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WOIMA ECOSYSTEM

Energy and Material Flows

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Maailmassa tuotetaan paljon jätteitä, jotka liian useissa valtioissa loppusijoitetaan kaatopaikalle. Jätteiden sisältämä arvokas energia pitää saada hyötykäyttöön. Jätteet myös sisältävät arvokasta materiaalia, josta saadaan jalostamalla raaka-aineita uusiin tuotteisiin.

Opinnäytetyössä tutkittiin Woima Corporationin moduulijätteenpolttolaitoksen ympärille rakentuvaa ekosysteemiä. Työssä selvitettiin eri prosessien energiantarve ja -tyyppi, alku- ja lopputuotteita, sekä näiden tuotteiden keskinäisiä riippuvuuksia. Jätteen, eli pääraaka-aineen, lisäksi kartoitettiin mahdollisten kemikaalien tarve.

Prosessien ja eri tekniikoiden vaatimuksia ja erityispiirteitä selvitettiin tutkimalla valmistajien nettisivuillaan jakamia tietoja, sekä etsimällä informaatiota tieteellisistä lähteistä.

Jätteen voi jalostaa hyvin monella tavalla suoraan energiaksi, polttoaineeksi tai raaka-aineeksi. Monet prosessit vaativat tarkan lajittelun. Jätteet pystytään hyödyntämään tehokkaasti lopputuotteeksi asti ilman, että syntyy loppusijoitettavaa jätettä kaatopaikalle.

Avainsanat Uusiutuva energia, jäte, ekosysteemi, biopolttoaine

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ABSTRACT

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Great amounts of waste are in produced in the world. Too often it will only be disposed to the landfill. The wastes contain a lot of valuable energy and it must be recovered. Wastes also contains valuable material, which can be refined to raw material.

The objective of this thesis work was to explore the ecosystem of Woima Corporation's waste-to-energy power plant. Different waste refining processes were studied in the thesis. The type and need of energy, the Input and output materials and the relationships between those materials were discovered.

The requirements and special features of processes and different technologies were investigated by exploring the information distributed by manufacturers on their website and by searching for information from scientific sources.

Waste can be processed in many ways directly into energy, fuel or raw material. Many processes require accurate sorting to ensure the quality of feedstock. Waste can be utilized effectively into the final product without residual waste that must be disposed of to the landfill.

Keywords Renewable Energy, waste, ecosystem, biofuel

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1 INTRODUCTION

The objective of this thesis work is to explore thecomplementary processes and material streams for wasteWOIMA power plant to create ecosystem. The ecosystem is created around the main power plant, which can for example, include biogas plant, waste water treatment, biogas upgrading and animal rendering. Those all facilities support each other to get the best benefit from feed stock, which is waste in different forms. This thesis explores the most suitable options for the ecosystem and processes, which can solve global problems and environmental issues.

The objective of the thesis is to map all the inputs (raw materials, feed stocks and energy) and outputs (end products, intermediate products and overstocks) off the processes. The purpose is also to find out the possible chemical need to execute the process, and the other materials than waste. The thesis strives to answer the following questions:

- What kind of energy is needed in the process?
- What does the process produce?
- What are the final products and possible by-products and, is it possible to utilize them?

It is important to know how all these processes work, by that way it is possible to find the methods to minimize overstocks and get the most out of the fuels. The used process should operate with environment friendly technologies to increase the total value of waste utilization.

The main fuels in this ecosystem are different kind of wastes. These wastes are collected and sorted, then targeted to the correct processes. Wastes are sorted by their suitability to different processes, for example, organic wastes with high moisture content go to the anaerobic digestion. After that useful outputs (final products and by-products) will be reused in other processes. Materials that cannot used in any process anymore will be disposed of, for example to the landfill. One of the aims in this thesis thesis is to find the connections between the process output and the input materials, and to minimize disposed wastes.

1.1 Ecosystem Planning

The main product of Woima Corporation is a waste-to-energy power plant and they want to offer bigger solutions than just a power plant. This ecosystem plan helps to develop an entity that the customer desires and can be customized by its needs. The ecosystem must be as effective as possible. Therefore, material and energy flows must be designed to work as well as possible. By managing those flows it is possible to design the efficient combination of renewable energy technologies.

There is a need for a sustainable and efficient way to get rid of waste, without producing more emissions, and also refine wastes to raw material for new ecological products. The world is currently producing about 1.3 billion tons of garbage a yearly /1/. Unfortunately, about 60 percent of this garbage will end up in landfills. Dumping and burying this mass in to the landfills is not a viable solution for our garbage disposal problems. There is not enough usable space to safely deposit billions of tons of this heavily contaminated material on an annual basis. Landfills are also bad option for environment, and economically they are a complete waste of money. /2/

Turning waste straight to energy or to fuel helps to decrease greenhouse gas emissions generated in landfills. Recovering the energy from waste does not benefit only the environment, it also adds value to waste. Materials that found in municipal waste can be utilized as raw material of new products. This helps to save energy, keep the nature, and to recycle limited resources. There are lot of facts that prove, that is a waste to waste the valuable waste. Social responsibility also drives countries and large corporations to manage their wastes. /2/

1.2 Benefits of Waste to Energy

The reduction of waste going to landfill sites is one big advantage. When the waste is delivered to a waste to energy facility, the methane that would have been emerged if it were sent to a landfill is avoided. Also, when generating energy from waste, the carbon emission that would have been generated from a fossil fuel source are avoided. At same time it is a more environment-friendly source of energy. The reliance on fossil fuel is deceased, fluctuations in oil prices and rising costs can be avoided. Waste to energy is great opportunity to the local community and economy. Plants are creating jobs locally, offer energy to local community and the fuel is collected from surrounding area. It is also domestic production of energy. Great amounts of waste are generated locally and hence there is no requirement of transportation of materials for this process from far out. /2-3/

2 WOIMA CORPORATION

This section gives information and details about Woima's product, the modular waste-to-energy power plant. The explanation of how the waste incineration plant operates is also given.

Woima Corporation is a Finnish company founded in 2016. Woima is located in Vaasa, which is called a world-renowned energy cluster capital. The mission of the company is to mitigate waste-induced problems across the globe. Woima is a supplier of containerized modular waste-to-energy power plants, and they are offering the “people-sized” solutions to waste problems especially for developing countries. /4/

2.1 Waste-to-Energy Power Plant

Woima’s first pledge in fighting pollution, poverty and social inequality is a containerized modular waste-to-energy power plant. The containers are pre-assembled in Finland. The main competitive advantages are quick installation, easy delivery, and cost efficiency in daily run and simple to maintain. It will obviously reduce the need to transport waste and-, eliminate the need for unproductive landfills. It will also support the development of electrical micro grids, and offer electricity, thermal energy and potable water for local industry. The plant will offer local jobs and training opportunities. /4/

A modular waste-to-energy plant produces:

- Steam 17 tons / h 400°C / 40 bar) OR
- Electricity 3,4 MWe (gross power) / 2,7 MWe (net power) or,
- Electricity 2 MWe and thermal energy 10 MWt and
- Potable water 200 m3 / day /5/

