DEA & EESD
Energy Partnership Programme
between Viet Nam and Denmark

Technology catalogue for Energy Efficient Boilers in the Vietnamese industry

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Viegand Maagøe

Aim and contents of catalogue

The overall aim of the catalogue is to describe solutions and measures to address when planning and purchasing new industrial boilers or when planning to rehabilitate existing boiler and heating systems.

The catalogue aims at creating a broad understanding of efficiency questions for industrial boiler systems in the wider context of the heat supply system, such as the heat demand, distribution system losses and feed water treatment.

The catalogue further describes a recommended workflow to address these questions to reach a detailed understanding of how to reduce TCO (Total costs of ownership).

Finally, aspects of CO_2-reductions are also included due to the fact that more and more international clients ask for carbon neutrality for Scope 1 and Scope 2-emissions[1]. Therefore, phasing out of coal and reduce the use of other fossil fuel boilers will be an important strategic question for many Vietnamese companies already in the near future.

The catalogue has the following contents:

- Section 1: Improving energy efficiency of industrial boilers
- Section 2: Selection and equipment of a new boiler
- Section 3: Procurement of new boiler installations

In annexes of the catalogue, more detailed information can be found:

- Annex 1: Check-list for energy efficiency of oil and gas-boiler installations
- Annex 2: Check-list for energy efficiency of solid fuel-boiler installations
- Annex 3: Selected national and international suppliers of oil- and gas-boilers
- Annex 4: Selected national and international suppliers of solid fuel boilers (biomass)

The catalogue further describes a number of cases for rehabilitating boiler installations as well as the business case for replacing old in-efficient fossil fuel boilers with new high-efficiency solid fuel boilers.

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[1] Scope 1 and 2-emissions is defined as emissions related to the company's own combustion of fossil fuels (Scope 1) or emissions related to import of by example electricity (Scope 2), see https://ghgprotocol.org/

Contents

1 Improving energy efficiency of industrial boilers

Even though boiler installations can be designed for a very high efficiency, significant losses often occur in the operation, and often the overall efficiency of a boiler and heating system can be very low.

In Table 1 below, typical design values for efficiency of new industrial boilers are shown along with typical efficiencies observed from real-life operation.

Table 1 Examples of best practice vs. real-life efficiency of industrial heating systems

Example of boiler installation and heating system	Design target for efficiency of new installations	Observed real-life efficiencies for existing installations
Hot water boiler using natural gas	100% (with condensation)	80 – 92%
Steam boiler using coal	95%	60 – 88%
Steam boiler using biomass	95%	50 – 86%

Below, measures influencing the efficiency of the boiler itself are described.

1.1 Improve fuel quality

For biomass and coal boilers, un-combusted fuels can be a problem leading to loss of efficiency if the combustion process is not properly controlled, or if the quality of the fuel varies significantly.

Fuel quality can vary when:

- The fuel consists of different size of materials
- The fuel has varying moisture content
- If the fuel is contaminated with soil etc.

Losses due to un-combusted fuels can be as high as 10% for problematic fuels. For oil- and gas-boilers un-combusted fuels are usually not a problem, but in some cases, severe soot production can be a result of a poorly controlled combustion, see the sections below.

Table 2 Guiding data for moisture content in biomass

Moisture content deviation from design condition:	
Best practice:	0%-points
Normal:	0-10%-points
Requires action:	15-20%-points

1.2 Control combustion for higher efficiency

If the combustion process in the boiler is not properly controlled, there is a risk of increased soot production and loss of efficiency – both via fouled surfaces and via excess oxygen in the flue gasses from the boiler.

Especially boilers with manual fuel feeding are exposed to periodically large variations in excess oxygen, with irregular fuel feeding and varying air access through the fuel feeding door.

Figure 1 Example of manually fed boiler

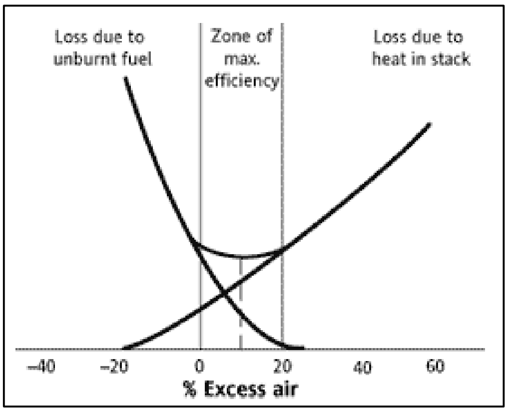
Excess of oxygen in the flue gas is essential to ensure proper combustion, but the level must not be too high. A high oxygen level increases heat loss in the stack and low oxygen level will increase fuel loss.

Overall, a continues O_2/CO_2-control system will control the combustion properly and results in efficiency gains of up to 0.5% in boiler efficiency per 1% decrease in excess O_2.[2]

Figure 2 below shows the principle of O_2-control.

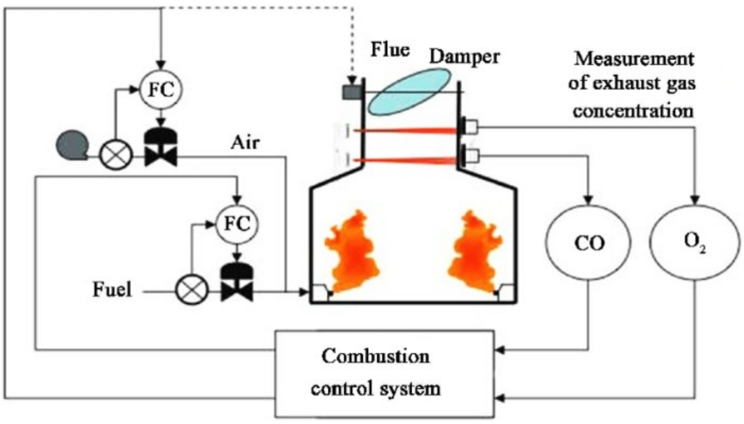
[2] *CED Engineering, https://www.cedengineering.com/userfiles/Improving%20Energy%20Efficiency%20Boilers%20R1.pdf*

Figure 2. Losses occurring by inaccurate of oxygen control



The best available technology for combustion control is a combined control system for O_2 / CO-control which monitors and regulates the mixture of gas and O_2 steplessly and momentarily according to the current O_2 / CO percent in the burner mixing chamber.

Figure 3. Principle of oxygen control



The O_2 & CO probe and temperature transmitter in the flue gas stack gives information to a module in the control system for calculation of set points sent to the regulation of fuel and air. Usually, oxygen control systems operate with pre-set parameters for fuel and O_2 volume parameters at each load step. These parameters are entered during commissioning.

Fuel	Recommended oxygen content in flue gas (volume-%)
Oil	1-3%
Gas	1-3%
Biomass	3-6%

Table 3. Design values for oxygen content in flue gases from various fuels.

In other applications with direct combustion like a spray tower or drying oven, the benefit from a combined control system for O_2 / CO is the same as for a boiler.

1.3 Install a grate in the boiler

Many solid fuel boilers are not equipped with a grate. The fuel is placed directly on the bottom of the boiler with poor conditions for mixing the combustion air with the fuel. As a result, the boiler needs to operate at a very high excess air rate in order to keep the CO levels at an acceptable level.

Upgrading existing boilers is however difficult. In some cases, a stationary grate can be retrofitted. Normally a new boiler must be considered and, in all cases, if it is, then a moving grate.

1.4 From manual to continuous fuel feeding

Boilers with manual feeding should change to automatic feeding, for example using a stoker. Fuel should be processed to become uniform enough to pass through the feeder. More uniform fuel will further increase the combustion efficiency.

This can be done by firing with wood chips instead of firing with firewood or waste wood in various sizes and shapes.

1.5 Utilization of heat in flue gases

Often, high temperatures of exhaust gases from the boilers can be measured in the stack leading to significant losses. Up to 1% efficiency can be gained for every 20 °C the temperature of the flue gas is decreased[3]. With flue gas condensation the efficiency can be improved by additionally up to 8%[4]. Table 4 below summarizes typical guiding data for flue gas temperatures.

Flue gas temperature should be as low as possible.	
Flue gas temperatures:	
Best practice:	80 °C
Normal:	120 °C
Requires action:	150 °C

Table 4. Guiding values for flue gas temperatures

Best practice will require condensation of the flue gases, which will be problematic for some fuels due to acid-content in the gas but can be solved with better materials in the heat exchangers. When installing economizers on existing boilers, the entire flue gas system, including the chimney, must be checked in relation to the acid content of the flue gas.[5]

1.5.1 Map out the flows that could be heated with flue gas heat

Hot flue gas is typically used to preheat boiler feed water as well as combustion air. But there may be other heat demands in the production facility that could be served partly from the flue gas heat.

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[3] *BREF on Energy Efficiency (February 2009), section 3.1.1.1.*

[4] *Technology Data Catalogue for Electricity and District Heating, Danish Energy Agency, Chapter 44.*

[5] *See also TCVN 8630:2019: Boilers-Energy efficiency and method for determination.*

To understand the optimal use of flue gas heat, the flows that need to be heated should be mapped out according to the below table.

Fluid	Inlet temperature °C	Outlet temperature max °C	Capacity flow MW[6]	Hot /cold
Flue gas				Hot
Feed water				Cold
Combustion air				Cold
Process water				Cold
…..				

Table 5. Example of data collection for low-temperature heat demands

From this mapping it is possible to identify which "cold" capacity flows (flows which need to be heated up) that could be heated by use of the flue gas heat.

In order to make maximum use of the flue gas heat, the temperature difference between the hot flue gas and the fluid being heated should be as little as possible.

1.5.2 Install an economizer

In Figure 4 below, the main components in an effective cooling of flue gases from a boiler are illustrated, i.e. a boiler with combustion air preheater and economizer to preheat feed water to the boiler.

