Concept of Energy Supply from Renewable Sources for Greenhouse Rose Cultivation in Poland

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“Nature is always able to give a lot to those who want to understand it…”

- Zofia Gerlach

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Abstract

Nowadays, worldwide problem is the struggle with global warming. The main source of the CO_2 are the fossil fuels. Due to this fact, Europe is trying to reduce the generation of energy from conventional sources with alternative ones. European Union members has to meet the requirements of the reducing the CO_2 emission and use the alternative ways of energy production. There is a significant amount of different ways to replace the conventional energy sources, possibly extracting the energy from nature as biomass, sun, geothermal and water, is an amazing concept.

The main goal of this thesis is to find the alternative ways of energy supply for the Greenhouse Roses Cultivation in Poland. Electricity and Heat necessary to run the farm are currently obtained from fossil fuels. In terms of sustainable development, it is still better to produce roses than to import them from abroad, due to the emission from transport. Firstly, will be presented the system describing electricity and heat demands, money that owner of the Greenhouse yearly spend for the energy, and emission of GHG. Followed by alternative ways of Energy production defined as Gasification of wasted roses and crops from the surrounding farms. At the beginning, the calculation of the energy production from wasted roses and crops was made leading to the next step, which was the description of the heat production based on gasification process, estimation of costs of such system. Last step will be the economic analysis of the current system and the system based on biomass gasification and comparison between the two.

Keywords: Biomass gasification, Calculation of Energy Production, Economic Analysis, GHG Emission

Resumo

Atualmente, o problema do aquecimento global está afetar o mundo todo. A principal fonte de CO2 são os combustíveis fósseis, pelo que a Europa está a tentar reduzir a geração de energia de fontes convencionais e promover o use de energias alternativas. Os membros da União Européia têm que cumprir os requisitos de redução da emissão de CO2 e usar formas alternativas de produção de energia.
Há uma quantidade significativa de maneiras diferentes de substituir as fontes de energia convencionais, possivelmente extraindo a energia da natureza como biomassa, sol, geotermia e água

O principal objetivo desta tese é encontrar formas alternativas de fornecimento de energia para o cultivo de rosas numa estufa na Polónia.
A eletricidade e o calor que são necessários são atualmente obtidos a partir de combustíveis fósseis. É feita uma descrição do sistema atual, nomeadamente dos usos de energia e das quantidades de eletricidade e de calor que são necessárias, dos custos anuais, que o proprietário da estufa tem e da emissão de GEE.
Após uma análise das formas alternativas de produção de energia foi definida como melhor opção a gaseificação de rosas desperdiçadas e de desperdícios das quintas vizinhas.
Foi feita a descrição da produção de calor com base no processo de gaseificação e, estimativa de custos de tal sistema. O último passo foi a análise económica do sistema atual e do sistema baseado na gasificação da biomassa e comparação entre os dois.

Palavras-chave: Gaseificação de Biomassa, Cálculo da Produção de Energia, Análise Econômica, Emissão de GEE

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1. Introduction

Today’s energy production is mainly based on fossil fuels. Their destructive impact on the environment is commonly known. However, it is difficult to find alternative fuel with high energy potential as having, for instance; coal or petroleum oil and at the same time high availability of the source and a quite low cost. This is the main reason why fossil fuels have an advantage over renewables. However, today the awareness of the environment is growing. More and more people want to prevent environmental catastrophe and popularity of renewable energy sources rising. To reduce the GHG emissions, alternative ways of energy production must be found, with not only reducing the pollutions, but the impact of mining and transportation for the environment need to be considered.

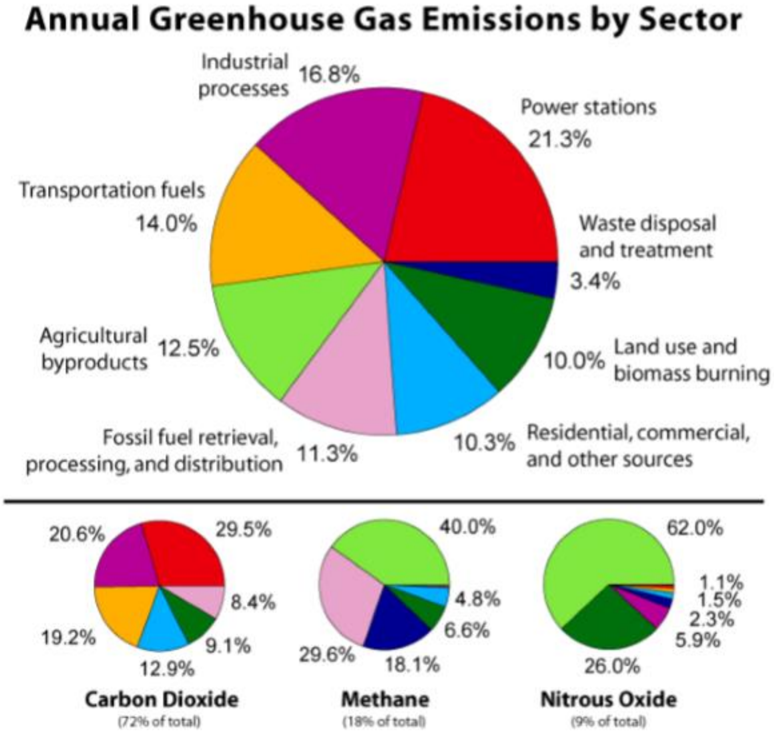


Fig. 1 Greenhouse Gas Emissions from eight categories of sources 2010 [1]

Figure 1 above shows the GHG emissions from diverse sectors and the global warming potential of individual gases (72% CO_2, 18% CH_4, 8% N_2O and 1% of others gases). Every sector is marked with a different colour to show comparable information about emissions by sector, representing each of the main greenhouse gases.

Sustainable development, for instance, can be defined as; “improvement the quality and standard of living in developing countries whilst maintaining the ecological process on which life depends” [2]. This concept must be applied at the local, international and national level. However, it is not an easy process. The quality of human lives is improving with a high environmental impact.

Wealthier society buys more products, a significant amount of products have a shorter life span and are disposable, therefore, popularity of a single person's households is growing.

Above factors contribute to the increasing level of the waste on our planet and at the same time, raising the number of fossil fuels used for the production of such "single using products". The future predictions show that such trend will continue with the growth of people life expectancy [2].

Fossil fuels such as oil, coal and natural gas, don't have any substitutes which would cover current energy demand. To some extent, a kind of replacement for conventional energy sources can be nuclear energy. However, in this technology, there are still some problems related to radioactive waste which is a risk of the explosion of the power plant and the opinions of society, which needs to be resolved. Energy acquisition from renewable sources as well as future clean energy from hydrogen, cell fuels and other sources, can contribute to the near future to decrease the energy demand from fossil fuels. However, it is unlikely that in the thirty years period, the new sources, as well as renewable energy, could cover in full or even a significant part the global energy demand [6]. Current oils sources are enough for 41 years, natural gas for 63 years, and coal, together with lignite 158 years. [6] It is widely known that energy demand will rise due to the fact of growing life expectancy and industrialization of countries.

The gasification process is an example of the clean energy generation. To compare with the combustion, in gasification a wider range of feedstock can be used. Despite the fact, such process is still under development, already a large number of power plants generating clean energy, existing around the world. Using the biomass as a feedstock for the gasification is very common nowadays. Different types of biomass can be used as wood, crops or even municipal wastes. What contributes to the reduce CO_2 emission and resolve the problem with the landfilling residues.

The case study is a Greenhouse Roses Cultivation in Poland, which consumes a large amount of the energy from fossil fuels and has a destructive impact on the quality of the air. The purpose of this work is to analyze the replacement of conventional energy sources by the renewables through the gasification process of biomass. Feedstock that will be used is wasted roses and crops. Analysis of the current energy system and proposal of the system on renewable with necessary equipment and economic analysis will be provided. An alternative way of energy production for the greenhouse is essential to reduce the GHG emission from the combustion process of coal, and at the same time, it would minimize the costs of the energy inputs.

The question is, if such investment is profitable and what will be the payback period. The aim of this work is also to increase the popularity of such clean energy source among local farmers.

2. Review of the literature

2.1 Energy sector in Poland

Fossil fuels dominate in the energy sector in Poland, it can be seen in figure 2. A significant part of energy production by the source is coal and lignite – 56% of demand.

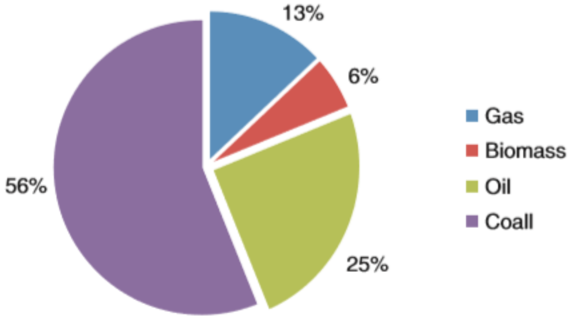


Fig. 2 Overall consumption of primary energy in Poland in 2011 [8]

According to the forecasts, primary energy consumption in Poland will rise until 2020 by 1.5%. Energy production from renewable should reach 12% by 2020.[7]

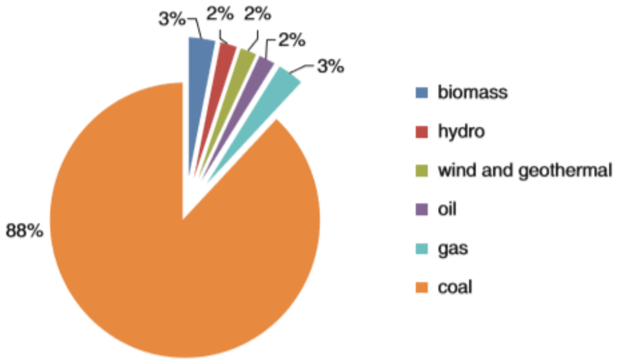


Fig. 3 Electricity generation in Poland by a source in 2012 [9]

Figure 3 shows that coal is the main source for electricity generation in Poland. Even though that this conventional energy source has high energy density compared with others, the problem connected with GHG emission and pollutant into the atmosphere is an essential issue for Poland. There are many ways to deal with this problem. Using Carbon Capture Technologies or replacing conventional energy sources by renewable energy would decrease the pollution emitted each year from coal power plants.[7] Polish renewable energy sources are developing very fast, especially the wind energy. In September 2012 there were 663 wind plants with a total capacity of 2341MW.[7] Wind turbines are placed in the north of Poland due to high wind potential.

The Polish government has made a forecast plan that aims to increase renewable energy sources in energy consumption, which is shown in the figure 4 below.

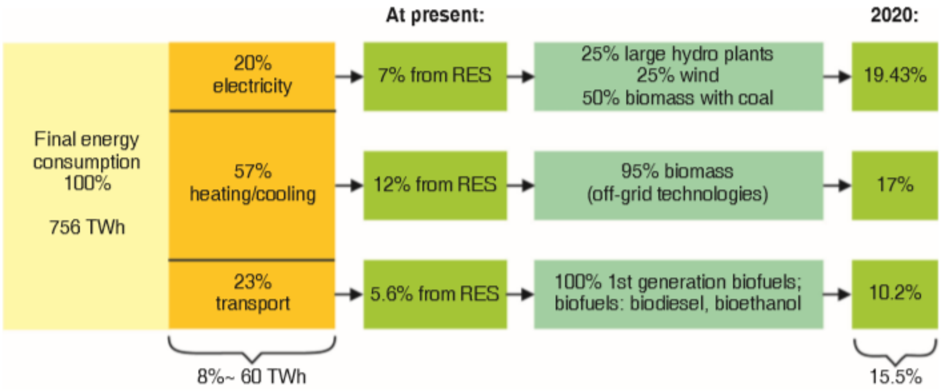


Fig. 4 Share of renewable energy sources (RES) in energy consumption and forecast for 2020 [10]

The plan for 2020 is to increase the amount of electricity production from hydropower plants, wind farms and energy extraction from biomass. Future ideas are connected with using biofuels in the transport sector that would significantly decrease the amount of GHG emissions.

2.2. Biomass market in Poland

Polish energy system is 95% based on own energy resources. Due to this fact, polish energy security does not depend on imported energy raw materials[11]. However, the coal is the primary energy source, due to a large number of such sources on Polish land. Because of this fact, the government in the eighties, instead of considering renewable energy sources, was more focused on developing the mining industry[12].

Polish coal mining achieved the highest level in 1980 which reached 195 million tons. After that, it decreased due to the difficulties of extracting from the deep layers. In 2000, it was 100 million tons, and in 2009 it was 77,4 million tons [11] Due to the growing energy demand and decreasing coal production, the government had to start considering other ways of meeting the needs of energy production in the country. The solar potential in Poland is shallow, compared with other developed countries in Europe. [12] Wind in Poland is potentially higher, especially in the north and west part of the country. According to the Polish Energy Policy, biomass seems to be the most attractive concept for the energy production system. [12] There is just one biomass power plant in Poland, which was established in 2013 and is the largest plant in Europe producing electricity from the combustion process of biomass. The installed power capacity is 205 MWe.[14] Polish government works on new projects to decrease the dependency on fossil fuels, at the same time improve the unfriendly environmental image of Poland in Europe due to the use of coal as main energy sources in national energy production.[13]

2.3 Characterization of biomass

Biomass has become one of the most exciting forms of renewable energies of the present options, as this is located almost around the world, and this can provide a partial solution to the current energy dependence of fossil fuels (nearly 80% of actual energy consumption) and has 10 to 14% share of global energy production as a primary use.[15]

Biomass is considered as a carbon neutral material, since the CO2 that is emitted, for instance, during the combustion process, is the CO2 that is absorbed from the atmosphere through the photosynthesis process when energy from solar radiation is converting into chemical and storage in the biomass cells. Nevertheless taking into account the thermochemical processes of biomass, feedstock needs to be dry to get rid of moisture which decreasing the heating value of material. Drying process demands significant amount of energy and at the same time contribute to emits an extra amount of CO2 into the atmosphere. Due to this biomass cannot be considered as a carbon neutral material in 100%. Another issue is fact that the growing process of threes is long and sometimes take time up to 20 years, it may increase the potential of seasonal biomass like crops or agricultural wastes.

Different types of biomass can be used, such as organic residues, forestry and agricultural residues, municipal and sludge waste with different moisture content. There are different ways of turning biomass into useful final products, for example; thermochemical conversion for woody biomass, and also pyrolysis for biofuels production or gasification for heat and power generation. The composition is $C_6H_{10}O_5$ having small variations with different physical properties of biomass. The stoichiometric ratio of air-fuel for complete combustion goes from 6:1 to 5:1, having an end product: CO_2 and H_2O [16].

