Overview and Categorization of European Biogas Technologies

- Gasification -

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DiBiCoo – Digital Global Biogas Cooperation
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Executive Summary of D2.2

The following document gives an overview of existing European gasification technologies and main gasification processes.

The structure following the introduction section about biomass conversion processes follows the biogas processing logic: from various gasifier technologies to feedstock specifics, storage, and necessary pre-treatment. Special chapters on important elements of any biogas plant are elaborated in detail (e.g. on measurement, control and regulation technologies).

Due to the amount of existing information available on this topic it may occur that not everything is included or considered extensively. We propose this deliverable as a solid starting point getting to know about gasification. This doesn´t replace special training courses and at least professional planning. In order to incorporate more relevant technologies and gasification applications, some additional sections relevant for gasification are already outlined in the document Overview and Categorization of European Biogas Technologies focusing on Anaerobic Digestion.

The detailed descriptions of certain technologies are not implying any preference to a technology, service provider or device. Similarly, pictures including company names shall not be seen as a preference to any specific company or technology. It is done for visualization purposes only.

Summary of the DiBiCoo Project

The **Digital Global Biogas Cooperation (DiBiCoo)** project is part of the EU’s Horizon 2020 Societal Challenge ‘Secure, clean and efficient energy’, under the call ‘Market Uptake Support’.

The target importing emerging and developing countries are Argentina, Ethiopia, Ghana, South Africa and Indonesia. Additionally, the project involves partners from Germany, Austria, Belgium and Latvia. The project started in October 2019 with a 33 months-timeline and a budget of 3 Million Euros. It is implemented by the consortium and coordinated by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

The overall objective of the project is to prepare markets in developing and emerging countries for the import of sustainable biogas/biomethane technologies from Europe. DiBiCoo aims to mutually benefit importing and exporting countries through facilitating dialogue between European biogas industries and biogas stakeholders or developers from emerging and developing markets. The consortium works to advance knowledge transfer and experience sharing to improve local policies that allow increased market uptake by target countries. This will be facilitated through a digital matchmaking platform and classical capacity development mechanisms for improved networking, information sharing, and technical/financial competences. Furthermore, DiBiCoo will identify five demo cases up to investment stages in the 5 importing countries. Thus, the project will help mitigate GHG emissions and increase the share of global renewable energy generation. The project also contributes to the UN Sustainable Development Goals (SDG 7) for ‘Affordable and clean energy”, among others.

Further information can be found on the DiBiCoo website: www.dibicoo.org.

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List of Abbreviations

CHP	Combined heat and power unit
H_i	Heating value inferior or caloric value Chemical bound energy in fuel which can be set free through a full combustion process where the temperature of exhaust gas has 25 °C and possible vapor is not condensed. $[MJ_{Hi}\ kg^{-1}; MJ_{Hi}\ l^{-1}]$
H_s	Heating value superior or gross calorific value Chemical bound energy in fuel which can be set free through a full combustion process where the temperature of exhaust gas has 25 °C and possible vapor is condensed. $[MJ_{Hs}\ kg^{-1}; MJ_{Hs}\ l^{-1}]$
λ	Lambda or excess air figure: ratio between added air to a combustion process to the needed air for a full stoichiometric combustion of all combustible elements. lambda = 1: exactly amount of air is added to the combustion process which is needed for full stoichiometric combustion of all combustible elements Lambda > 1: more oxygen is added to the combustion process as needed for combustion of all combustible elements
LCV	Low Calorific Value Gas
Nm^3	m^3 at: temperature: 0°C pressure: 1 013 mbar

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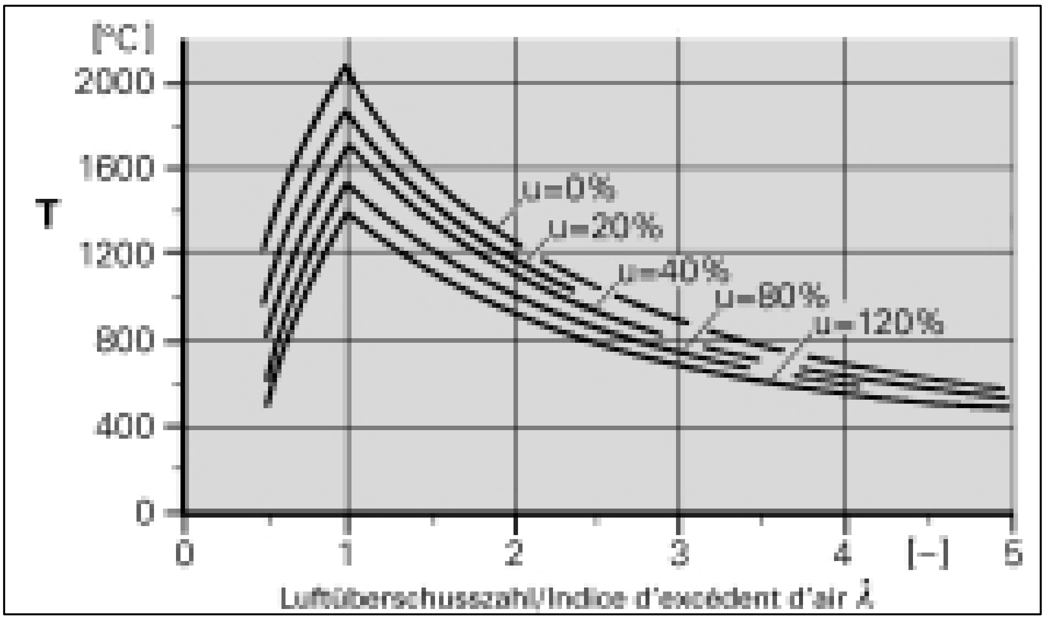

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1 Introduction: Gasification

The process producing gas from solid fuel was initially developed to produce gaseous fuel from coal or peat for lightning cities and for cooking in private households. Many cities in the US and Europe used that process already in the 19th century. Then, in 1839 the first wood fired fixed bed counterflow gasifier was invented by Karl Bischof. 1918 Georg Imbert developed a fixed bed current gasifier. Due to fuel constraints during the Second World War, wood gasifier were installed on passenger cars and even on trucks delivering gaseous fuel to fuel the engine (Ablinger, 2014, Hrbek, 2020). After the Second World War these techniques were overruled by fossil fuels and faded into oblivion. This entailed that no further development of the technique was done. Only a few people still tried to develop this technique further so it could be used also under stronger restrictions on emissions etc.

Picture 1: Wood fired gasifier to fuel trucks and cars; left: © AlfvanBeem, right: © Abc10

Compared to gasification of biomass the direct burning of wooden biomass in wood boilers or open fireplaces is perhaps the oldest form to use energy for cooking, heating and even lighting. This was done over a long period in open fireplaces or simple wood stoves. Installations were mostly built by locally experienced people or sometimes by the house owner himself. Skills were mainly based on traditional knowledge. Just during the last 40 years the wood burning process was focused in scientific research and a significant increase in efficiency, as well as lowering emissions etc. could be achieved (Schmidl & Lasselsberger, 2020). This scientific progress goes hand in hand with higher numbers of new installations of new biomass boilers. In total, it led to new knowledge of the biomass burning process and to a growing well trained and experienced community of scientists and skilled craftsmen.

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Picture 2: Biomass burning in open fireplaces

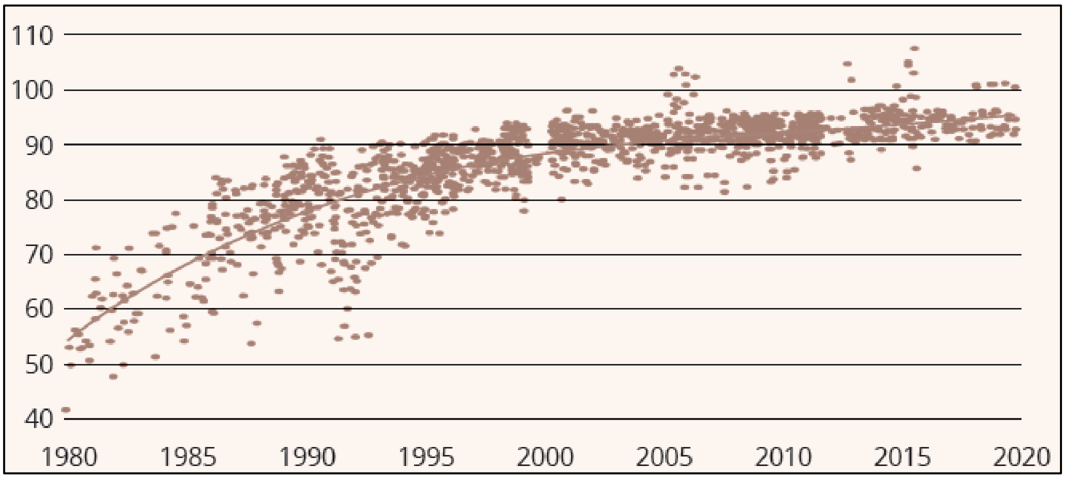

Figure 1: Development of the efficiency (η) of new wood fired boilers during type approval expressed in [%]; © Baumgartner, 2020

Through a complete change in the wooden biomass burning process from uncontrolled air inlet at one place to a staged combustion process with 2 or even more inlets for combustion-air at different places, a special designed combustion chamber until special heat exchangers efficiency could be highly raised and on the opposite side, emissions could be highly lowered. If the latter is designed to condensate the vapor of the exhaust gas, even combustion efficiencies above 100 % are possible. These developments were also done to decrease emissions of carbon monoxide and particulate matter over 90 % compared to emissions from boilers produced in the 1980ies (Schmidl & Lasselsberger 2020).

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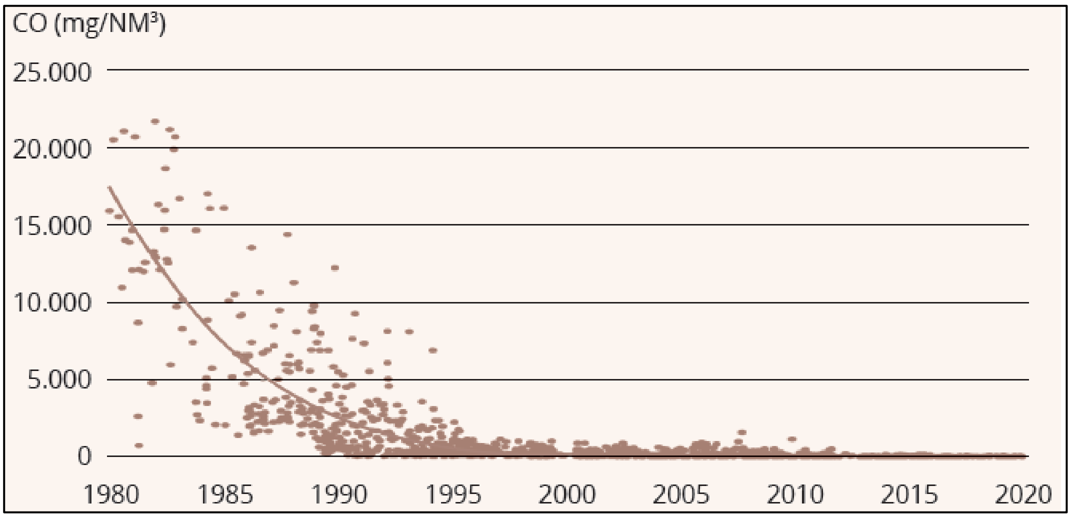

Figure 2: Development of carbon monoxide emissions of new wood fired boilers during type approval expressed in CO emissions [mg$_{CO}$ Nm^{-3}] © Baumgartner, 2020

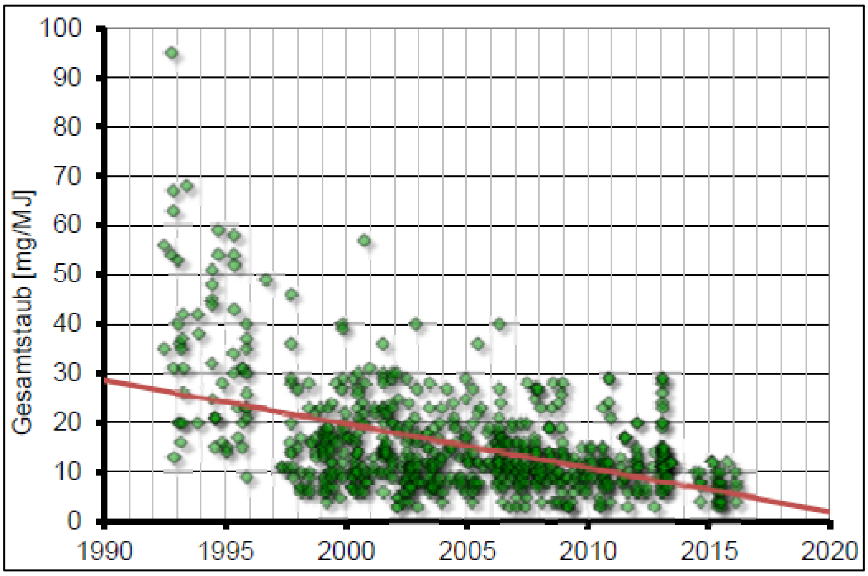

Figure 3: Development of particulate matter emissions in new wood fired boilers [mg$_{PM}$ MJ^{-1}] © Schwarz, 2019

This development went hand in hand with the discussions on air pollution and climate change. More and more the reduction of greenhouse gas emissions became the focus of interest and led to, amongst others, the first renewable energy directive of the European Union. The latest major legislative act is the Paris Agreement 2015 which has been signed by 195 nations so far.

Due to the fact that discussions about the raise of the share of renewable energies were mainly focused on renewable electricity, the biomass industry started to think about options also using biomass for electricity production. Besides other options, further development of gasification technique was considered as one possible solution. The ongoing increase in biomass boiler installations supported the development of gasification indirectly through the broad scientific community and craftsmen with their special knowledge in wooden biomass burning processes.

Although electricity from wooden biomass can also be produced through steam or organic ranking cycling processes, this report focuses only on biomass gasification processes.

