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# Introduction

This report aims to give a broad overview of the potential of using food waste for biofuel production in Norway. In 2010, Norway generated 1.5 million tons of wet organic waste (Stats Norway). As of July 2009, Norway instituted a law against the landfilling of biodegradable waste (Section 9.4a of Waste Regulations). Therefore a plan needs to be enacted to deal with food waste. This residual resource comes from households, manufacturing and the service industries. There is still value that can be derived from this resource and we would like to contribute to the conversation on how best to use it.

The situation has the potential of being a win-win-win situation from an economic, societal and environmental perspective. It means reducing a waste stream and replacing some fossil fuel production, thereby lowering carbon dioxide emissions, carbon taxes and global climate change effects. Using food waste serves to avoid land use and food price issues that face other biofuel feedstocks such as corn, because this resource is not currently productively used and should only compete with fossil fuel use.

This report will begin with an outline of supply considerations like the composition of wastes, origin and quantity available. We will present data based on research and consultation with experts regarding the average composition of this waste source.  
Section ... will give an overview of different chemical and biochemical processes, for example, anaerobic digestion. The organic compositions of waste foods and some other biodegradable substrates have to be conveniently treated by different methods to redude their adverse impacts on the environment. Anaerobic digestion (AD) for biogas production is an effective bioprocess to achieve this goal. In that biological process, microbes will excrete some extra-cellular enzymes that has significant roles in transferring organic materials into simpler compounds in the absence of oxygen. At the end of the century most of the world’s biogas systems were operating in Europe (91%),

with some in Asia (7%) percent and a few in the US (2%). Germany was the leader with 35% of all AD plants, followed by Denmark (16%) and Sweden and Switzerland and Austria (8%). (www.biogasworks.com (1998)). Norway’s first bio-waste treatment plant was launched by Cambi THP at Lillehammer started in December 1999 with capacity of 14,000 tonnes of waste/year for producing Electricity and steam. The municipalities of Oslo's new biogas plant is ready for launch for treating of biological food waste, and it is able to treat 50 000 tonnes of food waste a year.

Section ……. Will show the amount of product and by product we can get from the food waste in Norway(Aqueel)  
Section .... will look at the environmental impacts of this change, trying to use a Life Cycle Assessment perspective.

Our discussion section will conclude with a brief outline of the practical considerations of putting this project into action. These insights were gained during the Technoport Entrepreneurship Seminar.

Add

Info about the problem we will be solving ……….Samantha

Discussion about cost of using two reactor and optimal condition for producing high efficiency( vahid and Ly)

# Methodology

## 2.1 Supply of Feedstock.

**From Stats Norway - http://www.ssb.no/english/subjects/01/05/40/avfregno\_en/**

**Waste in Norway by material (final figures 1995-2007, preliminary figures 2008 and 2009), source and material (2008\*) and treatment and material (2008\*). 1 000 tonnes (Corrected 14 December 2011 at 13:50**

|  |  |
| --- | --- |
| **End of Life Treatment for Wet Organic Waste, Norway, 2010** | **Units 1,000 tonnes** |
| Sorted for material recovery | 343 |
| Biological treatment | 297 |
| Energy recovery | 535 |
| Cover material | 8 |
| Incin without energy recovery | 159 |
| Landfill | 71 |
| Other | 79 |

**Table 1..................**

|  |  |
| --- | --- |
| **Wet organic waste, for Norway, in 2010** | **Units 1,000 tonnes** |
| Households | 556 |
| Agriculture | 110 |
| Mining | 5 |
| Manufacturing | 401 |
| Electricity | 1 |
| Construction | 73 |
| Service Industry | 346 |
| Absolute Total | 1493 |
| Total for us | 1303 |

Take down table

In order to get an estimate of the amount of biogas we can produce from food waste in Norway, we need hard numbers of the amount of feedstock available, it’s composition and where it is produced. We decided that, for simplicity of logistics and information, initially we will not deal with agricultural residues, though it is a large portion of the biomass available. This allows room for our production to increase in the future. As shown in Table #?? Norway produces nearly 1.5 million tons of wet organic waste per year, using 2010 statistics (Stats Norway). As mentioned we will exclude agriculture, and we will also neglect mining, electricity and construction industries. This leaves approximately 1.3 million tons of biomass available for biogas production in all of Norway. Obviously not all of this waste will be available for our purposes so this is used as the higher boundary of our feedstock supply range. At the moment this resource is diverted as shown in Table #???. As of July 2009, Norway instituted a law against the landfilling of biodegradable waste (Section 9.4a of Waste Regulations). As we can see from the 2010 statistics, there are exceptions to this.