Biomass contains two main compounds which are organic matter and inorganic matter. The organic is represented by three basic components, i.e. cellulose, hemicellulose and lignin. Inorganic matter is mainly ash which contains silicon, calcium, potassium, sodium, phosphorus and magnesium components [17]

Cellulose is a “linear homopolymer composed of D-glucopyranose units linked by β-1,4-glycosidic bonds. It mainly contains carbon (44,44%), hydrogen (6.17%) and oxygen (49,39%). The chemical formula of cellulose is: $(C_6H_{10}O_5)_n$, where “n” represents the number of glucose groups ranging from hundreds to thousands or even ten thousand.”[18]

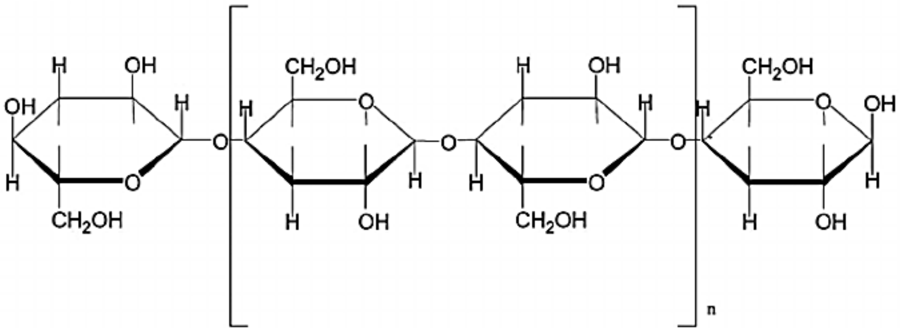


Fig 5. Cellulose structure [19]

Properties of cellulose depend on the length of the chain or the number of units of glucose constructing one molecule of polymer. Hydrogen bonds and Van der Waals forces, making the cellulose construction very strong and resistant to hydrolysis. [18]

Hemicellulose in contrast with cellulose consists of short chains of glucans (500 to 3000 units) and is branched, while cellulose is unbranched. It is a polysaccharide which is 20% of the biomass of plants. Hemicellulose is weaker than cellulose and can be decomposed at lower temperatures. The formula of hemicellulose is $(C_5H_8O_4)_n$. In the cell hemicellulose matrix is glucan which main components are xylan, xyloglucan, glucomannan, manna, galactomannan, callose etc. [18]

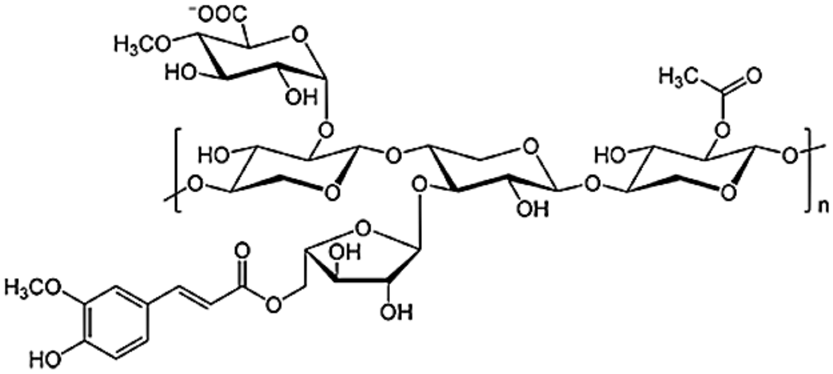


Fig. 6 Hemicellulose structure [20]

Lignin is, after cellulose, the most abundant organic polymer in plants. Main chemical components of lignin are gymnosperm and angiosperm. Lignin content in wood is around 20% and together with hemicellulose make the covalent bonds which providing a strength of woods cells. In the chemical structure, benzene rings are dominant. [18]

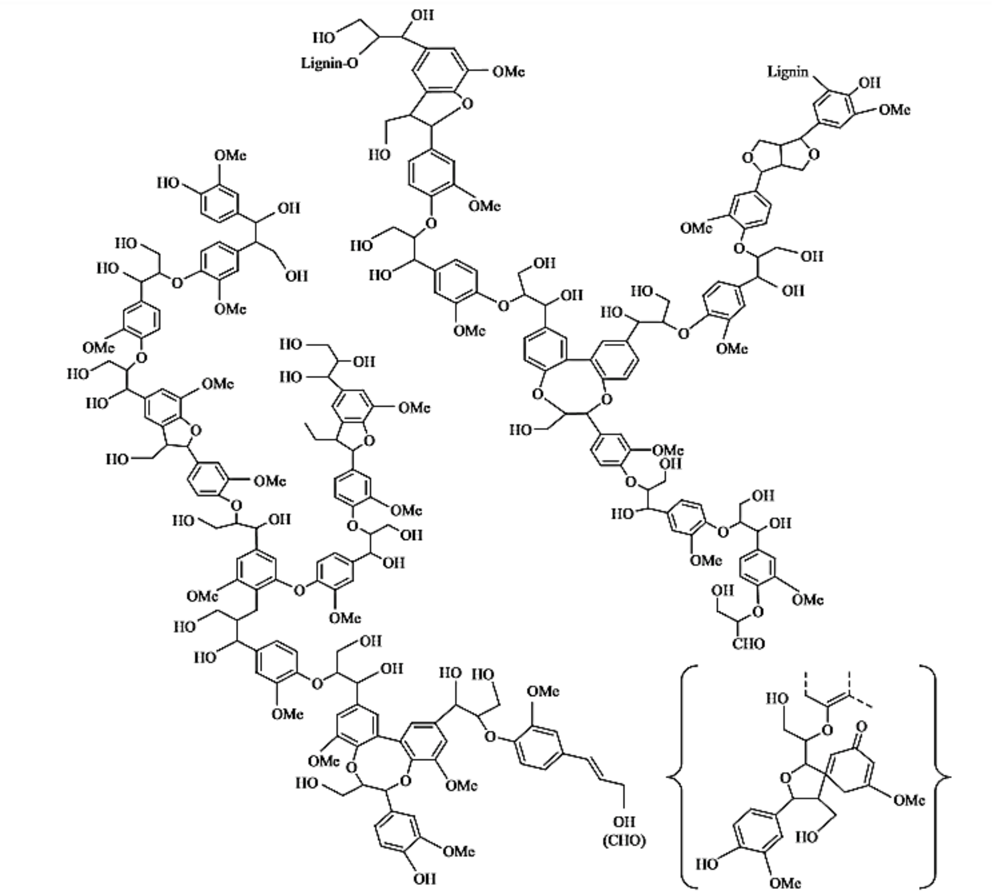


Fig. 7 Chemical Composition and Structure of Natural Lignocellulose [18]

2.4 Thermochemical conversion of biomass

Thermochemical biomass conversion is a process, which the main goal is to produce valuable fuel and other chemicals, using the biomass as a feedstock. There are several paths for the thermochemical biomass conversion. They all demand heat and some of the oxygen, to convert biomass materials or feedstock into energy. The three most known thermochemical conversion processes are combustion, pyrolysis and gasification.

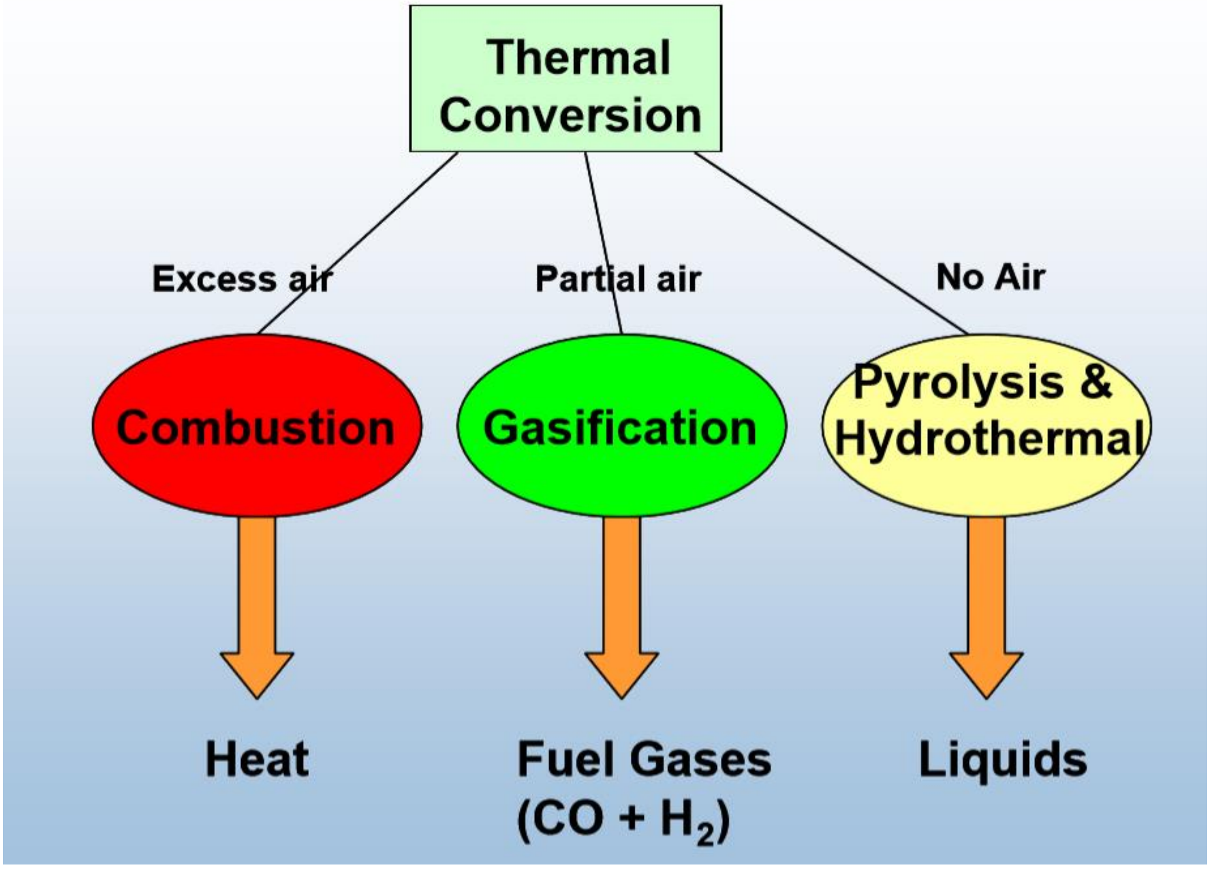


Fig. 8 Thermal conversions processes [23]

2.5 Combustion

The Direct combustion process is the most popular one and provides the quickest and cheapest way of energy production, moreover supply 90% of bioenergy produced worldwide [21]. Such conversion is a simple burning of biomass in the presence of oxygen. Equipment used in combustion processes are furnaces and boilers, which produce the steam used in heating systems or to drive turbines to generate electricity. In order to start the combustion process, a high temperature such as <=550°C is required and a sufficient amount of air. The combustion process is converting the chemical energy into the thermal energy, which is released as a flue gas output in the furnace.

Some stages that can be specified in the combustion:[22]

- Drying – to get rid of water content,
- Pyrolysis and reduction – biomass decomposition into gases and char,
- Combustion of the gases produced in the pyrolysis process together with releasing yellow flames,

- Combustion of tar – tar is burning with the small blue flames and tar pieces released during this stage.

Combustions process reactions are [23]:

$C(s) + O_2(g) \rightarrow CO_2(g)$
$H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l)$
$CH_4(g) + 2O_2 \rightarrow CO_2(g) + 2H_2O(l)$

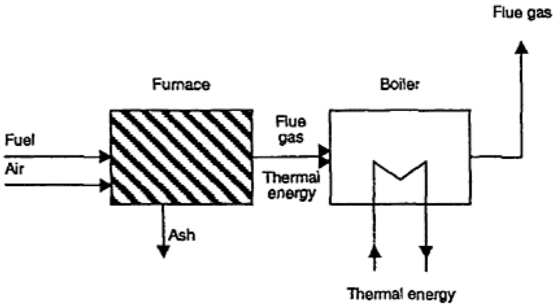


Fig.9 Biomass combustion process

Combustion is a simple, quick and cheap process. However, from the technological point of view, many reactions and reactants accompany the process. The reaction rate is high, increasing the amount of heat that is released. One of the disadvantages is the presence of moisture, which contributes to decrease the heating value. To compare with other fossil fuels like coal or natural gas, biomass contains less poisoning elements as sulphur or nitrogen, but the equipment used for the combustion process needs to provide the cleaning systems to reduce the GHG emission into the atmosphere. [21]

2.6 Gasification

Gasification is a thermochemical conversion of solid biomass into gas, with a lower presence of oxidant agent in the gasifier (gasifying reactor). With this technology, it is possible to turn biomass into different liquids and gas fuels that can be used for power generation, electricity production, transportation, etc. The main product from gasification is CO and H_2 which can be converted to synthetic gas (CH_4) by catalytic methanation of carbon monoxide (CO) and carbon dioxide (CO_2). A lot of feedstock's can be used, such as industrial waste, agro waste, biomass, and transformed to bioenergy to replace products derived from the petrochemical industry.[25] There are a few types of gasifying agent that can be used, which are air, pure oxygen, steam, and carbon dioxide. The most common, due to the lowest price, is the air. Characteristic of gas that is produced depends on the gasification agent that was used. For instance, to obtain hydrogen, steam is used, because during the process steam/biomass ratio rise, the amount of H_2 grows and the amount of CH_4 and CO_2 drop. [23]

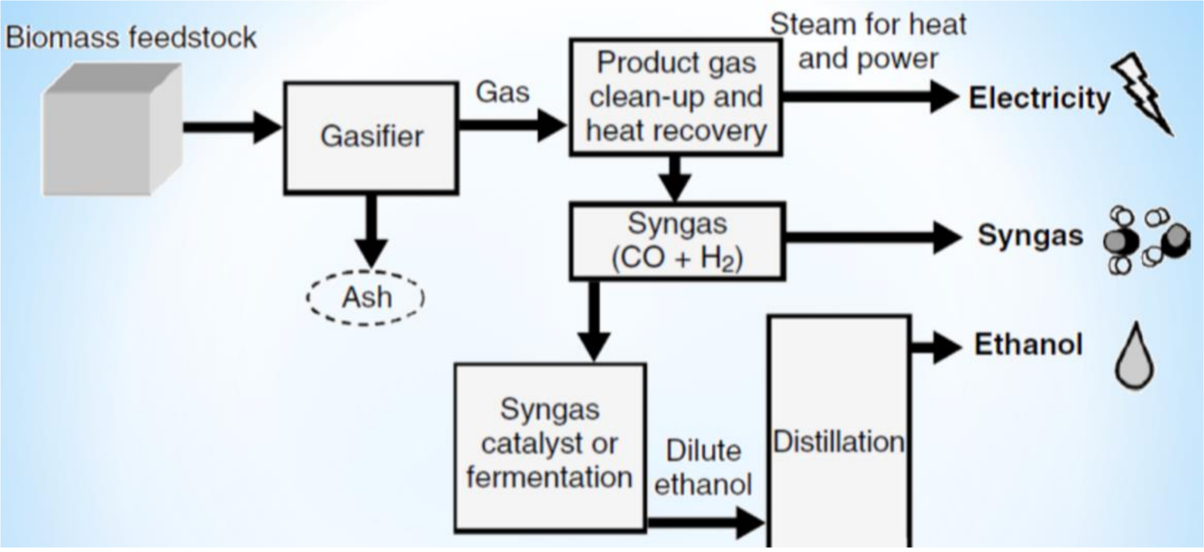


Fig. 10 Energy from gasification [24]

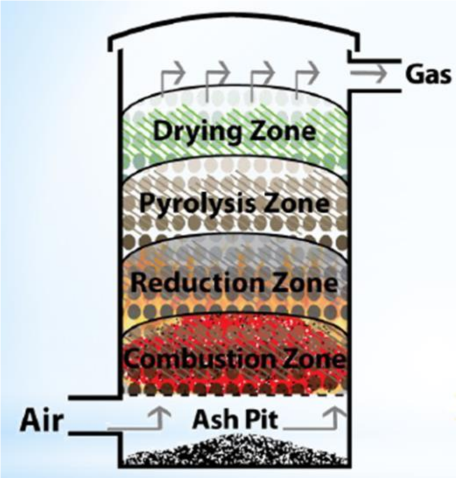


Fig. 11 Typical updraft gasifier unit [24]

Fig. 11 presenting stages of the gasification process [24]:

Drying zone – one of the most essential characteristics of biomass, is its moisture content, that typically varies from 5% to 35%. It lays a vital role in the quality of the product in this zone of the reactor. The typical temperature is around 100°C. The moisture content of the biomass is converted into steam, but the fuel that is present in the biomass does not have any thermal decomposition of the volatile matter. In this zone from a feedstock of biomass with moisture, the products are dry biomass and water. [25]

Pyrolysis zone – thermal decomposition in the absence of air. The process is usually taking place between 125 – 500°C. Products released are liquid tars (from the condensation of hydrocarbons), charcoal and gases. The proportion is dependent on the biomass used and the operating conditions. Below 200°C the drying zone is still taking place and also there is a reduction of constitute molecular weight. At 300°C and higher temperatures, the amorphous cellulose present in the biomass starts reducing to form a carbonyl, carboxyl group radicals, CO and CO_2.

