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Commissioning of Biogas Reactor

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Biogas reactors can utilize food waste as substrate to produce methane, which can be used as a source of energy. In addition, fertilizer can be obtained after anaerobic digestion of the waste. Thus, nowadays many organizations in Finland are establishing biogas reactors in their facilities to utilize their waste for obtaining energy. These reactors also follow the module of circular economy, which is a thriving environmental sustainability practice. Metropolia, Myyrmäki Campus is joining the bandwagon by establishing a HomeBiogas reactor in their premises to utilize food waste from the university canteen.

The purpose of this thesis was to ensure safety and proper functionality of the reactor being installed. This thesis investigates the parameters for optimum biogas production from the reactor with the help of various literatures. It also predicts the amount of biogas that can be produced in the University with the help of Buswell equation. As safety is an important aspect in any biogas system, a risk analysis of the potential hazards has been done.

Installation of various sensors are discussed as safety mechanism to minimize hazard risks, due to leaks from the system. This thesis also recommends type of food waste that should be fed into the digester for maximum biogas output.

Keywords	Anaerobic Digestion, Biogas, substrates, parameters, risk analysis, hazards, sensors

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Acknowledgements

I am extremely excited to graduate as an Environmental Engineer from Metropolia UAS. These last five years have been important learning curves in my life. This thesis reinvigorated my interest in working in the field of biogas energy after my graduation.

I would like to express my sincere gratitude to all my friends in Metropolia, who shared their knowledge and experiences with me. I am grateful to my supervisor, Mr. Antti Tohka who guided me in every step of this thesis. His knowledge and ideas were immensely helpful in this thesis writing.

Finally, I want to extend my love to my family who continued supporting me through my difficult times. I want to dedicate this thesis to my parents, as a small token of appreciation for everything that they have done for me. I want to thank my sister, and my uncle for always being there for me.

There might be errors in the thesis, that I am unaware of. I am fully responsible for all the errors and discrepancies.

April 2018,
Bibesh Gauli

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List of Symbols

$C_6H_{12}O_6$	glucose
H_2	hydrogen
CH_3CH_2COOH	propionic acid
H_2O	water
CH_3CH_2OH	ethanol
CO_2	carbon dioxide
$CH_3CH_2COO^-$	propanoate ion
CH_3COO^-	acetate
H^+	hydrogen ion
HCO_3^-	bicarbonate ion
CH_3COOH	acetic acid
CH_4	methane
CH_3OH	methanol
SO_4^{2-}	sulfate ion
H_2S	hydrogen Sulphide
Ni	nickel
Co	cobalt
Mo	molybdenum
Se	selenium
N_2	nitrogen
P	phosphorus
S	sulphur
C	carbon
O_2	oxygen
NH_3	ammonia
M^3	cubic meter
Cr^{3+}	chromium (III) ion
Cr^{6+}	chromium (VI) ion
Cu	copper
Cd	cadmium
Pb	lead
Zn	zinc

List of abbreviations

EU	European Union
UAS	university of applied sciences
AD	anaerobic Digestion
$KWhm^{-3}$	Kilowatt-hour per cubic meter
°C	degree Celsius
mV	millivolt
HRT	hydraulic retention time
VS	volatile solids
Mg	milligram
L	litre
VFA	volatile fatty acid
Wt	weight
TS	total Solids
VOC	volatile organic compound
LEL	lower explosive limit
CO	carbon monoxide

1 Introduction

Biogas production supports the concept of circular economy by tackling waste, energy, sustainable food production and nutrient recycling challenges. It closes the previously linear loop of sending wastes to landfill, using non- renewable resources for energy, and producing fertilizers from fossil fuels and chemicals. [1]. As rules of EU regarding the use of non-renewable resources for energy production and landfilling of wastes are tightening every year, biogas provides a sustainable and flexible renewable energy source [2]. According to Eurobarometer 2012, food waste every year amounts to 88 million tonnes which is roughly 173 kg per capita in EU. In Finland, the estimated food waste per person annually is 189 kg. [3]. Thus, utilization of anaerobic digestion for the production of biogas through use of bio-waste would provide long term solution for waste management.

According to the Directive 2009/28/EC of the European Parliament, 20% of final energy consumption for all member state should be provided by renewable sources by 2020 [4]. Due to this requirement, Europe has seen vast growth in the biogas sector. In Finland, many organizations have established their own biogas plants to efficiently turn their organic waste into energy. Similarly, Metropolia University of Applied Sciences is installing their own biogas reactor to obtain sustainable energy from organic wastes. This biogas system will reduce the amount of organic waste from Metropolia UAS entering the Finnish waste stream. The production of fertilizer that can be used to improve soil quality is an added benefit of the system.

The HomeBiogas system which is used, is the most advanced household biogas system in the market [5]. The reactor accepts around 6 litres of kitchen waste daily and produces 600 litres of biogas [6]. The biogas produced from the digester is stored in a gas tank above the system. As there are many possible leakage zones in the system, risk analysis of the system is vital. Methane, the desired output from anaerobic digestion, is 25 times more potent as a greenhouse gas than carbon dioxide [7]. It is also highly combustible. Therefore, the system needs to be located outdoors.

2 Objectives

This is the first time a biogas reactor is being installed in Metropolia, Myyrmäki Campus. This thesis deals with many parameters dealing with the functionality and safety aspects of the system. The main objectives of the thesis were:

- To study anaerobic digestion process and different microorganisms associated with this process.
- To study various parameters for biogas production.
- To study the composition of biogas and effects of various substrates on biogas production.
- To determine the risk analysis of the system and provide various precautionary measures.
- To obtain total biogas potential of Metropolia.
- To investigate the feasibility of use of different sensors for minimizing gas hazards.

3 Background

This thesis was conducted for Metropolia University of Applied Sciences, Myyrmäki Campus. A research was done by Sodexo Oy in this campus regarding food waste in the cafeteria. The data from the research indicated a large amount of waste in the campus. Thus, initiatives were taken to reduce and reuse the wastes. One of the initiatives taken for waste management was the purchase of a HomeBiogas reactor for biogas production.

HomeBiogas is a company based in Israel that sells anaerobic digesters, which convert food scraps and animal manure into energy and fertilizer daily [5]. The feasibility of this reactor in context of Metropolia UAS was studied in this thesis. Only food wastes are going to be used as substrates for the reactor.

The sensors discussed for the reactor are from Libelium, a company based in Zaragoza, Spain. These sensors can tabulate real time data and give precise information. The use of sensors for temperature, methane, carbon dioxide, and VOCs measurement will help

to detect leakage from the system and reduce health hazards during the operation of the reactor.

4 System Components of HomeBiogas System

The HomeBiogas system produces biogas from food waste through anaerobic digestion. The system consists of waste inlet sink, digester tank, sediment removal outlet, gas tank, fertilizer outlet and gas and drainage outlet components. The components of the system have been engineered to facilitate optimum methane production. The aluminium outer frame provides a rigid framework to the system. Biogas filter present in the system filters hydrogen sulphide produced inside the digester, thus decreasing hazards related to toxicity to hydrogen sulphide. The system should be located outdoors for safety and proper functionality. The outputs are biogas and organic fertilizer.

Food waste is fed into the system through the waste inlet sink. It is generally crushed into smaller particles to increase the surface area contact with the microorganisms. The anaerobic digestion of the waste takes place in the digester tank, where microorganisms produce biogas by breaking down the organic components. The biogas produced is collected in the gas tank located above the digester and supplied to the stove through gas pipes.

Organic fertilizer, a residue of the AD process, can be collected through the fertilizer outlet. There are chlorine tablets located in the fertilizer outlet chamber to reduce the colonies of pathogen in the fertilizer. If there are large chunks of sediments in the system, it can be removed from the sediment outlet pipe [6]. Figure 1 illustrates the components of the HomeBiogas System.