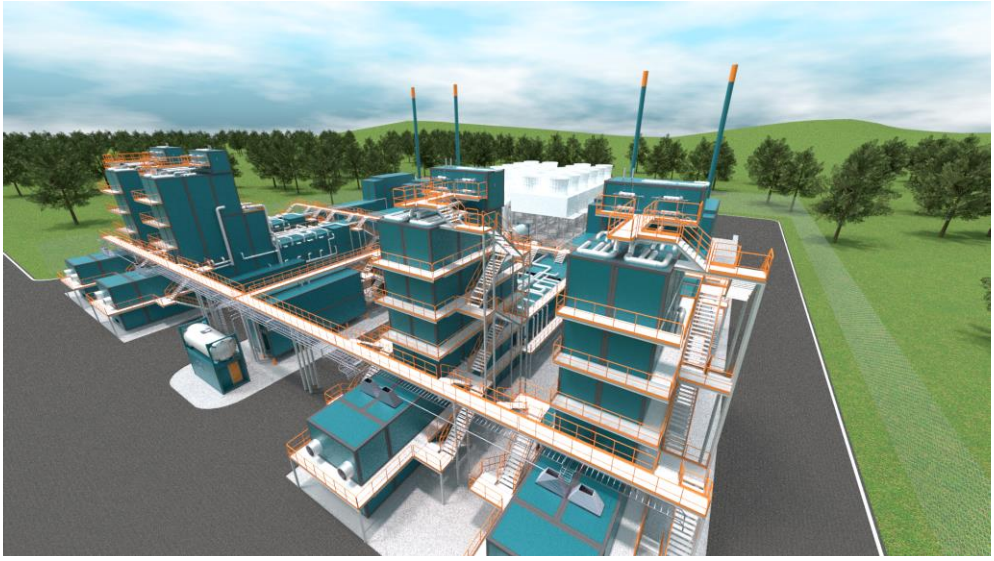

Figure 1. Waste to energy power plant. /4/

2.2 Incineration

The wasteWOIMA waste-to-energy power plant technology is based on a grate incineration. In the grate technology fed-in waste moves on the grate through the 3 combustion phases; drying pyrolysis and char combustion. After that bottom ash falls off into a cooling pool. Primary air is blowing through the grate to support full combustion. It also acts as a cooler for the grate reducing the need for maintenance work. The bottom ash is convoyed to an ash processing system by conveyor belts, where water is removed and returned to the cooling pond. The remaining ash is used in other processes. /5/

2.3 Heat Radiation and Cooling

The upper furnace opens from the middle to the adiabatic combustion chamber where the gasified fuels burn. The secondary and tertiary air is injected into the upper combustion chamber to ensure complete combustion of gases. Then gases flow into the radiation and cooling channel, where the vapor and water in the membrane walls piping absorbs the heat of the flue gases. The steam drum holds the partly evaporated mixture of steam and water, then gravity recirculates the water back into the membrane walls. The length of channel for gases guarantees the EU-standard residence time for flue gas, which is 2 seconds at 850 °C. These circumstances are required to fully burn out for the highly toxic elements in the flue gas. At the same time radiation channel cools down the hot flue gas to defend the heat recovery boiler from corrosion. /5/

2.4 Heat Recovery

The recovery boiler collects the heat from the radiation channel. This recovery boiler includes the superheater, evaporator, economizer and air preheater. They all are a series of piping arrays designed to collect the heat from the flue gas. The evaporator and superheater convert the steam from walls of channel into superheated steam for the steam genset. The purpose of the economizer is to preheat the water, which is flowing from the water tank into the steam drum. A function of the air preheater is to heat the primary, secondary and tertiary air for improve incineration. The flue gas contains the fly ash which accumulates on the wall and piping and that reduces its heat transfer efficiency. To make sure the proper functionality of the heat recovery boiler, an efficient soot removal process is needed. /5/

2.5 APC-system

The air pollution control of the WOIMA power plant is based on a dry APC-system. The system contains hydrated lime and activated carbon dozing systems. There is also a reactor with a combined fabric filtration system. Both systems are producing dry ash residue. The APC-system meets both,- the EU emission standards and World Banks air pollution guidelines. Both,- bottom and fly ashes are clean enough to be used as for example, construction material. But the APC-ash contains a high proportion of heavy metals and also other toxic residues. The APC-ash must be processed further or placed in a landfill. The bottom and fly ash quantity is about 15% and the APC ash is about 3% of the total incinerated waste weight. /5/

2.6 Power Generation

The saturated and superheated steam is moved to a steam turbine-generator set, which transforms steam into electricity. The plant uses a standard back-pressure of extraction turbine, depending on customer needs. After the turbine, the used steam is driven to the condensing system, where the steam is reduced back to water, then the production of steam continues in this closed circuit. The production of the power plant can be used in the form of electricity, steam, thermal power, potable water, or a different combination of the above. The plant has an auxiliary diesel generator set, which can be used during the start-up and shut-down of the plant. During the maintenance it can also offer power to the local operations in the plant without out-side power. /5/

The benefits of the technology and modular structure of this waste-to-energy power plant are:

- simple and strong structure
- high pre-fabrication rate
- quick assembly
- high efficiency
- low operating and maintenance cost
- potential for relocation /5/

3 ECOSYSTEM

The Woima ecosystem might include several different waste refining processes. Those all processes have different way to utilize wastes with various properties and qualities. Some of the techniques transfer waste to fuel for example, biogas production and some straight to the energy e.g. combustion of waste.

To understand energy and material flows all the different materials, chemicals and type of energy needed in process must be determined and, the final products must also be discovered. For that reason, out all input materials (raw materials, energy, feedstocks) and output materials (end products, intermediate products, overstocks) must found. When these materials are known, it is easy to find out the connections between different processes. Those connections mean the relationships between outputs and inputs of different processes. The basis for this chapter is (Appendix 1.). There are listed all possible processes and their input and output materials and energy need.

This chapter introduces the connections between processes. (Figure 2) Describes how materials and energy moves between different processes, it also gives information about final products. In (figure 3) are listed feasible processes, which are later introduced in chapter 4.