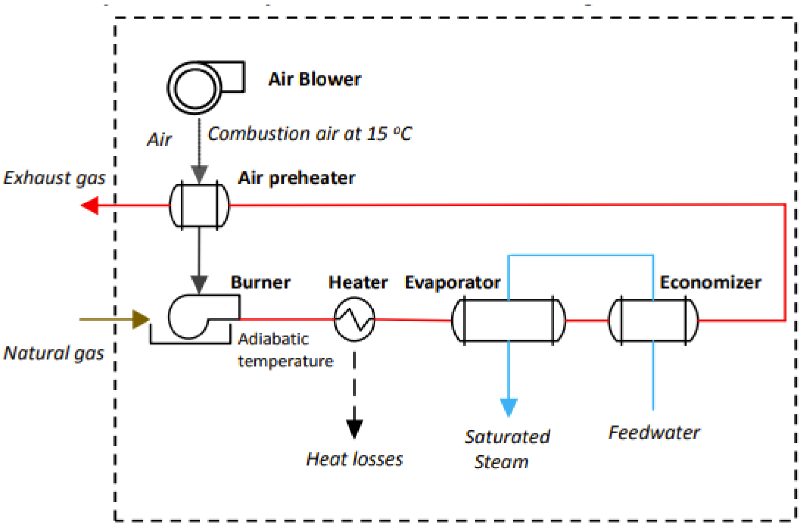

Figure 4. Main components in effective flue gas utilization

The efficiency of an economizer depends on how much it is possible to lower the flue gas temperature. The lowest possible temperature is depending on the temperature needed for heating the process fluid or feed water as well as the capacity flow.

It is normally feasible also to include a combustion air preheater on a boiler. Depending on the fuel and its contents, the acid dew point of the flue gas can limit how much the flue gas temperature can be reduced. In case of oil a high level of sulphur may set a lower limit of the flue gas temperature to 150°C. In case of gas the flue gas temperature should not exceed 50°C.

[6] *In this catalogue, the capacity unit "MW" is used – it could also be "MJ/s"*

This can set limitations for how much an economizer can cool the flue gasses.

The acid dew point can be calculated using this reference[7]. For gas boilers the design should normally result in a flue gas temperature below 50°C. For oil boilers the smokestack must be constructed with suitable corrosion resistant materials and condensate drain must be handled environmental properly.

1.5.3 Example of inclusion of air-preheater and economizer

A facility operates a boiler of 20 MW. The flue gas temperature after the boiler is 248°C. The factory needs steam at 16 bar and hot water at 80°C. In order to recover as much of the flue gas heat as possible, the flue gas heat is recovered in three steps as shown in Figure 5 below. After the three steps, the flue gas temperature is down to 47.5°C.

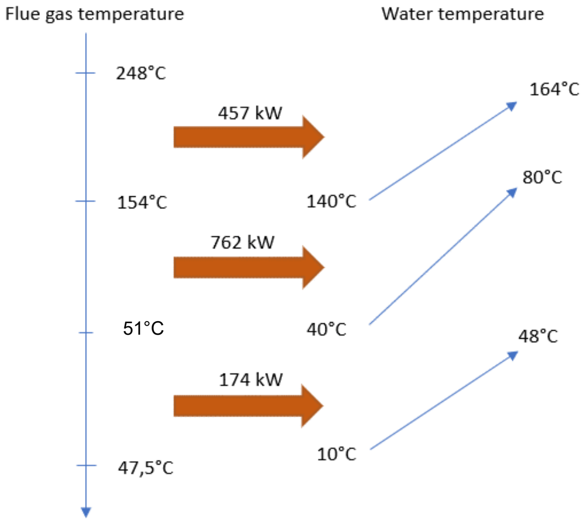

Figure 5. Example of an economizer design

As a result, 1,393 kW of heating energy is captured in the economizer, and this raises the boiler efficiency from 90.3% to 97.1%.

1.5.4 Recover humid heat from the flue gas

Additional energy can be recovered if the boiler can achieve condensation of the water in the flue gas. Condensation requires a sufficiently low temperature heat sink that can utilise this heat. Other than combustion air it could be cold process water and others.

If the hot flue gases are used for preheating of the combustion air, efficiency gains can also be achieved as higher temperatures will be reached in combustion. The efficiency may increase by up to 5%[8].
As showed in Figure 5 temperature levels depend on how the low temperature energy can be used most efficiently. Normally the preheating will lift the temperature of the combustion air to 70 – 100ºC.

1.6 Insulation standard for safety and energy efficiency

Boilers are usually delivered with insulation, but it is often seen that insulation deteriorates over time due to lack of maintenance etc.

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[7] How-to calculate the Acid Dew Point (ADP) of flue gas (heatmatrixgroup.com)

[8] *BREF on Energy Efficiency (February 2009), section 3.1.1.1 and 3.2.5.*

The losses occurring from missing insulation in boiler stations (including valves, ducts, piping etc.) can be as high as 10% of the overall heat load.

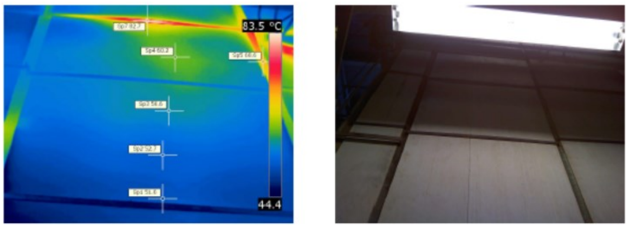
1.6.1 Ensure the boiler station is well insulated

All equipment with a temperature higher than 50°C must be insulated in a way that reduces the surface temperature of the insulation to 40°C or lower. Boilers, economizers, preheaters and other large equipment as well as piping and relevant pipe bearings are first priority, and secondary are all the manifolds, valves, steam traps, and other materials.

The energy efficiency improvement of this measure varies a lot depending on the existing level of insulation[9] etc. The losses from having large, hot uninsulated surfaces may be up to 10%[10]. Please refer to this reference for methodology of calculating heat losses from hot surfaces.

1.6.2 Example of improvement of boiler insulation

A company has two 40 MW steam boilers fired with gasoil been in operation for 20 years. A thermographic assessment was conducted. The result of the assessment showed in general many areas with too high surface temperature on the cladding:



Especially around covers, access points and instruments very high temperatures were found:

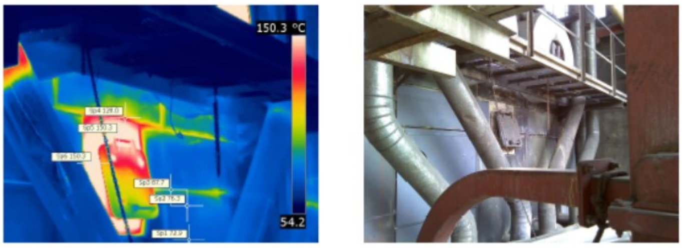


Figure 6. Thermographic pictures of heat loss in boiler station.

After the insulation was renewed, the radiation loss was reduced by 1,500 MWh per year equal to reducing the total fuel consumption by almost 1%. In other words, the total boiler efficiency was increased by 1%. In addition, the working environment in the boiler room was improved as a result of a significant lower temperature.

1.7 Reduce part-load operation

The boiler should first of all be operating with an operating point that enables good regulation and ensures high efficiency. The boiler should be designed with efficient operation in mind at different part

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[9] *https://prod-drupal-files.storage.googleapis.com/documents/resource/public/ASEAN-LCEP-Energy-efficiency-guidance-report-boilers-and-heat-distribution.pdf*

[10] *Reducing surface heat loss in steam boilers, https://www.degruyter.com/document/doi/10.1515/chem-2022-0241/html*

loads if the consumption has large peaks. If the boiler is always operating at a low part load, there will be relatively higher radiation and convection losses.

Also fluctuating load can lead to unstable combustion with soot production that fouls heat exchangers and impairs efficiencies of heat transfer.

1.7.1 Use VSD-control of blowers

Operating a steam or hot water boiler at part load requires less combustion air and thus a lower speed of the fan compared to full load operation. When the electric drive is not equipped with a frequency converter (VSD) the volume of sucked-in air is regulated by air dampers. When the drive for the air blower is equipped with a frequency converter the speed of the drive can be adjusted to the needs of the load of the steam boiler. Thus, a frequency converter saves electrical energy compared to regulating with air dampers.

1.7.2 Use damper in stack

If more than one boiler is connected to the same stack, and if a standby boiler doesn't have a damper to close the stack to minimize exhaust gas losses, extra energy will be used.

1.8 Reduce losses in deaerator

A deaerator is a device that is widely used for the removal of air and other dissolved gases from the feed water to a steam-generating boiler. Deaerators are used to reduce the oxygen, carbon dioxide and air content of the feed water and thereby minimize the risk of corrosion and erosion.

Deaerators are designed as both open and pressurized types. Open deaerators use the condensate to heat up the feed water close to 100°C, and vaporized water/-condensate will leave the deaerator and thereby a loss close to 1% of the boiler's added energy. A heat exchanger between the exhaust gases and the feed water cand be added to reduce this loss if the backpressure can be handled.

Furthermore, using open deaerators, usage of added chemicals are in need too. By using a pressurized deaerator, the loss of energy is minimal, and use of chemicals is not an issue. Furthermore, the mixed feed water and condensate will leave the deaerator with a temperature above 100°C.

1.9 Condensate return system

Many industries have a low return rate of condensate – either because of losses in the steam distribution system or because steam is injected directly for process heating or for maintaining a certain humidity in controlled areas. The losses from lost condensate are significant - for each 10% loss of steam and or condensate, the boiler efficiency is decreasing by 1%.

1.9.1 Monitor the purity of condensate return

If steam is not used directly in the product, it should be possible to get 90-100% returning to the boiler as condensate.

The most common reasons for not returning the full amount of condensate are leakages and pollution. Pollution will normally originate from leakages with product into the heating system. This can't totally be avoided as gaskets become worn out etc. and the solution is to monitor the return of useful condensate in percent of possible condensate return. It is advisable to set up a Key Performance Indicator (KPI) for this and supervise it continuously. To do so, introduction of surveillance equipment is necessary. It could be photometric or conductivity surveillance.

1.9.2 Example of condensate supervision

A producer of edible oils installed photometric surveillance on six condensate return pipes with automatic dumping to the drain in case of pollution. In combination with prompt initiation of the necessary maintenance, the utilised condensate increased from 62% to 94%. In addition, the risk of feeding the boiler with polluted condensate is significantly reduced.

1.10 Reduce losses from steam traps and venting

1.10.1 Avoid heat loss from flashing of steam

Losses in condensate occur from flashing and steam traps out of order. Condensate under pressure, which means a mix of condensate and steam, released in the condensate tank will flash off as free steam depending on the pressure difference and thereby causing a loss of energy.

To minimize this loss, re-evaporating at a lower pressure level or heat exchanging with a colder media are both ways to utilise the remaining energy instead of flashing it off.

1.10.2 Schedule supervision and maintenance of steam traps

Steam traps tend to lose their ability to separate steam and condensate. As a result, an increasing amount of steam will go with the condensate to the condensate tank, from where it will be lost to the ambient.

