as it should be. This is the part where the FAT and SAT are compared to each other. For example, variable frequency driven (VFD) electric motor testing generally consists of three main steps. First, the frequency converter is energized. After energization of the VFD, the motor can be energized and calibrated. After a successful calibration, the rotation direction of the motor is verified by starting it for a moment. Once these steps are completed, the motor can be tested as stated in the testing table; this consists of testing internal and external protecting functions, responsibility for adjustments, and a load run with proper startup conditions (ABB 2019).

Every device has a unique testing pattern defined by the vendor that needs to be completed in the cold commissioning phase. The test results are then documented, and a commissioning report is made from them. The cold commissioning phase can be called a “vendor startup”-phase since the first start of equipment is often done in collaboration with the equipment vendors.

4.4 Hot commissioning

Once the cold commissioning is done for the system, it can be transferred to the hot commissioning state. Hot commissioning means that the system-level testing of the equipment begins, devices are controlled from the distributed control system (DCS), the plant protection system is tested, and the system is operated with medium for the first time. It is essential to reserve enough time for hot commissioning since only then the computational calculation of the process can be proven in action. If there is for example an installation mistake that requires changes in the system, it easily takes days to weeks which affects the schedule majorly. After these tests, the precalculated process limits and alarms can be updated to match the test results.

Systems are moving to hot commissioning state one by one. Many points must be considered while preparing a hot commissioning state; some are listed below.

- Relativity of systems
  - What is needed for this exact system to begin hot commissioning?
- Site safety
  - Can the system be taken to online testing without endangering the surrounding ongoing installation works?
- Interfaces of systems
  - Does taking this partial system online hurt other system installations for example via an open pipeline?
- Schedule
  - When is this system needed online?
- Efficiency
  - Are there other systems dependent on this system?

These questions, among many others, must be considered when planning the system hot commissioning. Mastering all the moving parts is a difficult task, so efficient data management in commissioning planning is crucial for weeding out only the important information from the big data.

4.5 Steam boiler commissioning

Steam boiler commissioning projects typically have quite similar milestones, which were shown in the project parametric chapter 3.3 as KPIs. The commissioning phase accomplishes those milestones while performing the necessary tests.

The commissioning phase must be planned carefully, and it is essential to understand the big picture. One approach is to consider the steam boiler as one massive system with relation to many subsystems. These subsystems are required for the boiler to work as planned. Subsystems can be prioritized according to the commissioning KPIs. For example, the combustion air system is necessary for the first fire, but the boiler condensate cleaning system is not. These necessities are ranked in commissioning order planning from one milestone to another.

The first milestone is the beginning of cold commissioning. This milestone is achieved by starting the commissioning process on one of the systems. Usually, this system is related to either pressurized air or cooling water as these systems form the base structure for others.

The first fire can be considered the second main goal of commissioning. Fire readiness for the boiler means that everything necessary for safe combustion has been tested, and the furnace can see the live fire for the first time. Boiler first fire is a significant milestone but typically a relatively short process. In a fluidized bed boiler, one startup burner is ignited for 20 seconds and switched off. This test is repeated for all the startup burners, giving multiple ignitions each; this proves that the burners will work. Below is an image of a startup burner combusting with light oil.

Figure 6. Auxiliary fuel fire (Valtteri Liimatainen).

When the boiler is fire-ready, the following procedures will happen right after:

1. Boiler chemical cleaning
2. Piping restoration
3. Magnetite film formation
4. Steam blowing
5. Blowing restoration
6. Boiler hot commissioning.

The steam boiler's first fire indicates that the chemical cleaning process for boiler piping can start. The boiler must be fire-ready before the chemical cleaning to ensure that the magnetite film formation can be done immediately. The concept of chemical cleaning is to remove impurities and grease from boiler tubing. The chemical cleaning process starts with constructing a temporary piping system, which will be used to create the chemical circulation. Fabrication of this piping varies between boilers, but a typical duration is around one to three weeks. Actual chemical cleaning for a fluidized bed boiler can take one to three days, depending on the size of the boiler. Before the chemical cleaning process, there must be a thermal expansion walkthrough in which the boiler thermal expansion spaces will be confirmed. In the construction phase, there are a lot of scaffolds and other temporary structures; it is essential to confirm that the boiler has room to expand when heated for the first time.

After chemical cleaning, the boiler tubing will be restored to allow the magnetite film formation process. If there are no problems, chemical cleaning restoration takes a couple of days to around a week. Restoration includes welding high-pressure piping which is a precise job to accomplish on one try. Good welders are a must in this process.

The magnetite film needs to be made on a clean steel surface; otherwise, the film will not be as good. Magnetite formation must start immediately after the piping is restored. Magnetite film formation takes a couple of days, during which the boiler will be run at constant steam values. With magnetite film formation, the refractory curing of the boiler also starts; this limits the temperature-rising speed of the boiler. Magnetite film formation is an endothermal chemical reaction between boiler water and clean steel. The right temperature window for magnetite film formation is 250℃ - 570℃ (Huhtinen et al. 2000, 309).

After the film formation, the boiler must be steam blown. According to VGB-S-513-00-2014-07-EN, from now on VGB 2014, the reason for steam blowing the steam generator and steam carrying systems is to protect the steam turbine. Steam blowing should be done even without a steam turbine, but the reason is to clean the piping as stated in the standard. Impurities generate big problems when mixed with high-pressure equipment, for example, a steam turbine will suffer excess wear and erosion. For a steam blow, a temporary steam piping must be fabricated to direct the steam outside the boiler house. VGB (2014, 61) states three different options for steam discharge: into the atmosphere, into water and into a condenser. If the steam is released into the atmosphere, it will create a remarkable noise. The noise can be regulated with a silencer at the end of the piping. In Europe it is not typical to execute a blowout without a silencer since the noise level is very high. Below is an image of a steam-blowing silencer in the construction phase.

Figure 7. Steam blowing silencer in construction phase (Valtteri Liimatainen).

Steam blowing is done with precalculated steam values, which allow the disturbance factor of turbulent steam flow to be on the right level to ensure efficient cleaning (VGB 2014, 60). Typically, this happens with 10-20 bar_g. The typical length for each blowout differs on the blowout strategy. Blowouts can be done with a quick approach, which allows two blowouts per day, or a long approach where the boiler is blown once a day, but the blowout period is longer. When the blowout results seem promising, the boiler should be cooled down to under 100 °C to create a thermal shock (VGB 2014, 61). According to VGB, thermal shock is required but can be waived if the schedule is tight. VGB states that experience has shown that waiving this cooldown period will typically increase the required number of blowouts.

The temporary blowout pipe has a place for an impact plate to be put in the steam flow (VGB 2014, 60). This plate is changed and analyzed between every blowout. In analysis, the plate is examined for dents. The criteria depend on boilers and steam end users, but the focus is on the amount and size of the dents. Criteria for successful blowout can be, for example, none over 1mm dents and a maximum of 5 over 0,1mm dents. After the impact plate has been approved both by the contractor and the client, the restoration can begin. Restoration can take up to weeks to be completed as it includes cutting all the temporary piping away and welding high-pressure piping back together. Many instrument suppliers also suggest installing possible venturi steam flow meters to the piping only after steam blowing; this increases the amount of welding required.

Once the boiler is restored, the hot commissioning can begin. Hot commissioning means that the boiler will be tested with different power levels on auxiliary fuels and after that the next significant milestone will be reached: the solid fuel fire. In solid fuel fire, the boiler will be driven with primary fuel for the first time. After careful testing, the boiler can be transferred to be driven with only primary fuel; this typically takes a couple of days. In some cases, the solid fuel can be considered to be used also in the steam-blowing stage, but this is not a typical approach. Below is an image of a CFB boiler combusting with biomass fuel.

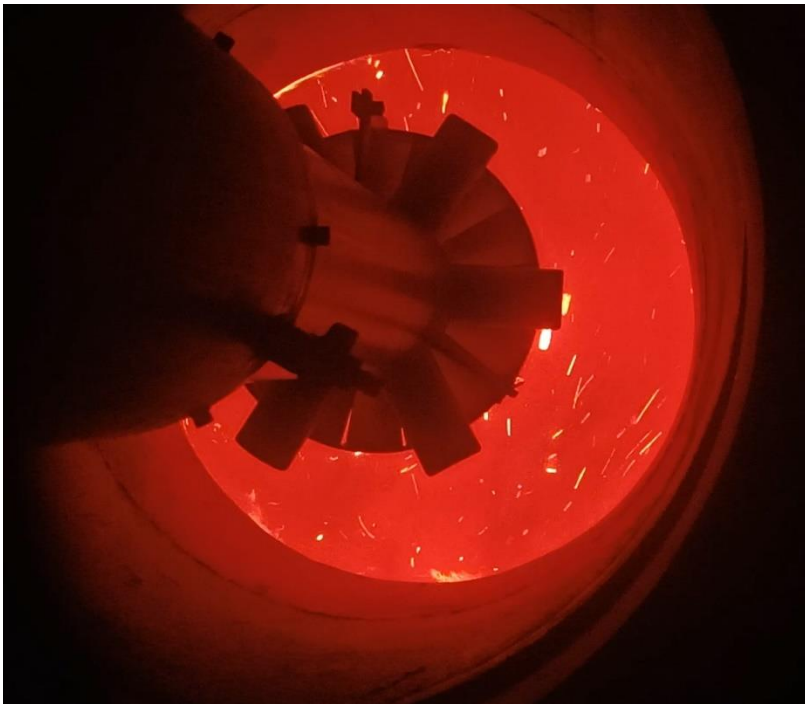


Figure 8. CFB boiler combusting with biomass fuel (Valtteri Liimatainen).

Image of the furnace is taken from the startup-burner’s sight glass, but the burner is retracted and not running anymore. The CFB boiler furnace has no visible flame, just an orange glow and sparks flying around. Here an observant viewer can make a statement: there is not a hot spot in the furnace, only a big mass of bed material with little temperature variation.

The hot commissioning phase for a fluidized bed boiler takes months to complete. It will bring the boiler to a state where the trial run can be started. The beginning of the trial run means that a contract has been made accepting the boiler in its current state with possible plans to fix any minor issues later. The length of the trial run is stated in the contract, and it can vary. One example of a trial run schedule is below:

Table 3. Trial run schedule.

Phase	Length
24h run	24 hours
Disturbed trial run	Two weeks
Undisturbed trial run	Two weeks

A trial run is always a contractual issue, and the client and supplier have agreed on the terms beforehand. In this example a 24-hour run is the first phase, it can include simulated errors or be regular operating. For completion, there must not be any issues with the boiler during that period. The second phase is the disturbed trial run. In a disturbed trial run, there can be pre-agreed problems with the boiler that do not void the trial period. For example, there can be a problem with fuel feeding limiting the boiler power, but if it is fixed within the pre-agreed time limit the trial run continues. The final phase is the undisturbed trial run. In an undistributed trial run, the boiler cannot have any issues, and it must operate as planned. When an issue occurs, it is again a contractual factor. One approach is to start the period from the beginning after fixing the issue.

After an accepted trial run the boiler can be handed over to the customer. A successful handover will start the guarantee period of the boiler. During handover, a punch list is made from possible flaws with the plant. Punch list items can be minor modifications to the plant that the supplier agrees to fix later, for example, in the next plant revision. The guarantee period is the final phase of an erection project. In the guarantee period plant is operated by the client and the supplier is responsible to response any problems caused by faulty equipment or design flaws.

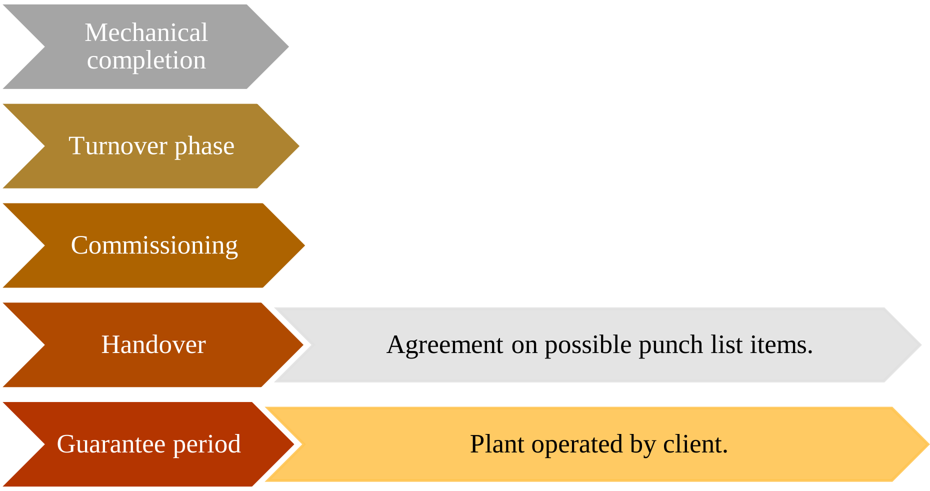


Figure 9. Plant handover and guarantee period.

This chapter concluded the basic activities in steam boiler commissioning with the perspective on fluidized bed combustion. Many of the phases are similar or completely the same with different burning technologies but variation also exists. A fluidized bed boiler is not the easiest burning technology to commission but after it has been adjusted, the burning efficiency is among the best.

5 Commissioning planning

After the basics of project planning and commissioning the research will focus on planning the commissioning activities. This chapter considers the commissioning planning process at the system level. The aim is to find the repeating patterns during the commissioning of every fluidized bed boiler.

Commissioning planning begins in the project's offering phase. When offering the project to a customer, an estimate of the project schedule and a guaranteed cost level need to be provided. In a project cost definition, the whole project from start to finish needs to be reviewed, and thus, the commissioning phase is also estimated. The first estimation of the commissioning plan will not be the final plan in the execution phase. This chapter concentrates on the more detailed version of the commissioning plan.