At temperatures above 300°C formed crystalline cellulose is decomposed into tar, char and gaseous products. Hemicellulose is decomposed into a polymer soluble forming volatile gases, tar and char. The lignin is decomposed in higher temperatures (300-500°C) forming acetic acid, methanol, acetone and water. For the chemical reactions that are below 300°C, the reactions are exothermic, so there is no requirement for external heating. The chemical reactions that take place above 300°C, are endothermic and for high-temperature pyrolysis, heating is needed to maximize the yield (liquid or gas). From dry feedstock and heat, the products are char and volatiles. [25]

Reduction zone – gasification/pyrolysis also have byproduct forming, mostly undesired ones as NO_x (due to the nitrogen content in air), SO_x and tar contents (inside biomass). This represents one of the biggest challenges in the utilization for power generation. It has been discovered that the a number of tar particles can be controlled by setting a proper temperature in the reduction zone, which is around 1000°C. In this zone, high-temperature reactions are taking place in a reduction atmosphere, yielding conversion of charcoal and gases. This reduction is done under endothermic conditions to generate combustible products, such as CO, H_2 and CH_4. [25]

The reactions are [24]:

$$C+CO_2 \rightarrow 2CO \quad - 172.6\ \text{kJ/(g*mol)} \tag{2.1}$$

$$C+ H_2O \rightarrow CO+ H_2 \quad - 131.4\ \text{kJ/(g*mol)} \tag{2.2}$$

$$CO+H_2O \rightarrow CO_2 +H_2 \quad + 42.3\ \text{kJ/(g*mol)} \tag{2.3}$$

$$C+ 2H_2 \rightarrow CH_4 \quad + 75\ \text{kJ/(g*mol)} \tag{2.4}$$

Combustion zone – volatile materials from biomass oxidize under exothermic reactions. Typical temperature varies from 1100° C to 1500°C, and gaseous fuels are produced, for example: CO, CO_2, H_2, H_2O. In this stage, the quality of the product depends on some of the key parameters (pressure, temperature, type of gasifying agents (like oxygen, air etc.). For power purposes, oxygen is recommended as a gasifying agent. Solid carbonized fuel and oxygen in air produce carbon dioxide and heat. Hydrogen is also combined with oxygen to produce water vapours.[25]

The reactions are:

$$C + O_2 \rightarrow CO_2 \quad + 406\ \text{kJ/(g*mol)} \tag{2.5}$$

$$2H_2 +O_2 \rightarrow H_2O + 242\ \text{MJ/(kg*mol)} \tag{2.6}$$

Produced syngas usually contains 30-60% of CO, 25-30% of H_2, 0-5% of CH_4 and 5-15% of CO_2 and some water vapours, ammonia, carbonyl sulfide and hydrogen sulfide. [26]

There is a significant number of advantages of the gasification. The most important one is the reduction of the dioxins, NO_x and SO_x, because the process requires low-oxygen conditions. As well as, the product of the gasification process is CO and H_2, not CO_2 like in the combustion process. The fact is that during the combustion process of syngas, carbon dioxide is produced, however, due to the high concentration after combustion, the flue gases cleaning unit can easily remove it. Another important advantage is that a variety of feedstock can be used in the process as; wastes, different types of biomass or coal. Moreover, the temperature of the process is lower, which prevents the volatilization of alkali and others metals.[24] Despite the benefits of the gasification process, some drawbacks also exist. One of the biggest is the fact that this process is still under development and it is more complex than combustion. The process is suitable only for small scale and is very difficult to operate and maintain.[24]

2.6.1 Fixed Bed Gasifier

Is called as moving-bed gasifier too. The bed of particles and gasifying agent pass upwards or downwards. This type of gasifier is the most simple in construction (concrete or steel) with a cylindrical vessel for the fuel and the agent, feeding unit for fuel, the collection unit and the exit. This type is operating on 25-30 atm of pressure, low velocity, long fuel residence time and high carbon conversion.

They are affected by tar content formation, but this has been able to be controlled recently with tar control methods. This type of gasifier is suitable for operations on a small scale for heat and power generations. [25]

Fixed bed gasifier share the following characteristics[33]:

- The construction is simple;
- Low oxygen and temperature requirement;
- Flexibility of the feedstock and less feedstock preparation;
- High thermal efficiency;
- High amount of methane present in produced gas;
- Process requires monitoring due to the possibility of an explosion.

2.6.2 Updraft Bed Gasifier

Updraft gasifier is the most popular type of gasifier in the biomass gasification process. The main goal of such gasifier is to produce heat. Due to this fact, a significant amount of tar is formed during the process. The updraft gasifier has a fixed bed of fuel, which is biomass or coal, and through this fuel, the so-called gasification agent flows. The gasification agent can be steam, oxygen or air. The gasification agent enters the gasifier at the bottom and flows through the bed until it exits at the top as gas. Fuel is fed at the top and goes down to the bottom of the gasifier. During the process, biomass undergoes pyrolysis and a dry process rise gases, which transfer heat, so the gases that leave the gasifier are cooled down and the process is thermally efficient. [34]

The order of zones is the following; drying, pyrolysis, reduction and oxidation. The temperature of the oxidation zone is around 1000°C, with the process of reducing the temperature to 750°C, and gases leaving the gasifier to have a temperature around 500°C. [35]

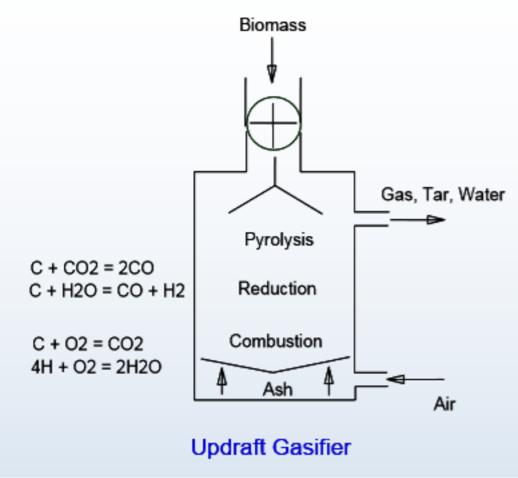


Fig .12 Updraft Gasifier [23]

2.6.3 Downdraft Bed Gasifier

To compare with updraft, the gasification agent is fed at the level of oxidation zone (in the middle of the reactor) and flows through the gasifier to the bottom, with Syngas leaving at the bottom. Fuel enters the gasifier at the top of the reactor. Zones have slightly different order than in updraft gasifier; drying, pyrolysis, oxidation, reduction.

Air entered into the reactor is rapidly consumed going through the combustion, reduction and pyrolysis zone, before it contacts with char and supports the flame. The gases leaving pyrolysis zone are mostly; CO_2, H_2O, CO and H_2. A significant part of tar cracked into hydrocarbons, due to this fact the gas leaving the reactor is clean. This gasifier is used in motive power generation because of converting the instable feedstock into the syngas containing a low amount of tar. [36]

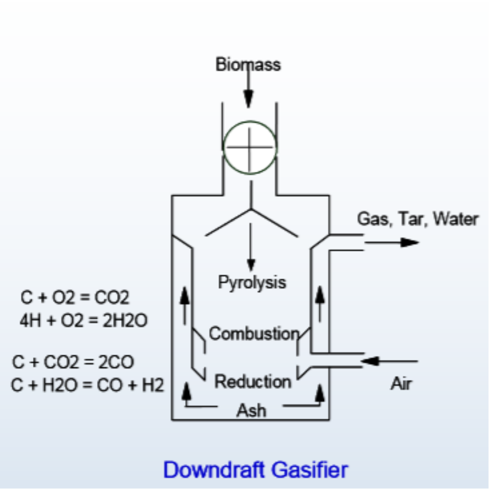


Fig. 13 Downdraft gasifier [23]

2.6.4 Crossdraft Bed Gasifier

Crossdraft gasifier is a type of reactor that has a lot in common with updraft gasifier. The air with high velocity enters into the reactor on one side and circulates in the bed and flows through the gasifier of char and fuel. The produced gas which is presented in the horizontal direction and leaves the bed at the other side of the reactor contains a high amount of CO and much lower H_2 and CH_4. The gasification process functions at a very high temperature (2000°C). [36]

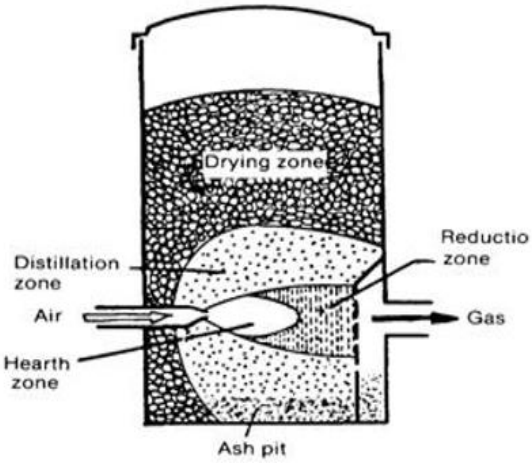


Fig. 14 Cross-draft gasifier [36]

2.6.5 Fluidized Bed Gasifier

This type of gasifier makes the fluid and the inter-bed material to act as a fluid. In this sector, the medium fluidization (air, steam, oxygen) is forced to go through the bed, making the mixture behave as a fluid. This leads to efficient mixing between the feedstock particles. As an inter material, silica is mostly used, but also sand, dolomite or glass beads have been used.

This type of gasifiers enhances heat transfer between the particles to improve the gasification process and operate in nearly isothermal conditions. The temperature depends on the melting point of the materials (800-900°C), due to this fact, the gasification does not accomplish chemical equilibrium (unless the catalyst is used). Also, short residence time can lead to the same issue. Due to this, the hydrocarbon content in these reactors is similar to fixed bed reactors. The carbon conversion efficiency is high (95%), and they are perfect for scaling up (due to the mixing properties, fuel particle range). [25]

Fluidized bed reactors use additives to help with the tar conversion. Some biomass that has high ash and alkali metal content (canes, wheat straw, grass) can form eutectics, if mixed with silica in the bed, which can produce stickiness of particles and defluidization, leading to shutting down the reactor for cleaning. This problem can be fixed by adding calcined limestone, that increases the melting point of the eutectic, increasing the gasification temperature for a more extended period of time. [25]

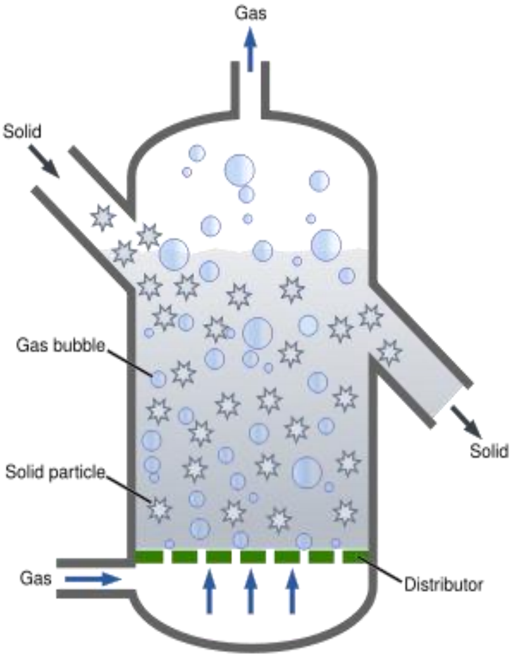


Fig. 15 Basic diagram of a fluidized bed reactor [27]

2.6.6 Entrained Flow Reactor

This type of reactor is the most popular in the processes of coal combustion. Feedstock and oxygen agent are fed co-currently. The velocity of gases is very high as well as the temperature inside the reactor (1200-1500°C). To convert fuel with the maximum efficiency, with the thermal conversion of tar and methane.[38] The residence time is a few seconds. Due to this fact, the fuel must be crushed to tiny particles, (50µm diameter) before the process.[38] This is the biggest problem in such type of gasifier regarding biomass gasification. The reduction of the size of particles is costly and demands a lot of energy. During the biomass gasification, some methane can appear too. The pre-treatment as torrefaction, is necessary to avoid this problem.

Due to the high temperature demanding for the gasification process, a higher amount of the gas product has to be oxidized, reducing cold gas efficiency. These requirements contribute to the problem with the choice of the right material.[37] This technology is still under the development concerning biomass.

Apart from many drawbacks, this technology has many advantages. There is the proper homogenous distribution of the temperature through the reactor, high conversion of carbon and from all technologies of gasification, products are the cleanest and the emission of pollutions is the lowest (syngas consists H_2, CO and CO_2 and is tar-free), ash is transformed into slag which is much easier to remove. [39]

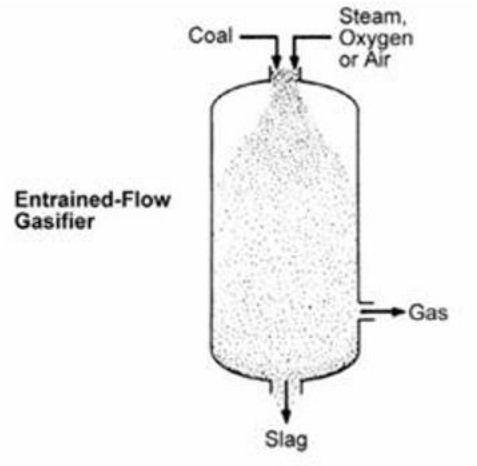


Fig. 16 Entrained flow bed gasifier [39]

2.7 Pyrolysis

Process of thermochemical decomposition of organic material carried-out in the absence of oxygen, without combustion occurring. The chemical compounds, i.e. cellulose, hemicellulose and lignin are decomposed into combustible gases and charcoal. The significant part of these gases is condensed into flammable liquid.[28] Pyrolysis is always the first step in combustion and gasification processes. Pyrolysis process is distinct from combustion regarding the oxygen conditions necessary for the opaeration. Combustion takes place if sufficient oxygen is present while pyrolysis occurs in the absence or very little oxygen. Due to this fact, pyrolysis doesn’t emit into the atmosphere as much CO_2 and other GHG, as the combustion process does. [30]

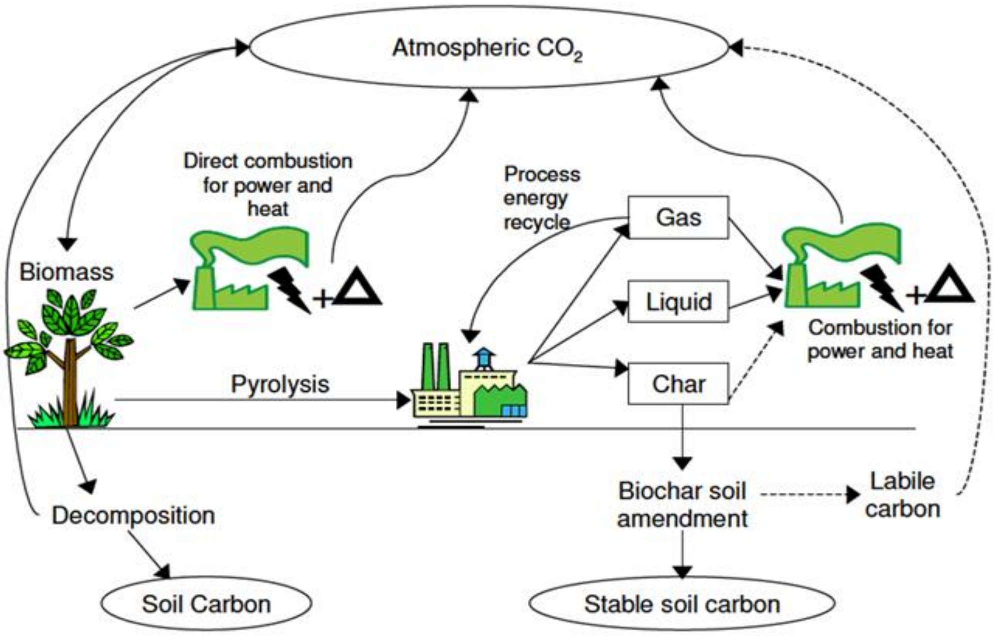


Fig. 17 Pyrolysis vs Direct Combustion [28]

This technology of thermochemical decomposition has a significant number of applications. Pyrolysis is very beneficial in obtaining valuable products from wasted materials like tires and plastic, thus reducing their impact on the environment. During the combustion process of tires, a lot of heavy metals are emitted into the atmosphere, while during the pyrolysis, they are transformed into the gas, oil and black carbon and sludge, which are desirable products for use in further processes. [30]

Three significant variations are usually acknowledged in the pyrolysis process:

- Torrefaction,
- Slow Pyrolysis,
- Fast Pyrolysis.