Figure 1: Components of the HomeBiogas System [5]

5 Literature Review

5.1 Anaerobic Digestion

Anaerobic digestion is a series of biological processes which involves the biodegradation of organic materials by microorganisms in the absence of oxygen [8]. Anaerobic digestion, a synergistic process, has four distinct phases. The phases are namely hydrolysis, acidogenesis, acetogenesis and methanogenesis [9]. Figure 2 illustrates the different phases of anaerobic digestion and types of products for each phase.

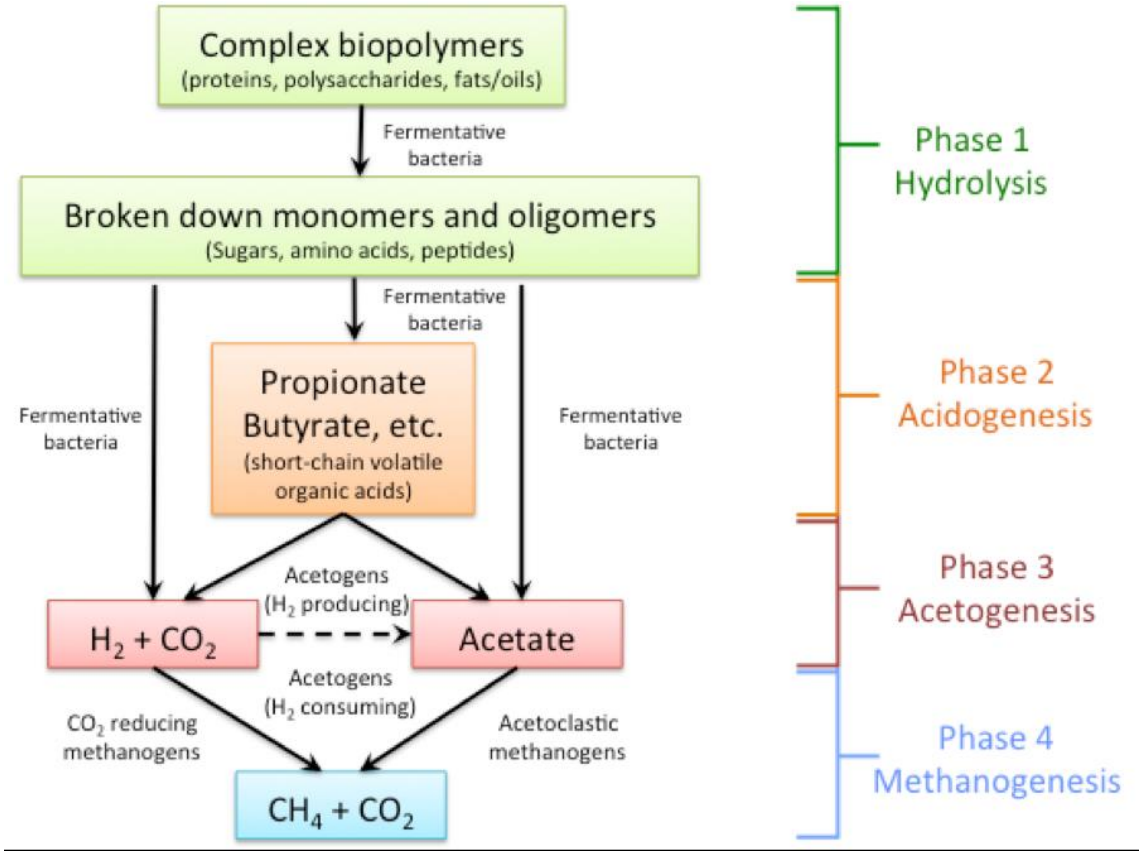

Figure 2: Stages of Anaerobic Digestion [10]

5.1.1 Hydrolysis

The breakdown of complex matter, such as protein and carbohydrates, into amino acids and sugar takes place in hydrolysis phase. These long-chain chemical compounds are broken down by water and enzymes into single molecules. The enzymes in this reaction are exoenzymes (e.g. cellulosome, and protease,) secreted by several bacteria, protozoa and fungi [11].

Hydrolysis reactions:

Biomass + H_2O → Monomers + H_2

Lipids → Fatty Acids

Polysaccharides → Monosaccharides

Protein → Amino Acids

Nucleic Acids → Purines and Pyrimidines [9]

5.1.2 Acidogenesis

In the second stage, soluble monomers are converted into small organic compounds such as short chain acids (propionic acid, formic acid), ketones (acetone, glycerol) and alcohols (ethanol, methanol). Acidogenesis reactions are shown below:

$C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + 2H_2O$

$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$ [9]

5.1.3 Acetogenesis

Acetogenic bacteria convert the acidogenesis intermediates to simple organic acid, carbon dioxide and hydrogen. The higher organic acids are transferred to acetic acid and hydrogen in this phase. In both acidification and acetogenic reactions, acetate and hydrogen are produced. Thus, it is sometimes difficult to draw a clear distinction between these reactions. *Syntrophobacter wolinii*, a propionate decomposer, and *Syntrophomonos wolfei*, a butyrate decomposer, are the examples of bacteria involved in this phase [12]. The reactions that occur during acetogenesis can be written as follows:

$CH_3CH_2COO^- + 3H_2O \rightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2$

$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2$

$CH_3CH_2OH + 2H_2O \rightarrow CH_3COO^- + 2H_2 + H^+$

$2HCO_3^- + 4H_2 + H^+ \rightarrow CH_3COO^- + 4H_2O$ [9]

5.1.4 Methanogenesis

The last phase of anaerobic digestion is the methanogenesis phase. Methane is produced in this phase either by the cleavage of acetic acid molecules or by the reduction of carbon dioxide with water. The bacteria involved in methanogenesis are called methanogens or methane formers. Some of the methanogenic bacteria are *methanobacterium*, *methanobacillus*, *methanosarcina*, and *methanococcus*. Methane is primarily formed from these reactions along with other gases like carbon dioxide, hydrogen sulphide and ammonia [12].The common reactions that occur during methanogenesis can be expressed as follows:

$2CH_3CH_2OH + CO_2 \rightarrow 2CH_3COOH + CH_4$

$CH_3COOH \rightarrow CH_4 + CO_2$

$CH_3OH \rightarrow CH_4 + H2O$

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

$CH_3COO^- + SO_4^{2-} + H^+ \rightarrow 2HCO_3 + H_2S$ [9]

6 Composition of Biogas

Biogas is formed in the methanogenic phase of anaerobic digestion. It is primarily composed of methane and carbon dioxide, but there are also traces of hydrogen sulphide, nitrogen, oxygen, hydrogen and ammonia present. Biogas with a methane content higher than 45% is flammable. Methane is the desired product from anaerobic digestion as it can be used as fuel. From the composition of biogas produced, the circumstances inside the digester can be known. Methane, carbon dioxide and other gases are produced in different proportions depending upon the parameters such as temperature, pH in the digester [13].

Table 1:Typical Composition and Properties of Biogas [12]

Compound	Percentage by Volume
Methane	55-70%
Carbon dioxide	30-45%
Water Vapor	1-5%
Ammonia	0-0.05%
Hydrogen Sulphide	0-0.5%
Nitrogen	0-5%
Energy content	6.0-6.5 $kWhm^{-3}$
Fuel equivalent	0-60-0.65L oil/m^3 biogas
Explosion limits	6-12% biogas in air
Ignition temperature	650-750°C
Critical pressure	75-89 bar
Critical temperature	-82.5°C
Normal density	1.2 kgm^{-3}
Smell	Bad eggs
Molar Mass	16.043 $kgkmol^{-1}$

Biogas production is relatively stable during continuous fermentation process. Any sharp decline in biogas production in the system may indicate presence of some inhibitors upsetting the fermentation process or occurrence of gas leak. If the ratio of methane / carbon dioxide falls in biogas, it is the sign of high rate of acid formation in the system. It might be caused by variation of input quantities or inhibition of methanogenic population inside the system.

