Waste wood for electricity production
- *Possible solutions for IKEA Industry*

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Abstract

This master thesis is written at the faculty of engineering at Lund University in collaboration with IKEA Industry. The aim is to analyze the potential in electricity production from excess wood biomass coming from production. The available biomass varies in form, quantity, size and moisture content. Various technologies, handling different kind of feedstock for electricity production were investigated. The focus during this work lied on gasification of biomass.

The purpose is to give an overview over which technologies would have the best match with IKEA Industry's feedstock. Electrical efficiency, technology maturity, initial investment cost and feedstock match were into account.

The project was started by IKEA Industry who initialized this project in the beginning of 2014. A Request For Information (RFI) was at that time sent to different Combined Heat and Power (CHP) contractors. In November the same year this thesis started. The work begun with gathering of information from IKEA Industry's sites regarding location, feedstock size, quality and quantity. Simultaneously several RFI´s were sent to additional companies. In the end, all companies with their provided information were put into a technology matrix. Their provided information was then evaluated and compared among themselves. The companies were ranked in a Quality function deployment (QFD) in order to find the most promising companies for IKEA Industry. The parameters that were included in this weighting matrix are low initial cost, high electrical efficiency, mature technology, feedstock match and validation of provided information. Points were given in the range between 1-5 where 5 is the best possible score. Thereafter IKEA Industry weighted these parameters with a number between 1 and 5. These were multiplied into the different categories and thereafter summed to show which companies are the most suitable companies for IKEA Industry.

The conclusion is, that for small sizes, below 5 MW, gasification would be a good solution looking at the price only due to lower electricity production costs. But one must bear in mind, that conventional combustion with steam turbine is a more mature technique and this is something that was weighted with the maximum value by IKEA Industry. That indicates that gasification might not have the maturity for being IKEA Industry's first choice.

Acknowledgements

We would like to thank everybody at the department of energy sciences at Lund University, and at IKEA Industry who helped us during our project.

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1 Introduction

This master thesis is written at the faculty of engineering at Lund University in cooperation with IKEA Industry in Ängelholm. The main aim is to analyze the potential in utilizing wood waste from production at IKEA Industry's sites to produce electricity and heat.

The IKEA group has the ambitious goal of becoming energy independent by August 2020, meaning that they will produce as much renewable energy as they consume in their total operations. Substantial resources have been put into investments in own wind farms and solar parks and the next step in the strategy is to utilize the excess biomass from production to generate electricity and heat. Today, the excess biomass is usually sold as pellets- briquettes or directly to the pulp industry.

IKEA Industry's goal is to maximize electricity production while minimizing the cost/kWh. Two main technologies have been studied to reach this goal; Combustion in combination with steam turbine and gasification with IC engine. 23 different potential CHP contractors have been contacted and involved with suggestions of how to best utilize the excess biomass. The work has resulted in one internal and one external report. The external report has the potential contractors listed as company A to K in order to prevent unauthorized use of potentially sensitive company information.

The following areas are described in this report:

- Technologies available for electricity production of biomass?
- How mature are these available technologies?
- Electrical efficiency of available technologies?
- Investment level for available technologies?
- How does variations of electricity, heat and biomass prices affect the project economics?

This thesis consists of three main parts:

- The first part gives a basic overview of technologies available today. Also the basics behind the conversion from biomass to useful energy is covered. The different divisions among IKEA Industry are described with aspects of available biomass and individual energy demand.
- The second part contains a basic overview of how changes of economic values for biomass, heat and energy certificates impacts the Payback (PB) and Net Present Value (NPV) for an investment.
- The third part is concentrated around solutions to best utilize the biomass at the different division.

2 Method

This project was initiated in February 2014, when IKEA Industry used external company LUX research to analyze available technologies for electricity and heat generation from biomass. LUX research should pick out potential suppliers of turnkey combined heat and power (CHP) plants below 15 MW_{el}. These companies and their technology and solutions have been evaluated with regard of IKEA Industry's needs and demands. A comprehensive request for information (RFI) was sent to the contractors together with three reference cases from IKEA Industry's sites. The reference cases were provided to let contractors present their suggestion of how to best utilize excess biomass when given the actual parameters at three different sites.

The completed RFIs and reference cases were analyzed and a continuous dialog was taken with respective company. The evaluation process has also included meetings and site visits. The result from this work is presented in a technology matrix available in Appendix B.

The locations of all IKEA Industry's sites were mapped in order to get a clear picture of where the potential of wood waste utilization lies. The available biomass at the factories in division Flatline and Solid Wood were collected through available data at IKEA Industry and through direct contact with the factories. The result is presented in Appendix C and D.

A quality function deployment (QFD) was made to evaluate the different companies with aspect of IKEA Industry's needs. Parts of the parameters presented in the technology matrix were included in the QFD and IKEA Industry's needs were transformed to quantitative parameters. The QFD is titled weighting matrix in this report. The result from the weighting matrix was used when the final discussion was made.

A calculation template has been used to illustrate how varying factors such as electricity- and heat price affects the PB and NPV for a project. Varying price for energy certificate has also been taken into account.

2.1 Project boundaries

The wide span of this project resulted in a high level evaluation of available technologies. A deeper analysis of a specific site has not been performed. This project can be seen as a pre study for IKEA Industry's future investment in CHP plants where available technologies are described, discussed and analyzed.

2.2 IKEA Industry

IKEA Industry is a group of companies that manufacture furniture and wood-based boards and panels for IKEA. The name IKEA Industry was founded 1st of September 2013 when Swedwood and Swedspan was merged together to one organization. IKEA Industry is the world's largest manufacturer of wooden furniture and has around 18,000 co-workers distributed over 11 countries.

IKEA Industry is divided into three different production divisions: Flatline, Solid Wood and Board. They all produce different products and have their own manufacturing processes and energy demands. The excess material from production does also vary between the different divisions in aspect of amount, particle size, moisture content and contamination. The locations of these sites are illustrated in Figure 1 below, although 1 factory in north America and 2 in China are excluded.

Figure 1. Locations of IKEA Industry sites in Europe. Yellow marker indicates Board factories and red indicates Flatline- and Solid Wood factories.

2.3 Biomass in different divisions

2.3.1 Collection of available biomass

The collection of data regarding existing biomass at the sites was performed by IKEA Industry in earlier projects and the amount of available biomass presented in this work is based on these values. Some further contact has been made with some factories to collect new data and in some cases to verify the existing data. The outcome of the verification process has been varying and the figures of available biomass should therefore be treated with care. Especially the data from division Solid Wood should be seen more as an indication rather than actual numbers.

2.3.2 Division Flatline

Division Flatline consist of furniture producing factories. They receive products from factories in division Board. Due to the manufacturing processes the excess material can contain contaminations consisting of ABS plastics, parts of adhesives or foil paper. These impurities can lead to that the excess material is classified as waste instead of biomass. This will affect the ability to receive energy certificates and other subsidies. The classification system vary from country to country and is not investigated in depth in this project. The excess material is mostly dust from grinding, edging and the particle size is generally under 1 mm for 95 % of the feedstock. The moisture content of the biomass is approximately 8-10 % and the heat demand for a typical Flatline factory is low compared to the other two divisions. The available biomass at the factories in division Flatline is presented in Appendix D.

2.3.3 Division Solid Wood

Division Solid Wood consists of sawmills, furniture- and/or glue board factories. The particle size of the excess material varies from sawdust and chips to large off cuts. The heat demand for the division is large with major heat consumption in the wood drying process.

Sawmills produce wooden planks from logs and the excess material from the process is classified as pure and wet biomass with a moisture content of approximately 50-60 %. The excess biomass consists to the majority of pure white chips and bark. The production of white chips is separate from the debarking process and these segments are thereby separated from each other. White chips are often sold to the paper industry while bark often is used in own boilers to fill the heat demand at the factory.

The excess biomass from a typical glue board factory consists of mostly sawdust from grinding, edging but also smaller amounts of off cuts. The biomass can contain impurities in forms of adhesives. The sawdust is generally used to produce pellets and/or briquettes.

The furniture factories in division Solid Wood have many similarities with the Flatline factories and the excess material is often dust containing impurities in forms of adhesives. The available biomass at the factories in division Solid Wood is presented in Appendix C.

2.3.4 Division Board

Division Board produce chip- and fiber boards for the furniture factories. This division is excluded from this project due to the fact that no excess material is created in the manufacturing process. All excess material is reused in the production of new boards or burned in own boilers. The heat demand for a typical board factory is large with major heat consumers in the drying- and pressing process.

2.4 Terms and units

2.4.1 Energy content

There are various terms and units of measurement regarding energy content of fuels. Primary energy, is the energy embodied in natural resources before any further process is made to utilize this energy (e.g. heat- or electricity generation). The amount of energy that is left after transformation to useful energy is called final energy.

The SI unit for measurement of energy is Joule (J) but other units are also commonly used. A common unit for electricity is the kilowatt-hour (kWh) and the relationship between these two units is expressed as the following.

$$J = kg \cdot \left(\frac{m}{s}\right)^2 = \frac{(kg \cdot m^2)}{s^2} = W \cdot s = \frac{1}{3{,}6 \cdot 10^6} kWh$$

The unit Calorie is the old unit for energy and was widely used before Joule was introduced as standard. The calorie unit is often expressed as kcal and is still used in the industry. The conversion factors between these three units for energy is presented in Table 1 below.

Electrical efficiency is in this report defined as net electricity generation divided by embodied energy in the biomass.

Table 1. conversions factors of commonly used energy units.

	kJ	kcal	kWh
1 kJ	1	0,239	$0{,}278 \cdot 10^{3}$
1 kcal	4,187	1	$1{,}163 \cdot 10^{3}$
1 kWh	$41{,}87 \cdot 10^{6}$	860	1

2.4.2 Gross- and net electricity generation

Gross generation is the total amount of electricity generated by a power plant. Net generation on the other hand is the amount of energy produced when the usage within the plant is taken into account. The usage within the plant can be electrical loads from e.g. pumps, motors, control devices or other technique specific processes. The net generation is the electricity delivered from the plant and is therefore of interest when comparing different technologies against each other.

$$Net\ generation = Gross\ generation - \sum inhouse\ loads$$

2.4.3 Lower- and higher heating value

The heating value of a specific fuel is the amount of heat produced by combustion of an unit quantity of that specific fuel. There are two different types of heating values; higher heating value (HHV) and lower heating value (LHV). The term net calorific value (NCV) can be used instead of lower heating value and gross calorific value (GCV) can be used instead of higher heating value.

The HHV is the amount of heat produced by the complete combustion of a specific quantity of fuel. The LHV is the amount of heat produced when the latent heat of vaporization of water formed by combustion is withdrawn from the HHV. The thermal energy available to do work (e.g. drive a piston, spinning a turbine) is reduced when vaporization of the water takes place.

The difference between HHV and LHV depends on the properties of the fuel but also on the layout of the plant. If the water vapor follows the exhaust gases without further process, the energy consumed when vaporizing water is lost. This is for example the case for IC engines in cars. Most boilers have secondary condenser systems recovering most of the latent heat carried in the vapor. The LHV is therefore the right value to use when systems without secondary condensers are used and the HHV should in contrary be used when a system utilizes the vapor [1].

2.4.4 Moisture content

Moisture content (MC) of wood is a measurement of how much water is in a piece of wood relative to the piece itself. The moisture content is expressed in percentage and it is possible that there is more water than wood, which results in a MC above 100% [2]. The MC for a specific piece can be measured by using a method where parts of the wood are dried in an oven to a completely dry state, then weighed and compared to the weight of the original piece of wood. The MC can be calculated using dry- or wet basis. In the report the dry basis will be used due to tradition in the industry. The MC is calculated as the following:

$$MC\ (\%) = \frac{\mathrm{m_{wet}} - m_{dry}}{m_{dry}}$$

Where,
MC (%) = moisture content based on dry base
m_{wet} = weight of wood before oven
m_{dry} = weight of wood after oven, absolutely dry wood
The calorific value for wood fuel varies when MC varies. The LHV or NCV will increase as the MC decreases due to lower percentage of water in the fuel, and consequently less heat is used to

vaporize water in the combustion chamber. A relationship between MC using dry basis and NCV is illustrated in Figure 2.

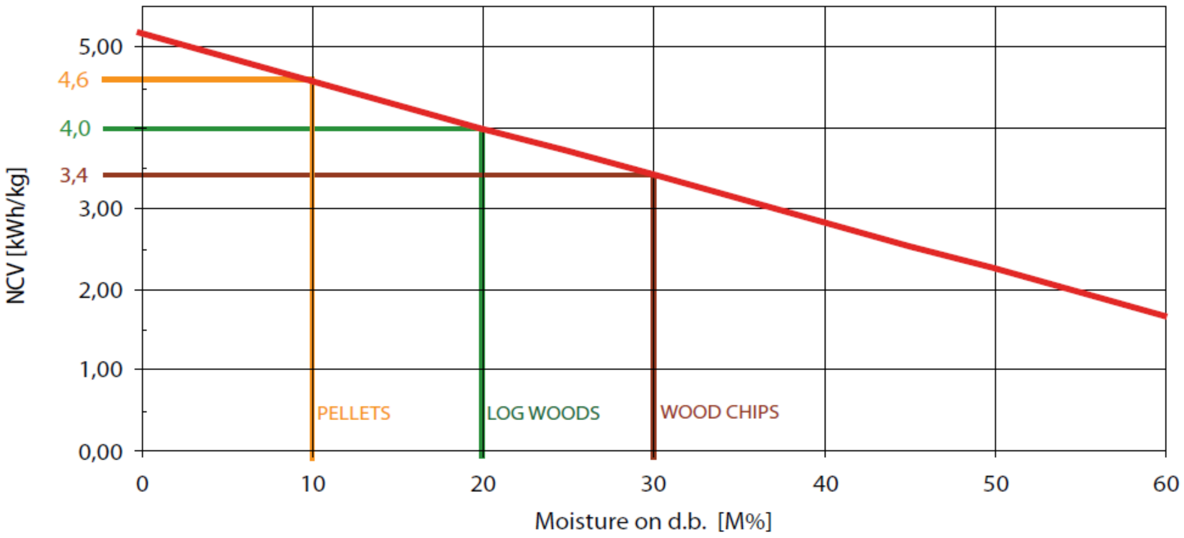

Figure 2. Relationship between moisture content on dry base and net calorific value. Oven-dry calorific value is 5,14 kWh/kg for this specific case.

2.4.5 Calorific value

The calorific value at oven-dry state (NCV_0) differs within a narrow interval for different species of wood. Typical values for different types of wood are presented in Table 2 below. Conifers has higher calorific values than broad-leaved wood, mainly due to a higher lignin content but also because of higher parts of resin, wax and oil [3]. This area is only briefly explained in this report due to the fact that species of wood is not a changeable parameter at IKEA Industry sites and a full wood fuel analysis is performed when making a deeper analysis of a specific site.

Table 2. Calorific value at oven dry state, ash content and ash-melting point of some common biomass fuels. Modified from Wood fuels handbook, AIEL- Italian Agriforestry Energy Association

	NCV_0 [MJ/kg]	Ash [wt%d.b]	Ash-melting point [°C]
Typical values for virgin coniferous wood	19,2 (18,8-19,8)	0,3 (0,2-0,6)	
Typical values for virgin decidous wood	19 (18,5-19,2)	0,3 (0,2-0,5)	
Typical values for virgin bark materials	20 (19-21)	1,5-2	
Spruce (with bark)	18,8	0,6	1426
Beech (with bark)	18,4	0,5	1340
Poplar (SRC)	18,5	1,8	1335
Willow (SRC)	18,4	2	1283
Bark (confierous trees)	19,2	3,8	1440
Vine wood (chips)	19,8	3,4	1450
Miscanthus	17,6	3,9	973
Wheat straw	17,2	5,7	998
Triticale (grains)	16,9	2,1	730

2.4.5.1 *Calorific value for IKEA Industry's biomass*

For IKEA Industry the calorific value of 4700 kWh/ton was chosen for dry biomass with moisture contents between 8-10 % MC. This values are based on in-house knowledge and was provided at the start of the project. A calorific value of 1700 kcal/kg (≈1975,8 kWh/ton) for wet biomass (50-60% MC) was also provided at the start of the project.

However, many of the reference cases were performed before this project started and a calorific value for dry biomass of 3400 kcal/kg (≈3951,6 kWh/ton) was then used. This value is an estimation of the calorific value for biomass between 6-20% MC. Since the biomass at IKEA Industry's sites are either dry (8-10% MC) or wet (50-60% MC), a calorific value of 4700 kWh/ton should be used for dry biomass.

3 Gasification

Gasification of biomass has a long history. It has been around for centuries and played an important role during the time of second world war where access to petrol was limited. During that time gasification units where set up on cars to supply the engines with propellant, syngas. Syngas is also known as producer gas. That stopped after the end of the war because cheap petrol was again available on the open market. In the seventies interest for the gasification technique increased because of the oil crises and many different types of gasifiers were developed and put into use but none of them became a mature technology. Because of global warming and the will to produce green power out of biomass many companies provide gasification technology and a lot of effort is put into R&D.

3.1 Introduction to gasification

Substantially two different ways of using the produced syngas were analyzed. Partly gasification in combination with IC engines and partly gasification with subsequent combustion and steam turbines. Beside these technologies even combustion and ORC, gasification and gas turbines, gasification and steam turbines and finally gasification and fuel cells were studied.