To estimate the lower boundary of this resource we looked to information gathered by the ForMat project in Norway, which aims to decrease usable food waste by 25% by 2015 (). They have found that each person in Norway throws away 51 kg of perfectly edible food every year. They found 377,000 tons of total food waste but they do not include primary production, large households, hotels or restaurants. Also for our purposes it is not relevant that the food still be edible. Therefore these numbers represent an absolute lower boundary of our feedstock supply.

This waste is currently collected by either the municipality or private collectors that are paid by the grocer or restaurant. (source)

According to the ForMat report, there are several categories of food waste that make up the majority. Milk and cream are the most often wasted, though they are emptied into the sink so that resource is not available for our purposes. Following dairy, the most wasted categories are fresh fruit, fresh vegetables, fresh baked goods and meal leftovers. Based on the 51.1 kg/person/year, fresh fruits and vegetables make up 12.5 kg/person/year, leftovers are 11.3 kg/person/year and fresh bread is 10.1 kg/person/year. This gives us an approximation of the composition of our food waste and allows us to choose appropriate biological tools and processes.

|  |
| --- |
| Table #?? Wasted Usable Food, Norway, 2011 |
| **Total wasted usable food: 377 000 tons** |
| **52 000 tons from producers** |
| **2 000 tons from wholesale** |
| **68 000 tons from retailers** |
| **255 000 tons from consumers** |

Table 3 .........

Waste Regulations Online. http://www.lovdata.no/cgi-wift/ldles?doc=/sf/sf/sf-20040601-0930.html#9-4)

## 2.2 Characterization of Food Waste:

Food waste characteristics are key to anaerobic digestion because they govern yield of biogas and process stability. There are different types of waste food characteristics which are very important such moisture content (MC), Volatile Solid (VS), biodegradability, Carbon to Nitrogen Ratio, nutrients etc. Some characteristics of food waste given in literature is represented in table.

### 2.2.1 Biodegradability:

Food waste is typically biodegradable organic waste and therefore it can be converted into biogas. The biodegradability of food waste is due to presence of carbohydrate, lipid, cellulose and protein and extent of biodegradability depends upon the relative amount of each component. The yield and production of biogas is directly related to biodegradability.

### 2.2.2 Carbohydrate and Lipid Contents:

The composition of food waste depends upon the type of food and on different factors such as season and location. Lets see the effect of type on the composition of food, for example, the waste from a meat processing plant will contain high fat and protein content. The fat content are lipid and therefore less degradable and harder to digest. However, lipid content has positive impact because they have very high energy content and through digestion they will yield high quality biogas. When lipid contents are 20-30%, it increases chemical oxygen demand COD removal rate (need to define before use) of 13% and methane production rate 7 to 15%. However if lipid content increases above 40%, the methagenosis is inhibited by long chain fatty acids.

Food waste coming from the canning industry contains carbohydrates such as sugar and starch which are easily degradable; from here we can see the effect of location on the composition of food.

### 2.2.3 Carbon to Nitrogen(C/N) Ration:

C/N ratio is an important factor for production of biogas from food waste. Presence of Nitrogen is important to build up bacterial communities which are essential for fermentation. The C/N ratio of 20-30 is optimum, if this ratio is high it will affect microorganisms. If the ratio is too low, nitrogen will come out from waste and accumulate at top in form of Ammonia, which increases the PH up to 8.5, which eventually affects methanogenic communities.   Anaerobic digestion process description

## 2.3 Pre-treatment

Pre-treatment is used to increasing productivity and decreasing HRT which has a direct impact on the size of the reactors. Pre-treatment process could be changed by varying the composition of the feedstock. Pre-treatment is divided to five main parts:

1. Size reduction
2. Separation
3. Hygienisation
4. Mechanical hydrolusis
5. Biochemical conversion  
   Different companies were reviewed and the detailed information extracted

### 2.3.1 Size Reduction

Size reduction usually take places in four different processes:

* **Grinding**
* **Maceration**
* **Pulverization**
* **Slurry**

Depends on the deed stock one or combination of these processes used for pretreatment. Since livestock from agriculture manure requires less pre-treatment than animal byproducts require considerable pre-processing.  
Nowadays, lots of companies work on producing biogas from food processing waste, slaughterhouse offal and animal mortalities. Pre-processing and equipment of each company varies as the feedstock changes.

### 2.3.2 Separation

Separation is mainly for ensuring whether all feedstock is biodegradable and clean organic material. Non-biodegradable material take space and have a negative impact on HRT and size of the reactor. Separation process for food waste usually contains three main steps:

* **Food Separation:** Separation in home, restaurant or food industry
* **Manual Sorting :** Remove inorganic material like rock and metal
* **Mechanical Sorters :** Screens, Rotating Trommels, magnetic separation.

### 2.3.3 Hygienisation:

Hygienisation is used for feedstock which contaminated in some form or contain pathogens or infectious material. Many companies don’t consider this part because pathogens is considered to be destroyed with simple mesosphilic 32C digestion.