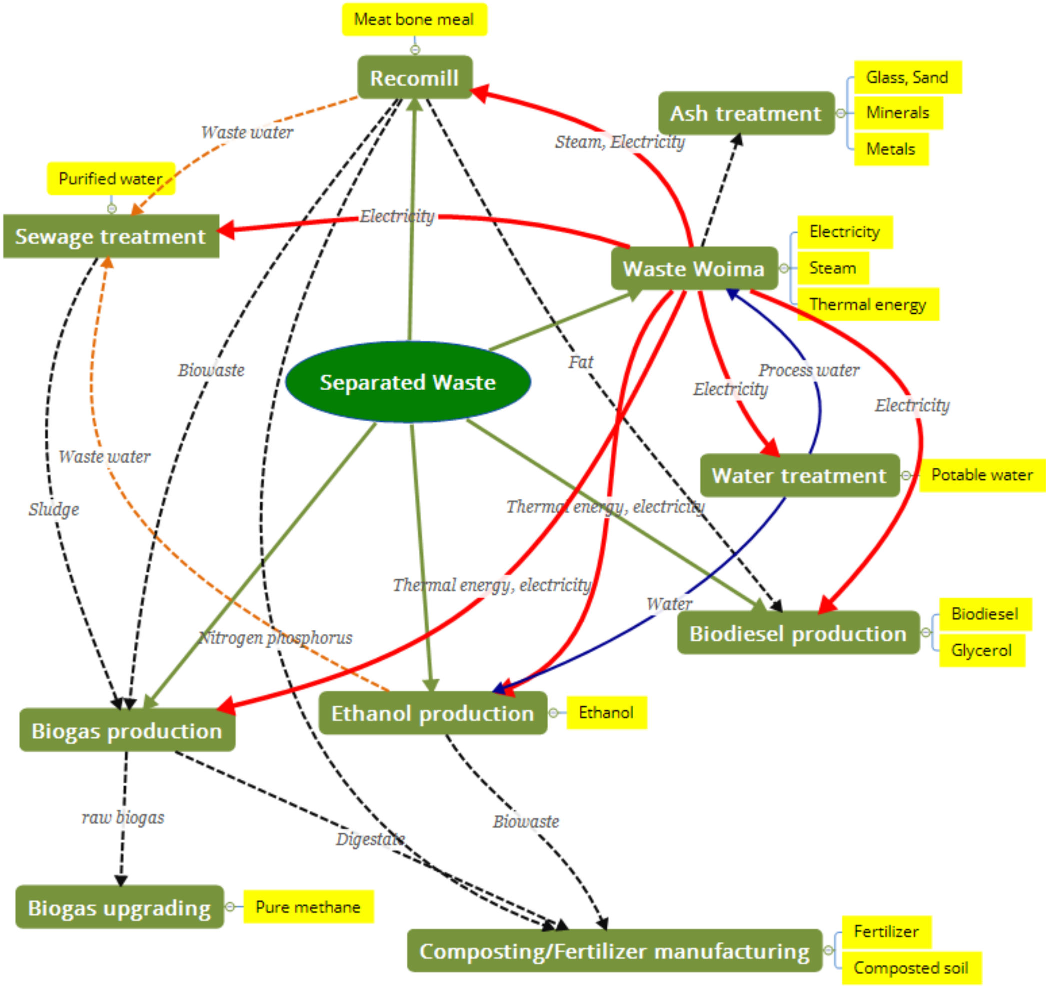

Figure 2. Material and energy flows.

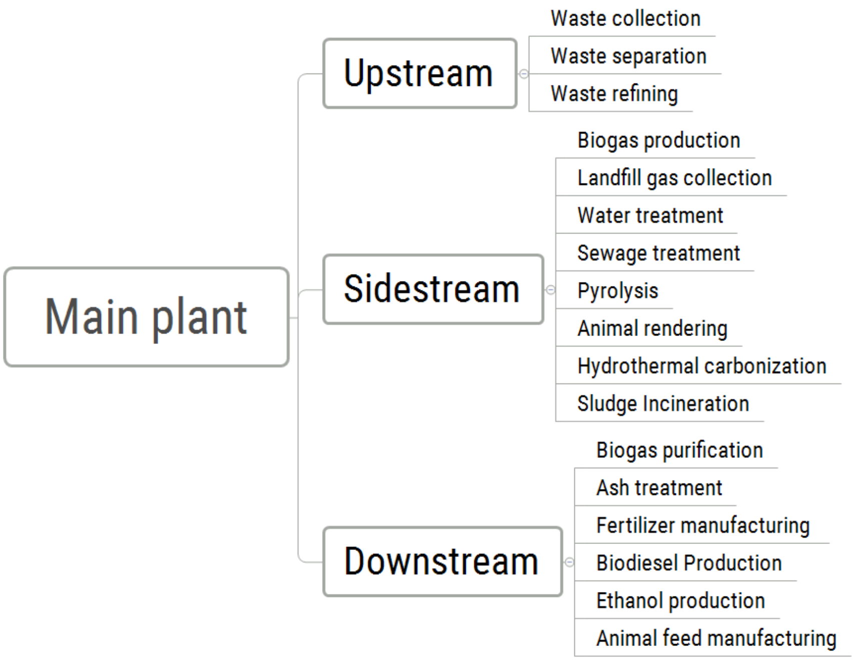

Figure 3.

3.1 Upstream

The first phase in waste processing is waste collecting and transporting to the plant area. Wastes are collected from the waste sources, for example, hospitals, farms and food industry facilities. Those wastes could be anything between basic household wastes to industrial wastes. The best solution for transporting is trucks. The ideal location for a plant is close to waste sources to reduce transportation costs. /6/

In refining, the wastes are separated to different qualities by suitability for different processes of the plant. Wastes, which are not suitable for any process at the plant are transported to other recovery facilities, for example different metal types or some hazardous wastes. Construction wastes might be also problematic for reuse or combustion, for example gypsum plasterboard and different types of wool. In separating some wastes may be found that are not suitable for any purposes. Those are transported to a final disposal dump. /6,7/

Separated wastes are feedstock for each process at the plant. Those wastes are directed by the quality and properties of wastes. For example, dry and burnable wastes got to incineration, the wastes with a high moisture content to digestion and fats and oils to biodiesel refining. There is an own process for electronic waste, where is possible to separate iron metals, aluminium and light alloys, copper, gold and other precious metals, and plastics. /8/

For recycled class there is also a solution, which is different types of crushed class products. Glass powder can be used for different industrial uses, for example to decrease wear and to improve resistance to chemicals. It can increase rigidity and help to control thermal expansion. Glass powder is also an effective blowing agent for many applications. Other glass product could be packaging cullet and float cullet. /9/

For collected batteries there is a possibility to turn them into fertilizer. The innovative chemical process turns alkaline batteries to Manganese and Zink-based liquid foliar fertilizer. There is enough raw material because 75-85% of the world’s batteries contain alkali. Now the most of alkali batteries goes to the landfill. /10/

3.2 The Main Plant

The waste incineration plant use separated combustible waste as a fuel. Large objects are crushed before incineration and metal objects are removed from waste, by manually or mechanically. Toxic waste is not allowed. Lime and activated carbon are needed to manage emissions and to control the quality of the exhaust gas. The plant has a possibility to produce steam, electricity, thermal heat or potable water. The option to distribute steam to the industry in the surrounding area and offer district heating to local community. These products can be utilized as energy in other processes, for example warming the anaerobic digestion tanks. Intermediate products, such as ash can be exploit in ash treatment processes. The APC-residue is hazardous overstock from incineration, it requires special treatment. /5/

3.3 Sidestream

Wet and organic wastes are usually directed to anaerobic digestion. To complete a full digestion, digesters need heating to maintain the optimal operating temperature. Thermal heat is available from waste-to-energy power plant. As a feedstock anaerobic digestion uses sludge, organic/bio waste and various sources of biomass (Figure 4.) such as , sludge from sewage treatment, biowaste from waste separation and animal rendering. Use of agricultural wastes is also possible. the anaerobic process generates biogas as a main product, biogas can also be co-incinerated in waste-WOIMA without purification. there are also available purification techniques for biogas. In addition to biogas digestate is also produced. The digestate can be manufactured to fertilizer or be composted. /11/

