1. The amount of waste is being produced on daily basis is 100kg.

2. Literature survey

a. <u>The varieties of available technologies</u>

There are many food waste valorization technologies developed to divert food waste into treasure. The two main technologies to process waste are non-biological conversion and biological conversion.

Biological conversion consists of *anaerobic digestion and fermentation*. (Iqbal, 2014) states that in anaerobic digestion, the waste food is collected into tanks-called digesters and by adding bacteria, stabilization process which encompasses complex interactions among bacteria is induced. During the stabilization process, waste food is converted into biogas and water. The simplified version of stabilization occurs in three phases: hydrolysis, acetogenesis, and methanogenesis (District, March 2008). Biogas contains 50-70% methane and 30-50% carbon dioxide. Methane would provide clean fuel and could substitute fossil fuel derived energy.

According to (Uduak George AKPAN*, Adamu Ali ALHAKIM, Udeme Joshua Josiah IJAH), during *ethanol fermentation*, the conversions of food waste were respectively carried out via acid and microbial hydrolysis. This was then converted into ethanol by fermentation process using Sacchromyces ceverisiae, a yeast cell which contains enzyme catalysts. Many ethanol fermentation methods have been developed like batch fermentation, fed-batch fermentation, Melle-Boinot semi-continuous fermentation and continuous fermentation process (Seong-Jun Kim, Lei Yang, Hongxian Li, Yong-Jin Kim, Myong-Jun Kim, Kwang Young Kim). Ethanol is an excellent candidate to replace gasoline (Leonidas Matsakas and Paul Christakopoulos, 2015).

Another food waste conversion technology is *hydrothermal pyrolysis*. It is a thermal cracking process used to convert carbonaceous materials, i.e. food waste, to energy. The destruction process by hydrothermal pyrolysis reaction proceeds through hydrolysis, oxidation and gasification. (Jomaa et al., 2003). (Wenzhi He∗, 2007) also states that oxidation is an ultimate method for the destruction of organic matter. It converts the fragmented organic matter into carbon dioxide, a gas and water. For example, from proteinaceous wastes, amino acids are produced from degradation of proteins. Amino acids further degrade to organic acids. In the case of cellulosic wastes, cellulose is mainly converted into glucose by hydrolysis. Glucose further decomposes to other products including aldehydes and ketones, from which organic acids are produced.

b. The reactions involved

Anaerobic digestion

Anaerobic digestion is a biological process that produces a gas principally composed of methane (CH4) and carbon dioxide (CO_2) otherwise known as biogas. These gases are produced from organic wastes such as livestock manure and food processing waste. The waste food is collected into tanks-called digesters and by adding bacteria, stabilization process which undergo hydrolysis, acetogenesis, and methanogenesis (District, March 2008).

Hydrolysis is the first step where complex organics are converted to soluble organics through extracellular enzymes. Complex organics include carbohydrates, proteins, and lipids (food waste). The soluble organics include glucose, amino acids, fatty acids.

Acetogenesis is a process which acetate is produced from CO_2 and an electron source (e.g., H_2, CO, formate) by anaerobic bacteria via the reductive acetyl-CoA or Wood-Ljungdahl pathway. Acetogenesis is the first complex step where acid producing bacteria (acetogens) convert soluble organics into volatile fatty acids, with acetic acid as the fully converted end point.

$$2\,CO2 + 4\,H2 \rightarrow CH3COOH + 2H2O \quad \textbf{(Actogenesis, generally)}$$

Methanogenesis or biomethanation is the formation of methane by microbes known as methanogens. Methanogens do not use oxygen to respire, in fact, oxygen inhibits the growth of methanogens. Methanogenesis is the next step where the volatile fatty acids are converted to methane, and carbon dioxide. The two best described pathways :

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2H_2O$$
$$CH_3COOH \rightarrow CH_4 + CO_2$$

Ethanol fermentation

The overall process of ethanol fermentation is as follows:

$$C_{12}H_{22}O_{11} + H_2O + \text{Invertase} \rightarrow C_6H_{12}O_6\ (1)$$

$$C_6H_{12}O_6 + \text{Zymase} \text{ ====> } (2CH_3CH_2OH) + (2CO_2) + \text{Energy (which is stored in ATP) (2)}$$

Sugar (Glucose) ====> Alcohol (Ethyl alcohol) + Carbon dioxide gas + Energy

The process of alcohol fermentation can be divided into two parts. In the first part, the yeast breaks down glucose to form 2 pyruvate molecules. This part is known as glycolysis.

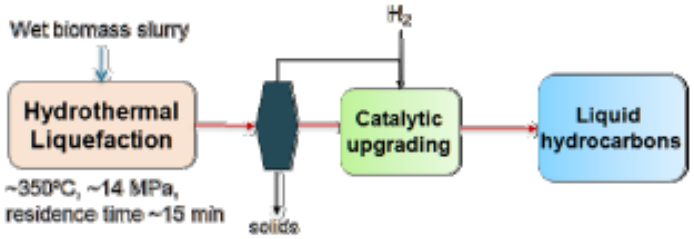
The second stage is the fermentation process to convert glucose into ethanol and CO2. Fermentation ethanol is a change of a mole of glucose into 2 moles of ethanol and 2 moles of CO2. The yeasts will mainly metabolize glucose and fructose to form pyruvic acid through the stages of the reaction pathway Embden-Meyerhof-Parnas, nevertheless pyruvic acid generated would be decarboxylated to acetaldehyde which then experiences dehydrogenation to ethanol.