Torrefaction is a process of biomass decomposition in the temperature between 200 and 300°C. The main products of this process are black solid, condensable (water, organic and lipids) and non-condensable gases (CO_2, CO and CH_4). In such process, around 70% of mass become a solid product and cover 90% of the primary energy, the rest 30% of the mass is transformed to condensable and non-condensable products. [31]

Torrefaction process generally improves biomass properties, especially calorific value (increase by 15-25%) and at the same time the moisture content decrease. Because during this process, the OH group is lost, biomass becomes hydrophobic and more resistant for the oxidation and degradation.

Slow pyrolysis process in which the residence time is in order of minutes. The temperature of this process is around 400°C. The biomass is heated very slowly with the rate of 10°C per minute. Due to the conditions in which the process is carried out, different products are created. In the slow pyrolysis case, the biochar is produced, which has a higher energy density and is better than normal char, especially for the industrial applications [32]

Fast pyrolysis process occurs when heating speed account for around 1000°C per minute and the temperature of the process is 500°C. The product of such oparetion is in 70% - bio-oil, in 20% - biochar and 10% - syngas. Such process is mainly used for the bio-oil production. [29]

2.8 Gasification applications

Gasification has been used for a long time, the same as pyrolysis, mainly to obtain gas and town gas, which was used for providing lighting and heat. Since 1920s, synthetic gas has been used for the production of chemical and fuels. In 1901, Thomas Parker built the first car run by wood gas. This type of vehicle became very popular during the Second World War, due to the problems with fuel in Europe and USA. [40]

Fig. 18 Gasifier in motor vehicle [40]

Nowadays, the gasification product, syngas, is 40% for the production of chemicals, 29% for motor fuels, 22% can be used as such for power generation and 9% for production of gaseous fuels. [41] The most valuable process is the one which in 1925 Franz Fisher and Hans Tropsch developed and patent. An oil-from-coal process which is the basis for the hydrocarbon production from carbonaceous materials:

- Gasification and Fisher-Trops Synthesis

$$nCO + (2n+1)H_2 \rightarrow CnH_2n_{+2} + nH_2O$$

- Bergius reaction

$$nC + (n+1)H_2 \rightarrow CnH_2n_{+2}$$

In such processes, carbon monoxide and hydrogen, produced during the gasification process, are converted into the liquid hydrocarbons as synthetic oil and synthetic fuel in the presence of certain metal catalysts (cobalt, iron, ruthenium) [24]. The huge advantages of such processes are becoming less dependent on oil resource. In figure 23 below are presented other possible applications of syngas. [42]

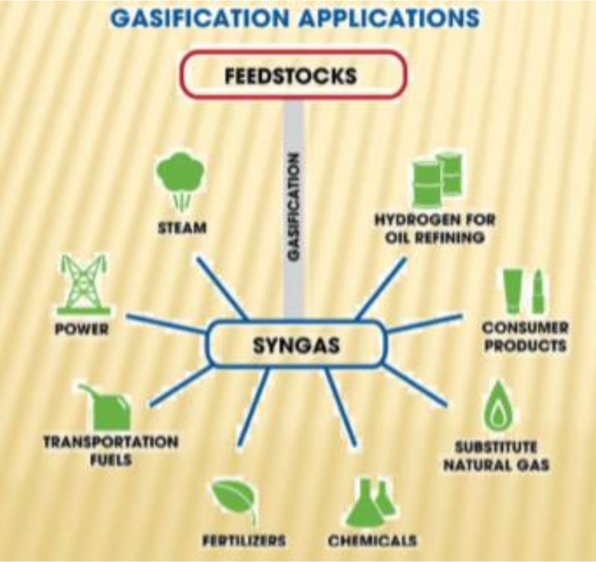


Fig. 19 SynGas applications[41]

The reaction conditions have an impact on the produced syngas calorific values[43]:

- Low BTU (<300 BTU/scf, <11MJ/m3)
- Medium BTU (between 300 and 700 BTU/scf, 11 and 26 MJ/m3
- Gigh BTU (around 1000 BTU/scf, 37 MJ/m3)

To produce electricity, the syngas with the low BTU – british heating value unit - is usually used.

An attractive concept is an Integrated Gas Combined Cycle (IGCC). In such process, coal is gasified into the synthetic gas (syngas), whereas the defective products can be easily removed, as SO_x, CO_2, NO_x, mercury or PM. The same system emits into the atmosphere fewer pollutants than the conventional direct coal combustion system. Moreover, the efficiency of such process is higher, because the leftover heat or steam is used to the power second turbine (combined cycle).[43]

2.9 Energy transition

The concept of Primary Energy, Final Energy and Useful Energy function mainly in issues related to the acquisition, processing and use of energy in the constriction, industry and transport sectors.

Useful Energy is used to meet needs. In the case of house heating, this is the amount of heat within the heating system is transmitted to the rooms. In the case of the boiling water for tea, useful energy is an amount of heat which kettle delivered to the water. It is the energy that is used by humans.

Final Energy is energy available for the customer. In the case of the heating house is the total that is used by the heating system, the one delivered into the rooms increased by the losses.

In the case of the kettle, it is the amount of electric energy that it will use to boil water. Energy used for heating up water, heating up the air near the kettle and electricity losses in cable on the way from the electricity meter to the kettle.

Primary Energy comes from non-renewable sources, necessary to deliver the final energy. For the kettle to consume 1 KWh of energy, the house needs to be transmitting 3 KWh chemical energy in a the form of coal from power plant. The efficiency of the electricity production is 30-40%, losses for the energy transport from the power plant to the socket accounts for 1/10 of energy delivered by the power plant to the electricity network [59]. In the case of coal, the primary energy will be increased by the energy used for the extraction, preparation and transportation.

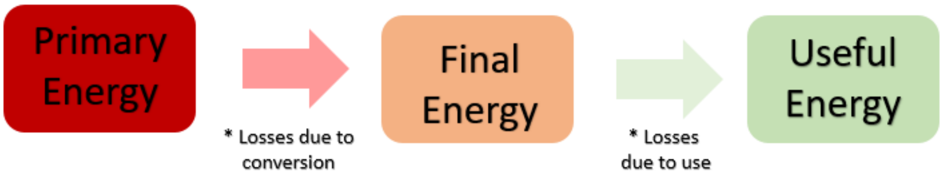


Fig. 20 Energy Loses between primary energy and useful energy

2.10 Greenhouses in Poland

Horticultural production of plants under cover is one of the most intensive energy and at the same time the most cost-intensive, especially in the countries with the less favorable weather conditions such as Poland. Average temperature and the intensity of solar radiation in the periods between October and March is lower compared not only with the countries of the Mediterranean basin but as well with countries like Holland which is the largest in Europe greenhouse farming.[50]

Due to the lower temperatures, thermal energy input for cultivation under the cover is 40% higher in Poland than in Holland [51]. In Portugal and Italy, the material used for covering the agriculture is much cheaper, and construction of the plastic tunnel is simple compared with planting in Poland. However, taking into account the emissions from transporting exported roses, more sustainable solution is to cultivate them in the country. In Poland, the area of greenhouses producing flowers accounts for 994.59ha [68].

This fact places Poland in an awkward position in the European market [50]. According to the research about the energy used during the greenhouses cultivation, thermal energy is the main component within expenditure and accounts for up to 90% of all energy inputs of the production process [52]. Because of such high demands, greenhouses look for the ways of decreasing energy consumption. The electricity demands are high due to the low solar radiation during the winter time. Due to this fact, electricity is used to provide the appropriate amount of light. To decrease the energy consumption, modernization of the heating system is necessary too, especially in the older greenhouses, as well as increased insulation of greenhouses walls to reduce the heat losses. To maximize the use of light, special equipment is essential with heat-insulating curtains and shading [53].

2.11 Motivation and scope of the thesis

Nowadays, the world fights with global warming and try to find alternative ways to replace fossil fuels, which have a harmful impact on the environmental. Poland is a country with the most significant dependency on fossil fuels in Europe. Polish Energy Market is 80% reliant on coal. This energy source contributes significantly to increasing CO_2 emissions. European Union is planning to implement new emission regulations and expand the sum for the carbon dioxide emission since 2020. For this reason, Poland needs to boost green energy development, biomass has the most significant potential in this country. As an alternative energy source, it can provide the energy to produce the electricity, and contributes to the reduction of greenhouse gases emissions and for agricultural and waste utilization.

The motivation for the energy supply from renewable sources for the greenhouse roses cultivation in Poland is to reduce the dependency on fossil fuels and increase CO_2 emission. Gasification process of the wasted roses is an attractive concept, not only because of the energy, but also because it is a solution to the problem of the accumulation of wasted roses. Starting from the small industries, we can change the world for better, thinking small is the secret to big success.

3. Research methodology

3.1 Introduction

Greenhouse Roses Cultivation located in Boguchwała, South East Poland produces around 10 mln pieces of roses per year. Such a vast production demands significant amounts of electricity and heat. The combustion process of coal provides heat. The electricity comes from the power plant. Apart from the fact that the owner has to spend a lot of money to afford it, such huge energy demand has a harmful impact on the environment (CO_2 and GHG emission etc.).

Fig.21 Roses cultivation

Fig.22 Greenhouse farm from the bird view

The scope of the thesis is to replace conventional energy sources by renewables. The study will include the energy and exergy analysis for the current situation and the study of alternative solutions – gasification of biomass from wasted roses.

3.2 Description of current system

The case study is a Polish company whose activity covers an area of seven hectares of greenhouses. The farm is separated into two running independently greenhouses. This thesis focuses on one of the greenhouse which covers 3,5 hectares (Fig.22, left part of the greenhouse). Yearly they produce 10 mln pieces. Around 20% out of 10 mln are wasted mainly due to the seasonal purification of old roses.

3.2.1 Luminous flux and efficiency of lamps

During the night, 1936 lamps with the power 1000W and efficiency 100 lm/W each provide the light essential for the roses growth. The Luminous flux of lamps that has a power consumption of 1000 watts and luminous efficiency of 100 lm/W can be calculated from the equation:

$$\Phi V(lm) = P(W) \times \eta(\frac{lm}{W}) \tag{3.1}$$

where:

$\Phi V(lm)$ – The luminous flux of the lamps,

$P(W)$ – The power of lamp in Watts,

$\eta(lm/W)$ – The luminous efficiency of LED lamps using in Greenhouse,

The total flux of 1963 LED lamps is equal 196 300 000 lumens.

Fig. 23 Lams provide light

Fig. 24 Roses Cultivation

Fig. 25 Roses Cultivation2

3.2.2 Electricity consumption

Total electricity demands for 2016 year is presented in the table below:

	Amount of electricity [MWh]	Money [PLN]	Money [Euro]
Jan-16	513.44	167054.44	38227.56064
Feb-16	557.241	175862.59	40243.15561
Mar-16	523.055	170973.09	39124.27689
Apr-16	488.836	158194.42	36200.09611
May-16	25.842	9586.53	2193.713959
Jun-16	25.462	9338.28	2136.906178
Jul-16	27.779	10759.03	2462.020595
Aug-16	24.316	9605.31	2198.011442
Sep-16	18.231	7642.93	1748.954233
Oct-16	26.504	10433.97	2387.636156
Nov-16	505.193	163949	37516.93364
Dec-16	554.96	177324.42	40577.67048
Total	3290.859	1070724.01	245016.9359

Tab.1 Electricity demand for year 2016

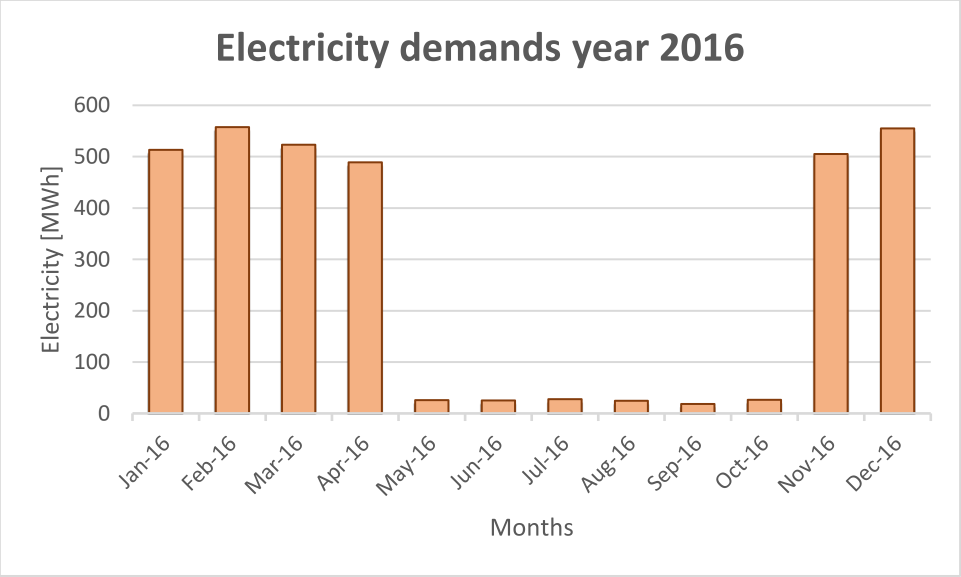


Fig. 26 Chart for electricity demands at 2016

Electricity mainly is used for the appropriate providing amount of light. The rest of the energy is used for other processes connecting with preparing roses for sale like cutting, decorating and cold storage. A significant difference in the energy demand between the period of November-April and the period of May-October is caused by the fact that every year with the 1st of May the light are off during the night because during the spring/summer time day is longer than night and the amount of sunlight is sufficient. With the 1st of November until the end of April light are on, because of the shorter day and long night.

The electricity used between November and April is 3142.725 MWh, in the period May – October – 148.134 MWh. The lights are on, during the winter time, 8.5 h per day - between 9 pm and 5:30 am. It means that during the winter period 1936 lamps with power 1000W are on per (8.5h×181days) 1538.5h. 1936W × 1538.5h = 2978.536MWh. 3142.725MWh – 2978.536 MWh = 164.189 MWh and this divided by the number of months (6) give the average amount of energy used for other processes (cutting, decorating and cold storage) – 27.47 MWh.

3.2.3 Heated space design heat load

Design heat load of a space is calculated in accordance with the following equation [62,63]:

$$\Phi_{HL,i} = \Phi_{T,i} + \Phi_{V,i} + \Phi_{RH,i} \text{ [W]} \tag{3.2}$$

where:

$\Phi_{T,i}$ – heated space design heat loss *i* through transmittance, transmission heat loss [W], $\Phi_{V,i}$ – heated space design ventilation heat loss *i* , ventilation heat loss [W],
$\Phi_{RH,i}$– thermal input surplus necessary to compensate effects of weakening heating of heated zone *i* , heating-up capacity [W].
Flow chart of calculating design heat load is presented on fig. 27.