When the project is sold, and the execution begins, a detailed version of a commissioning plan is made. In the detailed version of the commissioning plan, there need to be exact dates for the commissioning of every process plant system. In an ideal situation, the commissioning schedule creates the baseline schedule for installation. After seeing what systems must be prioritized, the installation planner can schedule the installation works correctly.

The process plant systems need to be thoroughly examined for an accurate timetable. This examination should be so exact that every relation between different systems can be defined. It is not always the case in the real world, and some problems may appear on the site, such as a piece of pipe missing or a valve in a completely wrong place. In this chapter, the relations between systems are discussed.

In this chapter, the basic boiler systems are separated into six bigger groups and examined. To succeed at commissioning planning, the commissioning planner must have a great understanding of systems engineering to perceive the big picture. To efficiently use the big data, finding the vital information between the data mass is essential. This data digging is easier by prefabricating a template that defines the usual relations between different systems. The case example aims to make a baseline for this.

Traditionally in SFW, this has been done with great experience. After planning multiple projects, it is easy to say what system belongs where. This manner of approach has two major stumbling blocks: for one, it still takes many hours to go through every piece of equipment to define which needs to be commissioned, and secondly, this manner does not work when planning new systems. The commissioning planning process needs to be standardized to a level where the planning process can efficiently happen with newer processes.

Part of this research is to define and analyse the commissioning procedures of different systems on a standard fluidized bed boiler. These results can be later utilized in the base product structure of SFW.

5.1 System-based thinking

One principle cannot be stated enough in the commissioning planning of every system: "The greater the cold commissioning, the easier the hot commissioning." This means that doing the right things in the cold commissioning phase will prevent many problems in hot commissioning. For example, blowing and flushing will remove impurities from pipelines, and valves and filters will work more predictably.

In system-based thinking, the pipes, valves, and instruments are viewed by the KKS code structure. This approach is used in SFW’s current commissioning planning process. In commissioning planning the interface between the construction and commissioning phases must be closely examined. Both construction and commissioning points of view are discussed in terms of work length and steps for planning the commissioning.

The system structure of a steam boiler can be observed using different approaches. Here the systems of a standard fluidized bed boiler are gathered into larger groups. The system structure is divided into six main sections:

1. Combustion air and flue gas systems
2. Furnace systems
3. Water and steam systems
4. Flue gas treatment systems
5. Auxiliary systems
6. HVAC and firefighting systems.

The system structure is split this way to help understand the partial process combinations used in a fluidized bed boiler and the most common systems under them are presented. It must be kept in mind that every power plant is constructed to the customer's needs, and the systems used vary between different sites and countries.

The system presentation also includes estimates on commissioning times. Variations between projects occur, so a strict estimation cannot be made on a general level. Most estimations are made for cold commissioning phases; hot commissioning of a system is a much more variable subject.

This chapter discusses the interface between installation and commissioning. In commissioning planning, the planner must understand both sides. After examining the basic system commissioning processes, a dependency analysis between systems is made. This knowledge can be utilized in the case section of this work.

5.2 Combustion air and flue gas systems

Combustion air and flue gas systems are responsible for bringing combustion air into the boiler and taking the flue gases out. A typical structure for a fluidized bed boiler consists of fans, ducts, and measurements. Combustion air utilization in a circulating fluidized bed boiler is following:

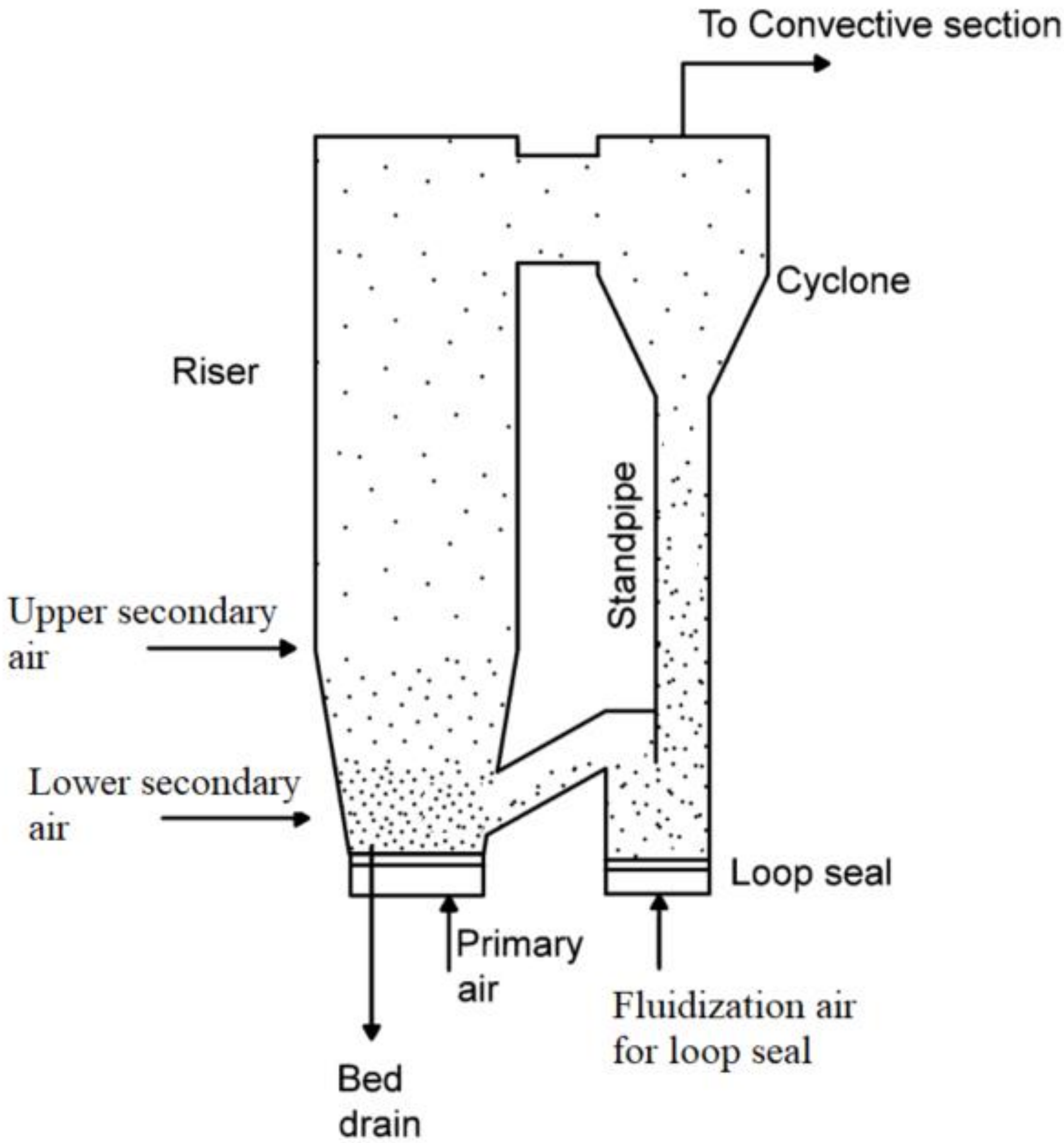


Figure 10. Combustion air for a CFB boiler. (Adapted from Basu 2015, 38).

This image is from a CFB boiler, but a BFB boiler's air distribution is similar with two exceptions: BFB does not need fluidization air for the loop seal, and there usually is a tertiary combustion air level where CFB usually has only primary and secondary. In the CFB the secondary air can be divided into lower and upper secondary levels, but they are located significantly lower than BFB's tertiary air feeding points.

The combustion air and flue gas systems must be cold commissioned for the first fire. Thus, these systems must be considered as priority systems to begin commissioning. It is also a good approach to test big equipment early; if there is a fault, the fixing takes easily couple of weeks. The combustion fan testing phase can be kept as a smaller milestone inside the cold commissioning phase of the boiler. Completed fan testing indicates that fire readiness is getting closer. Fan testing includes testing the furnace purging. Furnace purging means that the furnace and ducts must be ventilated with fresh air, for example, three times the volume. Purging the furnace is a requirement for ignition permission. Ignition permission means that the boiler is ready for fire and all required interlocks are in a good state. This precaution eliminates combustible substances in the furnace and ducts before ignition. A failed startup-burner ignition attempt will reset the purge, and the boiler must be purged again, as there might be combustibles in the furnace.

As with many electric motors, the fan motors can be rotation tested without couplings. Rotating without couplings means that the motors can be tested without the impellers of fans rotating. This way, the motors can be functionally tested before the fan operation requirements are completed. The functional testing saves time and allows fixing possible system errors before starting live fan testing. It is also a good practice to let the motors run without couplings for a couple of days. During this break-in period, the motor settles, and the bearings can be greased for commissioning. This method can be applied to many pumps and fans operated via electric motor; the motor testing can be done before the mechanical installation on the system is complete. This gives a time advantage.

CFB boilers require fluidization air for loop seal operation. Fluidization air is normally generated with a separate air system. This system is not required for the first fire, but it is needed for bed fluidization when bed material is taken inside the boiler. Cold commissioning of the fluidization air system takes one to two weeks; it consists of blower testing, measurement proving, and testing of control valves.

The main requirements for live fan testing are listed below. Strict requirements are always dependent on the site.

1. Electrification is complete
2. Fan installation is complete
3. Furnace installation works are completed
4. Air and flue gas ducts are installed and inspected
    a. Inspection 1: Installation
    b. Inspection 2: Commissioning readiness
5. The flue gas pathway is clear
6. Motor cooling is active.

Electrification is mentioned even though it is required for every electric device on the site. Fan motors electrification is emphasized since they are usually among the biggest electric motors on the whole site. Since they are big, the cabling and the VFDs are also bigger. VFD stands for a variable-frequency drive, a device that allows the adjustment of the parameters of an electric motor while it is running, for example, its rotating speed. Bigger VFDs have their separate commissioning programs and require extra care. Bigger cables also take longer to install so it is important to have those ready in the early stage of the project.

Fan installation requires a cautious approach as rotating equipment does not allow big tolerances. Concrete casting to create the bed for the fan and alignment of the motors and impeller housing take easily couple of weeks to complete. Furnace installation works must be completed before live fan testing. Furnace installation is not a small job; it includes refractory and grate installation. For a CFB boiler, the required refractory is more complicated compared to a BFB. Refractory installation for a CFB boiler can take months, whereas for BFB installation takes at least over a month. The length of the grate installation depends on the nozzle types and grate size. Below is an image of a step grate installed by SFW to a BFB boiler in Mikkeli Finland.

Figure 11. Step grate of a BFB boiler (Sumitomo SHI FW 2024).

Air and flue gas ducts must be installed and inspected for fan testing. Inspection has two main concerns; number one is the installation quality. Welding must comply with the quality standards and installation must be done correctly. This requires continuous supervision during installation and very careful inspection after the installation is complete. After the installation inspection, the ducts will be examined one more time before the inspection doors are closed. The final inspection includes possible cleaning of the duct. Installation debris causes problems if colliding with the fan impeller.

Another important factor is a clear flue gas pathway. Especially the newer combined heat and power (CHP) stations are equipped with flue gas thermal energy capture equipment. If a flue gas scrubber commissioning is ongoing and there is no bypass for it, the fans cannot be tested at the same time. This concern must be noted during commissioning planning.

During commissioning planning, the cooling of the fan motors and VFDs must be checked. If they are cooled with a separate cooling system, the cooling network must be commissioned before the fan operation. Bigger boilers typically have liquid-cooled VFDs, while smaller motors and VFDs are normally cooled with air.

5.3 Furnace systems

Furnace-related systems include startup-burners, bed material feeding, ash removal, and main fuel feeding. Furnace systems also contain combustion-related measurements, such as bed pressure, bed temperature, and furnace temperature.

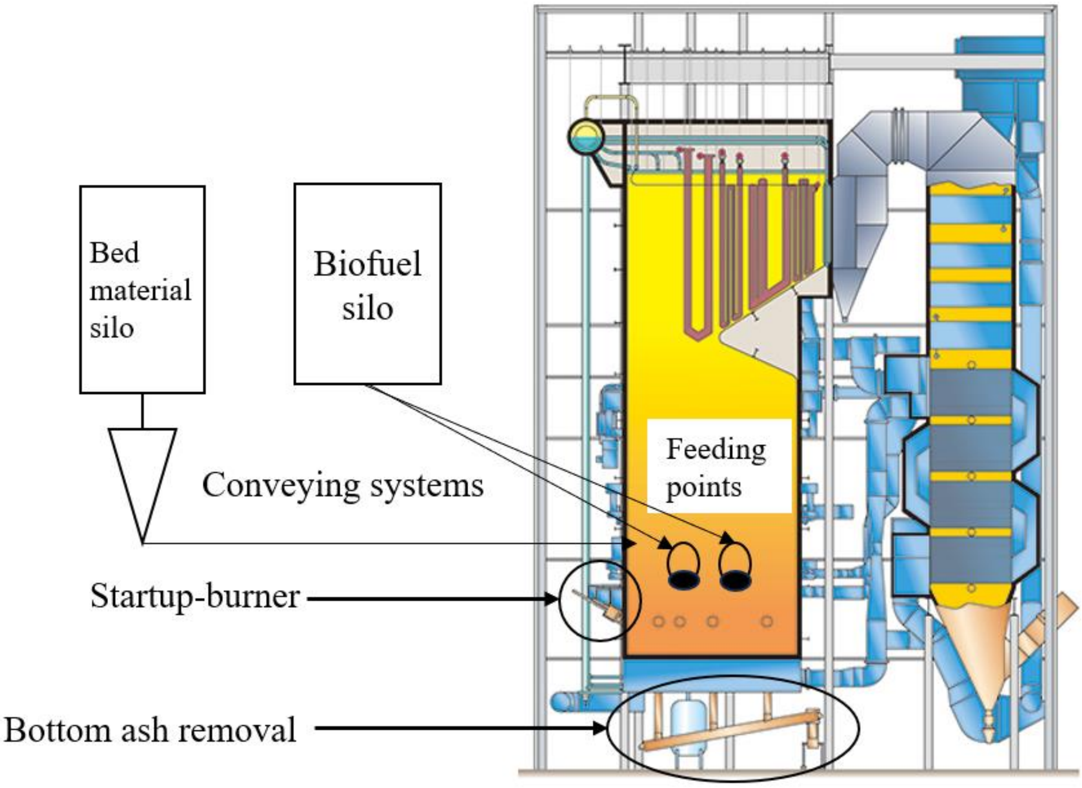


Figure 12. Furnace systems on a BFB boiler. (Adapted from SHI Ltd. 2024).