Unattended steam traps can be leaking steam for a long time before it is discovered as no indication is normally obvious. A regular survey of the steam traps followed up by maintenance is the preventive action to be taken[11].

Figure 7. Example of leaks from a steam distribution system

1.10.3 Example of steam trap survey

A food producing company used an external supplier to, once a year, conducting a survey of all steam traps. The average number of malfunctions was 11%. The company decided to invest in an ultrasonic meter themselves to monitor leakages and increased the frequency of survey and maintenance to every second month, which reduced the average number of malfunctions to 1%.

[11] https://www.rasmech.com/blog/steam-trap-maintenance/

1.11 Improve feedwater quality and efficiency, prevent corrosion

A good water quality is essential for a high boiler efficiency and a long service life of the equipment.

Well water shall be treated before used as feed water. Firstly, the incoming water must be analysed in order to design the water treatment plant. In many cases water treatment will consist of two processes, an ion exchange unit and a reverse osmosis unit.

The ion exchange chemical process works by removing dissolved ionic contaminants from the water, like magnesium and calcium ions.

A reverse osmosis system removes sediment and chlorine from water with a prefilter before it forces water through a semipermeable membrane to remove dissolved solids.

The following specification is a recommendation for boiler feed water in normal cases:

Water treatment plant	
Residual hardness	Max. 0.01 °dH
Conductivity	Max. 10 μS/cm (25°C)
Oxygen	Max. 0.02 mg/l
Chloride	Max. 0.5 mg/l
Sulfate	Max. 0.2 mg/l
Particles	Max. 1 mg/l

Table 6. Recommended chemical parameters for feed water to boilers

Higher water quality improves the boiler efficiency but to high demand for the water specifications will increase the costs for water treatment and an optimum must be found[12][13].

1.12 Reduce blowdown heat losses

Blowdown is necessary to remove impurities from the boiler, especially if no installation for feed water treatment is in place.

The efficiency gain from such a measure is up to 1% or more.

Install heat exchanger to recover blowdown heat

In many cases, the hot water from the blow down is led directly to the drain and a loss of 1% or more of energy consumption occurs. Some of this loss can be used in heat exchanging with fresh feed water for the boiler.

1.13 Check-lists for energy efficiency measures

In Annex 1, an overall check-list summarizing the energy efficiency measures for oil- and gas-boilers installations is attached.

In Annex 2, an overall check-list summarizing the energy efficiency measures for solid fuel boiler installations is attached.

[12] https://www.corrosionpedia.com/how-to-improve-feedwater-quality-to-prevent-boiler-corrosion/2/7317#feedwater-testing-and-quality-control
[13] See also TCVN 12728:2019: Boilers-Technical requirement of design, manufacture, installation, operation and maintenance.

2 Selection and equipment of a new boiler

Boilers used for production of steam, hot water or hot thermal oil can be based on different fuels and different boiler technologies.

This section aims at providing guidance on selection of type of boiler for a specific need. In addition, the section provides guidance on what specifications should be given to the new boiler in order to secure a high energy efficiency and a long lifetime. The section covers boilers fired by gas (natural gas, biogas or LPG), by gasoil or by solid fuels, mainly biomass.

In Annex 3 an overview of national and international suppliers of oil and gas boilers in Vietnam is attached. The list comprises suppliers that have been assessed to be able to deliver BAT-solutions (Best Available Technology), i.e. boiler installations with high energy efficiency.

2.1 Solid fuel or oil/gas fired boiler?

Solid fuels, be it coal or biomass, are considerably less expensive than oil or gas. But solid fuel boilers also come with a number of challenges, such as:

- Larger space requirements for the boilers as well as for the fuel storage and handling
- Dust
- Fire hazard
- More staff for operation and maintenance

Solid fuel boilers can be delivered as hybrid solutions enabling use of both coal and biomass as fuels.

2.2 Coal or biomass?

Whenever there is sufficient biomass available for the enterprise, either in the form of biomass waste from the production or from nearby sources, biomass tends to be the preferred option, with main benefits being low fuel costs compared to any type of fossil fuel, and potentially less environmental impact (CO_2 as well as SO_2).

Biomass can be many different types of fuels like rice husk, bagasse, straw, sawdust, wood pellets, coconut shell, cottonseeds, etc. The texture and the characteristics of the different fuels can vary substantially. The same is the case for the moist content and the acid content in the flue gas.

Biomass as a fuel is competitive with fossil fuels when there is a secure supply of the fuel at competitive prices. This is particularly the case when the industrial production involves the production of biomass waste, such as bagasse from the sugar industry or saw dust from the wood processing industry. In certain regions with ample supply of biomass resources, biomass fuel can even be available in the market at competitive prices. For other enterprises, biomass utilization is a way to minimize the carbon footprint and be an attractive supplier on the future international market focusing heavily on sustainability. See also Chapter 2.3.1.

2.3 Oil- and gas-fired boilers

Oil- and gas-boilers are either build as fire tube boilers or water tube boilers as illustrated in Figure 8 below.

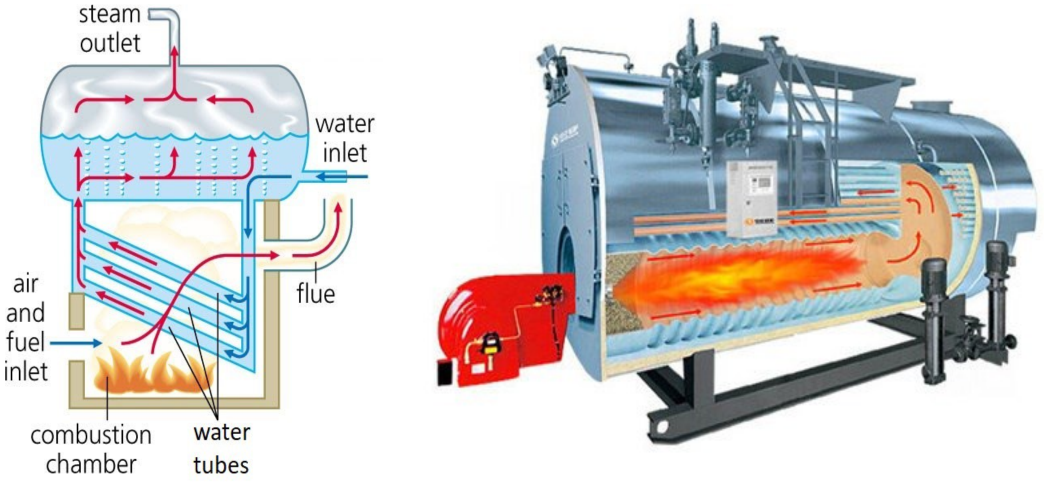

Figure 8. Schematic of a furnace producing steam or hot water. (Left) is a water tube boiler and (Right) is fire tube boiler.

Main characteristics of fire tube and water tube boilers

In Table 7 below, the two technologies illustrated above are described:

Technology	Output	Efficiency	Applications
Fire Tube Boiler The flue gases from the furnace, usually cylindrical, are conducted to flue passages, which consist of several parallel-connected tubes. The tubes run through the boiler vessel, which contains the feedwater. From the water space steam or pressurized water can be taken.	In hot water boilers the temperature normally is in the interval form 110 – 140°C. In steam applications the pressure is normally up 4 - 6 barg. Capacity from 0 - 1 MW.	70% - 85% In principle measures can be taken to lift the efficiency. Certain energy efficiency measures can be done for fire-tube boilers such as insulation, blowdown control, etc.	In applications with small and/or sessional demands. Before choosing a fire tube boiler a water tube boiler shall always be considered. In principle the technology can be used in all industries with a limited heat demand, but it is only recommended for minor sessional production.
Water Tube Boiler This boiler, usually cylindrical, can either be covered with refractory material like ceramic (dryback furnace) or be in contact with the boiler's water (wetback furnace) which significantly increases the heat-exchange surface. The end of the furnace is	The maximum temperature is (depending on the materials) up to 500°C. Superheated high pressure steam can be produced (40 – 80 barg) as well as low pressure steam and hot water.	85 – 100% (100% with condensing gas boilers). In new boilers the economizers should be designed to a maximum flue gas temperature at 50°C. The materials in the flue gas system must	A widespread used technology supplying all kind of industries with low- and high-pressure steam and/or hot water.

called the reversal chamber since the hot gases make a U-turn and are fed into the first tube-pass. At the end of the reversal chamber, the gas' temperature must be sufficiently low to avoid excessive thermal stress on the tubes. The water circulates in many parallel-connected tubes. The tubes are situated in the flue gas channel, and are heated by the flue gases, which are led from the furnace through the flue gas passage. The tubes, where water circulates, are welded together and form the furnace walls.		be resistant to the flue gas. Special attention shall be made to the sulphur content in oils.	

Table 7. Technologies applied in oil- and gas-boilers.

Both technologies can be used for steam supply and hot water supply to a facility and all energy efficiency measures described in section 2 above applies for both technologies as well.

2.4 Characteristics of different solid fuel boilers - biomass

The description of energy efficiency measures in section 1 above also applies to solid fuel boilers.

But compared to oil- and gas boilers there are a number of characteristics regarding solid fuel firing which require additional measures to be taken in order to maintain a high energy efficiency for a solid fuel boiler. The main focus of the section is on biomass boilers, but the descriptions also apply to coal fired boilers.

2.4.1 Biomass

Biomass is inhomogeneous and this gives a challenge when used for fuel in relation to:

- Physical appearance
- Chemical components
- Moister content
- Burning value

All aspects must be taken into consideration when a biomass boiler is designed. When the main fuel is selected the boiler must be optimized according to this. The boiler can be operated with comparable fuels.

Physical appearance. The fuel must be prepared for the boiler construction. This can be like:

- Firewood

- Briquettes
- Wood pellets
- Wood chips
- Dust (pulverized wood pellets or industrial residues)

This means that the fuel always shall be pretreated according to the boiler construction.

Chemical components. Some biomasses contain components that result in a very acidic flue gas or in a slag with low kindling temperature and this must be taken into account in construction and materials.

Moisture content. The boiler must be constructed according to moisture content in the biomass. This could be 10-15% for rice husk or 35-45% for wood chips. If the fuel deviate from the boiler construction, it must be pretreated to suit the boiler.

Burning value. With too much deviation in burning value of the fuel the temperatures slide away from the set point of the boiler and adjustments are necessary. In some cases, an alternative fuel is necessary for startup.