### 2.3.4 Mechanical hydrolysis:

Thermal pre-treatment (incineration) of MSW and Mechanical Biological pretreatment of waste are the most common methods in use for the pretreatment of municipal solid waste. Thermal pre-treatment of waste involves the controlled burning of waste, with or without energy recovery. This method of waste pre-treatment has increasingly been in use over the past few years mainly to reduce the amount of waste and to decrease their biological activity. However, this method of waste pre-treatment entails a much higher cost; longer pay back periods due to high capital investment and although, modern incinerators do comply with existing emission regulations, the public are still concerned with the adverse effects associated with the emissions from incinerators on health.

Thermal hydrolysis has many advantageous to use which brought bellow:

* Enhanced biogas production up to 55-65%
* The improved dewaterability after digestion by 50% - 100% results in energy savings
* Lower retention time and higher dry-solids content in digester which increase the capacity of the plant up to two or three times.[ http://www.cambi.no]

### 2.3.5 Biochemical conversion:

Energy conversion of organic materials can proceed along three main pathways—thermochemical, biochemical, and physicochemical. Currently, all three pathways are utilized to varying degrees with fossil fuel feedstocks.

Biochemical conversion proceeds at lower temperatures and lower reaction rates. Higher moisture feedstocks are generally good candidates for biochemical processes. Thermochemical conversion is characterized by higher temperatures and faster conversion rates. It is best suited for lower moisture feedstock.

Pre-treatment fulfills the first three components of the waste hierarchy mainly: reduction, reuse, recovery and disposal. As stated by SITA UK (2002), the following three criteria are considered to be fulfilled by pre-treatment technologies. It must be a physical/ thermal/, chemical or biological process including sorting.

1. Biological: focusing on aerobic (with air) or anaerobic (without air) waste processing techniques.
2. Chemical: study on pyrolysis, incineration and gasification technologies.
3. Physical: studies of waste processing plants that use autoclaving and thermotreatment techniques.

The pre-treatment process must permanently change the characteristics of waste; the process must facilitate the waste’s handling or recovery.

However, biological processes have become popular among other technologies and gained an interest in the field of waste treatment. These treatment technologies can maximize the recycling and recovery of waste components.

## 2.4 Stages for anaerobic digestion

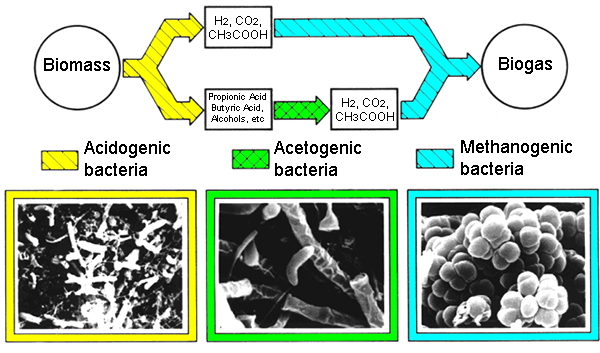
### 2.4.1 Hydrolysis

### 2.4.2 Acidification (or acid-forming stage)

Lignocellulosic material accounts for a significant fraction in solid components of food wastes and has direct effects to the acidification step during the production of biogas yield (Javad Asgari, 2011).

Acidogenesis comprises two different reactions of fermentation and acetogenesis. Acedogenic bateria are facultative anaerobes that can grow well in acid condition, therefore they can be used in fermentation stage to convert amino acids and sugars to organic compounds (fatty acids), acetate and NH3, alcohols and some other organic acids (Figure…). Among these products, the hydrogen, carbon dioxide and acetic acid will skip the acetogenesis stage and be used directly by the methanogenic bacteria to produce methane in the final stage (Nayono, 2009)

Futhermore, the rest of acedogenesis products will be transformed to hydrogen, carbon dioxide and acetic acid by acetogenic bacteria (Figure…). In acetogenesis stage, it is important to keep hydrogen partial pressure at low level in order to allow for the conversion reactions of acids occur in methane formation step (Javad Asgari, 2011).