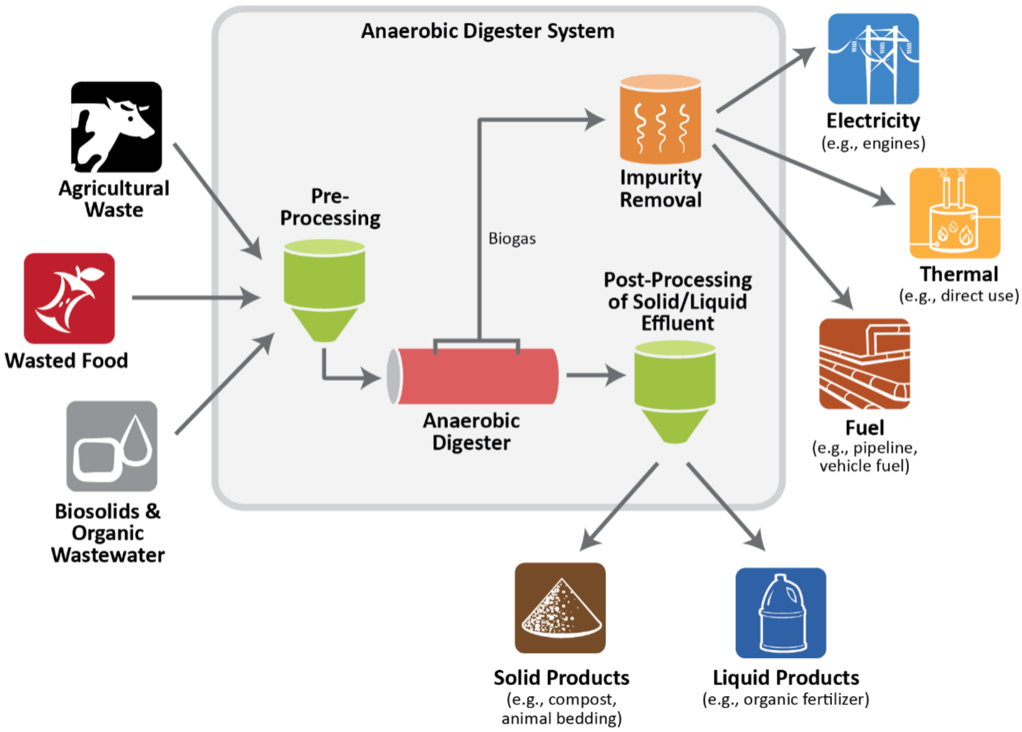

Figure 4. Anaerobic digestion feedstock and products. /12/

When an ecosystem is located close to an old landfill, it can be included in a landfill gas collection system. This collection system is technically quite simple. Collected landfill gas can be also co-incinerated at the power plant. /13/

The quality of water is very important for any kind of steam turbine plant. For that reason, an efficient water purification system is needed. Poor quality of process water may cause problems in different processes, solids on water might damage the turbine, and even low metal concentrations in the process water can cause layers inside the piping. Iron and copper with oxygen can form corrosion. The quality of process water decreases slightly, which why the little amounts of water are removed from the process and need to be recovered with clean water. Wastes that are produced in a water purifying process could be used as a feedstock in other processes. For example, they can be utilized in combustion or digestion. Water purification offers the opportunity to distribute water to outside the ecosystem. Countries where there is a need for this kind of waste solution there is also a true lack of fresh water for household use. There are chemical and biological options for water treatment. /14/

A huge ecosystem like this produces a lot of waste water, there are some systems which have waste water as a by-product, example the steam process of a power plant and biodiesel production. Produced waste water might contain chemicals and bacteria from processes. The waste water treatment produces sludge as a by-product and it can be utilized in other processes. Sludge can be feedstock of biogas production or it can be converted to fertilizer. It is necessary to take care of the most important natural resource of planet, the water. Water resources should be protected by returning waste water back to a water cycle. Wastewater contains many harmful toxins and substances and cannot be released back into the nature until it is treated. Untreated water is harmful for animals, plants and for whole ecosystem. /15/

The pyrolysis process is an efficient waste-to-fuel solution. It can convert plastic waste, tyres and rubber to biofuel (pyrolysis oil, syngas char). There is a possibility to make bitumen and recovered carbon black from tires. It is possible to obtain large amounts of plastic from separation. The process needs a high temperature to function. Thermal energy is easily available from the incineration process. /16/

Animal rendering is a process which use inedible animal-derived by-products. These products are generated by abattoirs and farms. The animal rendering solution produces fat and meat bone meal, which is feedstock material for fertilizer manufacturing, feed production and biodiesel refining and cosmetic industry. The process also produces clean water and thermal energy. This process is an efficient way to derive by-products from the food chain back to the production cycle. /17/

Hydrothermal carbonization and sludge incineration are good options to utilize wastes with a higher moisture content. In the incineration sludge is treated with high temperature to get fertilizing ash. Hydrothermal carbonization is a process, which utilize organic biomass or waste. Good feed stock materials for this process are: water treatment sludge, wet animal manure, municipal bio-waste, algae and water plants. To function, this technique needs thermal energy to heat the biomass. The final product is called hydrochar, which can be used as activated carbon. Activated carbon is needed in the APC-process of incineration. Both of these processes produce water, which need to be treated. /18,19/

3.4 Downstream

Only 60% of biogas is methane, the rest of it is mainly carbon dioxide, hydrogen sulphide and water vapour. Biogas need to be upgraded close to 100% methane. There are different techniques to upgrade, for example water washing and pressure swing adsorption. After upgrading biogas can be used instead of natural gas. As a by-product the purification produces carbon dioxide and hydrogen sulphide. If water washing is used, small amounts of waste water will be produced /20/

Incineration produces quite much ash; the bottom and fly ash quantity is about 15% and the APC ash is about 3% of the total incinerated waste amount. The bottom and fly ashes are enough clean to be used as, for example construction material. The material can be used as plasterboards and land filling material. The bottom ash contains lot of different metals, glass and rocks. These metals can be sold forward after the separation from ash. The APC-ash need special treatment to remove or neutralize all toxins from it. It can be treated locally or transported away, but after for example plasma treatment the APC-ash can be used also as construction material. Too often ashes are disposed of in landfills. /5/

There are few processes that produce material, which can be utilized in the manufacturing of fertilizer. These include sludge from a waste water treatment process, digestate from an anaerobic digestion process. Biomass is available from farms and also from ethanol and biodiesel production. Manufactured soil improvement/fertilizing material can be sold to local farmers. /21/

In biodiesel refining it is possible to use different kind of oils and fats as feedstock material; oil corps, animal oil/fats, tallow, recycle greases, cooking oil. The biodiesel production process requires also methanol, and some acid as a catalyst, for example sulphur acid. Also, sodium hydroxide or potassium hydroxide is needed. The process produces biodiesel which is also called methyl ester. The by-product of the process is glycerol. Depending on the process waste water may be generated. /22/

Bioethanol refining is a distillation process, where cellulosic wastes, grains, sugar cane or sugar beet are converted to ethanol. The process needs yeast and enzymes to function. This process needs also thermal heat and its easily available in ecosystem. The by-product of the process is mash, which can be utilized in anaerobic digestion or in animal feed production. /23/

In the production of animal feed it is possible to utilize different by-products from other processes, for example mash from distillation, and proteins from animal rendering. Products from agriculture can be also utilized./17,23/

4 FEASIBLE PROCESSES

This chapter introduces processes that might be part of the ecosystem and explains common and most usable techniques.