7 Factors Affecting Biogas Production

The metabolic activities of microorganisms involved in anaerobic digestion depend on numerous parameters; therefore, these parameters should be carefully controlled for optimum methane production in biogas reactor. Furthermore, microbes involved in different stages of anaerobic digestion have different environmental requirements to thrive [14]. The acidogenic and methanogenic bacteria have different parameter requirements, but usually methanogenic archaea requirements are considered with priority. The reason for the priority being methanogenic organisms' slower growth rate, longer regeneration time and higher susceptibility to change in environmental conditions.

Table 2:Important Parameters in Different Phases of Anaerobic Digestion [12]

Parameter	Hydrolysis / Acidogenesis	Methanogenesis
Temperature	25 - 35°C	Mesophilic: 30 - 40°C Thermophilic: 50 - 60°C
pH value	5.2 – 6.3	6.7 – 7.5
C: N ratio	10- 45	20 - 30
C: N: P: S ratio	500:15:5:3	600:15:5:3
Redox potential	+400 to -300 mV	Less than -250 mV
Trace elements	No special requirements	Essentials: Ni, Co, Mo, Se

7.1 Temperature

The rate of biogas production depends greatly on the temperature for fermentation. AD process generally occurs at three temperature ranges: psychrophilic (below 25°C), mesophilic (25°C - 45°C) and thermophilic (45°C - 70°C) [15]. The optimum temperature for anaerobic fermentation and methane forming bacteria is found to be between 29°C to 41°C or between 49°C to 60°C [15]. During biological decomposition and conversion processes, the rate of chemical reaction increases with the increase in the surrounding temperature. However, there should not be rapid temperature fluctuations during the digestion process, as relevant microorganisms cannot break down organic materials efficiently above or below optimum temperature range. A sudden change in temperature exceeding 30°C will hamper the methanogenic bacteria resulting in decreased biogas production.

Temperatures between 32°C - 35°C are found to be most efficient for continuous production of methane. There is a possibility of producing biogas containing a higher concentration of carbon dioxide and other gases in other temperature ranges. The biogas production decreases sharply below 20°C and the production stops at a temperature below 10°C. Thus, in cold countries the digester needs to be heated around 35°C or should be kept inside a greenhouse for temperature stability.

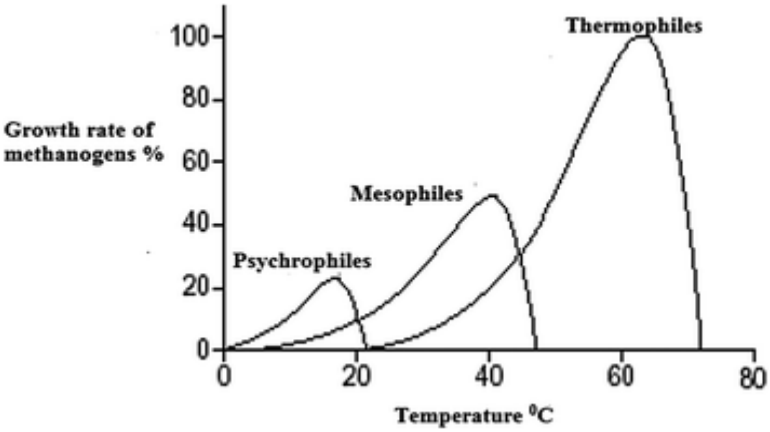

Figure 3:Relation Between Temperature and Growth Rate of Methanogens [16]

7.2 Hydraulic Retention Time

Hydraulic Retention Time (HRT) is the average time span that a given quantity of input organic material is retained in the digester, in contact with bacterial biomass [17]. The retention time depends upon the design and operating temperature of the digester; thus, it can vary from 35 to 50 days. HRT can be calculated as:

$$HRT = \frac{V_d}{V_i}$$

Where *HRT* is hydraulic retention time, V_d is the total volume of digester in m^3, and V_i is the total volume of input per unit time (m^3/t)

Longer retention time means more complete digestion of waste input in the digester by microorganisms. The degree of digestion increases with the retention time but a larger digester is required in such scenario. HRT is usually chosen to achieve 70% - 80% digestion [18].

7.3 pH Value or Hydronium Ion concentration

The hydronium ion concentration (pH value) expresses the degree of acidity or alkalinity of a substance and runs from 0-14 range. In anaerobic digestion, different microorganisms have specific optimum pH range. Hydrolysing and acid forming bacteria are efficient in breaking down of organic materials in the range of 5.2 - 6.3, whereas the optimal pH range for methanogenic and acetogenesis bacteria is 6.5 - 8. The hydrolysing and acid forming bacteria are not totally reliant on the optimum pH values. In contrast, a pH value in the neutral range of 6.5 – 8 is necessary for methanogenic bacteria as they cannot handle acidic or basic solution. Thus, the optimum pH value in anaerobic digester is 6.5 to 8 [19].

There is a carbonate and ammonia buffer in the digester system. Buffer capacity is an important parameter as it can resist pH changes in the system and maintain process stability. If excess organic acids accumulate in the system, the pH value of the system drops and buffer capacity of the system is exhausted. In such acidic system, the anaer-

obic digestion process will come to a sudden halt. Similarly, breakdown of organic nitrogen compounds leads to an increase of pH in the system due to the release of ammonia. Solution of ammonia with water is basic in nature and hampers the neutral balance of the system. If the solution inside the digester has a pH more than 10, it will lead to loss of bacterial activity in the fermenter.

7.4 Nutrients Concentration

The microorganisms involved in anaerobic digestion require various macronutrients and micronutrients for proper growth and functioning. The major nutrients required are N_2, P, S, C, H_2, and O_2. These nutrients help to accelerate the digestion rate; thus they need to be supplied in correct concentrations. The amount of methane obtained from the digester depends on the proportion of carbohydrates, fats and proteins supplied as substrates. Carbon from carbohydrates supplies energy to the organism, whereas nitrogen from protein is required for the formation of enzymes that support metabolism.

The C: N ratio of substrates is a really important factor in a biogas reactor. The microorganisms require roughly 30 times more carbon than nitrogen. Raw materials containing carbon-nitrogen ration of about 30:1 with 2% phosphorus is the ideal substrate for methane production [18]. A higher ratio will lead to availability of carbon even after nitrogen is consumed. The availability of surplus carbon means that the carbon present in the substrate is not completely metabolized, leading to decrease methane production. Conversely, a surplus of nitrogen will lead to abundance production of Ammonia (NH_3) in the system which inhibits bacterial growth [19]. Abundance of nitrogen even hampers the quality of fertilizer produced from this process as there will be nitrogen left over at the end of digestion.

7.5 Organic Loading Rate

The organic loading rate indicates the amount in kilograms of volatile solids which can be fed into per m^3 of working digester per unit time. It is expressed as VS/ (m^3. d). In other words, it is the amount of waste input supplied per day to the biogas digester. The optimum loading rate for biogas production is found to be 0.2kg/m^3 of digester capacity. If there are severe fluctuations in loading rate from the optimum value, it will reduce the

biogas production. The following equation can be used to calculate organic loading rate for different size digesters [19].

$$B_r = \frac{m \cdot c}{V_r \cdot 100} \text{ [kg VS m}^{-3}\text{ d}^{-1}\text{]}$$

where, B_r = Organic loading rate, m = amount of substrate added per unit time [kg/d], c = concentration of organic dry matter (% volatile solids), and V_r = Volume of reactor (m^3)

7.6 Toxic Substances

There are many harmful materials which have an inhibitory effect on the biogas-producing microorganisms. The presence of ammonia, heavy metals, detergents, excessive organic acids can reduce the fermentation rate in the digester considerably [18]. The digested slurry can be toxic to organism growth if it is not removed from the digester constantly. The concentration of these toxic substances should be diluted with water, if mistakenly fed to the digester.