2.4.2 Main characteristics of biomass boilers

The optimal choice of boiler type depends on a wide range of parameters, such as

- The characteristics of the biomass fuel
- The required thermal output capacity
- The requirements to energy efficiency

Table 8 below describes the type of technologies applied in solid fuel boilers.

Technology	Output	Efficiency	Applications
Stoker boiler In a stoker boiler, there is a horizontal screw that transports fuel from the storage into the grate in the combustion chamber. Air is supplied either with a blower on the intake or the flue gas is sucked out.	Hot water or steam up to 10 barg and 185°C. Normally for small capacities but overall up to 5 MW heat demand	60-90 % Because this type is chosen for the low investment-projects, there will often be no equipment to increase efficiency	In applications with small and/or sessional demands. Applications with a need above 1 MW should consider other types of boilers.
Moving grate The fuel is moved forward by the grate, either a walking floor or conveyer. The combustion takes place on a grate, where the fuel is dried, degassed and burned out over several minutes. The primary air is supplied under the grate and must dry the fuel and create a sub-stoichiometric	Steam 50 – 200 barg and up to 550°C. Capacity ranges from 50 to 500 MW	90-95%	For industries with high thermal demands. In many cases it is cogeneration plants. Can also be seen in smaller power plants.

combustion - i.e. an incomplete combustion with an oxygen deficit. The remaining, over-stoichiometric combustion takes place by supplying the secondary air above the grate layer. The challenge lies in keeping the grate layer and flame front constant when the fuel and boiler load varies.			
Suspension firing At the large plants, the fuel is burned in suspension - i.e. it is pulverized, blown into the boiler and burned out while hanging in the air (suspended). It burns out almost immediately (short residence time). The air is added below the blow-in of fuel and the pipes are located higher in the flue gas section.	Steam 100 – 300 barg and up to 600ºC. Capacity ranges from 100 to 1,000 MW.	90-95%	For cogeneration in lager industries or power plants.
Fluidized bed (FB) The fluidized bed technology consists in the combustion of the particulate solid fuel in an inert material bed (usually sand or limestone), which is fluidized due to the flow of a gas. The furnace is a vertical construction with the air chamber in the bottom, the material bed in the middle and the flue gas volume in the top. Particles in the flue gas are recycled from the cyclone back into the material bed.	Medium pressure steam up to 30 barg and 500ºC. The capacity range is normally from 10 to 75 MW.	80–100% depending on the moist content and flue gas condensation. Due to the scale of FB installations, they are normally combined with a high degree of energy recapture from the flue gas.	Can be used in supplying all kind of industries with medium-pressure steam.

Circulating fluidized bed (CFB) The normal construction is a vertical furnace chamber in connection with a cyclone. The circulating bed material (sand & ash-slag) flows together with flue gas through the furnace, after which it is separated from the gas and returned back to the lower part of the furnace with cyclones. This technology provides an even combustion temperature profile, which is optimal for handling a wide variety of fuel properties, such as heating value, moisture, ash content and a number of low melting point ash components. This also ensures low primary emissions with high combustion efficiency and excellent utilization of additives for sulfur removal and other special purposes. CFB reactors are very similar to fluidized bed reactors. The difference is that the residence time of the gases and particles is different.	The capacity range is normally from 25 to 1,500 MW. The output is high pressure steam up to 175 barg and 550ºC.	85 – 100% depending on the moister content. Due to the scale of CFB installations they are normally combined with a high degree of energy recapture from the flue gas.	Can be used in supplying all kind of industries with high-pressure steam. Often low-pressure steam is made in connection with electricity generation. The technology can used for multi fuel combustion and can handle difficult fuels. In biomass recycled wood, bagasse, industrial residues etc. Fossil fuels like coal residues, bituminous coal, petro coke, asphaltenes.
Thermal gasification The gasification process is to convert solid fuel into gaseous fuel in the gasifier to supply gas for various purposes (drying, boiler, gas turbine combined cycle, etc). The thermal gasification is produced from biomaterial and the output is produced gas			Thermal gasification is mainly used for heat only or CHP plants. However, it can also be used in a firing/sintering process and in melting/casting processes if natural gas can be replaced by gasification gas. The application of gasification process is limited by the content

(N_2, H_2, CO, CO_2, CH_4 and H_2O), which then can be used to be fired directly in the processes.			of particles in the produced gas- which, however, is lower than from conventional combustion processes. With the use of bag house filters or candle filters, it is possible to remove particles and tar from the gas produced by the gasification process. However, not all can be removed which is why the process and final product might still be exposed to the particulate matters and other impurity in the producer gas and flue gas[14].

Table 8. Boiler technologies applied for solid fuel-boilers

In addition to the boiler technologies, there must be special attention to fuel feeding and flue gas cleaning. Many of the biomasses have a high moisture content and the energy used for evaporating the moisture will be lost if the moisture is not condensed and the energy recaptured. The two main obstacles using the condensation heat are the need for heat at low temperatures (hot water) and if the biomass will cause acid condensate (can be solved using Glass Reinforced Plastic (GRP) instead of steel).

In Annex 4 an overview of national and international suppliers of solid fuel-boilers in Vietnam is attached. The list comprises suppliers that have been assessed to be able to deliver BAT-solutions (Best Available Technology), i.e. boiler installations with high energy efficiency.

2.5 Hybrid boiler solutions (coal to biomass)

For new installations, it is possible to design the boilers to use both coal and biomass as fuel – so called “hybrid”-boilers.

Also, for existing solid fuel-boilers it is possible to revamp old coal boilers to use biomass if the boiler is of the commonly used moving grate-type.

Such revamping is not an easy task, and the following issues should be addressed carefully:

- Reduction of boiler capacity due to lower heating value of biomass
- Suitability of flue gas cleaning
    - Change of flue gas flow and temperature profile
    - Sufficient removal of particulate matter
- Necessity of online cleaning of radiation and convection parts of boiler should be investigated.
- Can the existing fuel feeding system support the new fuel?
- Is the combustion air sufficiently preheated?
- New fuels can require increased feed water temperature to avoid boiler back-end corrosion due to different condensation point.

[14] *Danish Energy Agency, Technology Data for Industrial process heat, 2020, Technology Data catalogue. Version number 3.*

Case study – Replacement of coal boilers with hybrid-boiler (coal and biomass)

At Hanoi Dyeing Company (Hung Yen Branch), two old fixed-grate coal boilers producing respectively 4 and 6 ton/hour of steam at 5 bars and 150°C for the manufacturing processes at the facility. The annual consumption of anthracite coal was approximately 2,800 tons.

During an energy audit, the efficiency of the boiler has been assessed to be low, as the old boiler installations lack automatic controls and operates old economizers mostly in-effective due to leaks and fouling. The efficiency of the boilers was assessed to an average of approximately 73%.

Upon recommendations from the energy audit, it was recommended to install a new 10 ton/hour fluidized hybrid-boiler (dual fuel) able to use coal as well as biomass as fuel and including several energy efficiency measures compared to the old installation:

- An efficient economizer
- Automatic oxygen control
- Air-preheater
- Improved insulation

The old and new boilers are shown below.

Figure 9. New high-efficiency hybrid boiler for use of biomass (and coal)

The efficiency of the new boiler is projected to be approximately 87% so an improvement of efficiency of 14% is achieved.

With a total investment of 6.2 billion VND and annual cost savings of 2.0 billion VND, the payback time for the investment is approximately 3 years.

The improved energy efficiency alone results in CO_2-savings of almost 1,000 ton/year, while operation of the new boiler with biomass as fuel will result in CO_2 savings of almost 8,000 ton/year.

Due to automatic controls and operation, working environment at the facility also gained significant benefits from this project.

2.6 Boiler design features

After selection of the type of boiler most suitable for the needs in question, the details of the boiler design must be established.

It is important to have the necessary numbers of measurements (temperature and pressure) through the boiler in order to monitor the temperature profile and the pressure drop e.g. across a super heater bundle indicating potential time for manual cleaning.

It is important that the boiler is equipped with necessary automatic cleaning devices like soot blowers, water spray cleaning, rappers, etc. dependent on the specific boiler design.

2.6.1 Design according to the fuel to be used

Fuel texture and characteristics are very important for the design of biomass boiler plants, hereunder parameters like:

- Moisture content and hereby the calorific value of the fuel.
- Ash content
- Content of chlorine and sulphur
- Content of critical components like potassium
- Ash melting point

If the fuel is not as the boiler is designed for, there can be incomplete combustion of the fuel and blocking of the fuel feed if the particle sizes are not as designed.

2.6.2 Steam, thermal oil or hot water?

The default choice of heat carrier in most industries is steam, or, if high process temperatures are required, thermal oil may be preferred.

Steam systems involve several losses as mentioned in section 1. Using pressurized water instead may increase the efficiency by around 15% - or even more for in-efficient distribution systems.

In case of replacement of an existing steam boiler, the heat distribution system as well as the heat exchangers need to be replaced to be operated with water instead of steam.

2.6.3 Automatic control of fuel feeding and combustion air supply

The boiler should be equipped with an automatic fuel feeding system controlled by an output parameter from the boiler such as steam pressure or hot water temperature.

Likewise, combustion air should be controlled continuously to maintain optimal levels of O_2 and CO in the flue gas and thereby maintain an optimal combustion efficiency.

2.6.4 Optimized heat recovery system

The boiler should be equipped with an economizer designed to recover as much heat from the flue gas as possible, see section 1.5 above.

2.6.5 De-NOx system

NOx content in the flue gas is controlled via primary means like combustion air injection and circulation of flue gases and via secondary means like SNCR (Selective Non-Catalytic Reaction) or SCR (Selective Catalytic Reaction). Normally SNCR injecting ammonia water or urea in the combustion chamber is used. SCR, which is expensive, is only used if very stringent emission limits apply. It is important to inject e.g. ammonia water in the optimum temperature windows, otherwise the efficiency is low, and a slip of e.g. pure ammonia occurs. Therefore, more levels of injection nozzles are used. Automatic shift of level is necessary.

2.6.6 Easy removal of fouling and slags

The use of biomass has an impact on fouling and slagging in the boiler.
This is mainly due to alkali group metals such as Natrium and Kalium. These metals have low melting points and tend to melt on tube surfaces which increases the ash deposition on the tubes. The build-up of such deposits increases the thermal resistance of the tubes and therefore the tube temperature, enabling the melting of other substances. Besides, this leads to severe corrosion. Fouling and slagging seem to be worsened by the presence of chlorine which increases the mobility of inorganic compounds.

