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ACADEMY FOR CONTINUING EDUCATION

Development potential of a biogas CHP plant near city of Zagreb

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
Dipl.-Ing. Dr. Mario Ortner

Maria Magdalena Boricevic, mag. ing. mech.

12230442

Vienna, 19.09.2024

Affidavit

I, **MARIA MAGDALENA BORICEVIC, MAG. ING. MECH.**, hereby declare

1. that I am the sole author of the present Master's Thesis, "DEVELOPMENT POTENTIAL OF A BIOGAS CHP PLANT NEAR CITY OF ZAGREB", 77 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

The city of Zagreb is the capital of the Republic of Croatia and is, therefore, the most interesting area for energy. A little less than 1 million people live inside the city, and there are large production and industries in its surroundings.

Like the entire planet, the city of Zagreb and the Republic of Croatia are working to reduce Greenhouse Gas Emissions, and the best way to do this is through renewable energy sources. Although there are increasingly small, private investments in renewable energy sources, larger projects that would cover a larger number of households must be considered.

This thesis aims to investigate the potential and cost-effectiveness of building a biogas power plant near Zagreb and examine all their possibilities.

1. Introduction

The war in Ukraine and the Russian suspension of gas have brought instability and uncertainty to Europe and have raised questions of self-sustainability in the field of energy throughout Europe, including in the Republic of Croatia. At that time, countries with their own production and gas reserves were more secure. Encouraged by this situation, the area of biogas as an energy source began to be explored. Biogas is a gas produced by a simple natural anaerobic digestion process and can be injected into the existing gas network. Its great advantage is that organic substances, i.e., waste from various industries, are used for biogas production.

1.1. Aim and Scope

The topic of this paper was created as an incentive to make changes in the Croatian capital - City of Zagreb regarding food waste and renewable energy sources. Globally, large amounts of food are wasted in developed countries every day, while people in underdeveloped countries die of hunger and poverty. Food thrown away has no added value, but is a pure cost from the beginning of production until disposal as waste. In the world, it is necessary to encourage changes and move towards a better, more sustainable, and safer future. It is essential to educate people about a sustainable approach to nutrition and zero-waste cooking methodology, but this is difficult to achieve at the national level. Also, food that remains unused and is intended to be thrown away can hardly help hungry people on the other side of the world, so it is wise to find a way to somehow use it and not just waste it, that is, to make the solution acceptable from the ethical side.

This is how the idea of a biogas power plant in the area of the city of Zagreb was born.

1.2. Methodology of Study

To prepare for this task, the literature was studied and experts dealing with the field of biogas production were consulted.

Zagreb is in a good position for the production of biogas from food waste from household waste, restaurant waste, and waste from food manufacturers. About 800,000 inhabitants live in the city of Zagreb, and waste management within households and companies is regulated by law. Every citizen is provided with suitable bags and bins for separating waste, and residents are educated on what type of waste falls into which type. Therefore, bio-waste management is already at the city level.

As for production, there are large distribution centers and producers of fruit, vegetables, meat, and other food products within a radius of 10 km from Zagreb. Food waste from the industry is significant, and it is a shame to pass up the opportunity to add value to that waste.

Tools available online and research that can be compared with this case were used to size the power plant and decide on efficiency and economy. Also, the knowledge acquired during this study and during education at the Faculty of Mechanical Engineering and Naval Architecture in Zagreb were used to write this paper.

For the dimensioning of the biogas CHP power plant, online tools, research, and projects were used that can be compared with the power plant that would be built in the vicinity of Zagreb.

2. Basic Principles of Renewable Energy Sources

The word Energy in the field of physics was first defined by Thomas Young in 1800 but its effect has long been known. At the beginning of the 19th century, the need for a definition of the word "energy" arose, parallel to the development of the first industrial revolution and scientific discoveries in physics. Furthermore, in the middle of the 19th century, three physicists, Julius Robert von Mayer, James Prescott Joule, and Hermann von Helmholtz, gave the fundamental principle of the law of conservation of energy : (Alrasheed 2019, 53)

"Energy cannot be created or destroyed; it can only be transformed from one form to another."

"Energy is the ability to do work."

Although renewable energy sources have been used extensively in recent years and have become modern, their origins are much older. The simplest example is wood, a source of energy that has been used since the beginning of mankind. It is so simple that sometimes we forget that it is a source of energy, and a renewable one at that.

2.1. Forms of Energy

Energy is divided into primary, transformed, and useful forms.

Under primary forms, we consider those forms of energy that we can encounter in nature. They are divided into conventional (firewood, coal, crude oil and natural gas, nuclear fuels, hydropower and hot springs) and firewood, coal, crude oil and natural gas, nuclear fuels, hydropower and hot springs). Primary forms are found in nature, and in the case of conventional sources, they can be stored or left unused.

Primary forms must undergo energy transformation to obtain technically usable forms of energy. Each of the primary forms is a kind of energy source; that is, each of them possesses energy that needs to be transformed in order to benefit from them. Therefore, for example, wood, and crude oil are carriers of chemical energy; they possess fuel elements that will give another form of energy through a chemical reaction. Water power, tides, and waves are carriers of potential energy converted into mechanical work in turbines and machines. The sun is the carrier of radiant energy, which is converted into electrical energy using photovoltaic panels, or into thermal energy if the conversion is done through solar collectors. Wind is the carrier of kinetic energy, which is converted into mechanical work in the turbine rotor. (Sutlović)

From the above, it is evident how primary forms are transformed into other forms of energy using energy conversions. The result of this conversion is transformed forms of energy: mechanical, electrical, and thermal. Transformed forms of energy have characteristics that allow them to be used immediately but can be stored or transported to some other near or far distance. Mechanical energy cannot be transported but must be used immediately. Electric energy is suitable for long-distance transport and can be stored for a certain period of time, while thermal energy is transported over shorter distances. (Sutlović)

The last form of energy is useful, the form that is put to use by end users, namely mechanical, thermal, light, and chemical energy. It is immediately visible how mechanical and thermal energy are classified into transformed and useful forms. When discussing mechanical and thermal energy as transformed forms, it is understood that they were obtained by direct conversion from primary sources. Of course, the end users can obtain a useful form of energy directly from the transformed form but in some cases, additional energy transformations are required to use it. It should be remembered that every transformation of energy from one form to another results in losses due to the irreversibility of the process.

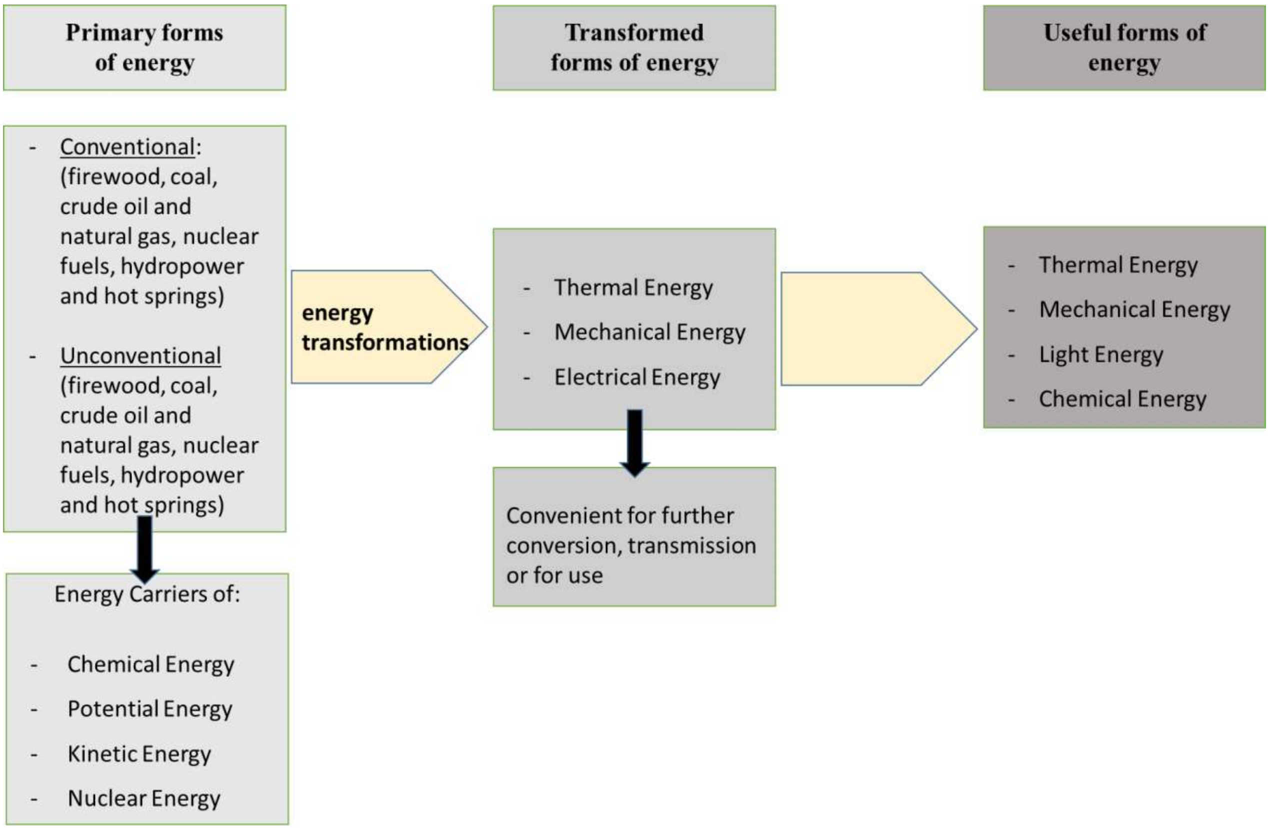

Figure 1 Forms of Energy

It is important to know that primary forms of energy can be additionally divided into renewable and non-renewable energy sources. Non-renewable energy sources, primarily fossil fuels, have a finite supply in nature and unlike them, renewable energy sources constantly appear in nature, but not always with the same intensity. They occur in nature in circular cycles.

2.2. The Impact of Energy on the Environment

Energy and its impact on the environment are closely related because, in today's world, we can not live without energy. People are often unaware of how much energy they really use and the impact of that energy on the environment. The vast majority of energy still comes from non-renewable sources that are major polluters of the environment and emit large amounts of gases and toxins, such as carbon dioxide, carbon monoxide, sulfur dioxide, and nitrogen oxides, into the atmosphere. The result is air and water pollution, climate change, and waste problems. Renewable energy sources are often considered as a solution to the problem of environmental pollution.

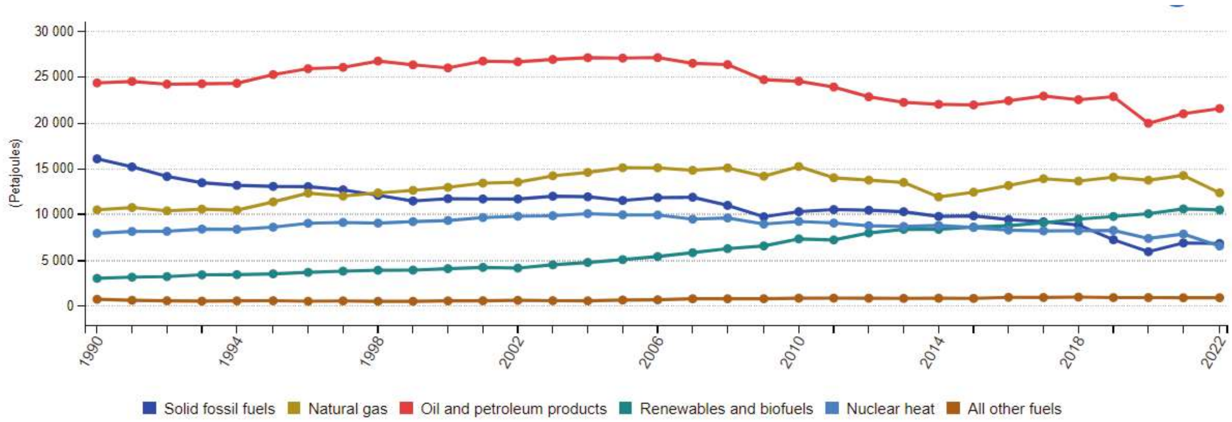

Figure 2 Gross available energy in the EU from 1990 to 2022 (Eurostat 2024)

Figure 2 shows the gross available energy in the European Union from 1990 to 2022. The graph shows that oil and petroleum products are the most common forms of primary energy in the last twenty years in the European Union, but there is a downward trend. It should be considered that the slightly more significant drop in 2020 resulted from the pandemic. The second most significant source of primary energy in Europe is natural gas, which is a non-renewable energy source. For 20 years, there has been a slight upward trend in the consumption of natural gas, which fell sharply in 2021 due to Russian aggression against Ukraine. The result is an increase in the share of renewable energy sources, which have the highest growth trend and have overtaken solid fossil fuels in 2018 and 2019.

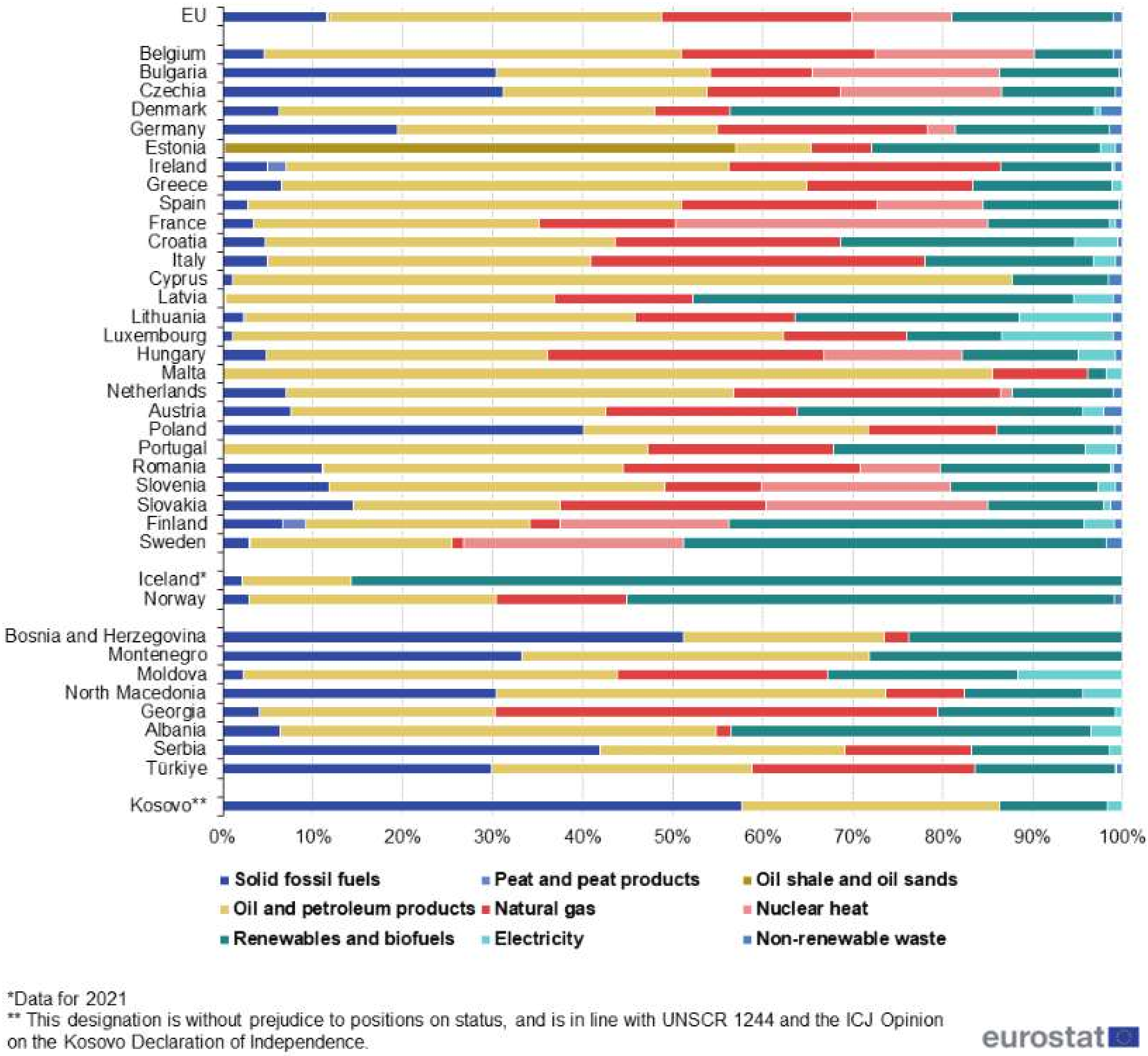

Figure 3 Gross available energy by fuel, 2022 (Eurostat 2024)

Figure 3 shows gross available energy by fuel in 2022 for the European Union, members of the European Union, and other European countries that are not members. The share of different fuels available in countries depends on the available sources and the country's economy and energy policies. When looking at the cumulative share of all significant fossil fuels in gross available energy, it can be noted that only two countries have less than 40%, Sweden and Finland, countries that, due to their geographical position and climate, have high utilization of renewable sources and biofuels. Also, Sweden and France have a large share of nuclear heat. Poland, the Czech Republic, and Bulgaria have the largest share of solid fossil fuels in the EU, in Poland as much as 40%.

Iceland has the largest share of renewable energy sources, over 85%.

The interesting thing in this graph is Estonia, which best shows how much influence natural sources and geographical location have. Only Estonia in Europe uses oil shale and oil sands and their share in gross available energy is over 55%.

Croatia's gross available energy by fuel distibution are roughly the same as the EU average. Crude oil and petroleum products have the largest share of gross available energy in Croatia, while natural gas, renewable sources, and biofuels take second place.

To see the impact on the environment, these data must be compared with energy consumption per capita Figure 4.

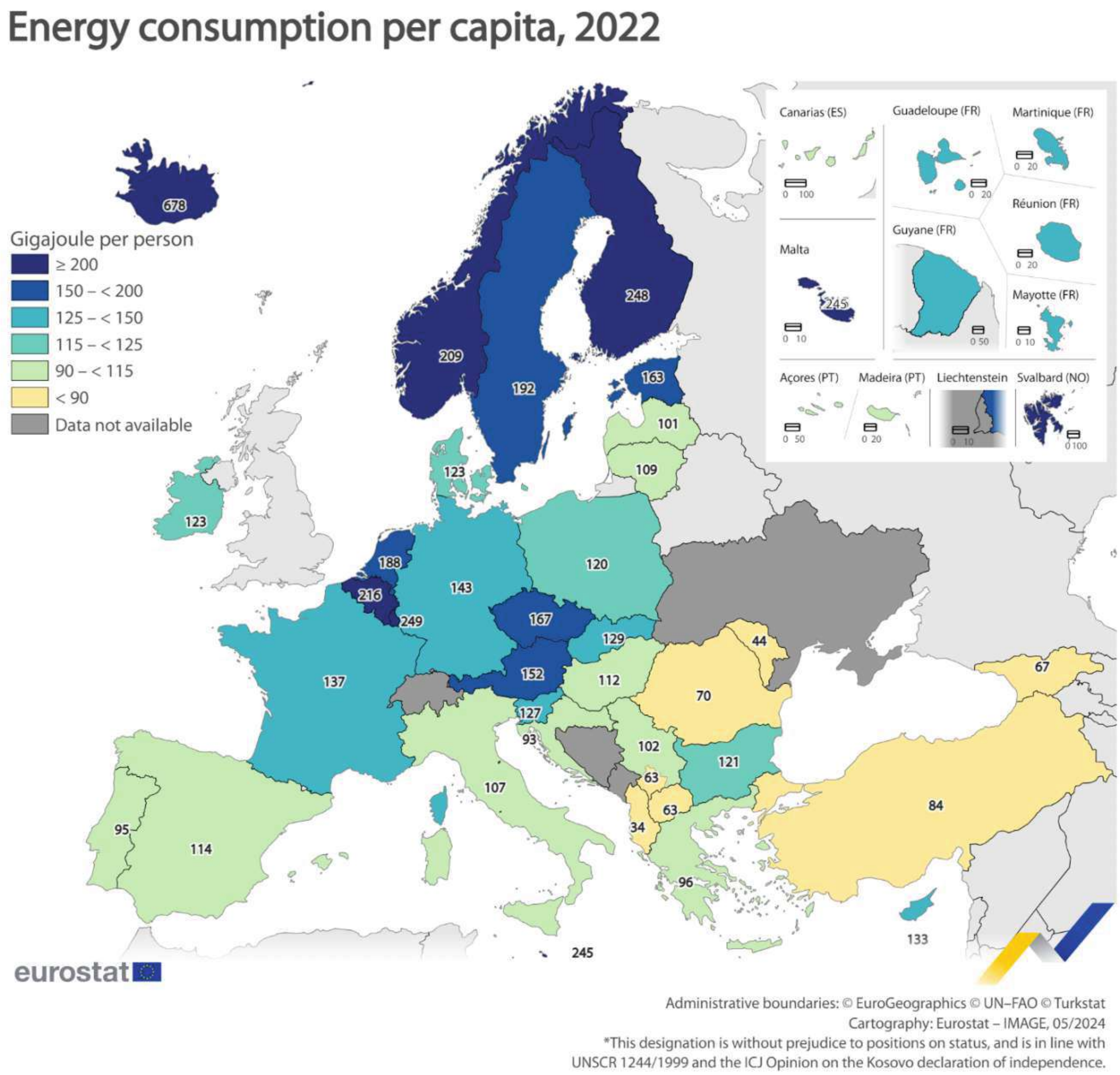

Figure 4 Energy consumption per capita in Europe, 2022 (Eurostat 2024)

Industrial development and climatic conditions are mainly factors that indicate the largest energy consumers per capita. Although Iceland is the largest consumer per capita, it also has the largest share of renewable energy sources.

From all the above data, it is evident that fossil fuels and natural gas are still Europe's leading energy sources. Such a distribution of fuel use is bad because it is the biggest polluter of the atmosphere, air, water, and soil.

"The Life Cycle Assessment of each source should be considered when characterizing energy sources as "good" and "bad" concerning the environment. Life Cycle Assessment (LCA) is a process of evaluating a product's effects on the environment over the entire period of its life, thereby increasing resource-use efficiency and decreasing liabilities." (EEA)

LCA's key elements are: (EEA)

- identify and quantify the environmental loads involved, e.g., the energy and raw materials consumed, the emissions and wastes generated;
- evaluate the potential environmental impacts of these loads; and
- assess the options available for reducing these environmental impacts.

With this approach, the critical points in terms of emissions in the life cycle of a particular product are accurately defined, and it is possible to respond to the way of adequate replacement or procedures, that is, ways to reduce emissions in the most critical parts of the process.

2.3. Types of Renewable Energy Sources

Renewable energy sources never disappear; they are natural self-replenishment and have zero harmful emissions. The most represented renewable energy sources include solar energy, wind energy, bioenergy, geothermal energy, hydropower, and ocean energy.

2.3.1. Solar Energy

Solar power has been the fastest-growing renewable energy source in the last 20 years. Solar radiation is the most abundant source of all energy sources. It is a fact that the solar energy emitted is 10,000 times greater than the energy consumed by humanity. (Arvizu, D., P. Balaya, L. Cabeza, T. Hollands, A. Jäger-Waldau, M. Kondo, C. Konseibo, V. Meleshko, W. Stein, Y. Tamaura, H. Xu, R. Zilles 2011)

The use of solar energy is becoming increasingly widespread since the development of technology and the market have made solar energy equipment affordable to a wide range of people. Solar technologies have enabled us to use solar energy for heating, cooling, natural light, electricity, and fuel.

Solar energy can be used passively or actively. Regarding the passive use of solar energy, we are talking about light and heating. To maximize passive solar energy for light and heating, houses and buildings must be optimally designed; that is, the position and orientation of the windows must be such that the sun's rays penetrate and illuminate the space as much as possible.

Active solar energy is used for solar heating. Solar correctors convert solar irradiation into heat using a carrier fluid to transfer heat to an insulated tank. Solar collectors are made of different materials, depending on the system and the climatic conditions in which they will operate.

Photovoltaic (PV) solar technology generates solar energy using the photovoltaic effect. The photovoltaic effect is the process of converting light into electricity. Each photovoltaic element, known as a solar cell, includes a p-n junction in a semiconductor material where light absorption has occurred. Direct current (DC) is generated from the semiconductor material as it receives photons in an illumination process. (Shiva Gorjian, Hossein Ebadi 2020)

With PV technology, electricity is generated as long as there is illumination. Unlike a battery, the advantage of photovoltaic technology is that it works continuously as long as there is illumination; that is, it does not require recharging.