Table 3:Inhibitory Effects of Heavy Metals [14]

Metal	Inhibition starting Value[1] [mgL^{-1}]	Toxicity to adopted[3] Microorganisms [mgL^{-1}]
Cr^{3+}	130	260
Cr^{6+}	110	420
Cu	40	170
Ni	10	30
Cd	70	600
Pb	340	340
Zn	400	600

Inhibitory concentration is the first value of concentration of heavy metals showing reduced biogas production, whereas toxic concentration is the concentration in which biogas production drops by 70%.

7.7 Redox Potential

In anaerobic digestion, low redox potential is necessary. Methanogenic bacteria need redox potential between -300 and -330 mV for optimum performance. If the redox potential increases, methanogens will stop producing methane leaving only CO_2 production for acetogens. This can cause high VFAs on the effluent and loss of biogas. Thus, oxidizing agents like oxygen, nitrate, nitrite and sulphate should not be added in the digester [12].

8 Biogas Production Potential

A research was conducted in the Metropolia University of Applied Sciences, Vantaa campus by Sodexo Oy to study the total waste produced in the campus daily. The research took place in October-November 2017. It calculated bio-waste and mixed waste data from the cafeteria and garbage bins. The bio-waste fraction includes left over food waste, kitchen waste, coffee waste and food scraps. Meanwhile, mixed waste consists of cardboard waste, milk, metal and all other waste fractions. Only the bio-waste fraction of the waste was analysed in this thesis as mixed waste might contain materials such as plastic that inhibits the production of biogas. Coffee waste which was the only constant bio-waste substrate throughout the research conducted by Sodexo, was also scrutinized.

The research did not deal with the substrate composition of bio-waste so, assumptions are necessary while predicting the biogas potential in Metropolia UAS. Total and volatile solid contents, protein, carbohydrate and lipid percentages of the feedstock are also unknown. Buswell and Mueller (1952) formula can be used for theoretical biogas composition calculation. The formula, which can be applied to the substrates with known elemental composition, can be expressed as follows:

$$C_cH_hO_oN_n + \left(c - \frac{h}{4} - \frac{o}{2} + \frac{3n}{4}\right)H_2O \rightarrow \left(\frac{c}{2} + \frac{h}{8} - \frac{o}{4} - \frac{3n}{8}\right)CH_4 + \left(\frac{c}{2} - \frac{h}{8} + \frac{o}{4} + \frac{3n}{8}\right)CO_2 + nNH_3$$

[20]

Figure 4 illustrates the total amount of coffee and biogas produced during November.

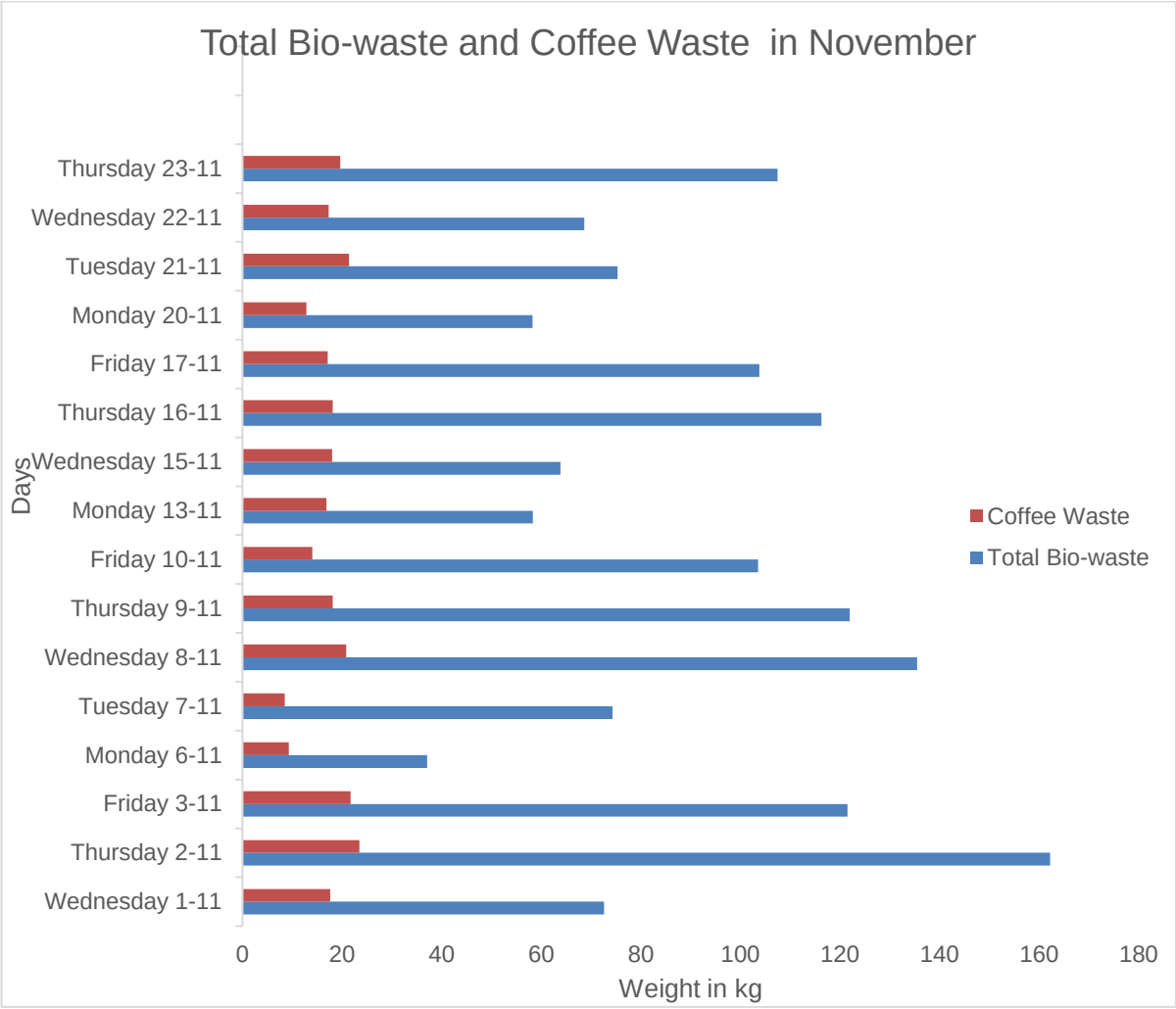

Figure 4: Bio-waste Production During November (Data compiled: Sodexo Oy)

The substrate composition of feedstock to calculate biogas potential was predicted using daily food menu from Sodexo website. Then the data of elemental composition of the food substrate was obtained from a research paper done in Hungary titled, "Physical and chemical analysis of canteen wastes for syngas production''. The elemental composition of 20 different substrates have been considered for theoretical calculations. The following table shows the number of different elements contained in varieties of samples.