Startup-burner cold commissioning must be completed before the boiler's first fire. In fluidized bed technology startup-burners are used to preheat the fluidized bed to a temperature that allows the solid fuel to be combusted. Boiler first fire, refractory curing, chemical cleaning, and steam-blowing all require startup-burners. The first fire of the steam boiler is one of the major milestones in the whole project. A typical fluidized bed boiler has lance-operated burners which can be retracted out from the furnace during normal operation, this helps to keep the burners cool and clean. Startup-burners have starting and stopping sequences that need to be tested carefully. Cold commissioning of these burners takes a minimum of two to three weeks. Startup-burners usually have dependencies on pressurized air to control and cool the burner.

Bed material feeding is typically done via a pneumatic conveyor. Other solutions can also be seen, for instance, screw feeding or mixing bed material to fuel before the furnace. Bed material pneumatic conveyor can be tested when the feeding line to the boiler is ready and pressurized air is available. Pneumatic conveyor cold commissioning can be done in a couple of days. In cold commissioning the feeding line is pressurized to check for leaks. Logic testing can be done before the conveying line is completed using only instrument air. It is a good practice to leave the conveyor to send empty deliveries for a couple of days to clean and dry the conveying piping. Bed material is not required for the first fire, but it is needed in the steam-blowing procedure to prevent overheating the grate nozzles. Refractory curing can also limit the feeding of bed material. Refractory suppliers can state that the refractory curing must be done without a bed to a certain temperature, for example, 300℃.

When bed material is inserted, there must be an option to take it out from the boiler as well. A bottom ash removal system is not necessary for the first fire as it is usually fired without a bed. Bottom ash removal typically has a dependency on cooling water. The removed bed material is very hot and thus needs to be cooled for the sake of conveyors and operational safety. The bottom ash removal cold commissioning procedure contains rotation testing, greasing, and interlock testing. Bottom ash conveyor functionalities are similar compared to solid fuel feeding ones, and quite the same commissioning procedures happen with both. The biggest difference is the mentioned requirement for cooling. The typical length of cold commissioning for a bottom ash system varies between two weeks to a month.

As discussed earlier, the startup-burners are required for the first fire, and they use auxiliary fuels for heating the furnace. The main fuel feeding usually comes into play after the steam-blowing procedure. Biomass fuel feeding to a fluidized bed boiler is carried out typically with conveyors, screw feeders, and rotary feeders. Solid fuel feeding can be tested in an early stage as its cold commissioning typically does not have dependencies on other systems. Solid fuel feeding testing procedure contains similar tests as bottom ash removal. It can be kept as a backup system for commissioning; if problems occur in more essential systems, solid fuel feeding can be tested in the meantime. Cold commissioning length for solid fuel feeding is around two weeks to a month. In some projects, the possibility of using solid fuel even in blowouts can be considered. It brings new problems to the table since the boiler cannot be adjusted very well to solid fuel combustion before steam blowing. Problems might occur with burning quality, and thus, residual oxygen levels in flue gases. There is a preset minimum for oxygen levels to ensure complete combustion in the furnace; if the limit is not met the boiler protection system will shut the boiler down.

5.4 Water and steam systems

Water and steam systems are a big scope. Depending on the project scope they can contain feedwater systems, steam generation systems, auxiliary steam systems, main condensate systems, auxiliary condensate systems, sample station, and chemical feeding systems. These systems are all required for a steam boiler to operate.

Water system pipelines must be at least flushed with clean water in pre-commissioning. Water systems contain pumps that need to be tested in cold commissioning. First rotation tests can be done by coupling unattached. When the pipeline is flushed properly, it can be restored, and the pump coupling attached. Every system flushing must be planned separately. After flushing, the pipeline must be bled, and then the system can be cold commissioned with the pump. In the cold commissioning of a liquid system the pump, valves, and measurements are tested. Pump interlocks are also verified with live testing. Typical interlocks for a pump are too low suction pressure, inlet filter pressure difference, and a minimum flow. Water system commissioning lengths depend on the system. Auxiliary condensate testing is rather quick, commissioning of feedwater pumps and high-pressure lines takes a longer time.

The feedwater system is usually commissioned in parts. Typically, the low-pressure side of the system is taken online earlier. The low-pressure side consists of a feedwater tank and feedwater pump suction lines. Feedwater system cold commissioning considering low-pressure and high-pressure sides takes weeks. In a common approach, the feedwater tank is hot commissioned early, right after the hot commissioning of auxiliary steam. Feedwater tank hot commissioning takes weeks. It consists of pressurizing the tank for the first time and flushing it with clean water. This is done for so long that the water chemistry is approved. This way the impurities do not travel to the boiler when it is filled with feedwater for the first time. When a feedwater tank is commissioned, it is a good practice to flush feedwater pump suction lines heavily. This will prevent the pump filters from getting blocked later when feedwater pumps and the boiler are operated. These small details in the cold commissioning phase make the hot commissioning part much more fluent.

Steam systems must also be cleaned carefully before regular operation. For feedwater, evaporator, and main steam piping this will be done during chemical cleaning, film formation, and steam blow procedures. The auxiliary steam system should also be blown, which can be done earlier than the boiler blowing. The auxiliary steam system is typically one of the first systems to enter the hot commissioning phase, it is required to pressurize the feedwater tank. Auxiliary steam system cold commissioning consists of instrument and valve testing; it can be done in a week.

Other typical systems are sample station and chemical feeding. The sample station is commissioned via parts. The feedwater tank sample line is usually commissioned with the feedwater tank. First samples are done with an external analyser, real analysers are taken online later. Chemical feeding is required when the feedwater tank hot commissioning starts, it is used to give the water correct PH- and conductivity values and remove excess oxygen from the water. It consists of tanks, measurements, and pumps. Pipelines and storage tanks must be flushed with clean demineralized water before adding chemicals. While handling chemicals, there must be put extra care on the tightness of the systems. Finding leaks when the chemicals are added into the tanks is always a hazard and solving them takes time since operating with chemicals requires heavy safety precautions. Sometimes leaks can happen even with careful testing. If the installation has used the wrong gaskets the system might be tight with water but once the chemical is taken in, it slowly eats its way through the gasket and starts leaking. This can be prevented with strict installation supervision before commissioning.

5.5 Flue gas treatment systems

Flue gas treatment systems are getting more advanced as the emission regulations get stricter. It is also in the interest of the plant owner to get the plant efficiency as high as possible. With flue gas thermal capture units this is possible, they clean the flue gases and capture energy at the same time. The main systems used in fluidized bed boilers are a dust removal system, sulphur and chloride reduction system, nitrogen oxide (NOx) reduction system, and a possible flue gas scrubber. The used fuel states the required systems. Chemical compositions between for example biomass and solid recovered fuel (SRF) are very different.

The main types of dust removal systems are bag filters, electrostatic precipitators (ESP), and flue gas scrubbers (Vakkilainen 2017, 160). Bag filters typically use pressurized air to clean the bags during operation. Pressurized air creates a pulse that shakes the external dust out from the bag to a hopper from which the dust can then be conveyed to an ash silo. The ash conveying can be done for example via a pneumatic conveyor. The figure below shows an example of a dust collection and conveying system.

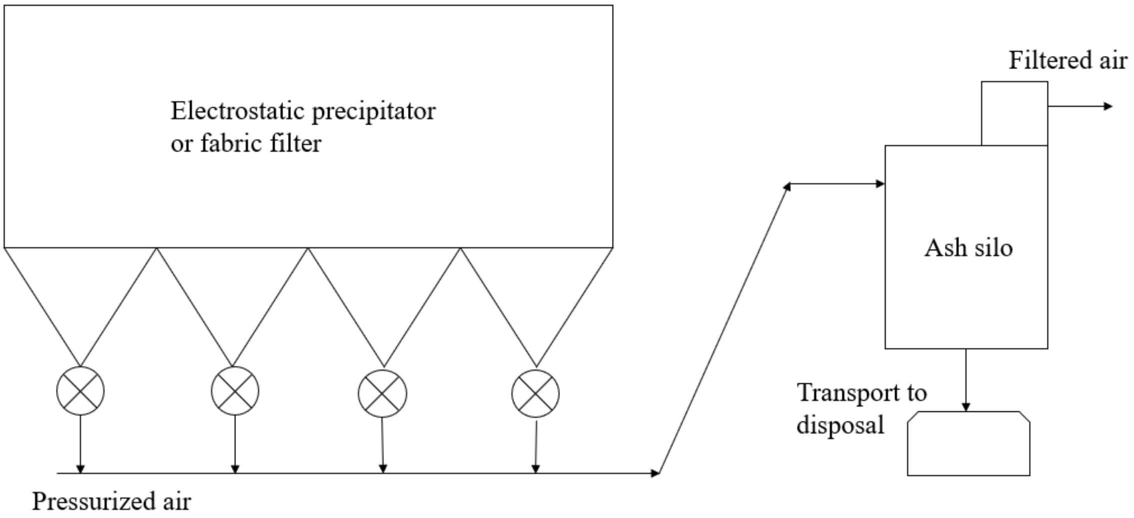


Figure 13. An example of a dust collection and conveying system. (Adapted from Vakkilainen 2017, 163.)

Bag filter cold commissioning consists of logic testing, leak testing, and precoating. Leak testing is done after the individual bags are installed in the filter to ensure the correct installation. It can be done with fluorescent powder that is injected into the dirty side of the filter. Afterwards, the clean side is inspected via an ultraviolet lamp to detect leakages. After approval of leakage testing, the filter is precoated with inert dust to make a protective layer for the bags. This testing interferes with fan testing. Usually, fan testing is done first, and bags are installed afterward. The flue gas fan is run during leak testing to create suction through the filter. Below is an image of installed bags after the fluorescent leak test powder has been applied.

Figure 14. Bag filter leak testing on the dirty side with fluorescent powder (Valtteri Liimatainen).

An ESP uses an electromagnetic field to gather dust from flue gases. Its commissioning differs a little from the bag filter, but it also requires cleaning pulses to drop the gathered ash into the hoppers. In an ESP, the electrode plates might have an external vibrator for cleaning.

Flue gas cleaning is done according to environmental regulations. Additive chemicals can be injected into flue gases before filtering to neutralize chemical compositions. Examples of additives used are activated carbon, sodium bicarbonate, and sulphur. One way to inject them into flue gases is via separate blowers. They require rotation testing as well. In fluidized bed boilers, the emission regulation is partially done in the furnace via the bed additives; this reduces the need to inject additives into flue gases.

NOx emissions are one emission type that is strictly regulated. With fluidized bed technology, the thermal NOx formation is low because of the rather low combustion temperatures (Vakkilainen 2017, 48). On the other hand, Vakkilainen states that biomass fuel contains nitrogen, which partially turns into NOx in combustion, regardless of the temperature. This might be an issue that must be dealt with. NOx emission reduction can be done by lowering combustion temperature with flue gas recirculation, air and fuel feed optimization, and using external chemical systems, says Vakkilainen. Chemical systems in a fluidized bed boiler can be split into two main types, selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR). Other boilers have different ways of handling NOx emissions since depending on combustion technology, the thermal NOx emissions can be much higher.

With the SCR system, there is a catalytic converter in the flue gas duct to boost the reactions, with SNCR the injected chemical uses the right temperature window to react with flue gases without an external catalyst. Both systems are used with fluidized bed boilers. Commissioning them differs a little but they also have things in common. Both systems use an external reducing agent chemical to react with flue gases. Typical chemicals used are ammonia-based substances, for example, urea, ammonium water, or waterless ammonium (Yara 2024a). Depending on the system, the reducing agent chemicals are injected either in the furnace or the flue gas duct. SNCR requires a higher reacting temperature, so it is typically injected in the top part of the furnace or at the beginning of the flue gas duct (Yara 2024b).

Chemical feeding units consist of storage tanks, feeding pumps, pipelines, and nozzles for injection. Nozzles can be operated, for example, via liquid pressure or atomizing air. Commissioning of these systems consists of a leakage test, blowing and flushing the pipelines, rotating the pumps, and testing the measurements. This system commissioning is quick if there are no issues; blowing can be done in a couple of days, flushing takes a couple of days next and then the pump can be tested. The concern with these systems is the chemicals running inside them; the pipeline must be proven leakproof before getting the chemicals in. NOx reduction system is not always required for the first fire and is typically hot commissioned after the boiler is already running on solid fuel. This is because the flue gas temperatures fluctuate a lot during burner testing and steam blowing so adjusting this system is complicated.