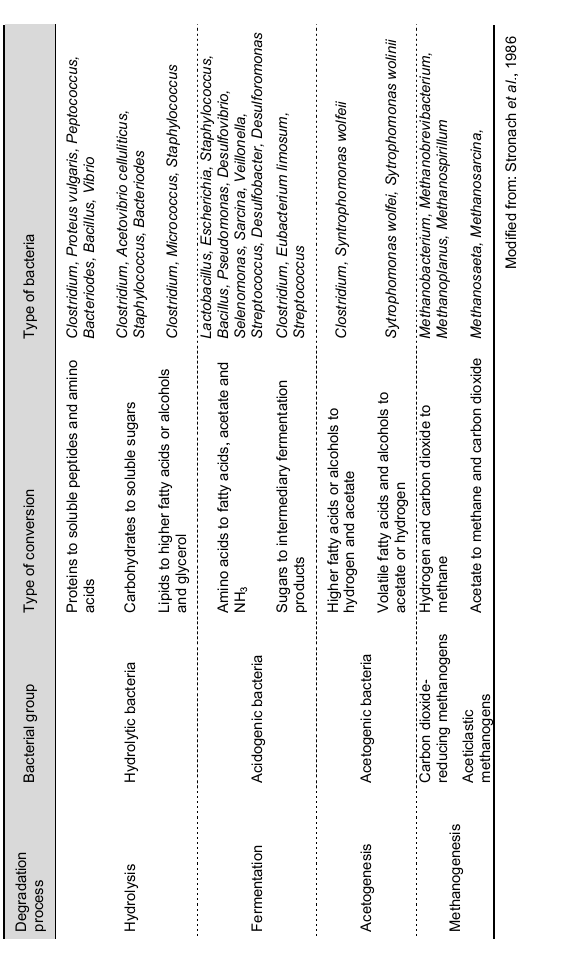


Figure…: Anaerobic methane generation from organic materials (with microorgnasims involved) (Aivasidis, A. (2000))

### 2.4.3 Methanogenesis (Methane formation)

The production of methane requires the presence of methane producing bacteria (called methanogens) (Javad Asgari, 2011). These bacteria prefer the environment with strict anaerobic conditions for their growth, are very sensitive to the changing of environment and has important function on converting hydrogen, carbon dioxide and acetic acid into methane and carbon dioxide (Javad Asgari, 2011).

During this stage, there is around 66% of methane that is produced from acetate and the fermentation of alcohol formed in the second stage by using acetoclastic methanogenic bacteria (*Methanosaeta spp*. and *Methanosarcina spp*.), and remaining 34% of methane is produced by using methanogenic bacteria to reduce carbon dioxide by hydrogen (Nayono, 2009). Table… indicates the bacterial groups that involved in each step of AD process.



**Table…:** Types of bacteria involved in each step of organic material **digestion**

#### 2.4.3.1 Important parameters in AD:

1. **pH**: the activities of microbes using in the anaerobic process are very sensity to the changing of pH in its environment. Therefore, the pH value of system is completely influential to the final product yield. The formation of methane is highest when the pH is kept at narrow desired range of 6.5 to 8.5, with an optimum pH between 7 to 8. In case the pH in anaerobic digester is lower than 7 or higher than 8, production yield of methane may decrease (Weiland, 2010)

In order to keep the value of pH on the equilibrium, buffer has to be added into the system, such as sodium carbonate, calcium carbonate, calcium hydroxide, lime... The addition of selected chemicals should be done slowly to prevent any adverse impacts on the growth and activities of bacteria. Because methanogenic bateria require bicarbonate alkalinity for their growth, so chemicals that are able to release bicarbonate alkalinity are preferred to use to provide optimum conditions for bacterial growth (Javad Asgari, 2011)

1. **Effects of temperature on biogas production:** Methanogenic bacteria are inactive in very low or very high temperature. Thus temperature in the digester is an important factor affecting to the biogas production and determines the degradation rate of organic substances in hydrolysis and methanogenesis (Nayono, 2009).

There are two common optimal temperature ranges in which anaerobic fermentation can be carried out, mesophilic and thermophilic.

1. **Mesophilic** (optimal temperature around 25-40oC): microbial communities in mesophilic reactors can suffer a greater environmental changes. The advandtages of this system are more stable, easier to maintain, lower investment cost, does not need additional energy for heating the system. However retention time of the content is longer and biogas yield is lower (ADD REFERENCES)
2. **Thermophilic (**50- 65oC): This process give higher methane production and pathogen removal. However, this method is more sensitive to toxic substances (the amount of free ammonia increase with temperature) and harder to maitain, require additional energy for digester heating (Javad Asgari, 2011)

HRT will be reduced when the temperature increase. Therefore, Thermophilic(~55C) is the faster process in comparison to Mesophilic(~33C). During the prosess of biogas production, it should be keep the temperature in bioreactor at nearly constant. If the temperature oscillates so much, biogas yield will be affect negatively.

1. **Hydraulic retention time (HRT):** is the average time that a substrate stays inside digester before coming out.

The shorter the substrate is kept under appropriate conditions, the higher the rish of active bacterial population will be washed out while longer HRT gives more complete degradation of substrate, but requires larger volume of digester. Futhermore, the reaction rate in digester is also decrease with longer HRT, so it is necessary to find an optimal retention time for a substrate in order to achieve best benefits during production process (Yadvika, 2004)

There are many factors that need to be controlled to achieve an appropriate HRT, such as types of feedstock, process temperature, total solid substrates and environmental conditions… It should be noted that the range of 14 to 30 days is suitable HRT for dry digestion and just about 3 days for wet digestion (Nayono, 2009).