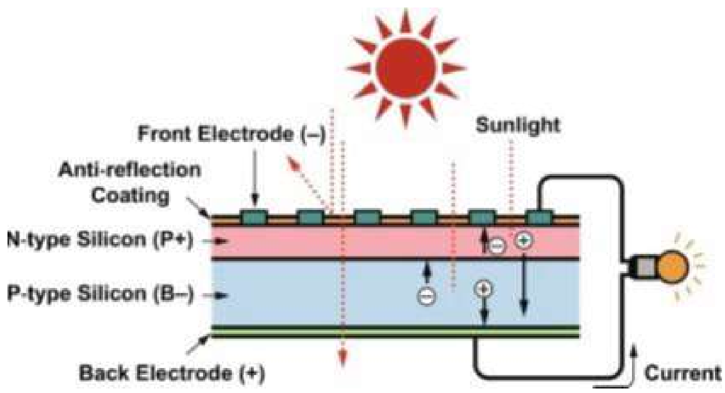

Figure 5 Photovoltaic effect in a solar cell (Shiva Gorjian, Hossein Ebadi 2020)

2.3.2. Wind Energy

The technology behind wind energy consists of a mechanism that converts the kinetic energy of the air in motion – wind into electricity. Wind turbines consist of rotor blades that move the wind, and the kinetic energy is converted into rotational energy. The obtained rotational energy is transmitted via the shaft to the generator that produces electricity.

Figure 6 shows how the obtained electricity is further transmitted via the power cab to the transformer, which converts it and sends it further into the network.

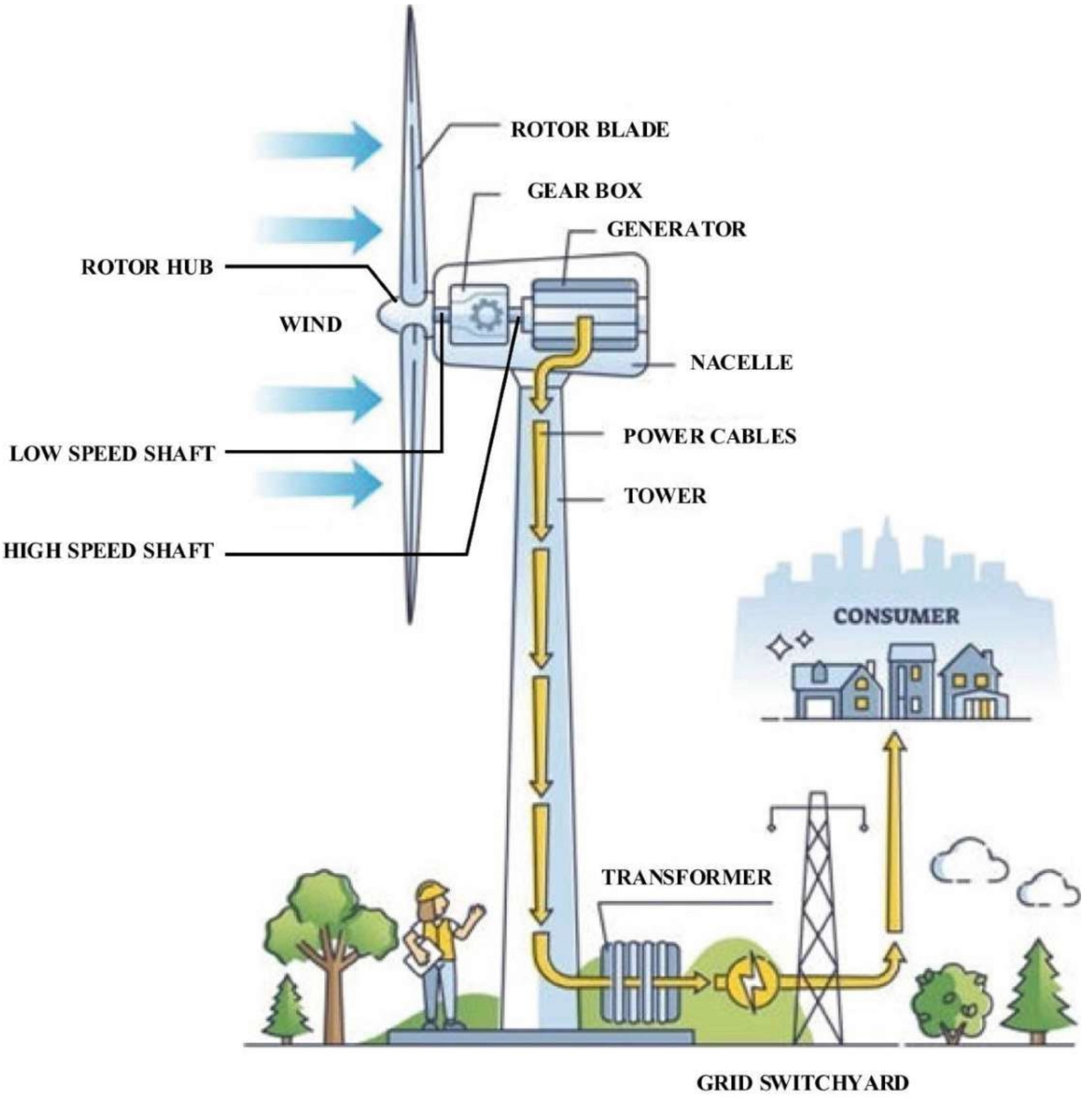

Figure 6 Wind energy - principle of operation (Mastoi, M.S., Zhuang, S., Haris, M 2023)

2.3.3. Bioenergy

Bioenergy is produced from organic matter—biomass. Biomass is the oldest form of energy because humanity has been heating itself using wood since the discovery of fire. The energy possessed by biomass comes from the sun since all organic substances have stored energy from the sun. The process behind it is called photosynthesis—it is a process through which plants convert radiant energy from the sun into the form of glucose.

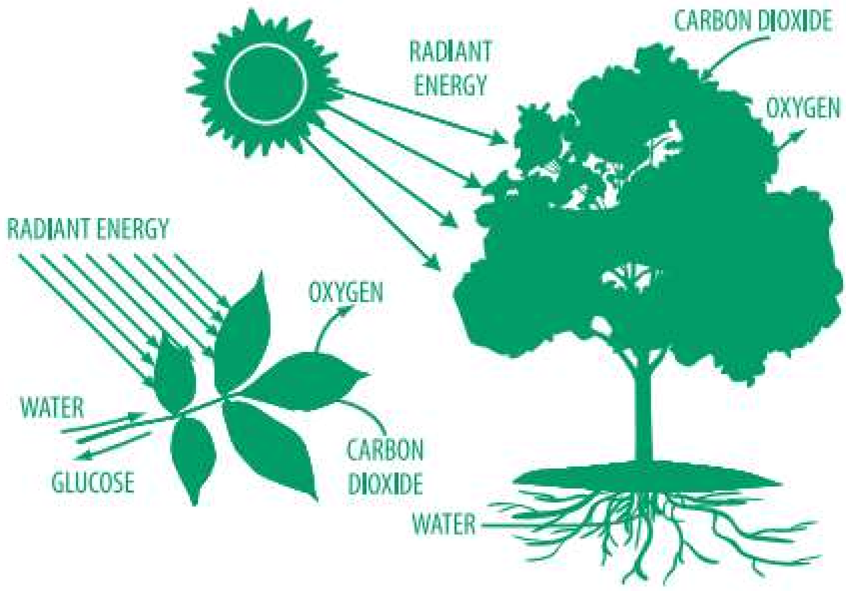

Figure 7 Process of Photosynthesis (NEED)

$$\text{water} + \text{carbon dioxide} + \text{sunlight} \rightarrow \text{glucose} + \text{oxygen} \qquad (1)$$

$$6\,H_2O + 6\,CO_2 + \text{radiant energy} \rightarrow C_6H_{12}O_6 + 6\,O_2 \qquad (2)$$

As the formulas show, sunlight gives plants energy to convert water and carbon dioxide into sugar and oxygen. Sugars produced by photosynthesis are called carbohydrates and provide energy to plants and animals that eat those plants.

Biomass is considered a renewable energy source because it is not limited in quantities; it is always possible to plant new trees and plants, and it will always exist.

When looking at the energy sources used to produce energy from biomass, there are four main types: (NEED)

• Wood and agricultural products;

• Solid waste;

• Landfill gas and biogas and

• Alcohol fuels.

2.3.3.1. *Wood and Agricultural Products*

The most widespread form of bioenergy is wood (logs, chips, bark, and sawdust) and agricultural products, which make up about 44% (NEED) of biomass energy. This includes all forms of organic matter since they all contain carbohydrates, an energy source.

Wood and wood waste are most often used to generate electricity in plants where wood waste is produced, and this process is called cogeneration.

2.3.3.2. *Solid Waste*

Burning waste can also be a source of energy; one ton of waste contains the same amount of thermal energy as 225 kg of coal. However, it should be noted that the waste is not entirely made of biomass; a large part of it also contains plastic.

2.3.3.3. *Landfill Gas and Biogas*

Landfills are places where aerobic[1] processes occur naturally during waste decomposition in the presence of fungi and bacteria. When the fungus comes to rotting waste, such as a rotting log, it feeds cellulose into sugar During this process, methane gas is released into the atmosphere. Methane must be collected as it is explosive and can cause fire. Landfills can collect the generated methane, purify it, and use it as fuel.

In addition, methane can be produced using agricultural waste and waste from food factories, restaurants, and households. Biogas power plants are used for this. They consist of an airtight tank inside which an anaerobic process takes place. During this process, biomethane is obtained, which can then be used for the production of electricity or sent to the gas grid.

2.3.3.4. *Alcohol Fuels*

Ethanol is an alcoholic fuel produced by the fermentation of sugar and starch found in plants. Ethanol can be made from any organic matter containing cellulose, starch, or sugar. The United States of America (USA) is the largest ethanol producer and there is ethanol produced primarily from corn. They also have an obligation to add ethanol to gasoline to reduce air pollution.

Biodiesel is obtained from vegetable oils, animal fats, or fats such as recycled grease from restaurants, but today, it is mainly produced from soybean oil. Biodiesel is added to petroleum diesel in specific proportions, from 2 to 20%. The great advantage of biodiesel over petroleum diesel is that it does not contain sulfur, which reduces sulfur emissions into the atmosphere. Although the sulfur in petroleum diesel is important for lubrication, biodiesel is an excellent lubricant by itself and can help reduce friction if only one to two percent is added to diesel fuel.

[1] Any biological or chemical process that requires or occurs in the presence of oxygen.

2.3.4. Geothermal Energy

Geothermal energy refers to heat stored inside the solid earth. This type of energy is reliable and constant since it is not dependent on weather conditions. It is necessary to drill deep sources in the ground to obtain geothermal energy. There, energy in the form of steam or hot water is present, which can be used to generate electricity, heat, or cooling on the surface of the earth.

The great advantage of geothermal energy is its constant availability; since it does not depend on the weather or feedstock, geothermal power plants can operate at maximum capacity, especially when other renewable energy sources are at a reduced capacity.

Geothermal energy comes deep from the Earth's core, whose temperature is approximately the same as on the sun's surface, about 6,000 °C. The heat of the earth's crust is transferred through all geothermal layers. The temperature in the mantle region is between 200 °C near the mantle-crust boundary and about 4,000 °C near the mantle-outer core boundary.

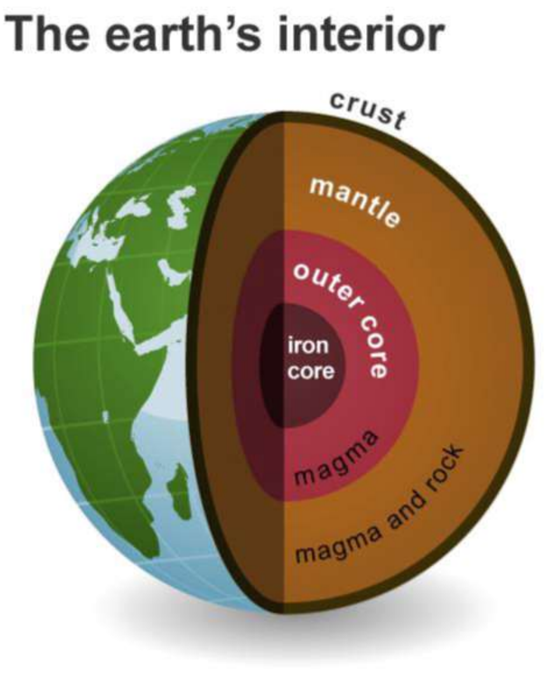

Figure 8 Geothermal layers of the Earth (EIA)

The geothermal power plant consists of a pump that brings hot water from underground through a well under high pressure. When the hot water reaches the Earth's surface, it turns into steam due to a pressure drop. The resulting steam spins a turbine connected to a generator that produces electricity. During the process inside the turbine, the steam cools and turns back into water through condensation. Finally, the cooled water is injected back into the ground to be reheated and used for a new process. (EPA)

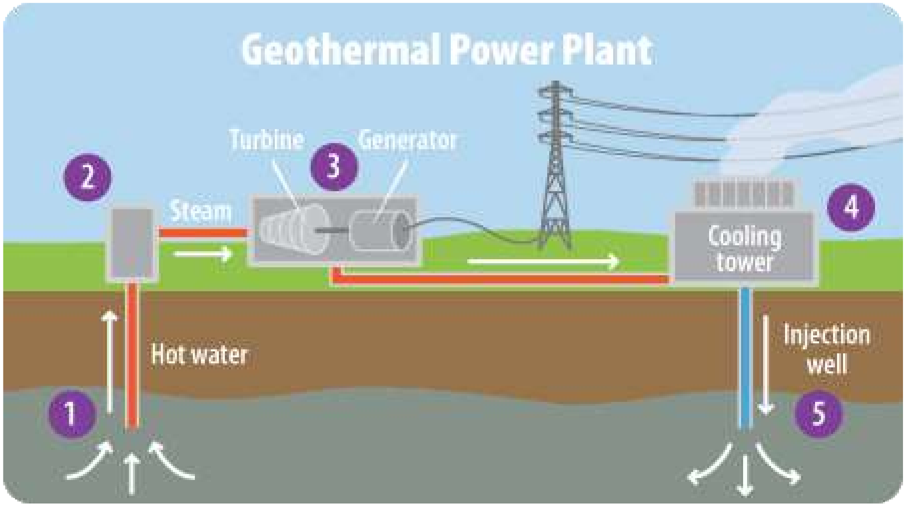

Figure 9 Geothermal Power Plant (EPA)

2.3.5. Hydropower

Hydropower is the energy produced by the flow of water that drives a turbine. It is one of the oldest renewable energy sources because water energy was used even in the pre-industrial era when there was no electricity. Water energy was also used in mills for grain processing.

There are several types of hydroelectric power plants, but they all work on the same principle of using the height difference. Hydropower plants are often built as impoundment facilities that use a dam on a flowing river to store river water in a reservoir. When the reservoir is full, water is released through turbines that rotate, activating a generator that produces electricity.

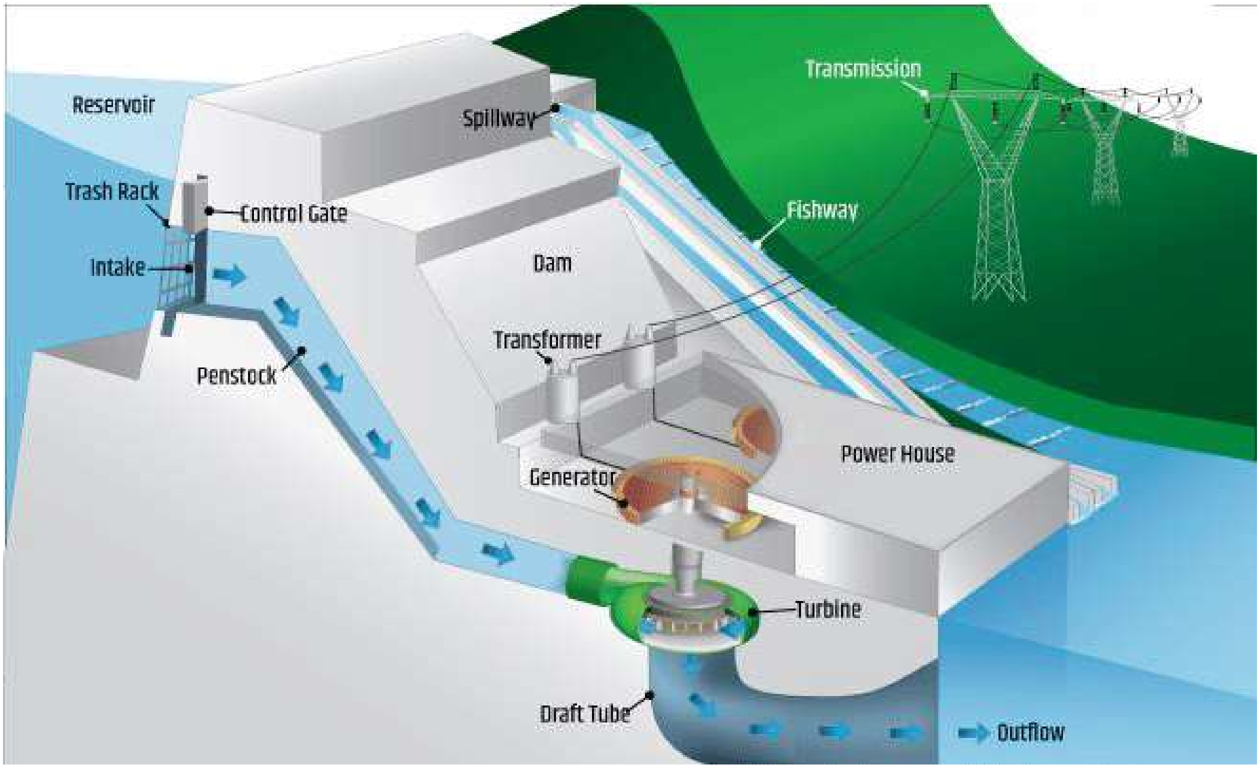

Figure 10 Impoundment Hydropower Plant (ENERGY.GOV)

Another type of hydropower plant is a derivation plant called "run-of-river." In this version, a channel is made on a part of the river through which a part of the river drains and/or a penstock to take advantage of the natural fall of the river bed. The penstock is a closed tube through which water flow is directed toward the turbines, and gates, valves, and turbines regulate it.

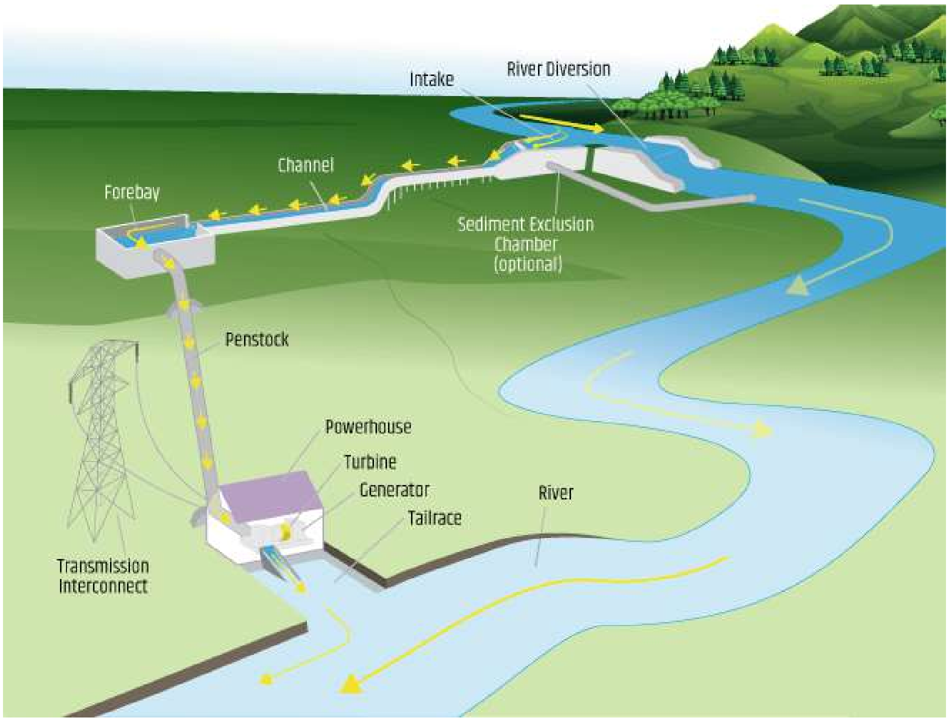

Figure 11 Diversion Hydropower Plant (ENERGY.GOV)

Pumped Storage is another type of hydropower that works on the principle of a large battery; it can store the generated energy. It is necessary to pump water from a low-altitude reservoir to a high-altitude reservoir in order to store energy. This process is mainly performed when the demand for electricity is reduced. Other renewable sources, such as PV panels, are used to pump water to a higher altitude. Water is released from the higher reservoir during high electricity demand and transferred to the lower one, thus driving the electricity turbines.

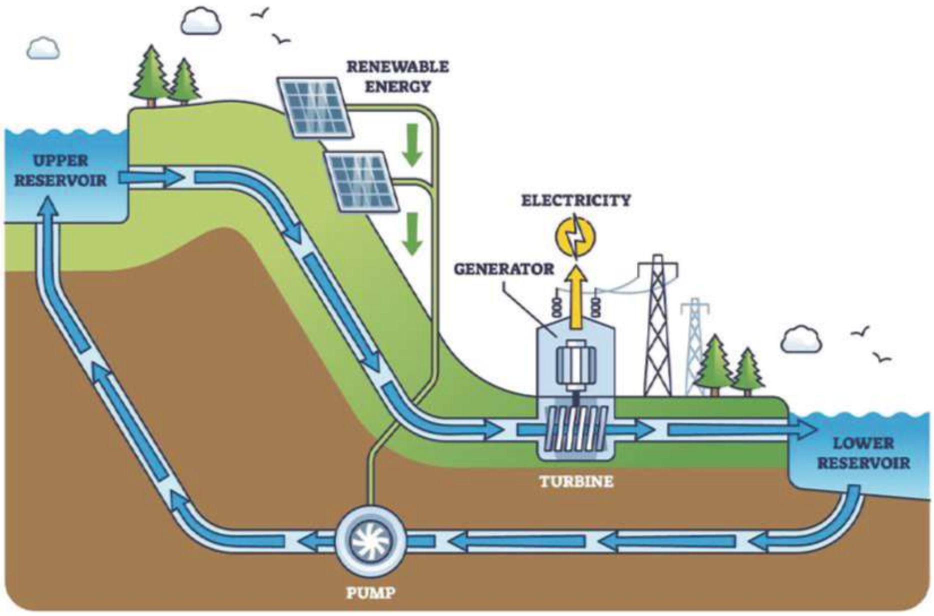

Figure 12 Pumped Storage Hydropower Plant (rtoinsider.com)

2.3.6. Ocean Energy

The ocean is not stagnant water; it moves constantly and changes its properties in terms of climate and conditions. Therefore, it also possesses enormous amounts of renewable energy. There are several sources of energy that the ocean possesses, and they are: (OES)

- Tidal and Currents – tidal has potential energy that can be collected by building a dam on the estuary and kinetic energy at sea that is collected by installing modular systems;
- Waves – modular technologies are used for harnessing the kinetic and potential energy of waves;
- Temperature Gradient – as it moves away from the ocean's surface, so does the temperature. Thermal energy can be used using various Ocean Thermal Energy Conversion (OTEC) processes;

- Salinity Gradient – at the mouth of the rivers, freshwater mixes with salt water, and during this, the salinity gradient changes, during which energy is released that can be harnessed using pressure-retarded reverse osmosis process and associated conversion technologies.

2.4. Prevalence of Renewable Energy Sources in the World

Renewable energy sources are currently gaining momentum, and according to forecasts, it is expected that from 2023 to 2028, more energy from renewable sources could be installed and used than in the last 100 years since the commercial use of renewable energy sources began, almost 3,700 GW, Figure 13.

By the end of 2024, wind and solar PV together should generate more electricity than hydropower, which is a significant change since hydropower was the first to be used for commercial purposes and, for a long time, was the only and largest renewable source that produces electricity.

The biggest growth is solar PV, whose installation price has fallen drastically in the last few years. The most responsible for this is China, which commissioned more in 2023 than the entire world in 2022.

According to predictions, by 2025, renewable sources should surpass coal and become the largest source of electricity generation. By 2028, renewable energy sources would account for over 42%

of the world's electricity generation, of which the share of PV, solar, and wind would amount to 25%.