1.1 General description of biomass conversion processes

Besides its main purpose combined with great opportunities for the use in construction, buildings, furniture etc., biomass is with its renewable carbon a great renewable energy source. As the energy is chemically bound it can also be seen as great source for energy storage. According to the statistical pocketbook 2020, published by the European Commission, the share of renewables reached 13.5 % of the worldwide energy supply in 2018. Within renewables the share of biomass reached 68 % and was by far the most important renewable energy source worldwide in 2018 (European Commission, 2020). Although so far most wooden biomass for energy production was directly used for heating and cooking via the combustion process, gasification of wooden biomass made huge progress within the last decade.

Categorisation of different biomass conversion technologies depending on excess air figure (lambda):

Within a direct combustion process the major goal is to fully combust the wooden biomass to convert the chemically stored energy within the biomass into thermal energy with high efficiency and very low emissions. Therefore, organic carbon should be converted as much as possible into CO_2 and exhaust gas should include combustible compounds as low as possible. The remaining ash should mainly include all not combustible elements like nutrients, trace elements etc. and not contain any further combustible organic carbon. Besides others, like

- temperature
- turbulences
- time

this will be achieved through at least 100 % oxygen needed for complete oxidation of all combustible compounds. Usually, the needed oxygen is delivered through the combustion-air. The ratio between actual combustion-air and needed combustion-air for full oxidation is called excess air figure (lambda). Lambda 1 states that the amount of oxygen within the combustion-air reaches exactly the amount which is needed to fully convert all combustible elements. Lambda > 1 is when excess combustion-air is given to the conversion process (usually all combustion processes run above lambda 1). Lambda < 1 is when not enough oxygen is given to fully convert all combustible elements (gasification or even pyrolysis process). This process is used to produce a calorific gas – the wood gas – which can be used in a further combustion process e.g., within a CHP to produce heat and power.

Table 1: Products of different biomass conversion technologies depending on excess air, H_i: Heating value inferior © Kaltschmitt, 2008

Conversion technology	**Conversion conditions**			**Products and their energy content**		
	Excess air	**Temperature**	**Pressure**	**Gases**	**fluids**	**solids**
	λ	[°C]	[bar]			
Combustion	≥ 1	800 - 1300	1 - 30	$H_i = 0$		$H_i = 0$
Gasification	0 < λ < 1	700 - 900		$H_i > 0$		$H_i \geq 0$
Pyrolysis	λ = 0	350 - 550		$H_i \geq 0$	$H_i > 0$	$H_i > 0$

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a) Combustion:

Wooden biomass does not combust as solid fuel directly, but rather after being released as gas. Within the first step of heating up the wooden biomass, free and cell-bound water will be released as vapor. At a temperature of around 150 °C gaseous fuel will be formed through a pyrolytic process. Within this process macro molecules will be broken through heat. Depending on process conditions, the built gaseous fuel is usually a CO_2, CH_4, H_4 and CO rich gas. This gaseous fuel will then be usually ignited but is still an endothermic process. Endothermic process means that the released energy from a process step is too low to keep the process ongoing. At around 250 °C and above, the process turns over in an exotherm reaction. Here the released energy is high enough to keep the process ongoing.

Table 2: Process differentiation exotherm vs. endotherm reaction © Kaltschmitt 2016

	Proportion between **Released energy: initial activation energy**	**Source of needed energy**
exotherm	released energy **>** initial activation energy	
endotherm	released energy **<** initial activation energy	
• autothermal		from supplied feedstock
• allothermal		From external e.g., vapor

Table 3: Process steps of biomass combustion, conditions, products and contribution to the reached energy output © Kaltschmitt, 2016

Biomass	**Temperature [°C]**	**reaction**	**products**	**Share of possible energy content [%]**
Heating up		endotherm	Cell unbound water will be set free	
Drying	> 100 °C	endotherm	Cell compound water will be vaporized	
Pyrolytic degradation	> 150 °C	Start of exotherm	Tar, CO and other combustible gases	~ 70 %
Gasification	> 250 °C	exotherm	CO and other combustible gases	
Burning of remaining carbon	> 500 °C	exotherm		~ 30 %

For a full combustion of wooden biomass lambda needs to be above 1 at each time for the whole process. In typical modern log wood boilers, the process steering is mostly done through a staged combustion process by dividing the needed air into primary and secondary air. Primary air is added below stochiometric conditions, to start and keep the process ongoing but is not sufficient to fully convert all combustible elements. Within this first step generated fuel gas will then be led into a special combustion chamber where it meets the secondary air to fully combust all combustible elements and produce heat. To reach the highest possible efficiency and to avoid emissions through combustible compounds, primary and secondary combustion-air will always be higher than the theoretically needed 100 % (lambda > 1). As each additional percentage of excess air needs to be heated up without bringing additional energy production this thereby lowers the efficiency of the combustion process. Therefore, well-developed combustion processes try to lower the total amount of input air close to lambda 1 (Schmidl; 2020, Kaltschmitt, 2016).

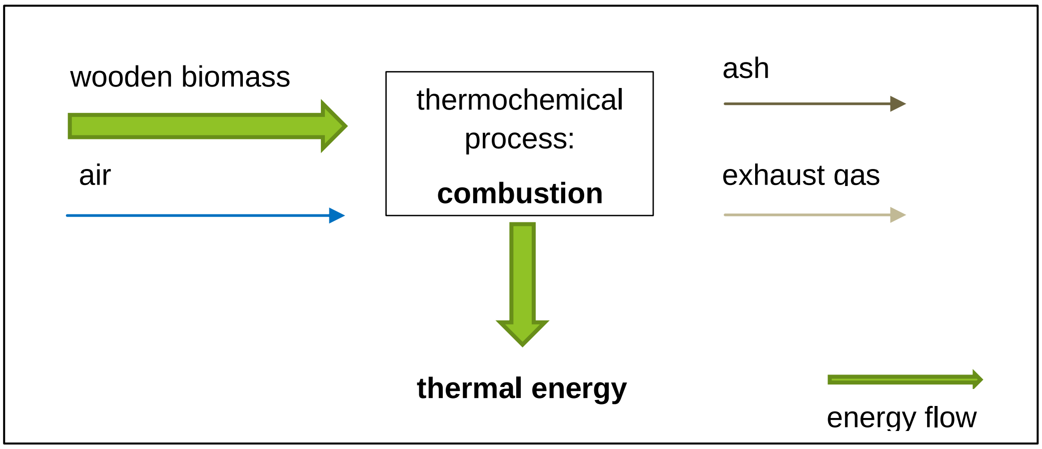

Figure 4: Theory of full combustion of wooden biomass

Picture 3: Process steps of biomass combustion: left: gaseous fuel passes out of heated up wooden biomass; right: burning of gaseous fuel

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Picture 4: Process steps of biomass combustion. Differentiated supply of primary and secondary air for full combustion of gaseous fuel (primary air below stochiometric conditions, secondary air over stochiometric conditions)

Picture 5: Process steps of biomass combustion: remaining charcoal combusts with a short light blue flame and at least without any flame like barbecue coal does

The usual goal of wooden biomass combustion is to produce heat for cooking and heating or even to produce steam.

b) Gasification

While the aim of the combustion of wooden biomass is to produce heat through a full combustion process, the gasification process can be seen as a wanted incomplete process of biomass combustion with the aim to produce a caloric gas which can be later fully combusted and, depending on the process, maybe also charcoal. In comparison to combustion this can be achieved by lowering the requested oxygen under the required amount for full combustion process of all combustible compounds (lambda $\lambda < 1$). Through this the process stays

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endothermic. In an endothermic process the activation energy to start the process is higher than the direct set free energy during the process. Hence, without further external energy supply the process would stop. The requested energy to continue this process can be supplied through partially burning of feedstock or produced gas (autothermal) or through external supply of energy (allothermal) like vapor or heated gasification sand etc. The full oxidation of the produced gas will be done in a second step (after gas cleaning) producing heat, steam, combined heat and power (CHP) or even, after another technical process, injected into the gas grid. For partly oxidizing the wooden biomass, different types of gasification medium can be used. The most common gasification medium is usually air but can also be oxygen or vapor. This second process then is – after an initial endotherm process starts – strong exotherm (released energy is higher than initial activation energy).

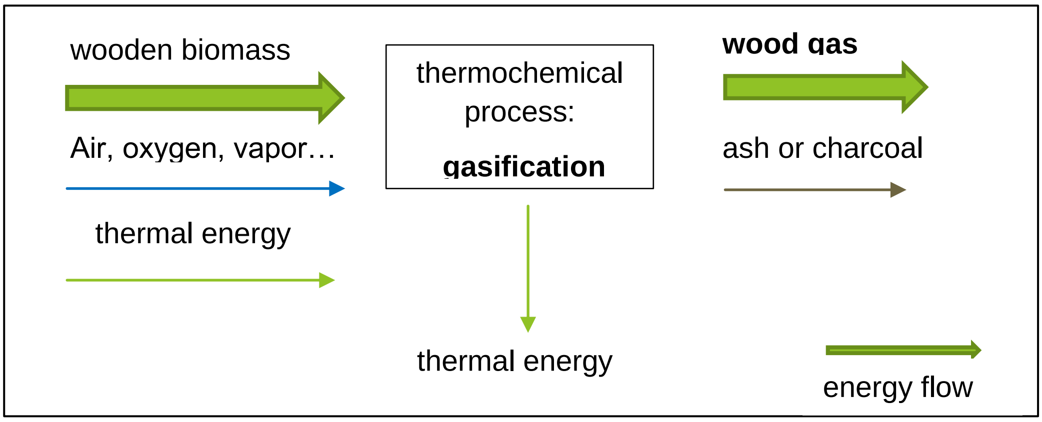
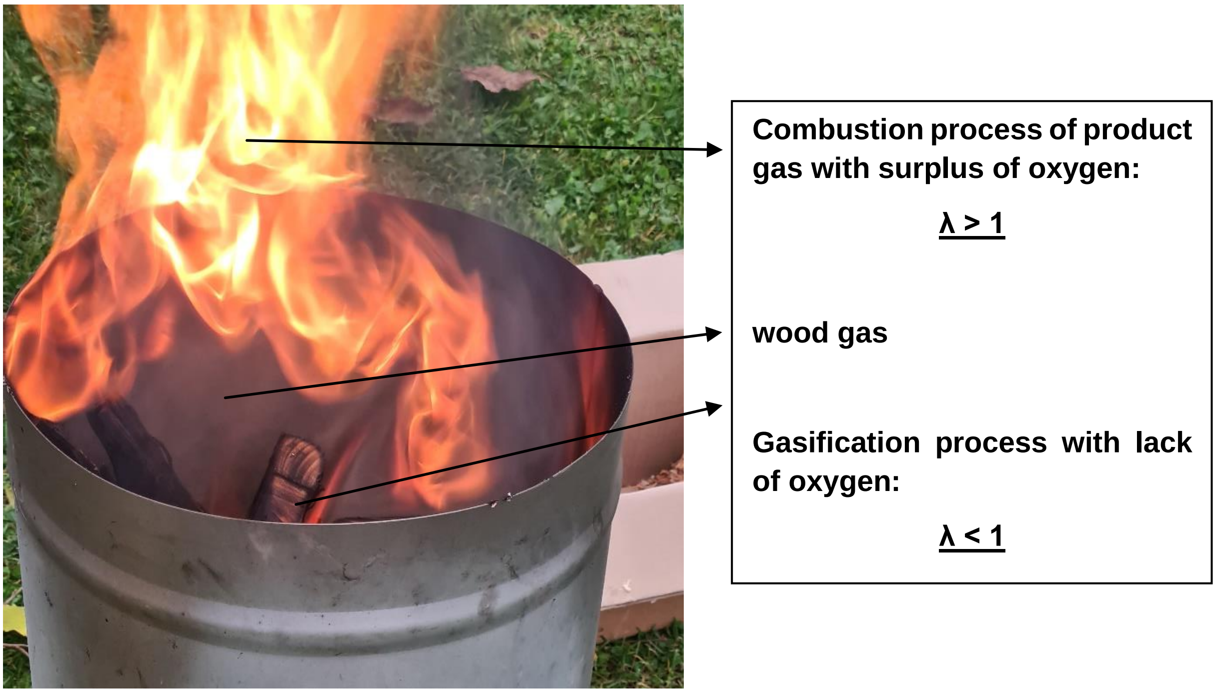


Figure 5: Theory of energy flow within a gasification process. Input thermal energy can come from partly combustion of wooden biomass (autothermal) or can be delivered from external source (allothermal). The thickness of arrows shows the main flows



Picture 6: Gasification and combustion of wooden biomass

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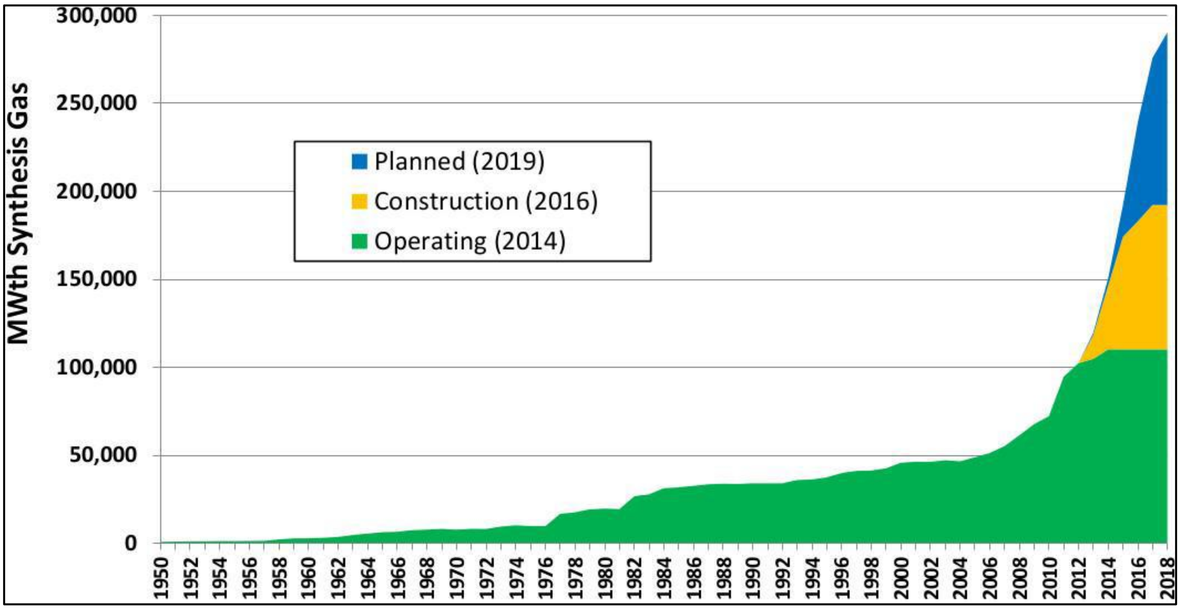
Charcoal, the possibly second product of gasification, is mainly used as soil conditioner and as activated carbon. It includes nearly all nutrients included in the feedstock and additionally the not combusted carbon.