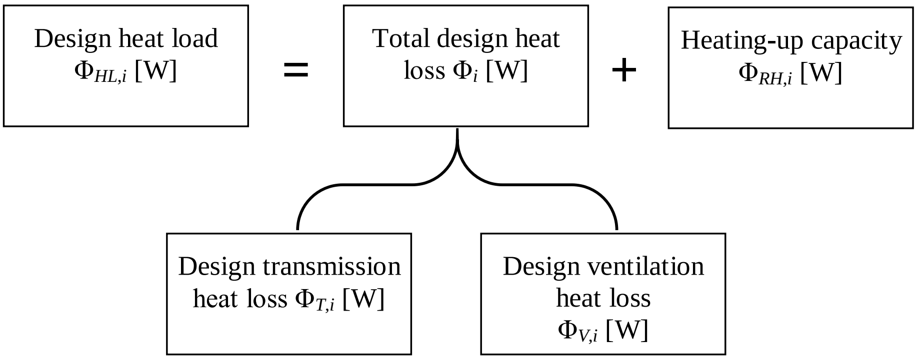


Fig. 27. Design heat load calculation scheme

In PN-EN 12831:2006 [63] the following equation for calculating design heat loss of heated space and through transmittance has been given:

$$\Phi_{T,i} \;=\; (H_{T,ie} + H_{T,iue} + H_{T,ig} + H_{T,ij}) \cdot (\theta_{int,i} - \theta_e) \text{ [W]} \tag{3.3}$$

where:

$H_{T,ie}$ – transmission heat loss coefficient from heated space *i* to external environment *e* through building casing [W/K],

$H_{T,iue}$ – transmission heat loss coefficient from heated space *ie* to environment through unheated space *u* [W/K],

$H_{T,ig}$ – transmission heat loss coefficient from heated space *i* to the ground *g* in certain circumstances [W/K],

$H_{T,ij}$ – transmission heat loss coefficient from heated space *i* to adjacent space *j* heated to significantly different temperature, i.e. adjacent heated space in the same part of a building or in adjacent part of a building [W/K],

$\theta_{int,i}$ – design internal temperature of a heated space *i* [°C],

θ_e – design external temperature [°C].

The transmission heat loss coefficient $H_{T,ie}$ is calculated in the following way:

$$H_{T,ie} = \sum_k A_k \cdot U_k \cdot e_k + \sum_l \Psi_l \cdot l_l \cdot e_l \text{ [W/K]} \tag{3.4}$$

where:

A_k – building element surface area *k* [m^2],

U_k – thermal transmittance of building element *k* [W/m^2·K],

Ψ_l – linear thermal transmittance of the linear thermal bridge *l* [W/m·K],

l_l – linear thermal bridge length *l* between internal and external space [m],

e_k, e_l – correction factors on the grounds of orientation, taking into consideration climate impacts, such as : different insulations, moisture absorption through building elements, wind velocity and air temperature, if the impacts were not taken into account before when determining factor U_k (PN-EN ISO 6946 [64]).

Approximate correction factors are given in National Annex to PN-EN 12831:2006 [63]: e_k = 1,0, e_l = 1,0, therefore equation (3.4) is simplified to:

$$H_{T,ie} = \sum_k A_k \cdot U_k + \sum_l \Psi_l \cdot l_l \text{ [W/K]} \tag{3.5}$$

Heat transmittance factor U_k is to be calculated according to:

- EN ISO 6946 – for non-transparent elements,
- EN ISO 10077-1 – for doors and windows [65],

or based on recommendations presented in European technical approvals.

Listed data concerning heat bridges is shown in [63]. List of typical bridges in construction industry is also contained in PN-EN ISO 14683 [66].

In heat loss through transmittance calculations heat bridges can be taken into account with **simplified method**. It is accepting heat transmittance factor corrected value:

$$U_{kc} = U_k + \Delta U_{tb} \ [\mathrm{W/m^2 \cdot K}] \tag{3.6}$$

where:

U_{kc} – corrected thermal transmittance of building element *k*, taking into account linear heat bridges [W/m^2·K],

ΔU_{tb} – correction factor depending on type of building element [W/m^2·K],

Approximate factor values ΔU_{Tb} for non-transparent barriers were given table 2 and 3 depending on whether building element intersect or does not intersect insulation. For window openings factor values ΔU_{Tb} are contained in table 2.

Number of ceilings intersecting insulation	**Number of intersected walls**	**ΔU_{tb} [W/m^2·K]**	
		cubic capacity ≤ 100 m^3	**cubic capacity > 100 m^3**
0	0	0,05	0
	1	0,10	0
	2	0,15	0,05
1	0	0,20	0,10
	1	0,25	0,15
	2	0,30	0,20
2	0	0,25	0,15
	1	0,30	0,20
	2	0,35	0,25

Tab. 2. Correction factor ΔU_{tb} for vertical building elements (based on entry [63])

Building element			**ΔU_{tb} [W/m^2·K]**
Lightweight floor (wood, metal and the like)			0
Heavyweight floor (concrete and others)	number of sides in contact with external environment	1	0,05
		2	0,10
		3	0,15
		4	0,20

Tab. 3. Correction factor ΔU_{tb} for horizontal building elements (based on entry [63])

Building element surface area	**ΔU_{tb} [W/m^2·K]**
0÷2 m^2	0,50
> 2÷4 m^2	0,40
> 4÷9 m^2	0,30
> 9÷20 m^2	0,20
> 20 m^2	0,10

Tab. 4. Correction factor ΔU_{tb} for openings (based on entry [63])

Simplified method of taking into account heat bridges merit is indisputably its ease of application. Whereas its drawback is that in some cases heat loss calculations may be significantly overestimated. The transmission heat loss coefficient $H_{T,ig}$ is calculated in the following way:

$$H_{T,ig} = f_{g1} \cdot f_{g2} \cdot (\sum_k A_k \cdot U_{equiv,k}) \cdot G_w \text{ [W/K]} \tag{3.7}$$

where:

f_{g1} – correction factor, taking into account external annual temperature fluctuation impact (according to national annex to PN-EN 12831:2006 [63] its approximate value is 1,45),

f_{g2} – temperature reduction factor, taking into account average annual external temperature and design external temperature difference,

A_k – building element surface area k touching the ground [m^2],

$U_{equiv,k}$ – equivalent heat transmittance factor of building element [W/m^2·K].

G_w – groundwater impact factor.

Temperature reduction factor is determined in accordance with :

$$f_{g2} = \frac{\theta_{int,i} - \theta_{m,e}}{\theta_{int,i} - \theta_e} \text{ [-]} \tag{3.8}$$

where:

$\theta_{m,e}$ – average annual external temperature [°C].

Groundwater has most likely negligible impact on heat exchange in the ground, unless it occurs at a small depth and its jet is strong. Factor including groundwater impact G_w is calculated according to approximate values given in national annex to PN-EN 12831:2006 [63].

In national annex there are two approximate values of factor G_w :

- G_w = if the distance between assumed groundwater level and floor plate is less than 1m,
- G_w = in other cases.

Equivalent heat transmittance factor of building element k: $U_{equiv,k}$ [W/m^2·K], is determined depending on characteristic parameter of floor B' and its location regarding the ground level and floor heat transmittance factor [64,65,66].

Characteristic parameter of floor B' defines relation between floor surface area on the ground and its circuit. Depending on determined parameter B', it is possible to determine equivalent heat transmittance factor k: $U_{equiv,k}$ for selected conditions of floor foundation and insulation on the ground.

Design ventilation heat loss is defined by the following equation:

$$\Phi_{V,i} = H_{V,i} \cdot \left(\theta_{int,i} - \theta_e\right) \text{ [W]} \tag{3.9}$$

where:

$H_{V,i}$ – design ventilation heat loss coefficient [W/K],

$\theta_{int,i}$ – design internal temperature of heated space i [°C],

θ_e – design external temperature [°C].

Design ventilation heat loss coefficient is defined by the following relation:

$$H_{V,i} = V_i \cdot \rho \cdot c_p \ \text{[W/K]} \tag{3.10}$$

where:

V_i – ventilated air flow rate of heated space i [m^3/h],

ρ – air density in temperature $\theta_{int,i}$ [kg/m^3],

c_p – specific heat capacity of the air in temperature $\theta_{int,i}$ [J/kg·K].

Assuming stability of density and specific heat of the air as function of temperature and introducing to equation (3.10) ρ = 1,2 kg/m^3, c_p = 1005 J/kg·K, [61], the following simplified equation may be assumed:

$$H_{V,i} = 0{,}34 \cdot \dot{V}_i \ \text{[W/K]} \tag{3.11}$$

where:

$\dot{V}_i$ – heated space volume flow of ventilated air i [m^3/h].

Thermal input surplus to compensate effects of weakening of heating is an additional element taken into account in methodology of calculating thermal input for the purpose of heating compared to former way of calculating heat demand. It has been introduced in order to obtain necessary design internal temperature in a certain time limit. It depends on a number of factors, especially on building elements heat capacity, heating time, temperature drop in time of weakening, barrier insulation, adjustment system characteristics. Thermal input surplus is not necessary when adjustment system is able to switch the weakening off during the coldest days or ventilation heat losses may be reduced during weakening. It should be agreed with the investor or client.

Surplus value can be determined in a precise way under the dynamic calculation procedures or calculated in a simplified way taking into account building type and heating time proportionally to heated spaces surface area, in accordance with the following equation:

$$\Phi_{RH,i} = A_i \cdot f_{RH} \ \text{[W]} \tag{3.12}$$

where: A_i – heated space internal surface area i [m^2],

f_{RH} – heating factor.

Heating factor f_{RH} depends on the assumed temperature drop in time of heating weakening and heating time, in which the required internal temperature is to be obtained. Heating factor values are given in national annex to PN-EN 12831:2006 (table 5) [63].

Values given in table 5 relate to internal floor surface area and can be applied to rooms, which average height do not exceed 3,5m. The values are not applied in case of accumulation electrical heating.

Heating time [hour]	**Heating factor f_{RH} [W/m^2]**								
	assumed temperature drop during weakening								
	2 K			**3 K**			**4 K**		
	building bulk			**building bulk**			**building bulk**		
	low	medium	high	low	medium	high	low	medium	High
1	18	23	25	27	30	27	36	27	31
2	9	16	22	18	20	23	22	24	25
3	6	13	18	11	16	18	18	18	18
4	4	11	16	6	13	16	11	16	16
In well insulated tight buildings the case of internal temperature drop during weakening by more than 2÷3 K is not highly probable. It depends on climate conditions and the building heat mass.									

Tab. 5. Heating factor fRH in non-residential buildings, night weakening for maximum 12 h (based on entry [63])

Results of the calculations for analysed greenhouse

The surface of the walls and roof of the greenhouse:

$A_k = 50875\ m^2$

Heat transfer coefficient for glass:

$U_k = 0.8\ W/m^2K$

Coefficient of thermal losses from the heated room to the surrounding through the glass walls

$H_{T,ie} = 40700\ W/K$

Transmission heat loss:

$\Phi_{T,I} = 1831500\ W$

Ventilation heat loss:

$\Phi_{v,i} = 53550\ W$

Coefficient of design ventilation heat loss:

$H_{v,I} = 1190$

Temperature inside:

$Q_{int} = 298\ K$

Outside temperature:

$Q_e = 253\ K$

Steam of ventilation air volume:
$V_i = 3500\ m^3/h$

Excess heat output:
$\Phi_{rhj} = 1085000\ W$

Floor area of the greenhouse:
$A_j = 35000\ m^2$

Heating coefficient:
$F_{RH} = 31$

Heat load:
$\Phi_{hl} = 2970050\ W$ what is 2.97005 MW

3.2.4 Production of Heat

The furnace EkoFire with power 5 MW and mechanical boiler is fed by coal. The temperature inside greenhouse during the night must be between 16-18°C and at the day 20-25°C. In order to maintain this temperature through the year 3000 tons of coal is used. The air temperature is controlled by the furnace's thermometer.

Culm parameters are presented in table below:

Parameter	**Symbol**	**Unit**	**Value**
Granulation		mm	31,5
The heating value	Q^r_i	MJ/Kg	22
Ash content	A^r	%	16
Sulfur content	S^r_t	%	0,8
Moisture content	W^r_t	%	8

Tab.6 Coal parameters [44]

Fig. 28 Coal feeder

Fig.29 Coal reserves

3.2.5 GHG emission

Yearly GHG emission of coal can be calculated from the equation below [45]:

$$E = B \times W \tag{3.13}$$

where:

E – Emission,

B – Fuel consumption,

W – Emission factor per unit of spent fuel.

Pollution	Unit of the indicator	Fixed grate				Mechanical grate
		Nominal thermal power of the boiler [MW]				
		≤ 0.5	≤0.5÷≤ 5	≤ 0.5	≤0.5÷≤ 5	≤0.5÷≤ 5
		Natural sequence		Artificial sequence		
SO_x/SO_2	**g/Mg**	16000 × s				
NO_x/NO_2		2200	1000	2000	3000	3200
CO		45000		70000	20000	10000
CO_2		1850000	2000000	1850000	2000000	2130000
TSP		1000 × A^r	1500 × A^r			2000 × A^r
benzopyrene		14				3.2

Tab. 7 Emission Factors for the coal [45]

In the table above are presented Emissions Factors for the combustion of fuel estimated by Polish National Center for Balancing and Emission Management

A^r it is the Ash content expresses in [%],

s – Sulphur content expresses in [%].

Calculations of GHG emissions

For SO_x/SO_2:

B = 3000 Mg

W = 16000 × 0,8 = 12800 g/Mg [45]

$$E = \frac{3000\,[Mg] \times 12800\,[\frac{g}{Mg}]}{1000} = 38400 \text{ kg}$$

For NO_x/NO_2:

B = 3000 Mg

W = 3200 g/Mg [45]

$$E = \frac{3000\ [Mg] \times 3200\ [\frac{g}{Mg}]}{1000} = 9600\ kg$$

For CO:

B = 3000 Mg

W = 10000 g/Mg [45]

$$E = \frac{3000\ [Mg] \times 10000 [\frac{g}{Mg}]}{1000} = 30000\ kg$$

For CO_2 :

B = 3000 Mg

W = 2130000 g/Mg [45]

$$E = \frac{3000\ [Mg] \times 2130000\ [\frac{g}{Mg}]}{1000} = 6390000\ kg$$

For TSP:

B = 3000 Mg

W = 2000 × 16 = 32000 g/Mg [45]

$$E = \frac{3000 [Mg] \times 32000 [\frac{g}{Mg}]}{1000} = 96000\ kg$$

According to resource [69] in order to produce, 1MWh of electricity 172.8kg of coal is needed, assuming the efficiency of power plant is 80%. 1GJ of coal produce 94600g of CO_2 during the process of electricity production [70]. Due to this fact to cover the energy demands for the greenhouse, 3290.856 MWh is needed. Taking into account that to produce 1MWh, 172.8 kg of coal is needed [69], to obtain the proper amount of electricity for the greenhouse, 568660.4kg of coal is required. This amount contains 12510.53 GJ assuming the heating value of coal 22MJ. If 1GJ of coal produce 94600g of CO_2 during the electricity production process [70], 12510.53 GJ will produce 1344881.846 kg of CO_2.

According to the estimates presented above, the calculations of the emissions resulting from the combustion process of coal the total CO_2 emission to cover the energy demands for the greenhouse is: 7734881.846 kg.

It's showing the amount of CO_2 that could be saved if the gasification process of biomass will replace the total energy production. Amount of CO2 emitted per year by the production of 1 rose in greenhouse account for 0.773 kg.

3.2.6 Amount of energy produce by furnace

Energy produced by furnace can be calculated from equation:

$$E = M \times Q^r_i \times \eta \tag{3.14}$$

where:

E- Produced energy,

M – Amount of used culm,

Q^r_i – Culm heating value,

η - furnance efficiency.

Calculations of energy produced by furnace

Power of furnace is 5 MW, and annual culm consumption is 3000 tons. Taking into account that the efficiency of the furnace according the manufacturer is 80%.