The flue gas scrubber is on the dust filter's clean side. A flue gas scrubber is used to reduce emissions and improve plant efficiency. Flue gas scrubber can be equipped with a condensing unit and even a combustion air moisturizer. Commissioning of flue gas scrubber can take some time since it consists of many pumps and automated valves. Scrubber commissioning cannot be done at the same time as fan testing, so that must be kept in mind when planning the commissioning. Flue gas scrubber cold commissioning can be done in parts but in total it takes multiple weeks.

5.6 Auxiliary systems

Fluidized bed boilers also have auxiliary systems, among others. Systems considered here are startup fuels, cooling water, compressed air, water treatment and distribution systems, and soot blowing.

The startup fuel system is vital for the startup of a fluidized bed boiler. Startup fuel is combusted via the previously mentioned startup-burners. Typical startup fuels for a fluidized bed boiler are natural gas and oil. Depending on the configuration, burners can use one or both options. When using oil, an external ignition gas system is required for an ignition flame before starting the main flame. Ignition gas can be external bottled gas or natural gas. The first option allows the oil to be used even when there is no natural gas available. Commissioning of oil systems is a bit more complicated compared to natural gas as oil is a liquid. Oil lines are blown with pressurized air, tightness is tested, and oil is taken in. Depending on the pump type they might not allow testing without couplings, this means that first rotation is done when there is oil in the system. Testing can be done this way, but it must be quick since the pump can break if it rotates in the wrong direction. The oil system is then flushed with oil and the instruments are tested. Oil system cold commissioning takes multiple weeks from blowouts to oil filling.

Commissioning of the natural gas line consists of blowing the line with pressurised air, a tightness and pressure test in co-operation with the mechanical team and testing of instruments. Natural gas lines need pressure control valves for efficient operation. Natural gas system cold commissioning takes multiple weeks.

The cooling water system plays an important role in the boiler operation. Typical places for cooling are HVAC systems, big electric equipment like motors and VFDs, feedwater pumps, bottom ash screws, and sample station. Depending on the plant there can be one or multiple cooling networks with different operational temperatures. Cooling water networks commissioning starts with air blowing, after that comes water flushing, bleeding, and pump testing. If everything goes smoothly it can be done in a week. Cooling water networks are typically the top priority to begin cold commissioning.

A compressed air system is typically among the first systems to enter operation in a fluidized bed boiler project. Pressurized air is required for multiple purposes during commissioning, for example, the mentioned blowout cleaning procedure of pipelines. Other important pressurized air users are air operated instruments; they cannot be tested if the pressurized air network is not up and running. One critical user of instrument air is the mentioned startup-burner, its lance is commonly operated via pressurized air. With good pre-commissioning preparations compressed air system can be cold commissioned in a couple of days.

Water distribution and treatment facilities come into play when the pipelines are required to be flushed and operated for the first time. Steam boilers can have different quality water for different uses. The boiler needs thoroughly purified demineralized water, but all water systems do not require that purity level. A water treatment facility is required for feedwater tank commissioning. There are different technologies used in water cleaning, one typical option in new plants is reverse osmosis technology, often called RO. RO-technology commissioning is a quite straightforward job, and in optimal conditions can be done in a week.

A soot-blowing system is required for fluidized bed boiler operation. Heat transfer surfaces are on the dirty side of the flue gas duct, and dust gathers on them. Soot blowers keep the heat transfer surfaces clean to ensure efficient heat transfer. The traditional approach to a fluidized bed boiler is steam soot blowing, but other options can also be considered, such as hammer and sonic soot blowing. Soot blowers' cold commissioning should be done before the first fire. In cold commissioning, the functionality must be proven from inside the flue gas duct. This means that the combustion fans cannot be tested simultaneously. In cold commissioning temperature advances of soot blowers must be adjusted to take the thermal expansion of the boiler into account. Cold commissioning of soot blowers takes one to two weeks, but it depends on the quantity of devices and might take even longer.

5.7 HVAC and firefighting systems

HVAC or heating ventilation, and air conditioning are among the first systems that need to be up and running. HVAC is needed when electrical equipment supply cabinets are powered on as they generate heat and need cooling. HVAC is dependent on cooling and heating circulations, as they both are required for air moisture removal. The commissioning procedure for HVAC systems considers rotation tests of pumps and blowers. HVAC system is usually commissioned in parts, first part cold commissioning can be done in a week or two.

Firefighting systems should be available also as early as possible. There are a lot of things happening in the construction phase at the same time, so it is good to have additional fire extinguishing equipment ready among the mandatory extinguishers. The firewater network commissioning procedure involves flushing, filling the network with water, and testing the hoses. Firewater system cold commissioning takes a week.

5.8 Findings

5.8.1 Dependencies on cold commissioning

Here the systems are overlooked from a dependency point of view, which systems in general allow the commissioning of other systems to begin. Electrical distribution systems are neglected here. An electrical distribution system must be commissioned before the electric equipment can be tested. Electrical distribution systems are divided into separate commissioning packages. The commissioning schedule for these distribution systems comes from the plant commissioning schedule. Typical first electrical systems taken online are related to uninterruptible power supplies (UPSs) to allow the commissioning of DCS. Below is the dependency analysis for cold commissioning.

Table 4. Dependency analysis of general systems cold commissioning.

System	Dependency
Compressed air	-
Make-up water	De-mineralized water
Water treatment	City water
HVAC	Cooling water
Combustion air	Cooling water
Flue gas	Cooling water
Startup-burner	Compressed air
Bed material	Compressed air
Bottom ash	Cooling water
Solid fuel	-
Feedwater	Make-up water
Steam generation	Make-up water
Main condensate	Make-up water
Auxiliary steam	External steam
Auxiliary condensate	Make-up water
Sample station	Cooling water
Chemical feeding	Make-up water
Dust filter	Compressed air
Emission reduction	Compressed air, Make-up water
Startup-fuel	Compressed air
Cooling water	Make-up water
Soot blowing	-
Firewater	City water

A pattern is developing regarding which systems are the most crucial from cold commissioning's perspective. The systems mentioned are the same ones that were emphasized earlier. Below is a figure of the number of dependencies.

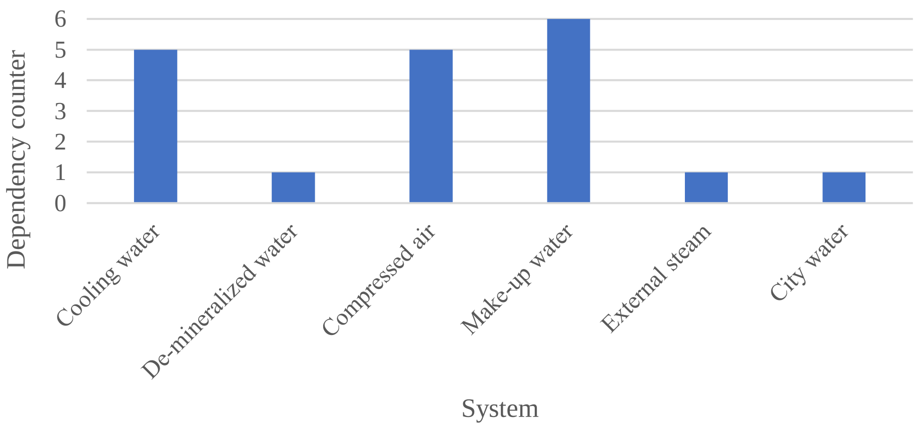


Figure 15. Number of dependencies.

The dependency counter means the number of other systems' cold commissioning processes depending on the mentioned system on the bottom. Three systems stand out clearly: cooling water, compressed air, and make-up water. These systems repeat on almost every project, it is a safe way of approach when prioritizing these as the first system to go under commissioning. One new object is external steam, external steam generation is required for auxiliary steam commissioning. Depending on the project the scope might have an auxiliary boiler to produce said steam or the client's existing steam network can be used.

After dependency analysis and based on what was stated earlier, the systems can now be categorized into priority groups. In this table, the systems mentioned are gathered according to commissioning interests. Priority I comes first, and priority IV comes last.

Table 5. Priority listing of general systems of fluidized bed boiler.

Priority I	**Priority II**	**Priority III**	**Priority IV**
Compressed air	Combustion air	Feedwater	Solid fuel
Make-up water	Flue gas	Chemical feeding	Steam generation
Water treatment	Auxiliary steam	Bed material	Main condensate
HVAC	Auxiliary condensate	Bottom ash	Sample station
Cooling water	Startup-fuel	Dust filter	Emission reduction
Firewater	Startup-burner	Soot blowing	

This table is general; differences between plants occur according to project scope, customer needs, and possible contractual milestones. Contractual milestones implement deadlines for certain activities. Client and supplier can, for example, have a contract that states that 20% of the plant price will be paid once the plant is generating steam. These can affect the final decision-making in prioritizing systems. Some similarities will be with every plant, pipelines need blowing and flushing, and a lot of equipment will need cooling. Prioritizing compressed air, water facilities, and distribution and cooling networks is a good base, regardless of the project. If those systems are in somebody else’s scope, it is important to emphasize their necessities for commissioning to succeed.

5.8.2 Dependencies on hot commissioning

The dependencies for hot commissioning differ from cold commissioning. While the system might be able to be tested without relevance to other systems, in the hot commissioning period the availability of other systems is more critical. The table below shows the same considered systems according to their dependencies on hot commissioning.

Table 6. Dependencies on hot commissioning.

System	Dependency
Compressed air	-
Make-up water	Water treatment
Water treatment	City water
HVAC	Cooling water, Heating water
Combustion air	Flue gas
Flue gas	-
Startup-burner	Compressed air, Startup-fuel, Dust filter, Combustion air, Flue gas
Bed material	Compressed air, Combustion air
Bottom ash	Cooling water, Bed material
Solid fuel	Startup-burner, Steam generation, Bed material, Bottom ash
Feedwater	Make-up water, Auxiliary steam
Steam generation	Make-up water, Feedwater, Startup-burner, Combustion air, Flue gas, Dust filter, Sample station
Main condensate	Steam generation
Auxiliary steam	External steam
Auxiliary condensate	Auxiliary steam
Sample station	Cooling water
Chemical feeding	Make-up water, Feedwater
Dust filter	Compressed air
Emission reduction	Compressed air, Make-up water
Startup-fuel	Startup-fuel, Dust filter, Startup-fuel
Cooling water	Make-up water
Soot blowing	Steam generation, Auxiliary condensate
Firewater	City water

This table is general but works as a good baseline. Differences between projects occur according to device choices and customer demands. For example, many motors and VFDs need liquid cooling, but this is not the case with smaller-scale boilers. The idea is to understand the requirements to allow other systems to continue testing. Below is a flow chart visualizing this hot commissioning dependency table.

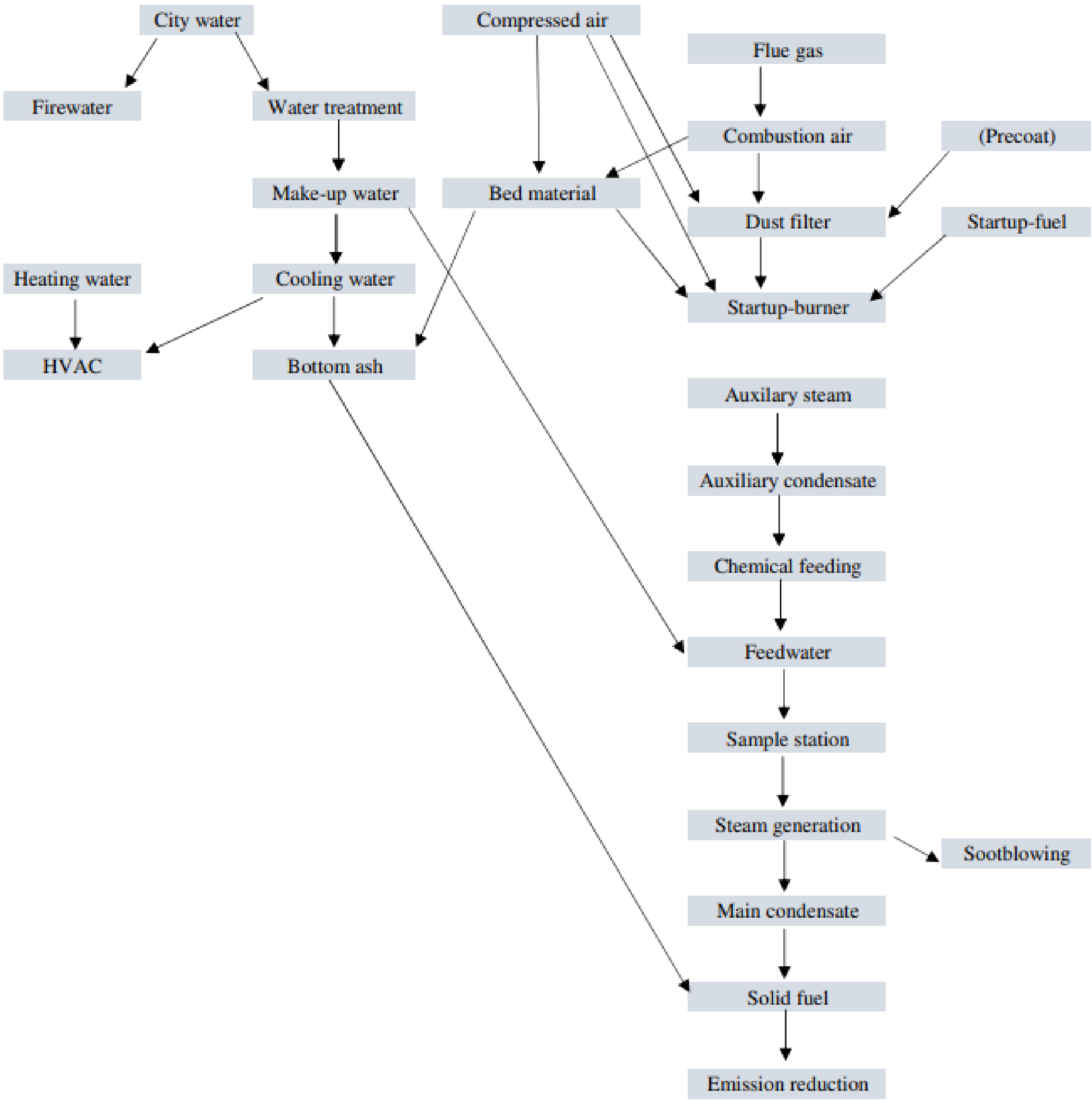


Figure 16. Flow diagram of dependencies.