Important parameters while studying these technologies are electricity efficiency (net output as % of biomass calorific value), investment level (€/kW), cost of generated electricity, feedstock limitations and flexibility and technology maturity. Almost all carbonaceous materials can be gasified, reaching from wood- to waste residues. The way gas is produced depends on the feedstock. The following subchapters will describe the different gasification processes.

3.2 The Gasification process

There are different approaches how biomass can be gasified depending on feedstock size and character (sawdust, pellets, briquettes, chips), moisture content, purity, ash-melting point and usage of the gas. What all technologies have in common is that the feedstock undergoes four phases where it through different chemical and physical reactions becomes syngas. These phases are shown below in Figure 3 on a downdraft gasifier. The first phase however is that the fed in biomass is dried until no moisture is left. Thereafter, in step two, pyrolysis takes place where a non-condensable gas, charcoal and tar is produced. During phase three, a part of the combustible gas and charcoal reacts with oxygen. This combustion takes place at temperatures between 500 and 1400 ºC and pressures ranging from atmospheric to 35 bars, supplying the entire process with heat and makes the process auto-thermal. How much oxygen that is needed depends on fuel parameters such as moisture content and the heat-loss during gasification. Regularly 60-70% for a stoichiometric combustion is added, i.e. a lambda value of 0.6-0.7. In the fourth and last phase hydrocarbons and charcoal are reacted with carbon dioxide and water producing carbon monoxide and hydrogen [4].

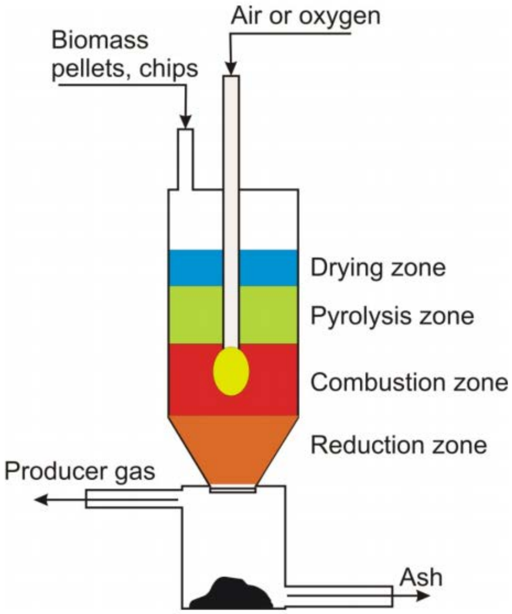

Figure 3 Schematic of a downdraft gasifier

3.3 Fixed Bed Gasifiers

3.3.1 Downdraft gasifier

In the downdraft gasifier the biomass is fed into the top of the gasifier. The top layer is dried in an almost oxygen free zone by the heat further down in the bed where the pyrolysis phase and even further down where the oxidation phase takes place. Air is provided from the top or from the side and moves in the same direction as the biomass and is led into the oxidation phase. Before the biomass, in form of ash, exits in the bottom of the gasifier the fuel traverses the reduction phase (phase with oxygen deficiency). The gas substantially produced in the pyrolysis phase through pyrolysis reaches high temperatures in the oxidation phase. These high temperatures can reach over 1000 ºC and contributes largely to that the gases have low tar contents [5].

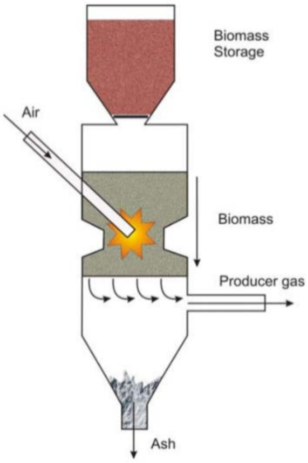

Figure 4 Schematic of a downdraft gasifier

3.3.2 Updraft gasifier

In an Updraft gasifier, the biomass is, similar to the downdraft gasifier, fed into the top of the gasifier. The major difference between this type and the downdraft gasifier is the way the gas is transported through the bed. That happens in the opposite direction, which means that air enters the gasifier at the bottom, where it is heated to high temperatures in the oxidation phase. That heat is used further up in the gasifier where it passes the reduction phase and the pyrolysis phase at temperatures around 200 ºC. The benefits of that technology are higher efficiency of gas production and lower requirements of feedstock quality. That means, biomass with higher levels of water content can be used. A great disadvantage is poor gas quality due to low temperatures at the gas outlet. The gas contains high amounts of tars and phenols [5].

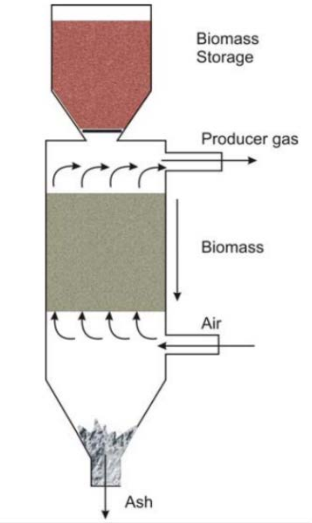

Figure 5 Schematic of an updraft gasifier

3.3.3 Crossdraft gasifier

The crossdraft gasifier is suitable for small syngas productions (<10kW) and for fuels with very low tar- and volatiles amounts, e.g. charcoal. It works with a fixed bed where the fuel enters from the top and exits as ash on the bottom. Air enters the gasifier from one side and exits as gas on the other perpendicular to the biomass flow [5].

3.4 Fluidized Bed Gasifiers

3.4.1 Bubbling fluidized bed gasifier

The ability to scale-up Bubbling fluidized bed (BFB) gasifiers in combination with low criteria on the feedstock regarding moisture- and ash content makes this technology suitable for larger installations.

The material that is fed into the gasifier is gasified in the fluidized bed. The fly ash produced in the gasification process leaves the gasifier together with the produced gas and is thereafter separated in cyclones. Bottom ash is fed out at the bottom of the gasifier. Since the temperature in the gasifier is relatively low the gas contains high amounts of tars [5].

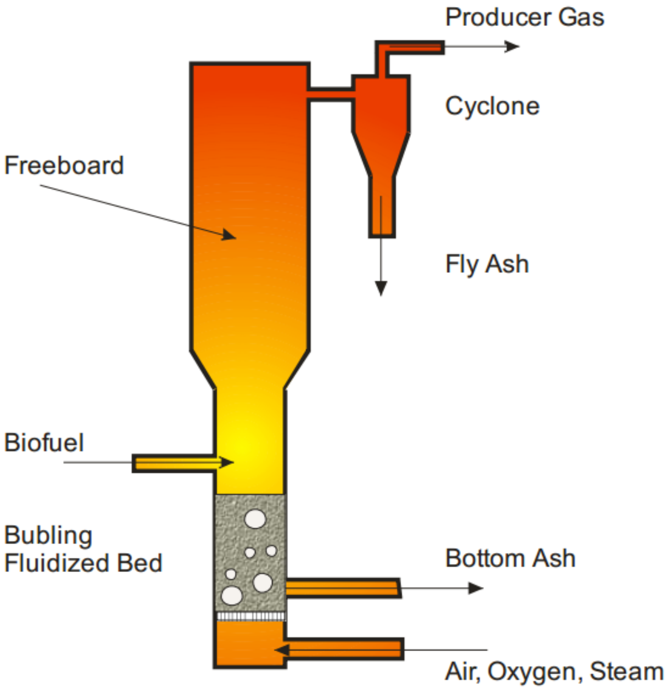

Figure 6 Schematic of a Bubbling Fluidized Bed gasifier

3.4.2 Circulating fluidized bed gasifier

The circulating fluidized bed (CFB) gasifier works similar to the BFB gasifier. The difference is that particles entrained with the produced gas are reversed back into the fluidized bed and not, as in the BFB gasifier, removed with the produced gas. The result is that the char, fed out in the bottom of the gasifier, has a bigger burnout. The produced gas contains lower amounts of tars compared with the tar content of the BFB gasifier [5].

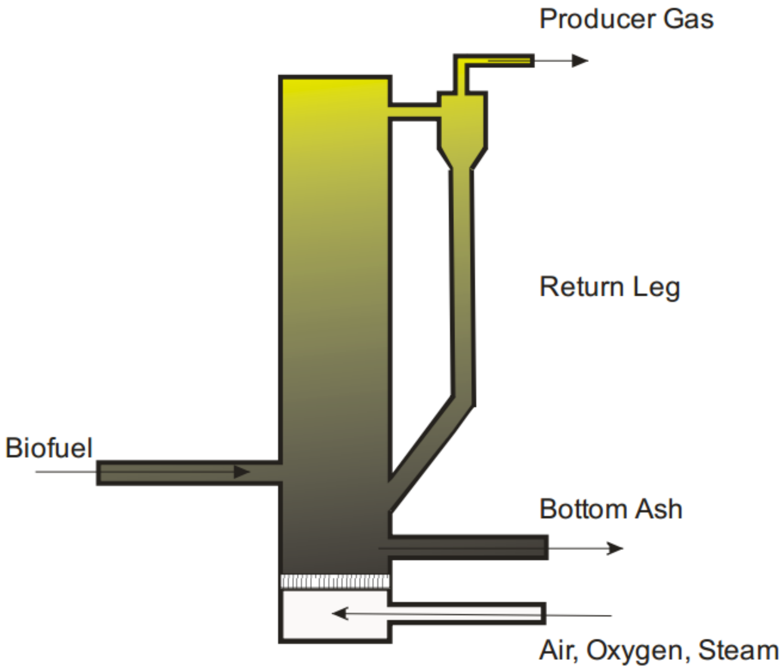

Figure 7 Schematic of a Circulating Fluidized Bed gasifier

3.5 Entrained-flow gasifier

In the Entrained flow (EF) gasifier, biomass is mixed with water to a slurry and injected into the gasifier where a pilot flame delivers heat for the gasification process. In some cases biomass is blown into the gasifier and water is sprayed in separately. The gasification process takes place under high temperatures around 1450 ºC. Due to these high temperatures most of the tars and lower hydrocarbons are converted. The produced gas is relatively clean and this minimizes the need for gas cleaning. The high temperature affects the ashes of the biomass and form slag. That slag is, depending of the gasifiers architecture, either cooled down and solidified by water jets after the feedstock has been gasified and thereafter removed after it ended up in a water bath in the bottom of the gasifier or solidified after it has drained down the gasifier walls ending up in a water bath were it due to the thermal shock is cracked into pieces and thereafter removed. A drawback of such high temperatures is that a large amount of feedstock is consumed to heat the gas which in turn leads to a lower efficiency. EF gasifiers are suitable for large applications (>100 MW_{th}) [5].

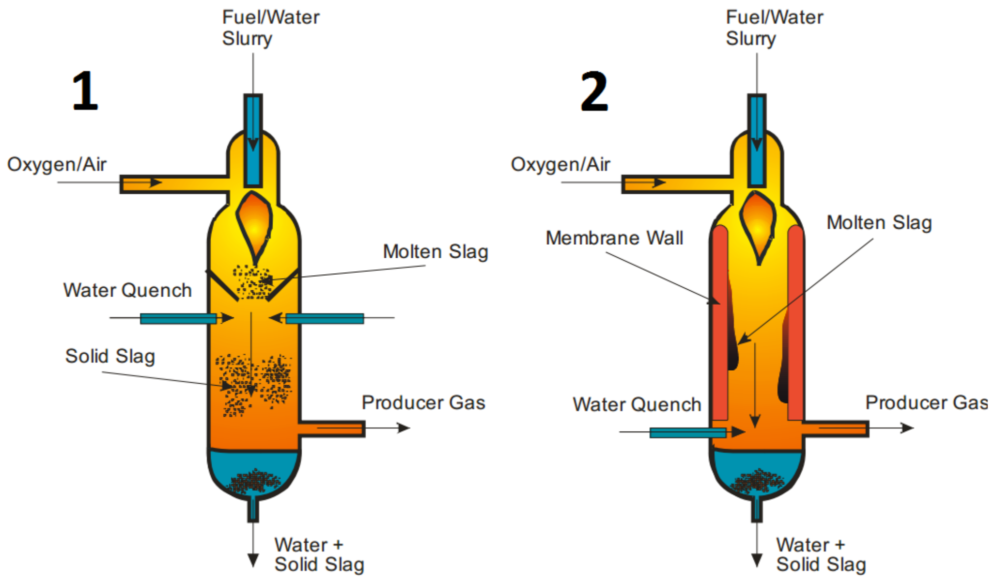

Figure 8 Schematic of Entrained-flow gasifiers

3.6 Plasma gasification

Plasma gasification is a more complex way to gasify carbonaceous waste materials. In general a plasma torch driven by an electric arc produces syngas and solid waste out of the feedstock. This occurs under very high temperatures reaching from 2200 to 13900ºC. The biggest advantage of this technology is that almost any material, even hazardous waste, can be gasified to a valuable syngas. The disadvantage is the very high investment cost [6].

3.7 Separate pyrolysis and char gasification

When gasifying biomass there is an ambition to produce as clean gas as possible to avoid or minimize gas cleaning. Separate pyrolysis and char gasification provides gas that needs low cleaning or no cleaning at all. There are several different designs for separate pyrolysis and char gasification. Figure 14 shows a typical design of such gasifiers. This gasifier is a two bed gasifier and known under the name Viking gasifier. Biomass is heated in a transport screw until pyrolysis starts. Thereafter the produced gas oxidates and the heat increases to above 1100ºC. After exiting the screw, the produced char falls down into a char bed where the hot gas gasifies it.

Another approach for separate pyrolysis and char gasification has been developed by a company named Cortus AB, the Woodroll gasifier. Here, biomass is fed into heated rotating drums where the pyrolysis takes place. Heat used for the rotating drums comes from the combustion of the pyrolysis gas and is done in a Kanthal-typ burner. The biomass than moves on as char is transported to a reactor where it is gasified.

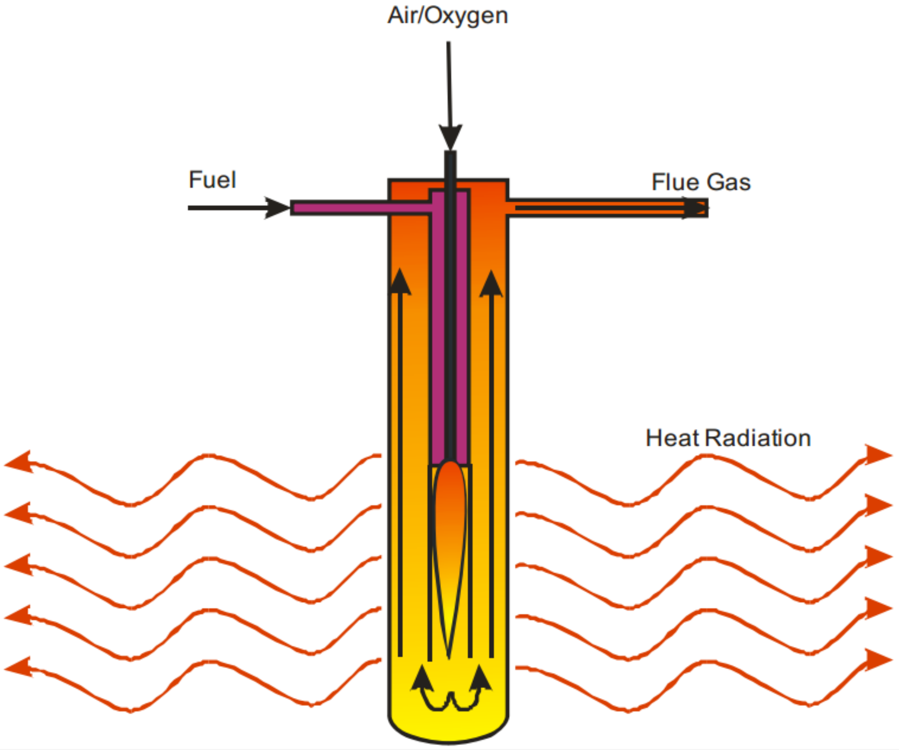

Figure 9 Schematic of Kanthal-typ burner

4 Case studies

Two case studies were performed during this project. The two visits are described below.

4.1 Cyclone gasifier

The Vipp Vortex cyclone gasifier was first developed by Luleå Technical University (LTU) and a first prototype was set up by the Energy Technology Center (ETC) in Piteå. Company A later purchased the rights for this technology and continues the development.

Company A´s demo facility in Hortlax was visited in the beginning of March 2015. The power plant was operating and delivering heat to the local district heating network. The produced syngas, aimed for the gas engine and power production was flared and not used in the IC engine. The gasifier has been operating for around 1000 hours at different times and the IC engine for around 30 hours at different times at the time of our visit.