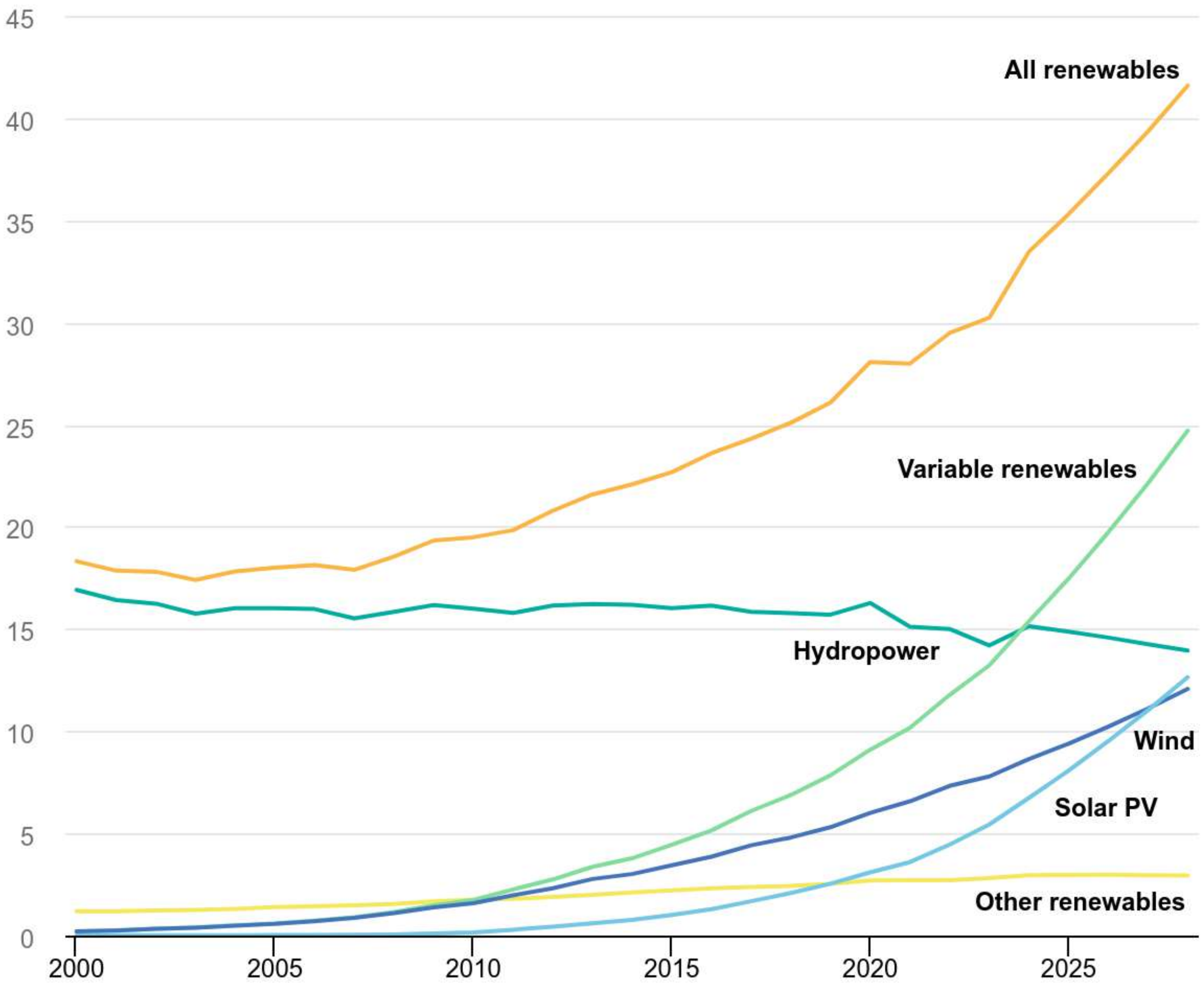

Figure 13 Share of renewable electricity generation by technology, 2000-2028 (IEA 2024)

Regarding heating, the situation regarding renewable sources is somewhat different, and the share 2of renewable sources compared to conventional sources has increased very little over the years. Bioenergy has the largest share of the heat consumption of renewable sources because it is distributed in the industrial sector. The most significant increase in the use of renewable heat has been in India in the last six years due to the increased production of sugarcane and ethanol, which use biomass residues. In addition, there has been a significant increase in the European Union due to the smarter use of municipal waste and biomass. Also, there has been an increase in the People's Republic of China since the electricity consumption for heat production has increased there in recent years, of which a large share is produced from renewable sources." (IEA 2024)

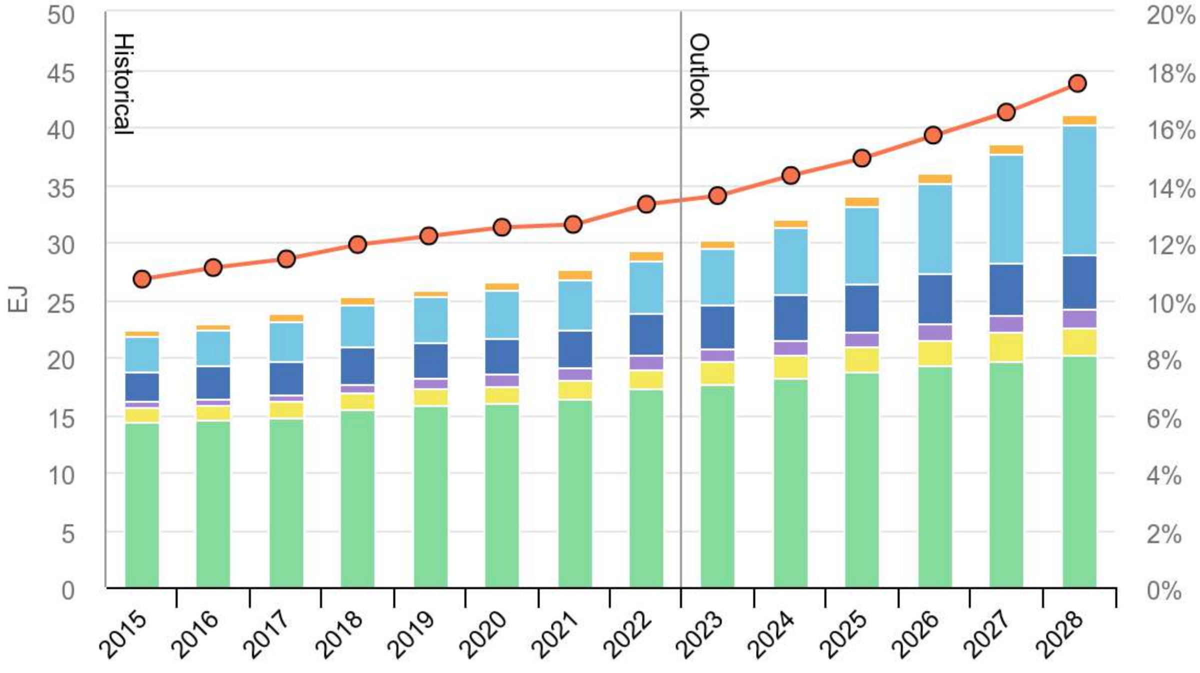

Figure 14 Global renewable heat consumption and share of renewables in total heat consumption, 2015-2028 (IEA 2024)

According to the graph, Figure 14, a slight increase in heat from renewable sources is expected during the outlook period, approximately 12 EJ from 2023 to 2028, which is double the increase compared to the period of the last six years.

3. Biogas as a Renewable Energy Source

Biogas is a colorless, combustible renewable energy source produced from the decomposition of organic matter. It is produced in anaerobic conditions and consists of methane, CO2, and small quantities of other gases.

3.1. Definition of Biogas Energy

The process of anaerobic digestion takes place with the help of various bacteria that break down organic substances and thus release a mixture of gases consisting of a mixture of methane (CH_4) and carbon dioxide (CO_2) - in different proportions - 45-85% methane and 25-50% carbon dioxide. Methane is a carrier of chemical energy that can then be converted into other forms of energy - electricity and heat.

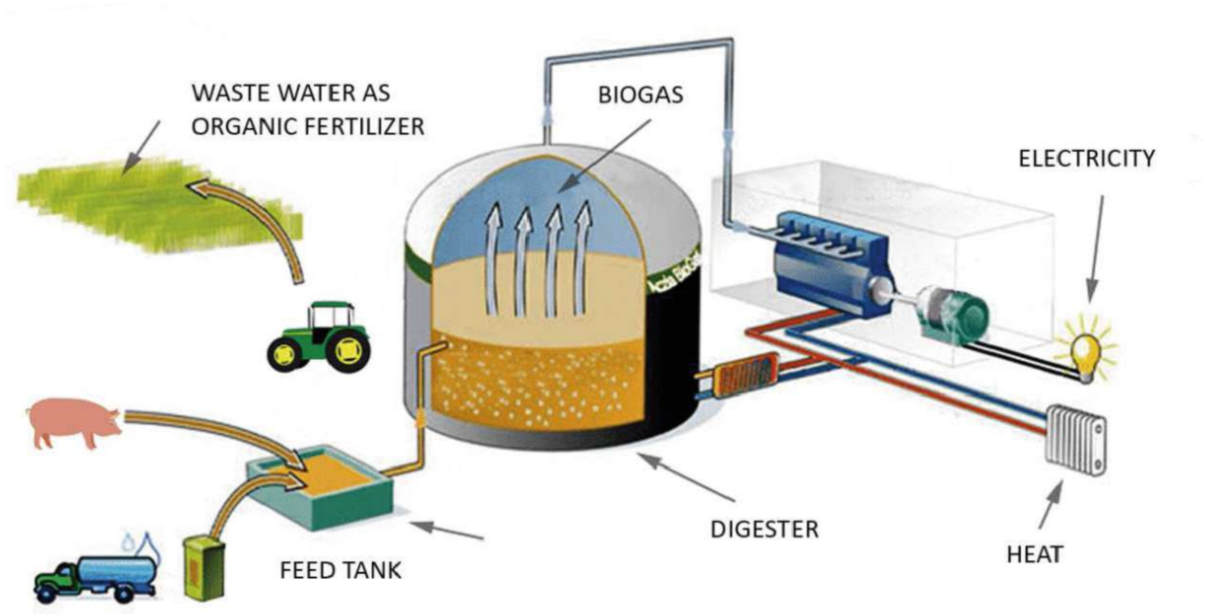

Figure 15 Biogas energy production (Soluciones Integrales De Combustion n.d.)

The biogas production process can be divided into five main stages: (Mohammed Khaleel Jameel, Mohammed Ahmed Mustafa, Hassan Safi Ahmed, Amira jassim Mohammed, Hameed Ghazy, Maha Noori Shakir, Amran Mezher Lawas, Saad khudhur Mohammed, Ameer Hassan Idan, Zaid H. Mahmoud, Hamidreza Sayadi, Ehsan Kianfar 2024)

- Zero phase – this phase includes the preparation of organic matter; after they have been cleaned of impurities, they are mixed with water and poured into the digester;

- First phase – during the first phase, anaerobic bacteria use enzymes to break down large molecules such as proteins, carbohydrates, fats, and cellulose into compounds with smaller molecular structures;
- Second phase – during this phase, branch compounds are processed into volatile acids with the presence of acid-forming bacteria. Proteins are first separated into amino acids and then into volatile acids; carbohydrates are first separated into simple sugars, then into fatty acids, which eventually change into volatile fatty acids;
- Third phase – during this phase, methanogenic bacteria decompose acids formed in the previous phase into methane and carbon dioxide. For the proper functioning of the digester and the processes within it, a proper ratio of methanogenic and anaerobic bacteria is required;
- Fourth phase – this phase can also be called the methane phase because methanogenic bacteria produce methane, carbon dioxide, and alkaline water.

3.2. Basic Properties of Biogas

The composition of biogas changes during the production process due to the action of bacteria.

Table 1 Process of converting biomass into biogas (Arvizu, D., P. Balaya, L. Cabeza, T. Hollands, A. Jäger-Waldau, M. Kondo, C. Konseibo, V. Meleshko, W. Stein, Y. Tamaura, H. Xu, R. Zilles 2011)

Zero phase (Input)	First phase (Hydrolysis)	Second phase (Acidification)	Third phase (Acidification)	Fourth phase (Methanogenesis)
Carbohydrates	sugars	Carbonic acid	Acetic acid	methane
Carbohydrates	sugars	Carbonic acid	Acetic acid	methane
fats	Fatty acids	Alcohols	hydrogen	Carbon dioxide
proteins	Amino acids	Carbon dioxide	Carbon dioxide	Carbon dioxide

As stated earlier, the two main components of biogas are methane and carbon dioxide. Other components, such as hydrogen (H2) and Hydrogen Sulfide (H2S), can be found in addition to them, and they are considered impurities. Such biogas composition is good enough for use in cooking and heating, but if quality needs to be improved, it is necessary to remove CO_2 and other impurities, especially H_2S. Such purified biogas consisting of 100% methane can be used in cars as fuel for internal combustion engines.

Table 2 The main properties of biogas and its components (Vilniškis, R. & Baltrenas, Pranas & Saulius, Vasarevicius & Baltrėnaitė-Gedienė, Edita 2011)

Property	Components				Biogas (60% CH_4+40%CO_2)
	CH_4	CO_2	H_2	H_2S	
Theoretical content	55-70	30-45	<1	<3	100
Calorific value [MJ/m^3]	37.7	-	10.8	22.8	22.6
Flash point [°C]	650-750	-	530-590	290-487	650-750
Lower explosion limits [%]	5-15	-	4-74	4-42	6-12
Density [kg/m^3]	0.72	1.98	0.09	1.54	1.2
Critical temperature [°C]	-82.5	31.0	-	100	-82.5
Critical pressure [MPa]	4.6	7.3	1.3	8.9	7.3-8.9

The composition and properties of biogas depend on the organic matter used in the fermentation process, as well as the temperature, duration of preservation, and load on the bioreactor.

"The calorific value of biogas varies from 5000 to 7000 kcal/m^3 and depends on the concentration of CH_4 in it. For comparison, one cubic meter of biogas is equal to 0.7 m3 of natural gas, 0.7 kg of fuel oil, 0.6 kg of kerosene, 0.4 kg of petrol, 3.5 kg of wood, 12 kg of manure briquettes, 4 kWh of electrical energy, 0.5 kg of carbon and 0.43 kg of butane." (Vilniškis, R. & Baltrenas, Pranas & Saulius, Vasarevicius & Baltrėnaitė-Gedienė, Edita 2011)

4. Biogas plants

It is necessary to correctly choose the type of biogas power plant and the energy sources used in the digester in order to obtain maximum utilization. These parameters correspond to the climate in which the power plant is built. For example, it is not appropriate to use household waste if the power plant is located hundreds of kilometers away from large settlements. The entire CO_2 footprint should always be considered, from raw material collection to energy distribution.

4.1. Types of Biogas Power Plants

Currently, there are three types of biogas plants that are most widespread in the world, the largest of which are in the United States of America, the United Kingdom, Germany, the Indian Subcontinent, and China.

The three most common types of biogas plants are: (Saleh 2015)

- Floating Gas Holder,
- Fixed Dome,
- Fixed Dome With Expansion Chamber.

The Floating Gas Holder consists of a digester made of brick and built underground. The inlet and outlet pipes pass through the digester, while on top, there is a floating steel gas holder inside which biogas is collected. The partition wall maintains the circulation of organic substances inside the digester. The gasholder is separated from the digester and moves up and down using the central guide pipe, depending on the generated and collected biogas. The floating steel gas holder maintains constant pressure. When the pressure in the digester increases due to increased production, the gas holder rises and releases the produced biogas through the supply pipe. When biogas production drops, the gas tank goes down. The significant disadvantage of this type of plant is the price since the floating gas holder is made of mild steel and the gas holder alone accounts for about 40% of the total cost of the power plant.

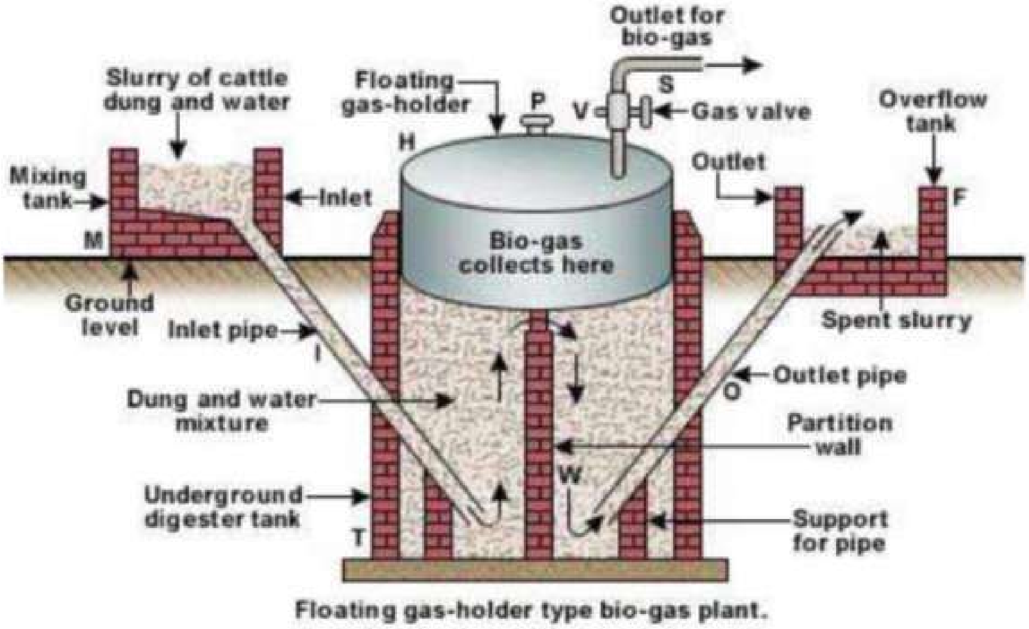

Figure 16 Floating Gas Holder (Saleh 2015)

In the Fixed Dome version, the gas holder and the digester are located together, the biogas rises naturally into the upper part of the digester, which acts as a gas holder. As the slurry level moves inside the digester, the necessary pressure is provided to release the gas. The pressure inside the digester depends on the amount of gas and slurry. This type of biogas plant is usually built below ground level and is common in areas with a cold climate. The costs of building a Fixed Dome plant are much lower considering that it can be made from simple and readily available materials and does not exclude any steel parts.

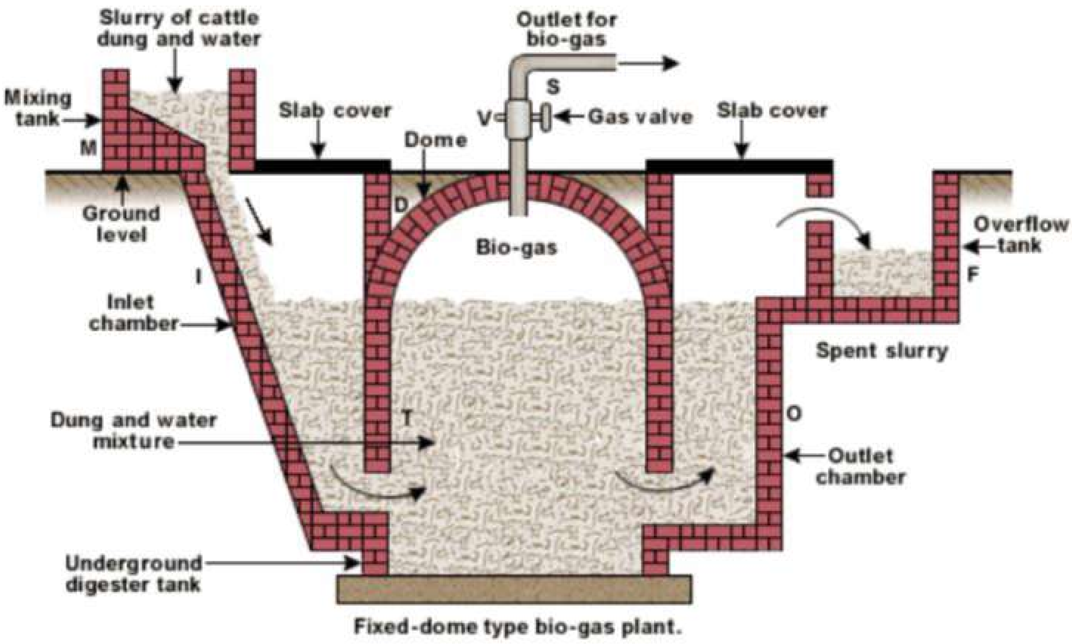

Figure 17 Fixed Dome (Saleh 2015)

The Fixed Dome with Expansion Chamber has a joint curved bottom and hemispherical top. Organic matter comes from the mixing tank to the digester through the inlet pipe. After the digestion process, the squeezed slurry goes into the displacement tank to free up space inside the digester for new organic matter coming through the entrance. This version of biogas plants is the cheapest and most common.

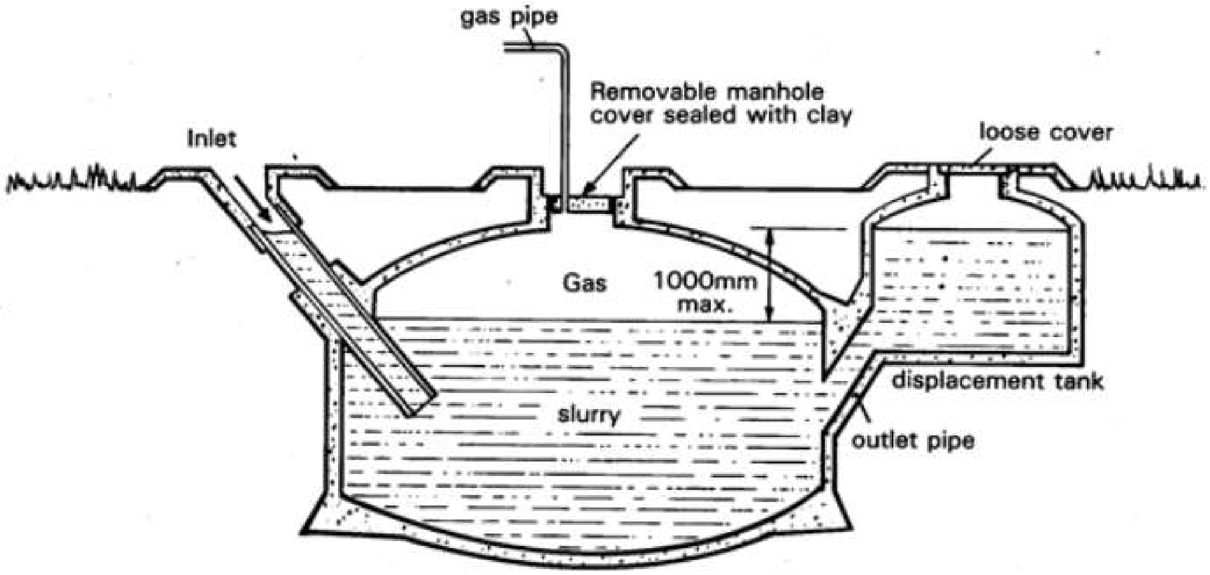

Figure 18 Fixed Dome with Expansion Chamber (Saleh 2015)

4.2. Biogas Resources

Although the process of anaerobic digestion was initially related to animal manure and slurries, over the years, branch waste from industry and municipal waste began to be used for biogas production, the result is an increase in ecological awareness but also an increase in the amount of organic waste since the population only grew. Thus, the amount of produced waste also increased. During the 1990s, cultivated crops such as maize, grasses, potatoes, and sunflowers were used to produce biogas. However, even today, this is a somewhat debatable topic from an ethical point of view because unused food is used to produce biogas. At the same time, there are large amounts of waste that are neglected and many people on earth starving.

The potential for biogas production exists worldwide because the feedstock is widespread and available. It does not depend on natural factors like crude oil or natural gas, is constantly present - in households, agriculture, and industry.