This figure demonstrates the complexity of system relevancies in hot commissioning. It is not easy to efficiently manage the timeline and allow system commissioning to begin at the right time.

5.9 Sector-based thinking

Another method to consider in installation, and thus, commissioning planning is sector-based thinking. In sector-based thinking the boiler mechanical installation is planned according to sectors, not according to the commissioning schedule. This gives a time-saving advantage in the installation process; big cables can be pulled simultaneously, and instruments for different systems can be installed at once. In system-based thinking, the installation can be fragmentary; workers must switch locations and tools more often and come to the same place multiple times to finish another system. Sector-based thinking can be carried out with different perspectives It can consider one type of equipment using the same type of resources, for example, the same cable rating or even a plant sector. Sector-based thinking for commissioning has more advantages in modularized projects. Mechanical erection can be done via sector-based thinking even though commissioning planning is system-based. Sector-based thinking will not be covered as profoundly as system-based.

6 COMOS tool

Siemens COMOS means Component Object Server. It is commonly used in process planning and design (Siemens 2011, 11). COMOS environment is widely used in SFW's engineering and design processes. Siemens points out that COMOS is not a database but an interface to utilize multiple databases. In this chapter, a new attribute will be developed for COMOS. According to Siemens (2011, 8):

"Attributes are the properties that turn a general object into a specific base or engineering object. The more attributes are added, the more precisely the object is described."

SFW's commissioning planning has traditionally been based on printing lists from COMOS to Microsoft Excel when the planning begins. The actual planning is then implemented on those Excel lists. The problem with these lists is that when the source data in COMOS is updated, the Excel list does not automatically update. If the list is instead updated in Excel, the new information must be later added to the source data in COMOS manually. This interface can be streamlined with the new attribute, allowing the updated data to be inputted straight into the source data.

Using Siemens COMOS environment, the user can add inheritable data attributes for devices, for example, via project data structure based on KKS. This function shall be used in this development section and a new inheritable data attribute for commissioning will be added to SFW's COMOS environment. The aim is to create an inheritable attribute that can be filled during the beginning of commissioning planning. If a system planner later decides to add a new component under the predetermined commissioning group, it will automatically inherit the information; the group does not need to be manually updated.

In this chapter, the term commissioning group will be discussed. The commissioning group and turnover package is the same but with different names. Turnover packages were decided to be called commissioning groups inside COMOS to prevent mix-ups.

6.1 Concept

Below is an illustration picture of the concept of inheriting the data.

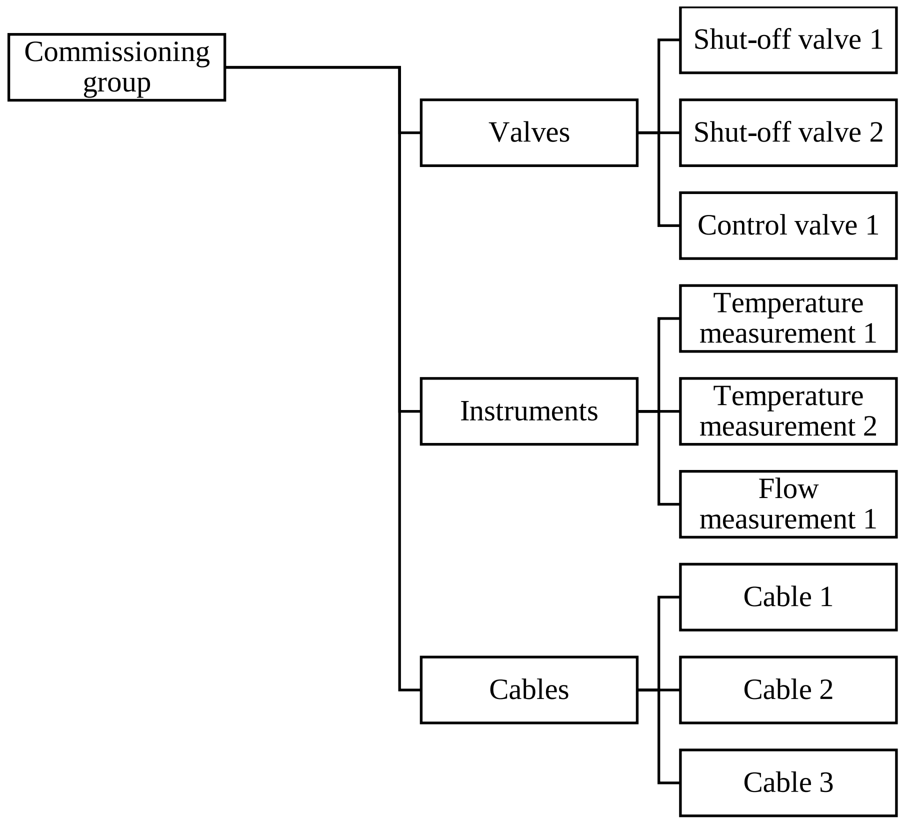


Figure 17. Example of inheriting the data.

Via this new function, the commissioning planning data can be added straight to the source data, and this way, the possible Excel list can be printed again without the need to be updated manually. Automatic list printing, for example, once a week can be considered. Implementing this approach will streamline the SFW's commissioning planning process and the progress tracking on site. Adding the new attribute allows a new way of data harvesting, which can later be utilized in, for example, the mentioned sector-based thinking. Equipment can be organized by their location, showing the commissioning groups related to that location.

6.2 Development

Development started in the autumn of 2023 with an SFW's internal meeting with experts in different fields. The result of this meeting was that a new data relation is needed, and this master's thesis shall be partly used for that. There are ongoing projects in the correct project phase simultaneously so that the new functionality can be tested in practice immediately.

The meeting in October agreed on a new gathering in November; during the meantime, the thesis worker could orientate oneself to the SFW's product structure.

The next meeting was held in November 2023. This meeting included the COMOS primary user from SFW. Main findings of this meeting:

- Preliminary visual structure of the new data window
  - The data window shall have two main parameters: one for determining the whole Turnover package and one for prioritizing parts of it.
  - A third parameter can also be added later: a standardized system description.
- Location of this new data window
  - The data window shall be located on the main attribute page of the component.

In the first attempt, there shall be two new data windows, one for turnover packages and one for prioritizing parts of the packages. The second attribute will allow the commissioning planner to add additional information on the systems already in the planning stage if the whole system is not immediately needed. The planner can prioritize part of the system to be finished earlier to allow other systems to start commissioning as well. This becomes useful when systems are dependent on other systems to begin commissioning. The turnover package function shall be called the commissioning group in COMOS to prevent mix-ups. Below is the view of the newly generated data window.

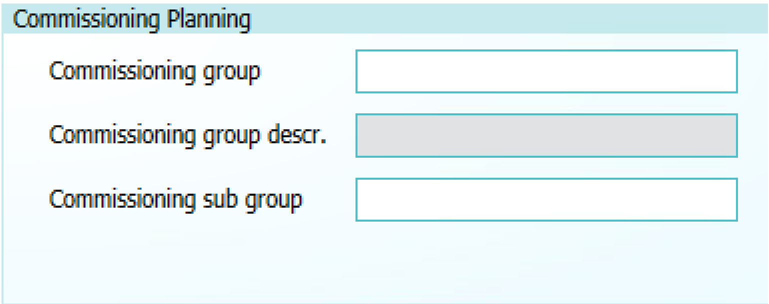


Figure 18. Data-window from COMOS.

The development phase window has three different places for data; the Commissioning group is planned to be the main group for creating the turnover packages, description will be a standardized dropdown menu with different options for a description. The subgroup is for prioritizing the commissioning groups. Subgroups can be called for example priority 1 and priority 2.

6.3 Testing

After the first phase of development, the testing of this data relation could be started. In this testing, the data was printed out from COMOS, and it was checked that the implemented data relation was inherited correctly. COMOS allows users to make working layers on projects. Exploiting this feature, the testing could be executed in a live environment without affecting the ongoing project. The function allowed the testing to be carried out on the following case study. The iterative process could then be repeated as long as necessary.

The testing phase was done with one of SFW's experienced COMOS users who was behind the concept of this new attribute. In the testing phase, one minor bug was found: the given attribute did not inherit correctly to all components in the project structure. Fixing this required adding another new functionality to SFW's COMOS. After adding the new function, the inheriting worked correctly, and implemented data could be found from every substructure under the given commissioning group.

The function was made simple: the wanted object is opened, the wished data is implemented, and change is then applied. A couple of different methods for data feeding were tried, and one method stood above the others. The simplest way is to use the data tree inside COMOS. It can be organized, for example, according to KKS codes. Below is a demonstration image.

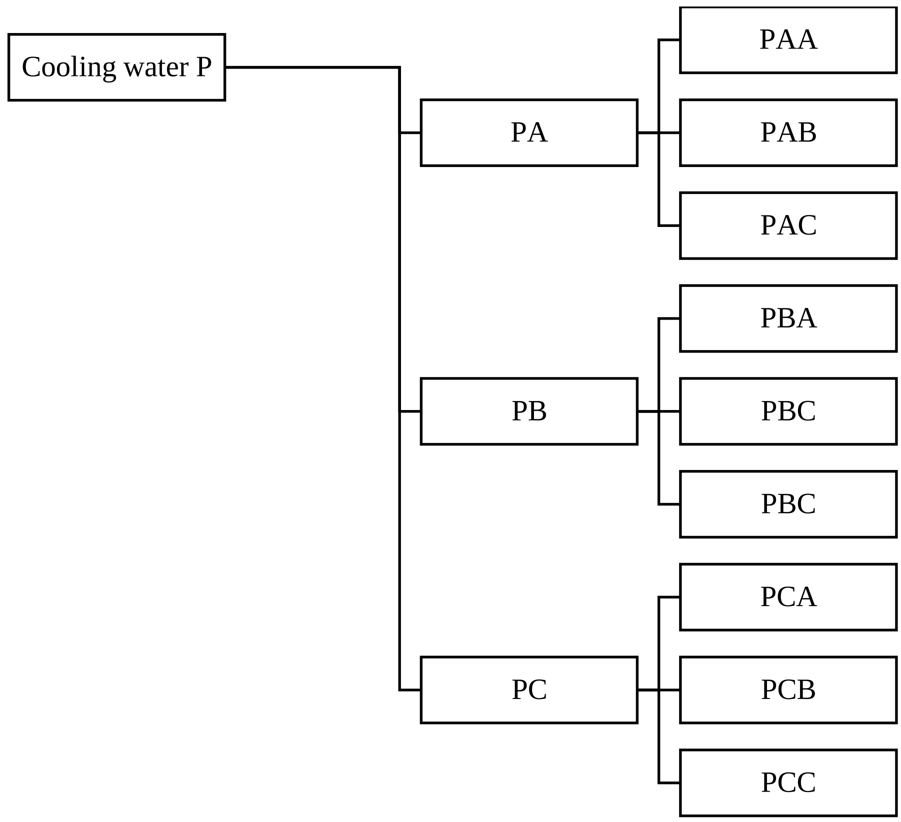


Figure 19. Example view of data tree based on KKS-codes.

Using the data tree view, the user can select block PA and decide that everything under it has a commissioning group called “CCW-cold.” This method is simple to use and can be used in quick fixings where the whole KKS structure is not required to be examined. The method for better results was found to be by creating a query with wanted functionalities and using the query to fill in the possible commissioning groups. Query is a function inside COMOS that searches for data. Using queries can get complicated, but the main idea behind them is that they are fully customizable for seeking and viewing data. Queries can be saved and used later. A query for commissioning group testing was made using the following criteria:

Table 7. Criteria for testing query.

Function	Explanation
Project scope	Checks if the sought item is in the project scope.
Code length	Allows the user to filter results according to KKS code length.
Full label	Icon and KKS-code of the item.
Long description	Description of the said item.
Commissioning group	Commissioning group.
Commissioning subgroup	Commissioning subgroup.
Schema	Drawing related to the item.
Location in plant	XYZ-coordinates of the item.

Different criteria were considered, but the ones mentioned gave the most relevant information for forming the commissioning groups. A project scope limiter is used in almost every query, it only includes hits in the project scope. Projects can have “ghost” objects that are not in the scope of delivery. The code length function had to be coded inside the COMOS; it was not initially included in the software base. Code length determines the length of the search results. Harvesting could be started from the system code base length of five symbols, “PGA05,” and then continued to more profound levels to check the more specific instruments. The full label function shows the icon and KKS code of the item. Schema function can come in handy when dealing with unfamiliar devices. Schema contains the drawing information of said device, and the user can view the drawing with the press of a button. XYZ-coordinates were also added to the query; this way, sector-based thinking can be examined at the same time as applying the commissioning groups. Below is an image from the manual inspection process query inside COMOS.