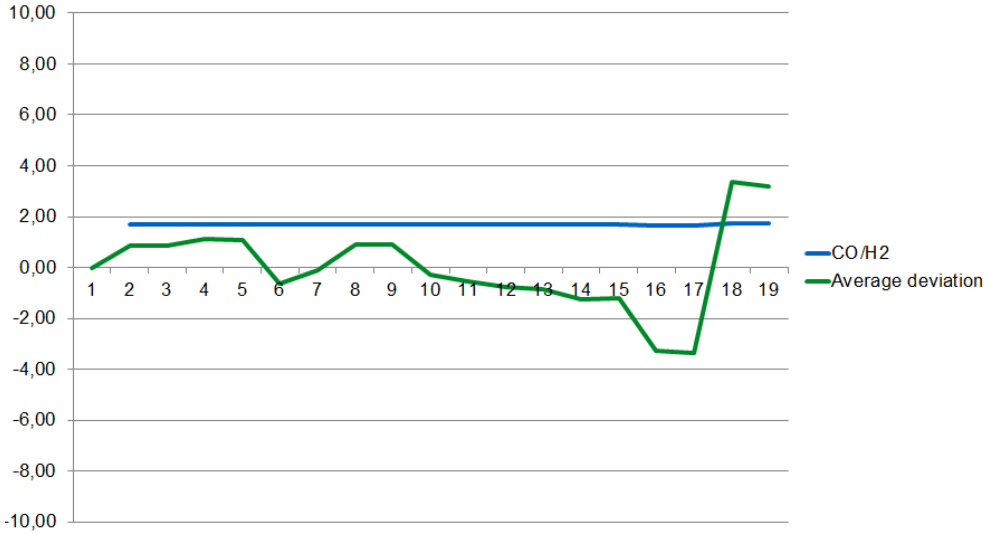

Figure 10 Samples taken at Hortlax 2015.03.02 and 2015.03.05. 19 in total

This gasifier works with fine particle biomass only, for example grinded pellets or sawdust. The biomass enters, under high velocity and temperature (around 900 °C), the top of the cyclone (Figure 11) where the pyrolysis starts. It thereafter moves down the cyclone in a helican pattern where the pyrolysis occurs. When the fuel reaches the bottom of the cyclone the fuel is totally gasified and only ash remains. The produced gas is lead up through the center of the cyclone while the ash is brought into a water filter. The gas produced by the Vipp Vortex gasifier is very constant regarding to the gas content, but not pure enough to be used in an IC engine at once. One reason is that the temperature in the gasifier is not high enough to crack all tars, and one reason is that the gas still contains ash that has not been divided from the gas in the cyclone gasifier. To remove these ashes and tars the gas traverses different gas cleaning stages. At first the produced gas is cleaned in a cyclone where particles heavier than the syngas are removed. Thereafter the gas is cleaned in an oil scrubber where tars and remaining particles are removed. In an final gas cleaning step an electrostatic precipitator removes the very last pieces of impurities. The ash produced in the process is recording to Company A free of hazardous substances. The cleaned gas is then send to a lean burn IC engine which is connected to a generator for electricity production. Company A started a cooperation with the engine manufacturer Cummins who also delivered the IC engine to the Hortlax facility. Regarding to Cummins it is of high importance for the engine, that the gasifier delivers gas of constant quality. They think that Company A´s produced gas delivers that. Figure 10 shows a sample of Company A gas quality.

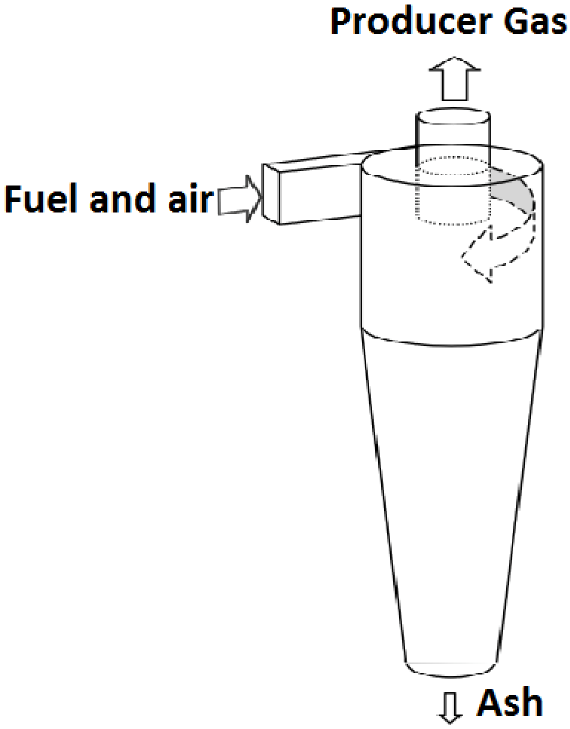

Figure 11 Schematic of a Cyclone gasifier

4.2 Viking gasifier

In the middle of January a visit at the pilot plant of Danmarks Tekniska Universitet´s (DTU) Viking gasifier in Risö, Denmark was made. The gasifier is fully developed by DTU and was commissioned in 2002. It is a small scale gasifier with a thermal output of 65kW and an electrical output of 20kW. The IC engine is a diesel engine converted to a lean burn gas engine. As feedstock, woodchips are used. The first year the demo plant was operating for about 2200 hours, producing 37 MWh of electricity.

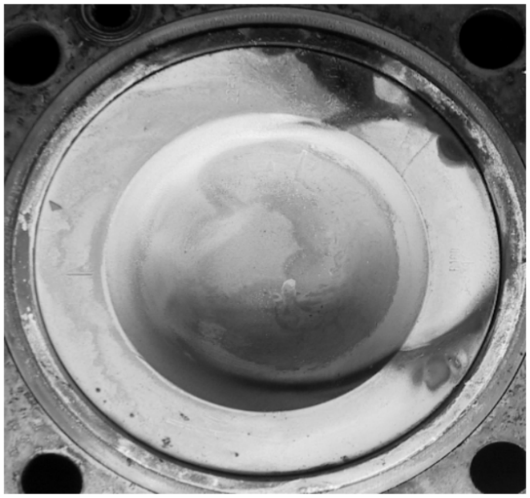

Figure 12 Picture of cylinder top after 1400 hours of operation.

The gasification process is based on a two stage gasification process. Char gasification and pyrolysis occur in two different stages and reactors. Woodchips are transported in a heated transport screw where the temperature increases successively. The heat used in the transport screw is taken from the gasification process. In between these reactors the pyrolysis product is partially oxidized which increases the temperature to over 1100 ºC, which in turn leads to decomposition of tars. This hot gas thereafter passes the char bed and gasifies it. The gas is thereafter cooled with heat exchangers and cleaned by filters to remove particles before entering the gas engine. Heat produced in the gas engine can also be recovered.

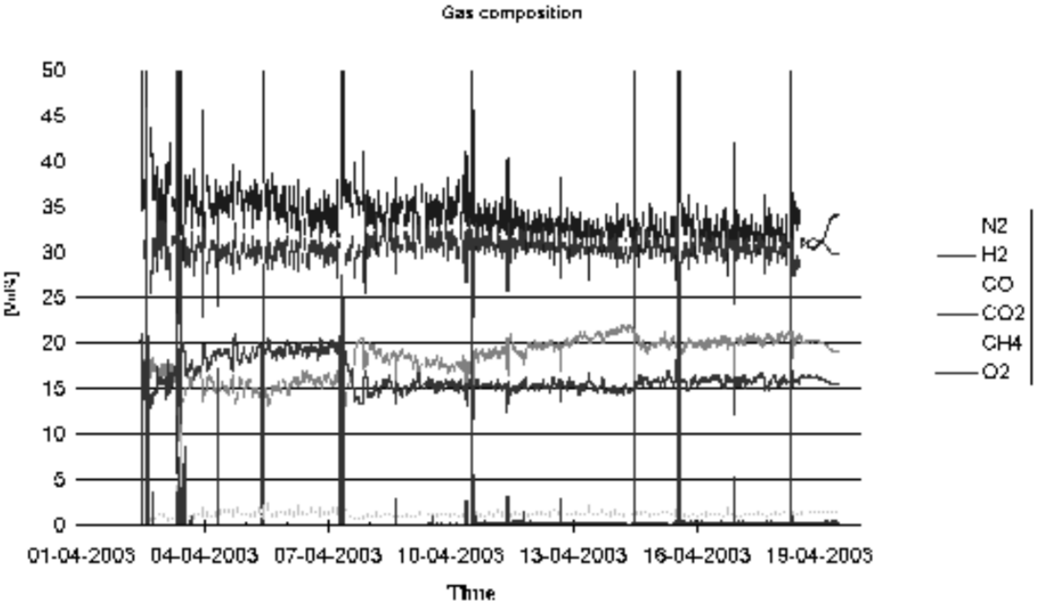

Figure 13 Gas quality during a 400 hour test run in April 2003

The Viking gasifier has been commercialized by the company Company G in different sizes. One power plant has been constructed in Hilleröd, Denmark. Unfortunately it wracked and it is not sure when it will be operating again. For the moment Company G does not provide the Viking gasification system. The future for the Viking gasifier seems, regarding to Company G, uncertain.

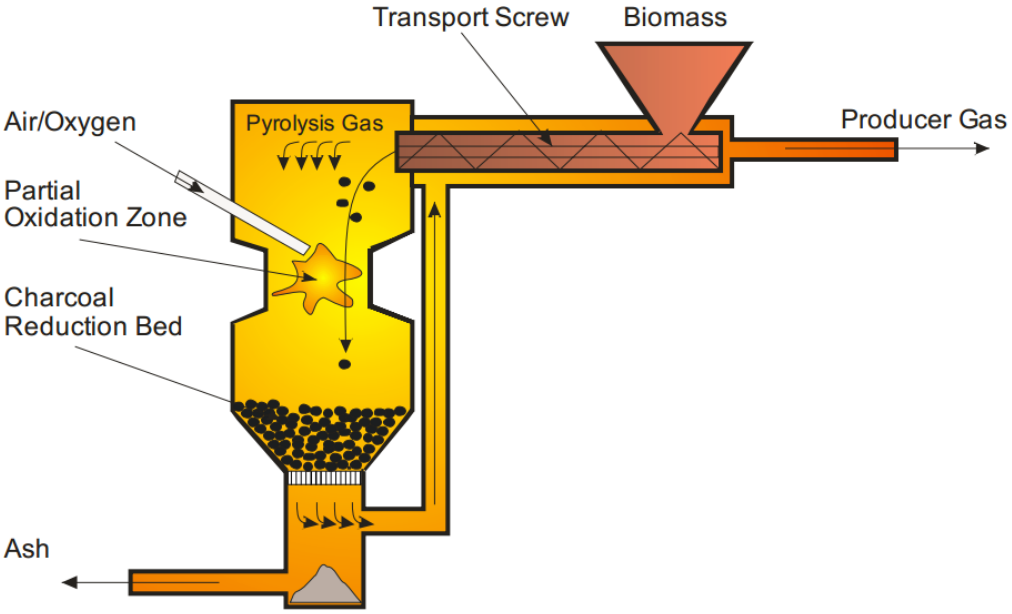

Figure 14 Schematic of the Viking gasifier

5 Gas cleaning

The goal for all gasification processes is to produce as clean gas as possible. In some cases it is enough to use simple bag filters to extrude fine particles but in most cases a more complex gas cleaning process is necessary to supply a clean gas. Most gases leaving gasifiers contain dust, ash, tars and other contaminations.

There are many ways to extract these contaminations and the most common techniques used today are cyclones, dust filters, oil scrubbers and electrostatic precipitators.

5.1 Ash and dust

5.1.1 Cyclones

Cyclones separate particles with a higher density than the gas used in the cyclone. The polluted gas is led into the top of a cyclone where it creates a strong vortex. Everything more dens than the gas itself is, because of the centripetal force, pushed through the cyclones inner surface. In the bottom of the cyclone these dens particles are transported to a deposit while the cleaned gas travels upwards through a tube in the center of the cyclone. Cyclones remove particles in the sizes from 1 mm down to 5 µm. Cyclones operates at temperatures up to 500 ºC [7].

5.1.2 Baghouse filter

There are many different designs and materials used for baghouse filters. The most common baghouse filters are long cylindrical tubes made out of woven or felted fabric. The polluted gas is led through filters were particles are separated from the gas. Particles stuck on the fabric will loosen and fall down from the surface when enough dust is stuck on it. Most baghouse filter systems are vibrated or back flushed to remove the buildup material (Filter Cake). These filters operate in a temperature range reaching up to 350 ºC [8].

5.1.3 Candle filters

Candle filters work the same way as baghouse filters but instead of fabrics they are made out of a porous ceramic or metallic material. These filters can be operated in a temperature range reaching up to 500 ºC [5].

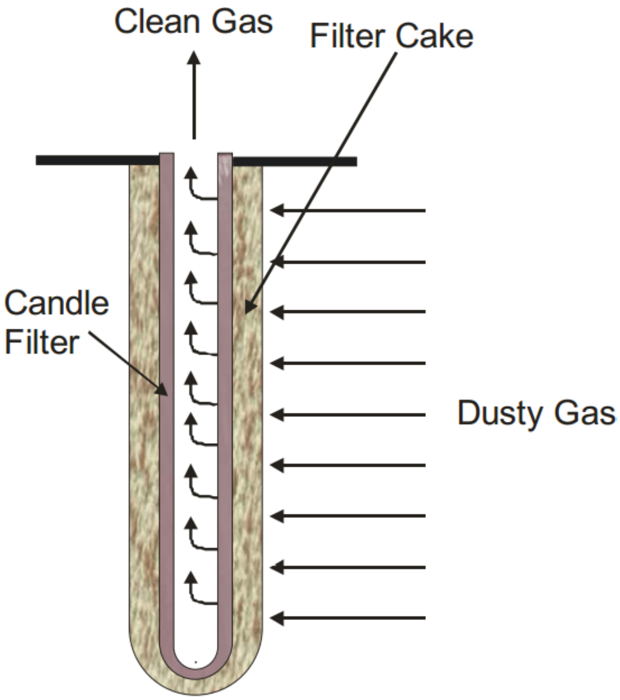

Figure 15 Schematic of a Candle filter

5.1.4 Electrostatic Precipitator

Electrostatic Precipitator filter devices separate particles from gas by using the force of an induced electrostatic charge. When dust particles pass an electrode, they receive a negative charge. These charged particles are thereafter attracted to a positive charged collector electrode. To avoid failure the collector electrode needs to be cleaned either by vibrating or by using an automatic brush on the surface to remove particles. Electrostatic precipitators operate in a temperature range reaching up to 400 °C [5].

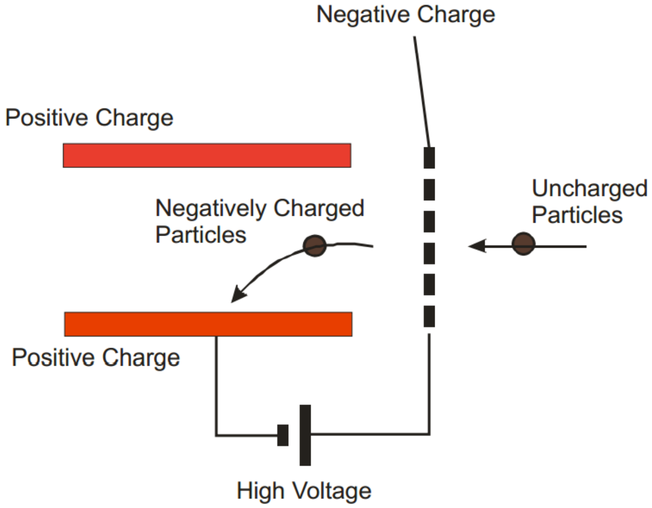

Figure 16 Schematic of an Electrostatic Precipitator

5.2 Tar cleaning

The biggest issue when producing syngas is the presence of tars. To commercialize gasification plants, the problem of separating tars must be solved. There are many different tar cleaning systems on the market. The most important thing is however to adjust the gasifier, so that it produces the lowest amounts of tars as possible. It is possible to produce gases where the content of tars is very low, for example in the entrained flow (EF) gasifier. These techniques require high temperatures during the gasification process and therefore a greater use of the chemical bound energy embedded in the feedstock which in turn leads to lower efficiencies.

5.3 Scrubber

There are bio-oil scrubbers on the market which cool down the produced gas until the gas reaches the condensing temperature of tars included in the gas. When the tars condense they are dissolved in the bio-oil. The bio-oil thereafter can be cleaned in a centrifuge and be reused. Tars contain high amounts of energy and can be burned in boilers.

5.4 Thermal reforming

By heating the produced gas, tar can be reformed to CO and hydrogen. This technique requires high temperatures, around 1300 ºC, and is therefore very energy consuming. Such a cleaning device could decrease the overall efficiency of a power plant [4].

6 IC Engines

The use of IC engines connected to generators in gasification applications is common. Today gas is used in IC engines for cars and busses. The Swedish Environmental Protection Agency claims that biogas driven engines reduces CO_2 emissions with 81% and engines operated by natural gas with 26% compared with engines running on gasoline [9].

Figure 17 Picture of a Jenbacher Type 6 gas engine

6.1 Engine efficiency

Engine efficiency can be alienated in four categories. Combustion efficiency, thermodynamic efficiency, gas exchange efficiency and mechanical efficiency [5].

6.1.1 Combustion efficiency

If the combustion of the injected fuel is not complete, parts of the exhaust gas will contain energy. To reach a high combustion efficiency it is of importance that as much of the fuel is converted into heat by combustion as possible. Diesel engines usually have a combustion efficiency higher than 99% while spark ignited engines have an efficiency between 90-95%.

6.1.2 Thermodynamic efficiency

Heat created through combustion is converted to mechanical work by a thermodynamic cycle. The theoretic maximum for thermodynamic efficiency is around 85% but applied efficiencies are not higher than 40% for spark ignited engines and 50% for diesel engines can be reached. The reason why the efficiency is so low are heat losses through the cylinder walls and heat leaving the engine as warm exhaust gas. In a stationary application these heat losses can, in some cases, be used for district heating and thereby increase the overall efficiency [5].