Table 4: Elemental Composition of Dried Samples, %m/m [21]

Different Samples	N	C	H	O
Boiled Potatoes	2	36.67	6.53	49.81
Mashed Potatoes	1.41	44.48	7.29	42.46

Rice(steamed)	1.13	41.13	6.9	48.1
Rice(cooked)	0.7	42.08	7.01	47.04
Cooked pasta	2.24	42.97	7	44.52
Mixed vegetable side dish	2.1	40.44	8.66	42.43
Baked beans	3.18	43.26	6.76	40.46
Green pea stew	2.3	44.16	7.38	41.3
Grilled chicken leg	7.89	53.31	8.35	23.77
Breaded Fried fish	12.91	49.69	9.5	19.33
Breaded fish fillet	8.19	51.45	10.17	23.25
White bread	1.9	44.02	7.07	42.65
Breaded pork cutlet	5.74	53.91	8.25	26.91
Withered Cabbage	3.85	42	5.48	38.16
Onion skins	1.68	25.28	4.92	60.93
Capsicum leftovers	2.67	41.6	5.14	41.93
Withered lettuce	3.58	56.64	5.75	24.95
Cucumber peels	3.32	52.4	6.23	29.29
Radish peels	3.63	44.78	5.88	35.81

The percentage composition of elements can be converted into mole fraction to get molecular formula of individual substrates. For example, in case of boiled potatoes, the number of moles of different components are calculated as follows:

Moles of Carbon: $36.67/12.0107 = 3.05$ [No. of moles= Given wt. / Molecular wt]

Moles of Hydrogen: $6.53/1.00794 = 6.47$

Moles of Oxygen: $49.81/15.99 = 3.11$

Moles of Nitrogen: $2/14 = 0.14$

Molar ratio = C: H: O: N

3.05: 6.47: 3.11: 0.14

After dividing this ration by minimum value which is 0.14 of Nitrogen,

C: H: O: N = 21: 45: 22: 1

Thus, molecular formula = $C_{21}H_{45}O_{22}N$

By substituting the molecular formula in the Buswell equation, the theoretical biogas yield and methane yield can be calculated. There is a simplified version of Buswell equation to calculate these yields [22].

$$Biogas\left[\frac{m^3}{kg_{VS}}\right] = \frac{c * 22.415}{12c + h + 16o + 14n}$$

$$Methane\left[\frac{m^3}{kg_{VS}}\right] = \frac{(\frac{4c+h-2o-3n}{8}) * 22.415}{12c + h + 16o + 14n}$$

The table below contains calculated molecular formula of various substrates and the amount of methane that can be obtained.

Table 5: Biogas and Methane Potential of Various Substrates

Substrate	Molecular formula	Biogas (m^3/kg)	Methane (m^3/kg)	Methane %
Boiled Potatoes	$C_{21}H_{45}0_{22}N$	0.712	0.35	50
Mashed Potatoes	$C_{37}H_{72}O_{26}N$	0.858	0.48	56
Rice(steamed)	$C_{42}H_{85}O_{26}N$	0.78	0.41	53
Rice(cooked)	$C_{70}H_{139}O_{59}N$	0.80	0.43	54
Cooked pasta	$C_{22}H_{44}O_{17}N$	0.81	0.44	53
Mixed vegetable side dish	$C_{22}H_{57}O_{18}N$	0.79	0.48	61
Baked beans	$C_{16}H_{29}O_{11}N$	0.85	0.46	54
Green pea stew	$C_{22}H_{44}O_{16}N$	0.85	0.48	56
Grilled chicken leg	$C_8H_{15}O_2N$	1.05	0.64	61
Breaded Fried fish	$C_4H_{10}O_2N$	1.00	0.63	63
Breaded fish fillet	$C_7H_{17}O_3N$	1.02	0.67	66
White bread	$C_{27}H_{52}O_{19}N$	0.84	0.46	55
Breaded pork cutlet	$C_{11}H_{20}O_4N$	1.04	0.63	60
Withered Cabbage	$C_{12}H_{20}O_9N$	0.86	0.43	50
Onion skins	$C_{17}H_{40}O_{32}N$	0.50	0.16	32
Capsicum leftovers	$C_{18}H_{26}O_{14}N$	0.84	0.40	48
Withered lettuce	$C_{19}H_{22}O_6N$	1.14	0.63	55
Cucumber peels	$C_{18}H_{26}O_8N$	1.05	0.59	56
Radish peels	$C_{14}H_{22}O_{26}N$	0.91	0.48	52

The actual methane yields obtained from biogas systems are lower than the calculated yield because the Buswell formula possesses certain limitations [22]. The formula assumes that the waste undergoes complete reaction in the digester, and neglects the presence of other trace elements in the waste. It also does not consider the temperature and bacterial conditions in the digester.

Lipids have the highest biogas potential among substrates as it is possible to extract almost 1 m^3 of biogas per kg of volatile solids containing them. Protein has more biogas producing capacity than carbohydrates, forming 0.53 m^3 of gas compared to 0.38m^3 for carbohydrate [23]. The methane content in biogas for lipid is also the most potential among substrates. However, it is recommended to mix various substrates while feeding the digester. Co-digestion of various materials optimizes biogas production, as co-digested mixture can produce more gas than individual substrates. The increased methane yield can be because of likelihood of availability of more essential nutrients for microbial growth [24]. Overabundance of lipids in the digester can lead to a decrease in pH value, thus inhibiting bacterial growth.

According to data compiled by Sodexo, spent coffee is one of the major fractions in biowaste of Metropolia. The share of coffee waste is approximately 17 kilograms daily. The biogas yield from coffee can be expected to be in the range of 0.5 - 0.598 m^3/kg dry organic matter. The methane percent in the yield varies from 55 – 61% [25]. High lipid content combined with low protein and ash contents make coffee suitable for biogas generation [26]. However, it has been found that coffee constituents such as caffeine could hamper the biogas production by minimizing the degradation process [27]. The anaerobic system can become unstable if a large volume of spent coffee is used as a substrate.

Metropolia produced approximately 92 kilograms of bio waste daily in November. Let's assume that the waste contained 15% vegetable side dishes, 15% salad, 20% main meal containing meat, 10% rice and pasta,18% spent coffee, 10% bread and 12% remaining kitchen wastes such as potato skins. The methane yield for each of them was obtained by taking the averages of their constituents from the Table 5. The dry organic matter was taken as 20% of the food waste from various literatures, as only dry matter contributes to the production of biogas. The methane production potential for vegetable side dishes was calculated as:

Weight of Vegetable side dishes: 15% of 92 kg = 13.8 kg

Dry organic matter = 20% of 13.8 kg = 2.76 kg

Methane production per kg = 0.48 m^3

Methane production from 2.76 kg = 1.32 m^3

Similarly, methane potential from various substrates was calculated.

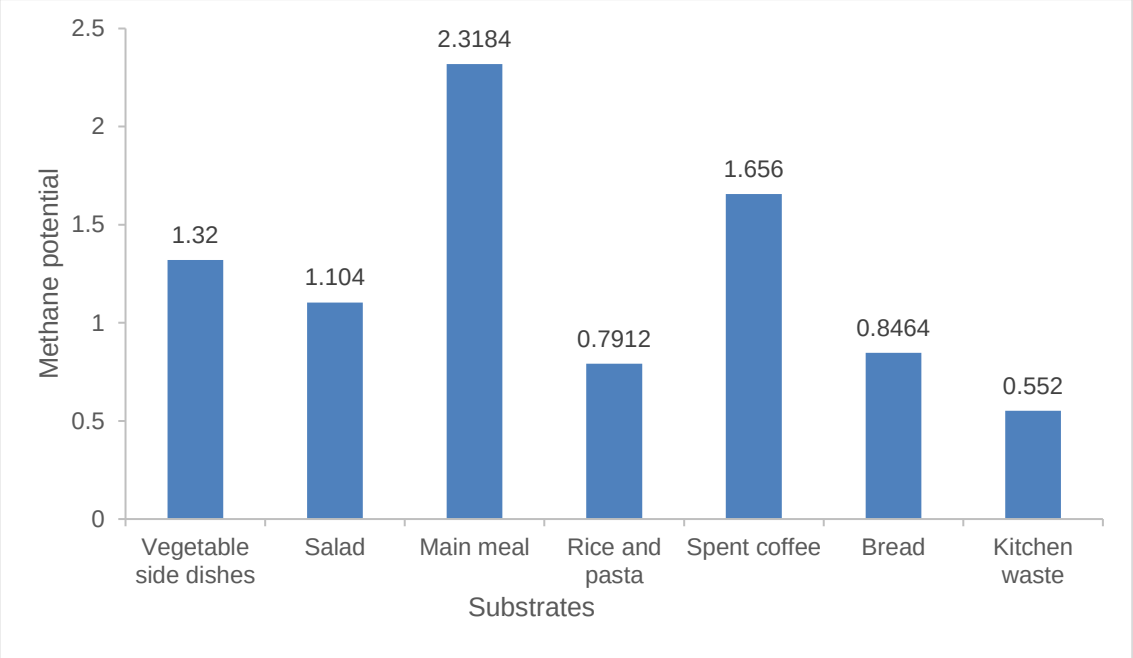

Figure 5: Methane Production from Various Substrates in Metropolia (in cubic meter)

The estimated methane potential in Metropolia is *8.58* m^3 daily. As, various assumptions were made to obtain the data, the actual methane yield might be in the range of *7.5 - 8.5* m^3.