4.1 Potable Water Treatment Techniques

Coagulation and flocculation are usually the first steps in modern water treatment. Chemicals with positive charge are added to the water, and these chemicals neutralize the negative charge of dirt and other dissolved matter in the water. When this chemical reaction occurs, the particles form larger particles, and that is called floc. In the sedimentation phase, the a floc sinks to the bottom of water supply. This process is called sedimentation. After the floc has settled down, the clear water on top passes through filters of varying compositions and pore sizes, to remove dissolved particles, such as bacteria, chemicals and dust. This process is called filtration. After the filtration, disinfectant chemical for example chlorine will be added in water to kill possible remaining bacteria or viruses. /15/

4.2 Waste Water Treatment

Waste water treatment plants are usually put to two different categories; chemical or physical treatment, and biological treatment. Biological waste treatment process works by using biological bacteria and matter to break down waste matter. The physical waste treatment process works by using chemical reactions and physical processes to treat wastewater. Biological treatment processes are the most suitable for treating wastewater from households and business locations. Physical wastewater plants are targeted for industrial and largescale use, because usually industrial waste water contains chemicals and toxins. /24/

4.3 Hydrothermal Carbonization

Hydrothermal carbonization is a chemical process for the conversion of organic compounds to structured carbons. It can be used to make different kinds of nanostructured carbons, and brown coal substitute. In the hydrothermal carbonization process, the structure of the sludge is transformed, removing chemically bound oxygen and hydrogen and intracellular water. The biomass is placed in a closed reactor and treated at about 180-250°C under self-generated pressure. The total sludge mass at the start of the hydrothermal carbonization process can be reduced by up to 70%, using only 25% of the energy compared to thermal drying. The remaining sludge press cake is explosion-safe and has good handling and transportation properties. /18,19/

Hydrothermal carbonization is the most effective way to produce carbon. The final product contains only very little amount of gas, also the liquid components stay between 5 to 20%. The greatest advantage of hydrothermal carbonization is its ability to handle moist feed materials directly, without the time-consuming and energy-wasting drainage stage. The temperature is enough to destroy the bacteria and viruses from the waste, which make waste management easier and faster, while the process is producing commercially and environmentally valuable biocarbon. /18,19/

4.4 Anaerobic Digestion

An anaerobic process is a microbiological process of decomposition of organic matter in the absence of oxygen. The two main products of the process are biogas and digestate. Biogas is a combustible gas, which is containing mainly the methane, carbon dioxide and water. The digestate is the decomposed substrate from the production of biogas. The heat is generated very little during the anaerobic digestion. /11/

The biogas formation process is a result of process phases, in which the material is continuously broken down into smaller and smaller units. Groups of micro-organisms are involved in each different phase. These micro-organisms successively decompose the products of the previous phases. The anaerobic digestion process consists of four main process phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis. /11/

The process phases run in parallel in time and space in the digester tank, (described in Figure 5). When processing substrates containing cellulose, hemi-cellulose and lignin, hydrolysis is the speed determining process. In hydrolysis, only small amounts of biogas are produced. The peak is reached during methanogenesis. /11/

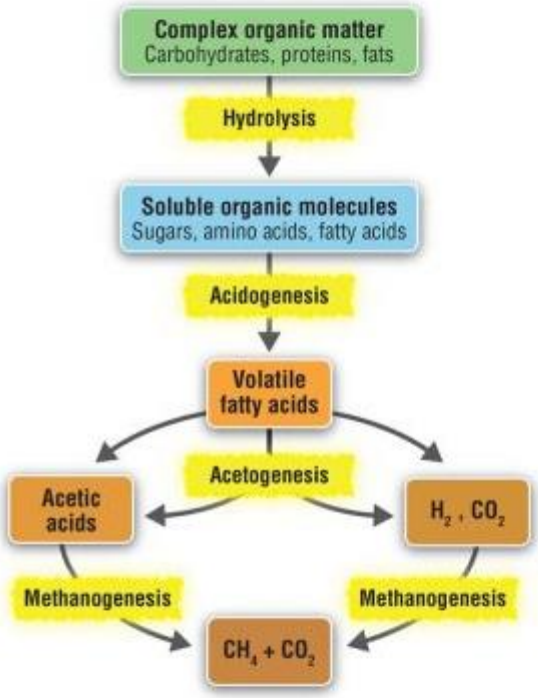

Figure 5. Anaerobic digestion process. /25/

4.4.1 Hydrolysis

Hydrolysis, theoretically the first phase of anaerobic digestion. During this phase the complex organic matter (polymers) is decomposed into smaller components (monomers and oligomers). During the hydrolysis lipids are converted to fatty acids and glycerol, polysaccharide to monosaccharide, proteins to amino acids. /11/

4.4.2 Acidogenesis

The products of hydrolysis phase are converted by acidogenic bacteria into methanogenic substrate. Sugar fatty and amino acids are degraded into carbon dioxide, acetate and hydrogen (70%) and also into volatile fatty acids and alcohols. /11/

4.4.3 Acetogenesis

Acidogenesis products, which cannot be directly converted to methane, are converted into methanogenic substrates in an acetogenesis process. Alcohols and volatile fatty acids are oxidised into methanogenic substrates (acetate, hydrogen and carbon dioxide). /11/

4.4.4 Methanogenesis

The production of methane and carbon dioxide is carried out by methanogenic bacteria. 70% of methane originates from acetate, while the 30% is produced from hydrogen and carbon dioxide. Methanogenesis is the most critical phase in the anaerobic digestion process. It is highly influenced by operation conditions: feeding rate, temperature, pH and composition of feedstock are examples of those factors. The decreasing of methane production can result in temperature changes, digester over loading or large entry of oxygen. /11/

4.5 Two Types of Anaerobic Digestion Processes

There are two main types of anaerobic digestion processes for treatment of biodegradable wastes: wet anaerobic digestion systems which use organic material with composition of 10–2% dry matter or less and dry anaerobic digestion systems for organic matter with composition of 20–>40% dry matter or more. The choice whether to use dry or wet digestion for the fermentation of the organic depend on dry matter content. /11/

4.5.1 Dry Anaerobic Digestion

Dry digestion in full-scale application can be performed in a continuous and discontinuous system. Dry digestion is discontinuous because biogas production is sequenced with loading and unloading phases. Systems with several digesters will operate in parallel and allow constant production of biogas. Dry anaerobic digestion is a more valuable solution than wet anaerobic digestion in order to optimize the value of manure. Actually, a wet anaerobic digestion plant is quite limited for the treatment of dry matter-based substrate. Dry system is very tolerant for contaminants (fibres, sand large particles). Dry anaerobic digestion systems allow to use substrates with a high content of livestock manure, crop residues and household waste. /26/

The dry system is a less complex system than wet AD systems. Power, heat and water needs are low, it also requires less critical equipment (pumps, agitation systems, feeding equipment). Because of simple system, dry AD requires less maintenance. The dry system has a possibility to be mobile biogas plant (container system). The dry system needs special technologies for loading and unloading of the digester. In discontinuous systems, the microbial process must start for each batch every time. The substrate will be not totally mixed in digesters. The investment and operating costs are higher than those in the wet anaerobic digestion system. The recommendation is to use dry anaerobic digestion, when the feedstock contains more than 10% of sand or large solids or other non-degradable materials such as synthetic materials (table 1). /26/

Table 1. Comparison of anaerobic digestion processes. /26/

Comparison Criteria	Wet Digestion	Dry Digestion
Input material	maximum 20% dry matter	20-40% dry matter
Water consumption	Dilution may be necessary	Percolat renewal
Process stability	Easier to intervene in the case of biological malfunction	Need to manage several digestors simultaneusly
Heat need	20 to 30% of the heat produced	Lower need for thermally insulated installations
Power need	Pumps and mixers	Low
Fuel need	None, except if dualfuel engine	None, except if dualfuel engine
Digestate	Pumpable	Removed with loader
Manpower need	Possible automation	Important for loading/unloading
Biogas production	Linear production	Sequenced production over time
Security	Plant commissioning = high risk period	Loading/unloading = high risk period