6.1.3 Gas exchange efficiency

After combustion the combusted gas is replaced with a new mixture of fresh air and gas. The energy needed to do so is the gas exchange efficiency. Gas exchange efficiency normally lies around 85-95% [5].

6.1.4 Mechanical efficiency

The friction that arises inside the engine, between different engine parts, consumes some of the engines power [5]. So does even auxiliaries such as oil pump, water pump etc. At full load efficiencies of 95% are possible.

6.1.5 Break efficiency

Break efficiency [5] is the total efficiency when taking all four above mentioned efficiencies into account.

6.1.6 Exhaust gas cleaning

To reduce harmful emissions, in a stoichiometric running engine, the exhaust gas can be treated with a three way catalytic converter reducing CO, HC and NO_x where CO and HC are oxidized with O_2 and NO_x is reduced with CO and HC due to catalytic reactions. Lean burn engines operate at lower temperatures which results in lower NO_x emissions [10]. Under some circumstances there are low amounts of CO and HC in the exhausted gas which makes reduction with these bonds difficult. In such cases a three way catalytic converter does not work and catalytic converters using urea injection or passive ammonia has to be used [11].

7 Other concepts

7.1 Syngas in gas turbines

Besides using syngas in IC engines there are other concepts. There have been attempts to use the produced gas in gas turbines. In Värnamo, Sweden, the world’s first complete IGCC Power Plant was built in the middle of the nineties. The gasifier was a pressurized fluidizing bed gasifier. It was meant to produce 6 MW_{el} and 9 MW_{th} from a fuel equivalent of 18 MW. Due to high problems with impurities in the gas this IGCC Power Plant was shut down a few years later. A great advantage of this technology would be high electrical efficiency.

7.2 Syngas and steam cycle

There are also setups where the syngas is burned in boilers to produce steam to operate a steam turbine. The major advantage when doing so is that gas cleaning gets unnecessary because the impurities are burned. This does also reduce the impurities in the exhaust gas.

7.3 Syngas for heat only Production

Besides using syngas for electricity production there are applications where the produced gas is burned in boilers and used for district heating. This way of utilizing the produced gas needs no cleaning before entering the boiler.

7.4 Syngas with IC engines and Organic Rankine Cycle

After the syngas has been burned in an IC engine the heat produced in the process can be recovered and used in an Organic Rankine Cycle (ORC). Regarding to INMIS Energy [12] a reciprocating engine connected with an ORC can increase the total electrical output with between 7-12%.

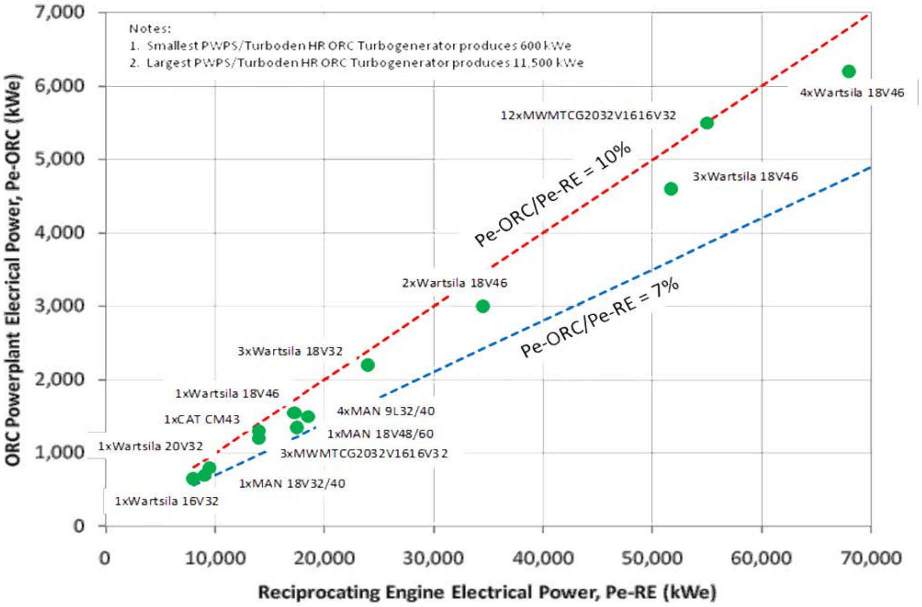

Figure 18 Reciprocating Engine Power output vs ORC Power output

7.5 Syngas and fuel cells

Fuel cells [13] generate electricity through a chemical reaction. Fuel is oxidized with an anode and reduced with a cathode. In between the anode and cathode the electrolyte is placed. The electrolyte consists of a substance that can conduct current and is designed so positive charged ions can pass it but negative charged electrons cannot. The electrons are led through a wire creating an electrical current. At the cathode ions and electrons unite and react with a third chemical and create water or carbon dioxide. The most common fuel for fuel cells is hydrogen and that is also what is produced in the gasification process.

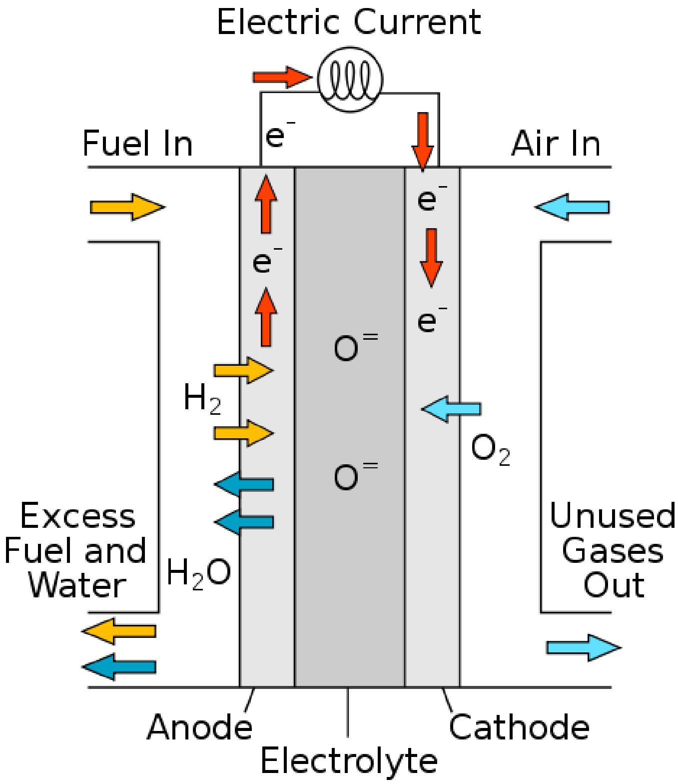

Figure 19 Schematic of a Fuel Cell

8 Steam power plant

Conventional combustion in a boiler where steam is used to power a steam turbine is an option for IKEA Industry to utilize the excess biomass. The technology is well proven and is considered to be in a mature state. A combined heat and power (CHP) plant is a plant that simultaneously generates useful heat and power in a single process.

The layout consists of a closed loop where usually water is used as a working fluid. Fuel (e.g. biomass) is combusted in a boiler adding heat to the process. The heat addition transforms the fluid to vapor, while the pressure of the fluid remains constant since the fluid is free to expand in the exchanger tubes.

The vapor enters a steam turbine where it expands causing the turbine to rotate. The turbine is connected to a generator producing electrical power. The aim when only producing electricity is to generate as much kinetic energy as possible in the turbine causing the vapor to have as low temperature and pressure as possible at the outlet. At a combined heat and power plant the process is balanced differently due to the value of the heat. The vapor is then allowed to leave the turbine at higher temperatures and the heat is later transferred to e.g. district heating or industrial process needs.

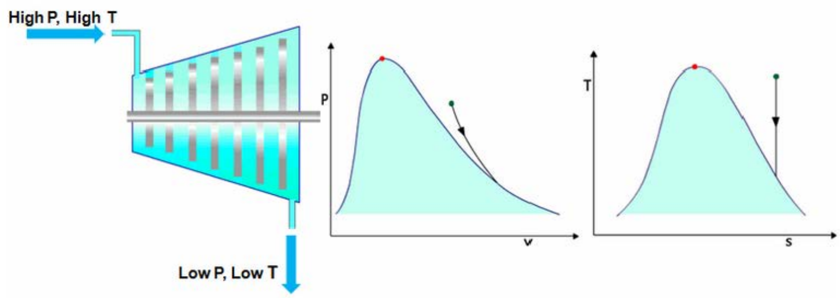

Figure 20. P-v and T-s diagram over the turbine process

A condenser is used after the turbine to transform the vapor back to liquid. Ideally there is no change in pressure during this process since the fluid is free to expand in the condenser. Cooling towers are an option to reject heat if only power is produced. Cooling towers absorb heat in the condenser and reject it to the surroundings by natural convection. The pressure in the condenser is connected to the cooling water temperature according to the vapor pressure curve.

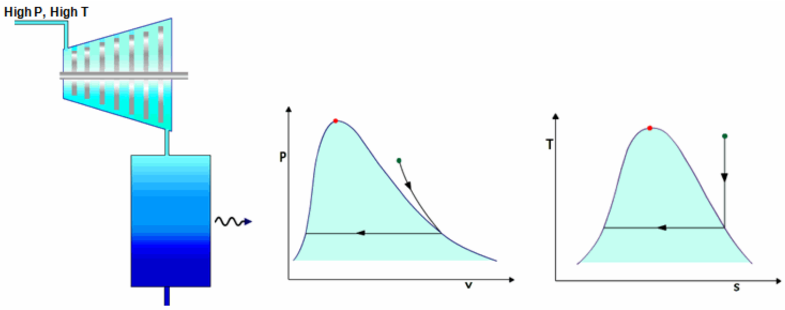

Figure 21. P-v and T-s diagram over the turbine and condenser process

The fluid is then returned to the boiler by a feed water pump raising the pressure and the cycle can start all over again. Figure 22 below illustrated a simple example of the described process. Feed water heaters can be used to utilize the waste heat from the turbine and thus improve the thermodynamic efficiency.

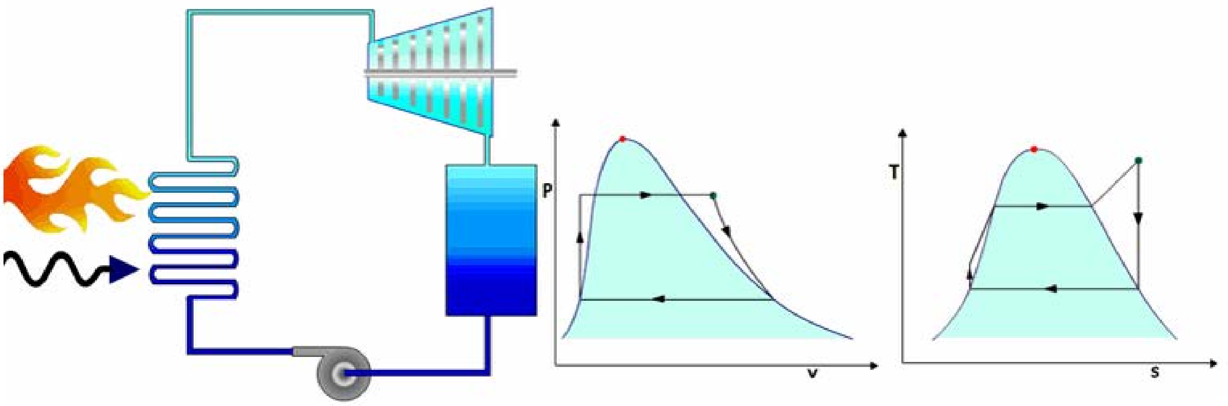

Figure 22. An illustration of full process and associated P-v and T-s diagram. [xx]

There are various parameters that can be optimized to reach a higher efficiency of the process. The second law of thermodynamics puts a limit on the thermal efficiency of the system according to:

$$\eta_c = 1 - \frac{T_1}{\mathrm{T}_m}$$

Where T_1 is the cooling water/ air temperature that is available for a specific location and T_m is the average temperature of the heat absorption for the system. The formula states that there are two ways to increase the efficiency; either to decrease T_1 or to increase T_m. The temperature of the coolant T_1 is usually fixed since this is equal to the surrounding water/ air temperature. The other option is to increase the average temperature T_m and there are a few ways to do so.

It is possible to increase the temperature by superheating the steam. In theory a higher temperature leads to a higher efficiency but this option is limited by material properties.

Another way to increase the electrical efficiency is to maximize the expansion of the vapor in the turbine and thus extract as much energy as possible from the vapor. It can be dangerous to expand the steam in the turbine to such an extent that the vapor reach saturation point. Condensed water droplets will then collide with the rotating turbine blades causing tip erosion to the blade. Up to 15 % wetness level is considered safe for steam turbine operation [14].

8.1 Boilers

There are several boiler types on the market and the most common ones are described below.

8.1.1 Fluidized beds

There are two main types of fluidized bed boilers, bubbling- and circulating fluidized beds. The choice between the two is not always obvious and decisions should be based on case-by-case basis. One benefit with fluidized bed combustion (FBC) is the wide variety of available fuel. Another benefit is the low emissions of nitric oxides and the possibility to remove sulfur by mixing limestone with the bed material. Fluidized bed combustion takes place at temperatures between 750-900 °C, which is well under the temperature for formation of nitrogen oxides (app. 1400 °C) [15]. This also avoids ash melting problems related to higher combustion temperature. There are two major groups of FBC systems; atmospheric- and pressurized systems. The first operate at atmospheric pressure while the later work at elevated pressure.

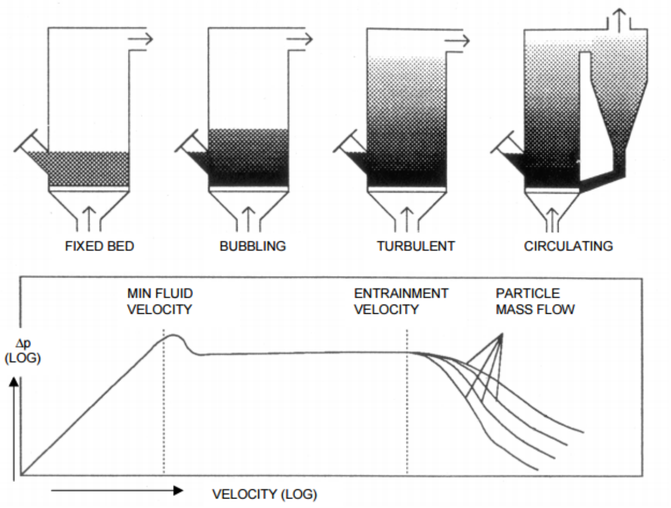

Figure 23. Different type of fluidized bed systems.

8.1.1.1 Circulating fluidized bed

A Circulating fluidized bed (CFB) is a bed of solid and inert particles that gets supplied with a stream of air from under the bed at high pressure. This causes the bed materials to lift and act like a bubbling fluid. The air velocity applied depends on size of fuel particles and density of air fuel mixture [16]. Fine particles of partly burned fuel, ash and bed materials are carried upwards in the furnace and led into a cyclone where heavier particles gets separated from the gas. The heavy particles are then returned to the furnace and used again as bed material. The bed material is usually sand mixed with ash from the combusted fuel. A major benefit with CFB is the great fuel flexibility and fuels with a wide range of heating values and properties can be used [17]. A CFB has the following advantages compared to the latter described BFB technology [18].

- Higher combustion efficiency
- Lower NO_x emissions
- Quicker response to load changes
- Lower consumption of limestone as bed material to remove

8.1.1.2 Bubbling fluidized bed

Bubbling fluidized beds (BFB) is often used in relatively small-scale applications with fuels with low heating value and high moisture content [18], [19]. The principal of a BFB is similar to a CFB but the air velocity applied from under the bed is lower. This causes the bed materials to remain in the lower part of the furnace.

8.1.2 Stoker grate boilers

Grate firing is a combustion system used for solid fuels. There are three main types of grates; travelling, reciprocating and vibrating grates and general capacity ranges from 0,3 to 175 MW_{th} [20]. All grates work with the same principle of mechanically transport the fuel from one side of the boiler to the other. This creates uneven burning of the fuel. This uneven combustion creates higher emissions and a higher content of unburned fuel in the ash which will decrease the boiler efficiency compared to the FBC technology [19].

8.1.3 Pulverized fuel boiler

The principle of a pulverized fuel (PF) boiler is to use the whole volume of the furnace for combustion of solid fuels. PF technology with coal as fuel is well proven and the system has many advantages such as varying quality of fuel and quick response to load changes [21]. The fuel is grinded into fine powder before it is blown in into the furnace by multiple nozzles.

8.1.4 Boiler differences

The difference between stoker grates boilers and fluidized bed boilers are illustrated In Table 3 below.

Table 3. Differences between stoker grate- and fluidized bed boilers. Performed by U.S Environmental Protection Agency.