Fouling and slagging can be minimized by avoiding small tube diameters and by the addition of some compounds containing sulphur (which seem to reduce the amount of deposits). In addition, an automatic cleaning system can be included in the boiler.

2.6.7 Fuel feeding

The type of fuel feeding system depends highly on the type of biomass and is typically tailor-made to the specific application. The exact type of transport and feeding depends totally on the type of biomass and especially its texture (fines, straw, pellets, etc.).

Explosion and fire risk must be carefully assessed, and the necessary actions taken.

2.6.8 Flue gas cleaning

The design of the flue gas cleaning system depends on the regulatory requirements on air emissions.

Typically, flue gas cleaning on a biomass combustion plant consists of a bag house filter, electrostatic precipitator or maybe just a cyclone.

Continuous emission measurement is dependent on the authority requirements but for the control of the boiler, especially continuous CO- and O_2-measurements are essential.

The flue gas often leaves the flue gas cleaning at e.g. around 130-150°C as this is the optimum temperature in bag house filter and well above the dew point. There is however and opportunity to increase the efficiency by introducing a flue gas cooler (cooling the flue gas down to e.g. 100°C but still above the dew point to avoid corrosion). Another option is to introduce flue gas condensation, which is especially interesting if biomass with high moisture content is used. Both flue gas cooler and flue gas condensation require that there is a need for hot water somewhere in the factory.

2.6.9 Water treatment

Proper water treatment controlling oxygen, pH etc. is necessary to keep a high standard of the boiler installation and the necessary sampling points in feed water, boiler drum and steam line with online measurement of e.g. conductivity must be included to monitor the water/steam quality. For more, see section 1.11 above.

If power production is included using of steam turbine, the requirements for water/steam quality is normally high.

It is important to clean the boiler and the steam line properly before introducing steam to the steam turbine. This is typically done e.g. via acid cleaning and/or steam purge/blowing, however very supplier dependent.

2.6.10 Fuel handling and storage

The need for storage facilities depends totally on the fuel in question but if the fuel is sourced from outside the factory, a storage capacity of at least 3 days to overcome weekend is preferred.

If more fuels are mixed, different storage systems may be needed, or the different types of biomass could be mixed in a bunker.

A storage covered by roof is the preference to avoid increase of the moisture content in the fuel.

If a very dry fuel is used, also fire extinguishing in the fuel bunker must be considered (smoke detectors, firefighting equipment, etc.)

2.6.11 Maintenance

It is important to install a proper maintenance system based upon inputs from the equipment suppliers in terms of change of lubrication, change of sealing and other regular maintenance issues. Maintenance must be preventive and not when the system is broken down.

It is recommendable to make a short stop before the annual major overhaul to plan the activities during the outage. The short stop is used to inspect the boiler knowing exactly the needs for the outage e.g. by checking wall thickness of critical components, amount of fouling in the boiler, etc. Having control of the maintenance will extend the lifetime of the plant.

2.6.12 Documentation

For the correct operation and maintenance of the boiler plant, it is crucial to have all relevant documentation, such as operation and maintenance manuals, available in a safe, accessible place.

It is important to have a tag numbering system securing correct identification of all components.

2.6.13 Example of biomass boiler

An enterprise needs 12 bar steam for their production, and it is provided by a wood chip boiler. The dust is removed from the flue gas in a cyclone and fines in a scrubber after it is cooled in the quencher.

A water circuit is preheated with the scrubber water and subsequently lifted by directly heat exchange in a two-stage economizer. The flue gas is cooled to 45 – 50°C and the water circuit is heated from 35°C to 68°C. Another source for heat recovery is the cooling of the combustion chamber and the movable grate and this used for preheating the air intake.

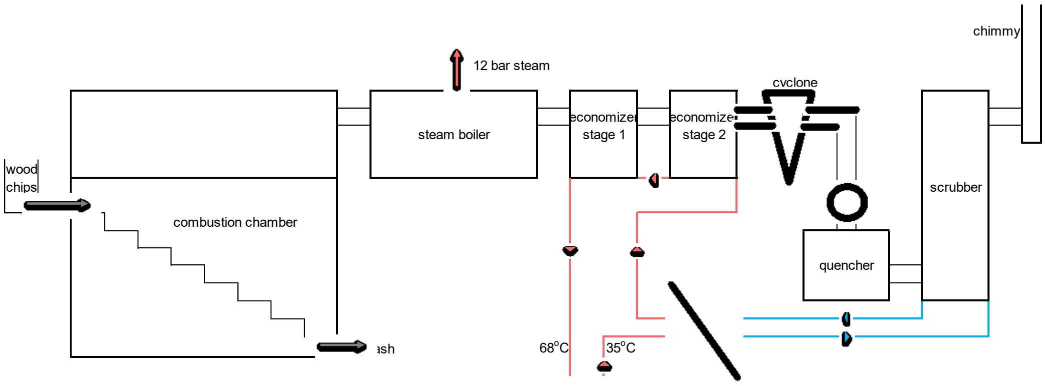

Figure 10. Heat recovering from a wood chip boiler

The yearly steam production is around 65,000 MWh and the potential of the hot water circuit is 18,000 MWh equal to a 28% increase of the energy output from the boiler.

The reason for this huge increase of the energy output is the moisture content in the interval of 38-45% in the wood chips and by lowering the flue gas temperature to the condensation point the evaporation energy is recaptured.

The enterprise cannot use so much energy at 68°C and therefore a setup is made to sell it externally.

2.6.14 Case study – Replacement of oil boiler with biomass boiler

At Da Nang Tobacco Company Limited, an oil boiler produces 2 tons of steam per hour for the manufacturing processes with good efficiency (90%) – however with relatively high operating costs due to the high cost of oil.

In order to reduce operating costs, the facility decided to install a wood pellet boiler simply replacing the oil boiler, producing 2 tons of steam per hour.

The old and new boilers are shown below.

Figure 11. New wood pellet boiler to replace oil boiler

The efficiency of the new boiler is projected to be approximately 85%.

With a total investment of 3 billion VND and annual cost savings of more than 8 billion VND, the payback time for the investment is as low as 0.3 years. Further, the replacement results in a significant reduction of the CO_2-emissions from the facility, a reduction of approximately 2,400 ton/year.

2.7 Electro boilers

Electro boilers has been around for decades but as electrification of the industry is very topical the penetration into the boiler market is accelerating.
The advantage of electro boilers is that no combustion takes place, only electricity is consumed, and CO_2 neutrality can be obtained by using electricity from renewable sources.
The boilers can be constructed for production of steam or hot water or from some vendors a combined solution is possible.
Electro boilers have a high efficiency (99.0% - 99.7%) and a wide control range (continuous from 0–100%) and a fast response time with down to 30 seconds response time from minimum to full load.
Electro boilers are used both as supplement to combustion boilers and as all-covering for thermal supply of industrial facilities.

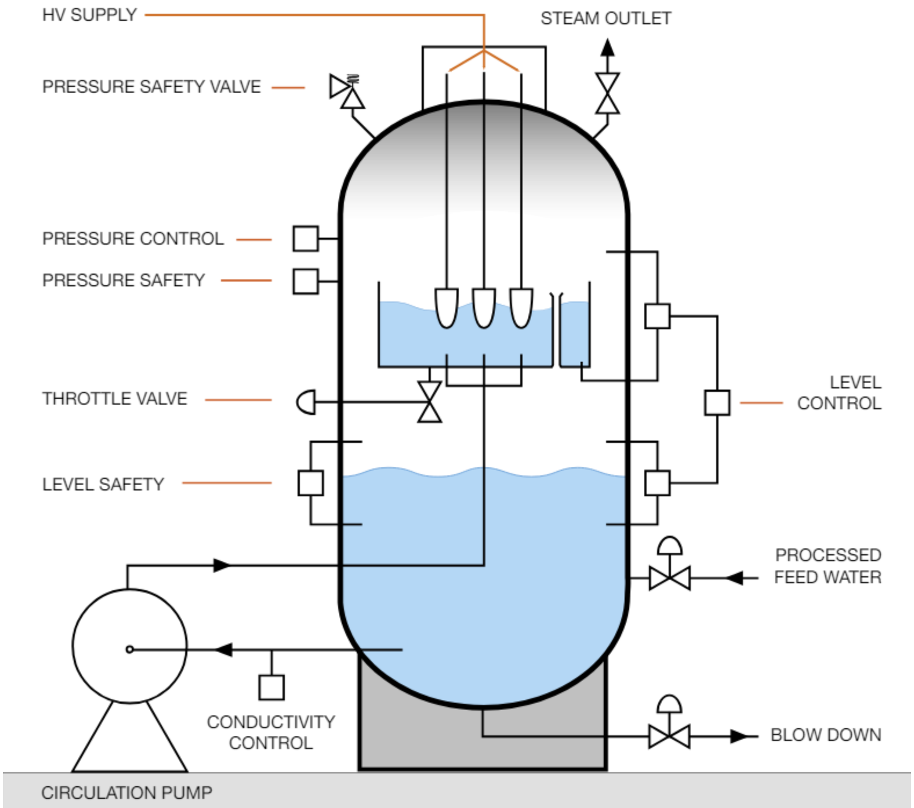

Figure 12 Schematic of an electro boiler for steam (source: Parat[15])

The main disadvantages of electro boilers are that it is often necessary to expand the electricity supply and the underlying electricity grid. Normally industrial boilers are connected to the middle voltage levels like 6 – 24 kV to lower the electric current. Only boilers below 1 MW can be considered connected to low voltage.

Investment in an electro boiler solution will in some cases be cheaper than a natural gas boiler solution. If the costs for additional electricity supply and upgrading the grid infrastructure are high an electro boiler solution be more expensive than a natural gas boiler solution.

A horizontal design requires approximately the same spacing as a natural gas boiler. A vertical design requires more height in the boiler room but a very small footprint. Normally an electro boiler can be installed without huge building costs and there are no costs for fuel storage and handling, flue gas cleaning and stack.

Operation is simple and the regulation is normally conducted with the water level around the electrodes. The maintenance is normally limited and with spare electrode in stock downtime can be kept on a limited extent. With a good water quality fouling on electrodes and surfaces will be low the intervals between cleaning can be long.

As no flue gas is involved and as no emission goes to the ambient air the environmental issues will not be related to an electro boiler installation. For companies close to residential areas this could be an additional motivation.

Electro boilers can also be used for special regulation like load balancing in gas turbine systems or support to frequency regulation in the grid.