FullLabel ▲	Long Description (English)	Commissioning group	Comm. sub group
37PG	*Closed cooling water system for conventional area*		
37PGA	*Piping system (supply), cold system if two separate sy*	CCW Cold	
37PGA05	*Cold closed cooling water*	*CCW Cold*	
37PGA05AA001	*Cold closed cooling water shut-off valve*	*CCW Cold*	
37PGA05AA002	*Cold closed cooling water shut-off valve*	*CCW Cold*	
37PGA05AA004	*Cold closed cooling water shut-off valve*	*CCW Cold*	
37PGA05AA006	*Cold closed cooling water shut-off valve*	*CCW Cold*	
37PGA05AA010	*Cold closed cooling water pipe for O2 scavenger shut-*	*CCW Cold*	
37PGA05AA602	*Cold closed cooling water pressure measurement root*	*CCW Cold*	
37PGA05AA604	*Cold closed cooling water pressure measurement root*	*CCW Cold*	
37PGA05AA605	*Cold closed cooling water pressure measurement root*	*CCW Cold*	
37PGA05AA606	*Cold closed cooling water pressure measurement root*	*CCW Cold*	

Figure 20. Screen capture from the inspection process.

During the testing procedure, the commissioning group data, according to the case study plant, was fed to COMOS. Stating the start object for the query allows the user to set where to search for the wanted information. In this shown capture, the search area was set to be 37PG, “closed cooling water for conventional area”. It is notable that the codes shown here are project-specific codes. Full-label information shows every object containing the wanted information. PGA’s commissioning group was set to be “CCW cold”. More information on this group formation can be found in the case study chapter. There is no prioritization made, and the commissioning subgroup block is empty. The commissioning subgroup was left with less attention in this work. Its main principle is to prioritize parts of the systems, if necessary. In this case, it was not seen as necessary. If the situation changes later, a commissioning engineer can log into COMOS from the site and update the prioritizing order according to the current condition of the project site.

As one can see, the description dropdown menu mentioned earlier is not discussed here. This is because, during the testing, it was decided not to implement the description dropdown menu to projects just yet. Taking this new description block online needs a separate time window for creating descriptions for every system. Descriptions need to be exact and well-explained so that no mix-ups can happen. Doing this to every system in SFW's product structure takes a time so long that it is not reasonable to implement in this work.

6.4 Findings

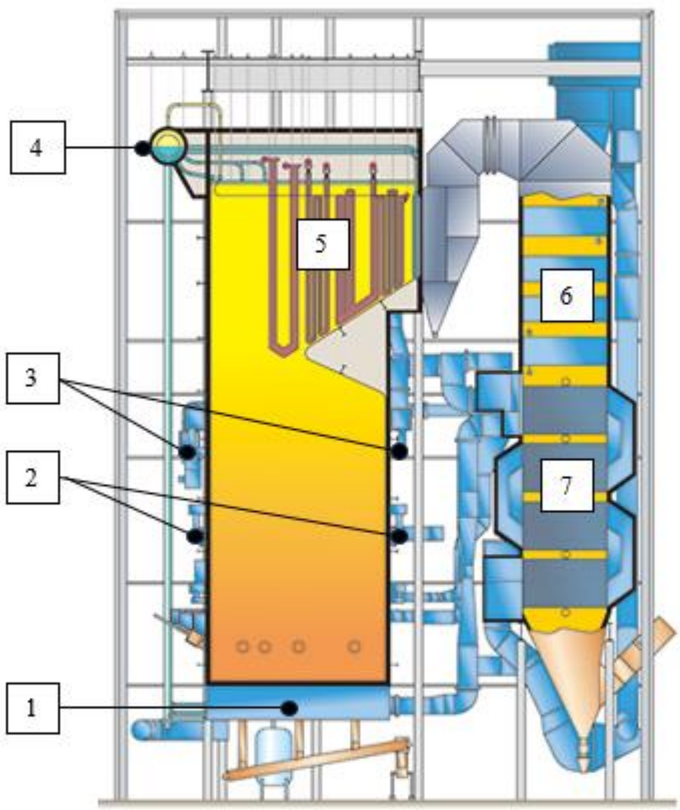
The tool development continues after this master thesis. This work allowed an excellent testing environment for the new functionalities. The new attribute worked well after fixing a couple of minor bugs. It is always a big and careful process to implement new functions inside a large project execution company's source data software. Implementing the attribute was done cautiously and with the help of experienced colleagues from SFW.

The new attribute can be used in different ways, and two of the most obvious ones were presented. From these two options, the query stood out quickly. With the query, the user could do the whole planning process inside COMOS. If the KKS codes are unfamiliar, the PI&D drawing can be opened via the schema link, and the process relativity can be checked. In this test phase external software solutions were used. One software was X-mind; which can be used to create mind maps, this helped to visualize the commissioning groups more easily. The other used software was Microsoft Excel. While the idea behind this new function was to get rid of using Excel, it can still be a useful secondary tool during the planning process.

The dropdown description function was not taken online yet as it needs internal guidelines for clear descriptions for every system. The tool worked as planned and the data could be implemented on the case project.

7 CASE study

This case study considers creating turnover packages for a ~100 MWth BFB boiler, which generates electricity and heat. The boiler uses biomass and pellets as its main fuel. The turnover packages for the case boiler are created, and the reasons for the choices are presented. Turnover packages are also analysed for dependencies in the cold commissioning phase. Hot commissioning dependencies are not considered. The developed COMOS tool is used for transferring the data into SFW's database. An example picture of a similar boiler is below.



1	Primary air feed (wind box)
2	Secondary air
3	Tertiary air
4	Steam drum
5	Superheaters
6	Feedwater preheaters (economizers)
7	Combustion air preheaters (luvos)

Figure 21. Construction of a typical BFB boiler. (Adapted from SHI Ltd. 2024).

Traditional BFB boiler is constructed as shown in the picture. Fluidization air is pushed to the bottom of the furnace via the earlier mentioned grate nozzles. The lower part of the furnace has a refractory protection on the tubing to withstand erosion and corrosion. Higher are the fuel feeding spots and ignition burners. Following the flue gas path, the next is the superheater section coloured red. A typical approach is to put superheaters on the top of or right after the furnace as the superheated steam has the highest required end temperature. Depending on the boiler solution there might be evaporative screen tubing before the superheaters. The purpose of the screen tubing is to gather the highest stress from the flue gases and furnace, protecting the more valuable superheater tubing. The first back pass has economizers coloured light blue and combustion air preheaters coloured light grey. With nowadays technology, the boiler configuration can be a bit more complicated as the efficiency is aimed to be as high as possible. Another driving trend is to make the boiler as compact as possible. These factors affect the whole construction of the boiler and new innovative placements and designs for heat transfer surfaces must be implemented. Possible emission reduction systems also can take a lot of room from the flue gas duct design.

7.1 Turnover package

The purpose of the turnover package is to streamline the interfaces between company departments. The package must be defined so that everyone in quality, electrification, installation, and commissioning knows what is required for this system to accomplish the turnover phase. The turnover package is a document collection of every department's necessary papers. The package shall be filled during erection and the required documents should be ready when the turnover phase begins.

Documents include pressure test log sheets, electrification measurement details, required system tests, and much more. Turnover packages are aimed at being as light as possible while keeping everything necessary intact. The turnover package is not tied to a cold commissioning or a hot commissioning phase; its purpose is to implement enough data between departments.

This case study focused on creating the turnover packages. Documentation inside the packages is not made, but the interfaces between systems are determined. It began by examining earlier SFW projects and comparing them to this project's scope. Examining earlier projects is a good idea when the project structure is similar. If not carefully considered, possible errors can easily be transferred to the new project. This case contained process parts that had not been delivered earlier, so innovation had to be implanted in those parts.

The turnover packages were divided based on KKS system codes. The plant scope includes ~130 different codes. The division was completed by going through the PI&Ds and finding the system codes related to each other from the commissioning perspective. System-based thinking was used as the approach. For example, the previously mentioned cooling water system PG was examined to see where it is used and whether it needs partial commissioning. The cooling water network, in this case, is split into two smaller networks with different operational temperatures. This separated the cooling water system into two smaller turnover packages.

This work cannot show process diagrams since they contain confidential data. The main idea behind every turnover package is explained as the package is presented. After the presentation, the results are analysed. The aim is to divide the systems based on KKS's system classification level "AAA"; if necessary, the numbering code elements of systems and sections of the plant can be used "AAANN." The created COMOS tool will be used to input turnover packages into SFW's database.

7.2 Scope of delivery

As discussed, one very essential factor in the project is the scope. Scope determines the areas of responsibility for the supplier. This project's scope includes a steam boiler with its auxiliary systems, a flue gas cleaning plant, and a water treatment facility. A simplified view of the scope can be seen below.

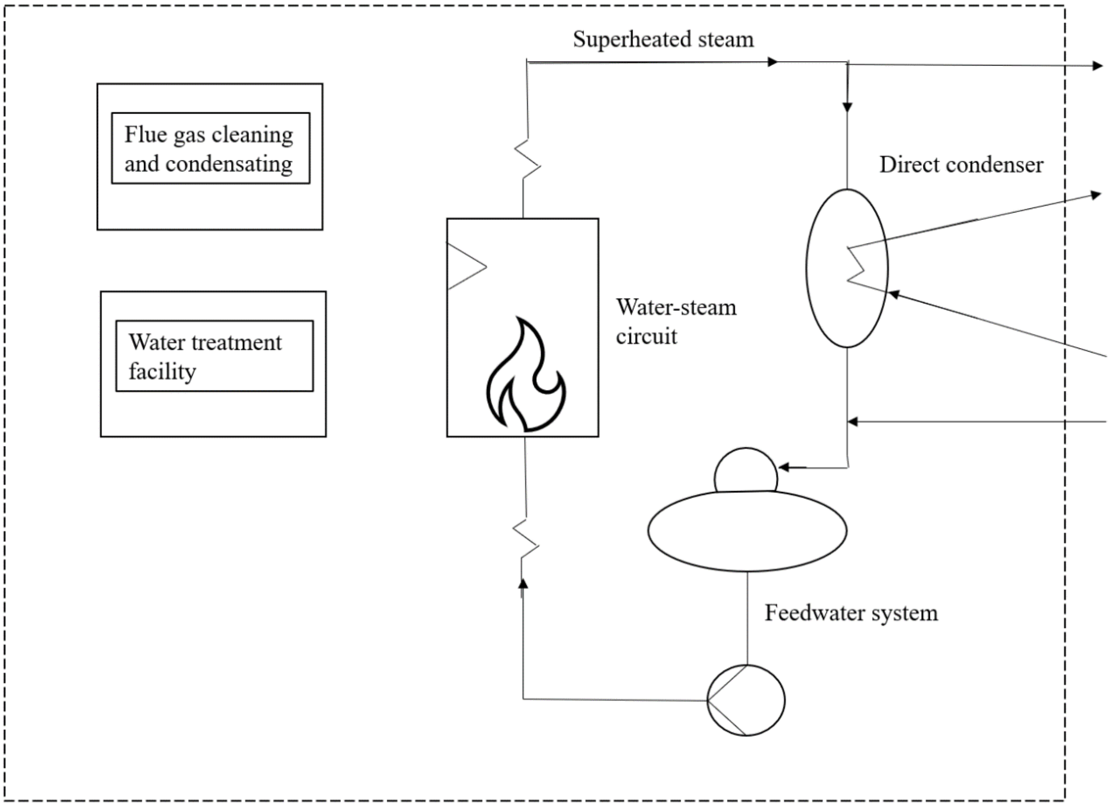


Figure 22. Simplified view of the scope of delivery.

With a scope this large, the number of turnover packages easily becomes inefficiently large. It is important to know how to link different commissioning processes to each other to keep the number of packages at a reasonable amount. For a scope this size, a reasonable amount is around twenty to thirty packages. Reducing the number of packages rationalizes the project documentation.

7.3 Results

Creating and analysing the turnover packages was one of the most time-consuming parts of this thesis. It included going through every system of the project scope and then examining their cold commissioning dependency on each other. Basic thoughts behind system-based thinking were shown earlier. Here, the results of applying system-based thinking are shown, and the thoughts behind chosen options are reviewed. Turnover packages are examined one by one, and the findings are concluded. Notably, commissioning can be done for multiple different systems at the same time. The table below presents the created turnover packages divided in six main categories.

Table 8. Turnover packages.

Combustion air and flue gas systems	**Furnace systems**	**Water and steam systems**	**Flue gas treatment systems**	**Auxiliary systems**	**HVAC and firewater systems**
Combustion air	Solid fuel	Water-steam circuit	Fly ash	Compressed air	HVAC
Flue gas	Combustion	Blowdown	Ammonia to the boiler, SCR	Startup fuel	Firewater
	Bed material	Feedwater	Flue gas dust removal and additives	Soot blowing	
	Startup-burners	High-pressure steam	Flue gas condenser	City water	
	Bottom ash	Auxiliary steam	Flue gas condensate treatment	Make-up water	
		Main condensate		District heat	
		Chemical feeding		CCW cold	
		Sample station		CCW hot	

Turnover packages were divided into the same categories as in the commissioning planning section. There are more packages here than the systems considered earlier. Every scope is different and this one is rather big. Unknown systems can be seen that have not been discussed before. These systems will be presented in the package analysis section.

7.4 Priority analysis

Prioritizing the commissioning packages is not straightforward, and it can change on the site if problems occur. Commissioning is also usually done for multiple systems simultaneously to save time. Here the possible prioritization options are discussed. These turnover packages are prioritized using the same method as presented earlier, by ranking their priority from I to IV. This is a listing of the systems in one typical commissioning priority order. The commissioning manager of the site will decide the final commissioning order. The results are in the table below.

Table 9. Turnover packages prioritized.