Feature	**Stoker boiler**	**Fluidized bed boiler**
Common fuel types	Sawdust, bark, chips, hog fuel, shavings, end cuts, sander dust	Wood residue, peat, wide variety of fuels
Feed size	6,4-50,8 mm // 0,25-2 in	<50, 8 mm // <2 in
Moisture content	10-50%	<60%
Capacity range	4 to 300 MW (manly in the 20 to 50 MW range)	Up to 300 MW (manly in the 20 to 25 MW range)
Combustion mechanism		
Flow of solid fuel	Transported on stoker	Fluidized by combustion air and circulated through the combustion chamber and cyclone
Combustion zone	On the stoker	Entire area of the combustion furnace
Mass transfer	Slow	Active vertical movement-mass and heat transfer
Combustion control		
Responsiveness	Slow response	Quick response
Excess air control	Difficult	Possible
Fuel issues		
Applicability to various fuels	Fair	High
Fuel pretreatment	Generally not possible	Lumps must be crushed
Environmental factors		
Low sulfur oxide (SO_x) combustion	In-furnace desulfurization not possible	High rate of in- furnace desulfurization
Low NO_x combustion	Difficult	Inherently low NO_x
Appropriate facility size	small	Medium to large

8.2 Organic Rankine Cycle

An Organic Rankine Cycle (ORC) works in the same way as the describes steam turbine cycle but use organic working fluids that have lower boiling points and higher vapor pressure than water. This allows ORCs to operate at lower temperatures. An ORC can be used instead of a steam turbine in a biomass fired CHP plant but can also be used in combination with a steam turbine. The waste heat from the steam cycle power production is then used to heat the working fluid in the ORC cycle as shown in Figure 24 below. The heated working fluid will then continue the cycle described in the beginning of chapter 8 and produce electricity. There are over 175 biomass fired ORC plants installed in Europe today [22]. The electrical efficiency of a biomass powered ORC is relatively low. Elforsk, the Swedish electricity industry R&D company, have estimated an electrical efficiency of 13 % when performing their calculations [22]. The technology is also relatively expensive, which can be seen in chapter 9.5 where cost/kWh is presented.

The general idea with waste heat ORC is to utilize heat that otherwise would go to waste. The waste heat can come from e.g. a factory process or from power turbines. Several Swedish industries use that technology [22]. This technology could be an alternative for IKEA Industry to utilize waste process heat, but it is not directly connected to available biomass and a solution with a waste heat ORC is therefore excluded in this report.

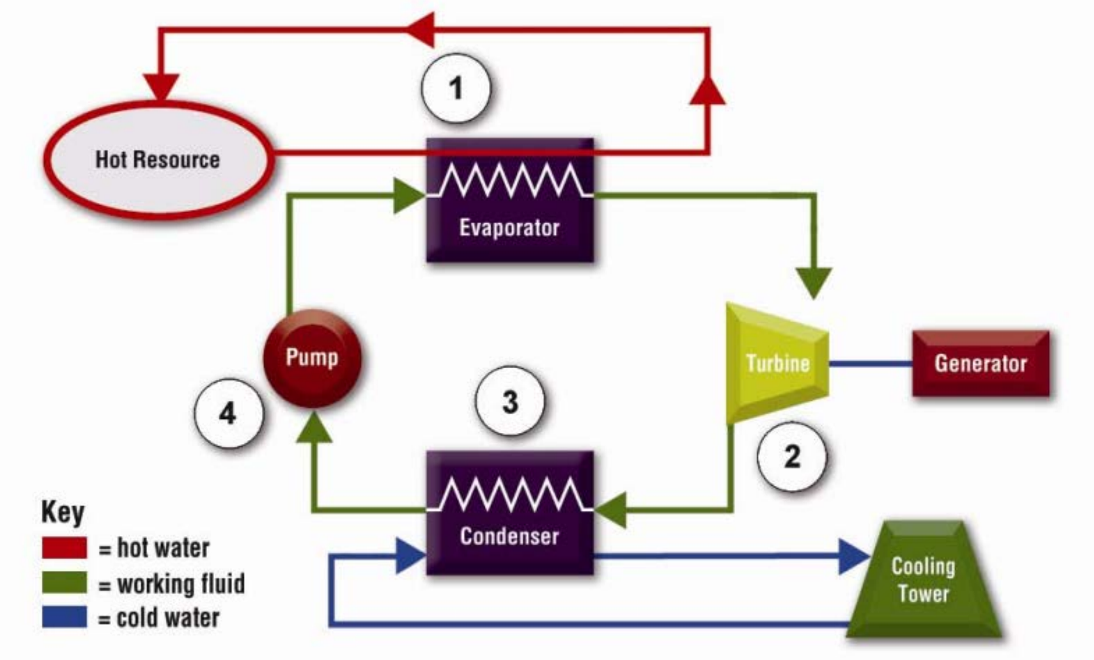

Figure 24. Simple layout of a Organic Rankine Cycle

9 Result

9.1 Weighting matrix

A quality function deployment (QFD) is used to rank the different companies in the technology matrix. The result is a weighting matrix where IKEA Industry's needs are transformed to quantitative parameters. The following parameters where used when the weighting matrix was developed.

- Low initial cost
- High electrical efficiency
- Mature technology
- Feedstock match
- Validation of provided information

IKEA Industry have provided an estimated value between 1-5 for every parameter. The value 5 is the highest attainable and the value 1 is in contrary the lowest. The weighting matrix does not include all alternatives that are presented in the technology matrix. The reasons for exclusion are varying but the common factor of the disqualified companies is that they are not an option for IKEA Industry.

The companies in the weighting matrix are rated after how well they respond to the above mention parameters. The rating guidelines are presented in Appendix A for further studies. IKEA Industry's value for a parameter is multiplied with the value attained by a specific company for the same parameter. The total points are summed and the total score is presented to the right in the matrix. The *total score with IKEA Industry values* is, as the name suggest, the total score when IKEA Industry's valuation of the parameters are taken into account. The column *total score* is the total score without the impact of IKEA Industry valuation.

The companies with the highest score in both categories, gasification and combustion, where highlighted in the weighing matrix. Yellow for gasification and green for combustion. A discussion regarding the results of the weighting matrix is available in the chapter 10.

A technology matrix was used to compile the provided information from the contacted companies. This matrix is presented in Appendix B.

	IKEA Industry needs	low initial cost	High electrical efficiency	Mature technology	Feedstock match	Validation of provided information		
Companies	Value 1-5	4	3	5	2	2	Total score with IKEA Industry values	Total score
Company A		4	4	3	5	4	61	20
Company B E3		3	2	4	3	4	52	16
Company B E3x36 modified		3	2	4	3	4	52	16
Company B 400 kW		1	4	4	3	4	50	16
Company C, steam turbine		2	3	4	5	3	53	17
Company D, P5		1	1	3	4	2	34	11
Company D, W15		1	5	3	4	2	46	15
Company E		2	5	2	4	3	47	16
Company F, Gasification		4	5	4	5	5	71	23
Company F, Combustion		5	4	5	5	5	77	24
Company G, Combustion		2	3	3	5	3	48	16
Company H, combustion		3	3	5	5	5	66	21
Company H, gasification		2	4	4	3	4	54	17
Company J, Harbore case		1	2	5	5	4	53	17
Company K		3	5	4	3	3	59	18
Company I		3	3	4	4	2	53	16

9.2 Investment calculations

A high level investment calculation, based on Company A´s spread sheet, was made with variable costs in the categories prices for biomass, heat value and energy certificate. All other costs where fixed and not changed.

Depending on geographical location and IKEA division, prices for biomass, heat value, energy certificate, power selling value and power consuming value vary and therefor effect the payback time (PB) and the net present value (NPV). For that reason a study was made with varying costs in the categories biomass cost per ton, heat value and energy certificate. The categories power selling values and power consuming values where not changed. The first three tables and graphics (Scenario 1-3) are considered to be examples for division Flatline with a lower cost for biomass, due to contaminations, while the last three tables and graphics (Scenario 4-6) are considered to be for division Solid Wood with a higher pricing level for the biomass. For every table three different scenarios where made to clarify how big impact the change of each parameter would get. Every case is divided in three additional cases where the power plant is meant to produce heat and electricity at 50 (green staple), 70 (red staple) and 90 (blue staple) percent of its uptime. The uptime rate also effects the PB and the NPV. The NPV is calculated for a time range of 15 years.

A discussion regarding the results of the investment calculations is available in chapter 10.

Table 4 shows Scenario 1 where cost of biomass per ton was given three different prices. No other values where changed. Figure 25 shows how PB and NPV changes in these three different cases. All cases except of Case 2 and Case 3 with an uptime of 50 percent gives a positive NPV which means that an investment would be profitable.

Table 4 Flatline Biomass cost per ton 10, 15, 20.

Scenario 1	Biomass cost per ton EUR/ton	Heat value EUR/MWh	Energy Certificate EUR/MWh	Power selling value EUR/MWh	Power consuming value EUR/MWh
Case 1	10	20	20	50	75
Case 2	15	20	20	50	75
Case 3	20	20	20	50	75

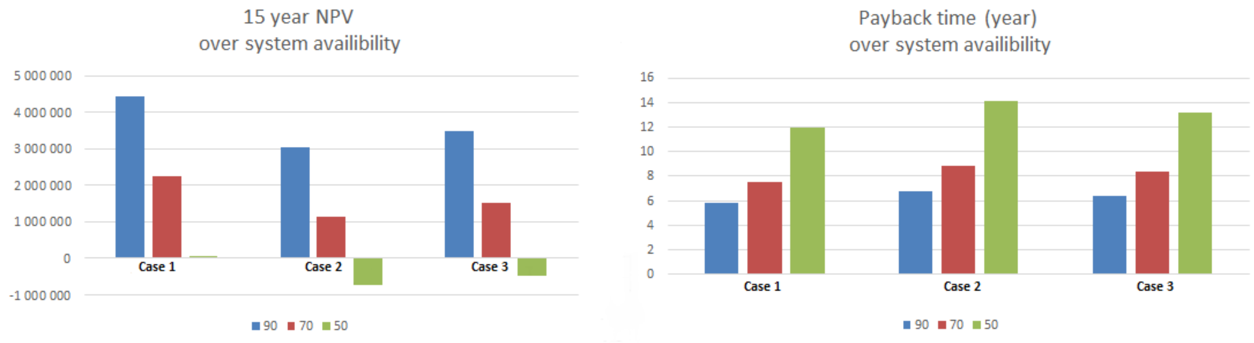

Figure 25 Flatline Impact of changes in biomass cost.

Table 5 shows Scenario 2 where the economic value for heat has been changed. No other values where changed. Figure 26 shows how PB and NPV changes in these three different cases. Case 3 is profitable and only uptimes of more than 50 percent gives a positive NPV for Case 2. Case 1 is not profitable and the PB for 50 and 70 percent uptime is so long it did not fit in the graph. This Scenario gets the shortest PB of all scenarios (under 4 years) in Case 3 with a high heat value.

Table 5 Flatline Heat value 0, 20, 40.

Scenario 2	Biomass cost per ton EUR/ton	Heat value EUR/MWh	Energy Certificate EUR/MWh	Power selling value EUR/MWh	Power consuming value EUR/MWh
Case 1	15	0	20	50	75
Case 2	15	20	20	50	75
Case 3	15	40	20	50	75

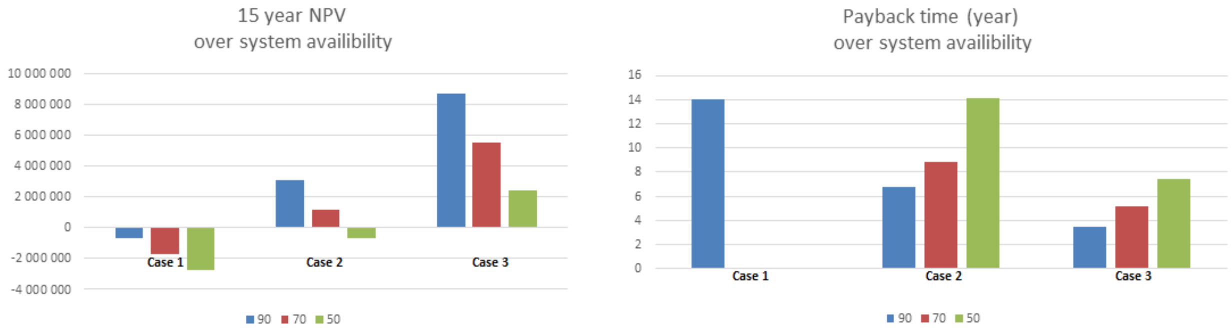

Figure 26 Flatline Impact of changes in heat value.

Table 6 shows Scenario 3 where values for energy certificates where changed. No other values where changed. The NPV shown in Figure 27 is negative with an uptime of 50 percent in Case 1 and Case 2, making these scenarios not profitable. All other cases and uptimes have a positive NPV and are profitable.

Table 6 Flatline Certificate 0, 20, 40.

Scenario 3	Biomass cost per ton EUR/ton	Heat value EUR/MWh	Energy Certificate EUR/MWh	Power selling value EUR/MWh	Power consuming value EUR/MWh
Case 1	15	20	0	50	75
Case 2	15	20	20	50	75
Case 3	15	20	40	50	75

Figure 27 Flatline Impact of changes in energy certificate.

Table 7 shows Scenario 4 where cost of biomass per ton was given three different prices. No other values where changed. Due to the high biomass cost per ton only case 1 with an uptime of 90 percent gets a positive NPV in Figure 28 and is therefore profitable.

Table 7 Solid Wood biomass cost per ton 50, 70, 90.

Scenario 4	Biomass cost per ton EUR/ton	Heat value EUR/MWh	Energy Certificate EUR/MWh	Power selling value EUR/MWh	Power consuming value EUR/MWh
Case 1	50	20	20	50	75
Case 2	70	20	20	50	75
Case 3	90	20	20	50	75

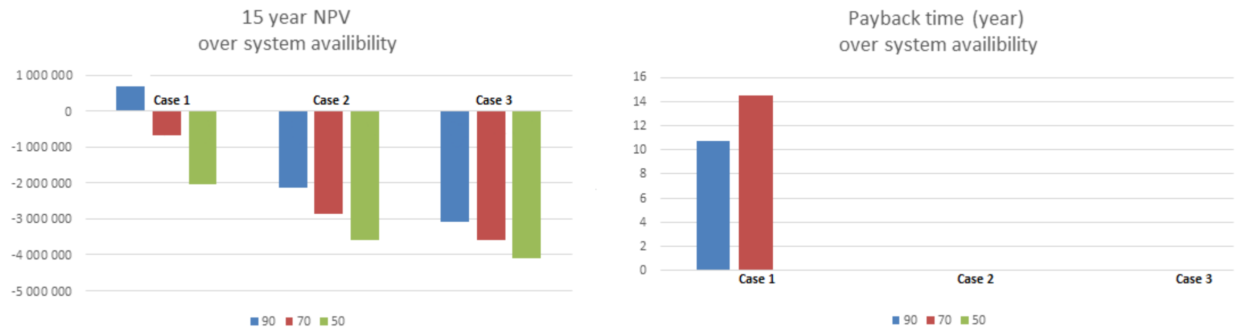

Figure 28 Solid Wood Impact of changes in biomass cost.

Table 8 shows Scenario 5 where the values for heat has been changed. No other values where changed. Figure 29 shows that Case 1 and Case 2 gets negative NPV´s for all uptimes. Case 3 has got a positive NPV for uptimes greater than 70 percent.

Table 8 Solid Wood heat value 0, 20, 40.

Scenario 5	Biomass cost per ton EUR/ton	Heat value EUR/MWh	Energy Certificate EUR/MWh	Power selling value EUR/MWh	Power consuming value EUR/MWh
Case 1	70	0	20	50	75
Case 2	70	20	20	50	75
Case 3	70	40	20	50	75

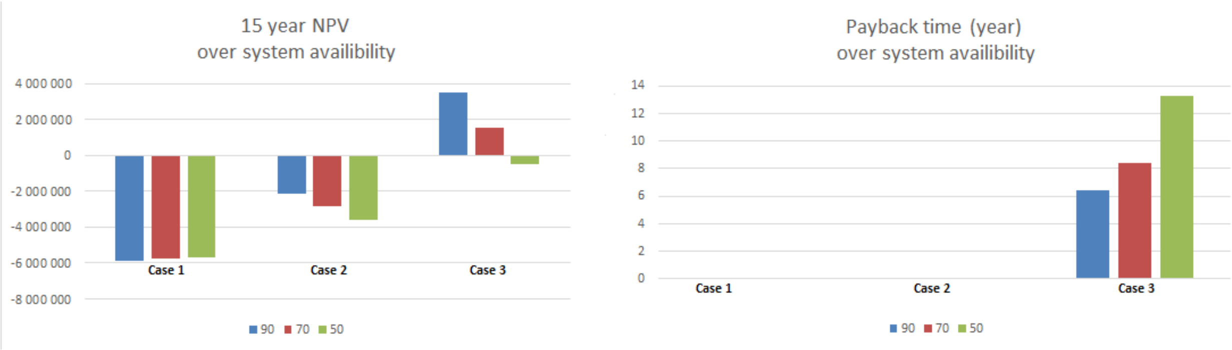

Figure 29 Solid Wood Impact of changes in heat value.

Table 9 shows Scenario 6 where values for energy certificates where changed. No other values where changed. Figure 30 shows that only Case 3 with an uptime of 90 percent gets positive values for the NPV. All other cases end up with a negative NPV and are therefore not profitable.

Table 9 Solid Wood energy certificate 0, 20, 40.

Scenario 6	Biomass cost per ton EUR/ton	Heat value EUR/MWh	Energy Certificate EUR/MWh	Power selling value EUR/MWh	Power consuming value EUR/MWh
Case 1	70	20	0	50	75
Case 2	70	20	20	50	75
Case 3	70	20	40	50	75

Figure 30 Solid Wood Impact of changes in energy certificate.