1. **Organic loading rate:** can be defined as the certain amount of organic matters (volatile solids or COD of feeding substrate) that are processed in anaerobic digester in a certain time.

* If the percentage of solids content is less than 15%, the system is known as “wet digestion”.
* If the amount of solids content is around 25-30%, the system is known as “dry digestion”

In both dry and wet digestion, water also needs to be added in order to lower the content of solids in digester (Nayono, 2009). The loading rate is strongly influential on gas production. Vartak et all (1997) was found that methane yield increase with reduction in loading rate. Besides, the rapid increase in loading rate is a potential risk of fatty acid accumulation in anaerobic digester, which leads to pH drop and reduces the activity of methanogenic bacteria or decreases the efficiency of the system . According to an experiment carried out on a 100 m3 biogas plant in Pennsylvania, if the loading rate of organic matters was changed from 346 kg VS/day to 1030 kg VS/day, gas production increased significantly from 67 to 202 m3/day. However, in case the increase in quatity of organic substrates is beyond the optimal level of loading rate, no more gas will be produced.

1. **Mixing condition:** Mixing can be considered as an important way to provide a sufficient contact between substrates and bacterial communities in digester system, enables the reduction in particle size as digestion processes and help to release produced gas from the digester contents.

Mixing can be performed throgh several methods such as mechanical mixers, recirculation of slurry (digesting sludge), or by injection of the produced biogas.

## 2.5 Estimation of Methane Production:

The production of biogas can be estimated from the food waste once we have some estimated formula for Food waste. The CH4 and CO2 contents then can be predicted from reaction derived from Buswell Equation. The Chemical formula for Food waste can be calculated from ultimate analysis of Food waste. Ultimate Analysis of typical food waste is given as follow.

|  |  |
| --- | --- |
| **Component** | **%** |
| **C** | **51** |
| **H** | **12** |
| **O** | **34.6** |
| **N** | **2.6** |

Considering 100 kg of food waste, the composition of which is given as above. Mole of Carbon, Hydrogen, Oxygen and Nitrogen are calculated as follow

Moles of Carbon = 0.51/12 \* 100 = 4.25 Kg moles

Moles of Hydrogen = 0.12/ 1.008 \* 100 = 6.3 Kg moles

Moles of Oxygen = 0.346/16 \* 100 = 2.35 Kg moles

Moles of Nitrogen = 0.026 / 14 \* 100 = 0.185 Kg moles

Molar Ratio

C : H : O : N

4 .26 : 11.9 : 2.1 : 0.186

Dividing by Minimum value

C : H : O : N

23 : 64 : 12 : 1

So the chemical formula for food waste calculated from ultimate analysis is given as C22H34O13N1 .Now, the biogas yield can be theoretically estimated using this chemical formula by Buswell’s Equation. Buswell devised equation based on chemical formula to predict theoretical yield of component products from digestion. The buswell’s equation is given as

Putting the values of a, b, c and d as given by the formula C22H34O13N1, gives equation

C22H34O13N1  + 1.75 H2O ------------- 16.6 CH4  + 6.7 CO 2  + NH3

Biogas production can be estimated for 110 tons per day from above calculated reaction of fermentation.

Mass of food waste entering = 110 ton/day = 1100000 kg/day

Moles of C22H34O13N1  = 202 kg mole

Moles of H2O required = 361 kg moles, Mass of H2O = 6501 kg/day

Moles of CH4 produced = 3268 kg moles , Mass of CH4 = 52296 kg/day

Moles of CO2 produced = 1357 Kg moles, Mass of CO2 = 59731 kg/day

Moles of NH3 produced = 202 Kg moles, Mass of NH3 = 3436 Kg/day

The results of calculations are given as

2.6 Post- Treatment:   
Bio gas as a product and fertilizer as a byproduct of the plant needs some preparation before selling to costumer.

### 2.6.1 Bio gas treatment:

1. **Hydrogen sulfide contents**

In order to combat the amount of the corrosive hydrogen sulfide (H2S) in the biogas produced by the process, a small quantity of air is injected into the digester head. This allows the H2S in the biogas to be converted by bacteria to elemental sulfur that will cling to the tank roof and be cleaned when necessary.

1. **Carbon di oxide contents:**

CO2 removal from bio gas is mandatory to meet the specifications of a natural gas grid since CO2 reduces the heating values of natural gas, is corrosive and increase the volume for storage and transportation of gas.