This is just a theoretical calculation about the total amount of methane that can be produced in Metropolia from the amount of organic wastes produced. In the reactor itself, meat-containing wastes are not going to be used. These wastes pose the risk of contamination of pathogens in the system and are hard to digest.

9 Potential Hazards

There are many hazards associated with production of biogas from homebiogas appliance. The potential hazards that can pose a threat to human health and the environment are the following:

- Gas Hazards
- Hazardous Substances
- Mechanical Hazards
- Vandalism
- Fire Hazards
- Heat
- Chemical Hazards
- Sludge Removal and Fertilizer Handling

9.1 Gas Hazards

Biogas typically consists of methane, carbon dioxide, nitrogen, hydrogen, hydrogen sulphide, VOCs and few traces of oxygen. Out of these gases, methane, carbon dioxide and hydrogen sulphide pose some risks to human health according to the materials safety data sheet.

9.1.1 Methane(CH_4)

Methane from the experiment is collected in the gas tank and supplied to the stove through the gas outlet pipe. If the apparatus is not air-tight, and there are some leaks, then the resulting methane leak can be hazardous.

CAS number: 74-82-8

- Methane is a highly flammable and high-pressure gas. It might form an explosive mixture with air and can cause rapid suffocation. The Lower Explosive Limit (LEL) for methane is 5% by volume [28]. Moderate concentrations of inhalation may cause headaches, drowsiness, dizziness, vomiting and unconsciousness [29].
- Hazard Scale: High

9.1.2 Carbon Dioxide (CO_2)

CAS number: 124-38-9

- CO_2 is a colorless, odorless gas which is lighter than air. Carbon dioxide acts as a simple asphyxiant by diluting the concentration of oxygen in air below the necessary level to support life. Headache, dizziness, and sweating occurs if the exposure is prolonged at a concentration of around 7.6 percent [30].

- Hazard scale: Moderate

9.1.3 Hydrogen Sulphide (H_2S)

CAS number: 07783-06-04

- H_2S is a colorless gas which smells like rotten eggs. In a concentration of 20 to 50 ppm, H_2S irritates the eyes. A higher concentration causes irritation of respiratory tract [31].
- Hazard Scale: Slight

Figure 6: Possible Gas Leakage Zones in Homebiogas System

9.1.4 Precautions and Controls for the Gas Hazard

Precautionary measures to control gas hazards are given below:

1. Do not light a fire near the system as there is serious risk of fire.
2. When installing, only the gas pipes supplied with the system should be used [6].

3. The system needs to be installed outdoors allowing any excess gas to be released into the atmosphere. If the experiment is conducted in confined space, there might be risks of suffocation and fire when there are leaks [6].
4. Gasoline or any other flammable vapors or liquids should not be stored near the system.
5. Safety cloth, goggles and gloves should be used while handling components of the system.
6. The gas filter present in the system filters Hydrogen Sulphide considerably.
7. The system should be checked constantly for leaks and use of VOC sensors to figure out leaks in the system.
8. The gas valve should be closed for methane to accumulate in the gas tank and to prevent leaks.
9. Fire extinguisher should be placed near the system.
10. If the fire is caused by leak, the fire shouldn't be extinguished until leak can be stopped safely [30].

9.2 Hazardous Substances

- Food waste, which is used as input for production might contain some micro-organisms. Similarly, bacteria starter kit used for activating the system contains micro-organisms needed for the stability of this process. The fertilizer produced after the anaerobic digestion may contain large colonies of bacteria. Leaks in the system might expose these micro-organisms to the external environment, posing risks to the human health.
- Hazard Scale: Serious

9.2.1 Precautions and Control

Precautionary measures to control hazardous substances are given below:

1. Safety gloves should be used whenever in contact with biodegradable waste. A lab coat and safety goggles are also recommended.
2. The bacteria starter kit used is supplied by the manufacturer and has been tested to see if it is harmful to humans or not. The kit is safe to use and can be stored safely.
3. The chlorine tablet used in the system helps to disinfect the fertilizer produced [6].

4. A plunger should be used to push the waste safely inside the digester through the waste inlet sink.
5. The system should be checked for leaks constantly.
6. When situating the system outdoors, the system should be placed at a considerable distance from cafeteria, where food contamination might occur in case of leaks.
7. Animal manure, large quantities of cooking oil, and large quantities of citrus fruit peel should not be used as it can disrupt the balance of the system [6].
8. Haphazard introduction of food waste from different sources might introduce different pathogens to the system affecting the colonies of bacteria needed for biogas production. Thus, waste from known source should be used.
9. There might be pathogens that affect human health too. Washing hands before eating, drinking and touching mucous membranes are recommended.

9.3 Mechanical Hazards

- The system comprises of different individual parts which need to be set up by the researcher. The manuals need to be followed carefully to assemble the system, as there are many delicate parts in the system. Any fault while assembly might result in disjointed and weak construction of the system that might collapse. The system should be constructed by at least two people, as some components are heavy. After construction, the system needs to be placed outdoors. Careful collaboration is needed while moving the system to a desired place as the system is heavy.
- Hazard Scale: Slight

9.3.1 Precautions and Control

Precautionary measures to control mechanical hazards are given below:

1. The manual should be followed precisely. Special attention is needed when connecting the gas pipes and valves.
2. There should be no dips or bends in the gas pipe where condensation might accumulate.
3. The system needs to be moved by 2 or more people.
4. The system should be placed in a manner that makes it stable.

9.4 Vandalism

- Outdoor location of the system makes it prone to vandalism. When the system is placed outside, there is always the risk of some mischievous people or animals causing harm to the exterior of the system. Any harms to the exterior part might result in leakage of the system, spilling sludge and releasing gases to the environment. Acts of vandalism pose health risk to the individual involved and economic risk to Metropolia.
- Hazard Scale: Severe

9.4.1 Precautions and Control

Precautionary measures to minimize vandalisms are given below:

1. The system should be in a place where there are no frequent visitors. Warning sign should be placed to warn the people about the consequences of vandalism.
2. The system is enclosed inside a metal protective cover, which makes it safe from animals to some extent.
3. The materials used in the gas tank and digester tank can withstand considerable stress.
4. The gas pipes should be protected from bending and breakage.

9.5 Fire Hazard

- Methane is produced in the reactions involved, thus there is a risk of fire breakout. The equipment needs to be located from any heat source that might cause fire.
- Hazard Scale: Moderate

9.5.1 Precautions and Control

Precautionary measures to control fire hazard are given below:

1. Do not light fire and store explosive substances near the equipment.
2. Do not construct the appliance near any machinery that produces considerable heat.