9.3 Large Combined heat and power plant

One option to utilize the access biomass could be to combine available biomass from different IKEA Industry sites to power one larger combined heat and power plant. This would involve daily transportation of biomass from the factories to the power plant. The general impression received at IKEA Industry is that this solution is not preferable and a deeper analysis performed by external CHP contractors has not been performed. High level cost/kW is instead presented by Elforsk, the Swedish electricity industry R&D company. Biomass fired CHP is a well proven technology and the cost has been estimated by collecting investment costs for newly built- and soon to be finished plants.

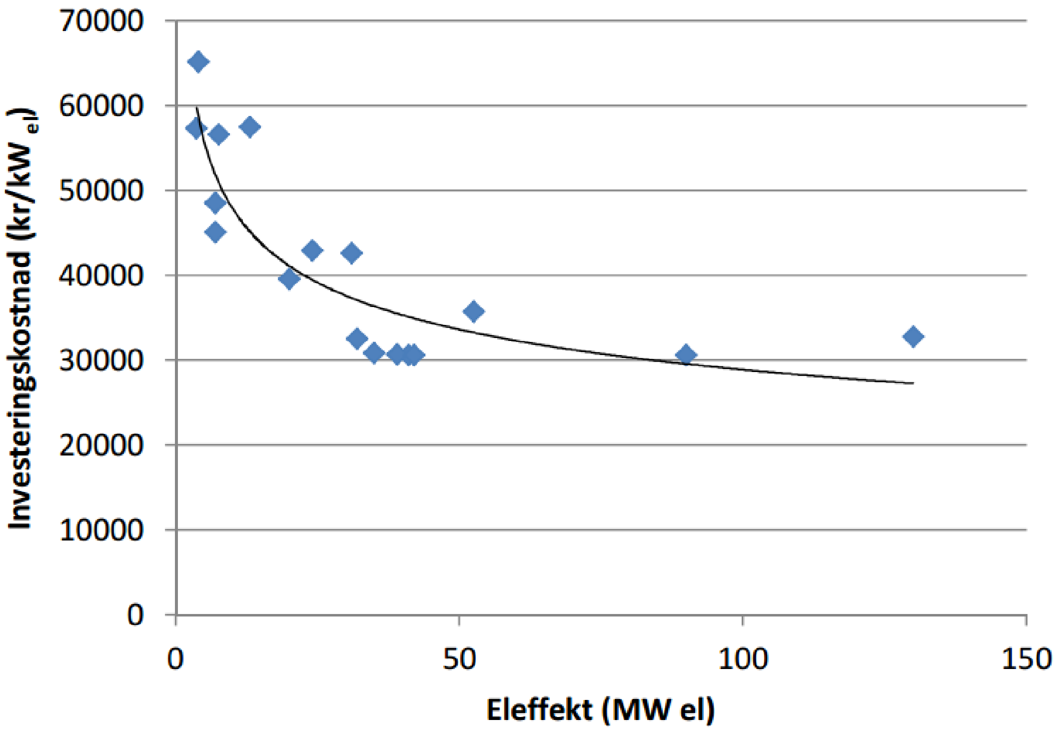

Figure 31. Investment costs for biomass fired CHP plant with aspect of net electricity production. One SEK is, at the time of writing, approximately 0,10662 EUR (www.xe.com, 2015-04-07).

Elforsk has also presented estimated cost/kWh for larger CHP plants as seen in Figure 32 below. Elforsk has made the assumption that the entire investment cost for the CHP plant is connected to the electricity production. Furthermore a price for biomass is estimated to 200 SEK/MWh (≈21,3 €/MWh). Fuel costs stands for a major part of the total production costs in this case, but the value of IKEA Industry excess biomass is about one fifth of this estimated value. The provided value of 20 €/ton for IKEA Industry dry biomass with energy content of 4,7 MWh/ton results in a value of approximately 4,2 €/MWh or 39,6 SEK/MWh with today’s exchange rate. The cost/kWh$_{el}$ is presented in Figure 32 below. Figure 31 and Figure 32 clearly illustrates that both the initial investment cost and the production cost will decrease when the size of the plant increases.

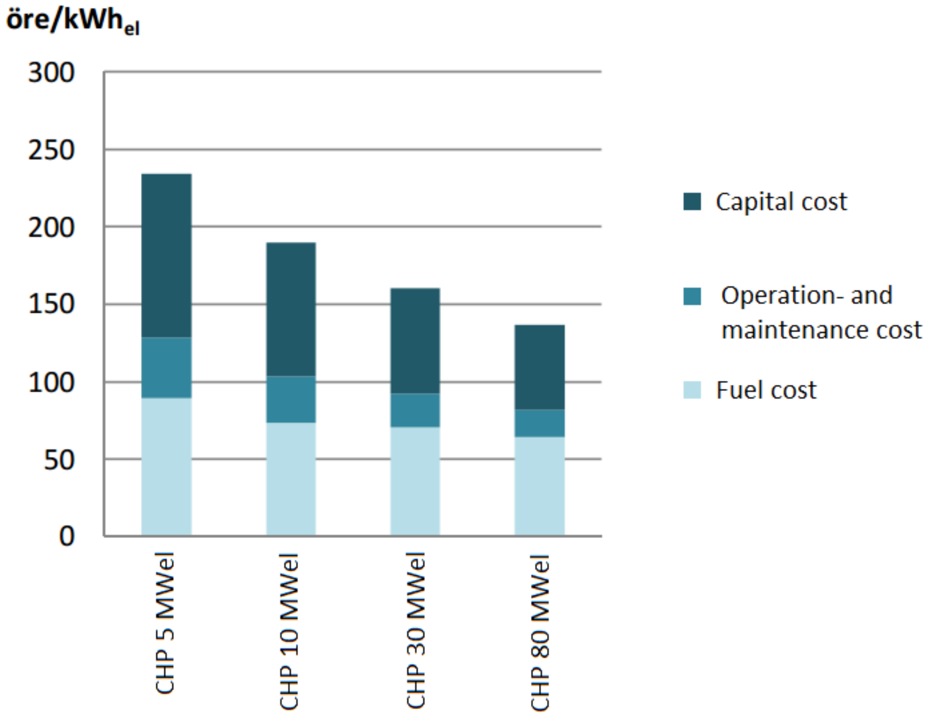

Figure 32. Cost for electricity production for biomass fired CHP without subsidies and heat crediting. One SEK is, at the time of writing, approximately 0,10662 EUR (www.xe.com, 2015-04-07).

9.4 Price comparison, IC engine vs. steam turbine

This price comparison is performed with a discount rate of 10%. All prices are in SEK. It includes heat crediting, meaning that produced heat obtains a value. Prices are based on the market price for a plant in Sweden (fuel, personnel, etc.). Depreciation time is set to 15 years.

Technique and size	Price öre/kWh
Gasification with IC engine 1MW	174
Gasification with IC engine 5MW	141
CHP (steam turbine) 5MW	159
CHP (steam turbine) 80MW	81

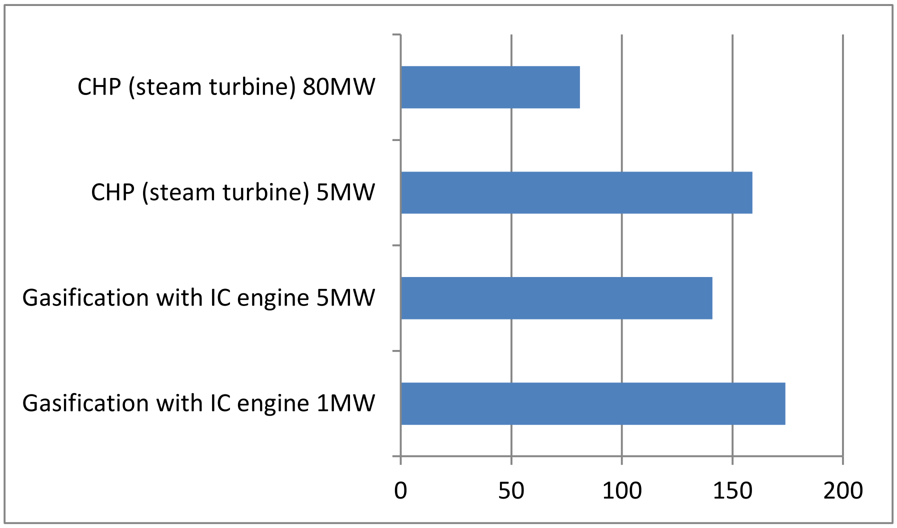

Figure 33. Price comparison IC engine vs steam turbine öre/kWh. One SEK is, at the time of writing, approximately 0,10662 EUR (www.xe.com, 2015-04-07).

Electricity production cost for gasification of biomass in combination with IC engines is linked to the size of such installations. The 1 MW power plant has got a higher capital cost per installed kW_{el} and a lower electrical efficiency compared to the 5 MW power plant. That leads to higher electricity production costs for the smaller plant compared with the bigger one.

Compared with the 5 MW biofuel CHP steam turbine application the electricity production cost is lower. That depends on the lower investment costs and a higher electrical efficiency for the gasification unit with the gas engine. The electricity production costs increases in all cases exponentially when the depreciation time is lowered.

9.5 Biomass fired ORC plant

Elforsk has presented a real-case cost of 137 MSEK (≈14,6 M€) for a complete 1,8 $MW_{el,\ net}$ biomass fired ORC plant [22]. This price includes facilities, process equipment, power-, water and district heat connection, fuel handling and project management costs. Elforsk has with background of this specific case and other sites estimated an investment cost of 75000 SEK/kW_{el} (≈8000 €/kW_{el}) for a 2 MW_{el} biomass fired ORC plant. Figure 34 below illustrates production cost for a biomass fired ORC plant based on Elforsk estimations, where the cost of biomass is set to be 200 SEK/MWh (≈21,3 €/MWh).

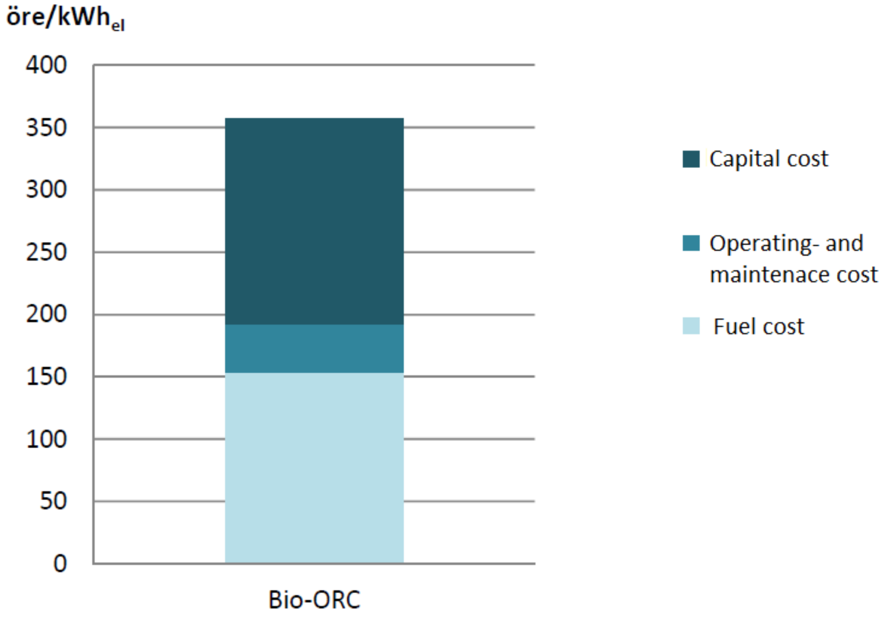

Figure 34. Cost for electricity production for biomass fired ORC plant without subsidies and heat crediting. One SEK is, at the time of writing, approximately 0,10662 EUR.

10 Discussion

This part of the report aims to analyze the presented result and highlight potential sources of errors. The discussion is divided in the following parts:

- The credibility of the weighting matrix
- Authenticity of provided information
- Promising gasification companies
- Project economics
- Selection of companies
- Gasification maturity
- Ways to go forward

10.1 The credibility of the weighting matrix

There are many companies on the market providing gasification technology, most of these companies offer newly developed technologies not yet proven to be reliable or economical. Only a few companies can show that their technique of gasifying biomass works and emphasize that with many uptime hours of their power plants. It is, unfortunately, not possible to evaluate how well new developed gasification technologies actually work in the span of this project. Provided information used in the technique matrix and further on used in the weighting matrix was provided directly from the CHP companies. The companies often validate their technology through demo and pilot plants. The provided information should be seen as relatively unproven if the technology has not yet been scaled up to commercial size.

Combustion in furnaces and electricity production with produced steam in turbines is on the other hand a mature technology. Information provided by companies regarding this technology should be correct. The absolute majority of the companies in the weighting matrix use gasification technology since focus in this report is on gasification.

The following parameters where used when the weighting matrix was developed:

- Low initial cost
- High electrical efficiency
- Mature technology
- Feedstock match
- Validation of provided information

How companies scored in these categories depends on the information provided. The reliability of information is varying, and this makes the result of the weighting matrix uncertain. In cases where provided information is within a span, the middle value was used.

It should also be mentioned that the guidelines for classifying the companies from 1-5 in the weighting matrix was solely decided by the authors. The guidelines are available in Appendix A. The result of the weighting matrix would off course change if IKEA Industry changes their valuation of parameters in the matrix. In summary, it should be clear that the weighting matrix in some cases is based on high level information and the model has a few sources that will affect the outcome; the guidelines for classification, the validity of the provided information, changes in IKEA Industry's demand.

10.2 Authenticity of provided information

One important aspect that will affect the outcome of this report is the authenticity of the provided information. The companies should of course be trusted, but one should remember that their incentive is to get a high score to be qualified for a further discussion. In the weighting matrix there is a parameter where the reliability of the provided information is valued. The reason is to penalize companies that have contributed information with low transparency or if the information is based on technology that has not yet been commercially proven. Below is a description of the parameters that are included in the weighting matrix.

10.2.1 Low initial cost

The parameter initial cost is not easy for the companies to answer. The cost of a plant varies from site to site and it can be difficult for a company to provide reliable information. They can rely on previous projects in a specific country, but this is off course difficult for smaller companies who are looking for their first full scale commercial plant.

Not all companies have been transparent of what has been included in the provided figures for cost per installed kW. Even if the cost for a turnkey plant was requested, some companies did at first only supply prices for the boiler island.

The cost does also off course depend on, if the biomass needs to be processed before entering the plant. Dryers, grinders or pelleting machines are equipment that are not included in the total cost if not clearly stated. The reason for that is that the pretreatment varies depending on type of feedstock. If, for example, the biomass is wet chips, then the pretreatment could be grinding and drying before entering the plant. If the biomass on the other hand is dry dust, then the biomass might need to be pelleted to fit some gasification technologies. These differences are illustrated in the technology matrix where feedstock type, size and moisture content for the different technologies are listed.

The initial cost/kW was ranked against each other with a simple mathematical model presented in Appendix A. The distribution of the point in this category have large impact on the final result since IKEA Industry puts a high value on this parameter. It should also be taken into account that most companies are placed within a relatively close span.

10.2.2 High electrical efficiency

The credibility of the figures of electrical efficiency varies if it is based on simulation, or have actually been proven at a full scale plant. The best way is off course to get figures from an identical commercially running plant with the same feedstock, but this is not the case for the majority of the companies.

The electrical efficiency was ranked against each other with a simple mathematical model presented in Appendix A. Most companies are placed in the span of electrical efficiency of 25-30 and this makes the distribution of points narrow. For example, a company with an electrical efficiency of 25% qualified for the value 2 while another company with electrical efficiency of 27% scored the value 4.

10.2.3 Mature technology

This parameter gained the highest value from IKEA Industry. It is understandable why IKEA Industry has put great value in having a mature technology since their core business is furniture, and not power production. The valuation of this parameter has not been based on information provided by the contractors but solely by the authors. The guidelines for the classifications are available at Appendix A.

10.2.4 Feedstock match

The feedstock match indicates how well a plant is designed for IKEA Industry’s feedstock. This parameter will only affect gasification companies in this case, since all companies providing combustion technology have been selected because of their experience from biomass powered power plants. Some gasification companies are however designed for garbage waste.

The selection of this parameter is done with background of the idea that plants that can take a wide span of feedstock often are more complex than plants designed for a specific fuel. Plasma gasification for example can handle a wide variety of both solid and liquids fuels but ended up being the most complex and the most expensive alternative [23].

10.3 Promising gasification companies

The two gasification companies that accumulated the highest scores in the weighting matrix was Company A and Company F.

10.3.1 Company A

Company A is the only gasification company that can operate with particle size under 1 mm. This makes Company A an ideal choice for an installation at Flatline factories where the feedstock consists of mostly dust. Other gasification technologies require larger particle size and the excess dust then needs to be transformed into pellets or briquettes.

If Company A's match with the Flatline feedstock is their biggest strength, then the low amount of commercially operating hours is their biggest weakness. The company has, at the time of writing, only produced 60 hours of commercial power production [24]. This is a major setback for Company A since IKEA Industry values technology maturity high. One factor that strengthen the muscles of Company A is the close cooperation with major engine supplier Cummins. This indicates that the technology has potential even if long operating periods are currently missing. Company A have their headquarters in Gothenburg, Sweden, and this could also be viewed as a positive factor since it creates a close geographical distance to IKEA Industry's office in Malmö.