Technology	Output	Efficiency	Applications
Electro boiler A vertical or horizontal construction.	Hot water or steam up to 70 barg and 300ºC.	99.0-99.7 %	Can be used in all kinds of industrial applications where hot

[15] PARAT homepage: PARAT IEH High Voltage Electrode boiler - PARAT Halvorsen AS

As no combustion take place equipment for fuel handling and flue gas are not required. Electrical supply in middle voltage, 6 kV – 24 kV, shall be sufficient and stable. Control range continuous from 0–100% Down to 30 seconds response time from minimum to full load.	Range from 0 to 60 MW in one unit. Very suitable for a modular solution where the total power is delivered with two or more units.	Electro boilers do not have the losses associated with combustion boilers but only radiation losses.	water or steam are required. Especially for companies where it is important to obtain: - Low CO_2 impact - No emission - Fast response time - A wide control range an electro boiler is a relevant solution. May also be relevant as a supplement to combustion boilers. It is a prerequisite for an electro boiler solution that the grid can deliver the required electricity.

Table 9. Electro boiler technologies

Figure 13. Example of an electro boiler installation.

3 The boiler procurement process

Procurement of new boiler installations is a significant investment project for most industries and necessitates a careful planning work to secure sustainable and cost-efficient solutions.

To do this, the procurement process should follow the steps below:

1. A pre-feasibility phase

2. A feasibility phase

3. A tendering phase

4. A tender evaluation phase

Later steps when implementing, testing and commissioning the boiler installation are not described in this context.

3.1 Pre-feasibility phase

The aim of the pre-feasibility phase is to define the project to carry out and evaluate alternative overall solutions so as it can be concluded what the most attractive way forward will be.

The dilemma most industries have to challenge in this phase is whether to select a cheap, low-efficient boiler solution or a more expensive and more efficient solution with lower operating costs. It is recommended to assess these alternatives carefully and well documented in order for the management to make the right choice.

Another consideration to be made before the purchase process is commenced is whether the current setup in the production will also be the right one in the future.

The easiest way forward will most often be to install a new boiler without further considerations, but more careful investigations might uncover alternative solution strategies. As such, a pre-feasibility phase should careful asses and document the design basis for the project and compare various elements in the solution strategy, by example:

1. What is the purpose of the project?

   It is important to be precise about for which reasons a new boiler installation is to be considered.

   The most common reasons for initiating a boiler-project will be the need for more capacity or because the company experience severe outages in heat generation for an old and poorly maintained boiler station.

   But a new boiler could also offer a range of other benefits, such as
   - Reduced operational costs (including energy, staff and maintenance)
   - Increased availability (less hours of production stop due to lack of heat supply)
   - Heat production capacity to match better with the demand
   - Improved working environment
   - Reduced emissions to the local environment
   - Reduced carbon footprint
   - Compliance with current regulation
   - Reduced risk of supply of energy
   - Reduced risk of energy price increase
   - Increased market value of the product as a result of lower environmental impacts.

The combined value of these benefits could very well supersede the value of the energy cost savings. It is important, therefore, to consider these already in the pre-feasibility study and highlight those that are deemed most important.

But also, a strategy to become more energy- and cost efficient or to become carbon neutral by phasing out fossil fuels can be the reason for starting a project.

2. What is the scope of the project?

   A boiler-project might be simple replacement project, i.e. a replacement of a worn-out boiler. But a boiler project might also comprise a completely new boiler house at a new plot at the facility.

   As such a boiler-project can be quite comprehensive and will include different disciplines and engineering works to plan and include in the investment estimates.

   During the early phases, the expected scope of the project shall be described in order to make it clear for all relevant parties which works that are underway.

3. Which heating demand is to be covered (MW)?

   A careful mapping shall take place to lock present and future capacity needs for heating at the facility, i.e. to decide what should be the rated capacity for the boiler solution.

   The boiler might replace an existing boiler installation with well-known capacity, but a detailed survey of heating demands to cover now and, in the future, should be established and described in a memo.

   This is not only an exercise to collect data about present and future heat demands, but also to look into heat saving opportunities, by example if heat recovery options in central processes can reduce heat demands or if waste heat from utility systems like cooling plants and compressed air plants can be utilized – by example via heat pumps and local distribution rings with heating media like hot water.

4. Selection of fuels

   As stated above, most companies will have different options for selection of fuels, and Capital Expenditures (CAPEX) and Operating Expenses (OPEX) for different solutions must be assessed along with estimated CO_2-emissions. Also, practicalities (space, manning, maintenance etc.) for different fuels have to be assessed carefully.

   For renewable fuels, any advantage from a customer and supply chain-perspective should be described along with any expected benefit from reduced CO_2-abatement costs.

5. Alternative and more efficient heating media

   The boiler might be planned to supply an existing steam system, but as large efficiency gains can be achieved when applying a hot water distribution system, the feasibility of a hot water boiler and a new distribution system should be assessed.

   Such solutions might cost more to establish due to extra costs when establishing new distribution systems, but over lifetime, operating costs will be much lower than the initial investment cost.

   As mentioned above, such solution can be local hot water systems, but sometimes there might be benefits from swapping the entire heat distribution systems from steam to hot water.

6. Alternative technology solutions

   Based on the above analysis, relevant alternative heat supply solutions should be identified.

   For each of the solutions, the total costs of ownership should be assessed, based on estimates of CAPEX and OPEX costs. In the pre-fs, the cost estimates may be based on reference costs from similar projects.

   In addition, the technology solutions should be discussed with regards to the other priority objectives, with particular focus on the more significant impacts. If for example the carbon footprint of the enterprise is an important parameter for the competitiveness of the enterprise, the pre-feasibility study should seek information about the choice of technology and fuel would impact on the competitiveness of the enterprise.

7. Other relevant project elements

   Next to immediate project elements listed above, also questions like space requirements, environmental questions and legal aspects of alternative solutions etc. should be discussed for each alternative solution in the pre-feasibility phase.

A pre-feasibility report shall describe the purpose of the project, the design basis for the project and expected investments (CAPEX) and expected operation costs (OPEX) should be assessed for each alternative solution identified.

As such, the pre-feasibility report shall describe the business case for the project including relevant alternative solutions. The business case shall include an assessment of Total Cost of Ownership (TCO) for alternative solutions.

The report shall be presented for the management in the company to decide on further steps, and often it should also be recommended also to initiate a dialogue with the bank regarding financing options for alternative solutions. Some banks will have attractive loan and financing options for sustainable solutions, which should be identified already in the early stages of the project development as this can have significant impact on financing costs etc.

On the basis of meetings with the management, further steps should be concluded. The scope of the project shall be described in a concluding memo and the feasibility phase initiated.

3.2 Feasibility phase

The aim of the feasibility phase is to carry out a preliminary solution design for the preferred solution and make a fairly accurate investment budget (CAPEX and OPEX) so as the management of the company can allocate funds for implementing the project.

Input and knowledge of vendors are important and beneficial when carrying out the feasibility study and can also give new inspiration to the configuration of the boiler house and the preferred solutions. Further, vendors can assist with more accurate budget prices.

The feasibility study and following the Feasibility report must include all considerations necessary to achieve at the most optimal solution and may include topics such as:

- Project scope
- Detailed description of the project
- Media (temperature level), what is required at the consuming equipment
- The right fuel also taking CO_2-emissions in consideration
- Optimization of total cost of ownership (TCO) over a ten-year period

- Financial analysis, i.e. investment and operation costs (CAPEX and OPEX)
- Financing options
- Assessment of impacts on the operations of the enterprise
- Assessment of other impacts
- Project risks
- Overview of approvals and legislative framework
- Time schedule for implementation
- Project organization incl. preferred suppliers
- Recommendations on further steps

The outcome of the feasibility study is a report to be used as basis for the management's decision on the investment.

The feasibility study shall – in case the company needs bank financing – be presented to relevant banks to learn about relevant financing options to present for the management as part of the CAPEX-approval.

Finally, the feasibility study shall be presented to the management to get approval of funds for the investments (CAPEX).

3.3 Tendering phase

On the basis of the feasibility study and approval of CAPEX from the management, the detailed project preparation will comprise a number of phases.

3.3.1 Final scope definition

The exact scope of the contract must be established, and the following items will usually be included:

- Complete steam boiler incl. various auxiliary equipment
- Flue gas duct and connection to existing chimney
- Connection to existing fuel supply
- Connection to existing steam supply
- Connection to existing feed water supply incl. new feeding pumps
- Connection to auxiliary systems such as air intake, bottom blower, safety valves, etc.
- Electrical connection
- Control system (interface to current control system)
- Delivery and assembly
- Insulation and panel cladding
- Platforms and stairs incl. connection to existing facilities
- Commissioning (in close cooperation with the owner)
- Site Acceptance Test (SAT)
- Trial operation
- Documentation
- Necessary installation approvals (like from the gas company)
- Emission measurement (If not done by the owner)
- Noise measurement (If not done by the owner)
- Spare parts (option)

Depending on the circumstances auxiliary equipment can also be required like:

- Distribution systems (also in the production)
- Water treatment
- Fuel storage (biomass)

- Deaerator
- Chimney
- Building

In case alternative solutions have been preferred – by example a hot water boiler with hot water distribution system, the lists above will be simpler, but other solutions are then to be defined and described.

3.3.2 Technical specifications

The requirements to equipment must be described unambiguously. It is particularly important to describe the overall delivery performance:

Environmental:
- Emissions, NOx, CO, dust
- Noise requirements

Functionality:
- Definition of the fuel(s)
- Unmanned operation, for how long time
- Output (MW) (and minimum load)
- Economizer output
- Pressure / temperature
- Max flue gas temperature (at 100% load)
- Total boiler efficiency (at 100% load)
- Uptime

Definition of how the performance test shall be conducted. It is important to be very specific to avoid discussion on methods, timing, sampling, calculation afterwards.

It shall also be described how deviations shall be handled and what shall be fulfilled before a handover can take place.

3.3.3 Performance guarantees

Before setting the conditions for the performance guarantees it is important to evaluate the operation conditions to make sure that it is possible to make the test runs.

3.3.4 Service contract

Taken spare parts and service of the plant into the contract will result in a fair price for the operation in the coming years.

3.3.5 Example of performance guarantee

An example of performance guarantees for a steam boiler with gas as fuel:

3.3.5.1 Output

If the steam flow is less than the guaranteed one, the plant must be rebuilt at the supplier's expense and handover will not take place before the performance has been verified.