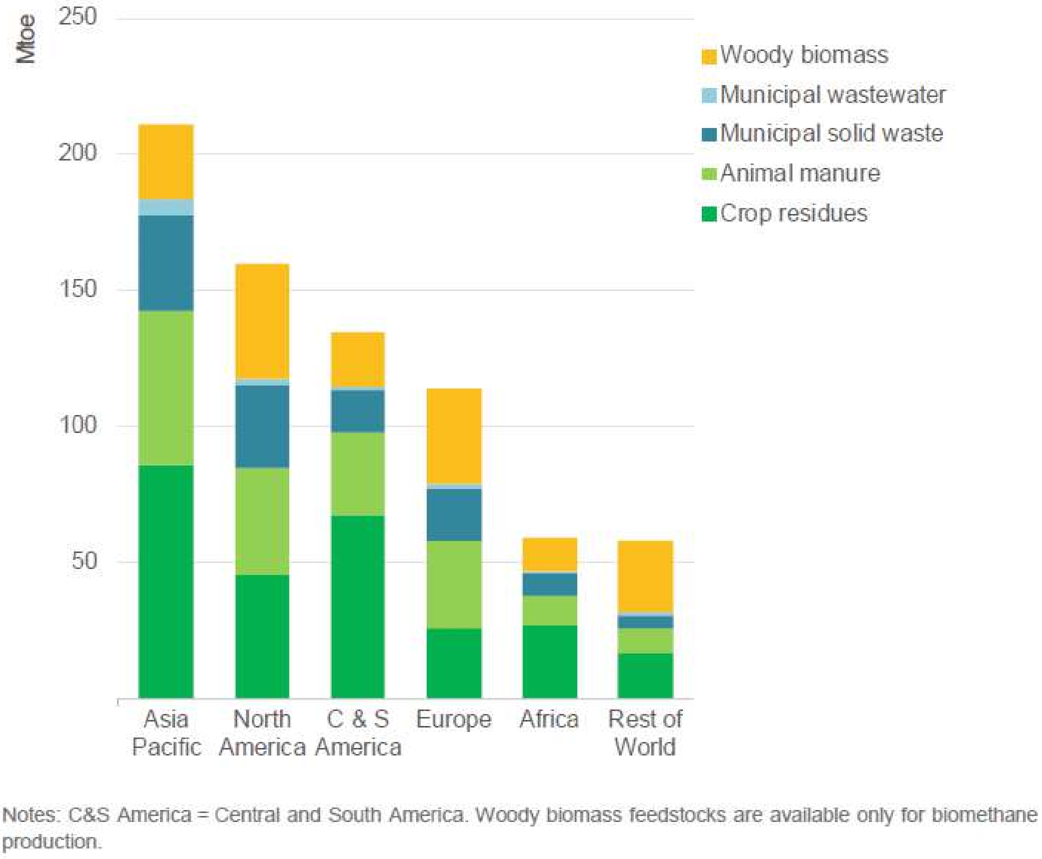

Figure 19 Production potential for biogas or biomethane by feedstock source, 2018 (IAE 2020)

In general, biomass resources can be divided into several categories depending on different criteria: (Teodorita Al Seadi Biosantech, Dominik Rutz, Rainer Janssen, Bernhard Drosg 2013)

- According to the taxonomic rank of their origin – vegetal or animal;
- According to the sector generating them – agricultural, industrial, and municipal.

Table 3 Characteristics of the most common biogas feedstocks (Teodorita Al Seadi Biosantech, Dominik Rutz, Rainer Janssen, Bernhard Drosg 2013)

Type of feedstock	Organic content	C:N ratio	DM[a] (%)	VS[b] % of DM	VS (%)	Methane yield (m^3 CH_4/ kg VS)	Methane production (m^3 CH_4/m^3)
Animal wastes and by-products							
Pig slurry	Carbohydrates, proteins, lipids	7	5	80.0	4.0	0.30	12.0
Pig manure, solid	Carbohydrates, proteins, lipids		20	80.0	16.0	0.30	48.0
Cattle slurry	Carbohydrates, proteins, lipids	13	8	80.0	6.4	0.20	12.8
Cattle manure, solid	Carbohydrates, proteins, lipids		20	80.0	16.0	0.2	32.0
Poultry droppings	Carbohydrates, proteins, lipids	7	5	80.0	4.0	0.30	12.6
Poultry manure, solid	Carbohydrates, proteins, lipids		20	80.0	16.0	0.30	48.0
Stomach/intestine content, cattle	Carbohydrates, proteins, lipids	4	12	80	9.6	0.40	38.4
Stomach/intestinal content, pig	Carbohydrates, proteins, lipids	4	12	80	9.6	0.46	44.2
Plant wastes and by-products							
Straw	Carbohydrates, lipids	90	70–90	80–90		0.15–0.35	
Garden wastes	Carbohydrates, lipids	125	60–70	90		0.20–0.50	
Grass	Carbohydrates, lipids	18	20–25	90		0.30–55	
Fruit wastes	Carbohydrates, lipids	35	15–20	75		0.25–0.50	
Organic wastes from industries							
Whey	75–80% lactose, 20–25% protein	—	5	90	4.5	0.33	15.0
Concentrated whey	75–80% lactose, 20–25% protein	—	10	90	9.0	0.54	31.5
Flotation sludge	65–70% proteins, 30–35% lipids	—	5	80	4.0	0.54	21.6
Fermentation slop	Carbohydrates	7	1–5	90		0.35–0.78	
Whole silage (grain)			12.6	91	11.5	0.47	53.9
Thin silage (grain)			8.5	86	7.3	0.50	36.5
*Fish oil	30–50% lipids	—	90	90	81.0	0.80	648.0
*Soya oil/ margarine	90% vegetable oil	—	95	90	85.5	0.80	684.0
*Alcohol	40% alcohol	—	40	95	38.0	0.40	152.0
*Bleach clay			98	40	39.2	0.8	313.6
Olive pulp		—	24	96	23	0.18	41.4
Brewers spent grains		—	20	90	18	0.33	59.4
*Glycerine							
Energy crops							
Grass silage		17	15–40	90		<0.45	
Maize silage							
Fodder beet silage							
Sewage sludge							
Waste water sludge			5	75	3.75	0.4	15.0
Conc. wastewater sludge			10	75	7.5	0.4	30.0
Food remains			10	80		0.5–0.60	

[a] Dry matter.
[b] Volatile solids.

4.2.1. Agricultural biogas feedstocks

Agricultural feedstock is the most commonly used substrate for biogas production. Most often, these are various residues and by-products in agricultural industries, such as animal manures and slurries from farms. A significant advantage of using animal manure for biogas production is the reduction of greenhouse gas emissions since the agricultural sector is responsible for as much as 18% of global greenhouse gas emissions. (InfoResources 2007). Many of these emissions fall on animal manure and slurries, which are no longer allowed to be freely scattered on the ground. However, most countries have and implement a policy for managing manure and slurries. Although the word manure is used collectively, it covers different types of manure with different characteristics.

Unfortunately, manure and slurry are not the best choices for biogas production because they have a low proportion of dry matter and, therefore, a low methane yield. Also, the transport of manure and slurry is expensive. Although manure has great potential, it must be mixed with additional substrates with a high methane yield.

Also, other residues from the processing of nutrients are used, such as straw, grasses, fruits, and whole plants, but in recent years, some crops have grown intending to produce biogas from them, such as maize, sunflowers, beets, and others. Plant residues are most often used as a co-substrate with animal manure. However, their disadvantage is that they usually require pre-treatment, which can be a straightforward removal of particles. In contrast, some require a complex process by which lingo-cellulosic molecules are torn to ensure access to anaerobic microorganisms.

Although energy crops have a high energy potential and methane yield, Table 4, their cultivation opens up some other environmental and ethical questions. For the cultivation of energy crops to be successful, it is necessary to use large amounts of fertilizers and pesticides, which affects. Also, as already mentioned, from the ethical side, the question arises as to whether it is appropriate to grow food and use it for fuel production when large amounts of already existing food are thrown away and can be used for biogas production.

Table 4 Methane yields of some joint energy crops (Teodorita Al Seadi Biosantech, Dominik Rutz, Rainer Janssen, Bernhard Drosg 2013)

Energy crop	Methane yield (m^3/VS)
Maize (whole crop)	205–450
Grass	298–467
Clover grass	290–390
Hemp	355–409
Sunflower	154–400
Oilseed rape	240–340
Potatoes	275–400
Sugar beet	236–381
Fodder beet	420–500
Barley	353–658
Triticale	337–555
Alfalfa	340–500
Ryegrass	390–410
Nettle	120–420
Straw	242–324
Leaves	417–453

4.2.2. Industrial biogas feedstock

The industry has great potential for using biowaste as a feedstock for biogas power plants. These include the food and beverage industry, fish production and processing, milk production, slaughterhouses, sugar production, starch, and non-food industries such as pharmaceutical, biochemical, cosmetic, and pulp and paper. Industrial waste varies in methane potential and dry matter content. Hence, the efficiency and productivity of the power plant depend on it, but most of the above have in common that they are easily degradable and rich in lipids, sugars, and proteins, making them suitable for anaerobic digestion. As stated in the previous chapter, the feedstock type is most often used as co-substrate animal manure because it improves the stability of the process and positively affects the income of the power plant since the industry pays the power plant a fee to treat their waste.

It is possible to use animal by-products that are not intended for human consumption, but some pre-treatment steps must be taken to ensure health and hygiene. Within the European Union, there is a regulatory agency, the Animal By-products Regulation (ABPR), which has listed the necessary steps of pre-treatment in Table 5.

Table 5 Animal by-products suitable for use in biogas plants, according to ABPR (Teodorita Al Seadi Biosantech, Dominik Rutz, Rainer Janssen, Bernhard Drosg 2013)

Examples of animal by-products suitable for AD	Required pre-treatment according to ABPR	ABPR category
Manure and digestive tract content from slaughterhouse	No pre-treatment	Category 2 Category 2
Milk and colostrum	No pre-treatment	Category 2
Perished animals	Pressure sterilization	Category 2
Slaughtered animals, not intended for human consumption	Pressure sterilization	Category 3 Category 3
Meat-containing wastes from foodstuff industry	Pasteurization	Category 3
Slaughterhouse wastes from animals fit for human consumption	Pasteurization	
Catering waste, except for waste from international transport (flights, trains, etc.)	In accordance with national regulation	

With the development of the biofuel industry, the potential feedstock for biogas is also growing. During the production of biofuel, large amounts of branched by-products are produced, which are suitable for anaerobic digestion. The only disadvantage of by-products from biorefineries is contamination with physical impurities, pathogens, heavy metals, and biological impurities that can be a risk to the environment and health.

4.2.3. Municipal waste as biogas feedstock

People currently generate large amounts of waste since we live a fast life where everything is always available to us, and we often do not think about the consequences. Households often throw away food that can still be used for another purpose if used properly. Within the European Union, there are instructions and guidelines on how to implement biowaste management, which member states must adopt and implement. Within the Republic of Croatia, citizen education has been carried out for the past few years, and a law has been established that requires every household to separate waste into plastic, paper and bio waste. Bio waste separated in this way is suitable for use in a biogas power plant and has great potential for biogas production. Most often, bio waste is used as a co-digest in animal manure-based plants.

Before use, bio waste should be treated and sanitized in order to clean it of impurities and potential pathogens that can often be found in household bio waste.

In areas where there is good waste management, and bio waste is regularly separated and collected, the costs of transportation and collection are not so high. A big drawback in bio waste power plants is impurities and old bodies that can be found in waste such as glass, plastic, and metal. Different processes are then needed to remove impurities before digestion.

Sewage sludge, created after the aerobic process of wastewater treatment, is a very frequently used technology worldwide, given that it has a good methane yield. However, sewage sludge has a high proportion of impurities that are difficult to remove, so there is a risk that they may also be found in the by-product of anaerobic digestion, fertilizer. National laws mainly regulate the use of sewage sludge.

4.3. Characteristics of Biogas Resources

Knowing the characteristics of a certain type of feedstock is necessary to choose a suitable feedstock and obtain the maximum yield.

The characteristics to look out for when choosing are: (Vilniškis, R. & Baltrenas, Pranas & Saulius, Vasarevicius & Baltrėnaitė-Gedienė, Edita 2011)

- Sustainability and availability
- Sustainability means that it is necessary to have a good ratio of various factors that influence the processing of organic substances and the digestion process itself, such as methane potential, dry matter content, pH, C:N ratio, particle size, etc. Availability implies that the feedstock is near the plant, that it is easily accessible and that it is always available in sufficient quantities so that the power plant can operate continuously and without interruption.
- Digestibility
- The entire biogas production process depends on feedstock digestibility. Given that various sources can be used as feedstock in a biogas power plant, it is necessary to know their macro composition in order to know how long the process takes and whether pre-treatments are needed to speed up the digestion process itself. Thus, simple carbohydrates, volatile fatty acids, and alcohols are easily processed, and their decomposition in the digester takes several hours. This process can take up to several days with proteins, lipids, and hemicelluloses, while pure cellulose needs several weeks to decompose. Also, fats and oils have a high methane yield but require a longer retention time and a larger volume than simple carbohydrates.

- Impurities

  Often, various impurities can cause a disturbing effect during the digestion process, which can cause a decrease in the active volume, foaming of the mixture, separation of phases, but also machine failure. Most often, there is sand that comes together with animal manure, but pieces of metal can also be found. Tree and straw. For this reason, it is necessary to carefully choose the feedstock and assess the possibility of impurities and treat it accordingly.
- Inhibitors

  Inhibitors are substances that slow down or stop chemical processes and thus negatively affect anaerobic digestion. Inhibitors are characteristic for certain sources of feedstock, and it is necessary to take care of this when planning the process and pre-treatment."
- Feedstock as methane booster

  As can be seen in the Table 3 there are some feedstocks that have a personally high methane yield and thus have a positive effect on methane production. Such components are precisely dosed into the digester in order to increase the efficiency and productivity of the power plant. Fatty materials such as fish oil, soya bean oil and margarine and residues from the beverage and sugar industry are most often used. Newer concepts also use by-product from bio refineries that produce biodiesel, thus making full use of the cultures used.
- Feedstock influence on plant operation
- Previous research has proven that different feedstocks have a different impact on the entire biogas production process. Feedstock impacts anaerobic as well as the quality of the biogas itself. Also, there are different motives for using certain types of feedstock. Thus, animal manure and slurry are used to reduce harmful gas emissions and bio waste from households to improve the efficiency of waste management, etc.
- Feedstock description and declaration

  Each feedstock must be declared and labeled in order to monitor quality and traceability. When receiving feedstock to the power plant, it is necessary to have basic information - origin, chemical composition, methane potential, description, particle size, area where it is collected, availability, potential contamination. With the help of this data, feedstock quality control is carried out, which should be carried out regularly.

4.4. Energy Conversion Methods of Biogas

Biogas power plants have the potential to produce other forms of energy using energy conversion methods. Depending on the size of the power plant and economic profitability, there are several ways to convert energy. Primarily, biogas can be used in its original form and, as such, is injected into the gas grid, reaching households where it is used for cooking and heating. The most common form of conversion of biogas energy into electricity is through internal combustion engines and Stirling engines when it comes to small-scale power plants and gas turbines for large-scale plants. Other forms of biogas energy conversion are not used so often, but they are believed to have a significant impact in the future. An overview of available biogas energy conversion methods follows below. (Moses Jeremiah Barasa Kabeyi, Oludolapo Akanni Olanrewaju 2022)

4.4.1. Electricity generation

Biogas can be used directly to generate electricity through the process of internal or external combustion in different engines.

The Generator can be used for the production of electricity, where the main fuel is the biogas that drives the prime movers. These are primarily synchronous machines, especially when it comes to the production of electricity that is fed into the network because they have the possibility of frequency control.

The Stirling Engine is an external combustion engine used in the Stirling process, a closed circular process in which the working fluid circulates between two heat reservoirs of different temperatures. The process involves two isothermal[2] expansion/compression and two isochoric[3] heat exchange reactions. (ScienceDirect 2018)

This process is mainly intended for producing electricity for smaller plants. Its efficiency is between 13% and 25%, but if it is used for cogeneration and regeneration, the total thermal efficiency goes up to 90%." (Moses Jeremiah Barasa Kabeyi, Oludolapo Akanni Olanrewaju 2022)

The Diesel Engine is an internal combustion engine in which ignition occurs due to increased temperature inside the cylinder during mechanical compression. When biogas is used inside a diesel engine, it is also necessary to use diesel, so it is performed as a dual fuel engine. The disadvantage of such a system is that it requires a large amount of expensive diesel fuel, which is a fossil fuel.

The Gasoline Engine is an internal combustion engine in which ignition occurs using a spark. Unlike diesel engines, they can only use biogas as fuel, but minor adjustments to the standard

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[2] A process during which the temperature is constant, and the pressure and/or volume change.

[3] A process during which the volume is constant, and the pressure and/or temperature change.

engine are required. The version that a small amount of gasoline is injected at the beginning of the process is often used to make the engine start faster and easier.

Gas turbines and microturbines are another way to use biogas to produce electricity. Gas turbines are often used for large power plants with a power of at least 3 MW to 5 MW. Their advantage is low maintenance cost and high efficiency. In the case of smaller power plants, it is possible to connect several microturbines in series with power from 25 kW to 350 kW. Microturbines are suitable for combined heat and power systems because their overall thermal efficiency is high and it reduces their overall environmental impact.

4.4.2. Biogas Cogeneration and Trigeneration

Cogeneration is the most efficient option for biogas energy because electrical and thermal energy are used simultaneously. Electric energy can be used only for the needs of the plant, or it can also be delivered to the network, while thermal energy can be delivered to the gas network. Cogeneration can be used with almost all of the previously mentioned engines and turbines, whose efficiency without cogeneration is between 25% and 45%, but through cogeneration, it rises to 90%. (Moses Jeremiah Barasa Kabeyi, Oludolapo Akanni Olanrewaju 2022)

With trigeneration, in addition to electricity and heating, cooling is also obtained. It improves the process's efficiency and environmental impact even more. The basic trigeneration system consists of a steam generator, a heat recovery system, an absorption heat pump, and a compression mechanical heat pump. In order to improve cooling, absorption refrigerators are used to generate cold heat. (Leonzio 2018) Such systems are mainly used by large consumers such as schools, hotels, hospitals, universities, and public buildings that need all three elements - electricity, heating, and cooling.

4.4.3. Biogas to Hydrogen

Biogas, or biomethane, can be converted into fuel cells, which are then used in hydrogen production. However, the production of hydrogen from biogas in combination with carbon dioxide capture and storage is currently more attractive and better for the environment.

4.4.4. Biogas in Transportation

Transport is still one of the biggest emitters of greenhouse gases; approximately 15% of all emissions go to transport. (EPA 2024) This is because the roads are still largely dominated by diesel and gasoline engines with high emissions.

“Biogas can be used in transport in the same way as regular gas, in the form of Bio-CNG (Compressed Natural Gas); it is only necessary to clean the obtained biogas of all impurities in order to obtain a composition that has >97% methane and <2% oxygen.” (Kari-Anne Lyng, Andreas Brekke 2019)

5. Case Study – CHP Biogas Plant near the City of Zagreb

Zagreb is the capital and largest city of the Republic of Croatia. It is located in the continental part of the country and is protected from the north by the Medvednica mountain. Zagreb is in a relatively good position regarding renewable energy sources, especially solar PV and biogas production. Although the number of sunny hours is significantly less than, for example, on the coast and islands, it is still large enough to use the potential of solar energy to produce electricity.

When it comes to biogas, Zagreb is suitable because it is located in the center of a small country. In the city's vicinity are large food and beverage plants, logistics centers, restaurants, meat processing industries, and farms. Also, the city of Zagreb is heated according to the principle of district heating, for which biogas can be used.

There is no significant biogas production in Croatia, including in Zagreb. According to the research, around 0.23 bcm of biogas is expected to be produced by 2030. (European Commission 2021)

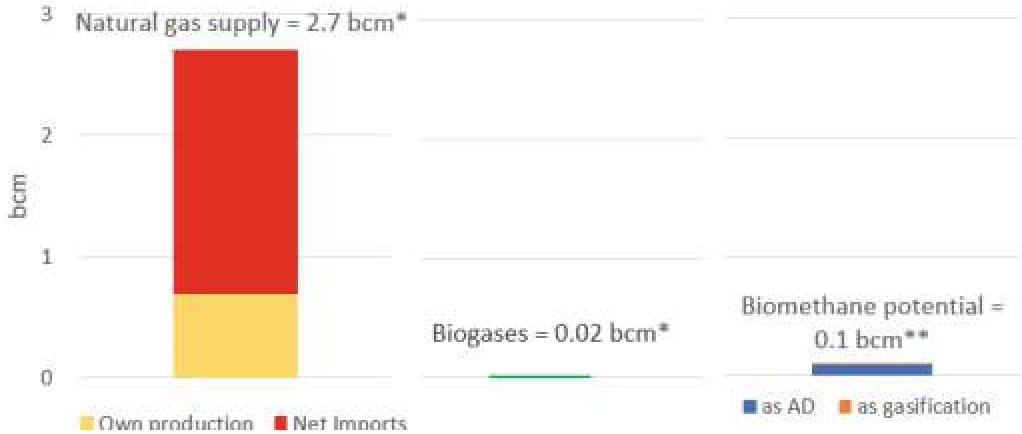

Figure 20 Comparison of current natural gas supply, biomethane production, and potential in Croatia (European Commission 2021)

5.1. Energy Consumption in the City of Zagreb

As previously stated, the City of Zagreb is the largest in the Republic of Croatia and, therefore, has the highest energy consumption. According to the data of the city council for 2022, it was consumed in Zagreb: (Zagreb.hr)

- 2,696 GWh of electrical energy
- 3,247 GWh of gas
- 48,473 km^3 of water

Currently, electricity is used mainly from non-renewable sources in the city, as in the rest of Croatia. Regarding renewable energy sources, Croatia has the most significant production from hydroelectric power plants, followed by wind power plants and solar PV. Like everywhere else in the world, Croatia is currently experiencing the highest growth in installed solar photovoltaic power plants.

The City of Zagreb plans to carry out the energy renovation of 50 public buildings by 2030, including installing photovoltaic power plants and charging stations for electric vehicles. The result should be more than 14.9 GWh of renewable electricity, eliminating 8,700 tons of carbon dioxide equivalent and saving 29.8 GWh of energy annually. (European Investment Bank n.d.)

The vast majority of gas used in Zagreb is for district heating. Although Zagreb has a moderate continental climate, winters can be cold, requiring much gas consumption.

A scientific study mapped the demand for gas and the assessment of district heating using bottom-up[4] and top-down[5] mapping.

Figure 21 Top-down heat demand for Central Croatia

Figure 21 shows heat demand according to top-down mapping for central Croatia. The area with the highest heat demand is the city of Zagreb.

[4][4]"Bottom-up mapping method has very fine resolution and it is based on building features such as surface floor area, building height, building use and the share of the heated area." (Drilon Meha, Tomislav Novosel, Neven Duić 2020)

[5] "Top-down mapping mapping method relies on energy balances and population distribution densities." (Drilon Meha, Tomislav Novosel, Neven Duić 2020)

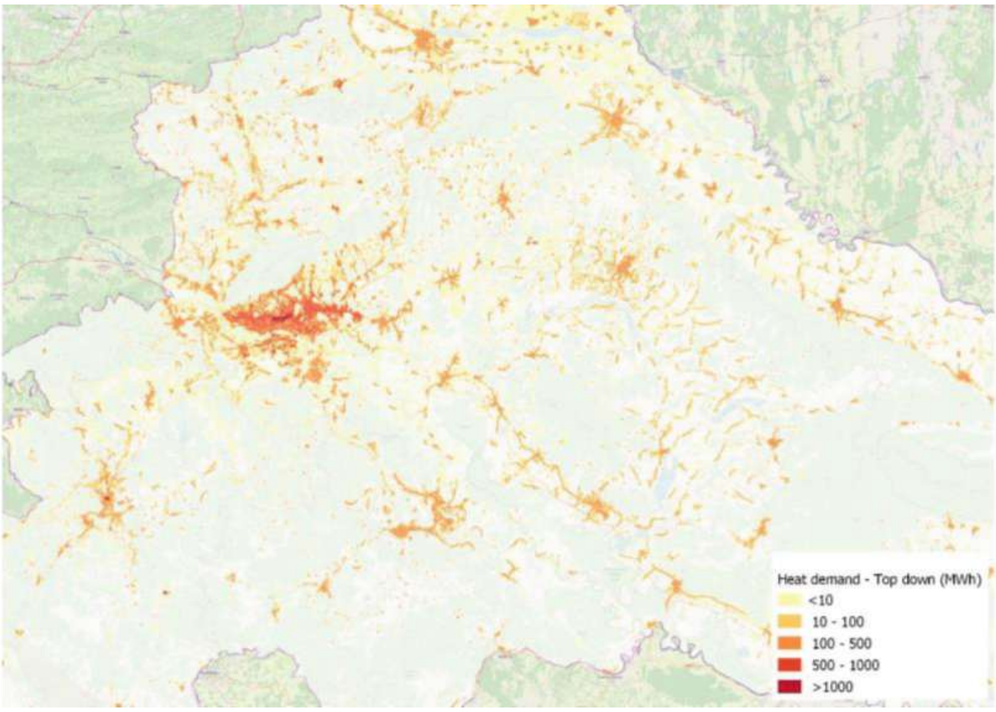

Figure 21 Top-down heat demand for Central Croatia (Novosel, T., Puškec T., Duić N., Domac J.)

Figure 22 shows the difference between bottom-up and top-down mapping in the example of the City of Zagreb. At first glance, the demand for heat looks very similar on both maps. It can be observed that the bottom-up has several smaller areas with higher demand densities. “This is because bottom-up uses an actual distribution of the built-up regions based on individual buildings, while top-down distribution uses a fixed resolution.” (Novosel, T., Puškec T., Duić N., Domac J.) Both maps show that the demand for heat mostly ranges from 100 to 1000 MWh, which means that the demand in the city of Zagreb is high and that there is room for increasing the capacity through the biogas plant.