Compared to combustion of wooden biomass, which has a long-standing tradition and important role in energy supply, gasification had an interim high between the world wars and during the Second World War and is now coming up very strong again (Graph 1: Cumulative worldwide capacity of gasification technique © Hrbek, 2020).



Graph 1: Cumulative worldwide capacity of gasification technique © Hrbek, 2020

c) Pyrolysis

The main difference between combustion and gasification compared to pyrolysis technique is that for the latter, the process will be performed only through adding heat but without any additional external oxygen (lambda = 0). The main products of pyrolysis differ depending on the chosen process, temperature and pressure. The macromolecules of wooden biomass will be cracked down and liquid and gaseous fuels are the outcomes of the process. Both products can then be cleaned, upgraded and used for energy production or new bio-based products.

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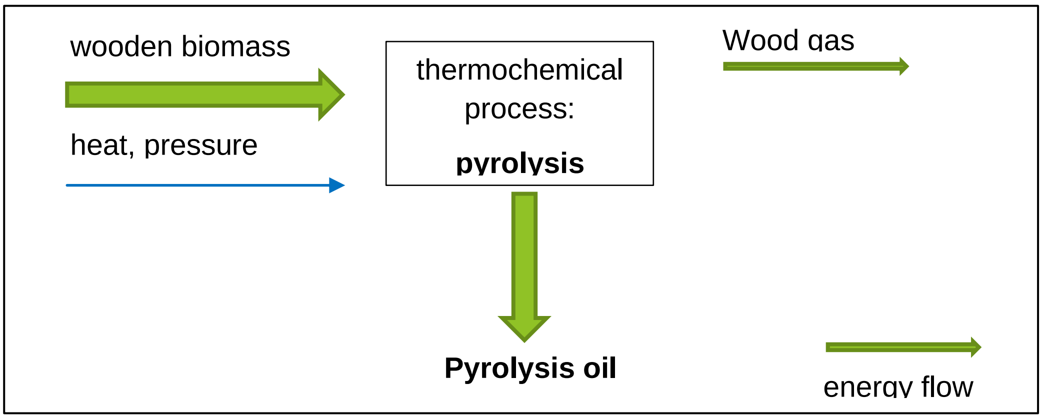

Figure 6: Theory of the energy flow within a pyrolysis process

1.2 Why gasification of wooden biomass

During the last decades scientists, companies and interested persons searched for the possibilities to extend the usage of wooden biomass for energy purposes. One major goal was to divide the combustion process from the place where the heat should be applied. In private households etc. this was done by installing a central heating system and distributing the produced heat through heated air or water-borne central heating instead of using tiled stoves in each room. Through installing a district system, the installation of the boiler to combust wooden biomass could even be situated on the outskirts. Another possibility is to only partly combust the wooden biomass to produce a low calorific wood gas which can be used to produce combusted gas at a different place or can be used to produce heat and electricity in a combined cycle called CHP.

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2 Differentiation and characterization of different gasification processes

Compared to combustion, gasification offers the opportunity to produce a combustible gas which can be applied at a different place. Although this gas is technically seen as a lower calorific value gas it offers several opportunities. For example, if the goal is to produce electricity, the electrical efficiency can be raised compared to a conventional steam process (© IEA bioenergy 2014). The produced gas can at least be shifted and used as renewable natural gas substitute and can be injected into the gas grid or transformed becoming a renewable oil substitute. Gasification is not per se a better biomass conversion process than combustion but offers many new opportunities and end-use applications. Over the last decades several different types of gasification techniques have been developed depending on the size, used feedstock and gasifier medium. Furthermore, the endothermic process can be divided into techniques with autothermic energy supply, where the used feedstock is partially combusted to supply with needed thermal energy, or allothermal energy supply, where needed thermal energy is supplied from outside through vapor, gasification sand etc.

Table 4: Differentiation of different types of gasification technologies

1. Types of gasifier		
	a)	**Fixed bed gasifier**
		Updraft
		Downdraft
	b)	**Fluidized bed gasifier**
		Standing fluidized bed
		Circulating fluidized bed
	c)	**Entrained flow gasifier**
2. Supply of needed thermal energy for the endothermic process		
	a)	**Autothermal: from supplied feedstock**
	b)	**Allothermal: external through vapor, gasifier material like sand etc.**
3. Gasifier medium		
	a)	**air**
	b)	**oxygen**
	c)	**vapor**
4. Pressure		
	a)	**atmospheric**
	b)	**pressurized**

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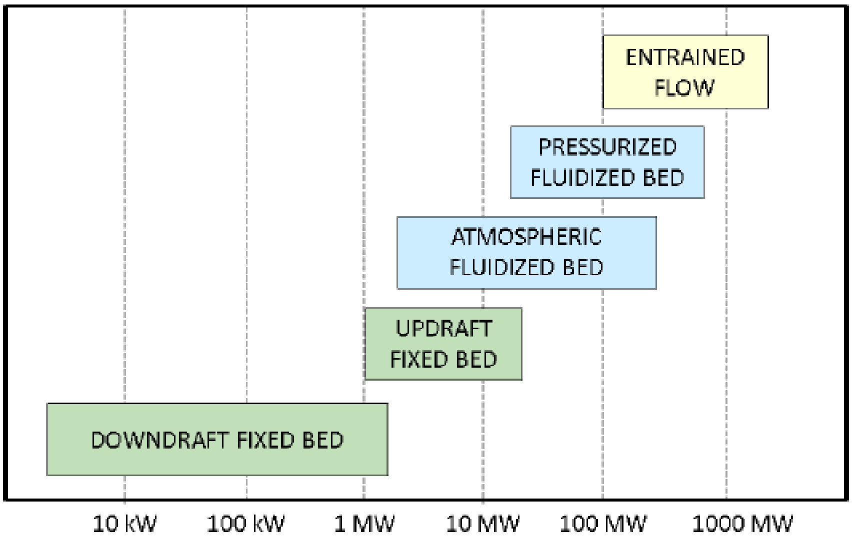

Figure 7: Types of gasifier techniques and their usual range of performance ©IEA, 2014

Based on the characteristic of how the feedstock flows through the gasifier, this differentiation will be elaborated in the subsequent description of different gasifier techniques. In total a very wide range of technologies is already available on the market. Although only fixed bed gasifiers and fluidized gasifier are considered in this report this shall not be seen as a periodization.

2.1 Fixed bed gasifier

Within a fixed bed gasifier, the wooden biomass is usually fed from one side into the gasification chamber and will be degraded and leaves as ash on the opposite site. The flow of biomass is not driven by the oxidant flow etc. If producing charcoal is also a topic, then the solid end product is not ash but charcoal. This will be achieved through steering the amount of oxidant: the less oxidant the less thermal energy outcome and the more energy in the wood gas and or charcoal. In order to be able to control the oxygen level closely far below stoichiometric conditions, the feeding system is usually conducted airtight. This is mostly done through a double slide system, a combination of a slide and an air bellow or a rotary valve. In all cases safety devices e.g., which detect a raise of temperature, the filling level etc., are installed between those locking devices. The biomass enters then the gasification chamber via gravity, if fed from above, or via an auger screw, if fed from the bottom. Within the gasification chambers the biomass will go through several process steps like:

- Heating up and drying
- Pyrolysis
- Oxidation
- Reduction

If the flow is from top to bottom, the biomass flow is usually done by gravity. The opposite flow can be achieved through an auger screw etc. The gasification medium and also the wood gas can have the same flow direction as the biomass. This is then called a downdraft gasifier. If the flow direction is against the biomass flow, then it is called an updraft gasifier. In the

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following subcategories a general description is given. Depending on the goal of the gasification process, carbon from wooden biomass can be nearly fully or partly oxidized. The latter is to achieve a charcoal which can be used for other purposes.

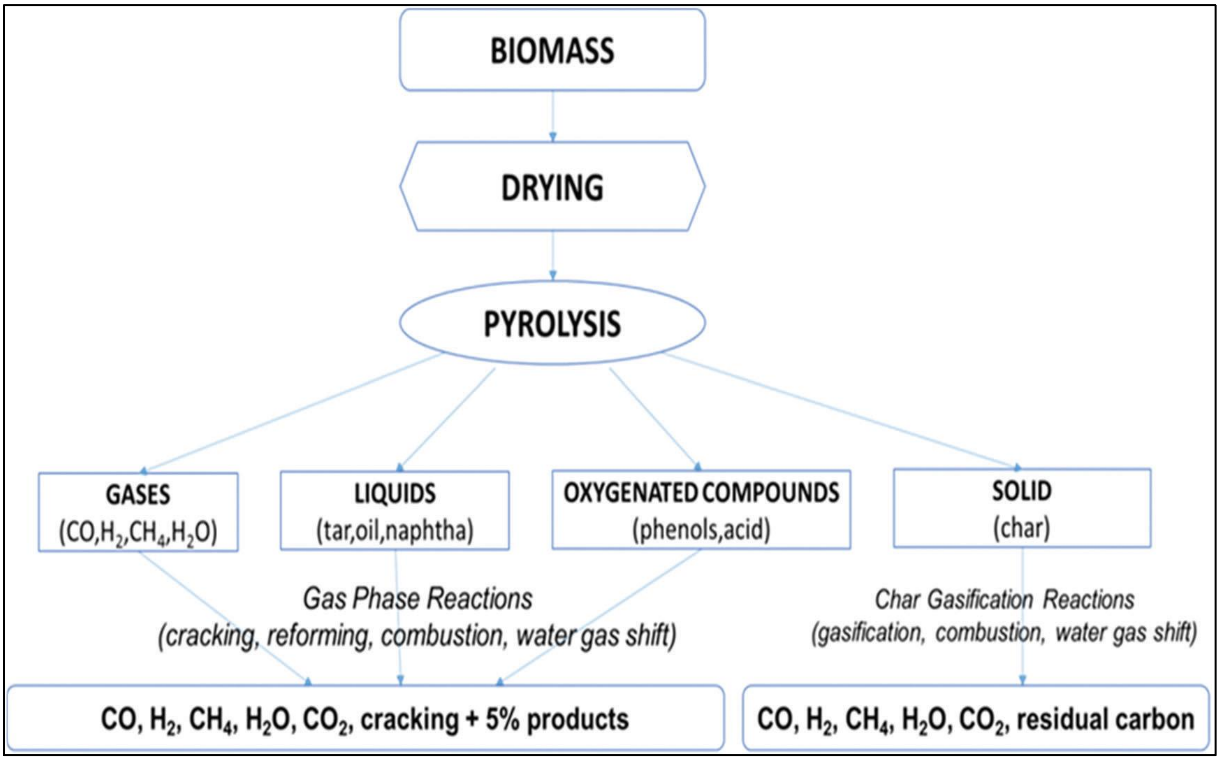

Figure 8: Process steps of gasification © Sikarwar, 2016

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Picture 7: Safety devices upfront of the gasifier: top left: double valves; top right: combination of slider and air cushion; bottom left: double slider; bottom right auger screw into gasifier

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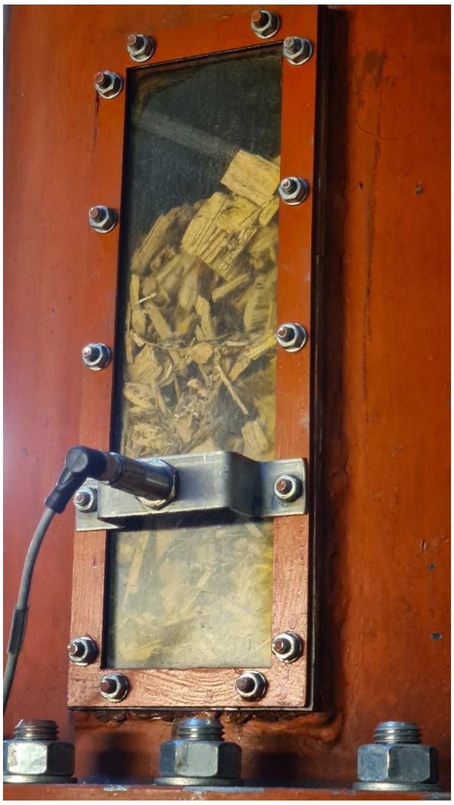

Picture 8: Feeding system: level sensor

Picture 9: Intake auger screw into an upstream gasifier

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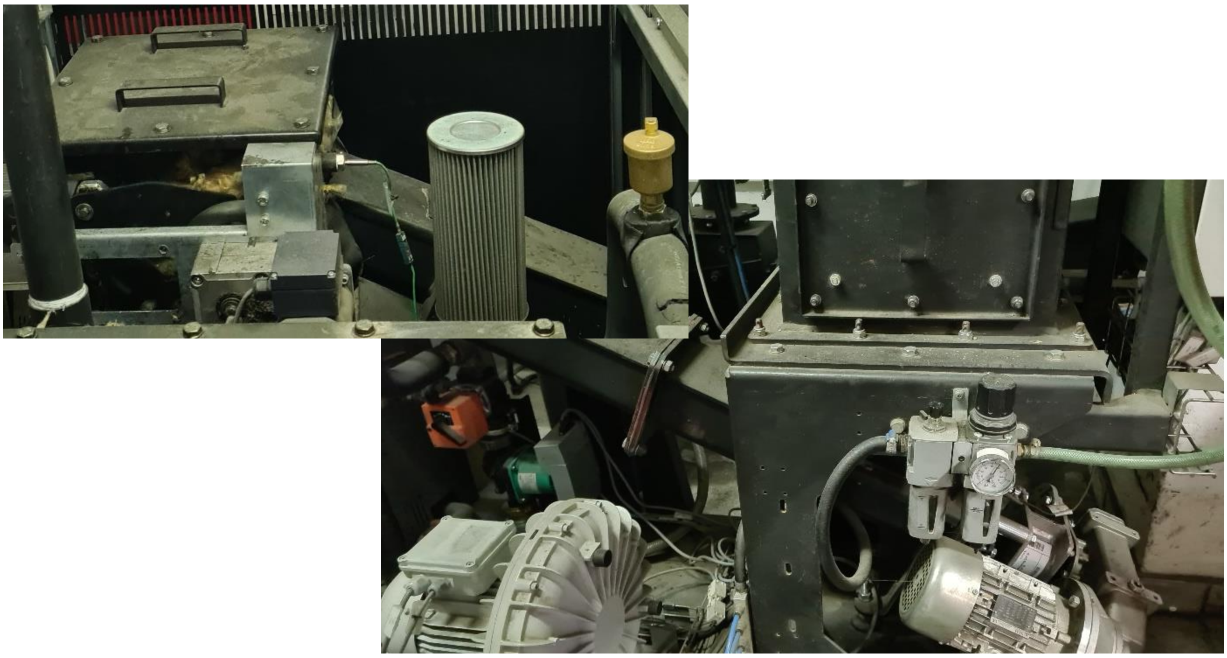
Picture 10: Downdraft gasifier with security system and feeding auger