4.6 Pyrolysis

Pyrolysis is a simple thermochemical treatment (Figure 6), which can be used to any carbon-based product. In this process the material is predisposed to high temperature, and in the absence of oxygen goes through physical and chemical separation into different molecules. When no oxygen is present the material does not combust but the chemical compounds that make up that material thermally decompose into combustible gases and charcoal. Most of these combustible gases can be condensed into a combustible liquid, called pyrolysis oil, though there are some permanent gases (CO¬2, CO, H2, light hydrocarbons). Pyrolysis can produce three products: liquid, (pyrolysis oil) solid (char), gaseous (syngas). /16/

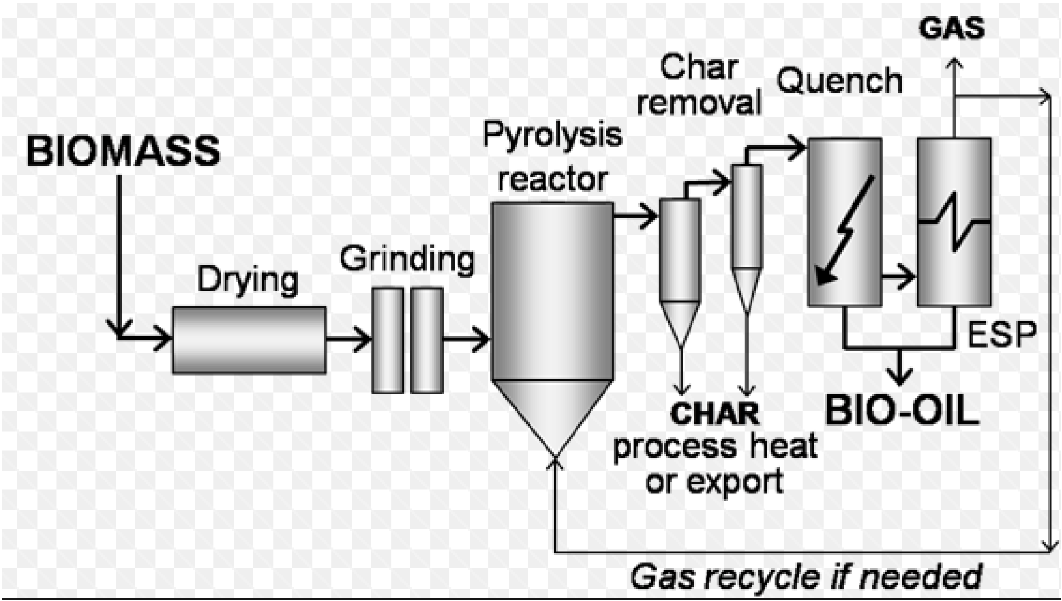

Figure 6. Pyrolysis process. /27/

4.6.1 Factors that Influence Pyrolysis Result

Each of major component of biomass or waste feature different temperatures of thermal decomposition, which means they must be treat in a different way in process. The Temperature of process has a major influence on the process results. Higher temperatures of pyrolysis offer greater quantity of non-condensable gases (syngas, synthetic gas), while lower temperatures provide the production of high-quality solid product (torrefied fuels, charcoal, bio-coal). /28/

The residence time of material in the pyrolysis chamber influences the degree of thermal conversion of received solid product. Also, the residence time of the vapour, influences the composition of vapours. Physical structure and particle size influence the speed in which material is subjected to pyrolysis. In general, smaller particle size materials are quicker affected by the thermal decomposition, which can result in bigger amounts of pyrolysis oil than in case of larger particle size. /28/

4.7 Landfill Gas Collection

Organic waste, which is located in a landfill produces landfill gas after the decomposing process. This gas contains mainly methane and carbon dioxide. Starting this process is normal and desirable. In conventional filling conditions, the duration of the process is several tens of years and the gas is discharged into the environment due to the overpressure within the landfill (Figure 7). Collecting of this gas is nature saving and offers a profitable way to produce energy. /10/

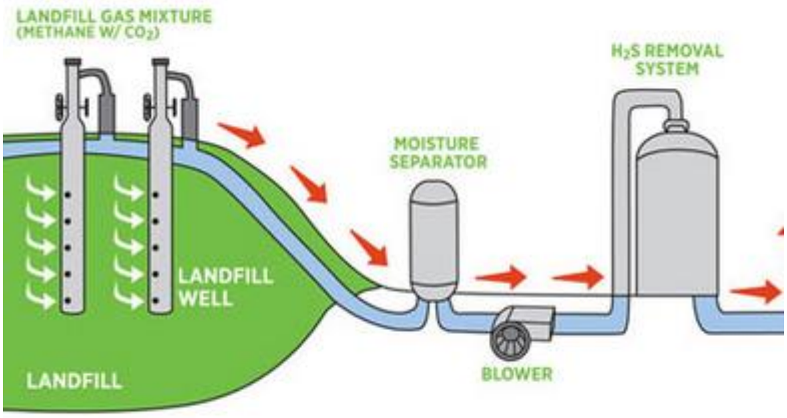

Figure 7. Typical landfill gas collection system. /29/

4.8 Sludge Incineration

The Paku-process is an example of sludge incineration technique. It is developed to treat waste water sludge locally, efficiently and economically. The process captures the energy and nutrients contained in the sludge, while removing contaminants, such as drug residues and microplastics. This technology reduce transported material from a wastewater treatment plant and the remaining ash can be used as a fertilizer. /30/

In addition to harmful compounds, sludge contains also useful fertilizers, such as phosphorus and nitrogen, which can be utilized when harmful compounds have been removed. With current sludge treatment methods such as composting or anaerobic digestion, these compounds cannot be eliminated. /30/

The mechanically dried sludge is fed to a rotary dryer, where it is dried over 95% dry matter content before entering to the circulating pulse reactor, where the sludge is thermally threated at 850 ˚C, destroying harmful organic compounds. The flue gases generated in the reactor are cleaned by removing the product and by-product flue and washing the sulphur compounds before entering the chimney. Heavy metals that cannot be thermally destroyed are separated from the ash, which are produced in the process (Figure 8). The ash can be used as a fertilizer. Only under 10% of the original mass of the sludge is transported in the form of ash. /30/