3.3.5.2 Boiler efficiency

- Boiler efficiency is measured as an average over 72 hours continuously operation with full load.
- Boiler efficiency is calculated as:

$$\text{Efficiency [in \%]} = \frac{\text{Steam in kg/hour * (enthalpy of steam – enthalpy of feed water (both in MJ/kg))}}{\text{Gas quantity in kg/hour * calorific value MJ/kg}} \times 100$$

- In case of an efficiency above 98.2% the requirement is met
- In case of an efficiency between 98.2 and 97.5% a fine shall be paid equal to 1% of the contract sum per 0.1% efficiency below 98.2%
- In case of an efficiency below 97.5%, the plant must be rebuilt so that requirements are met.

3.3.5.3 Uptime

The uptime must be proven in the first operating year after the handover has taken place. The uptime is calculated as:

$$\text{Uptime [in \%]} = \frac{\text{8,760 hours – planned downtime – unplanned downtime}}{\text{8,760 hours}} \times 100$$

A fine of 1% of the contract sum shall be paid for each percent the uptime is below 99%.

3.4 Contracting phase

The quotation evaluation has two main purposes:

- Identifying deviations from the tender documents
- Making the tenders comparable enabling price negotiations

In the technical clarification it is important to take a deep dive in the two most attractive quotations to ensure that there are not misunderstanding and deviations from the tender documents which are not immediately apparent.

After this clarifying and final price negotiation a contract can be completed.

3.5 Later project phases

It is important to following the installation and commissioning phase closely to monitor whether important design decisions in the feasibility and tendering phase are followed through.

Annex 1. Energy efficiency check-list for oil- and gas-boiler installations

Capacity utilization of boiler

Is the boiler operating as it was designed for?

Question	Inspection parameter	Potential loss	Possible solutions
Is the boiler running at or near its capacity design point?	Operational capacity as % of design capacity	Losses due to operation at low capacity can be up to 5% of full load capacity and thus a high percentage of the fuel consumed at low load.	It can be considered to replace the boiler by one with a suitable design capacity.

Combustion Control

Is all the fuel utilized?

Question	Inspection parameter	Potential loss	Possible solutions
Does the combustion process achieve complete combustion of the fuel?	Look for soot or black smoke from chimney. Check fuel feed relative to feed water for energy check.	Losses can be as high as 5% and equal to percentage share of unburnt fuel	Installation of continuous control of fuel/air ratio.

Is the combustion air monitored and controlled to achieve proper combustion?	Check the flame and soot presence in the boiler.	Rising flue gas temperatures or increased amount of unburned fuel. Losses can be as high as 5% and equal to percentage share of unburnt fuel	Installation of continuous control of fuel/air ratio.
Is the combustion stable? Are there fluctuations in steam temperature and/or pressure?	Check steam pressure over time	Depending on the individual situation	Adjust set points and smoothen the operation.
Is the boiler maintained regularly to avoid build-up of residues in the combustion chambers?	Monitor the combustion chamber periodically Check if the pressure drop over heat exchangers increases over design values.	**Potential losses [%]:** Best practice: 1% Normal: 2% Action required: 5%	Clean heat exchanger surfaces regularly to avoid build-up if fouling.
What is the oxygen percentage (O_2) of the flue gas?	The O_2 content in the flue gas should be checked: Natural gas: 1-3% of O_2 Fuel oil: 1-3% of O_2	**Potential losses [%]:** Best practice: 1-3% Normal: 2-4% Action required: 4-10%	Follow operating manual of boiler if available.

Flue gas heat recovery

How much energy is recovered relative to the measured fuel consumption? Does the energy output match the fuel feed?

Question	Inspection parameter	Potential loss	Possible solutions
What is the temperature of the flue gas out of the chimney?	**Flue gas temperatures:** Best practice: 80°C Normal: 120°C Action required: 150°C	The losses in exhaust gasses can typically be up to 5% or even 12-14% if condensing operation is possible.	If the flue gases are very hot or hotter than the design specifications, consider cleaning the heat exchangers.
Is the boiler designed for condensation and if so, is condensation achieved?	Is it possible to lower the flue gas temperature?	In best cases all the flue gas losses can be recaptured.	Additional economizer and system for utilizing the low temperature energy
Are the flue gases used for preheating of combustion air or feed water for the boiler?	Is it possible to lower the flue gas temperature? See above.	In best cases all the flue gas losses can be recaptured.	Additional economizer and system for utilizing the low temperature energy

Are multiple boilers connected to the same stack? If so, are there dampers in the stack to control flue gas flows?	Can all boilers be close off from the stack when not in operation?	Less than 1%	Install dampers.

Condensate and water quality

Is condensate recovered and utilized efficiently?

Ensuring water quality and condensate utilization can influence the operational efficiency and the frequency of maintenance shutdowns. If the condensate is lost, makeup water is required which requires treatment to a sufficiently high standard to avoid corrosion in the pipes and heat exchangers in the boiler.

Question	Inspection parameter	Potential loss	Possible solutions
Is all possible condensate returned?	If the amount of clean condensate retuned deducted the direct used steam is less than 80% action should be taken.	10% loss of condensate impairs boiler efficiency by 1%	Continuous surveillance of the percentage of reused condensate and inspect the installation if it drops.
What is the ratio of the water being discharged for blowdown relative to the feed water?	Check blowdown rate relative to steam production.	**Potential losses:** Best practice: 3% Normal: 3% Action required: 5%	High blowdown rates may indicate insufficient feed water treatment or insufficient monitoring of

			feedwater quality if blowdown is fixed.
Are steam traps periodically monitored?	Steam traps should be checked periodically. Losses depend on steam pressures. **Amount of steam trap failures:** Best practice: 5% Normal: 15% Action required: 30%	Losses in steam distribution systems can be as high as 10% of the total heating load if steam traps are not functioning well	Continuous surveillance of the function of the steam traps (noise level, temperature)
Is the heat from the vented air-steam mixture recovered from the deaerator?	The heat from the vented air-steam from the deaerator represent a continuous loss. If condensate is 3 bara, 30% of the energy can be recovered. If condensate is 10 bara, 50% of the energy can be recovered.	Up to 0.5%	If significant amounts of steam are blown off, heat recovery should be installed.

Insulation standard

Is the boiler and relevant installations properly insulated?

Ensuring a good insulation standard reduces losses and ensures a much better working environment

Question	Inspection parameter	Potential loss	Possible solutions
Are all surfaces of the boiler and related ducts insulated properly – also the back and the top?	Keep surface temperatures below 50°C for safety reasons and to reduce heat loss. **Surface temperatures:** Best practice: 35-40°C Normal: 40-50°C	1-5% depending on the measured surface temperatures	Complete the insulation. At valves etc. removable solutions like pillows shall be used.

	Action required: >50°C		
Are all pipes, valves and fittings in the boiler-house properly insulated?	Check insulation of all pipes, valves and fittings in the boiler-house.	1-5% depending on the measured surface temperatures In steam distribution systems, surface temperatures can be higher than 100° thus generating significant losses	Complete the insulation. At vales etc. removable solutions like pillows shall be used.

Annex 2. Energy efficiency check-list for solid fuel-boiler installations

Utilization of fuel Can the fuel be improved?			
Question	Inspection Parameter	Potential loss	Possible solutions
Is the moisture content of the fuel as the boiler was designed for?	**Check the deviation relative to designed for moisture content**: Best practice: 0%-points Normal: 0-10%-points Action required: 15-20%-points	Losses can be upward of 10%.[16]	Source fuel as the boiler was designed for or store it under roof to avoid soaking from rain.
Is the boiler operating with the designed fuel particle size?	Check of fuel size relative to design.	Individual	Make sure to purchase fuel at the design particle size

Capacity utilization of boiler Is the boiler operating as it was designed for?			
Question	Inspection parameter	Potential loss	Possible solutions
Is the boiler running at or near its capacity design point?	Operational capacity as % of design capacity Look for soot or black smoke from chimney. Check fuel feed relative to feedwater for energy check.	Losses from operation at low load can be up to 5% of the full load capacity.	Solution for consideration: replace boiler by one with a suitable design capacity.

[16] Source: BREF on Large Combustion Plants, Table 5.44

Combustion Control

Is all the fuel utilized?

Question	Inspection parameter	Potential loss	Possible solutions
Does the combustion process achieve full combustion of the fuel?	Monitor the TOC (Total Organic Carbon) of the ashes. **TOC content:** Best practice: 3-5% Normal: 5-6% Action required: 7+% Look for soot or black smoke from chimney. Check fuel feed relative to feed water for energy check.	Up to 5% of the fuel and in extreme cases more.	High TOC content in the ashes indicate insufficient combustion. Adjust air flows and/or fuel residence time to improve combustion conditions.
Is primary and secondary air monitored, and controlled to achieve proper combustion?	Monitor the combustion air volume flows of primary and secondary air and ensure they follow design and stable operation.	1-3%	Install automatic control system
If the boiler is designed with recirculation, it should be used to avoid corrosion and ensure proper operation according to operational instructions.	Compare operation with design data.	Individual	Follow the design criteria
Is the combustion stable? Are there fluctuations in steam temperature and/or pressure?	Check steam pressure over time	Individual	With biomass homogenizing of the fuel intake can be relevant. Adjust parameters to design criteria

Is the boiler maintained regularly to avoid build-up of residues in the combustion chambers?	Monitor continually and the flue gas temperature must not increase more than 40°C.	Potential losses [%]: Best practice: 1% Normal: 2% Requires action: 5%	Steam cleaning during operation and totally cleaning at maintains stops.
What is the oxygen percentage (O_2) of the flue gas?	Follow operating manual of boiler if available. **O_2 percentage in the flue gas**: Best practice: 3-4% Normal: 5-7% Action required: >8%	Potential losses [%]: Best practice: 2-4% Normal: 4-6% Requires action: 6-8%	Automatic control of oxygen level

Flue gas heat recovery

How much energy is recovered relative to the measured fuel consumption? Does the energy output match the fuel feed?

Question	Inspection parameter	Potential loss	Possible solutions
What is the temperature of the flue gas out of the chimney?	Flue gas temperature should be as low as possible. **Flue gas temperatures:** Best practice: 50 -80°C Normal: 80 -160°C Action required: above 160°C	Up to 10% if condensation is possible	Additional economizer stage
Is the boiler designed for condensation and if so, is condensation achieved?	Is condensate achieved with large heat recovered at low temperatures? Depends on boiler and heat sinks.	Up to 10%-points of heating can be recovered	Additional economizer stage. Requires a low

			temperature heat demand.
Are the flue gases used for preheating of combustion air or feed water for the boiler?	Monitor flue gas temperatures. Follow up on parameters for flue gas - see above.	Up to 10% if condensation is possible	Additional economizer stage
Are multiple boilers connected to the same stack? If so, are there dampers in the stack to control flue gas flows?	Can all boilers be close off from the stack when not in operation?	Less than 1%	Install dampers.