Picture 11: Auger screw into a downdraft gasifier

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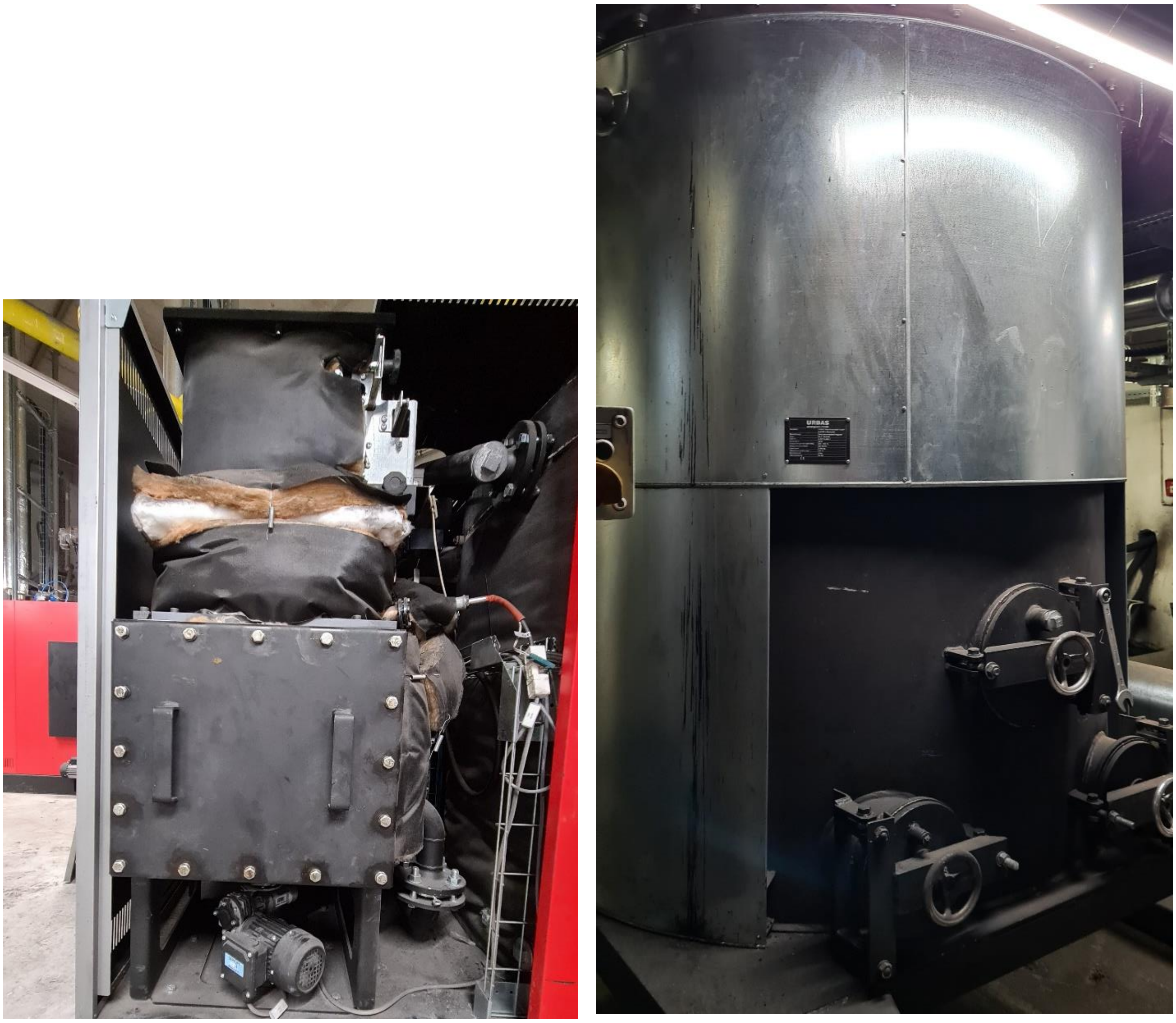

Picture 12: View of fixed bed gasifier; left: 50 kW$_{el.}$ right: 150 kW$_{el.}$ (only bottom part)

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Picture 13: Downdraft fixed bed gasifier: left: coat of gasifier with air pipes; right: insight from bottom

Picture 14: Rotating grate of a fixed bed downstream gasifier: left: taken apart; righ: assembled

2.1.1 Fixed bed downdraft gasifier

The principle of a fixed bed downdraft gasifier is that wood chips and wood gas have the same flow direction through the gasification process. This means after entering the gasifier wood chips will be heated up and dried followed by the pyrolysis process above 150 °C and still without injected oxidant. With the injection of the oxidant (usually air) the process heats up to ≥1000 °C. The last step then is a reduction process where partly built tar or pyrolysis oil from the pyrolysis process should be cracked down into gaseous fuel. At least a wood gas shall be leaving the process which is dry with minimum tar or pyrolysis oil. Achieving a relatively dry gas can be realized by avoiding wet biomass. Therefore, biomass will always be dried before gasification. As tar and pyrolysis oil will be released during the pyrolysis step it is important that it passes a hot oxidation followed by a reduction zone. Product flows without passing these zones must be avoided. This will be achieved by using mostly homogenous wood chips without fine dust or oversize parts and thereby guarantees that such dead zones cannot appear. Additionally, as the probability of such dead zones raises with bigger diameter of the gasifier, the size and therefore the performance is limited because here compression zones without gas flow could easier appear (Figure 7: Types of gasifier techniques and their usual range of performance ©IEA, 2014).

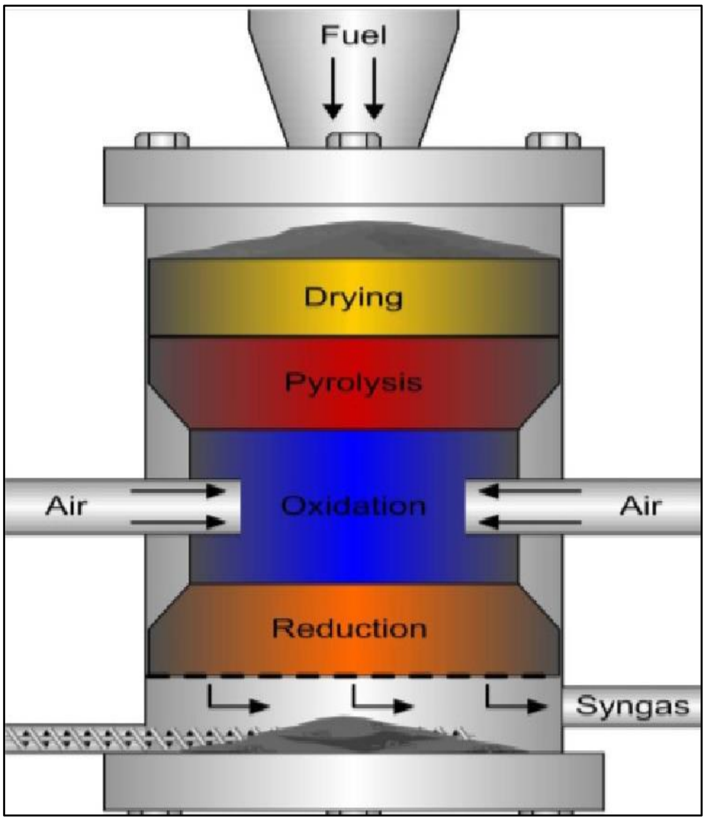

Figure 9: Scheme of a downdraft fixed bed gasifier ©A. Gandhi, 2012

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2.1.2 Fixed bed updraft gasifier

In contrast to a fixed bed downdraft gasifier, within an updraft gasifier the gas flow is contrary to the biomass flow. The oxidant usually enters at the bottom and reacts at first with the biomass laying directly above the grate. The so produced gas flows upwards and goes then through the following process steps:

- Reduction
- Pyrolysis
- Drying

The oxidation zone delivers the needed heat heating up the following zones through created wood gas. By passing zone after process zone, wood gas gets colder itself and consequently each passed zone as well. Within the second process step – the reduction zone – produced CO_2 will partly be reduced to CO and H_2O partly to H and CO. After passing the pyrolysis and drying zone the wood gas is cooled down to about 100 up to 200 °C. Cooling the gas via flowing through the different process steps after the oxidation step and heating up the other reaction zones is one of the major advantages of the technique. The updraft gasification process has lower requirements on feedstock quality like union size, fine dust and humidity. Additionally, possibly created particles will be complexed with the fed biomass and thus at least partly held back. This causes a gas when leaving the process which is already relatively cool and includes low particle content compared to gases from downdraft gasifiers. But on the other hand, as created gas from the pyrolysis process does not pass a hot zone anymore it includes higher amounts of tar, phenols etc. which then might cause problems when they condense afterwards. Besides the application in a direct combustion process, wood gas from an updraft gasification has higher requirements on gas cleaning.

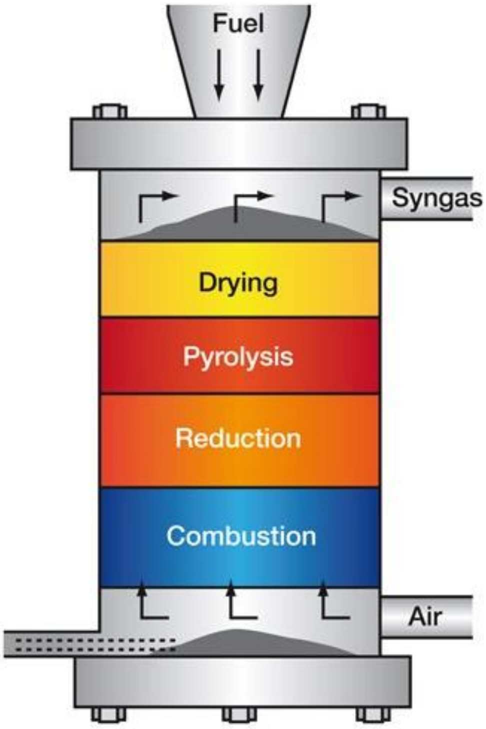

Figure 10: Scheme of updraft fixed bed gasifier © steemit

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2.1.3 Special designs: Double staged fixed bed gasifier

In order to overcome the problems of downdraft or updraft fixed bed gasifier, scientists and companies searched for further improvements. One solution could be dividing the process steps of gasification into at least two steps. Manufacturer of downdraft and updraft fixed bed gasifier have already developed very detailed designs especially of the gasifier, this much more occurs with double staged fixed bed gasifier. Within this gasifier type the process of pyrolysis and oxidation is usually divided into two steps. In the first step heating up, drying and pyrolysis takes place to produce wood gas and charcoal. The following oxidation and reduction process is used to reduce possible tar within the wood gas and to further oxidate carbon within the charcoal. The division into two steps makes it possible to run different rates of gasification gases within the different steps or even to use different gasification gases like vapor and air and thus to reduce nitrogen dioxide within the wood gas.

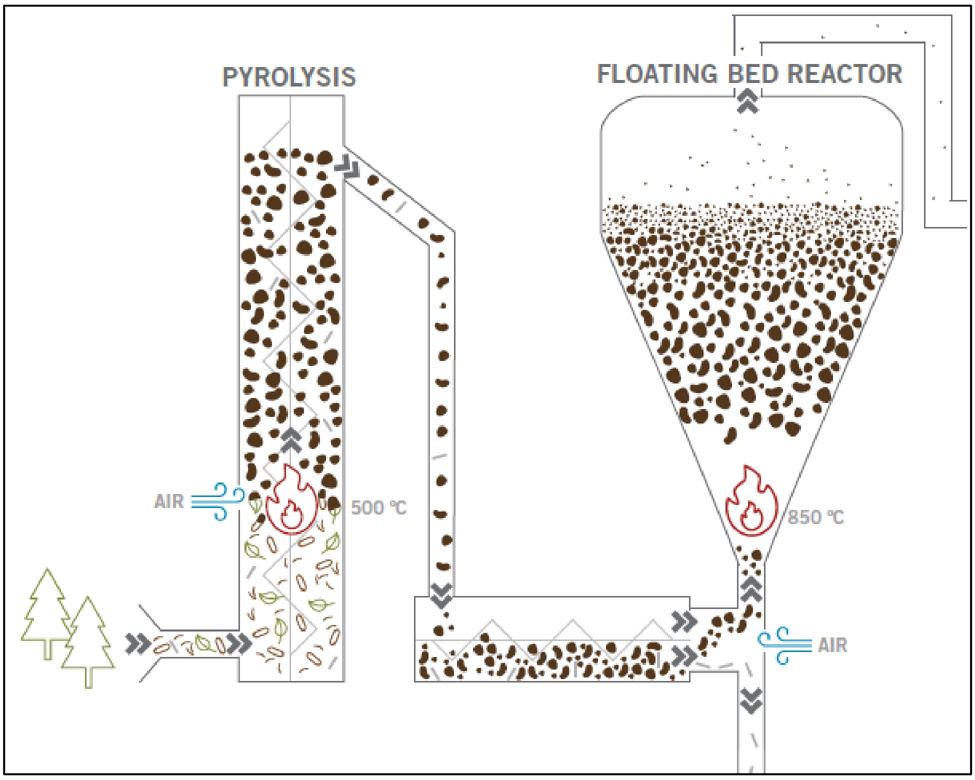

Figure 11 :Double staged gasification process; left: updraft pyrolysis; right updraft floating bed reactor © syncraft