9.6 Heat and pH

- Heat and pH are two important parameters of biogas production. Optimum production occurs at temperature of around 25 ° Celsius and 6-8 pH. When the parameters vary, the composition of biogas produced might differ. If the temperature falls below 15°C, carbon dioxide production from the system increases considerably [6]. Thus, any leakage from the system might result in symptoms of suffocation. If the system is placed around any heat source and the temperature increases considerably, methane stored in the gas tank becomes unstable resulting in risks of fire.
- Hazard Scale: Moderate

9.6.1 Precautions and Control

Precautionary measures to control hazards because of fluctuating heat and pH are given below:

1. The system needs appropriate temperature of around 32°C to function, thus the setting should be carefully chosen.
2. The pH of the system needs to be monitored constantly. If the pH is lower than 6.5, a kilo of sodium bicarbonate needs to be added to the system and mixed with plunger [6].
3. If the system is acidic, water should be added to dilute the contents of the system and the organic loading rate should be reduced.
4. The pH reading can be taken by draining around 2 liters of water from fertilizer outlet.
5. The temperature of the digester also needs to be reviewed constantly.

9.7 Chemical Hazards

- Sodium bicarbonate is used in biogas production to maintain the stability of the reaction, if the reaction becomes too acidic. The solution of sodium bicarbonate in water is a weak base which reacts with acids.
  CAS number: 144-55-8
  Hazard level: Slight
- Chlorine tablets are used in the overflow pipe to disinfect the slurry.
  CAS number: 7782-50-5

Hazard level: Moderate

9.7.1 Precautions and Control

Precautionary measures to minimize chemical hazards are given below:

1. Safety cloths, gloves and eye protection should be used while handling these chemicals
2. Chlorine tablets generate toxic gas in contact with acid, therefore they should be stored separately from any mineral acid.
3. Both chemicals are hazardous in case of skin, eye contact, ingestion and inhalation. In case of eye contact, wash eyes with cold water for 15 minutes [32].

9.8 Sludge Removal and Fertilizer Handling

- The sludge from the reactor should be removed when large chunks of organic matter are visible in the fertilizer outlet. If kitchen waste is being used, sludge should be removed once every three years [6]. This slurry removal process might pose some biohazard as there are various micro-organisms in it.
- The fertilizer obtained pose a potential biohazard risk, thus needs proper handling and storage.
- Hazard Scale: Moderate

9.8.1 Precautions and Control

Precautionary measures to be followed while removing sludge are given below:

- Slurry removal should be carried out only when there are no other alternatives for troubleshooting. The system takes around one and half months to stabilize after the slurry removal.
- Care should be given in the slurry removal as the system contains around 100 litres of slurry [6].
- Safety gloves need to be used when emptying the slurry, especially when dealing with the sludge removal sleeve.
- Collect the 100 litres sludge in buckets instead of releasing directly to drains.
- The slurry can be diluted and chlorine can be used as disinfectant. It can be released into the sewer after disinfection.

- The bacteria used for the system are not hazardous to the environment. Thus, the slurry can be used as a fertilizer or can be dried to be used as soil amendment.

Table 6:Summary of Risk Analysis of Homebiogas System

Potential Hazards	**Level of Risks**	**Mitigation Measures**
Gas hazard -Methane -Carbon dioxide -Hydrogen Sulphide	 High Moderate Slight	• System should be placed outdoors to allow any excess gas to escape to the atmosphere. • Use safety clothing. • Do not smoke near the system. • Use the gas pipes supplied with the system. • Use of VOC sensors to figure out leaks in the system.
Hazardous Substances	Serious	• Use of safety clothing and plunger while feeding the system. • Chlorine tablet should be used to disinfect the fertilizer. • Do not use animal manure and locating the system near the cafeteria should be avoided.
Mechanical Hazards	Slight	• Follow proper manual instructions during set up. • Move the system with the help of 2 or more people.
Vandalism	Severe	• Locate the system where there are not many frequent visitors. • Put some signs explaining the contents and risks associated with the system.

		• Configure the aluminium frame correctly using the manual, which provides added safety.
Fire hazard	Moderate	• Do not light fire or smoke near the system. • Do not place the system near any machinery that produces considerable heat.
Heat and pH	Moderate	• Maintain appropriate temperature and pH of the system. • Sodium bicarbonate should be added if the pH of system is lower than 6.5.
Chemical Hazards -Sodium bicarbonate -Chlorine tablets	 Slight Moderate	• Safety clothing needed • Avoid contact with eyes and skin • Chlorine tablets should be stored away from acids.
Sludge Removal and Fertilizer storage	Moderate	• Safety gloves should be worn and chlorine should be used as disinfectant. • Dilution of the sludge and disinfecting of the sludge needs to be done.

10 Minimizing Gas Hazards

It is visible from the risk analysis that various gases produced during anaerobic digestion are dangerous for human health. The gases produced are directly linked to the fire hazard, and chemical hazard associated with the system. Therefore, it is necessary to install some sensors as a safety mechanism to detect unusual spikes in gas concentrations from the system. In Metropolia, a Waspmote Plug and Sense- Smart Environment PRO node from Libelium, containing methane, carbon dioxide, carbon monoxide, and VOC

sensors, is going to be installed near the biogas system. In addition, temperature, humidity and pressure sensors are going to be used.

The sensor system consists of three components: Waspmote Smart Environment Pro node, different sensor probes and Meshlium gateway for connecting data from sensors to cloud platform. Waspmote Smart Environment Pro model has been designed to monitor environmental parameters such as temperature, pressure, and different gases. This model consists of six different sockets to attach sensor probes. Sensors should only be attached to their configured sockets such as temperature sensor to socket 'A', methane sensor to socket ‘A' or 'F', and carbon dioxide sensor to socket 'C' [33].

Waspmote Smart Environment Pro can be programmed through USB connection with the computer. The programming is done with Waspmote IDE software, which can be installed through Libelium website. In some cases, a device driver needs to be installed manually before launching the software. The coding for the functionality of sensors is carried out through this Waspmote IDE software. Sketches can be written for coding of the node and then can be uploaded to get sensor data. The correct serial port of the computer needs to be selected before uploading the sketch. Through the serial monitor, all the serial data being sent from the Waspmote board can be visualized. This node can be recharged using external solar panel.

The Meshlium gateway has 4 different radio interfaces for networking: a WiFi 2.4 GHz, a 4G/3G/GPRS/GSM and 2 XBee/RF radios. A web interface called Manager System controls all the interfaces and system operations conveniently using this Meshlium. Meshlium receives sensor data from Waspmote sensor devices equipped with RF (XBee) radios and sends it to the internet using Ethernet or 4G interface. Features such as monitoring of sensor data, adding new sensor, sending the data to different cloud platforms are available in the manager system of Meshlium device. The manager interface can be accessed through http://10.10.10.1/ManagerSystem [34]. When the Meshlium is connected to a power source, it gives out WiFi IP address. The manager system is accessed through the address or through ethernet cable.

Figure 7: Waspmote Smart Environment PRO Node with Temperature, Carbon Dioxide and Methane Sensor

10.1 Methane Sensor

Methane sensor will be used to detect leaks from the system which might be explosive. The methane emission should be measured also because of its potency as a greenhouse gas. The methane sensor has the measurement range of 500 – 1000 ppm (0 – 100% LEL). This sensor can operate in the temperature range of -10 °C to 40 °C. The calibration is done by the manufacturer which is +/- 0.15% LEL [33]. This sensor needs to be powered for minimum of 10 minutes to detect significant changes in methane concentration.

An example of coding required to obtain data from methane sensor probe is given below. The code generates real time methane concentration data, which can be accessed through serial monitor window. It is uploaded to Environment Pro node, containing methane senor in socket 'F'. The coding related to this system can be obtained from code generator application available in the Libelium website. Similar coding of other sensors can be done to generate different gaseous concentrations.