Table1.Bio gas composition [Rasi, 2007]

|  |  |  |  |
| --- | --- | --- | --- |
| **Process** | **Co2[%]** | **CH4[%]** | **H2s[ppm]** |
| **Farm biogas plant** | 37-38 | 55-58 | 32-169 |
| **Sewage digester** | 38.6 | 57.8 | 62.9 |
| **Landfill** | 37-41 | 47-57 | 36-115 |

As the table shows for direct usage of biogas after bio gas plant usually needs treatment. Nowadys biogas plants use PSA to reduce sulfur contents of the gas.

Deng *et al*. result’s indicated that membrane process with a CH4 recovery of 99% at a low operation cost could be designed to achieve natural gas grid specification which is more environmentally friendly technique[Deng, 2010]. Makaruk *et al.* pointed out that a membrane system provides enough flexibility for heat integration within biogas plants [Makaruk, 2010]. In 2008 MemfoACT was started to make membrane which has more concentrate on biogas recovery[([www.memfoact.no](http://www.memfoact.no))].

### 2.6.2 Fertilizer treatment:

Theremnant needs to be treated to meet the standard of fertilizer costumer. For separating the liquid inside of the digested effluent each company uses different method regarding the feedstock.

1. **Slope Screen Separator**

Cheapest but not the effective way to removesolid residuals from liquid effluent. The method is simple rundown of the influent to screening tilted plat.

1. **Centrifuge**

Using centrifugal force is the most common way to dewater digested feed.

## 2.7 Reactor Design:

### 2.7.1 Single Stage vs. Multistage

All three steps of fermentation take place together in one reactor which is cheaper and simpler even though it takes more time 14 or 28 days depending on the feed and operating temperature (Verma, 2002).

In multi stage, two or more reactors are used to separate each steps which reduce HRT. The retention time in multi stage fermentation is approximately seven days, three days for the methanogenesis and between two and four days in the hydrolysis phase. .[ <http://bta-technologie.de>] **Biologische Abfallverwertung GmbH & Co (Germany)**

Multi stage fermentation compared to single stage fermentation. Multi stage fermentation can process in one week the same amount of waste that a single stage can process in two weeks, although both method has the same efficiency.

### 2.7.2 Batch vs. Plug Flow vs. Continuous

An investigation was conducted into the suitability of either of the batch or continuous stirrer tank reactor (CSTR) digesters for anaerobic degradation of (MSW) in the production of biogas. Hilkia et al. the amount of methane produced per unit volume of the batch digester is about 4 times less than the amount per unit volume of the CSTR, the cost per unit volume of the batch digester ($5.98) is 6 times less than that of the CSTR ($33.8). So, it was concluded that the batch digester is better option for the digestion of MSW for biogas production, compared to the CSTR.[ Hilkia, 2008]

## 2.8 Bio gas storage tank

The two main types of storage tank is used in biogas plant is internal and the other is external. Internal is in low pressure and connected to digester while external is in high pressure and separated from the digester. High pressure makes safety and material costly, therefore low pressure connected storage tank is used in commercialized biogas plant.

2.9 Proposed Design:

Proposed design is based on food waste which gathered from household, restaurant and food industry carried out by truck to the place near the town. Non-biodegradable material which take space and have a negative impact on HRT and size of the reactor removed in separation preprocessing in two steps. First metals are removed by electromagnet then go roll crusher to reduce the size of the particle. In the pulper the waste is pre-heated by injecting recycled steam from the reactors and the flash tank. Pre-heated sludge is pumped into the reactor(s) where thermal hydrolysis at high pressure and temperature takes place at approximately 165ºC for 30 minutes (http://www.cambi.no ).Thermal hydrolysis can prevent very unpleasant odors in the hydrolysis steps. In addition biosolids in a pressure vessel, splitting the tough cell membranes of the microorganisms present, releasing and breaking down the long chain molecules, and making them readily digestible. In flash tank steam explosion disintegrates the organic material into easily digestible material. By using the thermal hydrolysis there is no need for because they are already digestable. ([www.Cambi.com](http://www.Cambi.com)) These material pass through heat exchanger for reaching 4040 C. In order to avoid corrosion by hydrogen sulfide (H2S) in the biogas produced by the process, a small quantity of air is injected into the digester head. Hydrolyzed organic material digested rapidly and produced biogas. Generated biogas is filtrated by new carbon membrane Company MemfoACT (www.memfoact.no) was launched in 2008 in Norway. Filtrated gas sent to gas holder to store for transporting or selling to costumer. Floating gas holders on the digester form a low-pressure storage option for biogas systems. These systems typically operate at pressures below 2 psi.