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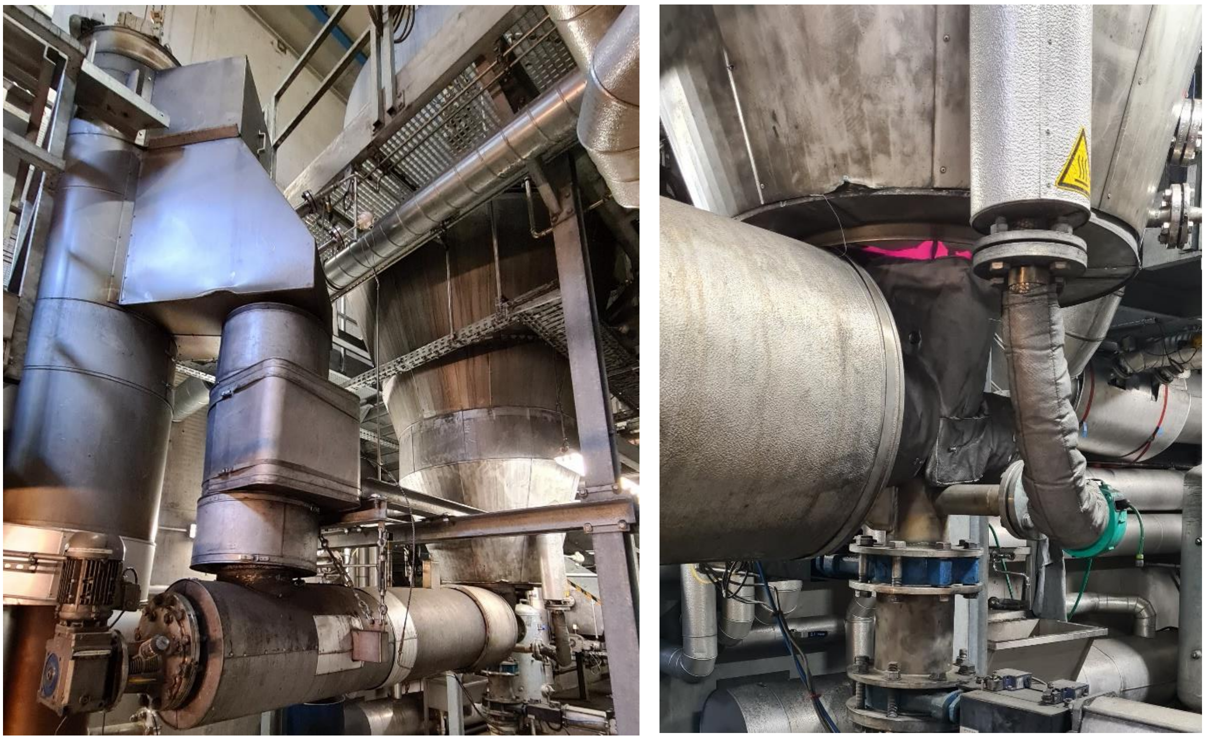

Picture 15: Left updraft pyrolysis with auger screw to move biomass upwards, drop shaft and floating bed reactor; right: bottom of floating bed reactor with oxidation flame and impurities disposal at the bottom

2.2 Fluidized bed gasifier

Contrary to fixed bed gasifier where wooden biomass flows slowly through the gasifier and passes one after another process step separately with their individual temperature zones and chemical processes, within a fluidized gasifier the biomass will be fed into a gasifier bed where it gets directly in contact with the heated-up gasifier bed medium. The gasifier bed medium shall bring fast intense gasification. The gasifier bed material can be quartz sand but also materials which additionally have catalytic properties like limestone, dolomite etc. This gasifier bed material will be held hovered by the gasifier medium which is usually air, oxygen or vapor. For this the velocity of the gasifier medium must be injected with a vector which hovers the bed material. The fluidized bed of the bed material guarantees an intense contact with the feedstock and the gasification process is done much faster than in a fixed bed gasifier and hence fluidized bed gasifier usually have a higher capacity. This can be increased by pressurizing the process but on the other hand causes higher investment and operating costs. Achieving an intense contact between bed material and wooden biomass, the latter must be much smaller than in fixed bed gasifier. The usual gasification temperature is limited on one hand by the ash melting point of the feedstock and on the other hand by the unwanted increase of tar components in the gas (~ 700 °C). Possible ash particles which leave the gasifier with the wood gas stream will be separated via cyclone separator. Recovering the heat within wood gas needs to be done via heat exchanger (© 2020 IEA bioenergy).

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2.2.1 Stationary fluidized bed

The stationary fluidized bed is achieved by the input velocity of the gasification medium. The velocity of the gasification medium (air, oxygen, vapor…) raises the gasification bed material so its starts fluidizing but does not take it out of the gasifier. Therefore, the density of the bed material and the velocity of the gasifier medium are directly linked. The height of the fluidized bed is usually 1 up to 2 m depending on geometry of the gasifier and secures an intense contact between fluidized bed material and fed biomass.

2.2.2 Circulating fluidized bed

Compared to stationary fluidized bed gasifier within the circulating fluidized gasification technique the velocity of gasification medium reaches a speed so that the fluidized bed material is not only hovered but also carried out of the gasifier with the produced wood gas. The recovery is done within the following cyclone separator.

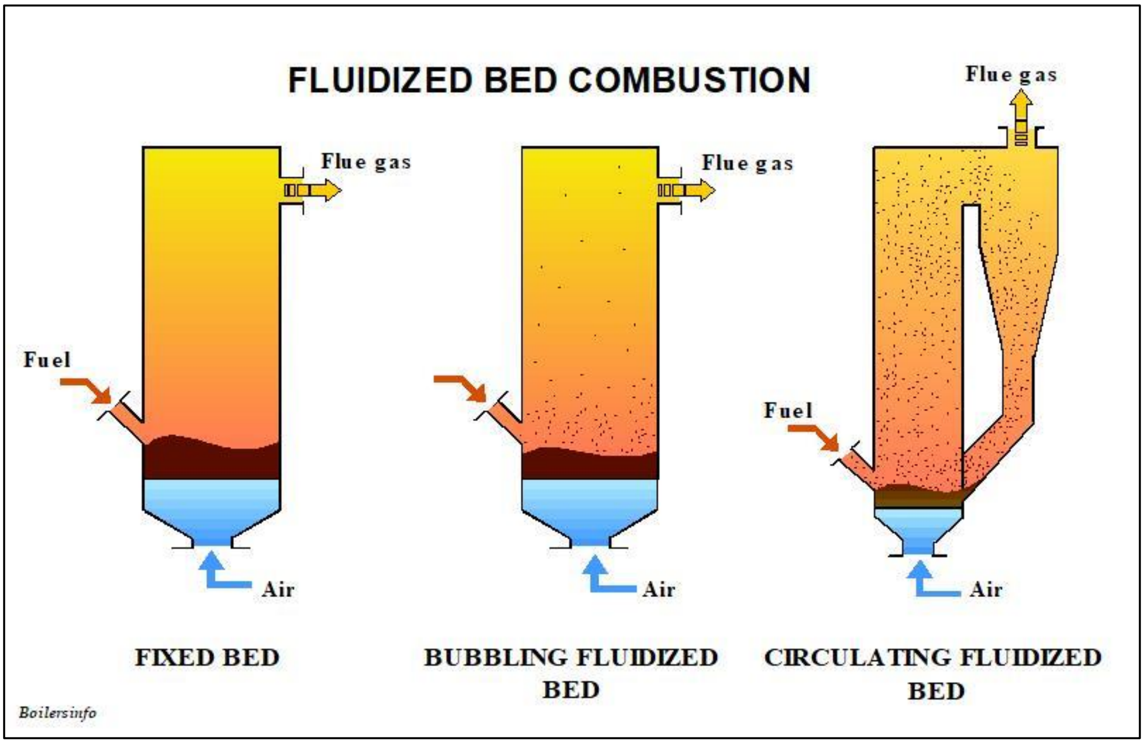

Figure 12: Types of different fluidized bed gasifiers ©boilersinfo.com, 2018

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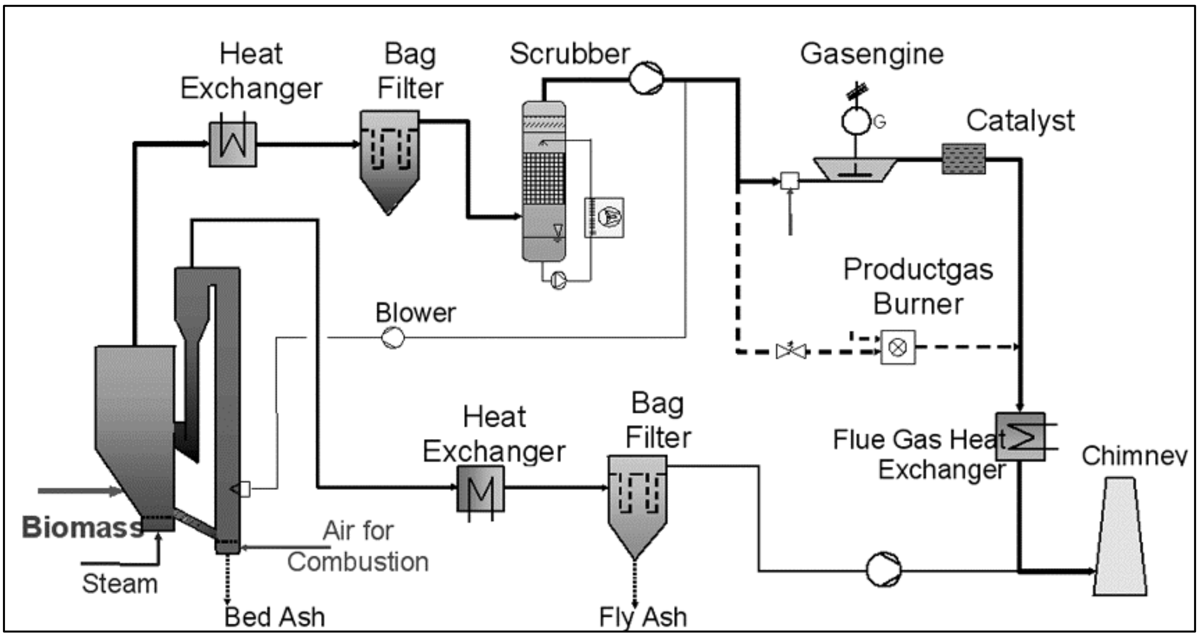

Figure 13: Schema of Fast Internally Circulating Fluidized Bed gasification (FICFB gasification) process © Hofbauer H. 2002

Picture 16: Fast Internally Circulating Fluidized Bed gasification plant in Güssing, Austria: left: whole plant; right: bottom of gasifier and autothermic bed recirculation chamber

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3 Feedstock: specification, storage, pretreatment and handling of feedstock

The wide range of gasification technologies offers also the opportunity to use a wide range of feedstock. For all kinds of solid fossil carbon to renewable carbon like wooden or agricultural biomass, gasification technology offers special technology options. Related to the described technologies within this report, feedstock types from wooden biomass are considered here.

3.1 Specifications and characteristics of feedstocks

3.1.1 Main components

Carbon is the main component of wooden biomass and combined with cell bound hydrogen the energy delivering source within these feedstocks. The third main component is oxygen which has an important role during the gasification or combustion process as it delivers already a part of the needed oxygen for oxidation of the feedstock. Compared to different kinds of grasses or cereals the carbon content of wooden biomass is higher (~ 50 $\%_{DM}$) and the amount of nutrients is lower. As chlorine may cause corrosion feedstock should have very low amounts of it. The ash content in wooden biomass is very low (~0.5 $\%_{DM}$) while bark already has a significant higher amount of ash. Consequently, wooden biomass with smaller diameter causes higher ash amounts as the share of bark is higher (Table 5). Besides possible emissions the included nutrients have an important role for the ash melting point (

Ash melting point 3.1.2).

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Table 5: Main ingredients of biomass fuel [$\%_m$, w=0] ©Beckmann, 2007; Kaltschmitt, 2016; Obernberger, 2001; Eltrop, 2014

Feedstock		C	H	O	N	K	Ca	Mg	P	S	Cl	ash
		[$\%_m$ within DM]										
Spruce	incl. bark	49.8	6.3	43.2	0.13	0.13	0.7	0.08	0.03	0.015	0.005	0.6
Beech		47.9	6.2	45.2	0.22	0.15	0.29	0.04	0.04	0.015	0.006	0.5
pine		53.2	5.9	40.4	0.1					0.06	0.005	0.4
oak		56.5	5.1	37	0.2					0.09	0.005	0.4
Bark of coniferous		51.4	5.7	38.7	0.5					0.085	0.019	3.8
Waste wood		45	5.63	36.37	0.37						0.12	0.8
sawdust		50	6.4		0.03					< 0.05	0.01	
Logging waste		50	6		0.03					< 0.05	0.01	
Olive kernels		50.7	5.89	36.97	1.36					0.3	0.18	
wheat	straw	45.6	5.8	42.4	0.48	1.01	0.31	0.1	0.1	0.08	0.2	5.1
Barley		47.5	5.8	41.4	0.46	1.38	0.49	0.07	0.21	0.089	0.4	4.8
corn		45.7	5.3	41.7	0.65					0.12	0.35	6.7
Landscaping hay		45.5	6.1	41.5	1.14	1.49	0.5	0.16	0.19	0.16	0.31	5.7
wheat		43.6	6.5	44.9	2.28	0.46	0.05	0.13	0.39	0.12	0.04	2.7

3.1.2 Ash melting point

Depending on the ingredients of feedstock, the feedstocks have different ash melting points. While calcium contributes to a higher ash melting point, potassium and magnesia lower the ash melting point. Exceeding the ash melting point during the gasification process might cause that melted ash starts to pack to technique equipment. This might then do damage to the grate, cyclone separator, exhaust exchanger or at least cause higher maintenance etc. Thus, it is important not to reach a temperature above the ash melting points (© Kaltschmitt, 2016).