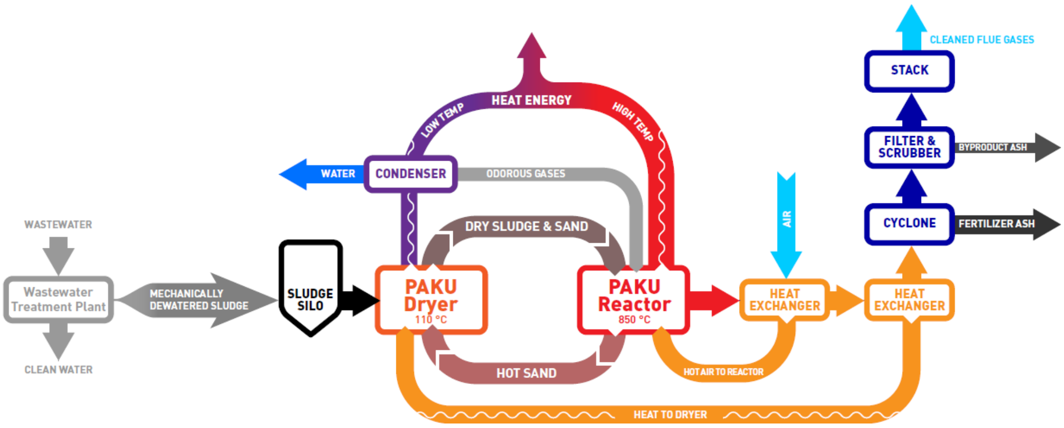

Figure 8. Sludge incineration process. /30/

4.9 Biodiesel Refining

Basic biodiesel production process is quite simple (Figure 9). The first step is esterification, in this process waste oils and fats, which contains free fatty acids, are converted to biodiesel by using methanol. Esterification needs acidic circumstances to occur. For that reason, the reaction needs sulphuric acid as a catalyst. At this part of the process water is produced as by product, which is removed later steps. The product of the esterification process is a mix of non-reacted raw material and biodiesel. This mix is moved to the next reaction step, which is trans-esterification.

The second important raw material after free fatty acids is glycerides, at this step it will produced to biodiesel. Methane is used with potassium hydroxide to create needed conditions. This process step produces glycerine as a by-product. Biodiesel and glycerine are separated by phase separation. /22/

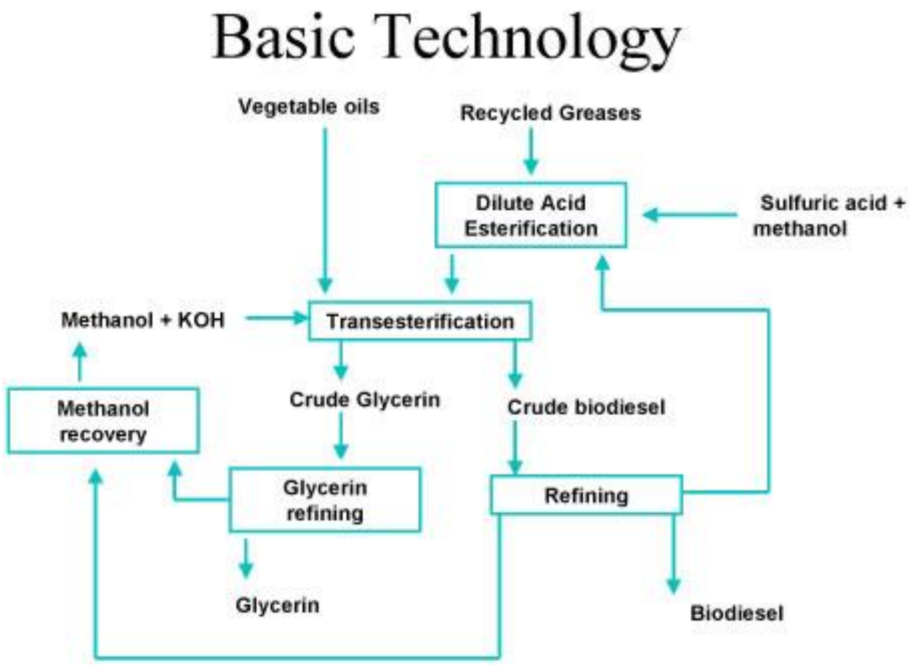

Figure 9. Basic biodiesel production process. /31/

From trans-esterification step the mixture comes to the refining phase. In this phase biodiesel is purified to meet the highest standards. Then comes by-product processing phase, where the by-products separated and purified to three main streams: methanol, raw glycerine and water. /22/

4.10 Biofuel Refining (Ethanol)

The ethanol production process includes few steps (Figure 10). At the beginning of the process the feedstock material is milled. Then water and enzymes are added to the meal to produce "mash". Cooking is the following step. In cooking, the cooker heats the mash to 210 degrees, liquefying the starch. The heat helps to reduce levels of bacteria in the mash by 90 %. In the hydrolysis enzymes are added to the mash to convert the starch to dextrose, a simple sugar. Then the mash continues through heat exchangers that cool it to 90 degrees, hotter than this would kill the yeast added during the fermentation. Fermentation is part where yeast is added to ferment the sugars. During this process, the yeast eats the sugars, and in the process produce heat, ethanol and carbon dioxide. It takes 48 hours for the mash to make it through the fermentation process. After the fermentation comes the distillation. During distillation the beer is continuously pumped through a multi-column system that separates the alcohol and stillage. The alcohol moves on to dehydration where the stillage is processed into distillers grains. Dehydration removes the last bit of water. /32/

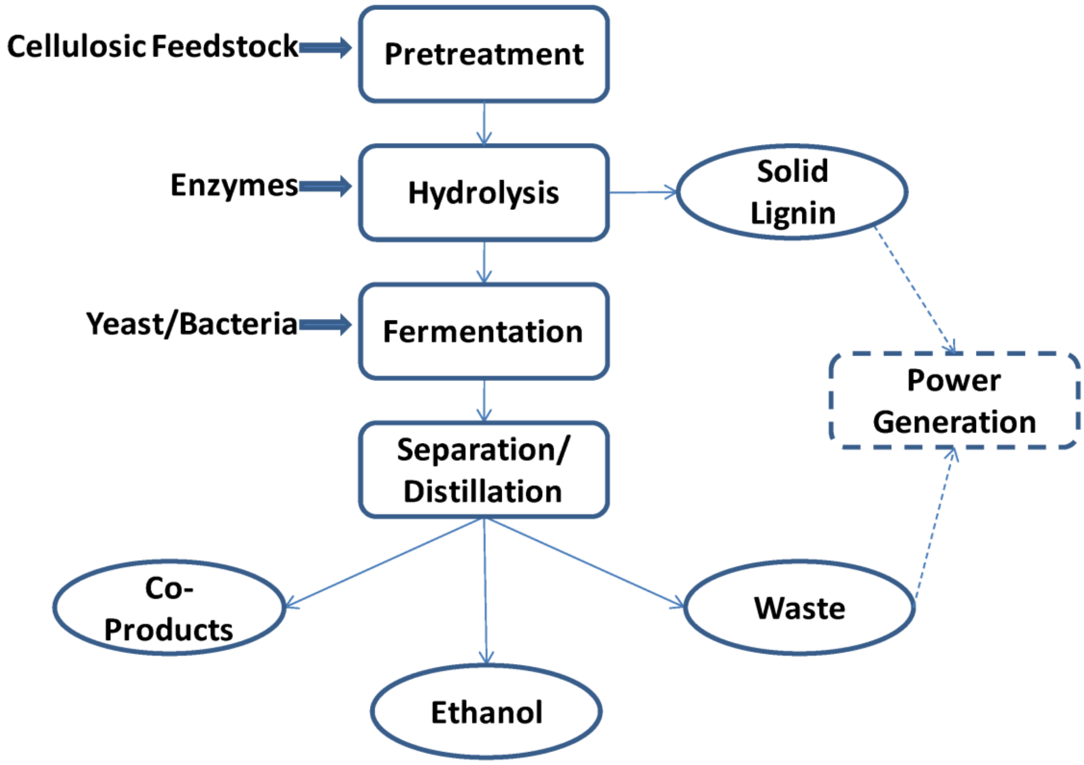

Figure 10. Ethanol production process. /33/

Now-a-days the most common ethanol feedstock materials are cellulosic wastes, grains, sugar cane and sugar beet. The process produces mash as a by-product, it can be utilized as an animal fed or in biogas production. /34/