****

Figure Process design flow sheet

# 3. Result & Discussion

Considering 110 tons/day of organic food waste available in feed stream which can be converted into biogas by anerobic digestion. The organic food waste is represented by C23H40O13N calculated from ultimate analysis. The estimated product biogas contains CH4, CO2 and NH3.

|  |  |  |  |
| --- | --- | --- | --- |
| **Biogas Production** | | | |
|  | Moles/day | Volume  M3 | Volume % |
| CH4 | 2663 | 69.3 | 54 |
| CO2 | 2060 | 53.6 | 41.8 |
| NH3 | 205 | 5.3 | 4.16 |

This estimation of biogas production showed that volume % of methane is larger than CO2 but still large portion of biogas contain CO2. The CO2 is not energy source and its presence decrease heating value of biogas. The calculation of biogas using ultimate analysis reveals that if % of H in ultimate analysis of organic mass is more in the

For poster:

We will produce biogas as our main product and fertilizer as a saleable byproduct. We would like to sell biogas to the transportation industry for example, AtB, because the buses already run on natural gas. Our product will be marketed as a cleaner energy source than their current fuel, and this is a matter of importance for public transportation. Also, due to lower carbon dioxide emissions, they could realize a reduction in carbon tax paid. Our byproduct will be sold directly to farmers, offsetting fertilizer production. We can pursue partnerships and R&D with universities and research institutes. Funds will be acquired from investors.

Business Plan EiT

During the Technoport Seminar on Entrepreneurship we had the opportunity to create a rough business plan for our idea. This helped us see the practical considerations of the project. We will now outline some of the details that we discussed during this process. We began by brainstorming on who our potential customers could be, in Trondheim in particular since that is the region we know best in Norway. We will likely have different customers for our product (biogas) and our by-product (fertilizer). For our biogas we would like to sell it to the transportation industry for example, AtB, because the buses already run on natural gas. We believe that they would be very interested in our product because it can be marketed as a cleaner energy source than their current fuel, and this is a matter of importance for public transportation. Also, due to lower carbon dioxide emissions, they could realize a reduction in carbon tax paid. Our byproduct will be sold directly to farmers. We would like to establish continuous relationships with our customers.

One of the more difficult topics that arose was that of channels, meaning how we actually sell the product. We debated several options. They are as follows. We could have our customers (buses) come to our facilities to receive the product. This would require our production to be centrally located. Another option would be to sell the product to a company that has an existing distribution network and consider ourselves exclusively a producer, not a distributor. We determined that we would need to gather more information on the current setup before decisions could be made.

We examined the key resources that we have to determine what activities we should control. It was agreed that we possess interdisciplinary knowledge, organizational skills, a network revolving around NTNU and management skills. Key activities that we would control would include the conversion process, optimizing technology, research and design including new feedstocks and products and the production of our product and by product. Within Norway we would like to explore partnerships with NTNU, Sintef, UMB, Bioforsk and waste collection experts, to name a few. This would supplement our knowledge and our project could contribute to ongoing discussions about how best to use food waste.

In terms of funding, we would look for investors in addition to our product revenue streams. There is potential to charge for the collection of our feedstock, since it is something that supermarkets currently pay to have taken away. Also, due to the environmentally friendly nature of our idea, we believe that we may be able to secure some government funding.

Due to the short nature of the Entrepreneurship Seminar, we could only briefly discuss costs, but pointed out some of the major categories. This project would have very large start-up costs, as we would need to invest in building a production plant. Our running costs would include transportation of the feedstock and potentially the product, salaries and operational costs associated with running the plant.

This exercise was very helpful for us to see the practical application of our idea.

**Comparison of one reactor and two reactor**:

There are three group of microorganisms for each step in AD process: fermentative bacteria, acetogenic bacteria and methanogens. Each group has a specific function in hydrolysis, acetogenesis and methanogenesis steps, respectively, in AD. In conventional AD system, the steps of acidogenesis and methane formation occur in a single reactor that may lead to the reduction of pH. Futhermore, the microorganisms that are using for these two steps require different optimal conditions for their growth. Therefore, it is a problem needed to be solved to get balance between them.

The separation of acetogenesis and methanogenesis into two different bioreactors was proposed to overcome this problem. If doing so, each group of microorganism will be provided an optimal environmental conditions for their growth and the stability of AD process will be enhanced and easier to control.

Introduction

According to the World Energy Outlook (2012), the transportation sector is responsible for more than 50% of the global consumption of oil and this share increases as the number of passenger vehicles reaches towards the projected 1.7 billion worldwide by 2035. Transportation is responsible for 23% of global CO2 emissions, with road transportation representing 74% (Kahn Ribeiro et al, 2007).

It is widely recognized that through carbon dioxide emissions, fossil fuel use is contributing to global climate change and destabilization. According to Cherubini et al. (2011) using biomass for energy is one of the “most promising renewable energy alternatives.” There can be, however, challenges to using biomass due to the effects on changing land use and rising prices of agricultural goods. The practice of using a waste resource (such as food waste) effectively avoids these pitfalls and may offer a bridge solution while we develop other renewable energy sources and reduce the overproduction and wastage of food.