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Table 6: Ash melting points of different feedstocks © Eltrop, 2014; Kaltschmitt 2016

Feedstock		**Ash melting points**		
		Deformation temperature	**Hemisphere temperature**	**Flow temperature**
		[°C]		
Spruce	incl. bark	1 426		1 583
Beech				
pine				
oak				
Bark of coniferous		1 440	1 460	1 490
Waste wood				
sawdust				
Logging waste				
Olive kernels				
wheat	straw	998	1 246	1 302
Barley		980	1 113	1 173
corn		1 050	1 120	1 140
Landscaping hay		1 026		1 228
wheat		687	887	933

3.1.3 Energy content and the influence of water content

Water content vs. moisture content:

As in nature water is an essential element for living, wooden biomass does not occur completely dry. Usually, within the fresh mass the water content is around 50%. Calculating the energy content, it is important to differ between possibly different used terms and their calculation equation. While in the calculation of the water content, the fresh mass is basis of the calculation, the dry mass is basis of the calculation in moisture content calculations. Usually, the water content is used.

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Table 7: Difference in reference base between water content and moisture content

Water content			**Moisture content**	
water	**Fresh mass** **= 100 %**		**water**	
Dry mass			**Dry mass**	**= 100 %**

Equation to calculate the water content:

$$w = \frac{m_W}{(m_B + m_W)} . 100$$

Equation to calculate the moisture content:

$$u = \frac{m_W}{m_B} . 100$$

w = water content

m_W = mass of water

m_B = mass of biomass

u = moisture content

Energy content

The energy content of biomass depends mainly on its carbon and hydrogen content. In practice also the water content plays an important role. Based on dry mass the difference in energy content is relatively small. Due to their content of resin, wood from conifers has an energy content that is a little bit higher than the one from hardwood. In total the energy content lays with small variations between 18 and 19 MJ_{Hi} kg_{DM}^{-1}.

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Table 8: Energy content of different types of biomass feedstock, H_i: heating value inferior, H_s: heating value superior © Obernberger, 2001; Kaltschmitt, 2016

Feedstock		$[MJ_{Hi}\ kg_{DM}^{-1}]$	$[MJ_{Hs}\ kg_{DM}^{-1}]$
Spruce	incl. bark	18.8	20.2
Beech		18.4	19.4
pine		19.2	20.5
oak		18.2	19.3
Bark of coniferous		19.2	20.5
Waste wood		18.3	19.7
sawdust			
Logging backlash			
Olive kernels		20.8	
wheat	straw	17.2	18.5
Barley		17.5	18.5
corn		17.7	18.9
Landscaping hay		17.4	18.9
wheat		17	18.4

Equation to calculate the energy content at given water content:

$$H_{u(w)} = \frac{H_{u\,(wf)} \cdot (100 - w) - 2{,}443\, w}{100}$$

$H_{i\,(w)}$ = heating value inferior at given water content $[MJ\ kg_{FM}^{-1}]$

$H_{i\,(wf)}$ = heating value inferior of wood species based on dry mass $[MJ\ kg_{DM}^{-1}]$

w = water content [%]

2.443 = enthalpy of vaporization of water based on 25 °C starting temperature $[MJ\ kg_{H2O}^{-1}]$

Water needs to be heated up and vaporized during the gasification or combustion process and thereby induces energy demand. Within a process without condensation the energy demand for vaporization of water has an influence with 2,26 MJ kg_{H2O}^{-1} while heating up of water needs only 0.004 MJ kg_{H2O}^{-1} $°C^{-1}$.

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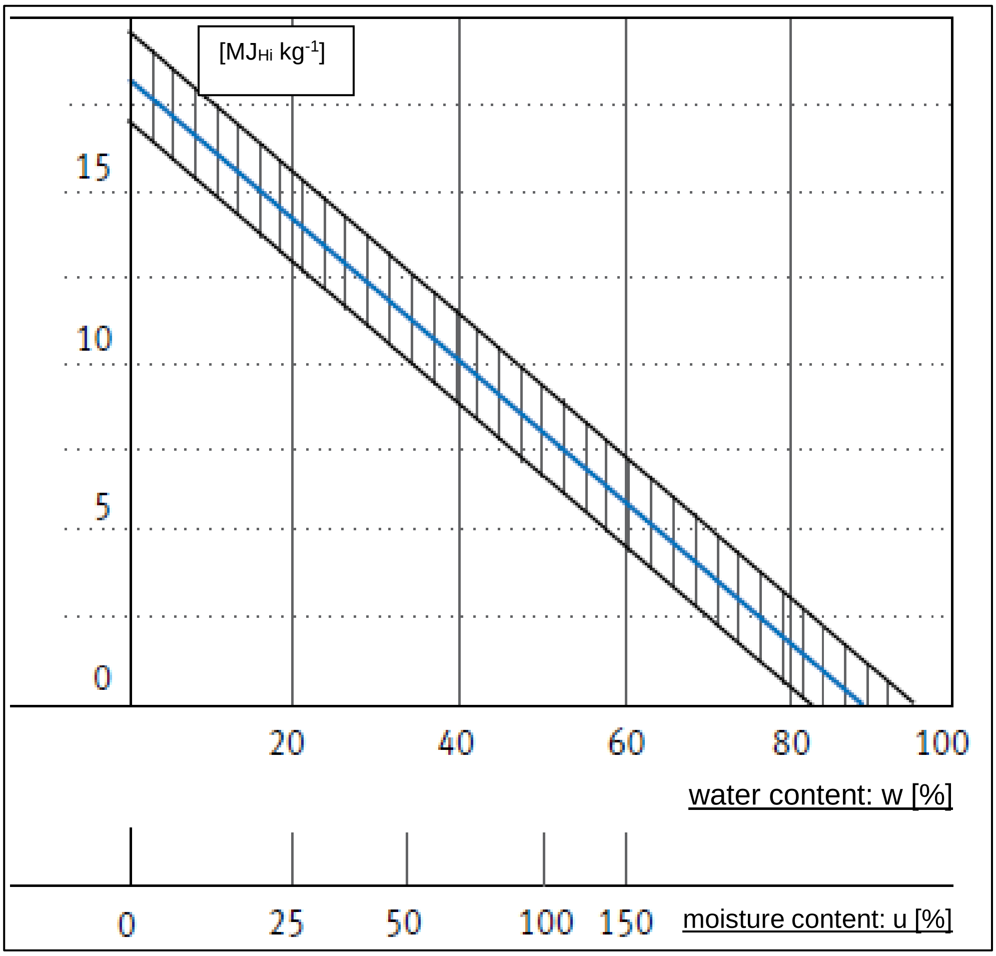

Graph 2: Heating value inferior of wooden biomass related to water content and moisture content, © Eltrop, 2014

Density of wood

Variations that should also be considered come from the density of different wood species contrary to the difference in energy content per kg_{DM}. Further differentiation between types of wood species occur due to growth conditions like climate, weather, sea level, availability of nutrients, water and sunlight availability etc.

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Table 9: Density of different wood species © Kaltschmitt, 2016

Soft wood	[g cm^{-3}]	Hard wood	[g cm^{-3}]
Spruce	0.41	Oak	0.67
Fir	0.41	Maple	0.59
Pine	0.51	Ash	0.67
Douglas fir	0.47	Beech	0.68
Larch	0.55	Birch	0.64
Alder	0.49	Robinia	0.73
Limetree	0.52	Elm	0.64
Poplar	0.41	Hazel	0.56
Willow	0.52		

3.2 Requirements for the use in gasifiers

Many problems in gasification occur because feedstock is not adjusted to the special requirement for the gasification. Dependent on the type of gasifier, feedstock requirements differ.

Table 10: Requirement on biomass dependent on gasifier technique © IEA bioenergy, 2019

Type of gasifier	Fuel specifications
Fixed bed gasifier	• Fuel particle size: 1 – 10 cm
	• Mechanically stable fuel particles (unblocked passage of gas through the bed)
	• Updraft gasification: more tolerant to water content of biomass
Fluidized bed gasifier	• Fuel particle size: relatively small to ensure good contact with bed material ○ Circulating fluidized bed: < 40 mm ○ Stationary fluidized bed: < 80 mm
	• Ash melting point: higher limit for operation temperature
	• Good fuel flexibility due to high thermal inertia of the bed
Entrained flow gasifier	• Fuel particle size: ~ 50 µm (pulverized for high fuel conversion
	• Attention to ash melting point behavior for process design
	• Low water content required

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3.2.1 Size, fine dust

Fixed bed gasifiers have relatively high requirements on the size of feedstock and here especially also on the share of possibly included fine dust. This is because within fixed bed gasifiers the gasification medium and also the produced wood gas needs to flow through the feedstock. Different flow resistances within the wood bed may cause dead zones where no gasification takes place or only tar etc. is formed but not further degraded anymore. Therefore, nearly each fixed bed gasification device runs a sieving device for fine dust. With the same device usually also oversized particles (mainly oversized in length) will be separated. Especially a downdraft fixed bed gasifier requires a higher lumpiness of the used wooden biomass. This is sometimes also done through special woodchipper which use an auger chipping device instead of a drum chipping device.

Picture 17: Different piles of chipped wood before sieving

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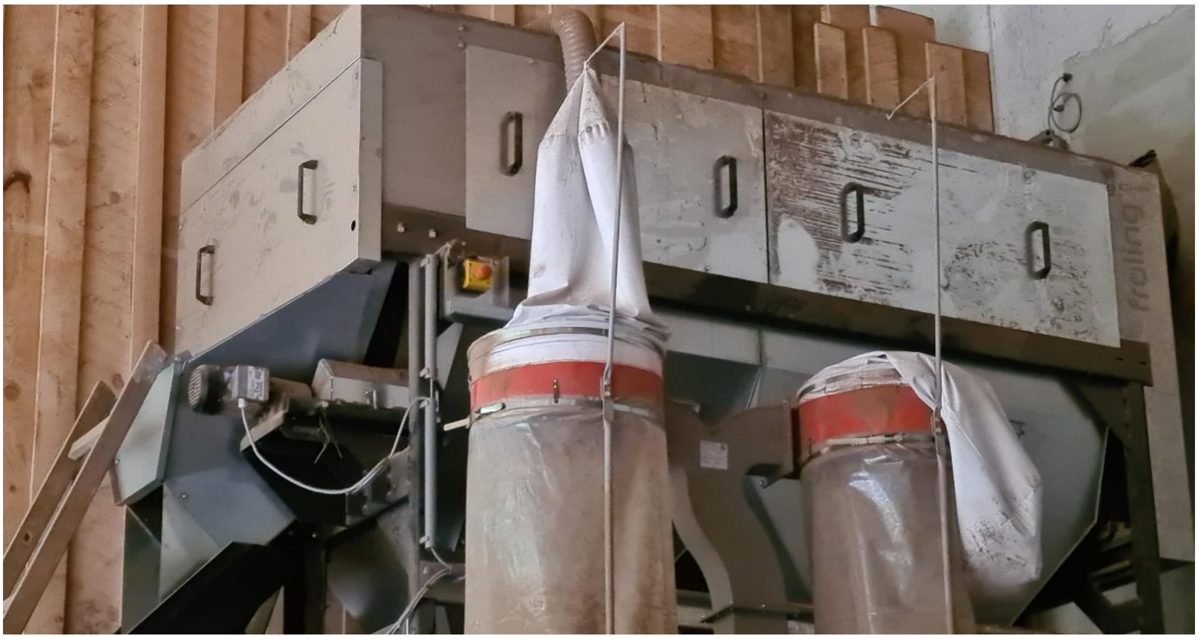

Picture 20: Drum sieve

Picture 19: Sieved wood chips

Picture 18: Left: fine dust, right: oversized particles after sieving

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Picture 21: Auger with welded on knife of an auger chipper

3.2.2 Water content

While in a combustion process without condensation the water content lowers the energy output and fires the temperature, it causes an additional problem in a gasification process: it might lead to a higher tar content and a wet wood gas. As wooden biomass usually has a water content of ~50 % when harvested it needs to be dried. This can be done in bunkers above a perforated bottom through which the heated air can flow, or in special belt or drum drier. Drying is usually done to a water content around 10 up to 15 % (© IEA bioenergy 2019).