Condensate and water quality

Is water recovered and utilized efficiently?

Ensuring water quality and condensate utilization can influence the operational efficiency and the frequency of maintenance shutdowns. If the condensate is lost, makeup water is required which requires treatment to a sufficiently high standard to avoid corrosion in the pipes and heat exchangers in the boiler.

Question	Inspection parameter	Potential loss	Possible solutions
Is all possible condensate returned?	If the amount of clean condensate retuned deducted the direct used steam is less than 80% action should be taken.	10% loss of condensate impairs boiler efficiency by 1%	Continuous surveillance of the percentage of reused condensate and inspect the installation if it drops.
What is the ratio of the water being discharged for blowdown relative to the feed water?	Check blowdown rate relative to steam production.	**Potential losses [%]:** Best practice: 1% Normal: 3% Action required: 5%	Secure sufficient feed water treatment and sufficient monitoring of feed water quality if blowdown is following a fixed schedule.

Are steam traps periodically monitored?	Steam traps should be checked periodically. Losses depend on steam pressures. **Loss % of steam traps below:** Best practice: 5% Normal: 15% Action required: 30%	Losses from non-functioning steam traps can be as high as 10%	Leaking steam traps requires maintenance or replacement to reduce steam system losses.
Is the heat from the vented air-steam mixture recovered from the deaerator?	Depends on vented steam flow and steam pressure. If condensate is 3 bara, 30% of the energy can be recovered. If condensate is 10 bara, 50% of the energy can be recovered.	Up to 0.5%	If significant amounts of steam are blown off, heat recovery should be installed.
Is the water quality as per the design specifications to avoid scaling and erosion in heat exchangers?	If water quality does not meet the specifications, the lifetime of the boiler will decrease due to corrosion along with reductions in operating efficiency.	Individual	Water steam cycle must be sufficiently monitored continuously

Insulation standard

Is the boiler and relevant installations properly insulated?

Ensuring a good insulation standard reduces losses and ensures a much better working environment

Question	Inspection parameter	Potential loss	Possible solutions
Are all surfaces of the boiler and related ducts insulated properly – also the back and the top?	Keep surface temperatures below 50 °C for safety reasons and to reduce heat loss. **Surface temperatures:** Best practice: 35-40°C Normal: 40-50°C Action required: >50°C	1-5% depending on the measured surface temperatures	Complete the insulation. At valves etc. removable solutions like pillows shall be used.

Are all pipes, valves and fittings in the boiler-house properly insulated?	Check insulation of all pipes, valves and fittings in the boiler-house.	1-5% depending on the measured surface temperatures In steam distribution systems, surface temperatures can be higher than 100°C thus generating significant losses	Complete the insulation. At vales etc. removable solutions like pillows shall be used.

Annex 3. Selected national and international suppliers of oil- and gas-boilers

Below an overview of national and international suppliers able to deliver BAT-solutions for industrial oil- and gas-boilers in Vietnam is provided.

	Company name	Address of factory	Maximum capacity that can be made, design efficiency (ton/h) (%)
Domestic suppliers			
1	Nam An Environmental Mechanical Joint Stock Company (Assured according to BAT)	Factory 1: TS8 Road, Tien Son Industrial Park, Tien Du District, Bac Ninh Province Factory 2: Ky Son Industrial Cluster, Ngoc Son Commune, Tu Ky District, Hai Duong Province NM3: Yen Phu Commune, Yen My District, Hung Yen Province	50 tons per hour
2	Vietnam Boiler Joint Stock Company (VBC)	Group 18, Dong Anh town, Dong Anh district, Hanoi	50 tons per hour and 90%
3	Asia Polytechnic Company Limited - Apolytech	No. 10, Hamlet 2, Nhut Chanh Commune, Ben Luc District, Long An Province	60 tons per hour (88% - 92%)
4	Mechanical - Heat - Electrical and Construction Technology Company Limited	Factory 1: Canh Hau Industrial Complex, Lam Ha, Kien An, Hai Phong Factory 2: Phuong Khe Street, Lam Ha, Kien An, Hai Phong	15 tons per hour ≥85%
5	Mac Tich Joint Stock Company	Nhon Trach III Industrial Park- Dong Nai Province	500 tons per hour 96%
6	Dong Anh Industrial Boiler Joint Stock Company	Group 21, Dong Anh Town, Dong Anh District, Hanoi City	5 tons per hour 90%
7	Bach Khoa Pressure Equipment Joint Stock Company	No. 15 Ta Quang Buu, Bach Khoa Ward, Hai Ba Trung District, Hanoi	2 tons per hour 95%
8	Maruse Engineering Vietnam Co., Ltd	Floor 1, Kiosk No. 03, Building N09B1, Dich Vong Urban Area, Dich Vong Ward, Cau Giay District, Hanoi	2 tons per hour 96%
9	Dong Anh Pressure Equipment Joint Stock Company	Km 2.5 National Road 3, Dong Dau Village, Duc Tu Commune, Dong Anh District, Hanoi City	12 tons per hour 90%
10	Duc Duong Steam Heat Equipment Co., Ltd	Factory: Dong Thap Commune Industrial Park, Dan Phuong Dist., Hanoi	15 tons per hour ≥ 85%
International suppliers			

11	Forbes Mar-shall (India)	Forbes Marshall Private Limited Representative Office in Hanoi City 1624-B62, CSC Vietnam, T16, ICON4 tower, 243A De La Thanh, Lang Thuong Ward, Dong Da District, Hanoi Phone No.+84 909880218	25 tons per hour 94%
12	Thermax (India)	1624-B62, CSC Vietnam, T16, ICON4 tower, 243A De La Thanh, Lang Thuong Ward, Dong Da District, Hanoi	500 tons per hour
13	Hyundai Heavy Industries Power Systems	Phone No.+84 909880218	350 tons per hour
14	Spirax Sarco	Spirax Sarco Vietnam 4th Floor, Nam Song Tien Tower 180 Nguyen Van Troi St, Phu Nhuan District Ho Chi Minh City, Vietnam Tel: +84 028 3997 6000 Fax: +84 028 3997 6062 Spirax.Vietnam@vn.spiraxsarco.com	

Annex 4. Selected national and international suppliers of solid fuel boilers

Below an overview of national and international suppliers able to deliver BAT-solutions for industrial solid fuel-boilers in Vietnam is provided.

No	Company name	Address of factory	Maximum capacity that can be made, design efficiency		
			Static log boiler (ton/h) (%)	Chain grate boiler (ton/h) (%)	Fluidized bed boiler (ton/h) (%)
Domestic suppliers					
1	Nam An Environmental Mechanical Joint Stock Company (Assured according to BAT)	Factory 1: TS8 Road, Tien Son Industrial Park, Tien Du District, Bac Ninh Province Factory 2: Ky Son Industrial Cluster, Ngoc Son Commune, Tu Ky District, Hai Duong Province Factory 3: Yen Phu Commune, Yen My District, Hung Yen Province	9	75	200
2	Vietnam Boiler Joint Stock Company (VBC)	Group 18, Dong Anh town, Dong Anh district, Hanoi	10 tons per hour and 75%	50 tons per hour and 78%	50 tons per hour and 83%
3	Asia Polytechnic Company Limited - Apolytech	No. 10, Hamlet 2, Nhut Chanh Commune, Ben Luc District, Long An Province	15 tons per hour (70%)	30 tons per hour (83%-85%)	80 tons per hour (85 -87 %)
4	Mechanical - Heat - Electrical and Construction Technology Company Limited	Factory 1: Canh Hau Industrial Complex, Lam Ha, Kien An, Hai Phong Factory 2: Phuong Khe Street, Lam Ha, Kien An, Hai Phong	8 tons per hour ≥75%	30 tons per hour ≥78%	50 tons per hour ≥85%
5	Mac Tich Joint Stock Company	Nhon Trach III Industrial Park- Dong Nai Province		150 tons per hour ≥85%	300 tons per hour ≥87%
6	Dong Anh Industrial Boiler Joint Stock Company	Group 21, Dong Anh Town, Dong Anh District, Hanoi City		3 tons per hour 74-78%	10 tons per hour 84-86%

7	Bach Khoa Pressure Equipment Joint Stock Company	No. 15 Ta Quang Buu, Bach Khoa Ward, Hai Ba Trung District, Hanoi	6 tons per hour 80%		
8	Dai Cuong Thermal Mechanical Co., Ltd	555A Truong Chinh, An Khe Ward, Thanh Khe District, City. Danang	6 tons per hour 85%	20 tons per hour 83%	30 tons per hour 86%
9	Dong Anh Pressure Equipment Joint Stock Company	Km 2.5 National Road 3, Dong Dau Village, Duc Tu Commune, Dong Anh District, Hanoi		50 tons per hour 78%	30 tons per hour 86%
10	Duc Duong Steam Heat Equipment Co., Ltd	Factory: Dong Thap Commune Industrial Park, Dan Phuong Dist., Hanoi		30 tons per hour ≥78%	
11	DIVI Group Co., Ltd	Office: 588 Pham Van Chieu, Ward 16, Go Vap District, Ho Chi Minh City Factory: Khanh Binh 10 Street, Khanh Van Quarter, Khanh Binh Ward, Tan Uyen, Binh Duong			70 tons per hour 89%
International suppliers					
12	Thermax (India)	Thermax Limited The Vista building, 628 C, Hanoi Highway, 3rd Floor, Toong co-working space, An Phu Ward, District. 2, Ho chi Minh City, Vietnam +84 24 3926 3888 Ext 1062	300 tons per hour	300 tons per hour	
13	Bab-cock&Wilcox Vølund	Babcock & Wilcox Vietnam Company Limited Level 14, Tower 1, Saigon Centre, 65 Le Loi Street Ben Nghe Ward, District 1, Ho Chi Minh City, Vietnam Phone: +84 28 3971 9395			544 tons per hour
14	Valmet	Valmet Co., Ltd No. 106 Nguyen Van Troi Street, Ward 08, Phu Nhuan District, Ho Chi Minh City, Vietnam			400 MW_{th} 90%

15	Andritz	Andritz Vietnam Company Limited Room 1410, No. 360 Kim Ma Street, Ngoc Khanh Ward, Ba Dinh District, Hanoi.			450 tons per hour