3000t = 3000000kg

22MJ/kg = 22000 kJ/kg

$$E = 3\times10^6\ [kg] \times 22000\ [kJ/kg] = 6.6 \times 10^{10}\ [kJ]$$

$$6.6 \times 10^{10}\ [kJ] \times 0.8 = 5.28\times10^{10}\ [kJ]$$

$$5.28\times10^{10}[kJ]\ /3600s = 14666.67\ [MWh]$$

Average annual power of furnace:

$$P = (M/\text{amount of hours in year}/3600) \times Q^r_i \times \eta \tag{3.15}$$

$$P = (3\times10^6\ [kg]/8760h/3600s\ ) \times 22000\ [kJ/kg] = 2.09285\ MW$$

$$P = 2.09285\ [MW] \times 0.8 = 1.67428\ [MW]$$

Calculations above show that furnace annually produce 14666.67 MWh and works with average power of – 1.67428 MW.

Average furnace power in winter period of time is:

$$P = (3\times10^6\,[kg]\ /4380h/3600s) \times 22000\ [kJ/kg] = 4.1857\ MW$$

$$P = 4.1857\ [\mathrm{MW}] \times 0.8 = 3.34856\ \mathrm{MW}$$

Average temperature inside the furnace depends on coal quality and ranges between 500-800°C while the water leaving the furnace has an average temperature of 85°C.

3.2.7 Quantity of primary energy associated with Heat and the Electricity Consumption

Primary and Final Energy Consumption

Final energy indicator determines annual demand for final energy per unit area.

$$EF = \frac{Ef}{A} \tag{3.16}$$

where:

EF – Final energy indicator,

Ef – Final energy,

A – Usable area.

Primary energy indicator determines annual demand for non-renewable primary energy per unit area.

$$EP = \frac{Ep}{A} \tag{3.17}$$

where:

EP – Primary Energy indicator,

Ep – Primary Energy,

A – usable area.

Depending on the type of fuel, the value of the final energy demand is multiplied by the coefficient of primary energy generation w_i

$$Ep = Ef \times wi \tag{3.18}$$

The individual types of fuel correspond with different coefficient of primary energy generation are presented in Table 8.

Way of energy supply	Type of energy carrier	wi
Local energy production in the building	heating oil	1.1
	natural gas	
	coal	
	lignite	
	solar power	0.0
	wind power	
	geothermal power	
	Biomass	0.2
	Biogas	0.5
Heating form plant with cogeneration	Coal or natural gas	0.8
	Biomass	0.15
Heating from heating plant	Coal	1.3
	Gas or heating oil	1.2
System power grid	Electric Energy	3

Tab.8 Coefficient of primary energy generation [56]

Energy conversion efficiency is calculated from equation:

$$\eta = \frac{EF}{EP} \tag{3.19}$$

where:

η - energy conversion efficiency,

EF – final energy indicator,

EP – primary energy indicator.

Calculations of primary and final energy from coal

Final Energy in the greenhouse was calculated above and is equal: = 14666.67 [MWh]

Finally Energy Indicator:

$$EF = \frac{14666.67[MWh]}{35000[m^2 \times year]} = 0.419 \left[\frac{MWh}{m^2 \times year}\right]$$

For the greenhouse and energy produced from coal w_i is equal 1.1 [56]

$$EP = 0.419 \left[\frac{MWh}{m^2 \times year}\right] \times 1.1 = 0.4609\left[\frac{MWh}{m^2 \times year}\right]$$

Energy conversion efficiency can be calculated from the equation:

$$\eta = \frac{0.419}{0.4609}\left[\frac{MWh}{m^2 \times year}\right] = 0.9 = 90\%$$

Calculations of primary and final energy associated with electricity.

Final Energy in greenhouse is 3290.859 MWh

$$EF = \frac{3290.859[MWh]}{35000[m^2 \times year]} = 0.94\left[\frac{MWh}{m^2 \times year}\right]$$

$W_i = 3.0$ [56]

$$EP = 0.94\left[\frac{MWh}{m^2 \times year}\right] \times 3.0 = 2.82\left[\frac{MWh}{m^2 \times year}\right]$$

According to equation energy conversion is equal:

$$\eta = \frac{0.94}{2.82}\left[\frac{MWh}{m^2 \times year}\right] = 0.33 = 33\%$$

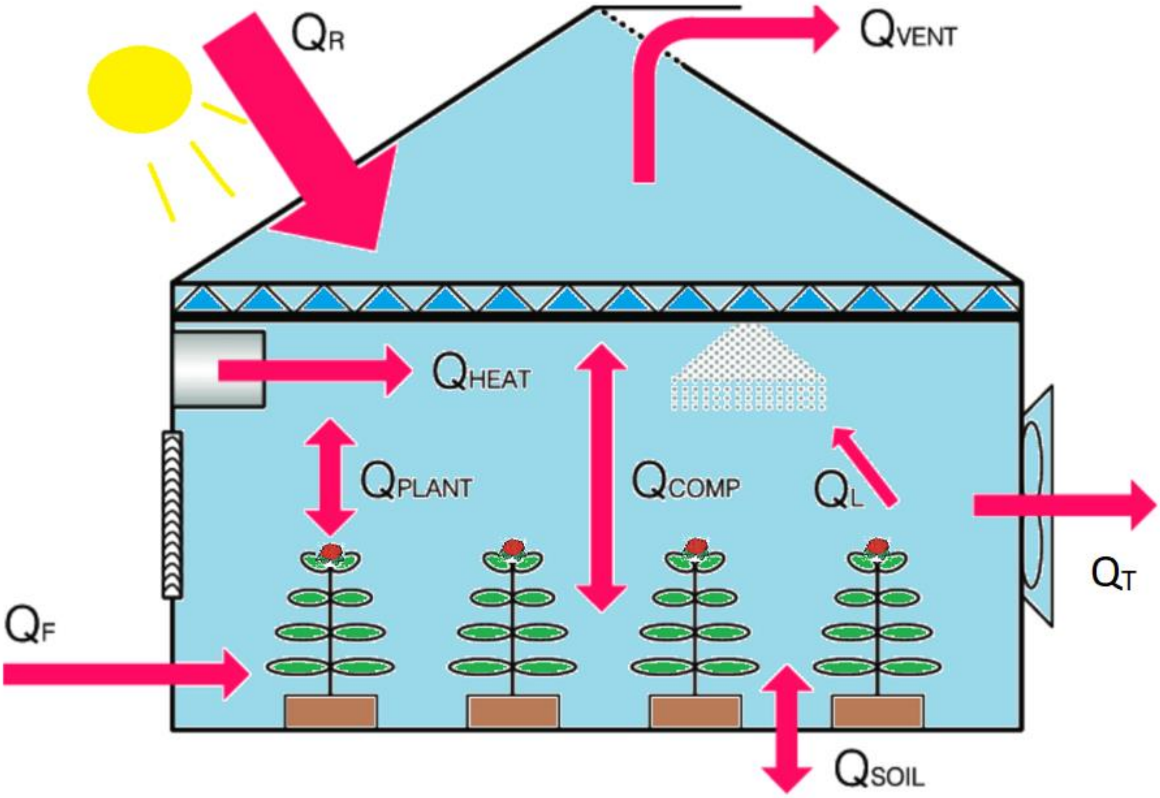


Fig. 30 Greenhouse Energy Balance [71]

Q_R – heat transfer by radiation

Q_F – heat transfer across the glazing via conduction and connection

Q_{comp} – heat transfer by the various greenhouse components

Q_{soil} – heat transfer by evaporation of plants

Q_L – latent heat transfer of sensible energy in the air to water in form of fog droplets

Q_{vert} – heat transfer by natural and mechanical ventilation

Q_{heat} – energy added to the greenhouse by a heating system

Q_T – heat transfer by transmission through the construction material

3.3 Potential of wasted roses

Per year the Greenhouse produces around 10 mln. pieces of roses. 20% of this production is wasted, it means that 2-3 mln roses need to be utilized. Roses reach max 80cm high and weight around 30g after drying. The calorific value is around 17 MJ/Kg in the dry state [46].

Fig. 31 Wasted Roses

Fig. 32 Developed Roses

The amount of 2 to 3 mln pieces of roses before drying process, has average weight 40g before drying, contain 5-8.4 % of ash, 8 to 20% of moisture[46], which lead to the lower product gas heating value. To get rid of the unwanted moisture, the pre-treatment processes are used, during which biomass is heated, usually in the oven, in the temperature around 100°C. [47]

The weight of dry roses 30000 kg contains 510000 MJ and 285.6 MWh of energy. The efficiency of the gasification process accounts for around 71% [48]. The Energy obtained from the gasification of the wasted roses is 202.78 MWh.

Because greenhouse is located at the agricultural area, where the farmers waste significant part of crops and different types of the biomass resources, an appropriate amount of crops, can be used by the greenhouse in the gasification process, to produce the energy.

Estimation of the number of crops needs to cover energy demands:

Energy demands: 18179.53 MWh

Energy obtained from roses: 202.78 MWh

18179.53 [MWh] – 202.78 [MWh] = 17976.75 [MWh] is a amount of energy that is needed from crops. Average calorific value of crops: 17.5 MJ/kg in the dry state [46] Because 17976.75 MWh is 65446308 MJ, taking into account that efficiency of the gasification process: 70% [48] amount of energy needed from crops is equal: 93494725.71MJ Knowing this, the number of crops necessary to meet the energy needs can be calculated and is equal: 5342555.755kg = 5342.6t

Production of roses in Poland demands a lot of energy to compare with others countries, especially Portugal, Spain or Italy and at the same time contribute to the GHG emission. Take into account that single track can fit 42000 roses; to transport 10 mln pieces 240 tracks are needed. Can be assumed that average distance from, for instance, Portugal to Poland is 3000 km and average fuel consumption accounts for 30l/100km of diesel [67]. The single track requires 900l of fuel to cover the distance. Diesel emits 1.61 Nm^3 of CO_2 per 1 kg of fuel [67]. The mass of 900l of diesel is 756 kg (taking into account that diesel density is 0.84 kg/dm^3). 1 m^3 of CO_2 contains 44.64 moles of this compound, by multiplying 44.64 moles of CO_2 by it's molar mass (44g/mol) weight of $1m^3$ is calculated – 1964.3g. Emission of CO_2 from single track according to the assumptions is: 756kg × $1.61Nm^3$ × 1.964 kg = 2390.5kg. To sum up, 240 tracks emits into the atmosphere 1147440 kg of CO_2 during the journey to Portugal and back. Knowing that total amount of CO_2 that is emitted by the greenhouse accounts for 7734881.846 kg, transportation would release less CO_2.

3.4 Description of the system based on gasification of wasted roses and crops

3.4.1 Receiving and storage

Wasted roses and crops will be used as a feedstock in such system. Biomass will be collected in the Greenhouse, since the significant part of waste come from the process of pruning of old roses. However, some amount of unsealed roses will be transported back to greenhouse by the companies' tracks. Because Greenhouse is located on the agricultural area, crops will be collected directly from the surrounding farms.

Such a large amount of biomass needs some space for storage. The owner has a vast undeveloped area, which can be used for biomass storage. The storage system used at the production site can significantly affect the cost and the quality of the fuel. The residence time would not be extended, maximum 1-2 months, because biomass will be collecting after seasonal harvest (August and September) and the heating season starting at November. A silo is used as a storage buffer in cases of storage 100 to 680 tons/day [48]. The bottom of the silo moves the fuel to the collector conveyors.

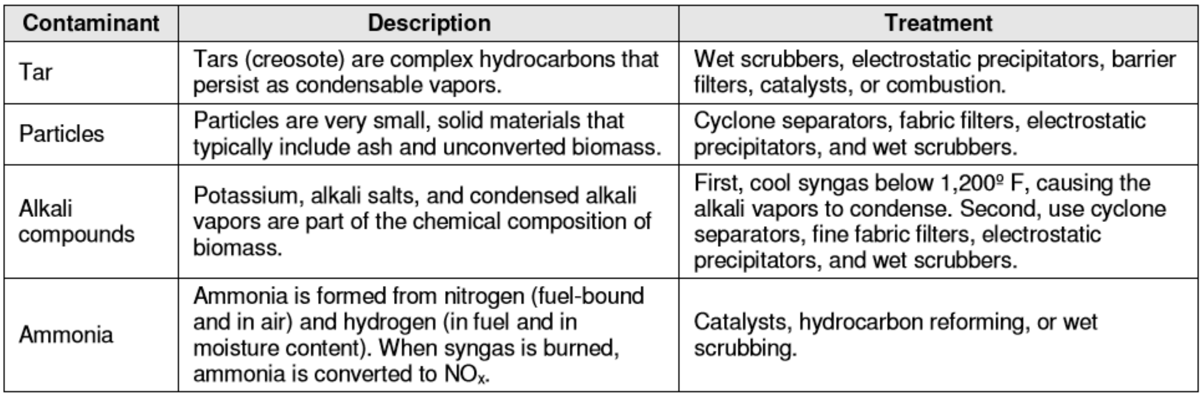
3.4.2 Processing of biomass

The main goal of the processing system is to treat the biomass prior to charging the conversion of energy process. This process includes all reduction methods like separation, sizing, grinding etc. The grinder chops the biomass into smaller pieces and conveys them into the wood silo, where the chopped roses are stored until the boiler need fuel. Fluidized bed boiler is able to accept the feedstock with a size around 2 centimeters. [48] Apart from chopping, sometimes biomass needs to be dried. The lower the moisture content of biomass, the higher energy efficiency of the conversion process. Water consume a significant amount of energy in the gasification process. In the case of excess of moisture, the gasification process cannot carry without an external source of heat. Biomass collected in the greenhouse will be dried using natural solar radiation, because the collection will take place during the summer time. Fluidized bed reactors accept the biomass with moisture content less than 20%. If biomass is wet and needs to be dried, the costs of equipment rise significantly and cover the savings cost of using the biomass as feedstock.

3.4.3 Conversion of biomass

The conversion process of wasted roses will take place in the boilers. Updraft fluidized bed gasifiers accept the feedstock with size 1-9 cm, furthermore is the best for the big scale application, like such case of the greenhouse, is cheaper and can handle high moisture (30%). Gasification process takes place with high efficiency due to the enhancement of the heat transfer between particles what makes the reactor works in the isothermal conditions. The operating temperature is between 790°C and 1400°C, it is constructed from mild steel and has a 5MW capacity.[48] The efficiency of the gasification in fluidized bed is around 60-80%.

The operation control is simple. Gasification process is finishing with the production of the mixture of the syngas. The syngas which leaves gasifier contains a range of chemicals which have destructive influence for the equipment, quality of ash and the emission. The gas cleanup system is required to get rid of such contaminants. The table below shows the type of undesired products that syngas contain and ways of treatment.[48]



Contaminant	Description	Treatment
Tar	Tars (creosote) are complex hydrocarbons that persist as condensable vapors.	Wet scrubbers, electrostatic precipitators, barrier filters, catalysts, or combustion.
Particles	Particles are very small, solid materials that typically include ash and unconverted biomass.	Cyclone separators, fabric filters, electrostatic precipitators, and wet scrubbers.
Alkali compounds	Potassium, alkali salts, and condensed alkali vapors are part of the chemical composition of biomass.	First, cool syngas below 1,200º F, causing the alkali vapors to condense. Second, use cyclone separators, fine fabric filters, electrostatic precipitators, and wet scrubbers.
Ammonia	Ammonia is formed from nitrogen (fuel-bound and in air) and hydrogen (in fuel and in moisture content). When syngas is burned, ammonia is converted to NO_x.	Catalysts, hydrocarbon reforming, or wet scrubbing.