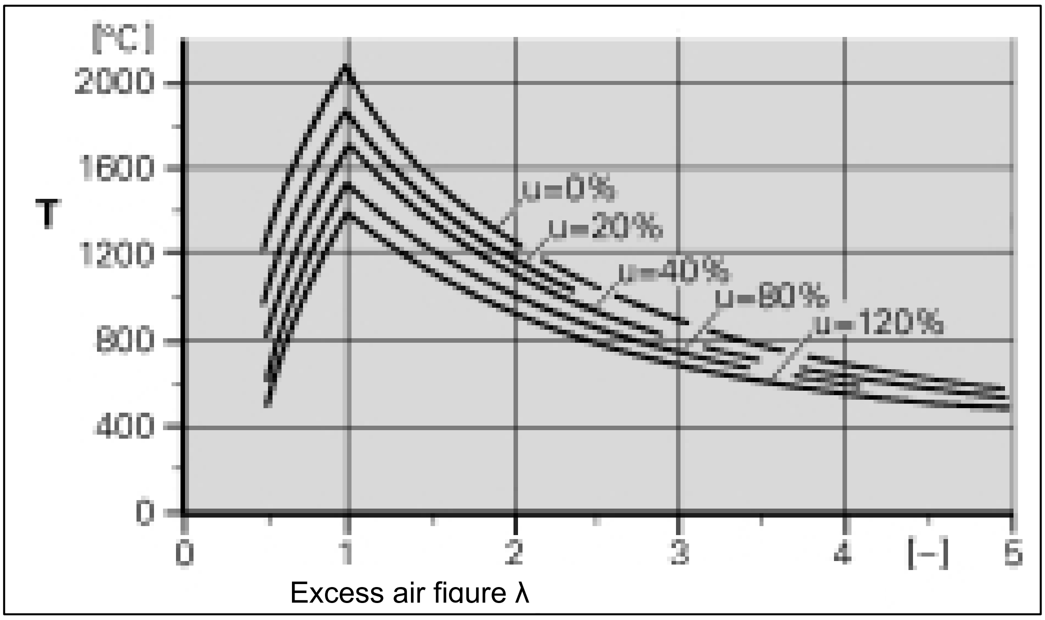
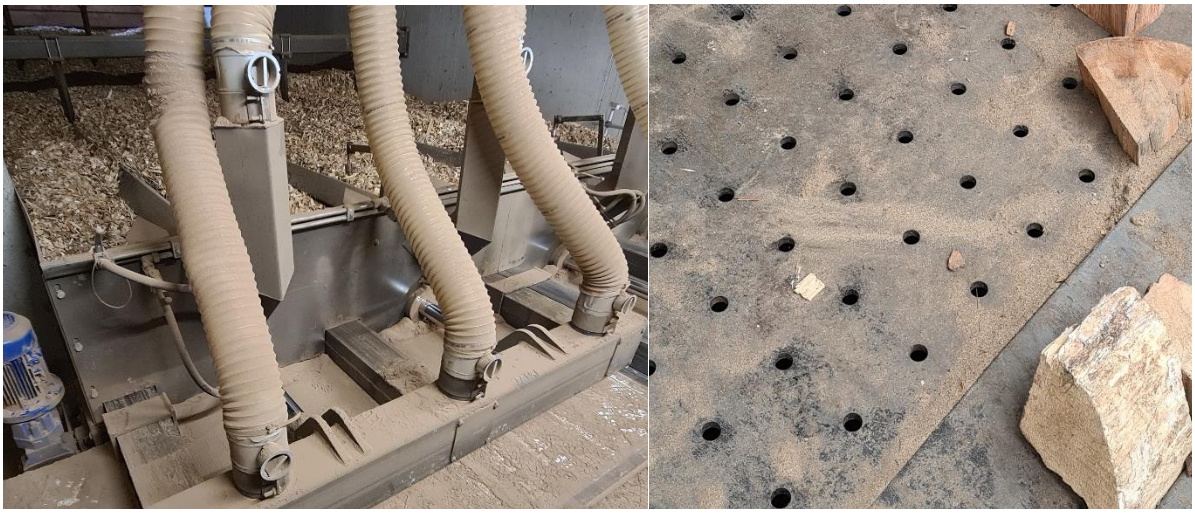


Figure 14: Firing temperature of wooden biomass depending on water content and excess air content © Nußbaumer, 2000



Picture 22: Left: grate dryer with sliding floor and air pipes, right: perforated floor

Picture 23: Belt dryer

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4 Products of gasification

The main aim of the gasification of wooden biomass is to produce a calorific gas which is mainly used as fuel for CHP so far but could also be used as fuel for shifting to renewable methane and thus becoming a natural gas substitute. The second product is the remaining ash. Depending on the gasification process the latter may also include organic carbon or only inert substances from feedstock like nutrients, trace elements and possible impurities.

4.1 Wood gas

Wood gas appears in many different compositions. There are many factors which have an influence on the composition of produced wood gas like:

- Feedstock: size, moisture content, chemical composition of wooden biomass
- Catalytic additives
- Gasifier type
- Gasification temperature
- Gasification medium: air, oxygen, vapor..
- Pressure within the gasifier
- Retention time within the reactive zone

The kind of gasification medium: ambient air, oxygen, vapor or CO_2 influences the composition of the wood gas mainly regarding atmospheric nitrogen content and hydrogen content in the wood gas. Air as gasification medium causes a wood gas with a relatively high share of athmospheric nitrogen. In total wood gas is usually a gas with a **L**ow **C**alorific **V**alue (LCV). Through a change of the gasification medium to oxygen or vapor, the content of hydrogen and the energy content can be significantly raised. Some processes use different gasification media within the process stages like oxygen or vapor in the first stage to produce a wood gas with no atmospheric nitrogen in it, but use ambient air in the second process step to fully oxidise the remaining carbon and to produce the needed heat for the endothermic first process step. The exhaust gas of the second process step has then a high content on CO_2 and athmospheric nitrogen.

Table 11: General influence of gasification medium to energy, hydrogen and atmospheric nitrogen content of wood gas © Eltrop, 2014

	Gasification (endothermal process)			
Source of needed heat	**Autothermal** (partial combustion of carbon)		**Allothermal** (from external)	
Gasification medium	Air	Oxygen/vapor	vapor	CO2
Energy content: [H_i]	low	middle	middle	middle
Hydrogen [H_2]	low	high	high	middle
Atmospheric Nitrogen [N_2]	high	zero	zero	zero

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Table 12: Typical composition and energy content of dry wood gas depending on gasification medium, values in column = average © Kaltschmitt, 2016; FNR, 2014; Nilsson, 2011

Component		**Gasification medium**	
		air	**Vapor, O**
		[%$_{Vol.}$]	
Carbon monoxide	[CO]	16.3	28.1
Hydrogen	[H_2]	12.5	38.1
Methane	[CH_4]	4.4	8.6
Longer chain hydrocarbons	[C_2+]	1.2	3
Carbon dioxide	[CO_2]	13.5	21.2
Atmospheric nitrogen	[N_2]	52	0
Energy content	[kWh$_{Hi}$ Nm^{-3}]	0.8 – 1.8 (1.4)	3.3 – 4.4 (3.7)
	[MJ$_{Hi}$ Nm^{-3}]	3 – 6.5 (5.1)	12 – 16 (13.2)

Depending on the requested application of the produced wood gas manufacterer have the possibility to steer the composition of produced wood gas to some extent in a certain direction. The main components which deliver the energy content are carbon monoxide, hydrogen and methane while carbon dioxide, vapor and atmospheric nitrogen are the main inert parts in the gas composition.

Table 13: Typical ingredients of wood gas divided in components including energy content and without © Kaltschmitt, 2016

	Component		**[kWh$_{Hi}$ Nm^{-3}]**	**[MJ$_{Hi}$ Nm^{-3}]**
Delivering energy	Carbon monoxide	[CO]	3.5	12.633
	Hydrogen	[H_2]	2.995	10.783
	Methane	[CH_4]	9.968	35.883
	Longer chain hydrocarbons e.g.	[C_2+]	Depending on specific composition	
	• Ethane	[C_2H_6]	17.874	64.345
	• Ethene	[C_2H_4]	16.52	59.457
inert	Carbon dioxide	[CO_2]		
	vapor	[H_2O]		
	Atmospheric nitrogen	[N_2]		

Also the incfluence of the used feestock should be considered. In order to show the influence of different feedstock streams within gasification the GoBiGas plant in Gothenburg did some trials with different biomass feedstocks while other criteria were kept nearly the same. The plant was a double fluidized bed gasifier.

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Table 14: Composition of wood gas depending on feedstock at the GoBiGas plant in Sweden ©Hrbek, Larsson 2017

		Wood pellets	Wood chips	bark	Return wood
Gasifier temp.	[°C]	870 - 830	790 - 830	850 - 820	830
Hydrogen	[$\%_{\text{vol. dry}}$]	39 - 42	39 - 41	39 - 43	39 - 43
Carbon monoxide		21 - 24	22 - 23	17 - 21	17 – 21
Carbon Dioxide		20 - 27	21 - 23	23 - 25	23 - 25
Methane		8 - 9	7.9 – 8.6	7.1 – 8.7	7.1 – 8.7
Tar (excluding BTX)	[g Nm^{-3} dry gas]	3 - 8.7	8.9 – 12.7	7.9 - 15	8.5 - 14
Tar (including BTX)		9.7 – 23.3	22.1 – 29.5	21.7 – 33.4	22 - 26

One important criterion is to produce a relatively clean gas for which there is not too much effort needed on the pretreatment before the application in a CHP. HCL and S might come from specific feedstocks like straw and might cause corrosion and therefore choosing the right feedstock is of high importance. An excessive content on fine dust and tar causes major problems or makes further application even impossible. Therefore producing a wood gas with low fine dust and tar content is of high importance. This can be achieved through several measures like low water content and low fine dust content of feedstock, avoidance of death zones in fixed bed gasifiers, guaranteed reduction process zone in the gasification process etc.

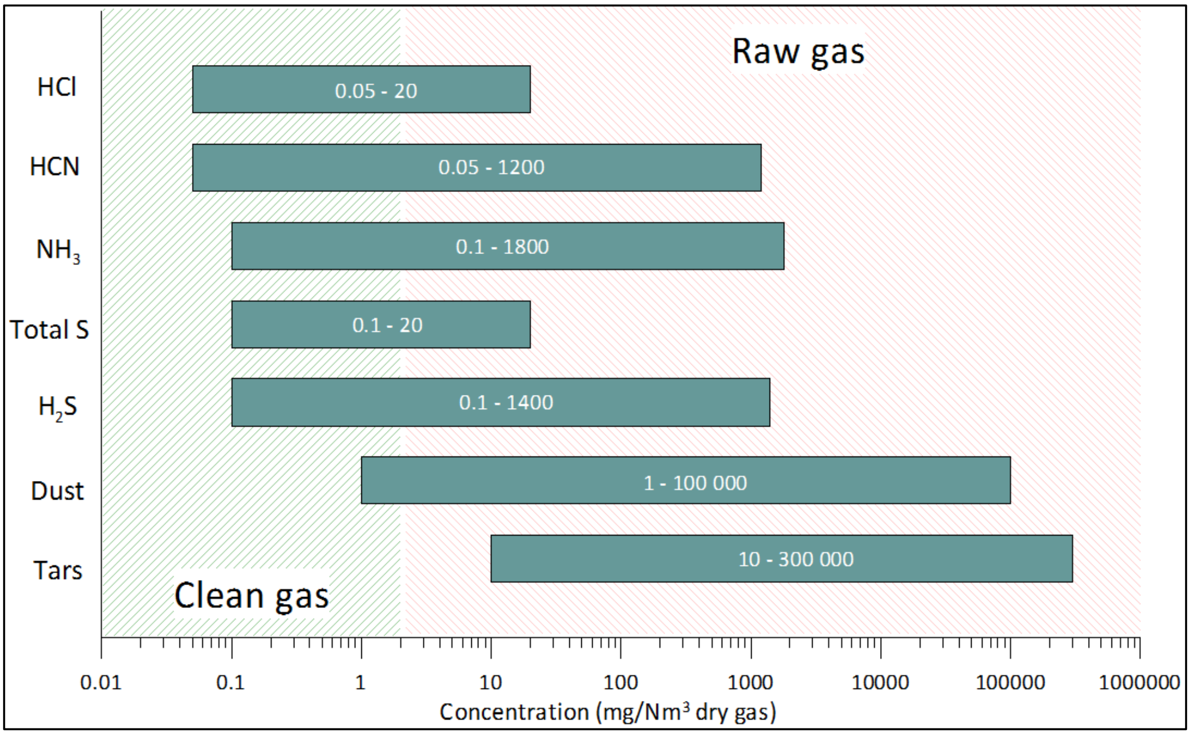

Figure 15: Typical concentrations of contaminants within wood gas © Aranda Almansa, 2019

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Besides others the chosen technology influences the content on particles and tar and requires different further cleaning steps.

Table 15: Usual particle and tar content of raw wood gas depending on gasification type © Kaltschmitt, 2016

	Fixed bed gasifier		**Fluidized gasifier**	
	updraft	downdraft	Stationary fluidized bed	Circulating fluidized bed
	[g Nm^{-3}]			
Fine dust	0.1 – 3 (1)	0.2 – 8 (1)	1 – 100 (4)	8 – 100 (20)
Tar	10 – 150 (50)	0.1 – 6 (0.5)	1 – 23 (12)	1 – 30 (8)

With a combination of gas cleaning devices, a successful operation of CHP plants should be possible. Each manufacturer of such devices has its own requirements on fine dust, tar and other gas impurities.

Table 16: Usual requirement of internal combustion engines running on wood gas © Eltrop, 2014

		CHP requirements
Particle size	[µm]	< 3
Particulate matter	[mg Nm^{-3}]	< 50
Tar content		< 100
Alkali content		< 50
Ammonia content [NH_3]		< 55
Sulphur content [S]		< 1150
Chloride content [Cl]		< 500

In order to achieve an application-friendly gas, the wood gas is usually pre-treated before the application in several process steps as

- Cyclone separator
- Hot gas filter
- Cooler
- Scrubber

The therefore used equipment and its technical arrangement is very individual by each manufacturer. Cleaning must also secure that pipes, valves and other devices are not clogged by tar, dust or condensed water. If the plant is running constantly at peak load this might cause seldom problems but after a standstill clogged pipes with tar etc. are major issues.

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Particles will be usually separated with cyclone separator or hot gas filter, electrostatic air filter or scrubber. Also, with electrostatic filter or scrubber tar will be mostly removed. The advantage of an electrostatic filter is to remove particles and tar in one device.