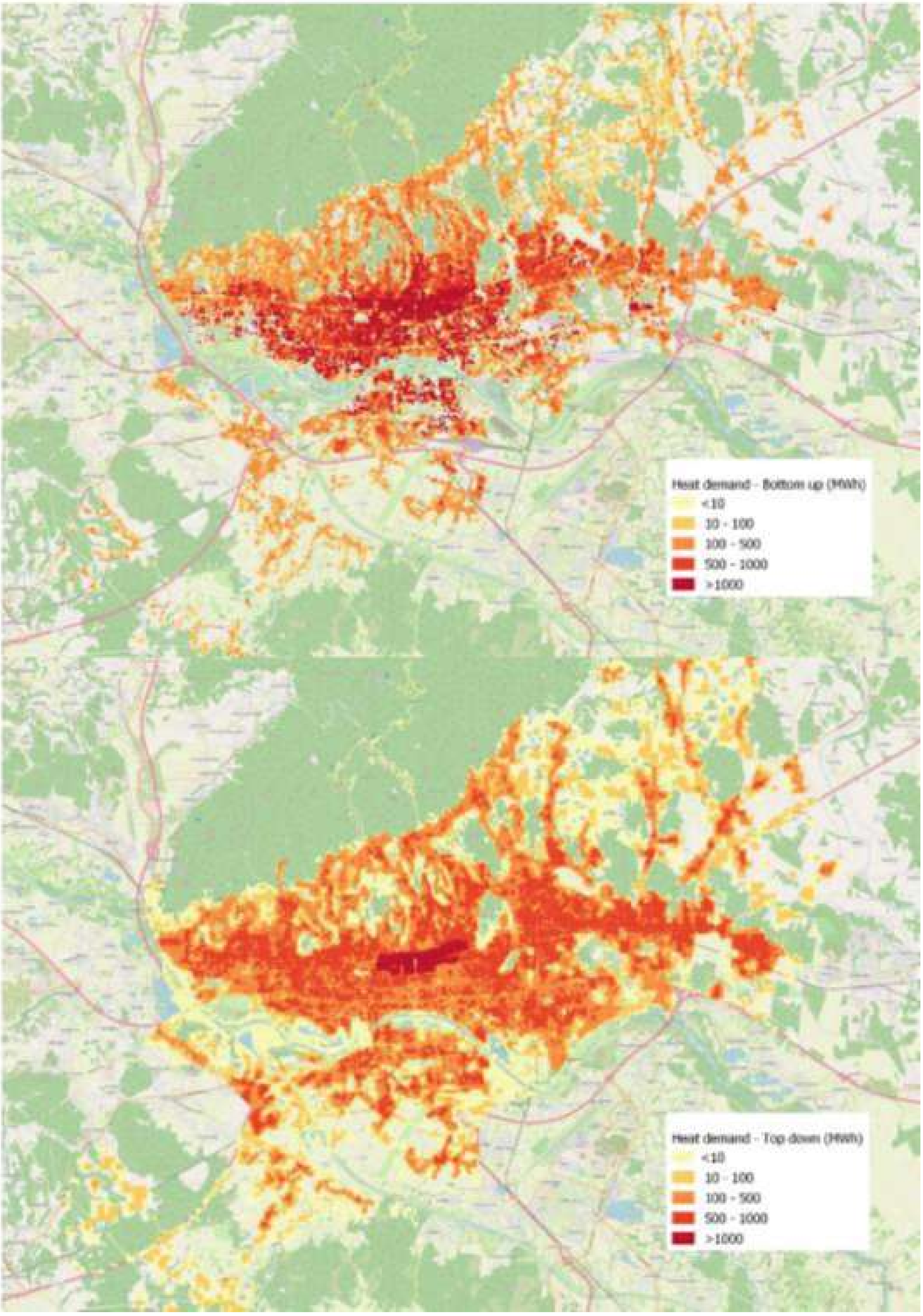

Figure 22 Difference between bottom-up (up) and top-down (down) heat demand for the City of Zagreb (Novosel, T., Puškec T., Duić N., Domac J.)

Also, graphs and curves of the heat demand distribution were made within the research, which can be used in this case to assess the power plant's capacity. "Figure 23 shows the heat demand for both mapping methods for each ha square depending on their location and magnitude. Although it is hard to see on the display, both folders have very similar peak demands.” (Novosel, T., Puškec T., Duić N., Domac J. n.d.)

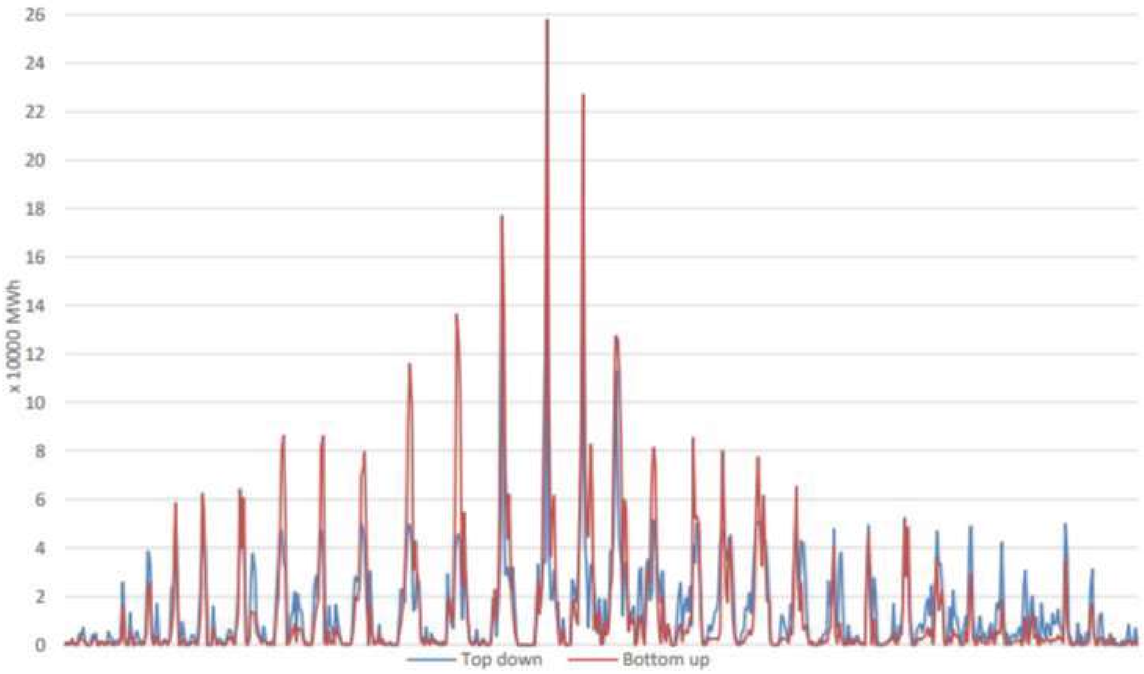

Figure 23 Distribution graph of top-down and bottom-up heat demand (Novosel, T., Puškec T., Duić N., Domac J.)

Figure 24 shows the load curve for both folders as a load duration curve. This graph shows that the peak demand for both mapping methods is very similar. (Novosel, T., Puškec T., Duić N., Domac J.)

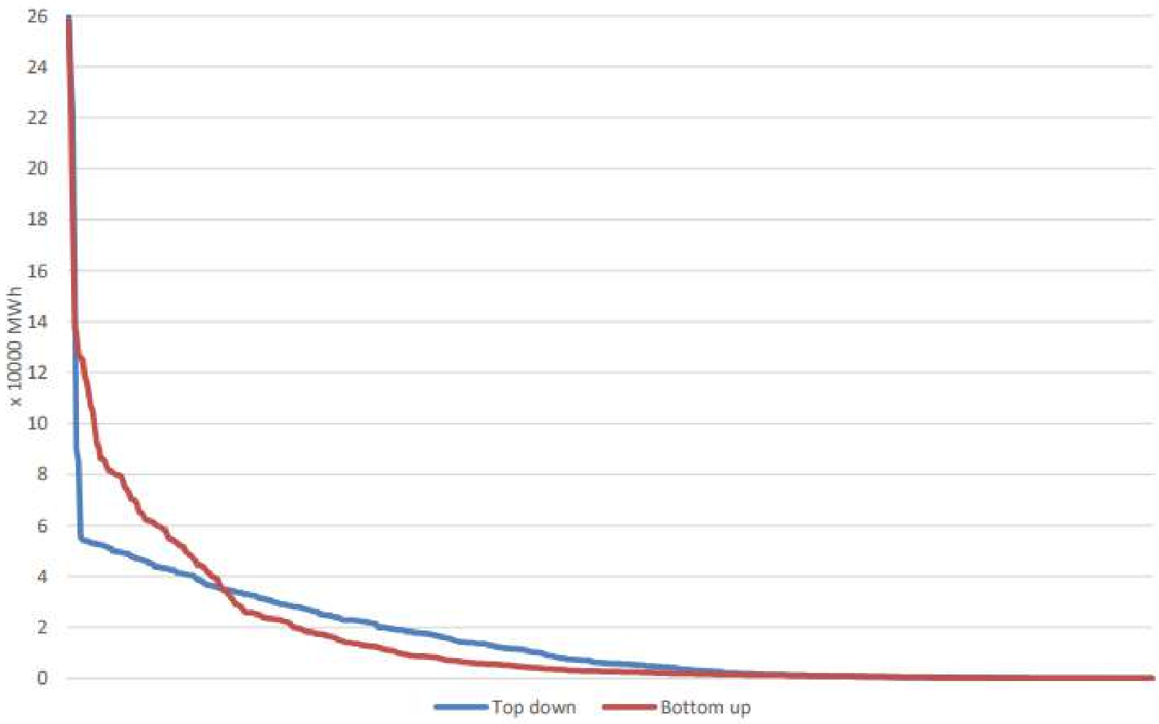

Figure 24 Distribution curve of top-down and bottom-up heat demand (Novosel, T., Puškec T., Duić N., Domac J.)

5.2. Market Research of Biomass Feedstock

Annually in Europe, around 131 kg of bio waste is generated per capita within the household. Of that, 70 kg is generated within the household, 9 kg during retail and other food distribution, and 11 kg during primary production. 12 kg in restaurants and food service and 28 kg during the production of food products and beverages. (Eurostat 2023)

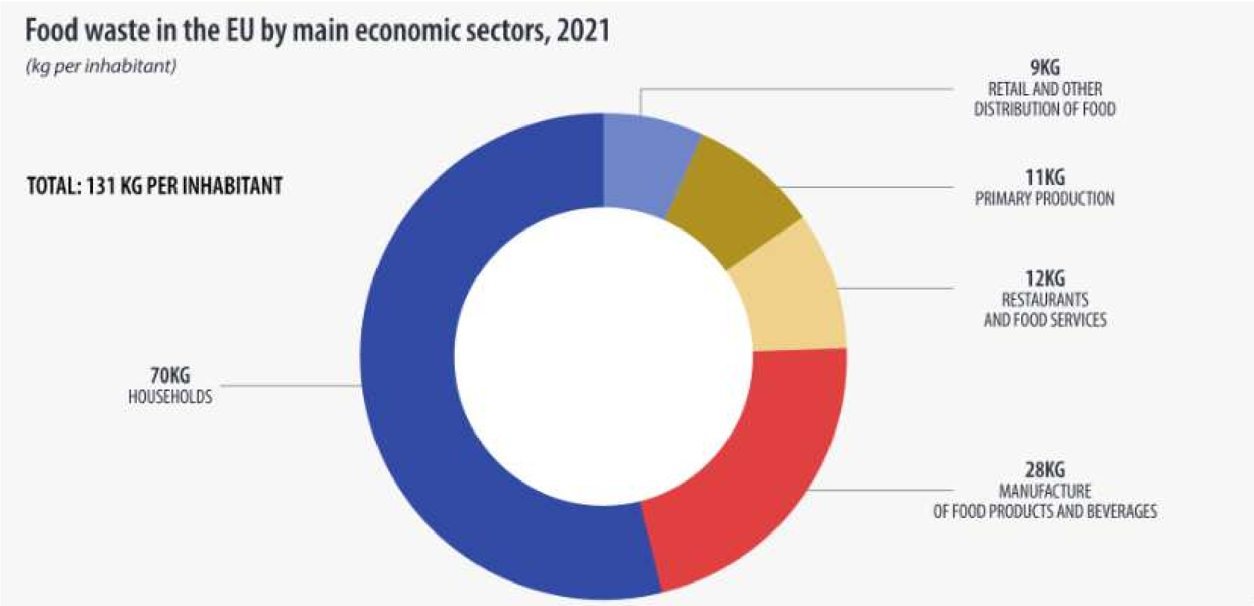

Figure 25 Food waste in EU per capita (europa.eu)

According to the latest population census, about 767,000 inhabitants of the City of Zagreb are legally obliged to separate bio waste. For calculation, it was assumed that approximately 500,000 citizens correctly separate waste, which is collected and brought to the power plant.

In the vicinity of the city of Zagreb, there are various food productions, such as the largest supplier of fruits and vegetables for Croatia, the largest factory of sweets and chocolates, and several meat productions. Also, there are several smaller active breweries in the city of Zagreb, and the surroundings of Zagreb are known for wine production, so these by-products are also taken into account for collection.

Since Zagreb is in the center of Croatia, in the vicinity of the city there are also the largest distribution and logistics centers for supermarkets that generate and throw away large amounts of food and bio waste every day.

Also, Zagreb is a tourist city and in the center alone there are about 50 restaurants that prepare large quantities of food every day. During the preparation and serving of food, bio waste is also generated which can be used for the production of bio gas.

All the above data are entered in an Excel table, Appendix A, which gives an estimate of the annual production of biogas and biomethane, taking into account the characteristics of biomass such as dry matter content, biogas yield, and methane flow. Mean values were used for the purposes of this paper.

		Default values			Actual values									
Waste category	Substrates	Dry matter	Biogas yield	Methane	Dry matter	Biogas yield	Methane	Amount of substrate/ waste	Cost of substrate	Revenue for waste	Total biogas yield	Total methane yield	Total costs	Total revenues
		[%]	[m^3/t FM]	[%]	[%]	[m^3/t FM]	[%]	[t FM/a]	[€/t FM]	[€/t FM]	[m^3/a]	[m^3/a]	[€/a]	[€/a]
Waste from the food industry	Mash from fruits	3-5	250 - 540	63	4	450	63	70	5	20	31.500	19.845	350	1.400
	Baking waste	60 - 80	400 - 500	62	70	450	62	40	5	10	18.000	11.160	200	400
	Vinasse from alcohol prod.	8-12	50	55	10	50	55	10	5	15	500	275	50	150
Vegetables, greens, grass	Mixed vegetable waste	5-20	300 - 400	62	12	350	62	35	5	15	12.250	7.595	175	525
Wastes from households and canteens	Mixed biowaste from households*	35 - 75	100 - 200	62	42	160	62	35.000	5	10	5.600.000	3.472.000	175.000	350.000
	Grass, green waste	25	180	56	25	180	56	10	5	20	1.800	1.008	50	200
	Food leftovers (kitchen)*	9-37	150 - 300	58	23	225	58	500	5	10	112.500	65.250	2.500	5.000
	Waste from food retail (supermarkets)*	9 - 90	200 - 400	55	50	300	55	100	5	15	30.000	16.500	500	1.500
	Frying oil and fat	50 - 70	600 – 750	62	60	650	62	15	5	40	9.750	6.045	75	600
	Meat and bone meal	8-27	750 – 1,100	-	16	930		40	5	15	37.200	0	200	600

Annual biogas production	5.853.500	[m^3/a]
Annual methane production	3.599.678	[m^3/a]
Annual substrate costs	179.100	[€/a]
Annual revenues from waste	360.375	[€/a]
Annual input of fresh mass	35.820	[t FM/a]

Figure 26 Assessment of the annual production of biogas and biomethane concerning the planned feedstock and its characteristics

5.3. Analysis of Construction Site for CHP Biogas Plant

When choosing a location for the construction of a biogas power plant, it is preferable to use a top-down method that can be divided into several steps, Figure 27: (Dr. Christian Epp, Dominik Rutz, Michael Köttner, Tobias Finsterwalder 2008)

Step 1: Selecting suitable regions and available substrates

Step 2: Defining suitable neighborhoods within the selected region

Step 3: Defining suitable sites within the selected neighborhoods

Step 4: Fulfilling soft requirements for selected sites

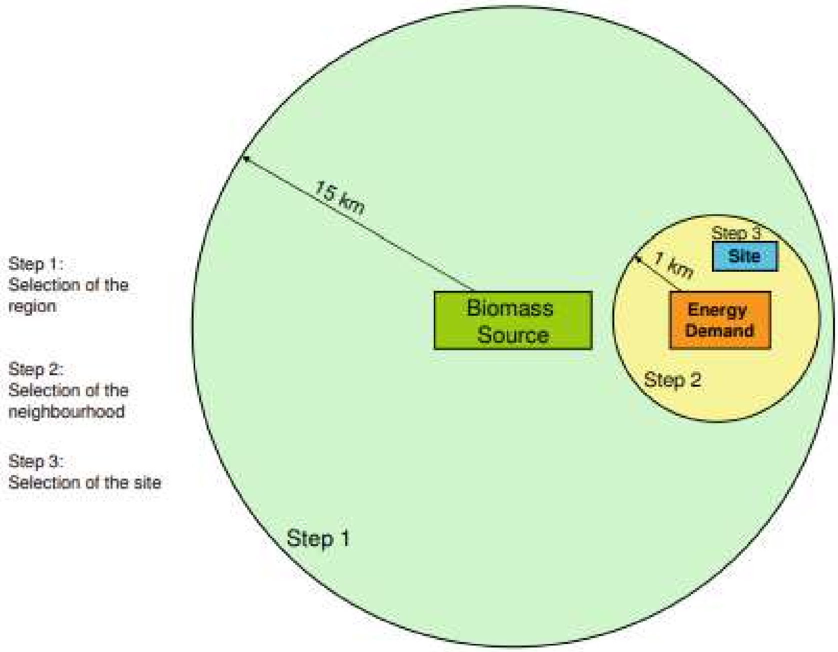

Figure 27 Top-down site selection methodology (Dr. Christian Epp, Dominik Rutz, Michael Köttner, Tobias Finsterwalder 2008)

5.3.1. Selecting suitable regions and available substrates

When choosing a location for constructing a biogas power plant, it is necessary to consider that the optimal maximum radius within which the feedstock is collected is about 15 km, as this is how the economic and energy efficiency of the project is met.

In this case study, the collection is planned at locations in the City of Zagreb and in the southeastern part of the area around the city of Zagreb, where the three largest logistics-distribution centers (LTC) are located; these two areas are approximately 30 km apart; figure. The primary feedstock is bio waste and waste from food industries in Zagreb, while two distribution logistics centers are at the farthest location. Therefore, for the location of the power plant, the area marked with a red cross in Figure 28 is proposed, from which most of the feedstock collection areas are within a radius of 10 km. The collection from distribution-logistics centers will still be carried out because it is mainly about goods with damaged packaging that are not spoiled. The collection will not take place every day, but the dynamics of the collection will be determined when a large enough amount is collected.

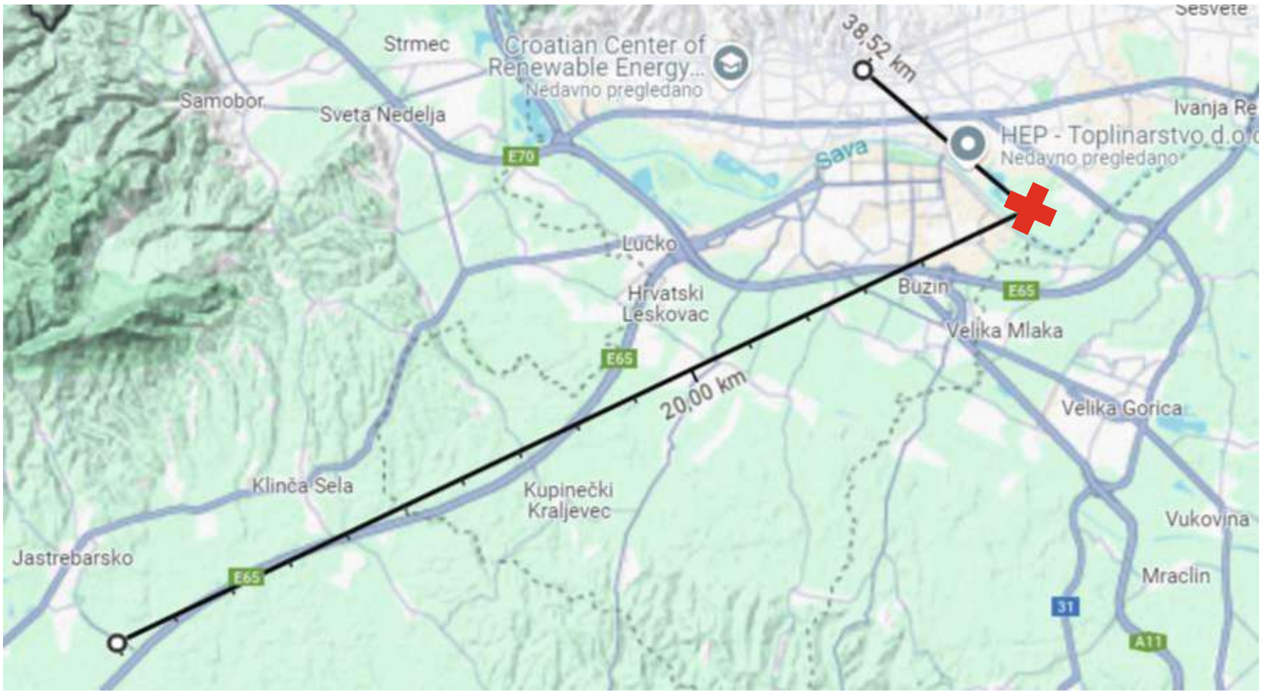

Figure 28 The distance between the two furthest feedstock collection locations (Google Maps)

5.3.2. Selecting the biogas neighborhood

During the construction of the power plant, it is necessary to ensure that the distance between the power plant and the utility infrastructure is as small as possible. It is recommended that this distance is up to 1 km. (Dr. Christian Epp, Dominik Rutz, Michael Köttner, Tobias Finsterwalder 2008)

When selling electricity, it is necessary to take care of the voltage. The electricity received in the generator or motor is mostly low voltage, and it needs to be transformed through a transformer into high voltage when it is fed into the network.

Regarding the sale of heat, it should be remembered that the power plant produces heat throughout the year, and most consumers only need heat in winter. Good customers for this type of energy are industrial and agricultural plants. The advantage of this location is the proximity of the district heat plant, pinned on the map in Figure 28Given that there is a district heat network nearby, it can distribute heat to users. In winter, heat is also needed to maintain the temperature of the fermenter, while in summer, the excess heat can be used for an additional business that would also bring income, such as drying logs.

The last option is to sell biomethane so that the obtained biogas is purified and thus injected into gas networks. It is later used in households and industry for heating, cooking, and transport fuel. Given that the systems for upgrading biogas have become economically acceptable and profitable, this option will also be considered to continue the work.

The selected location has access to the gas network and electricity at a distance of less than 500 m.

5.3.3. Selecting Biogas Site

A cadastral parcel must meet certain minimum conditions to be suitable for constructing a biogas power plant.

A large enough area is needed to build a power plant and all accompanying facilities and machines, such as a fermenter, gas storage, electricity generator, and auxiliary facilities. An average power plant that produces 1,500 kW_{el} requires about 4,000 m^2 of space. For a power plant of the same size primarily using agricultural products as feedstock, an additional 5,400 m^2 is needed for storage. It should be taken into account that an additional storage area of 4,000 m^2 is required for the 500 kW_{el} power plant in which the obtained digestate is stored, mainly used in the fields during spring and summer. (Dr. Christian Epp, Dominik Rutz, Michael Köttner, Tobias Finsterwalder 2008)

In the selected area, many large empty plots are far enough away from the houses but still close to the main road, which is connected to them by Macadam roads. Considering that the price per m2 in that area is not high, between 10 and 15 €/m^2, the plan is to buy about 20,000 m^2 of land.

5.3.4. Optimising soft requirements for the selected site

The project's profitability is also affected by the so-called soft requirements, which should be taken into account when planning the construction of such a facility.

First of all, political support is needed because, like all energy issues, the construction of a biogas power plant attracts the interest of citizens and, therefore, offers political options for support or obstruction. Political support is needed, especially at the local level, because the citizens who live closest will be most interested, especially in matters of odor and air quality.

Like any plant, know-how is necessary for this type of power plant. Experts in this field must be engaged to improve the power plant and enable even greater biogas production. This is achieved by proper management and maintenance of the plant.

When developing a project, in addition to an experienced developer for biogas power plants, local support is also necessary. The project developer is in charge of creating projects with maximum economic and environmental efficiency, while the local designer serves as a link between the project developer and investors, the state, the municipality, and the like. His task is to help the developer with his practical knowledge.