The library function included in this code provides the sketch with set of instructions to easily configure and read the sensors connected to the gas board. The outputs of the code give below are: Voltage of the methane sensor, Resistance of the methane sensor and Estimated methane concentration in ppm.

methane | Waspmote Waspmote PRO IDE

File Edit Sketch Tools Help

methane

```
// Library include
#include <WaspSensorGas_v30.h>
#include <WaspFrame.h>
// CH4 Sensor can be connected in SOCKET_6 or SOCKET_7
CH4SensorClass CH4Sensor(SOCKET_6);
char node_ID[] = "CH4_example";
void setup()
{
  // Configure the USB port
  USB.ON();
  USB.println(F("CH4 Sensor reading for v30..."));
  // Concentratios used in calibration process (in PPM)
  CH4Sensor.concentrations[POINT_1] = 100.0;  // <--- Ro value at this concentration
  CH4Sensor.concentrations[POINT_2] = 300.0 ;
  CH4Sensor.concentrations[POINT_3] = 1000.0;
// Calibration resistances obtained during calibration process (in Kohms)
  CH4Sensor.values[POINT_1] = 230.30; // <-- Ro Resistance at 100 ppm. Necessary value.
  CH4Sensor.values[POINT_2] = 40.665; //
  CH4Sensor.values[POINT_3] = 20.300; //

  // Define the number of calibration points
  CH4Sensor.numPoints = 3;
  // Calculate the slope and the intersection of the logarithmic function
  CH4Sensor.setCalibrationPoints();
// 1. Turn on the board and the SOCKET
// Switch ON and configure the Gases Board
  Gases.ON();
```

```
  // Switch ON the sensor socket
  CH4Sensor.ON();
}
void loop()
{
  // 2. Read sensors
 float CH4Vol = CH4Sensor.readVoltage();           // Voltage value of the sensor
  float CH4Res = CH4Sensor.readResistance();        // Resistance of the sensor
  float CH4PPM = CH4Sensor.readConcentration();  // PPM value of CH4
// Print of the results
  USB.print(F(" CH4 Sensor Voltage: "));
  USB.print(CH4Vol);
  USB.print(F(" V |"));
 // Print of the results
  USB.print(F(" CH4 Sensor Resistance: "));
  USB.print(CH4Res);
  USB.print(F(" Ohms |"));
USB.print(F(" CH4 concentration Estimated: "));
  USB.print(CH4PPM);
  USB.println(F(" ppm"));

  // 3. Create ASCII frame
   // Create new frame (ASCII)
  frame.createFrame(ASCII, node_ID);
  // Add CH4 PPM value
  frame.addSensor(SENSOR_GASES_CH4, CH4PPM);
  // Show the frame
```

Figure 8: Sketch for Displaying Methane Concentrations in Waspmote Pro IDE [35]

10.2 Carbon Dioxide Sensor

Carbon dioxide sensor detects any sharp changes in CO_2 concentration near the system. An increase in the CO_2 concentration indicates leaks in the system, and a decrease in ambient air quality. The measurement range for the sensor is 350 to 1000 ppm. It can operate at a temperature from -10 °C to 50 °C and is calibrated by the manufacturer. The sensor needs to be powered for at least 10 minutes to get precise measurement. The main coding needed to operate this sensor is given below [33]:

```
{
// Switch ON and configure the Gases Board
Gases.ON();
// Switch ON the CO2 Sensor SOCKET2
```

```
CO2Sensor.ON();
// PPM value of CO2
float co2Vol = CO2Sensor.readVoltage();
float co2ValPPM = CO2Sensor.readConcentration();
}
```

10.3 VOC Sensor

At a standard pressure of 101.3 kPa, organic chemical compounds with a boiling point less than or equal to 250 °C are VOCs [36]. Biogas production from food waste results in the production of VOC such as p-cymene and d-limonene [37]. These compounds can cause nausea, headache and irritation to throat and nose [38]. They produce unpleasant smell too. VOC sensor accurately measures hydrocarbons, CO, and VOCs. The measurement range for this sensor is from 30 to 400 ppm. It operates in the temperature range of -30 ºC to 85 ºC [33].

10.4 Temperature, Humidity and Pressure Sensor

Parameters such as temperature, humidity and pressure is measured by this sensor. Any fluctuation in temperature around 30 ºC can hamper biogas production, thus this sensor is vital for the functioning of the system. Temperature, humidity and pressure ranges of this sensor are -40 to 85 ºC, 0 to 100% HR, and 30 to 110 kPa respectively. In the range of 0 to 65 ºC, the sensor has a preciseness of +/- 1 ºC [33].

The calibrated Libelium sensors have a high level of accuracy. These sensors allow real time detection and can detect even the slightest emission of gases. They can be programmed by a combination of C and C++ programming languages.

11 SWOT Analysis

A SWOT analysis for installing biogas system in Metropolia UAS is presented below. This analysis will highlight all the strengths, weaknesses, opportunities and threats arising in the campus from the new anaerobic digester. The analysis will help to analyse the weaknesses and threats of the system and optimize the opportunities for maximum benefits of the organization.

STRENGTHS

- Environment-friendly solution. Utilizes organic waste from the university.
- Produces sustainable energy and fertilizer.
- Can utilize diverse kind of biomass as substrate.
- Follows the module of circular economy.
- Decreases amount of waste going to Finnish waste stream.
- Less maintenance required.

WEAKNESSES

- Anaerobic Digestion is dependent on various factors. Changes in parameters such as temperature, pH affects biogas production.
- HomeBiogas reactor does not have enough capacity to handle all the organic waste of the campus.
- Food waste containing meat cannot be used because of fear of contamination.

OPPORTUNITIES

- Bigger reactor will solve the waste problems in the campus.
- Huge biogas potential in Metropolia.
- Can be economically viable option in the long run.
- Fertilizers can be used in the garden during the summer time.
- Use of sensors might help to optimize biogas production by data recording and analyzing.

THREATS

- Many potential hazards from the system such as vandalism, and gas hazard.
- Methane is highly combustible and might be dangerous if any leaks in the system.
- Risk of pathogenic contaminations while feeding the digester and collecting the fertilizer.

12 Conclusion

Biodegradable waste provides a great opportunity for sustainable energy manufacturing. The use of biogas reactor for food waste management will not only provide environmental benefits but also financial benefits for Metropolia. The biogas reactor in Metropolia will support the commitment towards circular economy of the campus. The theoretical studies conducted in this thesis clearly indicate that large volumes of biogas can be produced from the food waste in our campus. The HomeBiogas reactor being used is an extremely efficient reactor but the digesting capacity of the reactor is extremely less, compared to the waste produced. Thus, after the testing phase of this reactor, a bigger biogas plant can be installed in the future to cope up with the food waste.

As the biogas reactor can accept only around 6 kg of kitchen waste every day, food waste substrate containing lipids and proteins should be used for maximum biogas production. Co-digestion of vegetable wastes and breads can be used as a possible substrate in the reactor. From the risk analysis table, it is clearly visible that there are many potential hazards associated with the system. Gas hazards and vandalism are established as the most serious risks. The precautionary measures for all the hazards should be studied before using the system. The sensors studied in this thesis will provide a safety mechanism for detection of leakages in the system.

During installing the system outdoors, the setting should be carefully chosen considering availability of maximum sunlight, less chances of contamination due to leakages and chances of vandalism. The temperature might be a hindering factor for biogas production, especially in the Finnish winter. In a scenario where the temperature drops drastically, a heater needs to be used to increase the temperature.

Based on this thesis, it can be concluded that Metropolia has huge biogas potential. The risks associated with the biogas system however should not be overlooked. Factors such as substrate selection, sensors use, risk analysis study, contribute to the safe and efficient operation of the system.

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