Table 17: Performance of different types of gas cleaning techniques © Kaltschmitt 2016, Eltrop 2014

Device	To eliminate	advantages	disadvantages
Cyclone	Dust, tar Particle size: > 5 µm	Low pressure loss low cost possible high temperature	Low degree of separation for particle < 5 µm
Baghouse filter	Dust, tar, bases particle size: < 0.5 µm	High separation performance	High loss of pressure Temperature: < 350 °C
Washer	Dust, tar, bases, N- and S- compounds	Common and universal useable	High loss of pressure Cooling needed Wastewater
Electrostatic filter	Dust, tar, bases	Low pressure loss High separation performance	Expensive Particle size > 5 µm Wastewater (depending on process technique)
Hot gas filter	Dust, (tar), bases	Temperature ≤ 900 °C High separation performance	Expensive High pressure loss Problems if tar occurs Problems with bases
Catalytic	Tar, Nitrogen compounds	No wastewater No cooling required	High costs Deactivation by occurrence of catalyst poison
Thermal tar removal	Tar	No wastewater	Loss of efficiency (partly combustion), incomplete tar removal

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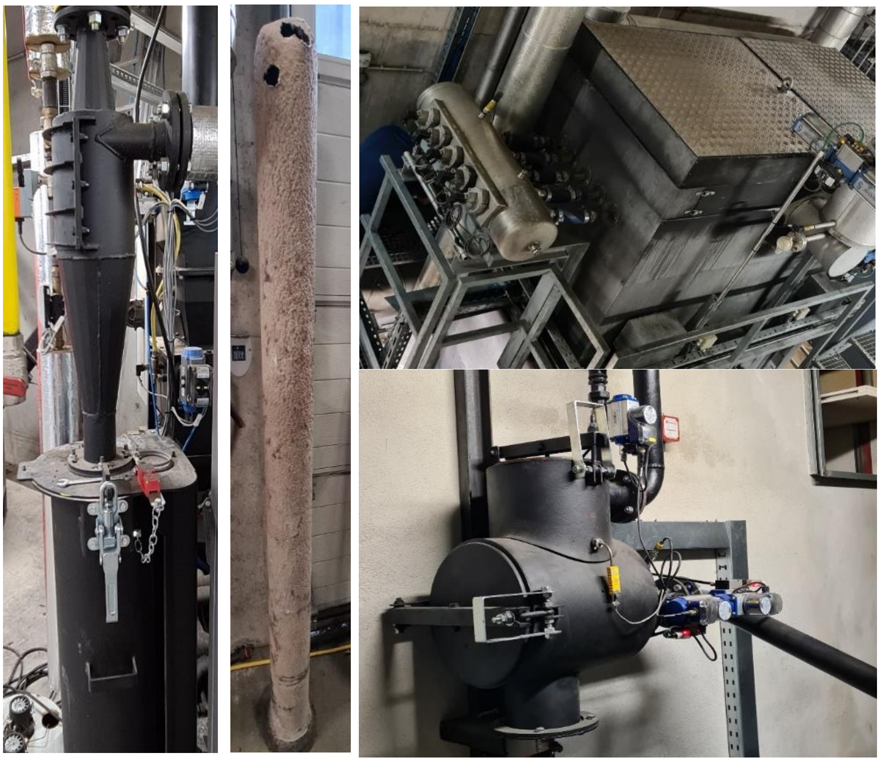

Picture 24: From left to right: cyclone, single cartridge of a cartridge filter, cartridge filter with automatic cleaning device, baghouse filter

Picture 25: CHP unit to produce combined heat and power from wood gas

4.2 Ash and or charcoal

Depending on the gasification process and additionally on its steering, the ash contains mainly nutrients and trace elements and possibly impurities and heavy metal but can also contain amounts of un-combusted carbon. The latter is sometimes appreciated to produce soil improver. The amount of ash depends on the feedstock. Wood generates only around 0.5 %$_{DM}$ ash, while bark may cause 5 to 8 %$_{DM}$ ash and straw even above 10 % (© Meyer, 2009). The kinds of ashes can be differentiated between bottom ash, cyclone ash and from electrostatic or cartridge filter. Amounts of heavy metals will mostly be found in the latter ones while the bottom ash is usually not polluted. Depending on its recycling rate of the bed material, fluidized bed gasifiers have additionally bed material in its ash. The amount of heavy metals differs depending on source (type of feedstock; untreated/treated), geological background and regional air pollution.

Table 18: Composition of different feedstock and received ashes after treatment in large scale gasifier © Fryda, 2015

	Ash	C	H	N	O	P	K	Cl	S	Ca	Si	pH
	[%]					[g kg^{-1}]						
Oak wood	2.8	52	6.7	1.6	38	0.8	13.8	0.22	0.2	15.5	0.2	
Beech wood	2.5	47	6.4	0.2	49	0.1	1.3	0.35	0.2	2.96	0.24	
Residual garden waste	4	46	5.8	0.5	42	0.6	3.1	0.23	0.5	8	5.2	
Rice husk	18	36	5.2	0.3	38	0.16	0.49	0.04	0.31	1.63	76.9	
	Large scale Gasification											
Beech Wood	23.8	72.3	1.2	0.4	0.6	0.7	13	1.13	0.24	16	85	11.9
Residual garden waste	10.7	82	1.5	0.8	2.9	2.6	11	0.72	0.47	23	17	8.5

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Table 19: Composition of different types of ashes, their nutrient and heavy metal content and their distribution in bottom ash, cyclone ash and cartridge filter ash © Eltrop 2014

		Bottom ash	**Cyclone ash**	**Cartridge filter ash**
			[$\%_{DM}$]	
Feed-stock	bark and wood chips	60 - 90	10 - 30	2 - 10
	sawdust	20 - 30	50 - 70	10 - 20
Nutrient content	CaO	41.7	35.2	32.2
	MgO	6	4.4	3.6
	K_2O	6.4	6.8	14.3
	P_2O_5	2.6	2.5	2.8
	NaO	0.7	0.6	0.8
Heavy metals			[mg kg_{DM}^{-1}]	
	Cu	164	153	389
	Zn	432	1 870	12 980
	Co	21	19	17.5
	Mo	2.8	4.2	13.2
	As	4.1	6.7	37.4
	Ni	66	59.6	63.4
	Cr	325	158	231
	Pb	13.6	57.6	1 053
	Cd	1.2	21.6	80.7
	V	43	40.5	23.6
	Hg	0.01	0.04	1.47

If the organic carbon is degraded and goes into the gas phase within the gasification process, then the bottom ash appears in bright grey color. The more carbon is included the darker is the ash. Depending on the gasification process ash sometimes needs to be further cooled, electrostatic discharged etc. before it can be stored. As carbon from gasification has a huge surface area it can also be further developed as soil improver or even for application in husbandry (Fryda, 2015).

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Picture 26: Left: ash of full combusted wood; right: raw charcoal

Picture 27: From left to right: ash transporting device with double security valve, humidification device avoiding dust and self-ignition, humidified ash, hot dry ash

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Picture 28: Untreated charcoal, charcoal can with labelling, filling station for charcoal into big bags

5 MCR: Measurement, control and regulation techniques and safety equipment

Most gasification plants are constructed and built by a general contractor. These companies deliver the whole plant: beginning from the feedstock drying to the needed feedstock pretreatment, the gasification and until the treatment of the produced wood gas. One major device which interacts with all others is the MSR technique. Within this device sensitive parameter of each parts of the plant come together, are recorded, analyzed and used to guarantee a stable gasification process, to optimize the process and on the other hand to guarantee a safe process. Depending on the gasification type and control strategy of MSR usually the following data might be collected (besides the manually checked and recorded data):

- Pressure
- Temperature
- Filling levels
- Gases: Oxygen, Hydrogen, Methane, Carbon Dioxide, Carbon Monoxide
- Optical barrier
- Position of valves and sliders etc.
- Produced energy

In order to guarantee that no produced gas will flow back, usually the pressure is checked beginning from the feedstock conveying system until the application of wood gas within the CHP. Temperature sensors are mainly used in the gasification process and gas cooling devices but can also be used as safety devices. Additionally, through the temperature measurement within the different steps of the gasifier, the process can be steered.

Picture 29: Sensor to check the filling level and to secure the feedstock conveying system

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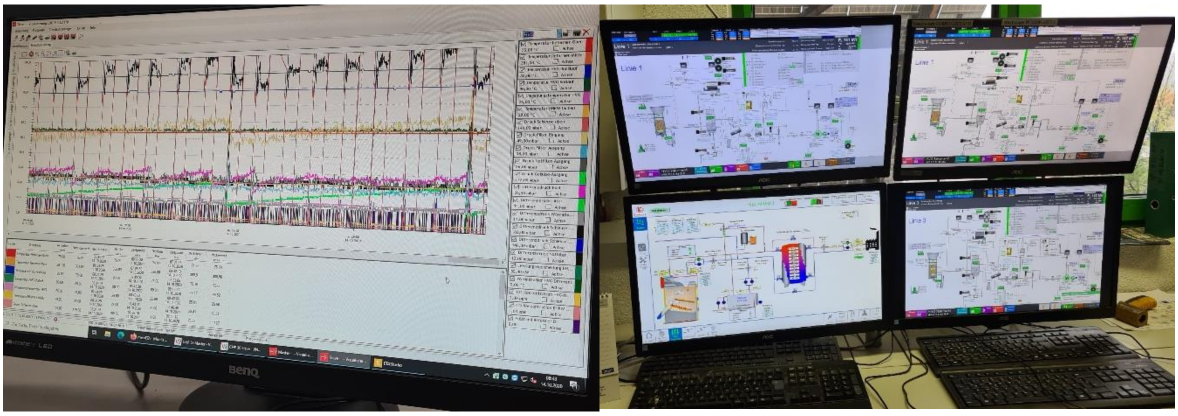
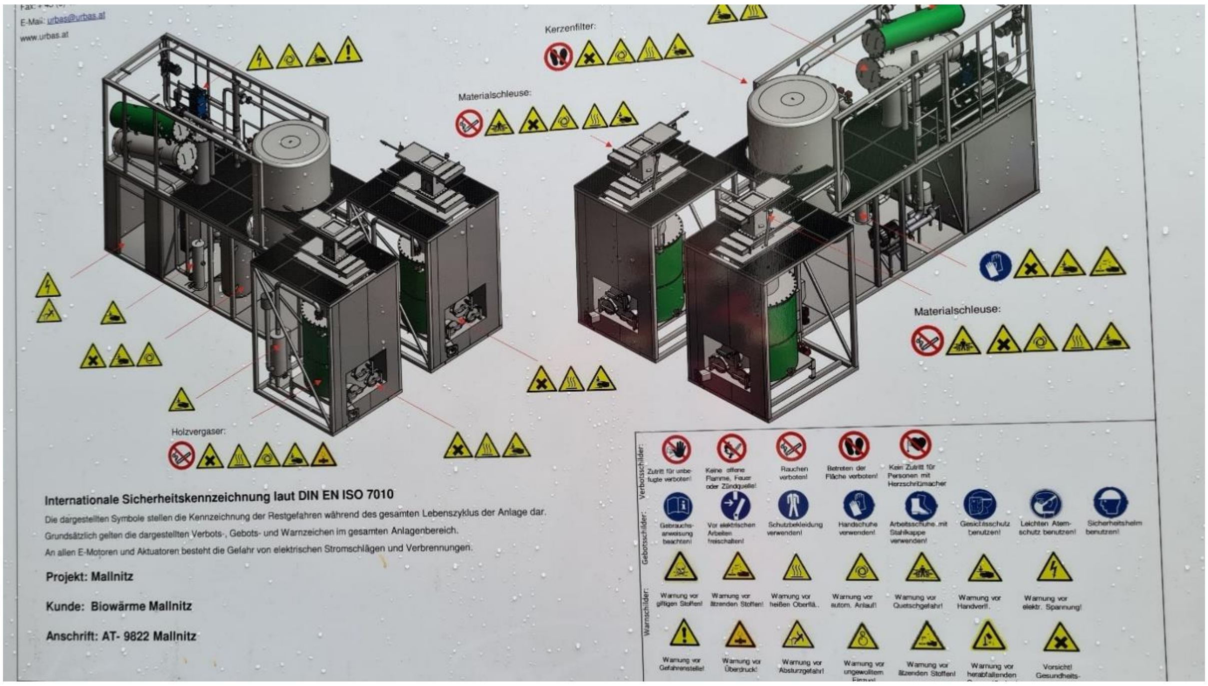
Picture 30: Left: delinking of ambient air to the gasifier via water barrier, right: torch

Picture 31: Sensor to check the gasification process



Picture 32: Visualisation of the measurement, control and regulation unit



Internationale Sicherheitskennzeichnung laut DIN EN ISO 7010

Die dargestellten Symbole stellen die Kennzeichnung der Restgefahren während des gesamten Lebenszyklus der Anlage dar.
Grundsätzlich gelten die dargestellten Verbots-, Gebots- und Warnzeichen im gesamten Anlagenbereich.
An allen E-Motoren und Aktuatoren besteht die Gefahr von elektrischen Stromschlägen und Verbrennungen.

Projekt: Mallnitz

Kunde: Biowärme Mallnitz

Anschrift: AT- 9822 Mallnitz

Picture 33: Hazard Plan

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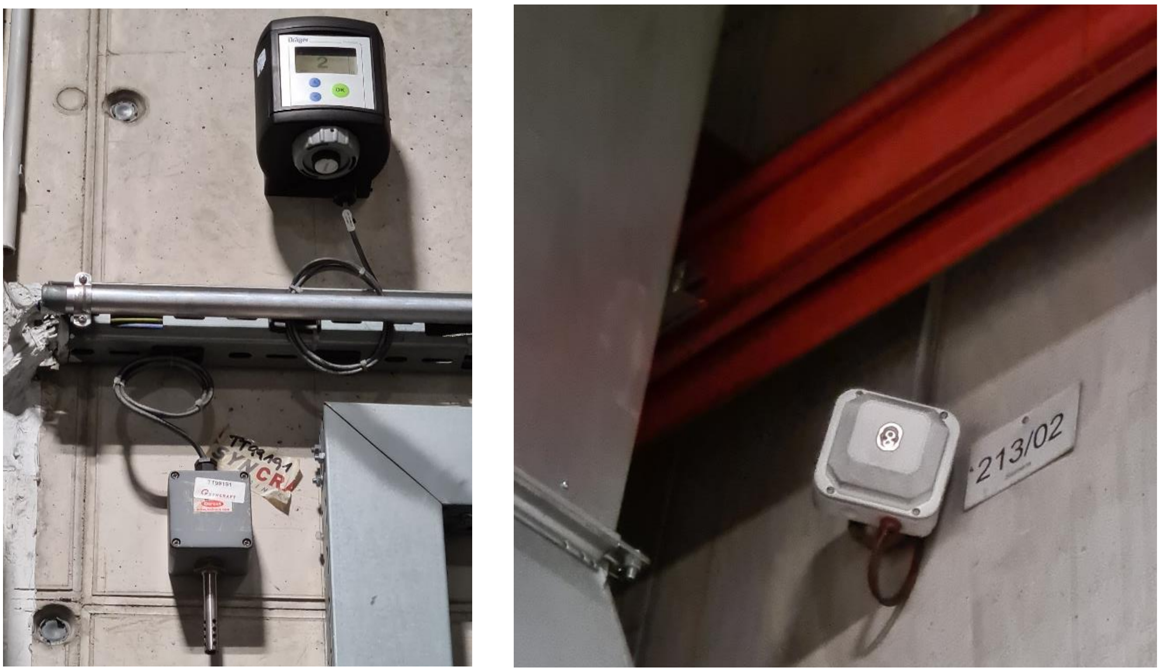

Picture 34: Fix installed safety devices (gas and flame detection)

Picture 35: Handheld safety device to detect different types of gases (toxic, explosive)

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