5.4. Technology Overview for CHP Biogas Plant

The block diagram in Figure 29 shows how this power plant works. Organic waste comes to the power plant and is weighed and pre-treated, followed by a digestion process that produces two products: biogas and separation liquid/solid. Biogas is used for CHP, while separation solid and liquid, in the form of crude compost and sewage water, are further disposed of. Crude compost is used to obtain high-quality compost that is further sold and brings income, while liquids are treated and returned to the digester.

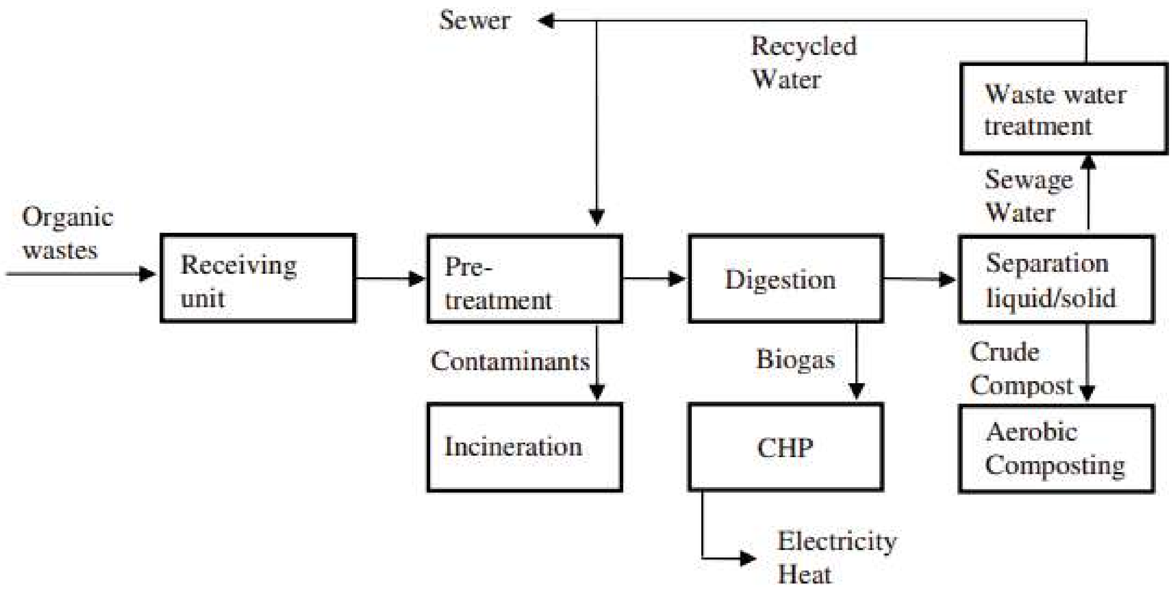

Figure 29 Block diagram of a typical biogas plant for organic waste treatment (Dr. Christian Epp, Dominik Rutz, Michael Köttner, Tobias Finsterwalder 2008)

During anaerobic digestion, thermal energy is released, directly delivered to the user. The obtained biogas will be converted into electricity using several smaller turbines, which need to be transformed into mains voltage in the transformer.

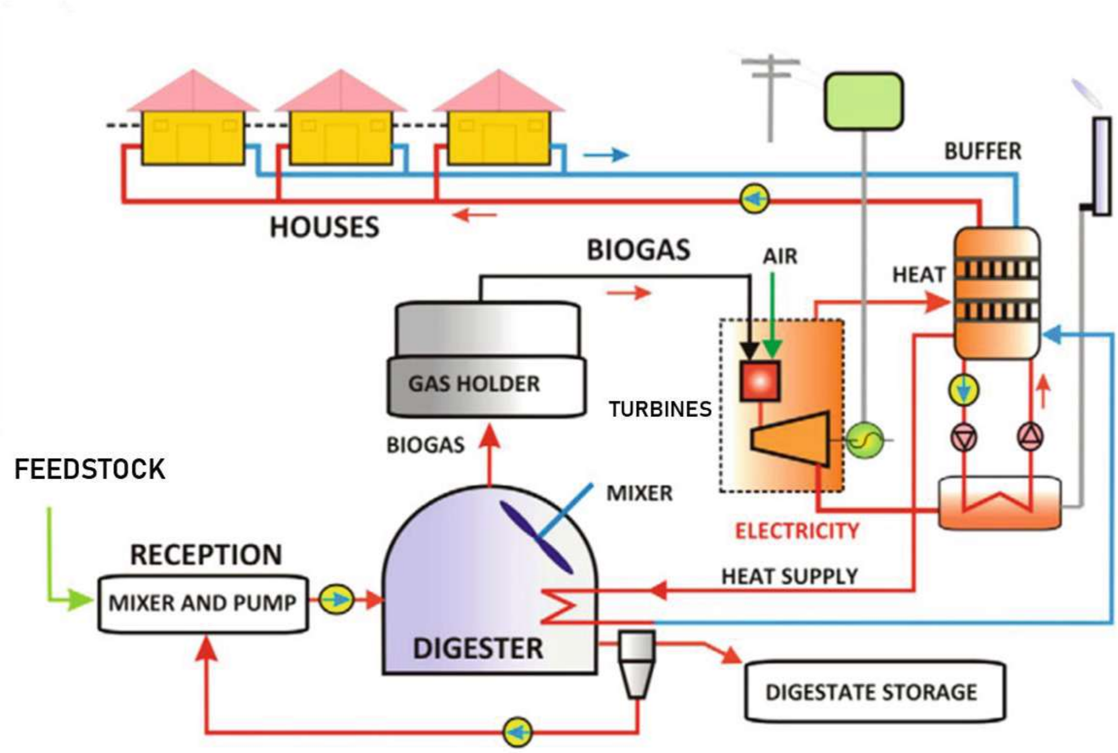

Figure 30 Proposed anaerobic digestion CHP process

5.5. Financial Analysis

This analysis evaluates the financial feasibility of an anaerobic digestion project using Appendix B - "Cost of Renewable Energy Spreadsheet Tool (CREST) for Anaerobic Digestion, version 1.4" developed by Sustainable Energy Advantage, LLC. The primary objective is calculating the Net Year-One Cost of Energy (COE) required to cover all costs and meet the investor's target after-tax return requirements. The analysis consists of 5 key sheets within the model: the Introduction, Inputs, Summary Results, Annual Cash flows and returns, and Cash Flow. This comprehensive analysis aims to describe each sheet's content and investigate how the inputs affect the derived financial results.

5.5.1. Input Values

The Inputs sheet is the backbone of the model because it contains data that influence and shape all calculations and key performance indicators. This sheet contains essential inputs such as project size and performance, capital costs, operation and maintenance costs, financing terms and incentive parameters as well as supplemental revenue streams such as tipping fees. In the model, for example, there are specific inputs such as generator nameplate capacity set at 1,500 kW, an energy content per cubic foot set at 550 BTU/Cubic foot, as well as an assumed electrical conversion efficiency of

35% that directly determine the expected energy output that ultimately affects the projected revenues. Capital costs in this case are estimated at 6,545,000 (Table 6) and 45% of this amount is planned to be financed with a bank loan. The bank's debt would be contracted with an interest rate of 7% with a repayment period of thirteen years, which will be reflected in the cash flow statement through annual debt service.

Table 6 Input data for Capital Costs

Generation Equipment	$	$3.700.000
Balance of Plant	$	$1.500.000
Interconnection	$	$300.000
Development Costs & Fee	$	$200.000
Reserves & Financing Costs	$	$845.000

The model optimistically targets a minimum annual Debt Service Coverage Ratio (DSCR) of 2.01, with a total DSCR target of 1.45. Furthermore, the target after-tax equity Internal Rate of Return (IRR) is set at 15%, which means that this return would ensure a positive NPV for any WACC that is less than 15%. An essential input element is supplemental revenues that can be earned as a positive externality of the primary process. For example, the model assumes a tipping fee of $12.00 for Source #1 – bio waste with an output of 35,000 tons per year and a tipping fee of $11.00 for Source #2 – food leftovers (kitchens) with an output of 500 tons per year. Additionally, digestate revenue is estimated at $5.50 per gallon, with an annual output of 10,000 gallons. These supplemental revenues are estimated to generate at least $481,050 annually, with significant contributions to the overall financial performance of the project.

Operating costs are another crucial input. Annual maintenance costs are estimated at $189 per kW and project management costs at $30,000. These expenses directly reduce the net cash flows generated by the project each year. Furthermore, tax-related inputs, such as a federal tax rate of 18%, substantially impact the project's net income and cash flows. Notably, the model incorporates tax benefits and the operating-loss carry forward rule. This allows the investor to avoid paying taxes during the early years when losses are accumulated. A critical financial advantage is the state cash incentive - calculated by multiplying the annual electricity production by 1.5 and dividing by 100. It provides a crucial financial injection that enhances the project's feasibility during its first decade.

Another important input is maintenance and operation costs, estimated at $189 per kW. The project management cost, in this case, is $30,000. These costs are substantial because they significantly reduce and determine the annually generated cash flows. Additionally, tax-related inputs such as the federal tax rate of 18% are of great importance because they directly impact both cash flow and net income. A significant tax relief applied in the model is the so-called operating-loss carry forward rule, which allows investors to avoid paying taxes in the initial years of the unprofitable stage when losses accumulate. A critical financial advantage is the state cash incentive. This value is calculated by multiplying the annual electricity production by 1.5 and dividing it by 100. It provides a crucial financial injection that enhances the project's feasibility during its first decade.

The depreciation method that was chosen for the project also significantly affects cash flow and net income. The model combines and uses 5-year and 15-year MACRS together with 15- and 20-year amortization schedules and a small part of the assets is non-depreciable according to the law and applicable regulations. The most considerable portion of the asset, valued at $3,230,000, is depreciated over the first five years using the 5-year MACRS method. This method allows for larger deductions in the early years of the asset's life, reducing taxable income and enhancing early cash flows. This strategy is well aligned with the rule of carrying forward operating losses and helps the project cope with financial challenges during the initial phase.

5.5.2. Results Summary

The Summary Results sheet consolidates the financial model's outputs into key performance indicators (KPIs) crucial for assessing the project's viability. These metrics include the Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, and levelized cost of Energy (LCOE).

For example, the inputs provided lead to an NPV of $2,189,088 after 20 years, with an estimated Weighted Average Cost of Capital (WACC) of 5.70 %.

$$WACC = \left(\frac{E}{E+D} \times Re\right) + \left(\frac{D}{E+D} \times Rd \times (1 - Tc)\right) \qquad 3$$

E = market value of the company’s equity → $3,135,000

D = market value of the company’s debt → $3,410,000

Tc = corporate tax rate → 26.20 %

Re = cost of equity → 6.20 %

Rd = cost of debt → 7.00 %

A positive NPV generally indicates that the discounted earnings generated on a project exceed the projected cost over the project's life. A significant NPV, as in this case, is an extremely positive and encouraging indicator because it provides a buffer against potential macroeconomic shocks. In this case, the project's IRR is 15.06% and is significantly higher than the predicted WACC, making it strong and attractive for investors. The calculated COE of $0.0075 per kWh suggests and confirms that the energy produced in this project is cost-effective because the stated price is significantly more competitive than the market price.

The provided inputs directly influence all mentioned indicators, and cost optimization or, for example, finding more favorable financing conditions can only further improve NPV and IRR. Furthermore, factors such as the size of the project or the improvement of efficiency can result in an even more competitive COE, making the project even more attractive to potential investors.

Depreciation:	**Project Cost Allocation**									
Project/Contract Year	Before	%	After	0	1	2	3	4	5	6
Depreciation Schedules, Half-Year Convention	Adjustments	Allocation	Adjustments							
5 Year MACRS	$3.230.000	71%	$3.230.000		20,00%	32,00%	19,20%	11,52%	11,52%	5,76%
7 Year MACRS	$0	0%	$0		14,29%	24,49%	17,49%	12,49%	8,93%	8,92%
15 Year MACRS	$200.000	4%	$200.000		5,00%	9,50%	8,55%	7,70%	6,93%	6,23%
20 Year MACRS	$0	0%	$0		3,75%	7,22%	6,68%	6,18%	5,71%	5,29%
5 Year SL	$0	0%	$0		10,00%	20,00%	20,00%	20,00%	20,00%	10,00%
15 Year SL	$255.000	6%	$255.000		3,33%	6,67%	6,67%	6,67%	6,67%	6,67%
20 Year SL	$457.422	10%	$457.422		2,50%	5,00%	5,00%	5,00%	5,00%	5,00%
39 Year SL	$0	0%	$0		1,28%	2,56%	2,56%	2,56%	2,56%	2,56%
Bonus Depreciation			$0		100,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Non-Depreciable	$412.422	9%	$412.422							

Figure 31 Project Cost Allocation

5.5.3. Annual Cash Flow and Returns

The Annual Cash Flows & Returns sheet provides a detailed year-by-year breakdown of the project’s financial performance. It encompasses revenue from energy and supplemental sales, operating expenses, debt service payments, taxes, and net cash flows to equity.

In the first year, energy sales are projected at $1.5 million. These numbers are based on an energy price of $0.0775 per kWh and an output of 10,879 MWh. This revenue is a crucial determinant of the project's cash flow. Operating expenses directly reduce this cash flow with a total of $733,964 for maintenance and feedstock. Debt service payments used to cover borrowed investment funds, derived from the earlier financing inputs, amount to $375,105 annually at an interest rate of 7 %, further impacting the cash flow.

Net cash flow is significantly higher at the beginning of the project due to high and stable revenue and cash inflow, state cash incentives, and tax exemptions, **Error! Not a valid bookmark self-reference.**. These advantages help to overcome the burden and cost of a significant initial investment and stabilize the project financially in the infancy phase. Despite this, it can be noticed that as the project progresses, the cash flow gradually decreases due to the onset of tax payments, continued debt service, and the halt of cash incentives after ten years of the project. In the twelfth year of the project, the cash flow becomes negative for the first time, mainly due to the absence of cash incentives, while the debt service still exists. However, from the fourteenth year of the project onwards, the cash flow starts to improve after the debt is fully repaid and after the income begins to hike moderately.

Table 7 Annual project cash flows and returns

Annual Project Cash Flows, Returns & Other Metrics

Project Year	Tariff or Market Value ¢/kWh	Revenue $	Operating Expenses $	Debt Service $	Reserves $	Pre-Tax Cash Flow $	Federal Taxable Income $	State Taxable Income $	Federal Tax Benefit/ (Liability) $	State Tax Benefit/ (Liability) $	After Tax Cash Flow $	Cumulative Cash Flow $	After Tax IRR %	Debt Service Coverage
0											($3.410.000)	($3.410.000)		
1	7,75	$1.496.393	($733.964)	($375.105)	$0	$387.324	($468.604)	($468.604)	$198.095	$63.180	$648.600	($2.761.401)	-80,98%	2,03
2	7,91	$1.517.071	($748.643)	($375.105)	$0	$393.323	($1.074.501)	($1.074.501)	$298.694	$124.096	$816.113	($1.945.287)	-40,65%	2,05
3	8,06	$1.538.157	($763.616)	($375.105)	$0	$399.436	($434.040)	($434.040)	$197.432	$60.383	$657.251	($1.288.036)	-20,44%	2,06
4	8,22	$1.559.659	($778.888)	($375.105)	$0	$405.665	($40.675)	($40.675)	$136.249	$21.386	$563.301	($724.735)	-9,19%	2,08
5	8,39	$1.581.586	($794.466)	($375.105)	$0	$412.014	($18.099)	($18.099)	$135.185	$19.475	$566.674	($158.061)	-1,63%	2,10
6	8,56	$1.603.945	($810.356)	($375.105)	$0	$418.484	$283.883	$283.883	$88.909	($10.370)	$497.024	$338.962	2,96%	2,12
7	8,73	$1.626.746	($826.563)	($375.105)	$0	$425.078	$585.604	$585.604	$42.728	($40.182)	$427.625	$766.587	5,86%	2,13
8	8,90	$1.649.997	($843.094)	($375.105)	$0	$431.798	$608.676	$608.676	$41.743	($42.121)	$431.419	$1.198.006	8,06%	2,15
9	9,08	$1.673.707	($859.956)	($375.105)	$0	$438.646	$632.983	$632.983	$40.612	($44.177)	$435.081	$1.633.087	9,75%	2,17
10	9,26	$1.697.886	($877.155)	($375.105)	$0	$445.625	$658.721	$658.721	$39.305	($46.368)	$438.563	$2.071.650	11,06%	2,19
11	9,45	$1.523.604	($894.698)	($375.105)	$0	$253.800	$486.890	$486.890	($78.876)	($48.689)	$126.235	$2.197.885	11,37%	1,68
12	9,64	$1.544.768	($912.592)	($375.105)	$0	$257.071	$511.670	$511.670	($82.891)	($51.167)	$123.013	$2.320.898	11,63%	1,69
13	9,83	$1.566.350	($930.844)	($375.105)	$0	$260.401	$537.897	$537.897	($87.139)	($53.790)	$119.472	$2.440.369	11,85%	1,69
14	10,03	$1.586.950	($949.461)	$0	$187.553	$825.042	$564.458	$564.458	($91.442)	($56.446)	$677.154	$3.117.524	12,83%	N/A
15	10,23	$1.607.985	($968.450)	$0	$0	$639.535	$566.466	$566.466	($91.767)	($56.647)	$491.121	$3.608.645	13,38%	N/A
16	10,43	$1.630.869	($987.819)	$0	$0	$643.050	$593.871	$593.871	($96.207)	($59.387)	$487.455	$4.096.100	13,82%	N/A
17	10,64	$1.654.204	($1.007.575)	$0	$0	$646.628	$621.303	$621.303	($100.651)	($62.130)	$483.847	$4.579.947	14,17%	N/A
18	10,85	$1.677.999	($1.027.727)	$0	$0	$650.272	$624.947	$624.947	($101.241)	($62.495)	$486.536	$5.066.483	14,45%	N/A
19	11,07	$1.702.264	($1.048.281)	$0	$0	$653.983	$628.658	$628.658	($101.843)	($62.866)	$489.274	$5.555.758	14,69%	N/A
20	11,29	$1.723.664	($1.069.247)	$0	$445.835	$1.100.252	$629.092	$629.092	($101.913)	($62.909)	$935.430	$6.491.187	15,06%	N/A

Critical financial indicators such as DSCR, IRR, and cumulative cash flow demonstrate that a Net Year-One Cost of Energy (COE) of $0.0775 per kWh ensures the project's smooth financial execution.

The cumulative IRR of 15.06% and the average DSCR of 2.01 are far above the required minimum. These values indicate a solid and high-quality financial structure for the project. The high NPV of $2,601,656 with an average WACC of 5.70% further validates the financial viability and assures that the project can withstand unexpected economic shocks and crises that would significantly affect the cost of capital, **Error! Not a valid bookmark self-reference.**.

Table 8 Net present value

Pre-Tax (Cash-only) Equity IRR (over defined Useful Life)	**11,43%**
After Tax Equity IRR (over defined Useful Life)	**15,06%**
Net present value @ 5,70 % (over defined Useful life)	$2.601.656

5.5.4. Cash Flow

The Cash Flow sheet contains all cash inflows and outflows during the project's duration and provides crucial insights into the project's liquidity, solvency, and long-term financial health.

The extensive initial investment results in a significant negative outflow of $6,545,000 in the project's initial year, gradually offset by generated revenue and cash incentives in the following years. The cash flow statement meticulously tracks how these revenues, operating expenses, debt service, and taxes impact the project's financial position. Over time, as the debt is paid off and the project stabilizes, the net cash flow from operations becomes positive, showcasing the high-quality financial capacity of the project. The timing and magnitude of these cash flows are closely linked to the inputs provided. Higher operating costs or lower-than-anticipated energy prices could reduce net cash flows, potentially challenging the project's financial stability. Conversely, optimizing capital costs or providing additional tax incentives could increase cash flow, strengthening the project's economic foundations.

6. Conclusions

Certain conclusions can be drawn after the research and planning of the biogas power plant. First of all, it should be emphasized that the maximum effort should be made to use renewable sources in everyday life because small changes lead to bigger ones. State and European Union policies set general laws and rules, and we must adhere to them.

Regarding bioenergy, it is noticeable that this branch is relatively low globally, especially in Croatia. However, the European Union is currently implementing incentives to encourage biogas production, which brings a certain degree of energy independence. The advantage of bioenergy, especially biogas production, is sustainability because it not only results in biogas that can be used as standard gas but also solves the issue of bio waste, waste from the food industry, and animal manure, which is a significant emitter of CO_2. The biogas plant does not pollute the environment in any way, and it even has high-quality fertilizer as a by-product, which is then used in the agricultural industry.

In this paper, the possibility and potential for the construction of a biogas plant in the city of Zagreb, which would have a CHP intention, were investigated. Potential suppliers of feedstock and construction locations were examined to obtain an approximate output of biogas and biomethane, and based on this, a financial analysis was made to determine the profitability of the project.

For cost-effectiveness and simplicity, most of the feedstock would be supplied within a radius of a maximum of 10 km. The location was chosen near the existing heat district plant for easier energy distribution.

After the financial analysis, the conclusion is that the LCOE, set at $0.0775 per kWh, offers insight into the cost-effectiveness of the energy produced by the project, ensuring that the project remains competitive within the market. These derived figures are directly influenced by the inputs provided. Since the current heating and electricity prices are much higher than $0.0775 per kWh, this project is financially profitable and profitable. Current prices on the energy market are dynamic. According to data from the Hungarian Power Exchange, where electricity prices are similar to those in Croatia, the trend of electricity price changes from 2010 to 2023 is shown in the Figure 32.

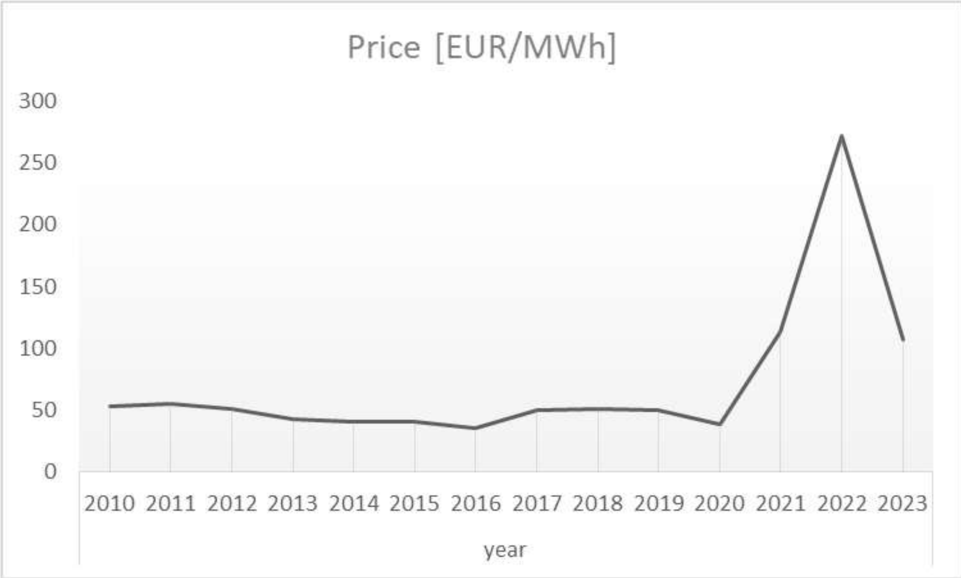

Figure 32 Average yearly electricity price change in Hungary from 2010 to 2023 (hupx)

If broader picture is assumed, the prices of electricity have been slowly increasing over the years, and for this reason, the Tariff has been increased by 2% over the years, Table 7. Considering the current price on the market and the slight upward trend in prices. LCOE $0.0775 is a pretty good base price. This is the minimum price that ensures the return of the investment after 5 years. Also, that price is competitive on the market because it is lower than the current market price, and buyers will be interested in buying it.

For instance, optimizing the operating costs or securing more favorable financing terms could further improve the NPV and IRR. At the same time, adjustments to project size or efficiency could enhance the LCOE, making the project even more profitable. By carefully analyzing these inputs and their effects, stakeholders can make informed decisions about the project's feasibility and profitability. The analysis demonstrates that, with the current assumptions, the project is financially viable and resilient to potential fluctuations in the economic environment, ensuring long-term sustainability and profitability.

The planned power plant is of medium size, and there is an option to increase it. In that case, a biogas upgrade could be considered. This would obtain high-purity biomethane, which is ready to be injected into the gas network.

Considering the relatively small production of heat and the state of the heat market during the summer, it is recommended to consider a biogas upgrade. Depending on the situation, this would easily balance the energy market and choose whether to sell gas or electricity.

Such a project would improve the energy picture of Zagreb and Croatia as a whole. It would also set an example for other cities and municipalities to improve their energy status and possibly achieve energy independence.