A factory visit was done at Company A's plant in Hortlax just outside of Piteå in the beginning of March. The general impression was that the company is fully committed to take the next step in their development and build a fully commercial plant. It is not hard to see how important this next step will be for the credibility of the company. The question is if IKEA Industry is willing to take on the challenges and risks that are associated with this journey.

10.3.2 Company F

Company F is a company with its origin in Uruguay and provides both combustion and gasification solutions. They have at the time of writing seven different biomass powered plants based on gasification technology. The feedstock applicable for this technology is chips, bark and rejects which will make it suitable for the feedstock in Solid Wood. The provided information from Company F is comprehensive in relation to their competitors. A meeting took place early in December in Copenhagen and the general impression was that Company F could be an interesting solution for IKEA Industry. Company F has sites in France and Turkey that could be interesting to visit to get a clearer picture of the company. One of the biggest advantages with Company F is the large amount of commercial operating plants. The fact that Company F has built 5 different plants since 2010 indicates that the company has momentum and that the technology has received good feedback from existing plants.

Worth mentioning is that Company F combusts the produced syngas in a torsional combustion chamber and use the produced steam to power a steam turbine. The torsional combustion chamber was developed by the company in the late 70s and also allows direct combustion of wood dust particles. This makes Company F to a possible solution for the Flatline feedstock.

10.3.3 Company J

Company J is a Danish company that is fully owned by Babcock & Wilcox Power Generation Group, Inc in Ohio, USA. The company has a 1 MW_{el} gasification facility in Harbøre, Denmark that has over 120.000 hours of operation [25]. They also have 3 units of 5 MW_{el} operating in Japan. Company J offers off the shelf solutions of 2 MW_{el}. In Japan, two of these solutions are connected and set to work at higher pressure to reach a total plant size of 5 MW_{el}. The technology works on bark and wood chips and is therefore suitable for Solid Wood feedstock. The company did not score to well in the weighting matrix. Even so, the general impression is that a further discussion should be made. One reason for the vague result in the rankings could be that the figures provided was for the 1 MW_{el} Harbøre case. Figures for the 2 MW_{el} were not provided. A visit to Company Js headquarters in Copenhagen and the plant in Harbøre could be a natural way to continue the dialog with the company.

10.3.4 Company B Energy

Company B Energy Inc got acquired by Germany-based Entrade Group in 2013. The company says to be in a very expansive phase with many projects on the horizon. As today, Company B Energy has two plants that run constantly and two test facilities. They have reached around 3000 hours of operation. Company B Energy offers a solution containing 36 engines of 45 kW_{el} each. This is claimed to result in the lowest possible cost/kWh but this has not been proven in this report since cost/kWh has not been received from other companies.

IKEA Industry visited Company B Energy before this project started and a continuous dialog was engaged. The company has offered to lend IKEA Industry an E3 gasification unit to test at the Board factory in Orla. This could be a natural way to test the technology without committing fully. The factory in Orla was visited during this project and the site has large amount of excess wood material that is currently classified as waste and not biomass. This piled up low value wood waste could fit well as feedstock for Company B Energy´s E3 solution. A dialog has been initiated between the technical manager at the Orla factory and Company B Energy but the project was stalled due to lack of available resources at the factory.

10.3.5 Company C

Company C is a Canada based company that offer steam based gasification technology. At the beginning of this project they offered IC engines as well but withdrew this option at the end of the project. The solution with IC engine reached 300 hours of operation before the heat exchanger broke down and economic incentive is currently missing to fix it. This could be the reason that a solution with IC engines has been abandoned. The technology works with woodchip and bark and is therefore suitable for Solid Wood feedstock. Company C has nine different CHP plants operating today where the closest one is in England. The provided information from Company C is not very transparent. The cost/kWh is for example provided in the span 3000-7000 €/kW. This makes it hard to come to a conclusion about Company C’s potential.

10.3.6 Company H

Company H is an Austrian based company that provides both gasification and combustion technologies. They have one 6 MW_{el} gasification plant in Skive, Denmark, that have accumulated over 30 000 operating hours. The gasification unit use pellets or wood chips which makes it suitable for Solid Wood feedstock. The company says to have an extensive research program regarding gasification and the general impression is that the company could be an alternative for IKEA Industry. As today, there is only one reference case and no further plants are planned.

10.4 Project economics

The economic model used in this report was provided by Company A. It is used in this report to show how big impact changes of biomass cost, heating value and energy certificate has on PB and NPV. If the same model had used for a different technology with different pricing parameters the PB and NPV would change. Power selling and power consuming value were constant during the calculations and a change of these values would also have an impact of PB and NPV.

An interesting parameter is levelized cost. Unfortunately it is hard to get trusty numbers on that parameter when it comes to gasification due to lack of commercial plants. The fact that no actual location is selected makes it almost impossible to get reliable information regarding levelized cost.

10.4.1 Investment calculations

Six different investment calculations where performed where both PB and NPV were investigated. The calculations made are on a high level basis and made for the Swedish market. The same calculations made for other markets would give different numbers. Power selling value and power consuming value were not changed during the calculations. That could of course have been done but since power selling and consuming prices don't vary regarding to geographical location within a country they were kept static.

The results performed are for division Flatline and division Solid Wood. If the pricing for biomass, heat value and energy certificate is within a correct span depends on the provided information from IKEA Industry.

The result of Figure 25 for case 1 shows a positive NPV for all uptimes. If investing would be wise with an uptime of only 50 percent is questionable due to the very low NPV and a PB time of 12 years.

The best result is performed in Figure 26, case 3 with a very high NPV and a PB of under 4 years. That is for low biomass costs and a high heat value. If that scenario occurs in reality is uncertain. Case 1, with a heating value 0 EUR/MWh is also extreme with all negative NPV and a very long PB with an uptime of 90%. For the uptimes 70% and 50% the PB is that high, it is not even shown in the figure. This scenario is unlikely to happen because of the existing heat demand at all IKEA Industry sites.

The most uneconomical scenarios are shown in Figure 28 and Figure 30, where in Figure 28 only case 1 performs with a positive NPV and in Figure 30 only case 3 performs a positive NPV. In Figure 25 that positive NPV comes out of low biomass costs and for Figure 30 the positive NPV is the result of high energy certificates. Division Solid Wood in general has difficulties to reach good values for NPV and PB because of their high feedstock value.

Which scenario is the most likely, is for IKEA Industry to determine. In all cases a deeper analysis has to be made in order to set more exact numbers on all variables. The simulation performed gives a hint of which parameters are the most important ones to look at.

The calculations made for uptimes of 50% and 70% do not take into account that the facility would last for a longer time with everything that entails. Longer intervals of engine and scrubber maintenance etc., would lead to a longer lifetime for the entire plant. Doubtless, PB and NPV would look different if that would have been considered within the calculations.

10.5 Selection of companies

IKEA Industry used external company, LUX Research, to get knowledge of potential CHP contractors using gasification technology. It has been shown that the list provided by LUX Research was not comprehensive. Their list was short of many companies and the most interesting companies presented in this report was instead found by the authors.

A scan of available gasification companies was performed at the beginning of this project. The aim was to include as many interesting companies as possible. Even if the scan was relatively comprehensive, there were still gasification companies that were found at a later stage of the project when the market supposed to be scanned. This indicates that there could be more potential CHP contractors out there that are not included in this report. It could be interesting to investigate this further before IKEA Industry decides to go forward with one of the evaluated companies in this report.

10.6 Ways to go forward

There are many ways for IKEA Industry to go forward. One option is to continue the process through a continues dialog with the most promising companies in this report. The list of available biomass, Appendix C and D could also be a good place to start. This can give an idea of where potential CHP plants could be installed. A deeper study of a specific location should be performed before CHP contractors are engaged further. When a location is selected, country specific costs, potential subsidies and certificates can be collected. This will increase the credibility of provided information from potential CHP contractors.

Since IKEA Industry´s core business is manufacturing and selling furniture they might not have the competence in operating power plants. The impression is that IKEA Industry, currently is missing knowledge about gasification. Some gasification plants supposed to be fully automated and require as little as 1 hour of review per day. Nonetheless, it seems obvious that a responsible person needs more knowledge of a gasification plant. IKEA Industry should consider the option to increase the in house knowledge about gasification before fully committing to the technology

An alternative way could be a cooperation with an external energy company with the right competences to operate a power plant. IKEA Industry could for example provide land, feedstock and money needed for the construction of a site while an energy company could operate the power plant and deliver produced electricity and heat. A potential company that showed interest for that type of solution during this project was E.ON and a future discussion on the matter is at hand. Other examples for potential companies for that type of solution could be Vattenfall, Fortum, Göteborgs Energi, Sysav and Öresundskraft etc.

10.7 Gasification maturity

The general impression is that gasification and IC engines is a relatively risky business. During the writing of this report for example two companies withdrew a solution that was available at the beginning of this project. This indicates that the technology might not work in the expected way. Such scenarios make the investment in such techniques more uncertain. On the other hand some companies showed themselves to provide a more mature technology with thousands of commercial operating hours. However, it seems that many companies are in the startup phase and a lot is going to happen in the field of gasification in the next few years. Several companies are construction plants right now and have others plants planned for 2016. This shows the potential in the gasification technology.

The Elforsk report states gasification to be a semi commercial technique [22]. Some major gas engine suppliers are active in the field of syngas and engine development occurs in several areas. Both engine efficiency can increase and costs can be cut [22]. A great potential for improvement of efficiency lies in the technique of waste heat recovery for drying or ORC cycles. In some cases gas engine suppliers act as partners with the gasification companies. That could be seen as a sign that gasification techniques are close to a breakthrough.

Elforsk predicts that the continuously development of the gasification technology will result in higher electrical efficiencies, bigger plats and lower investment costs than today [22].

10.8 Maturity of other techniques

Besides gasification and usage of IC engines there are many other concepts in various maturity stages. Summarized, syngas used in fuel cells and gas turbines are immature technologies. Fuel cells are still in a development phase [26] and the world's first gas turbine working on syngas is not connected to the grid anymore due to problems with impurities in the produced syngas. These two techniques utilizing syngas cannot be considered mature. Syngas burned in boilers for district heating or steam production making it possible to operate a steam turbine are semi commercial and used by different companies today.

11 Conclusion

There is no doubt that gasification of biomass is an interesting solution for IKEA Industry to utilize their excess biomass. The aim for IKEA Industry is to have a high electrical efficiency while having low cost/kWh.

At small plant sizes, the gasification technology seems to be the answer. As seen in Figure 33 the cost/kWh for a 5 MW_{el} gasification plant is 11 % lower than the cost/kWh for a 5 MW_{el} plant powered by a steam turbine. It would be convenient to point out a breaking point to where the gasification- or combustion technology is more efficient. But this has not been possible in this project.

IKEA Industry has put a high value on the maturity and dependability of a technology. The market today has many suppliers of gasification technologies but far from all have proven their concept with satisfactory number of commercial operating hours. This indicates that the market for gasification has big potential but might not yet have landed in the maturity that IKEA Industry is looking for.

Conventional combustion technology might be more expensive at 5 MW_{el} size but is on the other hand a well proven technology. It is not obvious to point out a solutions for IKEA Industry since both technologies have their advantages and disadvantages.

One option for IKEA Industry, if a gasification solution is chosen, could be to collaborate with an external energy producer to split the risk.

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14 Appendix

14.1 Apendix A - Guidelines for the weighting matrix

The following guidelines are used when the different companies and technologies are valued and benchmarked. Below are descriptions of what properties that qualify for the values 1-5 for the categories mature technology, feedstock match, validation of provided information, validation of cost per kW installed and validation of high electrical efficiency.

14.1.1 Mature technology

Value	Description
1	A company/technology gets the value 1 if there is no pilot plant in operation.
2	A company/technology gets the value 2 if there are at least a pilot plant in operation and the total operation exceeds 300 hours.
3	A company/technology gets the value 3 if there are at least one demonstration plant in operation. And/or the total operation exceeds 500 hours. And/or commercial plants are planned.
4	A company/technology gets the value 4 if there are at least one commercial plant in operation and the total operation exceeds 3000 hours. And/or commercial plants are planned.
5	A company/technology gets the value 5 if there are at least 10 commercial plant in operation and/or the total operation exceeds 50 000 hours.

14.1.2 Feedstock match

Value	Description
1	The plant is not designed for biomass.
2	The plant is designed for biomass and/or agriculture waste. Feedstock has to be processed before entering the plant (i.e. dryied, grained and pelleted).
3	The plant is designed for biomass. Feedstock has to be processed before entering the plant, dried or grained or pelleted.
4	The plant is designed for the wood industry and biomass from sawmills and furniture production. No further processing needed.
5	The plant is designed especially for the wood industry and biomass from sawmills and/or furniture production and further studies of IKEA Industry’s biomass has been made.

14.1.3 Validation of provided information

Value	Description
1	Provided information is based on theory and simulation and not real operation. And/or information is partly inadequate.
2	Provided information is based on theory and small pilot scale operation. And/or low transparency in provided economic figures.
3	Provided information is based on pilot plant. And/or simulation of larger future commercial plant. And/or Medium transparency in provided information.
4	Provided information is based on running commercial plant and the company and/or the company have experience from providing these plants. And/or there is transparency in provided information.
5	Provided information is based on several commercial plants and the company has high transparency in provided information.

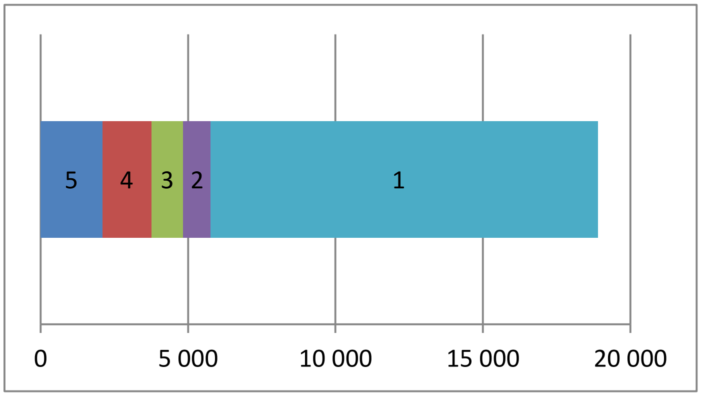
14.1.4 Cost per kW installed

To provide a fair distribution of points in the category low initial cost, the prices were divided into quantiles, shown in the graphic below where the quartiles create the border between the scores.

Company	Price EUR/kW
Company A	3 136
Company B E3	4681,2
Company B E3x36 modified	3750
Company B 400 kW	8000
Company C, steam turbine	5000
Company D, P5	18900
Company D, W15	6615
Company E	5500
Company F, combustion	2090,0
Company F, gasification	2933,96
Company K	4000
Company I	4200
Company G, combustion	5000
Company H, combustion	3750
Company H, gasification	5000
Company J	7559

	Quartiles	Differences
Min	2 090	2 090
Q1	3750	1 660
Med	4840,6	1090,6
Q3	5778,75	938,15
Max	18 900	13 121

Score	Range
5	<=2090
4	2091-3700
3	3701-4800
2	4801-5800
1	>5800



Quantiles in EUR/kW.

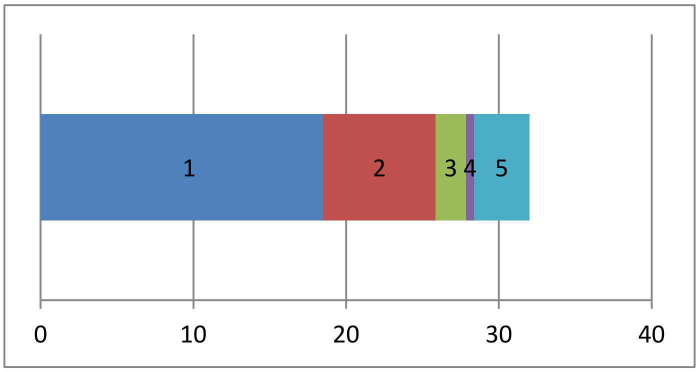
14.1.5 High electrical efficiency

To provide a fair distribution of points in the category electrical efficiency, the efficiencys were divided into quantiles, shown in the graphic below where the quartiles create the border between the scores.