Yeasts often used in alcoholic fermentation are Saccharomyces cerevisiae, because it can produce high tolerance to alcohol (12-18% v / v), resistance to high sugar levels and remain active in the fermentation at a temperature of 4-32℃.

After fermentation is completed, the distillation process can separate ethanol based on boiling point. The boiling point of pure ethanol is 78 ℃ while the water is 100℃ (standard conditions). (Xueying, 2011)

Hydrothermal pyrolysis

Hydrothermal pyrolysis of biomass is a well-known process that is used to convert moisture-rich carbonaceous materials to liquid fuels.



In the HTL process shown in the diagram above shows the conversion done with wet biomass at elevated temperatures (300°–350°C or 570°–660°F). Steam generated by heating the wet biomass results in high pressures (15–20 MPa or 2,200–3,000 psi). The conversion is done in a matter of minutes (5–20 minutes). (National Advanced Biofuels Consortium, 2011)

The general pathway of conversion likely takes place via the following steps: 1) hydrolysis; 2) further degradation; and 3) repolymerization of some of the smaller compounds into more complex hydrocarbons. It is important to note that only the volatile, or organic, components of the wet biomass can be converted to biocrude via HTL. (Keener)

c. The pros and constraints of these technologies

In the industry, every technology serves for different physical and chemical conditions. Thus, an advantage of a technology to a project may be a disadvantage to others.

For waste conversion using anaerobic digester technology, among the advantages is that it has consistent power to operate. Since the power is obtained from the waste itself, and the amount of waste is produced continually, there is a constant stream of inputs into the digester, creating a stable source of electricity generation. It also produces valuable and renewable by-products. However, this technology is not convenient to small-scale production because it has a high installation and operation cost, and requires large land area for the waste tank making it only economically ideal for larger operations. (Anaerobic Digester: Pros & Cons)

Ethanol fermentation involves microbial conversion which combines cellulose production, cellulose hydrolysis and glucose fermentation into a single step. Thus, this process reduces the number of reactors needed and simplifies the operation which then leads to the reduction of the chemicals cost. However, this type of conversion yields low amount of product. Also, there will be undesirable metabolic byproducts produced and unwanted product inhibition. (Chapter 7. Processing of Biorenewable Resources into Chemicals and Fuels.)

For hydrothermal pyrolysis, it is a highly effective (~90%) technology, which is a very big plus point. On top of that, it is also eco-friendly as it contributes to no pollution and burn without access of oxygen. Another thing is, hydrothermal pyrolysis is also a low-cost operation since it does not need drying prior treatment. However, this process requires a high initial capital. (UNIVERSITY)

d. The researchers or practitioners that made these technologies successful in their local area

Summit Foods, a Cornelius, OR company that produces dried fruit for commercial bakeries leaves them with a lot of biodegradable leftovers. Summit Foods converted a waste byproduct- juice into fuel for race cars. It has an 18-tank ethanol plant that will turn the waste from its food processing plants in Cornelius and North Plains into combustible fuel. The liquid waste is fermented then distilled into alcohol and sold as ethanol fuel. Summit has a capacity of about 2 million gallons of fuel.(Wrona)

San Jose ’s first large-scale commercial anaerobic digestion facility, privately owned and operated by *Zero Waste Energy Development Company* has 16 anaerobic digesters which use bacteria to break down the material in an oxygen-depleted environment to create a biogas rich in methane. During its first ten months of operation in 2014, the ZWED facility has recycled more than 30,000 tons of food scraps from restaurants and grocery stores that would otherwise go to

the landfill. This food waste generates 500 kilowatts per hour of electricity that is used to power onsite operations, and it has produced approximately 6,000 tons of compost. (Skadowski)

Changing World Technologies (CWT), in Carthage MO, uses a similar high temperature-high pressure depolymerization process for the production of bio-diesel from poultry offal. A subsidiary of CWT, Thermo-Depolymerization Process, LLC (TDP) also developed a pilot and demonstration facility in 1999 in Philadelphia, PA. CWT had a production capacity of 400 barrels/day of bio oil. (Keener)

e. <u>The way forward that would help your project</u>

Basically there are three technologies found in our literature survey which are available to divert food waste into wealth for example, anaerobic digestion, ethanol fermentation and hydrothermal pyrolysis.

Anaerobic digestion is a process where the food waste are kept inside a tank and digested by bacteria to produce biogas or also known as carbon dioxide and methane gas (District, March 2008). It brings many advantages such as stable source of electricity generation, renewable and produces valuable products. However, it has high installation cost and requires large area of land to install the tank for the large operations. (Anaerobic Digester: Pros & Cons)

Ethanol fermentation is a process of converting glucose sugar to alcohol and carbon dioxide gas via acid and microbial hydrolysis (Uduak George AKPAN*, 2008). This hydrolysis is a combination of cellulose hydrolysis and glucose fermentation hence reducing the number of reactor required for the entire process as well as the operating cost. However, it only produces a very small amount of energy.

Hydrothermal pyrolysis is a thermal cracking process to convert carbonaceous material using hydrolysis, oxidation and gasifaction. This process is highly effective, environmental friendly as it does not contribute to pollution and burn without oxygen. Moreover, it has a low-cost operation as well as maintenance. However, this is a long term industry, therefore it needs a huge initial capital to start using it (AARHUS University, 2013).

In conclusion, we need a method to convert all the food waste into wealth particularly energy production. However, in order to pick the right technology, it has to be sustainable, manageable operating cost as well as the size of the production plant is suitable to the nearest area of the food waste and do not affect the housing area nearby. **Based on the comparisons above, it is best to choose the hydrothermal pyrolysis as the right technology to be used in the converting the food waste into sustainable energy production.**

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