Priority I	Priority II	Priority III	Priority IV
Firewater	Startup-burners	Sample station	Ammonia to boiler
City water	Startup-fuels	Bed material	Main condensate
Make-up water	Flue gas	District heat	
CCW cold	Combustion air	Soot blowing	
HVAC	Flue gas condenser	Solid fuel	
Compressed air	Combustion system	Water-steam circuit	
CCW hot	Flue gas dust removal and additives	High-pressure steam	
Flue gas condensate treatment	Fly ash	Bottom ash	
	Auxiliary steam		
	Blowdown		
	Chemical feeding		
	Feedwater		

In priority on this plant are the traditional system complexes: firewater, water systems, cooling, and compressed air. Commissioning's interest is to test combustion fans, hot commission feedwater tank, and get the first fire out efficiently. This can be seen in the prioritization choices. Turnover packages are presented individually to review the choices behind system choices and define their importance.

Once the traditional system complexes are tested, the focus moves on to allow fan testing. Commissioning of combustion fans interferes with other systems that need to be noted in the schedule:

1. Flue gas condenser
2. Soot blowing
3. Bag filter.

At the beginning of fan testing, the commissioning organization's focus narrows to testing the fans. Depending on the number of site personnel, other commissioning activities might completely stop during this phase.

Another important milestone is the hot commissioning of the auxiliary steam system and feedwater tank. They also gather focus when heat and pressure are applied for the first time. Many checks are done to confirm, for instance, the thermal movements. When new equipment is warmed for the first time, a cautious approach must be taken to confirm that piping and tanks move as planned.

7.5 Package analysis

Turnover packages contain the KKS codes included in the package. A complete KKS sheet explaining every code is not sufficient to present for the sake of simplicity. In the table below are the first letters explained to give an understanding of where the KKSs are related:

Table 10. KKS-code explanations (VGB 2018, 83).

KKS	Meaning
E	Conventional fuel supply and residues disposal
G	Water supply and disposal
H	Conventional heat generation
L	Steam, water, and gas cycles
M	Main machine sets
N	Process energy/fluid supply for external users
P	Cooling water systems
Q	Auxiliary systems
S	Ancillary systems

The relativity of every turnover package is explained in the function section of the package. Turnover packages are constructed as follows: with bolded text is the package name, then from left to right are the KKS systems included in the considered package, dependency, function, and priority. KKS codes in this case study are project-specific codes. The dependency section states if the considered package's cold commissioning start is dependent on other systems. It only focuses on the beginning of cold commissioning; hot commissioning is not considered in this cases dependency analysis.

The function parameter states what systems or functionalities are included in the package. It also works as an explanation for the KKS codes. Priority numbering states the package's commissioning order. This package consideration only focuses on power plant systems and stays out of electrification.

The firewater package (Table 11) includes the firewater ring network that supplies the extinguishing cabinets. Firewater commissioning depends on the client, as the network's water supply is outside SFW's scope. Firewater network commissioning considers flushing the line and bleeding it for operation. Cold commissioning can be done in a day or two. The firewater network is always pressurized and ready for operation in an emergency.

Table 11. Turnover package for fire water system.

Firewater			
KKS included	Dependency	Function	Priority
SGA	Firewater (client).	Firewater network, supplying extinguishing cabinets.	I

City water (Table 12) is a base product for this plant's water treatment facility. Purified water is required for flushing and filling of other systems, for example, following closed cooling water. City water comes from the client's side. SFW's scope is piping and water delivery to other systems, such as the mentioned water treatment unit, emergency cooling, and emergency showers. Commissioning of city water system allows the commissioning of make-up water system.

Table 12. Turnover package for city water.

City water			
KKS included	Dependency	Function	Importance
GAC, GHE, GKG	City water (client).	City water to water treatment plants, emergency showers.	I

Make-up water (Table 13) depends on city water as it is used as a base product for purifying. The considered plant uses reverse osmosis as its water-cleaning technology. This package includes the water treatment facility and demineralized water distribution systems. There are many users for make-up water such as feedwater tank and cooling networks. It is also used in the flushing and pressure testing of many systems. Make-up water is required for closed cooling water networks commissioning.

Table 13. Turnover package for the make-up water plant.

Make-up water			
KKS included	Dependency	Function	Priority
GCB, GCD, GCF, GCR, GCK, GCL, GHC, GHL, GHM, GHP, GHQ	City water.	Reverse osmosis, filters, and distribution to end users. For example, cooling networks and feedwater tank.	I

CCW cold (Table 14) is cold cooling water. In this package the system classification level was insufficient, and the two numbers had to be added. This plant has two separate cooling networks with different operational temperatures and heat sinks. Cold cooling water is cooled via lake water supplied from the client's side. The secondary lake water circuit must run for the cooling network to operate. Commissioning can be started earlier with line flushing and pump testing if make-up water is available. CCW cold is used for HVAC, air compressors, feedwater pumps, sample station, and steam turbine cooling. HVAC means heating, ventilation, and air conditioning. This package includes the discussed subdivision of systems and section of plant which means three letters and two numbers. This is caused by the CCW hot presented later, both CCW systems share the same system classification codes.

Table 14. Turnover package for cold cooling water.

CCW cold			
KKS included	Dependency	Function	Priority
PAB, PGA, PGB, PGC10, PGC20, PGD10, PGD20, PGJ	Make-up water, lake water on secondary circuit (client).	Cold cooling water. Cooling of HVAC, compressors, steam turbine, feedwater pumps, and sample station.	I

HVAC (Table 15) again contains a lot of system codes. HVAC is required to be commissioned early since the electrical cabinets start producing heat once energized and require cooling. HVAC is usually commissioned in stages, in the first stage only the electrical building ventilation is taken online. This is done so since there is still a lot of erection work ongoing and increased airflow makes welding harder and installation rubbish spreads easier.

Table 15. Turnover package for heating, ventilation, and air conditioning.

HVAC			
KKS included	Dependency	Function	Priority
SAE, SAF, SAH, SBA, SBB, SBC, SBD, SBE, SBF, SBG, SBH	HVAC cooling network, cooling lake water (client), district heat (client).	Cooling and heating. Air distribution. Partial commissioning in an early stage.	I

Compressed air package (Table 16) contains pressurized air generation and distribution. It is typical for the power plant to have separate networks for so-called “work air” and instrument air. In this case, QE refers to work air, and QF to instrument air. Dependency is cooling for the compressor; this plant has water-cooled compressors. Priority is marked as I; it is required to be cold commissioned and ready for operation after the cold cooling water is in service. If the plant can use pressurized air from another supply, the pressurized air piping network can be commissioned earlier. This also allows the new compressors to be left on standby after testing. Ongoing installation works are dusty; if the machine takes its work air from the same room, the filters must be changed often.

Table 16. Turnover package for compressed air.

Compressed air			
KKS included	Dependency	Function	Priority
QE, QF	CCW cold.	Pressurized air and instrument air production and distribution.	I

The CCW hot (Table 17) is used for places that do not require as cool water as the ones mentioned earlier. Hot cooling water transfers heat to returning district heat network water. In new boilers, the heat recovery is advanced, and waste heat is gathered as well as possible. Hot cooling water is vital for boiler operation. Bottom ash screws have interlocks on cooling, if CCW hot is not running the bed cannot be removed from the boiler. Some heat can be recovered in the sample station by cooling the sample with CCW hot and then with CCW cold. Analyzers require cool water for an accurate reading.

Table 17. Turnover package for hot cooling water.

CCW hot			
KKS included	Dependency	Function	Priority
PGC30, PGC40, PGD30, PGD40, PGE, PGF, PGJ	Make-up water, district heating (client).	Bottom ash screws cooling, continuous blowdown cooling, main condensate cooling, sample station cooling.	I

Flue gas condensate treatment (Table 18) can be commissioned when city water is available. Condensate treatment cleans the impurities to a level that the condensate can then be considered as city water. UF stands for ultra-filter, and it is used for wastewater purification (Segneanu et al. 2013, 70).

Condensate treatment has an interface with make-up water preparation; once the condensate is cleaned it is fed to the make-up water generation tank. This approach is typical in a modern flue gas thermal energy capture plant. Configuring the process this way leads to smaller water consumption of the plant – once the boiler is running the make-up water is created from the moisture of combusted fuel.

Table 18. Turnover package for flue gas condensate treatment.

Flue gas condensate treatment			
KKS included	Dependency	Function	Priority
GNB, GNF, GNJ, GNK, GNN	City water.	Prefilters from UF, RO for condensate, condensate cooling, condensate piping, heavy metal filters, and resin filling for them.	I

Startup-burner package (Table 19) contains the burners and their auxiliaries. In this boiler, the startup-burners are operated with light oil. They depend on the burner operation air and the atomizing air for the oil. Burners are also cooled with compressed air. Startup-burners are important to get tested early as the cold commissioning takes weeks.

Table 19. Turnover package for startup-burners.

Startup-burners			
KKS included	Dependency	Function	Priority
HJA, HJN, HJQ	Compressed air.	Heating the furnace.	II

The startup-fuels package (Table 20) contains the fuel supply system to startup-burners and ignition gas for them. Since natural gas is unavailable the ignition gas is brought from an external tank. Control valves are pneumatic and require compressed air.

Table 20. Turnover package for startup-fuels.

Startup-fuels			
KKS included	Dependency	Function	Priority
HJF, HJG	Compressed air.	Fuels for startup burners. Ignition gas and oil.	II

The flue gas package (Table 21) contains the flue gas fan, recirculation gas fan, and emission monitoring systems. Flue gas fan commissioning allows the commissioning of combustion air system. While commissioning the first systems, the installation has time to install the final ducting and mount the fans in place. The furnace inner works should also be finished.

Table 21. Turnover package for flue gas system

Flue gas			
KKS included	Dependency	Function	Priority
HNA, HNC, HNE, HNF, HNG	-	Flue gas fan, recirculation gas fan, emission monitoring	II

Combustion air package (Table 22) contains ducting and fans. Fans can be tested once the flue gas fan is functional. Combustion air fan operation requires a flue gas fan to protect the furnace from overpressure. Furnace combustion pressure design depends on the boiler, but pressurizing the furnace is an unwanted phenomenon in normal combustion. During fan operation, the flue gas condenser cannot be tested. The condenser is put in the same priority category; the commissioning of these complexes needs to be timed so that they do not interfere with each other.

Table 22. Turnover package for combustion air.

Combustion air			
KKS included	Dependency	Function	Priority
HHS, HHW, HJL, HLA, HLB, HLE, HLL	Flue gas.	Combustion air distribution systems, air humidifier, sealant air for fuel feeding, and combustion air for startup burners.	II

The flue gas condenser package (Table 23) contains condenser, reject water feeding and emergency cooling. Condenser will have to be running when there is a fire in the boiler; before the first fire, the condenser must be cold commissioned and tested. Flue gas scrubbing units often use plastics inside that will melt if water is not circulating when the boiler is running. Reject water from the condenser means impurities gathered from the flue gas condenser will be injected back into the furnace to be combusted again. This way the harmful chemicals can be destroyed. Condenser uses firewater to fill its tanks before starting.

Table 23. Turnover package for flue gas condenser.

Flue gas condenser			
KKS included	Dependency	Function	Priority
HHJ, HTD, HTQ	Firewater.	Reject water feeding from flue gas condenser, condenser, and condenser emergency cooling.	II

The combustion system (Table 24) includes measurements of the furnace and flue gas ducts. When the fans are tested, these measurements should be online to indicate the pressure levels on the furnace, air box, and flue gas ducts. Compressed air is needed for the measurements.

Table 24. Turnover package for combustion system.

Combustion system			
KKS included	Dependency	Function	Priority
HHA	Compressed air.	Combustion system, furnace measurements.	II

Flue gas dust removal and additives (Table 25) contains a fabric filter, and additive feeding systems. The fabric filter removes flue gas dust. The plant feeds active carbon and sodium bicarbonate to flue gases for emission reduction purposes. Filter bag installation takes time, and during this period, fans cannot be tested. Fabric filter needs compressed air for cleaning pulses of the bags.

Table 25. Turnover package for flue gas dust removal and additives.

Flue gas dust removal and additives			
KKS included	Dependency	Function	Priority
HTE, HTC, HTJ	Compressed air.	Fabric filter, active carbon, sodium bicarbonate.	II

The fly ash system (Table 26) must be online once the fabric filter is precoated. Using a separate suction device to clean the external precoat powder away from the ash transmitters is a good practice before taking them into operation. Fly ash transmitters should send empty deliveries for a week or two before starting the boiler. At this time, the pipeline will completely dry from possible condensation water. Water and fine ash are not a good combination and will quickly cause blockages. Compressed air is used for the transmitters. Fly ash silos do have a wet discharge option that needs firewater.

Table 26. Turnover package for fly ash.

Fly ash			
KKS included	Dependency	Function	Priority
ET, HDC	Compressed air, firewater.	Fly ash removal, conveying, and storage. First back pass ash recirculation.	II

Auxiliary steam system (Table 27) cold commissioning consists of instrument and device testing. Auxiliary steam hot commissioning is required for feedwater tank hot commissioning. Before using the steam network, it must be thoroughly cleaned; this takes time. SCAH stands for steam coil air heater, which is used for combustion air preheating. A good practice is to have auxiliary steam blowouts before taking it online, this is why external steam is marked as a dependency.

Table 27. Turnover package for auxiliary steam.

Auxiliary steam			
KKS included	Dependency	Function	Priority
LBD, LBG, LCN, SGH, HLC10	External steam (client).	Auxiliary steam + auxiliary condensate, extinguishing steam, SCAH.	II

Blowdown system (Table 28) consists of continuous blowdown (CBD), blowdown, bleeding, and draining of the boiler. Blowdown is a wastewater system for the boiler and its auxiliary circuits. CBD comes from steam drum; its purpose is to remove impurities from the boiler water. The blowdown water is hot and requires cooling. Firewater is used for blowdown-tank cooling and must be tested before hot commissioning of the system.