Tab. 9 Description and ways of treatment of undesired gas contaminant [48]

The types and amount of impurities depend on the nature of biomass that is used as a feedstock. For gasification of wasted roses and crops, the gas cleanup section has to contain ash removal, quench, bag filter, wet scrubber and heat exchangers to cool the gas and at the same time provide the heat necessary in the others part of the process. Such a system together with the gasification reactor determines the main cost of the gasification system. The sensor and control are need to maintain emissions at the target level, as well as fuel properties and atmospheric conditions.[48]

3.4.4 Biomass Gasification Power Generation System

The proposal for Greenhouse is presented on schematic representation at the picture below with the direct-fired atmospheric gasification system. Gasification system is producing power and steam in gas turbine combined-cycle configuration.

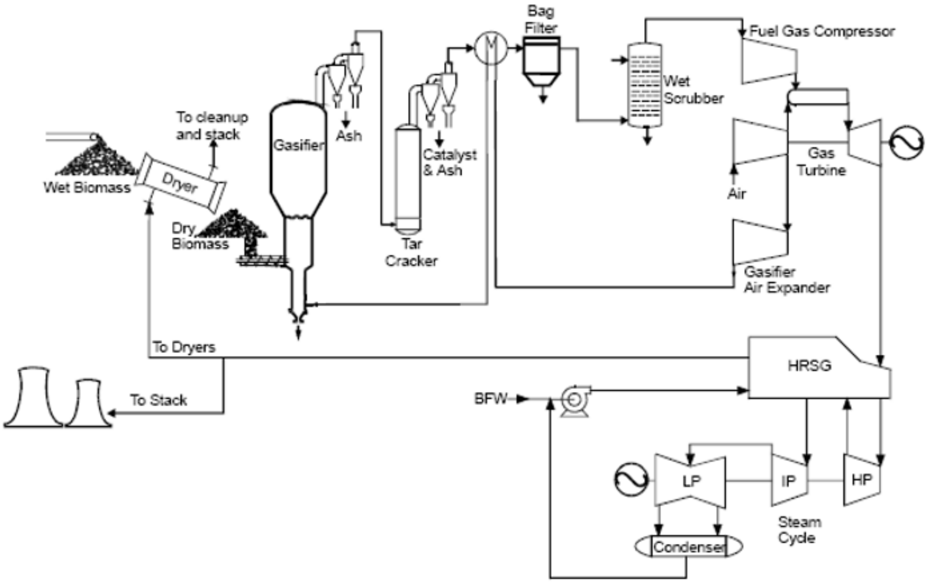
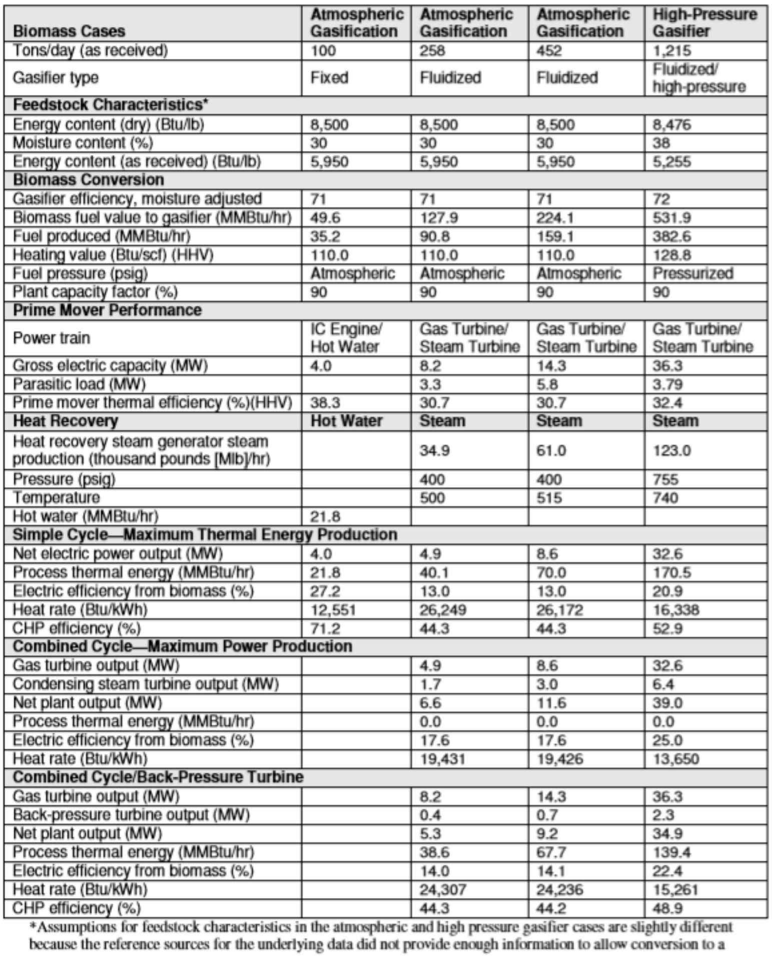


Fig. 33 Atmospheric Pressure Biomass Gasification Combined-Cycle [48]



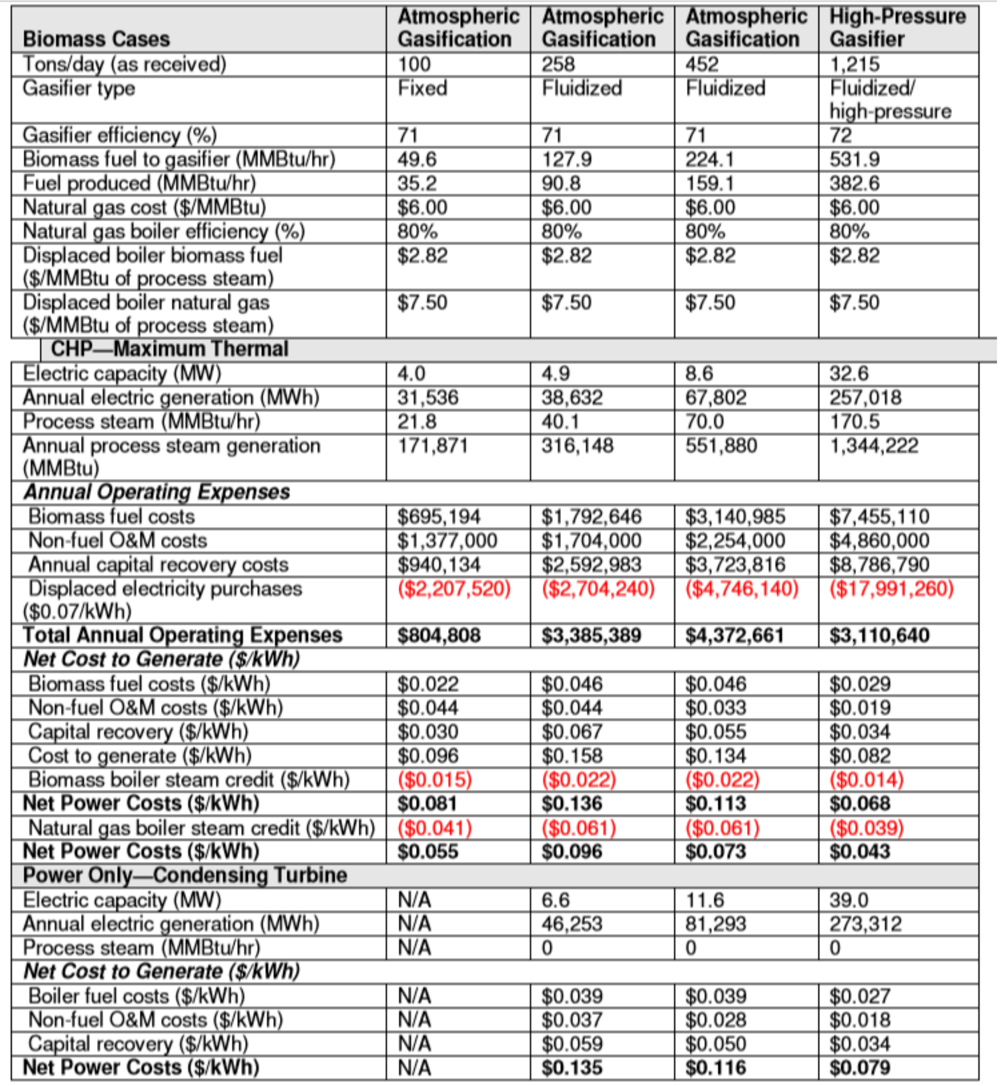
Biomass Cases	Atmospheric Gasification	Atmospheric Gasification	Atmospheric Gasification	High-Pressure Gasifier
Tons/day (as received)	100	258	452	1,215
Gasifier type	Fixed	Fluidized	Fluidized	Fluidized/ high-pressure
Feedstock Characteristics*				
Energy content (dry) (Btu/lb)	8,500	8,500	8,500	8,476
Moisture content (%)	30	30	30	38
Energy content (as received) (Btu/lb)	5,950	5,950	5,950	5,255
Biomass Conversion				
Gasifier efficiency, moisture adjusted	71	71	71	72
Biomass fuel value to gasifier (MMBtu/hr)	49.6	127.9	224.1	531.9
Fuel produced (MMBtu/hr)	35.2	90.8	159.1	382.6
Heating value (Btu/scf) (HHV)	110.0	110.0	110.0	128.8
Fuel pressure (psig)	Atmospheric	Atmospheric	Atmospheric	Pressurized
Plant capacity factor (%)	90	90	90	90
Prime Mover Performance				
Power train	IC Engine/ Hot Water	Gas Turbine/ Steam Turbine	Gas Turbine/ Steam Turbine	Gas Turbine/ Steam Turbine
Gross electric capacity (MW)	4.0	8.2	14.3	36.3
Parasitic load (MW)		3.3	5.8	3.79
Prime mover thermal efficiency (%)(HHV)	38.3	30.7	30.7	32.4
Heat Recovery	**Hot Water**	**Steam**	**Steam**	**Steam**
Heat recovery steam generator steam production (thousand pounds [Mlb]/hr)		34.9	61.0	123.0
Pressure (psig)		400	400	755
Temperature		500	515	740
Hot water (MMBtu/hr)	21.8			
Simple Cycle—Maximum Thermal Energy Production				
Net electric power output (MW)	4.0	4.9	8.6	32.6
Process thermal energy (MMBtu/hr)	21.8	40.1	70.0	170.5
Electric efficiency from biomass (%)	27.2	13.0	13.0	20.9
Heat rate (Btu/kWh)	12,551	26,249	26,172	16,338
CHP efficiency (%)	71.2	44.3	44.3	52.9
Combined Cycle—Maximum Power Production				
Gas turbine output (MW)		4.9	8.6	32.6
Condensing steam turbine output (MW)		1.7	3.0	6.4
Net plant output (MW)		6.6	11.6	39.0
Process thermal energy (MMBtu/hr)		0.0	0.0	0.0
Electric efficiency from biomass (%)		17.6	17.6	25.0
Heat rate (Btu/kWh)		19,431	19,426	13,650
Combined Cycle/Back-Pressure Turbine				
Gas turbine output (MW)		8.2	14.3	36.3
Back-pressure turbine output (MW)		0.4	0.7	2.3
Net plant output (MW)		5.3	9.2	34.9
Process thermal energy (MMBtu/hr)		38.6	67.7	139.4
Electric efficiency from biomass (%)		14.0	14.1	22.4
Heat rate (Btu/kWh)		24,307	24,236	15,261
CHP efficiency (%)		44.3	44.2	48.9

*Assumptions for feedstock characteristics in the atmospheric and high pressure gasifier cases are slightly different because the reference sources for the underlying data did not provide enough information to allow conversion to a

Fig 34 Representative Biomass CHP System Performance Profiles [48]

For the Greenhouse installation of Atmospheric gasification system with 258 Tons/day received biomass with energy content 8.5 Btu/lb and moisture 30% and gasifier efficiency of 70%. The Maximum Power production: 4.9 MW.

Cost of such installation is presented in the table below.



Biomass Cases	**Atmospheric Gasification**	**Atmospheric Gasification**	**Atmospheric Gasification**	**High-Pressure Gasifier**
Tons/day (as received)	100	258	452	1,215
Gasifier type	Fixed	Fluidized	Fluidized	Fluidized/ high-pressure
Gasifier efficiency (%)	71	71	71	72
Biomass fuel to gasifier (MMBtu/hr)	49.6	127.9	224.1	531.9
Fuel produced (MMBtu/hr)	35.2	90.8	159.1	382.6
Natural gas cost ($/MMBtu)	$6.00	$6.00	$6.00	$6.00
Natural gas boiler efficiency (%)	80%	80%	80%	80%
Displaced boiler biomass fuel ($/MMBtu of process steam)	$2.82	$2.82	$2.82	$2.82
Displaced boiler natural gas ($/MMBtu of process steam)	$7.50	$7.50	$7.50	$7.50
CHP—Maximum Thermal				
Electric capacity (MW)	4.0	4.9	8.6	32.6
Annual electric generation (MWh)	31,536	38,632	67,802	257,018
Process steam (MMBtu/hr)	21.8	40.1	70.0	170.5
Annual process steam generation (MMBtu)	171,871	316,148	551,880	1,344,222
Annual Operating Expenses				
Biomass fuel costs	$695,194	$1,792,646	$3,140,985	$7,455,110
Non-fuel O&M costs	$1,377,000	$1,704,000	$2,254,000	$4,860,000
Annual capital recovery costs	$940,134	$2,592,983	$3,723,816	$8,786,790
Displaced electricity purchases ($0.07/kWh)	($2,207,520)	($2,704,240)	($4,746,140)	($17,991,260)
Total Annual Operating Expenses	**$804,808**	**$3,385,389**	**$4,372,661**	**$3,110,640**
Net Cost to Generate ($/kWh)				
Biomass fuel costs ($/kWh)	$0.022	$0.046	$0.046	$0.029
Non-fuel O&M costs ($/kWh)	$0.044	$0.044	$0.033	$0.019
Capital recovery ($/kWh)	$0.030	$0.067	$0.055	$0.034
Cost to generate ($/kWh)	$0.096	$0.158	$0.134	$0.082
Biomass boiler steam credit ($/kWh)	($0.015)	($0.022)	($0.022)	($0.014)
Net Power Costs ($/kWh)	**$0.081**	**$0.136**	**$0.113**	**$0.068**
Natural gas boiler steam credit ($/kWh)	($0.041)	($0.061)	($0.061)	($0.039)
Net Power Costs ($/kWh)	**$0.055**	**$0.096**	**$0.073**	**$0.043**
Power Only—Condensing Turbine				
Electric capacity (MW)	N/A	6.6	11.6	39.0
Annual electric generation (MWh)	N/A	46,253	81,293	273,312
Process steam (MMBtu/hr)	N/A	0	0	0
Net Cost to Generate ($/kWh)				
Boiler fuel costs ($/kWh)	N/A	$0.039	$0.039	$0.027
Non-fuel O&M costs ($/kWh)	N/A	$0.037	$0.028	$0.018
Capital recovery ($/kWh)	N/A	$0.059	$0.050	$0.034
Net Power Costs ($/kWh)	N/A	**$0.135**	**$0.116**	**$0.079**

Fig. 35 Biomass Gasification Power Generation System – Net Cost to Generate Power[48]

3.5 Economic analysis and discussion

System based on fossil fuels:

	Electricity	**Heat**
Energy demands	3290.859 MWh	14888.67 MWh
Amount of coal	-	3000 t
Supplier	Power Plant	Combustion process at the site
Cost	€245016.94	€4737009(1)
Total Annual Costs	€718716.94	

Tab.10 Total yearly analysis of electricity and heat energy demands

(1) Cost of 1t of Coal is 690PLN = €159.7 [54]

System based on renewable:

Process	**Coal Combustion**	**Electricity production**	**Biomass gasification**	
Type of fuel	Coal	Coal	Wasted Roses	Crops
Amount of fuel	3000 t	568.660 t	60t	5342.6t
Cost of fuel	€4737009	€245016.94	€0	€0
Produced energy	14666.67 MWh	3290.859 MWh	202.78 MWh	18076.07 MWh
Cost of investment	-		€1747325.88 (2)	

Tab 11 Comparison of gasification and combustion processes

(2) Overall, system will cost 14888670kWh × \$0.135 = \$2024859 = €1747325.88

Economic analysis presented above shows that the cost of installation with all necessary equipment is high. However, the operating equipment cost is even higher €899283.26/year. The main reason of high price is the fact that commercial application of gasification is not that popular yet and the operation is very complicated. However, because Europe and Poland care more and more about the environment and especially about clean air, this trend has a chance to change. Nevertheless, taking into account the amount of money the owner has to spend every year on coal, and the growing price of this fuel, it can say that the investment won't be profitable. Currently in Poland government working on projects with co-financing to reduce the GHG emission, what is connected with the requirements of the European Union to reduce emissions of CO_2. It is possible that appropriate project will appear, and maybe this huge investment will be in some part covered by the government. It would be profit for the Owner of the Greenhouse, Government and especially for our environment.