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Appendix A: Biomethane Tool for economic analysis of biogas production, gas upgrading and utilization of biomethane (Philipp Novakovits, Christina Doczekal 2016)

		Default values			Actual values									
Waste category	Substrates	Dry matter	Biogas yield	Methane	Dry matter	Biogas yield	Methane	Amount of substrate/ waste	Cost of substrate	Revenue for waste	Total biogas yield	Total methane yield	Total costs	Total revenues
		[%]	[m^3/t FM]	[%]	[%]	[m^3/t FM]	[%]	[t FM/a]	[€/t FM]	[€/t FM]	[m^3/a]	[m^3/a]	[€/a]	[€/a]
Waste from the food industry	Mash from fruits	3-5	250 - 540	63	4	450	63	70	5	20	31.500	19.845	350	1.400
	Baking waste	60 - 80	400 - 500	62	70	450	62	40	5	10	18.000	11.160	200	400
	Vinasse from alcohol prod.	8-12	50	55	10	50	55	10	5	15	500	275	50	150
Vegetables, greens, grass	Mixed vegetable waste	5-20	300 - 400	62	12	350	62	35	5	15	12.250	7.595	175	525
Wastes from households and canteens	Mixed biowaste from households*	35 - 75	100 - 200	62	42	160	62	35.000	5	10	5.600.000	3.472.000	175.000	350.000
	Grass, green waste	25	180	56	25	180	56	10	5	20	1.800	1.008	50	200
	Food leftovers (kitchen)*	9-37	150 - 300	58	23	225	58	500	5	10	112.500	65.250	2.500	5.000
	Waste from food retail (supermarkets)*	9 - 90	200 - 400	55	50	300	55	100	5	15	30.000	16.500	500	1.500
	Frying oil and fat	50 - 70	600 – 750	62	60	650	62	15	5	40	9.750	6.045	75	600
	Meat and bone meal	8-27	750 – 1,100	-	16	930		40	5	15	37.200	0	200	600

Annual biogas production	5.853.500	[m^3/a]
Annual methane production	3.599.678	[m^3/a]
Annual substrate costs	179.100	[€/a]
Annual revenues from waste	360.375	[€/a]
Annual input of fresh mass	35.820	[t FM/a]

General data

input of fresh mass	35.820	[t FM/a]
annual biogas production	5.853.500	[m^3/a]
annual methane production	3.599.678	[m^3/a]
average methane content	61	[%]
caloric value of biogas (lower heating value)	35.889	[MWh/a]
theoretical electric capacity of biogas plant	1.502	[kW_{el}]

Appendix B: Cost of Renewable Energy Spreadsheet Tool (CREST) for Anaerobic Digestion, version 1.4, Sustainable Energy Advantage, LLC (NREL)

Input data

Project Size and Performance	Units	Input Value	
Generator Nameplate Capacity	kW	1.500	?
Biogas Consumption per Day	cubic feet/day	638.088	?
Biogas Consumption per Year	cubic feet/year	232.902.234	?
Energy Content per Cubic Foot	BTU/cubic foot	550	?
Energy Content per Year	MMBTU/year	128.096	?
Electrical Conversion Efficiency	%	35%	?
Heat Rate	BTU/kWh	9.749	?
Availability	%	92%	?
Station Service (Parasitic Load)	%	10%	?
Production, Year 1	kWh	10.879.920	?
Annual Production Price Escalation	%	0,0%	?
Project Useful Life	years	20	?

Capital Costs	Units	Input Value	
Select Cost Level of Detail		Intermediate	?
Generation Equipment	$	$3.700.000	?
Balance of Plant	$	$1.500.000	?
Interconnection	$	$300.000	?
Development Costs & Fee	$	$200.000	?
Reserves & Financing Costs	$	$845.000	?
Total Installed Cost (before grants, if applicable)	$	$6.545.000	?
Total Installed Cost (before grants, if applicable)	$/kW	$4.363	?

Operations & Maintenance	Units	Input Value	
Select Cost Level of Detail		Intermediate	?
Fixed O&M Expense, Yr 1	$/kW-yr	$189,00	?
Variable O&M Expense, Yr 1	¢/kWh	3,00	?
O&M Cost Inflation, initial period	%	2,0%	?
Initial Period ends last day of:	year	10	?
O&M Cost Inflation, thereafter	%	2,0%	?
Insurance, Yr 1 (% of Total Cost)	%	0,4%	?
Insurance, Yr 1 ($) (Provided for reference)	$	$22.800	?
Project Management Yr 1	$/yr	$30.000	?
Feedstock Expense, if applicable	$/ton	$0	?
Feedstock Expense Escalation Factor	%	2,0%	?
Feedstock - Quantity	tons per year	10.000	?
Water & Sewer Expenses	$/yr	$10.000	?
Water & Sewer Expense Escalation Factor	%	2,0%	?
Digestate Disposal (if handled as an expense)	$/gallon	$0	?
Digestate Disposal Escalation Factor	%	2,0%	?
Digestate - Quantity	gallons per year	5.000.000	?
Property Tax or PILOT, Yr 1	$/yr	$0	?
Annual Property Tax Adjustment Factor	%	0,0%	?
Land Lease	$/yr	$25.000	?
Royalties (% of revenue)	%	0,0%	?
Royalties, Yr 1 ($) (Provided for reference)	$	$0	?

Construction Financing	Units	Input Value	
Construction Period	months	9	?
Interest Rate (Annual)	%	5,5%	?
Interest During Construction	$	$117.563	?

Permanent Financing	Units	Input Value	
% Debt (% of hard costs) (mortgage-style amort.)	%	55%	?
Debt Term	years	13	?
Interest Rate on Term Debt	%	7,00%	?
Lender's Fee (% of total borrowing)	%	3,0%	?
Required Minimum Annual DSCR		1,20	?
Actual Minimum DSCR, occurs in →	Year 11	1,68	?
Minimum DSCR Check Cell (If "Fail," read note ==>)	Pass/Fail	Pass	?
Required Average DSCR		1,45	?
Actual Average DSCR		2,01	?
Average DSCR Check Cell (If "Fail," read note ==>)	Pass/Fail	Pass	?
% Equity (% hard costs) (soft costs also equity funded)	%	45%	?
Target After-Tax Equity IRR	%	15,00%	?
Weighted Average Cost of Capital (WACC)	%	5,70%	?
Other Closing Costs	$	$0	?

Summary of Sources of Funding for Total Installed Cost			
Senior Debt (funds portion of hard costs)	48%	$3.135.000	?
Equity (funds balance of hard costs + all soft costs)	52%	$3.410.000	?
Total Value of Grants (excl. pmt in lieu of ITC, if applicabl	0%	$0	?
Total Installed Cost	$	**$6.545.000**	?

Tax	Units	Input Value	
Is owner a taxable entity?		Yes	?
Federal Income Tax Rate	%	18,0%	?
Federal Tax Benefits used as generated or carried forward?		As Generated	?
State Income Tax Rate	%	10,0%	?
State Tax Benefits used as generated or carried forward?		As Generated	?
Effective Income Tax Rate	%	26,20%	?
Depreciation Allocation		see table ==>	?

Depreciation Allocation	*Input Values*		
Bonus Depreciation	No		?
			?

Allocation of Costs	5-year MACRS	7-year MACRS	15-year MACRS	20-year MACRS	5-year SL	15-year SL	20-year SL	39-year SL	Non-Depreciable
Generation Equipment	96,0%	0,0%	2,0%	0,0%	0,0%	0,0%	2,0%	0,0%	0,0%
Balance of Plant	75,0%	0,0%	0,0%	0,0%	0,0%	25,0%	0,0%	0,0%	0,0%
Interconnection	0,0%	0,0%	100,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Development Costs & Fee	80,0%	0,0%	0,0%	0,0%	0,0%	5,0%	5,0%	0,0%	10,0%
Reserves & Financing Costs	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	50,0%	0,0%	50,0%

Supplemental Revenue Streams: Tipping Fees	Units	Input Value	
Tipping Fee - Source #1	$/ton	$12,00	?
Quantity Received Each Year	tons per year	35.000	?
Tipping Fee - Source #2	$/ton	$11,00	?
Quantity Received Each Year	tons per year	500	?
Tipping Fee - Source #3	$/ton	$17,00	?
Quantity Received Each Year	tons per year	0	?
Digestate (if merchantable for additional revenue)	$/gallon	$5,50	?
Digestate Revenue Escalation Factor	%	1,0%	?
Digestate - Quantity	gallons per year	10.000	?
Waste Heat -- Heat Capture Efficiency	%	85%	?
Waste Heat -- BTUs available for sale	BTU/kWh	5.386	?
Waste Heat -- Selling Price/Avoided Cost	$/therm	$0,00	?
Waste Heat -- Selling Price Escalation Factor	%	2,0%	?

Cost-Based Tariff Rate Structure	Units	Input Value	
Payment Duration for Cost-Based Tariff	years	20	?
% of Year-One Tariff Rate Escalated	%	0,0%	?
Cost-Based Tariff Escalation Rate	%	0,0%	?

Forecasted Market Value of Production; applies after Incentive Expiration			?

Federal Incentives	Units	Input Value	
Select Form of Federal Incentives		Performance-Based	?
			?
Is PBI Tax-Based (PTC) or Cash-Based (REPI)?		Tax Credit	?
PBI Rate	¢/kWh	1,15	?
PBI Utilization or Availability Factor, if applicable	%	100,0%	
PBI Duration	yrs	10	?
PBI Escalation Rate	%	2,0%	?
Additional Federal Grants (Other than Section 1603)	$	$0	?
Federal Grants Treated as Taxable Income?		Yes	?

State Rebates, Tax Credits and/or REC Revenue	Units	Input Value	
Select Form of State Incentive		Performance-Based	?
Utilization Factor, if applicable	%	100%	
Is Performance-Based Incentive Tax Credit or Cash Pmt?		Cash	?
Annual $ Cap on Performance-Based Incentive	$	$500.000	?
If cash, is state PBI or REC taxable?		No	?
PBI or REC Rate	¢/kWh	1,50	?
PBI Utilization Factor, if applicable	%	100%	
PBI or REC PaymentDuration	yrs	10	?
PBI or REC Escalation Rate (pos. or neg.)	%	2,0%	?
Additional State Rebates/Grants	$/kW	$0	?
Total $ Cap on State Rebates/Grants	$	$500.000	?
State Grants Treated as Taxable Income?		Yes	?

Capital Expenditures During Operations (capitalized and depreciated)			
1st Equipment Replacement	year	7	?
1st Replacement Cost ($ in year replaced)	$/kW	$0	?
2nd Equipment Replacement	year	14	?
2nd Replacement Cost ($ in year replaced)	$/kW	$0	?
3rd Equipment Replacement	year	15	?
3rd Replacement Cost ($ in year replaced)	$/kW	$0	?
4th Equipment Replacement	year	20	?
4th Replacement Cost ($ in year replaced)	$/kW	$0	?

Reserves Funded from Operations	Units	Input Value	
Decommissioning Reserve			
Fund from Operations or Salvage Value?		Salvage	?

Initial Funding of Reserve Accounts	Units	Input Value	
Debt Service Reserve			
# of months of Debt Service	months	6	?
Initial Debt Service Reserve	$	$187.553	?
O&M Reserve/Working Capital			
# of months of O&M Expense	months	6	?
Initial O&M and WC Reserve	$	$445.835	?
Interest on All Reserves	%	1,5%	?

Results summary

Outputs Summary	units	Current Model Run
Net Year-One Cost of Energy (COE)	¢/kWh	**7,75**
Annual Escalation of Year-One COE	%	0,0%
Percentage of Tariff Escalated	%	0,0%
Does modeled project meet *minimum* DSCR requirements?		Yes
Does modeled project meet *average* DSCR requirements?		Yes
Did you confirm that all minimum required inputs have green check cells?		

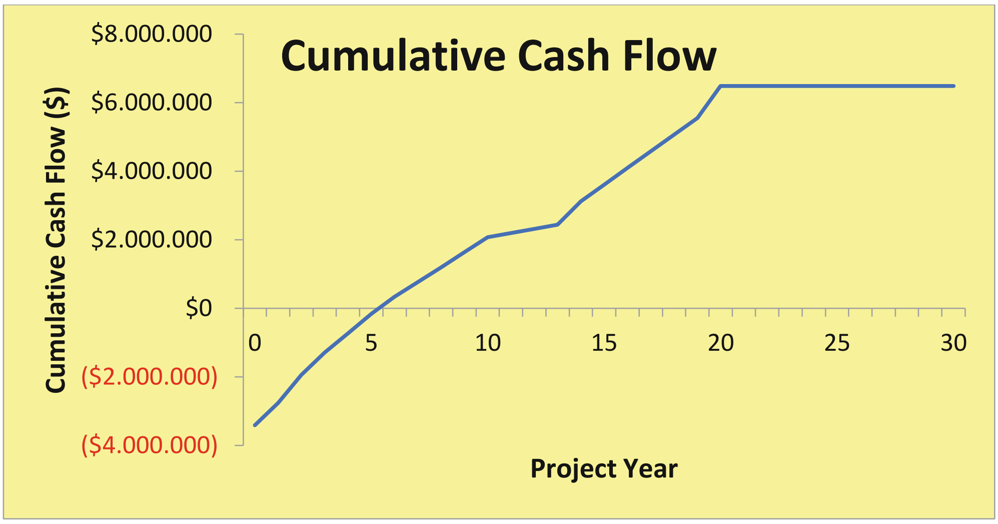
Net Nominal Levelized Cost of Energy	¢/kWh	**8,66**

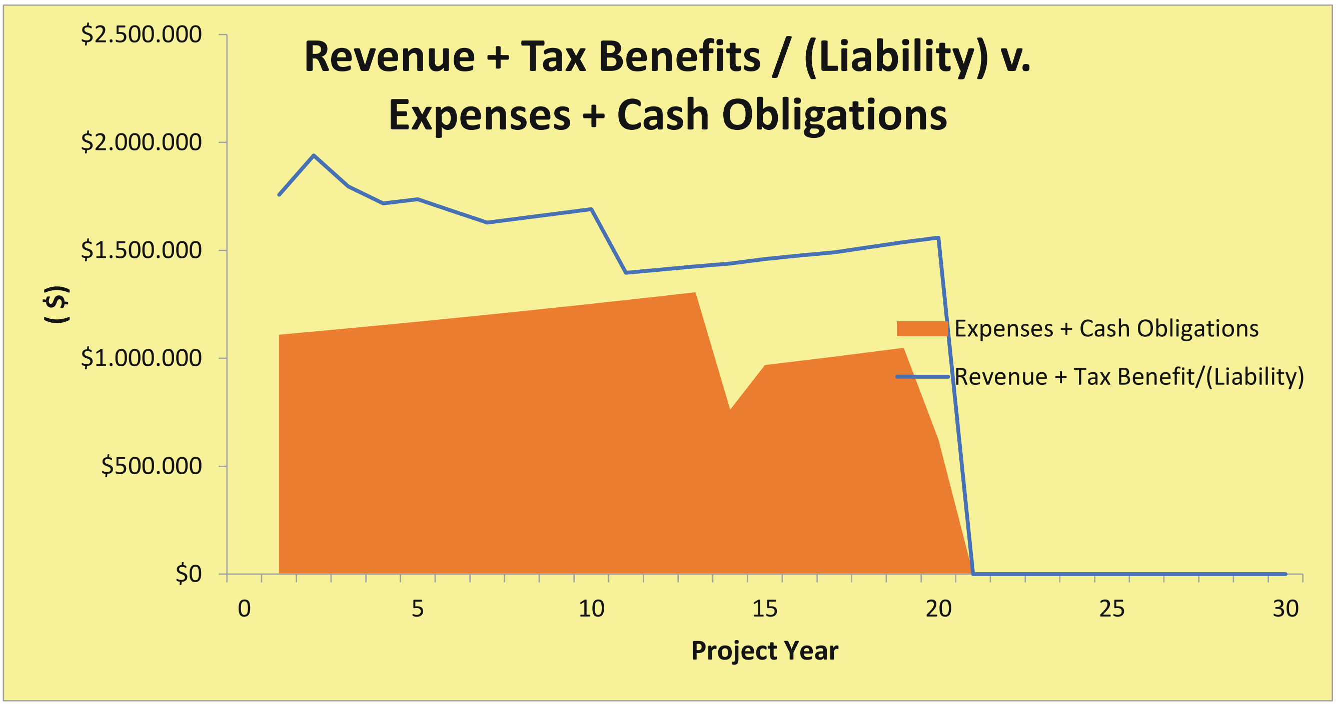
Inputs Summary		
Generator Nameplate Capacity	kW	1.500
Biogas Consumption per Year	cubic feet/year	232.902.234
Energy Content per Cubic Foot	BTU/cubic foot	550
Heat Rate	BTU/kWh	9.749
Availability	%	92%
Station Service (Parasitic Load)	%	10%
Production, Yr 1	kWh	10.879.920
Project Useful Life	Years	20
Payment Duration for Cost-Based Tariff	Years	20
% of Year 1 Tariff Rate Escalated	%	0%
Net Installed Cost (Total Installed Cost less Grants)	$	$6.545.000
Net Installed Cost (Total Installed Cost less Grants)	$/kW	$4.363
Supplemental Revenue		
Tipping Fee - Source #1	$/ton	$12,00
Quantity Received Each Year	tons per year	35.000
Tipping Fee - Source #2	$/ton	$11,00
Quantity Received Each Year	tons per year	500
Tipping Fee - Source #3	$/ton	$17,00
Quantity Received Each Year	tons per year	0
Operating Expenses, Aggregated, Yr 1	¢/kWh	-6,75
% Equity (% hard costs) (soft costs also equity funded)	%	45%
Target After-Tax Equity IRR	%	15,00%
% Debt (% of hard costs) (mortgage-style amort.)	%	55%
Debt Term	Years	13
Interest Rate on Term Debt	%	7,00%
Is owner a taxable entity?		Yes
Federal Tax Benefits Used "as generated" or "carried forward"?		As Generated
State Tax Benefits Used "as generated" or "carried forward"?		As Generated
Type of Federal Incentive Assumed		Performance-Based
Tax Credit- or Cash- Based?		Tax Credit
Other Grants or Rebates		No
Total of Grants or Rebates	$	NA
Bonus Depreciation assumed?		No

Annual Cash flows and Returns

Annual Project Cash Flows, Returns & Other Metrics

Project Year	Tariff or Market Value ¢/kWh	Revenue $	Operating Expenses $	Debt Service $	Reserves $	Pre-Tax Cash Flow $	Federal Taxable Income $	State Taxable Income $	Federal Tax Benefit/ (Liability) $	State Tax Benefit/ (Liability) $	After Tax Cash Flow $	Cumulative Cash Flow $	After Tax IRR %	Debt Service Coverage
0											($3.410.000)	($3.410.000)		
1	7,75	$1.496.393	($733.964)	($375.105)	$0	$387.324	($468.604)	($468.604)	$198.095	$63.180	$648.600	($2.761.401)	-80,98%	2,03
2	7,91	$1.517.071	($748.643)	($375.105)	$0	$393.323	($1.074.501)	($1.074.501)	$298.694	$124.096	$816.113	($1.945.287)	-40,65%	2,05
3	8,06	$1.538.157	($763.616)	($375.105)	$0	$399.436	($434.040)	($434.040)	$197.432	$60.383	$657.251	($1.288.036)	-20,44%	2,06
4	8,22	$1.559.659	($778.888)	($375.105)	$0	$405.665	($40.675)	($40.675)	$136.249	$21.386	$563.301	($724.735)	-9,19%	2,08
5	8,39	$1.581.586	($794.466)	($375.105)	$0	$412.014	($18.099)	($18.099)	$135.185	$19.475	$566.674	($158.061)	-1,63%	2,10
6	8,56	$1.603.945	($810.356)	($375.105)	$0	$418.484	$283.883	$283.883	$88.909	($10.370)	$497.024	$338.962	2,96%	2,12
7	8,73	$1.626.746	($826.563)	($375.105)	$0	$425.078	$585.604	$585.604	$42.728	($40.182)	$427.625	$766.587	5,86%	2,13
8	8,90	$1.649.997	($843.094)	($375.105)	$0	$431.798	$608.676	$608.676	$41.743	($42.121)	$431.419	$1.198.006	8,06%	2,15
9	9,08	$1.673.707	($859.956)	($375.105)	$0	$438.646	$632.983	$632.983	$40.612	($44.177)	$435.081	$1.633.087	9,75%	2,17
10	9,26	$1.697.886	($877.155)	($375.105)	$0	$445.625	$658.721	$658.721	$39.305	($46.368)	$438.563	$2.071.650	11,06%	2,19
11	9,45	$1.523.604	($894.698)	($375.105)	$0	$253.800	$486.890	$486.890	($78.876)	($48.689)	$126.235	$2.197.885	11,37%	1,68
12	9,64	$1.544.768	($912.592)	($375.105)	$0	$257.071	$511.670	$511.670	($82.891)	($51.167)	$123.013	$2.320.898	11,63%	1,69
13	9,83	$1.566.350	($930.844)	($375.105)	$0	$260.401	$537.897	$537.897	($87.139)	($53.790)	$119.472	$2.440.369	11,85%	1,69
14	10,03	$1.586.950	($949.461)	$0	$187.553	$825.042	$564.458	$564.458	($91.442)	($56.446)	$677.154	$3.117.524	12,83%	N/A
15	10,23	$1.607.985	($968.450)	$0	$0	$639.535	$566.466	$566.466	($91.767)	($56.647)	$491.121	$3.608.645	13,38%	N/A
16	10,43	$1.630.869	($987.819)	$0	$0	$643.050	$593.871	$593.871	($96.207)	($59.387)	$487.455	$4.096.100	13,82%	N/A
17	10,64	$1.654.204	($1.007.575)	$0	$0	$646.628	$621.303	$621.303	($100.651)	($62.130)	$483.847	$4.579.947	14,17%	N/A
18	10,85	$1.677.999	($1.027.727)	$0	$0	$650.272	$624.947	$624.947	($101.241)	($62.495)	$486.536	$5.066.483	14,45%	N/A
19	11,07	$1.702.264	($1.048.281)	$0	$0	$653.983	$628.658	$628.658	($101.843)	($62.866)	$489.274	$5.555.758	14,69%	N/A
20	11,29	$1.723.664	($1.069.247)	$0	$445.835	$1.100.252	$629.092	$629.092	($101.913)	($62.909)	$935.430	$6.491.187	15,06%	N/A