Table 28. Turnover package for blowdown.

Blowdown			
KKS included	Dependency	Function	Priority
LCL, LCQ	Firewater.	Boiler blowdown system.	II

A chemical feeding system (Table 29) adjusts the boiler's water chemistry. The water treatment systems differ depending on the boiler. In this boiler, the chemicals are adjusted straight to the feedwater tank. Chemicals must be online before taking water into the feedwater tank. Chemical feeding units need make-up water for adjust the concentrations of the chemical solutions.

Table 29. Turnover package for chemical feeding.

Chemical feeding			
KKS included	Dependency	Function	Priority
QCA, QCB	Make-up water.	Boiler water treatment chemicals.	II

The turnover package for feedwater (Table 30) contains the feedwater tank, pumps, piping, and a WCAH. In this plant combustion air is heated via feedwater, this heat exchanger is called water-cooled air heater. Cold commissioning of feedwater tanks consists of testing valves and instruments. Before the man door hatch is closed and the hot commissioning is started the tank should be fully decreased to help the water chemistry reach sufficient levels.

Table 30. Turnover package for feedwater.

Feedwater			
KKS included	Dependency	Function	Priority
LAA, LAB, LAC, LAD, LAE, LAF, LAY, HLC01	Make-up water.	Feedwater tank, pumps, pressure piping, control, and protection equipment, WCAH.	II

The sample station (Table 31) will be commissioned in parts. The feedwater sample line must be finished before hot commissioning the feedwater tank. Sample station cooling circulation must be flushed along with the rest to remove the impurities.

Table 31. Turnover package for sample station.

Sample station			
KKS included	Dependency	Function	Priority
QUA, QUB, QUC, QUD, QUG, QUH, QUU	CCW cold, CCW hot.	Water quality analyzation from different parts of the boiler process.	III

The bed material system (Table 32) is dependent on compressed air. Bed material is required for the boiler magnetite film run, but refractory curing should be started without it.

Table 32. Turnover package for bed material system.

Bed material system			
KKS included	Dependency	Function	Priority
HHH	Compressed air.	Bed material feeding to the furnace.	III

District heat package (Table 33) contains a direct condenser and district heat circulation for HVAC. The first steam to direct condenser will be done after the steam blowing of the boiler. The direct condenser must be flushed properly beforehand. Client’s district heat network is used for the condenser and HVAC systems.

Table 33. Turnover package for district heat.

District heat			
KKS included	Dependency	Function	Priority
NDA, NDB, NDC, NDD	Client.	Heat transfer to client’s district heat network, HVAC heating.	III

Soot blowing package (Table 34) contains soot blowers and their auxiliaries. Soot blowers must be cold commissioned when the flue gas duct hatches are still open. Cold commissioning considers checking the functionality of the soot blower from the inside. This means that they cannot be tested at the same time with blowers. They can be tested before or after, in tight spots even in the evening hours after fan testing can be considered. Cold commissioning is quick, limit switches are set, thermal allowances are adjusted, and equipment is driven from the home limit to the outer limit and back. Limit switches are used in valves and moving equipment to tell DCS when to stop driving equipment and turn them around. Soot blowing cold commissioning requires compressed air.

Table 34. Turnover package for soot blowing.

Soot blowing			
KKS included	Dependency	Function	Priority
HCB	Compressed air.	Cleaning flue gas ducts, and steam soot blowers.	III

Solid fuel feeding package (Table 35) contains the feeding systems for biomass and pellet. Cold commissioning of solid fuel feeding is not dependent on anything in this plant. For scheduling purposes solid fuel feeding can be kept as a backup system for testing if the original schedule does not hold. Solid fuels in this plant are biomass and pellets. Both fuels have separate silos and feeding devices. Fire extinguishing of biomass feeding is done by extinguishing steam. For the pellet, the fire protection is executed with fire water. Both fire protection systems must be hot tested before the solid fuel-feeding hot commissioning can begin.

Table 35. Turnover package for solid fuel.

Solid fuel			
KKS included	Dependency	Function	Priority
HHE, HHK, HHV	-	Biomass feeding, pellet feeding, lubrication units.	III

Water-steam circuit (Table 36) contains economizer, evaporator, high pressure super heaters and condensate removal. From the boiler provider's point of view, the water-steam circuit is the most familiar system to commission. For mechanical completion, the pressure frame must complete pressure testing. In cold commissioning, the boiler is filled for the first time with water from the feedwater tank. Chemical cleaning and steam blowing are also considered cold commissioning. Hot commissioning begins after restoration after steam blowing.

Table 36. Turnover package for the water-steam circuit.

Water-steam circuit			
KKS included	Dependency	Function	Priority
HAC, HAD, HAH, LCL, LCQ	Feedwater.	Economizer, evaporator, high-pressure superheaters, condensate removal.	III

High-pressure steam package (Table 37) starts where the water-steam circuit ends, after the last superheater. High-pressure steam cold commissioning shakes hands with the water-steam circuit. Cold commissioning considers testing of safety valves and reduction stations. The startup valve system is used in the steam steam-blowing procedure to adjust the boiler pressure before starting the steam-blowing.

Table 37. Turnover package for high-pressure steam.

High-pressure steam			
KKS included	Dependency	Function	Priority
LBA, LBF, LBH, LBQ, LBU, LBY, MA, MK	-	High-pressure piping, reduction stations, startup valve system, HP-preheater steam, safety valve exhausts, safety valves + their control unit, Steam to turbine auxiliaries, generator.	III

Bottom ash system (Table 38) contains bottoms ash removal and recirculation. By recirculating part of the bottom ash, the usage of fresh bed material can be decreased. Bottom ash is filtered for bigger impurities, for example, metal particles before sending it back to the furnace. Cold commissioning considers flushing the cooling lines in the screws, rotation testing, and interlock testing. This turnover package considers bottom ash removal sand recirculation systems. Bottom ash screws are cooled with hot closed cooling water.

Table 38. Turnover package for bottom ash.

Bottom ash			
KKS included	Dependency	Function	Priority
HDA, HDB	CCW hot.	Bottom ash removal and recirculation.	III

The main condensate system (Table 39) must be flushed and cold commissioned before the completion of the steam blowing of the boiler. Hot commissioning of the condensate system starts after the boiler is restored from steam blowing.

Table 39. Turnover package for main condensate.

Main condensate			
KKS included	Dependency	Function	Priority
LCA, LCB, LCH	-	Main steam condensate from the direct condenser and steam turbine, high-pressure preheater condensate.	IV

The SCR system (Table 40) uses ammonia water as a catalyst. A SCR system is used for emission control. As mentioned earlier, chemical equipment must be commissioned with extra care. This package contains the ammonia storage tank, feeding system, spraying system and a flue gas circulation system.

Table 40. Turnover package for ammonia to boiler, SCR.

Ammonia to boiler, SCR			
KKS included	Dependency	Function	Priority
HSD, HSJ, HSK	Compressed air, make-up water.	Ammonia storage tank, ammonia feeding to chemical water treatment, ammonia spraying to flue gases, flue gas circulating system.	IV

The number of packages realizes the extent of this project's scope. Even with careful consideration, a total of thirty packages were created. Some detailed information from each package was presented. Explaining the whole commissioning process is a much broader subject. The turnover package creation was time-consuming as it involved digging through the whole process structure of the plant. The cold commissioning dependencies differ a little compared to the ones presented earlier. The dependencies change with every project, but a particular main principle will hold. While forming the packages, the data was inputted to the developed COMOS tool. In the future, standardized turnover package relations could be implemented in the product structure. There could also be a preliminary version of the system dependencies for commissioning.

7.6 Dependency analysis

The cold commissioning dependencies are examined. Hot commissioning dependencies are excluded since analysing their prioritization would require an insufficiently large examination. In this work, the main scope was to create the turnover packages. For cold commissioning, the dependencies are similar to those mentioned in the commissioning planning chapter with some exceptions, for example, compressed air system is water cooled. Cold commissioning dependencies of turnover packages are below.

Table 41. Dependency analysis for cold commissioning of turnover packages.

System	Dependency
Firewater	Firewater (client).
City water	City water (client).
Make-up water	City water.
CCW cold	Make-up water, lake water on secondary circuit (client).
HVAC	HVAC cooling network, cooling lake water (client), district heat (client).
Compressed air	CCW cold.
CCW hot	Make-up water, district heat (client).
Flue gas condensate treatment	City water.
Startup-burners	Compressed air.
Startup-fuels	Compressed air.
Flue gas	-
Combustion air	Flue gas.
Flue gas condenser	Firewater.
Combustion system	Compressed air.
Flue gas dust removal and additives	Compressed air.
Fly ash	Compressed air, firewater.
Auxiliary steam	External steam (client).
Blowdown	Firewater.
Chemical feeding	Make-up water.
Feedwater	Make-up water.
Sample station	CCW cold, CCW hot.
Bed material system	Compressed air.
District heat	Client.
Soot blowing	Compressed air.
Solid fuel	-
Water-steam circuit	Feedwater.
High-pressure steam	-
Bottom ash	CCW hot.
Main condensate	-
Ammonia to boiler, SCR	Compressed air, make-up water.

There are a couple of systems standing out clearly. Below is a graph illustrating the dependencies.

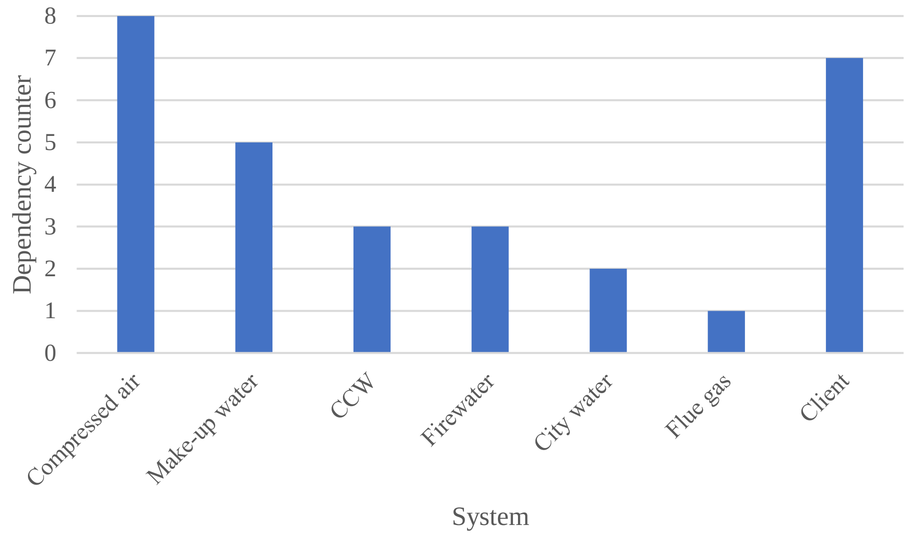


Figure 23. Turnover packages dependency analysis.

Compressed air and make-up water are the main systems that hold back other systems' cold commissioning. Notable is that these numbers only include the direct impact on cold commissioning via devices requiring these substances to operate. In the real world, the amount is even more significant considering earlier facts about the importance of blowing and flushing. The client has a notable effect on the system cold-commissioning schedule. It is essential to emphasize the presented requirements during the erection phase of the project to ensure smooth cold commissioning.

8 Conclusions and future

This thesis considered steam boiler commissioning and commissioning planning. The research was limited to fluidized bed boiler commissioning. The basics behind fluidized bed technology, KKS structure, and project planning were discussed. The commissioning and commissioning planning sections examined the principles of fluidized bed boiler commissioning and how the different systems are prioritized.

The research section added a new attribute to the Siemens COMOS environment. The attribute's scope was to streamline data usage in the commissioning planning phase. This scope was achieved, and the new attribute makes the planning process more accessible by allowing data inheritance. This functionality can be exploited during the project offering and executing phases.

The case section worked as a test environment for the new attribute. Turnover packages for the plant were created, and the new attribute was used to input the data to SFW's project structure. The packages were formed according to the principles stated in earlier chapters. The data implementation went well, and the attribute worked as planned. Even with little experience with COMOS, the attribute was easy to use. Once the commissioning groups are specified in the project structure, they do not need manual updating, even if new equipment is added to the systems later. Based on this project reference, the attribute can be easily applied to new SFW solutions, streamlining the commissioning planning process. This thesis is a good test report for SFW's future commissioning planning development, where new products must be considered.

Multiple people can work on the same project simultaneously using separate working layers; this function allows people to examine unfinished work before publication. Sometimes, this can help to see in which direction objects are developing. The development of this function and possible sister functions will continue after this thesis. The next step for this tool is to implement the base commissioning group assumptions to the SFW's product structure, which can be automatically inherited for a new project. Inheriting the data and future commissioning group assumptions will help the commissioning planning as new systems are unfamiliar.

The data attribute can be utilized in other commissioning activities, such as SFW's Circular Carbon solutions. After this work, the basic structure for commissioning grouping can be implemented in SFW's product structure. At the beginning of a new project, every device already has a determined commissioning group and only needs the planner's verification.

The possibility of using data inheriting inside COMOS has not been explored in this scale earlier. The inheriting function could be applied to other cross-departmental functions, such as quality control and procurement. Having a joint base for source data simplifies data harvesting as one does not need to use hours to find the correct database. Increased user groups for COMOS should be considered inside SFW for this exact reason.

In the future, boiler erection and commissioning planning procedures could be developed using sector-based thinking. These findings create a reasonable basis for implementing the commissioning planning data into SFW's system structure. This will make the commissioning planning more straightforward, as preliminary assumptions on prioritizing and planning the systems can be printed with a press of a button.

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