Investment maybe is not profitable for the owner, which has to change all thermal system and necessary equipment (costs of investment + operational costs). However, presented gasification system would be a good option for the new greenhouse, where the owner has to choose new thermal energy supply scheme.

3.6 Biomass gasification plant in Bulgaria

In Bulgaria, 5MW gasification system was built with similar energy needs like a greenhouse. To reduce the dependency of this country from the imported energy a landmark biomass-to-energy plant powered by GE's Jenbacher gas engine technology was built. This 5MW use three engines powered by syngas derived from straw and wood chips. Such system produces enough electricity to power 2000 homes. Spanish company, Ebioss Energy AD, has a plan to apply IBGPP – Integrated Biomass Gasification Cogeneration Power Plant around Europe to increase the energy production from renewable sources. [62] It could be an attractive concept for Greenhouse.

4. Conclusions

To sum up, what has been presented in this thesis work, brief summations of each chapter will be provided.

Greenhouse roses cultivation has a vast energy demand what contribute to the CO_2 and GHG emission in Poland. Due to the European Union restriction, alternative ways of energy production must be applied.

Greenhouse energy demands reach the highest peak in the period from 1st of November until the end of April, because winter period cannot provide a proper amount of natural light, artificial one must be provided for the proper roses growth. Differences between this periods are huge: 3142.635 MWh – for period November – April and 148.224 MWh for period May – October. Electricity is provided from the PGE power plant in Rzeszów, which has modern and efficient electricity generating system powered by natural gas with the cogeneration. However, the losses for processing and transmission are greater than electricity consumption. Nevertheless, the fuel that runs the power plant in Rzeszów is natural gas; it means the electricity production in power plant has a less harmful impact to the environment than the process of burning the coal in the greenhouse to provide heat.

Heated space design heat load are 2.97 MW and are calculated for the winter period when the average temperature outside is -20°C. Such calculations give information about heat demands in the winter period and the power of the thermal system that is required to cover energy needs.

The amount of coal burning every year is massive, the quantity of the GHG emission indicate that combustion of coal has a destructive impact on the environment, especially the amount of CO_2 emits into the atmosphere every year.

Every year 3000t of coal is used with the heating value 22MJ/Kg. Furnace annually produce 14666.67 MWh and works with average power 1.67428MW. Average power during the winter period accounts for 3.34856 MW; it means that the stove does not use its power potential, which is 5MW, however in Poland temperature can sometimes drop to -30°C, due to this fact thermal system needs to have higher potential than the average power.

Calculations of the primary and final energy from coal indicate that energy conversion is equal to 90% what is higher than the energy conversion for electricity (33%). Such difference results from the fact that electricity production is connected with significant losses for the transmission and processing.

Energy potential from wasted roses is not that great. According to the calculation, the Energy that can be obtained from the number of roses that are wasted per year is just 285.6 MWh. However, it is not just about the energy potential, but also the problem with the utilization of wasted roses could be resolved.

Moreover, the fact that Greenhouse is located in the agricultural area where a significant amount of farmers is willing to get rid of crops. Missing part to fulfil the heat demand can be obtained from the gasification of crops. According to the estimates apart from 60t of wasted roses, 5342.6t of crops is needed. According to calculations, transporting roses from different countries would be more profitable regarding sustainable development. However in calculations are not assuming the energy demands for the cold storage, especially in case of transporting from hotter countries.

Economic analysis says that the amount of money that owner spending per year for the coal and electricity is €718716.94. The cost of investment for the gasification of biomass is estimated at €1747325.88. The investment itself is not that big, but the annual operating cost is high. Due to this fact, the investment is not profitable for the owner. However taking into account the growing coal prices tendency, rising the popularity of the renewable energy sources and European Union restriction on CO_2 emission, is highly likely to get some co-financing from the Polish Government. Such an investment would bring profits not only to the greenhouse but surplus electricity would be used by local farmers to power their homes. This is an attractive idea, however, requires additional research and findings. Such an idea would be a good option for the new greenhouse, where the owner has to choose thermal system anyway.

Bibliography

[1] **Robert A. Rohde**, Emission Debates for Global Atmospheric Research, 2000.

[2] **Twidell J.,Weir T.** Renewable Energy Resources, (1986)

[3] **Lemos F.&MA,** Lecture, Waste to Energy – Waste scenario – introduction, 2017

[4] **M. Abrantes/F. Lemos/ MA. Lemos** –; Key World Energy Statistics 2015 (International Energy Agency -http://www.iea.org), 2017

[5] **António Falco**; Renewable Energy – Wind Energy, –2017 ,14

[6] **Eugeniusz Mokrzyski, Roman Ney, Jakub Siemek** ŚWIATOWE ZASOBY SUROWCÓW ENERGETYCZNYCH – WNIOSKI DLA POLSKI ,2008

[7] **Polish Information and foreign investment agency**, Energy sector in Poland, 2011

[8] **Energy Mix 2050**. Analysis of Scenarios for Poland. Ministry of Economy 2011, page 7

[9] **Poland Energy Report**, Enerdata, July 2012

[10] **PIGEO**; National Renewable Energy Action Plan, 2017

[11] **Antoni Tajduś, Piotr Czaja, Zbigniew Kasztelewicz**. Rola węgla w energetyce i strategia polskiego górnictwa węgla brunatnego w I połowie XXI wieku. Zeszyt 3, Górnictwo i Geoinżynieria, 2011.

[12] **Janusz Kotowicz, Łukasz Bartela**. Application of wood biomass – overview of technologies. “Rynek Energii” no. 6/2007

[13] **Ryszard Gajewski.** Rynek biomasy w Polsce – stan obecny i perspektywy rozwoju. POLSKA IZBA BIOMASY, www.biomasa.org.pl, Warsaw, November 2014,

[14] **OdnawialneZrodlaEnergii**. www.odnawialnezrodlaenergii.pl, [july 2018]

[15] **Lukáš Gašparovič, Zuzana Koreňová, Ľudovít Jelemensk**. Kinetic study of wood chips decomposition by TG. 36th International Conference of SSCHE in 2009

[16**] S. K. Sansaniwal, K. Pal, M. A. Rosen, and S. K. Tyagi**, “Recent advances in the development of biomass gasification technology : A comprehensive review,” vol. 72, no. December 2016, pp. 363–384, 2017.

[17] **Jianjun Dai, Jean Saayman, John R. Grace, and Naoko Elli**. Gasification of Woody Biomass. Vancouver 2015 - https://www.ncbi.nlm.nih.gov/pubmed/26247289

[18] **Chen H**. Biotechnology of Lignocellulose Theory and practice, 2014

[19] **Vijay Kumar Thakur, Manju Kumari Thakur, Raju Kumar Gupta. Review**: Raw Natural Fiber–Based Polymer Composites. 19, 256–271, International Journal of Polymer Analysis and Characterization, 2014

[20] **Caroline Burgess Clifford. John A. Dutton e-Education Institute** – College of Earth and Mineral Sciences. EGEE 439, ALTERNATIVE FUELS FROM BIOMASS SOURCES, 2016. https://www.e-education.psu.edu

[21] **Sjaak van Loo, Jaap Koppejan.** The handbook of Biomass combustion and Co-firing. Earthscan. London, 2008.

[22] **Peter Quaak, Harrie Knoef,Hubert E. Stassen**. Energy from Biomass: A Review of Combustion and Gasification. World Bank Publications, 1999 – 78

[23] **Richard L. Bain, Group Manager**, Thermochemical Conversion National Bioenergy Center. An introduction to biomass thermochemical conversion, Biomass and Solar Workshops August 3-4, 2004

[24**] F. Lemos, MA. Lemos,** Waste to Energy, Thermochemical Conversion, 2017

[25] **S. K. Sansaniwal, K. Pal, M. A. Rosen, and S. K. Tyagi**, “Recent advances in the development of biomass gasi fi cation technology : A comprehensive review,” vol. 72, no. December 2016, pp. 363–384, 2017.

[26] **U.S. Department of Energy**. National Energy Technology Laboratory. http://www.netl.doe.gov, [july 2018]

[27]https://en.wikipedia.org/wiki/Fluidized_bed_reactor#/media/File:Fluidized_Bed_Reactor_Graphic.svg , [july 2018]

[28] **L.M.C. Gato**, Biomass and Biofuels, Renewable Energies, 2017

[29] **A.V. Bridgwater**, “Review of fast pyrolysis of biomass and product upgrading”, Biomass Bioenergy 38 (2012) 68-94

[30**] Boslaugh Sarah E.** Pyrolysis, Encyclopedia Britanica, www.britanica.com, [july 2018]

[31] **Jaya Shankar Tumuluru, S. Sokhansanj, J R. Hess, C.T. Wright and R.D. Boardman**, A review on Biomass torrefaction process and product properties for energy applications, 2008

[32] **F. Lemos, MA. Lemos**, Waste to Energy, Pyrolysis 3, 2017

[33] **National Energy TechnologLaboratory**, https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/fmb, [july2018]

[34]**Biofuels Education in Chemical Engineering**,Biofuels Academy,www.biofuelsacademy.org, [july 2018]

[35] **N.L. Panwar, Richa Kothari, V.V. Tyagi**. Thermochemical conversion of biomass eco-friendly energy routes. 16, Renewable and Sustainable Energy Review.

[36] **S. Nirapure, M. Singh, VikramMaran, S. Nigam**, Downdraft Gasifier: A Review, Jul.-Aug. 2015

[37] **Knoef, H., Ed**.; Handbook Biomass Gasification; BTG: Enschede The Netherlands, 2005

[38] **M. Siedlecki, Wiebren de Jong and Adrian H.M. Verkooijen**, Fluidized Bed Gasification as a Mature And Reliable Technology for the Production of Bio-Gas and Applied in the Production of Liquid Transportation Fuels – A Review, 2011

[39] **NationalEnergy Technology Laboratory**–Commercial Gasifiers: https://www.netl.doe.gov [july 2018]

[40] **Fluidized bed gasifier** http://www.build-a-gasifier.com/ [September 2018]

[41] **Gasification and Syngas Technologies Council**, http://www.gasification-syngas.org/ [august 2018]

[42] **John Collings, Mind over Matter** - The Sasol Story – A Half-Century of Technological Innovation, 2011

[43] **F.Lemos, M.A. Lemos** – Energy Storage - Solar fuels, 2017

[44] http://www.khw.pl/oferta/mial.html, [august 2018]

[45] **KOBiZE**, Wskaźnik Emisji Zanieczyszczeń ze spalania paliw, kotły o naminalnej mocy cieplnej do 5 MW, Warszawa 2015

[46] **Er. Anii Kumar Dubey&Dr Pitam Chandra**, Energy from Cotton Stalk and other agro residues, Central Institute of Agricultural Engineering BHOPAL, 2011

[47] **Wendy E. M. Hughes, Eric D. Larson**, Effect Of Fuel Moisture Content On Biomass – IGCC Performance, Princeton University, 2010

[48] **U.S. Enviromental Protection Agency Combined Heat and Power Partnership**, Biomass Combined Heat and Power Catalog of Technologies, CHP, September 2017

[49] https://www.iea.org/ [august 2018]

[50] **L. Jabłońska, D. Olewnicki**, Zmiany w powierzchni upraw ogrodniczych pod osłonami w Polsce w pierwszej dekadzie XXI w., SGGW Warszawa 2006

[51] **Jabłonska L**. Określenie perspektyw polskiego kwiaciarstwa na podstawie długookresowej analizy porównawczej jego rozwoju w Polsce i Holandii. Fundacja „Rozwój SGGW", Warszawa, 1995

[52] **Kloc T. Kurpaska S.** Energochłonność i efektywność bezpośredniego ogrzewania gleby w szklarni. Zeszyty naukowe AR. Nr 6. Kraków. s. 53-62. 1988.

[53] **K. Rutkowski,** Analiza Energetyczna Wybranych Typów Szklarni, Uniwersytet Rolniczy w Krakowie, 2006

[54] https://imexpiechota.pl/wp-content/uploads/cennik-wegiel-luzem.pdf [august 2018]

[55] **Energia Pierwotna i Użytkowa** https://www.muratorplus.pl/technika/ogrzewanie/oszczedzanie-energii-podstawowe-pojecia-energia-pierwotna-uzytkowa-i-koncowa-aa-QfWj-ZFYH-FXM2.html [august 2018]

[56] http://prawo.sejm.gov.pl/ [august 2018]

[57] **Viessmann**, Wytyczne projektowe i eksploatacyjne dotyczące kotłów wodnych wysokotemperaturowych, 5824 427PL, 2013

[58] **Viessmann**, Cennik 2018 PL, Systemy Grzewcze, www.viessmann.pl [august 2018]

[59] **Primary, Final and Useful Energy**, http://krzysztoflis.pro/energia-pierwotna-koncowa-i-uzytkowa/ [august 2018]

[60] **The path towards energy transition: the necessity to redefine our consumption patterns,** https://citizens4energytransition.org/what-do-you-know-about-energy/ [august 2018]

[61] **Jan Szargut,** Analiza Egzergetyczna Procesów Cieplnych, Instytut Techniki Cieplnej Politechniki Śląskiej, 1996

[62] **Biomass gasification plant in Bulgaria to use GE technology** http://biomassmagazine.com/articles/10229/biomass-gasification-plant-in-bulgaria-to-use-ge-technology [august 2018]

[63] **PN-EN 12831:2006**, Instalacje ogrzewcze w budynkach -- Metoda obliczania projektowego obciążenia cieplnego

[64] **PN-EN ISO 6946**, Komponenty budowlane i elementy budynku -- Opór cieplny i współczynnik przenikania ciepła -- Metoda obliczania

[65] **PN-EN ISO 10077-1**, Cieplne właściwości użytkowe okien, drzwi i żaluzji -- Obliczanie współczynnika przenikania ciepła -- Część 1: Postanowienia ogólne

[66] **PN-EN ISO 14683**, Mostki cieplne w budynkach -- Liniowy współczynnik przenikania ciepła -- Metody uproszczone i wartości orientacyjne

[67] **Polskie Towarzystwo Naukowe Silników Spalinowych,** Combustion Engines – Scientific Magazine, december 2007

[68] **Powierzchnia i produkcja upraw szklarniowych,** http://www.sppiopo.pl/warzywa-pod-oslonami-w-Polsce-powierzchnia-uprawy-i-produkcja [november 2018]

[69] **Emisja CO_2 z energii elektrycznej w Polsce,** http://www.rynekinstalacyjny.pl/artykul/id3856,emisja-co2-z-energii-elektrycznej-w-polsce, [november 2018]

[70] **Krajowy Ośrodek Bilansowania i Zarządzania Emisjami,** Warości opałowe i wskaźniki emisji $C0_2$ w roku 2012 do raportowania w ramach Wspólnotowego Systemu Handlu Uprawnieniami do Emisji za rok 2015, Warszawa, Październik 2014

[71] **Luuk Graamans, Andy van den Dobbelsteen, Esther Meinen, Cecylia Stanghellini,** Plant Factories; crop transpiration and energy balance, January 2017