Company	Efficiency in %
Company A	28
Company B E3	24,0
Company B E3x36 modified	25
Company B 400 kW	28
Company C, steam turbine	26
Company D, P5	19
Company D, W15	28,9
Company E	32
Company F, combustion	28,3
Company F, gasification	28,70
Company K	31,7
Company I	27,1
Company G, combustion	26,5
Company H, combustion	27,7
Company H, gasification	28
Company J, 2MW case	25,5

		Differences
Min	19	19
Q1	25,875	7
Med	27,85	1,975
Q3	28,4	0,55
Max	32	4

Score	Range
5	>28,4
4	28-28,4
3	26-27,9
2	19,1-25,9
1	<=19



Quantiles in %

14.2 Appendix B – Technology matrix

Technology matrix

Companies	**Technology**	**Effect net [kW$_{el}$]**	**Effect net [kW$_{th}$]**
Company A	Gasification, VIPP, IC engine	1200	2400
Company B E3	Gasification, fixed bed, IC engine	22	55
Company B E3x36 modified	Gasification, fixed bed, IC engine	1600	3800
Company B 400 kW	Gasification, fixed bed, IC engine	345	630
Company C, case 1	Gasification, updraft, steam turbine	1400 - 10000	-
Company C, case 2	Gasification, updraft, IC engine	2000 - 10000	3000 - 15000
Company D, P5	Plasma gasification	2750	-
Company D, W15	Plasma gasification	10000	-
Company E	Gasification, WoodRoll, IC engine	1800-2200	2600-3000
Company F, Zbasyn case	Combustion, steam turbine	10000	7000
Company F, Lubawa case	Combustion, steam turbine	2500	6500
Company F, Wielbark case	Gasification, updraft, steam turbine	5300	10000
Company G, Hilleröd case	Gasification, Viking gasifier, IC engine	500	1000
Company G	Combustion, steam turbine	1150	4800
Company H, combustion	Combustion, steam turbine	9000	23000
Company H, gasification	Gasification, IC engine	5400	11300
Company H, 6 MW case Skive	Gasification, BFB, 3 IC engine	5100	9000
Company I	Gasification,	1000	1200
Company J, 1 MW case Harbore	Gasification, updraft, IC engine	1000	1900
Company J, 2MW case	Gasification, updraft, IC engine	1790	2160
Company K	Gasification	1820	2600

Disqualified companies

Company L, combustion	Disqualified, feedstock mismatch	-	-
Company M	Disqualified, not reach pilot stage	-	-
Company N	Disqualified, to big boilers	-	-
Company O	Disqualified, feedstock mismatch	-	-
Company P	Disqualified, only gasification of RDF	-	-
Company Q	Disqualified, no turnkey solution	-	-
Company R	Not in focus due to low el efficiency	-	-
Company S	Disqualified by IKEA	-	-
Company T	Disqualified by IKEA	-	-
Company U	Disqualified by IKEA	-	-
Company V	Disqualified by IKEA	-	-
Company X	Disqualified by IKEA	-	-

Technology matrix

Companies	Electrical efficiency [%]	Total efficiency [%]	Fuel consumption [kg/h]
Company A	26-29	85	960
Company B E3	24	85	18
Company B E3x36 modified	25	83	36
Company B 400 kW	30 gross	80	330
Company C, case 1	22-29	40-53	1040-10400
Company C, case 2	30 (HHV)	60-64	1458-5833
Company D, P5	18,5	-	30 000 ton/year
Company D, W15	28,9	-	80 000 ton/year
Company E	32%	≈85	≈1500
Company F, Zbasyn case	28,23	38,8	83 000 ton/year
Company F, Lubawa case	28,45	59,2	30 000 ton/year
Company F, Wielbark case	28,7	50,9	164 000 ton/year
Company G, Hilleröd case	25-30	-	300-575
Company G	26-27	90	
Company H, combustion	27,7	86,5	14000
Company H, gasification	28	85	4100
Company H, 6 MW case Skive	30	85,4	5500
Company I	39	44	780
Company J, 1 MW case Harbore	28	94	-
Company J, 2MW case	25,5	-	2523
Company K	31,7	76	1216-1737

Disqualified companies			
Company L, combustion	-	-	-
Company M	-	-	-
Company N	-	-	-
Company O	-	-	-
Company P	-	-	-
Company Q	-	-	-
Company R	-	-	-
Company S	-	-	-
Company T	-	-	-
Company U	-	-	-
Company V	-	-	-
Company X	-	-	-

Technology matrix

Companies	Feedstock type and size	Moisture content [%]	Cost per kW installed [€/kW_{el}]	Operating time [h/year]
Company A	Dust <1mm	<10%	3 136	8000
Company B E3	pellets	<10%	4681,2	7500
Company B E3x36 modified	pellets	<10%	3750	6000
Company B 400 kW	pellets, woodchip	<20	8000	7600
Company C, case 1	<60 mm	6-60%	3000-7000	8200
Company C, case 2	<60 mm	6-25%	-	-
Company D, P5	sawdust - 250 mm	20	18900	-
Company D, W15	sawdust - 250 mm	20	6615	-
Company E	Sawdust - max 25x25x50	<45%	5450- 5555	8000
Company F, Zbasyn case	Dust <1 mm	<40%	#REF!	8000-8200
Company F, Lubawa case	Dust <1 mm	<40%	#REF!	8000-8200
Company F, Wielbark case	Chips, bark, rejects	55%	#REF!	8000-8200
Company G, Hilleröd case	Chips	35-50%	-	-
Company G	350x100x50	10-55	4000-6000	7600
Company H, combustion	<300 mm	0-60	1500-2000	8000<
Company H, gasification	8-45 mm	<20	5000	7300
Company H, 6 MW case Skive	pellets, 8-45 mm	<20	-	-
Company I	no restrictions	<30	4200	8000
Company J, 1 MW case Harbore	bark, wood chips	<50	-	-
Company J, 2MW case	bark, wood chips	<50	7559	8000
Company K	25-100 mm	5-17,5%	4000	7900

Disqualified companies

Company L, combustion	-	-	-	-
Company M	-	-	-	-
Company N	-	-	-	-
Company O	-	-	-	-
Company P	-	-	-	-
Company Q	-	-	-	-
Company R	-	-	-	-
Company S	-	-	-	-
Company T	-	-	-	-
Company U	-	-	-	-
Company V	-	-	-	-
Company X	-	-	-	-

Technology matrix

Companies	**Life span [year]**	**Commercial hours of operation [h]**	**Commercial running plants**
Company A	20	30 h el/ 1000 h th	1 unit. 1,2 MW_{el} in Hortlax
Company B E3	20	3000	2 units running constantly, 2 test units
Company B E3x36 modified	20	3000	2 units running constantly, 2 test units
Company B 400 kW	20	-	-
Company C, case 1	20	175 000 thermal	1 unit. 2 MW_{el}
Company C, case 2	20	300	1 unit. 2 Mwel
Company D, P5	30	-	-
Company D, W15	30	-	-
Company E	20	0	None. A 5 MW site planned in Italy in 2016
Company F, Zbasyn case	20	since 1985	-
Company F, Lubawa case	20	since 1985	-
Company F, Wielbark case	20	since 1985	7 sites
Company G, Hilleröd case	10	≈6500	1 unit. 500kW. Not operational due to failure.
Company G	20	0	none
Company H, combustion	20-40	-	-
Company H, gasification	20-40	30000	1 unit 6 MW Skive
Company H, 6 MW case Skive	20-40		-
Company I	20	27000 full load	1 unit in Magdeburg
Company J, 1 MW case Harbore	-	80000<	
Company J, 2MW case	20	120000	4 units. 1 1 MW site in Harbore, Denmark, 3 units of 5 MW_{el} sites in japan.
Company K	20	3000	2 decommissioned units, 1 in Germany, 1 in Ireland, 1 planned in Bulgaria
Disqualified companies			
Company L, combustion	-	-	
Company M	-	-	
Company N	-	-	
Company O	-	-	
Company P	-	-	
Company Q	-	-	
Company R	-	-	
Company S	-	-	
Company T	-	-	
Company U	-	-	
Company V	-	-	
Company X	-	-	

14.3 Appendix C - Available biomass in division Solid Wood

IKEA Industry Solid Wood sites

		PL Pine sawmills	**Wielbark**	**Incukalns**	**Goleniow**
1	**Feedstock**				
1.1	Type (Dust, shredded reject, % if mixed)				
1.2	Particle size [mm]				
1.3	Dry biomass (8-10 % humidity)				
1.3.1	Quantity available dry [ton]	0	39500	15000	12000
1.3.2	Value dry [€/ton]				
1.3.3	Consumed dry [ton]	0	0	0	0
1.3.4	Products sold dry [ton]	0	39500	15000	12000
1.4	Wet biomass (app. 50 % humidity)				
1.4.1	Quantity available wet (bark, chips, dust) [ton]	139590	125066	112864	830
1.4.2	Value wet [€/ton]				
1.4.3	Consumed wet [ton]	6400	16800	30740	830
1.4.4	Products sold wet [ton]	133190	108266	82124	0

		Resko	**Stepnica/ Ivar**	**Konstantinow**	**Skoczow**
1	**Feedstock**				
1.1	Type (Dust, shredded reject, % if mixed)				
1.2	Particle size [mm]				
1.3	Dry biomass (8-10 % humidity)				
1.3.1	Quantity available dry [ton]	38000	10000	4000	8000
1.3.2	Value dry [€/ton]				
1.3.3	Consumed dry [ton]	0	0	0	0
1.3.4	Products sold dry [ton]	38000	10000	4000	8000
1.4	Wet biomass (app. 50 % humidity)				
1.4.1	Quantity available wet (bark, chips, dust) [ton]	6478	0	0	0
1.4.2	Value wet [€/ton]				
1.4.3	Consumed wet [ton]	6478	0	0	0
1.4.4	Products sold wet [ton]	0	0	0	0

		Stalowa Wola	**Jasna**
1	**Feedstock**		
1.1	Type (Dust, shredded reject, % if mixed)		
1.2	Particle size [mm]		
1.3	Dry biomass (8-10 % humidity)		
1.3.1	Quantity available dry [ton]	0	11000
1.3.2	Value dry [€/ton]		
1.3.3	Consumed dry [ton]	0	0
1.3.4	Products sold dry [ton]	0	11000
1.4	Wet biomass (app. 50 % humidity)		
1.4.1	Quantity available wet (bark, chips, dust) [ton]	21300	0
1.4.2	Value wet [€/ton]	0	0
1.4.3	Consumed wet [ton]	2700	0
1.4.4	Products sold wet [ton]	18600	0

14.4 Appendix D - Available biomass in division Flatline

	IKEA Industry Flatline sites				
		Älmhult	**Lubawa**	**Zbaszyn**	**Majcichov**
1	**Feedstock**				
1.1	Particle size [mm]		95% < 1 mm	95% < 1 mm	
1.2	**Dry biomass (dust)**				
1.2.1	Quantity available dry [ton]			83000	
1.2.2	Value dry [€/ton]				
1.2.3	Consumed quantity dry [ton]			6000	
1.2.4	Sold quantity dry [ton]			77000	
1.3	**Dry Contaminated biomass (Reject, Mixed dust/ABS)**				
1.3.1	Quantity available contaminated [ton]	4230	30000	0	
1.3.3	Value contaminated [€/ton]	-	-		
1.3.4	Consumed quantity contaminated [ton]	4230	6800	0	370
1.3.5	Sold quantity contaminated [ton]	1650	23200	0	
2	**Boiler info**				
2.1	**Boiler #1**	HOTAB, 2006	Hotab, 2004	Hotab/Danstoker, 2005	Justsen, 2006
2.1.2	Heat power [kW]	3200	5000	5000	2000
2.1.3	Pressure [bar]	6	6	6	5,3
2.1.4	Temperature out of boiler [°C]	110	125	145	110
2..1.5	Temperature in to boiler [°C]				
2.2	**Boiler #2**		Vyncke, 2013	WEISS, 1999	
2.2.2	Heat power [kW]		4000	2500	
2.2.3	Pressure [bar]		6	3,5	
2.2.4	Temperature out of boiler [°C]		110	115	
2.2.5	Temperature in to boiler [°C]				
2.2	**Boiler #3**			WEISS, 1999	
2.2.2	Heat power [kW]			2500	
2.2.3	Pressure [bar]			3,5	
2.2.4	Temperature out of boiler [°C]			115	
2.2.5	Temperature in to boiler [°C]				
2.3	Total Boiler capacity installed	3200	9000	10000	2000
3	**Electricity**				
3.1	Price [€/kWh]		0,087	0,087	
3.2	Yearly consumption [GWh 2013]		39,63	106,46	

	IKEA Industry Flatline sites			
		Sopron	**Zbaszynek**	**Babimost**
1	**Feedstock**			
1.1	Particle size [mm]	15% < 1mm 1 mm < 75% < 10mm 10% ~ 30mm		
1.2	**Dry biomass (dust)**			
1.2.1	Quantity available dry [ton]		14770	10860
1.2.2	Value dry [€/ton]			
1.2.3	Consumed quantity dry [ton]		3510	1970
1.2.4	Sold quantity dry [ton]		11690	9220
1.3	**Dry Contaminated biomass (Reject, Mixed dust/ABS)**			
1.3.1	Quantity available contaminated [ton]	6200	51930	5700
1.3.3	Value contaminated [€/ton]			
1.3.4	Consumed quantity contaminated [ton]	4300		
1.3.5	Sold quantity contaminated [ton]	1900	50500	5700
2	**Boiler info**			
2.1	**Boiler #1**	System Kurri, 2000	Weiss, 1999	Weiss, 1997
2.1.2	Heat power [kW]	1500	2500	1400
2.1.3	Pressure [bar]	3,5	3,5	3
2.1.4	Temperature out of boiler [°C]	100	115	115
2.1.5.	Temperature in to boiler [°C]			
2.2	**Boiler #2**	KIV d.d. 2008	Weiss, 1999	Weiss, 2002
2.2.2	Heat power [kW]	2000	2500	1600
2.2.3	Pressure [bar]	4	3,5	3
2.2.4	Temperature out of boiler [°C]	110	115	115
2.2.5	Temperature in to boiler [°C]			
2.2	**Boiler #3**	KIV d.d. 2008	Hotab/ Danstoker 2004	Vyncke, 2013
2.2.2	Heat power [kW]	2000	5000	4000
2.2.3	Pressure [bar]	4	6	3,5
2.2.4	Temperature out of boiler [°C]	110	145	110
2.2.5	Temperature in to boiler [°C]			
2.3	Total Boiler capacity installed	5500	10000	7000
3	**Electricity**			
3.1	Price [€/kWh]	0,067		
3.2	Yearly consumption [GWh 2013]	18,542		

IKEA Industry Flatline sites

		Esipovo	Trnava	Pacos de Ferreira
1	**Feedstock**			
1.1	Particle size [mm]	95% < 1 mm	75% < 1 mm	95% < 1 mm
1.2	**Dry biomass (dust)**			
1.2.1	Quantity available dry [ton]	7910	6021	9580
1.2.2	Value dry [€/ton]			
1.2.3	Consumed quantity dry [ton]	1090	4025	4636
1.2.4	Sold quantity dry [ton]	6820	1966	4300
1.3	**Dry Contaminated biomass (Reject, Mixed dust/ABS)**			
1.3.1	Quantity available contaminated [ton]	140	150	22000
1.3.3	Value contaminated [€/ton]			0
1.3.4	Consumed quantity contaminated [ton]	0	100	0
1.3.5	Sold quantity contaminated [ton]	140	50	22000
2	**Boiler info**			
2.1	**Boiler #1**	Danstoker, 2005	2x WEISS, 1999	2007
2.1.2	Heat power [kW]	2000	4800	2300
2.1.3	Pressure [bar]	6	4	low pressure
2.1.4	Temperature out of boiler [°C]	130	110	110
2..1.5	Temperature in to boiler [°C]			
2.2	**Boiler #2**	Danstoker, 2005	WEISS, 2006	2010
2.2.2	Heat power [kW]	2000	2200	4600
2.2.3	Pressure [bar]	6	6	low pressure
2.2.4	Temperature out of boiler [°C]	130	130	110
2.2.5	Temperature in to boiler [°C]			
2.2	**Boiler #3**		CKD, 1990	
2.2.2	Heat power [kW]		2000	
2.2.3	Pressure [bar]		4	
2.2.4	Temperature out of boiler [°C]		100	
2.2.5	Temperature in to boiler [°C]			
2.3	Total Boiler capacity installed	4000	9000	6900
3	**Electricity**			
3.1	Price [€/kWh]		0,102	0,11
3.2	Yearly consumption [GWh 2013]		20,93	47,18

IKEA Industry Flatline sites

		Nantong	Malacky	Danville	Kazlu Ruda	Hultsfred
1	**Feedstock**					
1.1	Particle size [mm]	95% < 1 mm	-	-	-	-
1.2	**Dry biomass (dust)**					
1.2.1	Quantity available dry [ton]		-	-	-	-
1.2.2	Value dry [€/ton]		-	-	-	-
1.2.3	Consumed quantity dry [ton]		-	-	-	-
1.2.4	Sold quantity dry [ton]		-	-	-	-
1.3	**Dry Contaminated biomass (Reject, Mixed dust/ABS)**					
1.3.1	Quantity available contaminated [ton]	7200	-	-	-	-
1.3.3	Value contaminated [€/ton]	7,39	-	-	-	-
1.3.4	Consumed quantity contaminated [ton]	0	-	-	-	-
1.3.5	Sold quantity contaminated [ton]	7200	-	-	-	-
2	**Boiler info**					
2.1	**Boiler #1**					
2.1.2	Heat power [kW]	-	-	-	-	-
2.1.3	Pressure [bar]	-	-	-	-	-
2.1.4	Temperature out of boiler [°C]	-	-	-	-	-
2..1.5	Temperature in to boiler [°C]	-	-	-	-	-
2.2	**Boiler #2**		-	-	-	
2.2.2	Heat power [kW]	-	-	-	-	-
2.2.3	Pressure [bar]	-	-	-	-	-
2.2.4	Temperature out of boiler [°C]	-	-	-	-	-
2.2.5	Temperature in to boiler [°C]	-	-	-	-	-
2.2	**Boiler #3**		-	-	-	
2.2.2	Heat power [kW]	-	-	-	-	-
2.2.3	Pressure [bar]	-	-	-	-	-
2.2.4	Temperature out of boiler [°C]	-	-	-	-	-
2.2.5	Temperature in to boiler [°C]	-	-	-	-	-
2.3	Total Boiler capacity installed	-	-	-	-	-
3	**Electricity**					
3.1	Price [€/kWh]	0,086	-	-	-	-
3.2	Yearly consumption [GWh 2013]	8,43	-	-	-	-