Environmental Impacts of Process

Compare against natural gas

As discussed above, biogas production from food waste has the potential to reduce environmental impacts, in multiple ways. We have chosen to use the Life Cycle Assessment (LCA) method to evaluate the environmental impacts of this process and compare it to alternatives. LCA has become a popular method to evaluate bioenergy systems because it takes a holistic picture of the situation, considering direct and indirect emissions and effects of all activities involved in delivering a service. Therefore it allows us to identify “problem shifting”, the case where improvements are realized in one area, say carbon dioxide emissions, but performance in another area decreases, for example eutrophication.

In the past, LCA studies of bioenergy systems have used a GWP factor of zero for biogenic CO2, effectively saying that it has no impact due to regrowth of the feedstock. (Cherubini et al, 2011)

There are three areas where we will consider environmental improvements:

- improvement over other fuel types, namely natural gas

- improvement over other management regimes for food waste

- improvement over other fertilizing regimes.

In theory we would like to estimate all of the impacts associated with the process, but in this report we will only give a brief overview and rough quantification. We will primarily focus on global warming potential (GWP) because this is the measure relating greenhouse gas emissions to climate change and climate change is the main concern of the transportation sector. Biogas from food waste will be compared to natural gas to get an idea of comparative environmental impacts.

Heading- Biogas compared to Natural Gas

We chose natural gas due to our assumption that biogas will replace natural gas used in transportation.

The emissions from the growth, processing and transportation of the food are not attributable to our product because it is not produced for our purposes, we are only taking advantage of inefficiencies within the food system. We need only to consider the emissions from the processing within our plant, operational emissions and the building of the plant itself. Through processing we emit 2.13 kg CO2 per kg biogas produced. Our membrane technology is very effective so we assume that methane is not leaked from the system into the environment. The carbon dioxide is removed entirely from the fuel so virtually none is released during combustion. We have not incorporated the emissions from building the plant, nor the upstream emissions of our energy use within the plant. We assume electricity is generated from hydropower and therefore has a minimal CO2 contribution but given more time we would include everything.

Heading- Different Food Waste Management Options

A study done in the United States compared different ways of managing food waste with a focus on environmental impacts (Levis, 2010). They compared composting, anaerobic digestion and landfilling. Anaerobic digestion was found to be the most beneficial process, with a net reduction of CO2 in the atmosphere. Their conclusion was that for every 1000 kg of food waste (plus 550 kg branches), 395 kg of CO2 is removed from the atmosphere. Some reasons for this are: the energy offset by the recovery of methane (considered to replace coal and natural gas) and the storage of carbon in the soil by way of the fertilizer byproduct. This is a very positive result, but it cannot be applied directly to our case. We are not replacing coal here in Norway so the offset will certainly be less. Also, we are not including branches in our process, though it is unclear how they will affect the environmental performance.

Heading- Offsets from Fertilizer

We assume that the use of our fertilizer by-product serves to offset the production of mineral fertilizers and peat extraction. These are

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Kahn Ribeiro, S., S. Kobayashi, M. Beuthe, J. Gasca, D. Greene, D. S. Lee, Y. Muromachi, P. J. Newton, S. Plotkin, D. Sperling, R. Wit, P. J. Zhou. 2007. Transport and its infrastructure. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter5.pdf>

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International Energy Agency. 2012. World Energy Outlook 2012 Executive Summary.

<http://www.iea.org/publications/freepublications/publication/English.pdf>

<Accessed March 21, 2013>

Levis, J. W. and M. A. Barlaz (2011). "What Is the Most Environmentally Beneficial Way to Treat Commercial Food Waste?" Environmental Science & Technology **45**(17): 7438-7444.

90640 kg CO2/99790.3 kg waste food

biogas per day = 42600 kg biogas????

2.13 kg CO2 for every kg biogas.

**Natural gas** 0.056 kg CO2/MJ

NG 3kg co2/kg ng

Natural Gas Life Cycle CO2 emissions = 75 kg CO2/GJ 4.02 kg CO2/kg (<http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,163182&_dad=portal&_schema=PORTAL>)

Energy Density Natural Gas = 53.6 MJ/kg

Environmental Improvements related to our project

- Our product has 50% less global warming potential than natural gas:

(Biogas 2.13 kg CO2eq/kg fuel. NG 4 kg CO2eq/kg fuel)

- Anaerobic digestion is the most environmentally friendly waste management strategy. It removes 395 kg CO2 from atmosphere per 1000 kg food waste. Better than composting or landfilling.

- Our byproduct offsets production of mineral fertilizer and peat excavation