4.11 Ash Treatment

APC-residues are generated in incineration process. The weight of APC-residue is typically 2-5% of waste which go through incineration. It is classified as hazardous waste, because it contains volatile heavy metals, dioxins, Furans, chlorines and high levels of alkalinity. One way to produce this hazard waste into construction material is Tetronics Plasma APC solution. Tetronics has an innovative technology, which uses plasma arc heat sources to melt, gasify or vaporise the APC-residue and fly ash to treat, recover and generate valuable commercial products. /35/

Inashco offers technology for ash recycling. Their solution helps to separate valuable parts of ash: iron scrap, non-ferrous metal scrap, organic materials and aggregate. Full recovery for metals, and minerals collecting for different applications like: blocks, bricks and pipes. /36/

4.12 Biogas Purification Techniques

Carbonoro and Puregas Solutions have very similar systems which operate with amines. Carbonoro's amine solution works with two simple cylindrical vessels containing absorber and desorber. The amine is pumped from the absorber tank to the desorber tank and back to the absorber tank in a continuous process. Raw gas enters the absorber tank in ambient conditions. The amine flows to the bottom with the gas stream and absorbs carbon dioxide from the gas. The cleaned gas evaporates at the top of the cylinder. The amine transports the carbon dioxide to the desorber where it is released by heating the tank. Puregas Solutions CApure process works in a very similar way but it uses water with the amine. /37–38/

4.12.1 Pressure Swing Adsorption

Pressure swing adsorption is a very commonly used technology for purification of biogases. This process is reached by reducing the pressure. The basic principle is to swing the pressure from high to low. By that it is possible to adsorb a large amount of moisture at the higher pressure. After that moisture is released by lowering the pressure. This is called pressure swing adsorption technique. The basic pressure swing adsorption system uses four to sixteen large vessels, which are connected by network of piping and valves to control the gas flows between those vessels. /39/

4.12.2 Water Scrubbing

Water scrubbing is an advanced and energy-efficient biogas purification technology. The system utilises a technology, which purifies biogas by using regular water. This method has a lower environmental impact than any other purification technology. Compared with solvent-based methods, the system is safe for both, the operating staff and the environment. Carbon dioxide and hydrogen sulphide are removed from raw biogas by water scrubbing. The method is based on a basic physical phenomenon. Biogas is forced through water flow at 6-10 bar pressure in 40 Celsius heat. Carbon dioxide and hydrogen sulphide are absorbed into water. After this treatment the gas is dried by cooling down or increasing the pressure. This system is automated and has low operating costs. The system can achieve a methane content of 99 %. /20/

5 CONCLUSIONS

Thesis work included many different process with various techniques. Collecting of all the information about the feed stock materials, by-products, etc. was very time consuming. The subject of this thesis was very interesting and versatile, but at the same time it was challenging.

Waste can be processed in many ways directly into energy, fuel or raw material. Many processes require accurate sorting to ensure the quality of feedstock. Energy of the waste can be recovered effectively by the waste-to-energy and waste-to-fuel processes, which have been explored in this thesis. Wastes can be utilized into the final product almost without none of the residual waste, which must be disposed to the landfill.

When quality and properties of feed stock wastes are known, can designed plant with various combination of waste refining processes. Demands of customer also affect to selecting of processes. Different techniques can utilize same raw materials like other techniques, which also offers some selection between processes. Only waste incineration, rendering solution and anaerobic digestion offers great solution for waste utilization. Naturally, when there are versatile and well-sorted waste available can be provided a wide range of different utilization techniques.

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Ecosystem					
	Input		Output		
Upstream	**Raw material / Energy**	**Feed stock (Waste etc.)**	**End product**	**Intermediate product**	**Overstock (Waste etc.)**
Waste collection		Municipal waste	Municipal waste		
Waste refining	Electric power	Municipal waste	Metals	separated combustable waste, glass, ceramics, Wood	Rocks
Electronic waste	Electric power	Electronic waste	Metals	Organic material, glass, ceramics	
Glass recycling	Electric power	Glass waste	Cullet, Class powder		
Battery recycling	Electric power	battery waste	Fertilizer (Manganese Zinc)		
Water borehole	Electric power			Water	
Sidestream					
Biogas production	Thermal energy	Sludge, Organic waste, Biomass		Biogas(60% methane), digestate	
Landfill gas collection				Biogas	
Composting solution		Organic waste	Composted soil		
Water treatment (potable water)	Electrical power, chlorine, permanganate, peroxide, ozone, activated carbon, zeolite, sodium hypochlorite,	Water,	Fresh water		
Sewage treatment (drying)	Electrical power, Methanol, ferrous sulfate, alkalinization chemical	Sewage water	Water	Sludge, Biogas, Phosphore	
Pyrolysis (rubber)	Thermal energy	Rubber, Tires	Pyrolysis oil, Syngas(CO, CO2, CH4, CnHm, NH3), Bitumen, Recovered carbon black	Char	Ash
Pyrolysis (plastics)	Thermal energy	Plastic waste	Syngas(CO, CO2, CH4, CnHm, NH3), pyrolyisis oil	Char	ash
Contaminated soil remediation	electrical power		Clean soil		
Animal rendering solution	Steam, Electrical power	Animal by-products	Clean water, Thermal energy	Bio waste, waste water, Fat, protein, Nitrogen phosphorus,	
MiniWOIMAplant		Municipal waste	Electricity, Thermal power, Steam, Cold	Ash	
Sludge incineration	Thermal power	Sludge, digestate	Thermal Power,	Fertilizing ash	
Woimaplant	Lime, Activated carbon	Segregated solid waste	Electricity, Thermal power, Steam, Potable Water	Ash, Residue	
hydrothermal carbonization	Thermal power, electrical power	Sludge, Biomass,	Hydrochar, phosphorus	water	
Downstream					
Bio/landfill gas purification	Electrical power	Raw biogas, water	Methane	Carbon dioxide, Hydrogen sulfide	
Biogas upgrading	Upgrading amine	Biogas	Methane		
Ash treatment solution	carbon8 aggregate, electric power	ash	Construction material(concrete, brick)		
Ash treatment solution(plasmarock)	Electric power	APCr, Fly Ash	Plasmarok (material for construction and ceramics industries)	Hydrochloric Acid	
Ash metals recovery solution	Electric power	Ash	Heavy non-ferrous scrap products, Aluminium scrap products, Ferrous scrap products		
Fertilizer manufacturing	Electric power	Sludge, Digestate, biomass	Plant fertilizer		
Bio diesel refining	Methanol, Sodium hydroxide/Potassium hydroxide	Oil corps, Animal oil/fats, Tallow, Recycle greases, cooking oil	Biodiesel, Glyserol	biomass (fertilizer)	
Bio fuel refining (ethanol)	Thermal energy, Water, Enzymes, Yeast	Food industry waste, Bio waste, Biomass	Ethanol	Fertilizer, Animal feed, waste water	
Animal feed manufacturing		Fat, protein	Feed		
Sorption technologies	Electric power, Thermal energy		Cold/heat		
CO2 production		Flue gas	CO2		