Cash flow

Project/Contract Year	units	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Production Degradation Factor			1,00	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Electricity Production	kWh		10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	10.879.920	0	0	0	0	0	0	0	0	0	0
Heat Available for Sale	therms		586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	586.002	0	0	0	0	0	0	0	0	0	0
Digestate Revenue Escalation Factor			1,00	1,010	1,020	1,030	1,041	1,051	1,062	1,072	1,083	1,094	1,105	1,116	1,127	1,138	1,149	1,161	1,173	1,184	1,196	1,208	1,220	1,232	1,245	1,257	1,270	1,282	1,295	1,308	1,321	1,335
Waste Heat Selling Rate Escalation Factor			1,00	1,020	1,040	1,061	1,082	1,104	1,126	1,149	1,172	1,195	1,219	1,243	1,268	1,294	1,319	1,346	1,373	1,400	1,428	1,457	1,486	1,516	1,546	1,577	1,608	1,641	1,673	1,707	1,741	1,776
Tariff Rate & Cash Incentives																																
Tariff Rate Escalator, if applicable			1,00	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Federal PBI Escalator, if applicable			1,00	1,020	1,040	1,061	1,082	1,104	1,126	1,149	1,172	1,195	1,219	1,243	1,268	1,294	1,319	1,346	1,373	1,400	1,428	1,457	1,486	1,516	1,546	1,577	1,608	1,641	1,673	1,707	1,741	1,776
State PBI Escalator, if applicable			1,00	1,020	1,040	1,061	1,082	1,104	1,126	1,149	1,172	1,195	1,219	1,243	1,268	1,294	1,319	1,346	1,373	1,400	1,428	1,457	1,486	1,516	1,546	1,577	1,608	1,641	1,673	1,707	1,741	1,776
Tariff Rate (Fixed Portion)	¢/kWh	100%	7,75	7,91	8,06	8,22	8,39	8,56	8,73	8,90	9,08	9,26	9,45	9,64	9,83	10,03	10,23	10,43	10,64	10,85	11,07	11,29	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Tariff Rate (Escalating Portion)	¢/kWh	0%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Tariff Rate (Total)	¢/kWh		7,75	7,91	8,06	8,22	8,39	8,56	8,73	8,90	9,08	9,26	9,45	9,64	9,83	10,03	10,23	10,43	10,64	10,85	11,07	11,29	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Revenue from Tariff	$		$843.194	$860.058	$877.259	$894.804	$912.700	$930.954	$949.573	$968.565	$987.936	$1.007.695	$1.027.849	$1.048.406	$1.069.374	$1.090.761	$1.112.576	$1.134.828	$1.157.524	$1.180.675	$1.204.288	$1.228.374	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Post-Tariff Market Value of Production	¢/kWh		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Market Revenue	$		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Federal Cash Incentive Rate	¢/kWh		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Federal Cash Incentive	$		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
State Cash Incentive Rate	¢/kWh		1,50	1,53	1,56	1,59	1,62	1,66	1,69	1,72	1,76	1,79	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
State Cash Incentive	$		$163.199	$166.463	$169.792	$173.188	$176.652	$180.185	$183.788	$187.464	$191.213	$195.038	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Interest Earned on Reserve Accounts	$		$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$8.094	$6.688	$6.688	$6.688	$6.688	$6.688	$3.344	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Tipping Fees	$		$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$425.500	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Digestate (if merchantable for additional revenue)	$		$55.000	$55.550	$56.106	$56.667	$57.233	$57.806	$58.384	$58.967	$59.557	$60.153	$60.754	$61.362	$61.975	$62.595	$63.221	$63.853	$64.492	$65.137	$65.788	$66.446	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Sale/Avoided Cost of Waste Heat	$		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Project Revenue, All Sources	$		**$1.496.393**	**$1.517.071**	**$1.538.157**	**$1.559.659**	**$1.581.586**	**$1.603.945**	**$1.626.746**	**$1.649.997**	**$1.673.707**	**$1.697.886**	**$1.523.604**	**$1.544.768**	**$1.566.350**	**$1.586.950**	**$1.607.985**	**$1.630.869**	**$1.654.204**	**$1.677.999**	**$1.702.264**	**$1.723.664**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Project Expenses																																
Operating Expense Inflation Factor			1,00	1,0200	1,0404	1,0612	1,0824	1,1041	1,1262	1,1487	1,1717	1,1951	1,2190	1,2434	1,2682	1,2936	1,3195	1,3459	1,3728	1,4002	1,4282	1,4568	1,4859	1,5157	1,5460	1,5769	1,6084	1,6406	1,6734	1,7069	1,7410	1,7758
Feedstock Escalation Factor			1,00	1,0200	1,0404	1,0612	1,0824	1,1041	1,1262	1,1487	1,1717	1,1951	1,2190	1,2434	1,2682	1,2936	1,3195	1,3459	1,3728	1,4002	1,4282	1,4568	1,4859	1,5157	1,5460	1,5769	1,6084	1,6406	1,6734	1,7069	1,7410	1,7758
Water & Sewer Escalation Factor			1,00	1,0200	1,0404	1,0612	1,0824	1,1041	1,1262	1,1487	1,1717	1,1951	1,2190	1,2434	1,2682	1,2936	1,3195	1,3459	1,3728	1,4002	1,4282	1,4568	1,4859	1,5157	1,5460	1,5769	1,6084	1,6406	1,6734	1,7069	1,7410	1,7758
Digestate Disposal Escalation Factor			1,00	1,0200	1,0404	1,0612	1,0824	1,1041	1,1262	1,1487	1,1717	1,1951	1,2190	1,2434	1,2682	1,2936	1,3195	1,3459	1,3728	1,4002	1,4282	1,4568	1,4859	1,5157	1,5460	1,5769	1,6084	1,6406	1,6734	1,7069	1,7410	1,7758
Fixed O&M Expense	$		($283.500)	($289.170)	($294.953)	($300.852)	($306.870)	($313.007)	($319.267)	($325.652)	($332.165)	($338.809)	($345.585)	($352.497)	($359.547)	($366.737)	($374.072)	($381.554)	($389.185)	($396.968)	($404.908)	($413.006)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Variable O&M Expense	$		($362.664)	($369.917)	($377.316)	($384.862)	($392.559)	($400.410)	($408.419)	($416.587)	($424.919)	($433.417)	($442.085)	($450.927)	($459.946)	($469.145)	($478.527)	($488.098)	($497.860)	($507.817)	($517.973)	($528.333)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Insurance	$		($22.800)	($23.256)	($23.721)	($24.196)	($24.679)	($25.173)	($25.677)	($26.190)	($26.714)	($27.248)	($27.793)	($28.349)	($28.916)	($29.494)	($30.084)	($30.686)	($31.300)	($31.926)	($32.564)	($33.215)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Project Administration	$		($30.000)	($30.600)	($31.212)	($31.836)	($32.473)	($33.122)	($33.785)	($34.461)	($35.150)	($35.853)	($36.570)	($37.301)	($38.047)	($38.808)	($39.584)	($40.376)	($41.184)	($42.007)	($42.847)	($43.704)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Feedstock Expense	$		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Water & Sewer Expenses	$		($10.000)	($10.200)	($10.404)	($10.612)	($10.824)	($11.041)	($11.262)	($11.487)	($11.717)	($11.951)	($12.190)	($12.434)	($12.682)	($12.936)	($13.195)	($13.459)	($13.728)	($14.002)	($14.282)	($14.568)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Digestate (if treated as an expense	$		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Property Tax or Payment in Lieu of Taxes (PILOT)	$		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Land Lease	$		($25.000)	($25.500)	($26.010)	($26.530)	($27.061)	($27.602)	($28.154)	($28.717)	($29.291)	($29.877)	($30.475)	($31.084)	($31.706)	($32.340)	($32.987)	($33.647)	($34.320)	($35.006)	($35.706)	($36.420)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Royalties	$		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Operating Expenses	$		**($733.964)**	**($748.643)**	**($763.616)**	**($778.888)**	**($794.466)**	**($810.356)**	**($826.563)**	**($843.094)**	**($859.956)**	**($877.155)**	**($894.698)**	**($912.592)**	**($930.844)**	**($949.461)**	**($968.450)**	**($987.819)**	**($1.007.575)**	**($1.027.727)**	**($1.048.281)**	**($1.069.247)**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Operating Expenses	¢/kWh		-6,75	-6,88	-7,02	-7,16	-7,30	-7,45	-7,60	-7,75	-7,90	-8,06	-8,22	-8,39	-8,56	-8,73	-8,90	-9,08	-9,26	-9,45	-9,64	-9,83	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
EBITDA (Operating Income)	$		**$762.429**	**$768.428**	**$774.541**	**$780.771**	**$787.120**	**$793.590**	**$800.183**	**$806.903**	**$813.751**	**$820.731**	**$628.906**	**$632.176**	**$635.506**	**$637.490**	**$639.535**	**$643.050**	**$646.628**	**$650.272**	**$653.983**	**$654.417**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
	Avg. DSCR	*Min DSCR*																														
Annual Debt Service Coverage Ratio	*2,01*	*1,68*	*2,03*	*2,05*	*2,06*	*2,08*	*2,10*	*2,12*	*2,13*	*2,15*	*2,17*	*2,19*	*1,68*	*1,69*	*1,69*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
Minimum DSSCR Year													*Year 11*																			
Loan Interest Expense			($219.450)	($208.554)	($196.896)	($184.421)	($171.073)	($156.791)	($141.509)	($125.157)	($107.660)	($88.939)	($68.908)	($47.474)	($24.540)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Operating Income After Interest Expense			**$542.979**	**$559.874**	**$577.645**	**$596.350**	**$616.047**	**$636.799**	**$658.675**	**$681.746**	**$706.091**	**$731.792**	**$559.998**	**$584.702**	**$610.966**	**$637.490**	**$639.535**	**$643.050**	**$646.628**	**$650.272**	**$653.983**	**$654.417**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Repayment of Loan Principal			($155.655)	($166.551)	($178.210)	($190.685)	($204.032)	($218.315)	($233.597)	($249.949)	($267.445)	($286.166)	($306.198)	($327.632)	($350.566)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
(Contributions to), and Liquidation of, Reserve Accounts			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$187.553	$0	$0	$0	$0	$0	$445.835	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Adjustment(s) for Major Equipment Replacement(s)			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Pre-Tax Cash Flow to Equity			**$387.324**	**$393.323**	**$399.436**	**$405.665**	**$412.014**	**$418.484**	**$425.078**	**$431.798**	**$438.646**	**$445.625**	**$253.800**	**$257.071**	**$260.401**	**$825.042**	**$639.535**	**$643.050**	**$646.628**	**$650.272**	**$653.983**	**$1.100.252**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Project Cash Flows																																
Equity Investment		($3.410.000)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Pre-Tax Cash Flow to Equity			$387.324	$393.323	$399.436	$405.665	$412.014	$418.484	$425.078	$431.798	$438.646	$445.625	$253.800	$257.071	$260.401	$825.042	$639.535	$643.050	$646.628	$650.272	$653.983	$1.100.252	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Net Pre-Tax Cash Flow to Equity		($3.410.000)	$387.324	$393.323	$399.436	$405.665	$412.014	$418.484	$425.078	$431.798	$438.646	$445.625	$253.800	$257.071	$260.401	$825.042	$639.535	$643.050	$646.628	$650.272	$653.983	$1.100.252	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Running IRR (Cash Only)			*-88,6%*	*-59,9%*	*-38,7%*	*-24,7%*	*-15,4%*	*-8,9%*	*-4,3%*	*-0,9%*	*1,7%*	*3,7%*	*4,6%*	*5,4%*	*6,1%*	*7,7%*	*8,6%*	*9,4%*	*10,0%*	*10,5%*	*10,9%*	*11,4%*	*11,4%*	*11,4%*	*11,4%*	*11,4%*	*11,4%*	*11,4%*	*11,4%*	*11,4%*	*11,4%*	*11,4%*
Depreciation Expense			($1.011.583)	($1.634.375)	($1.011.686)	($637.025)	($634.145)	($352.916)	($73.071)	($73.071)	($73.108)	($73.071)	($73.108)	($73.032)	($73.069)	($73.032)	($73.069)	($49.179)	($25.325)	($25.325)	($25.325)	($25.325)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxable Income (operating loss used as generated)			($468.604)	($1.074.501)	($434.040)	($40.675)	($18.099)	$283.883	$585.604	$608.676	$632.983	$658.721	$486.890	$511.670	$537.897	$564.458	$566.466	$593.871	$621.303	$624.947	$628.658	$629.092	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxable Income (Federal), operating loss treatment ==>>		*As Generated*	($468.604)	($1.074.501)	($434.040)	($40.675)	($18.099)	$283.883	$585.604	$608.676	$632.983	$658.721	$486.890	$511.670	$537.897	$564.458	$566.466	$593.871	$621.303	$624.947	$628.658	$629.092	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxable Income (State), operating loss treatment ==>>		*As Generated*	($468.604)	($1.074.501)	($434.040)	($40.675)	($18.099)	$283.883	$585.604	$608.676	$632.983	$658.721	$486.890	$511.670	$537.897	$564.458	$566.466	$593.871	$621.303	$624.947	$628.658	$629.092	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Federal Income Taxes Saved / (Paid), before ITC/PTC			$72.976	$171.073	$67.258	$3.472	($248)	($49.232)	($98.176)	($101.980)	($105.985)	($110.223)	($78.876)	($82.891)	($87.139)	($91.442)	($91.767)	($96.207)	($100.651)	($101.241)	($101.843)	($101.913)	($0)	$0	$0	$0	$0	$0	$0	$0	$0	$0
State Income Taxes Saved / (Paid), before ITC/PTC			$63.180	$124.096	$60.383	$21.386	$19.475	($10.370)	($40.182)	($42.121)	($44.177)	($46.368)	($48.689)	($51.167)	($53.790)	($56.446)	($56.647)	($59.387)	($62.130)	($62.495)	($62.866)	($62.909)	($0)	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cash Benefit of Federal ITC, Cash Grant, or PTC			$125.119	$127.621	$130.174	$132.777	$135.433	$138.142	$140.904	$143.722	$146.597	$149.529	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cash Benefit of State ITC and/or PTC			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
After-Tax Cash Flow to Equity		**($3.410.000)**	**$648.600**	**$816.113**	**$657.251**	**$563.301**	**$566.674**	**$497.024**	**$427.625**	**$431.419**	**$435.081**	**$438.563**	**$126.235**	**$123.013**	**$119.472**	**$677.154**	**$491.121**	**$487.455**	**$483.847**	**$486.536**	**$489.274**	**$935.430**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Running IRR (After Tax)			*-81,0%*	*-40,7%*	*-20,4%*	*-9,2%*	*-1,6%*	*3,0%*	*5,9%*	*8,1%*	*9,8%*	*11,1%*	*11,4%*	*11,6%*	*11,8%*	*12,8%*	*13,4%*	*13,8%*	*14,2%*	*14,5%*	*14,7%*	*15,1%*	*15,1%*	*15,1%*	*15,1%*	*15,1%*	*15,1%*	*15,1%*	*15,1%*	*15,1%*	*15,1%*	*15,1%*

Pre-Tax (Cash-only) Equity IRR (over defined Useful Life)	**11,43%**
After Tax Equity IRR (over defined Useful Life)	**15,06%**
Net present value @ 5,70 % (over defined Useful life)	$2.601.656

Yr 1 COE
(cents/kWh)

Supporting calculations

	Before Adjustments	% Allocation	After Adjustments	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Debt Service:																	
Debt Sizing (Defined Capital Structure Method)																	
Installed Cost (excluding cost of financing)				5.700.000													
Defined Debt-to-Total-Capital				55%													
Size of Debt				3.135.000													
Loan Repayment																	
Structured Debt Service Payment				-	($375.105)	($375.105)	($375.105)	($375.105)	($375.105)	($375.105)	($375.105)	($375.105)	($375.105)	($375.105)	($375.105)	($375.105)	($375.105)
Interest				-	($219.450)	($208.554)	($196.896)	($184.421)	($171.073)	($156.791)	($141.509)	($125.157)	($107.660)	($88.939)	($68.908)	($47.474)	($24.540)
Principal				-	($155.655)	($166.551)	($178.210)	($190.685)	($204.032)	($218.315)	($233.597)	($249.949)	($267.445)	($286.166)	($306.198)	($327.632)	($350.566)
Loan Amortization																	
Beginning Balance				-	3.135.000	2.979.345	2.812.793	2.634.583	2.443.899	2.239.866	2.021.552	1.787.955	1.538.006	1.270.561	984.395	678.197	350.566
Drawdowns				3.135.000	-	-	-	-	-	-	-	-	-	-	-	-	-
Principal Repayments				-	($155.655)	($166.551)	($178.210)	($190.685)	($204.032)	($218.315)	($233.597)	($249.949)	($267.445)	($286.166)	($306.198)	($327.632)	($350.566)
Ending Balance				3.135.000	2.979.345	2.812.793	2.634.583	2.443.899	2.239.866	2.021.552	1.787.955	1.538.006	1.270.561	984.395	678.197	350.566	-
Depreciation:	**Project Cost Allocation**																
Project/Contract Year	Before Adjustments	% Allocation	After Adjustments	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Depreciation Schedules, Half-Year Convention																	
5 Year MACRS	$4.837.000	74%	$4.837.000		20,00%	32,00%	19,20%	11,52%	11,52%	5,76%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
7 Year MACRS	$0	0%	$0		14,29%	24,49%	17,49%	12,49%	8,93%	8,92%	8,93%	4,46%	0,00%	0,00%	0,00%	0,00%	0,00%
15 Year MACRS	$374.000	6%	$374.000		5,00%	9,50%	8,55%	7,70%	6,93%	6,23%	5,90%	5,90%	5,91%	5,90%	5,91%	5,90%	5,91%
20 Year MACRS	$0	0%	$0		3,75%	7,22%	6,68%	6,18%	5,71%	5,29%	4,89%	4,52%	4,46%	4,46%	4,46%	4,46%	4,46%
5 Year SL	$0	0%	$0		10,00%	20,00%	20,00%	20,00%	20,00%	10,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
15 Year SL	$385.000	6%	$385.000		3,33%	6,67%	6,67%	6,67%	6,67%	6,67%	6,67%	6,67%	6,67%	6,67%	6,67%	6,66%	6,66%
20 Year SL	$506.500	8%	$506.500		2,50%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%
39 Year SL	$0	0%	$0		1,28%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%
Bonus Depreciation			$0		100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Non-Depreciable	$442.500	7%	$442.500														
	Unadjusted		**Adjusted**														
Project Cost Basis	$6.545.000	100%	$6.545.000														
	OK	*OK*	*OK*														
Adjustment to Cost Basis for ITC & Non-taxable Grants	$0																
Annual Depreciation Expense, Initial Installation																	
Total Project Cost, adj for ITC/Grant if applicable			*check*														
5 Year MACRS			$4.837.000		$967.400	$1.547.840	$928.704	$557.222	$557.222	$278.611	$0	$0	$0	$0	$0	$0	$0
7 Year MACRS			$0		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15 Year MACRS			$374.000		$18.700	$35.530	$31.977	$28.798	$25.918	$23.300	$22.066	$22.066	$22.103	$22.066	$22.103	$22.066	$22.103
20 Year MACRS			$0		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5 Year SL			$0		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15 Year SL			$385.000		$12.821	$25.680	$25.680	$25.680	$25.680	$25.680	$25.680	$25.680	$25.680	$25.680	$25.680	$25.641	$25.641
20 Year SL			$506.500		$12.663	$25.325	$25.325	$25.325	$25.325	$25.325	$25.325	$25.325	$25.325	$25.325	$25.325	$25.325	$25.325
39 Year SL			$0		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Bonus Depreciation			$0		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non-Depreciable			$442.500														
Total			$6.545.000	*OK*													
Annual Depreciation Expense, Repairs & Replacements																	
1st Replacement			$0		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Depreciation Timing					0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation Expense					$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2nd Replacement			$0		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Depreciation Timing					0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation Expense					$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3rd Replacement			$0		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Depreciation Timing					0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation Expense					$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4th Replacement			$0		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Depreciation Timing					0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation Expense					$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Depreciation Expense					$1.011.583	$1.634.375	$1.011.686	$637.025	$634.145	$352.916	$73.071	$73.071	$73.108	$73.071	$73.108	$73.032	$73.069
Annual Depreciation Benefit					$265.035	$428.206	$265.062	$166.901	$166.146	$92.464	$19.144	$19.144	$19.154	$19.144	$19.154	$19.134	$19.144

	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Structured Debt Service Payment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Interest	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Principal	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Beginning Balance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drawdowns	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Principal Repayments	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Ending Balance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5 Year MACRS	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
7 Year MACRS	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
15 Year MACRS	5,90%	5,91%	2,95%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
20 Year MACRS	4,46%	4,46%	4,46%	4,46%	4,46%	4,46%	4,46%	2,23%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
5 Year SL	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
15 Year SL	6,66%	6,66%	3,33%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
20 Year SL	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	5,00%	2,50%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
39 Year SL	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%	2,56%
Bonus Depreciation	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
5 Year MACRS (expense)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7 Year MACRS (expense)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15 Year MACRS (expense)	$22.066	$22.103	$11.033	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20 Year MACRS (expense)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5 Year SL (expense)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15 Year SL (expense)	$25.641	$25.641	$12.821	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20 Year SL (expense)	$25.325	$25.325	$25.325	$25.325	$25.325	$25.325	$25.325	$12.663	$0	$0	$0	$0	$0	$0	$0	$0	$0
39 Year SL (expense)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Bonus Depreciation (expense)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
1st Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Depreciation Timing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation Expense	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2nd Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Depreciation Timing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation Expense	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3rd Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Depreciation Timing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation Expense	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4th Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Depreciation Timing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depreciation Expense	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Depreciation Expense	$73.032	$73.069	$49.179	$25.325	$25.325	$25.325	$25.325	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Depreciation Benefit	$19.134	$19.144	$12.885	$6.635	$6.635	$6.635	$6.635	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Operating Loss Carry-Forward, if applicable:																																	
Taxable Income / (Operating Loss)				($468.604)	($1.074.501)	($434.040)	($40.675)	($18.099)	$283.883	$585.604	$608.676	$632.983	$658.721	$486.890	$511.670	$537.897	$564.458	$566.466	$593.871	$621.303	$624.947	$628.658	$629.092	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Federal Carry-Forward																																	
Operating Loss Carry-Forward, Beginning Balance				$0	$468.604	$1.543.104	$1.977.144	$2.017.819	$2.035.918	$1.752.035	$1.166.431	$557.755	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Additional Operating Loss Carried-Forward				$468.604	$1.074.501	$434.040	$40.675	$18.099	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Utilization of Operating Loss Carry-Forward				$0	$0	$0	$0	$0	($283.883)	($585.604)	($608.676)	($557.755)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Operating Loss Carry-Forward, Ending Balance				$468.604	$1.543.104	$1.977.144	$2.017.819	$2.035.918	$1.752.035	$1.166.431	$557.755	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxable Income with Operating Loss Carry-Forward				$0	$0	$0	$0	$0	$0	$0	$0	$75.228	$658.721	$486.890	$511.670	$537.897	$564.458	$566.466	$593.871	$621.303	$624.947	$628.658	$629.092	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
State Carry-Forward																																	
Operating Loss Carry-Forward, Beginning Balance				$0	$468.604	$1.543.104	$1.977.144	$2.017.819	$2.035.918	$1.752.035	$1.166.431	$557.755	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Additional Operating Loss Carried-Forward				$468.604	$1.074.501	$434.040	$40.675	$18.099	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Utilization of Operating Loss Carry-Forward				$0	$0	$0	$0	$0	($283.883)	($585.604)	($608.676)	($557.755)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Operating Loss Carry-Forward, Ending Balance				$468.604	$1.543.104	$1.977.144	$2.017.819	$2.035.918	$1.752.035	$1.166.431	$557.755	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxable Income with Operating Loss Carry-Forward				$0	$0	$0	$0	$0	$0	$0	$0	$75.228	$658.721	$486.890	$511.670	$537.897	$564.458	$566.466	$593.871	$621.303	$624.947	$628.658	$629.092	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Federal Tax Credit Benefits, if applicable:																																	
Federal ITC (as generated)				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Federal PTC (as generated)				$125.119	$127.621	$130.174	$132.777	$135.433	$138.142	$140.904	$143.722	$146.597	$149.529	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Applicable Tax Credits, as generated				$125.119	$127.621	$130.174	$132.777	$135.433	$138.142	$140.904	$143.722	$146.597	$149.529	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Carry-Forward Scenario:																																	
Federal Income Taxes Saved / (Paid), before ITC/PTC				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tax Benefit Carry-Forward, Beginning Balance				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Additional Tax Benefit Carry-Forward				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Utilization of Tax Benefit Carry-Forward				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Tax Benefit Carry-Forward, Ending Balance			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
State Tax Credit Benefits, if applicable:																																	
State ITC (as generated)				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
State PTC (as generated)				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Applicable Tax Credits, as generated				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Carry-Forward Scenario:																																	
State Income Taxes Saved / (Paid), before ITC/PTC				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tax Benefit Carry-Forward, Beginning Balance				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Additional Tax Benefit Carry-Forward				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Utilization of Tax Benefit Carry-Forward				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Tax Benefit Carry-Forward, Ending Balance			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Reserve Accounts:																																	
Beginning Balance			$0	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$445.835	$445.835	$445.835	$445.835	$445.835	$445.835	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Debt Service Reserve			$187.553	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	($187.553)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
O&M/Working Capital Reserve			$445.835	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	($445.835)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Major Equipment Replacement Reserves #1	(max funding period, yrs)	10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Major Equipment Replacement Reserves #2	(max funding period, yrs)	10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Major Equipment Replacement Reserves #3	(max funding period, yrs)	10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Major Equipment Replacement Reserves #4	(max funding period, yrs)	10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Decommissioning Reserve			$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Ending Balance			$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$633.388	$445.835	$445.835	$445.835	$445.835	$445.835	$445.835	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Interest on Reserves				$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$9.501	$8.094	$6.688	$6.688	$6.688	$6.688	$6.688	$3.344	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Annual Contributions to/(Liquidations of) Reserves				$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	($187.553)	$0	$0	$0	$0	$0	($445.835)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

COE Data Tables		NPV			NPV				NPV			Range Min	Range Max
Calculation of COE when tax benefits are "Carried Forward"		$8.098			$8.098				$8.098			7,7	7,8
	0	($3.776.380)		0,0	($3.776.380)			7,0	($358.142)				
	10	$1.106.817	$1.106.817	1,0	($3.288.060)			7,1	($309.310)				
	20	$5.990.013		2,0	($2.799.740)			7,2	($260.478)				
	30	$10.873.210		3,0	($2.311.421)			7,3	($211.646)				
	40	$15.756.407		4,0	($1.823.101)			7,4	($162.814)				
	50	$20.639.603		5,0	($1.334.781)			7,5	($113.982)				
	60	$25.522.800		6,0	($846.462)			7,6	($65.150)				
	70	$30.405.997		7,0	($358.142)	($358.142)		7,7	($16.318)	($16.318)			
	80	$35.289.193		8,0	$130.178		$130.178	7,8	$32.514		$32.514		
	90	$40.172.390		9,0	$618.497			7,9	$81.346				
	100	$45.055.587		10,0	$1.106.817			8,0	$130.178				