EPS - Biogas

Wasteconverters

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Final report for *European Project Semester*

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Abstract

In general economy seems to be aware of climate change and greenhouse gases' effects thus the demand for renewals resources and the utilization of many forms of waste as a energy resource have raised in the recent years. One of those potential resources that match this category is every form of bio-waste, which is transformable into biogas. Biogas again provides the opportunity to substitute natural gas increasingly and to use it for energy production such as heat, electricity or for even for transportation as a fuel.

The first task of this project was to map the substrates available in the region. A bigger part of this task has already been addressed by a previous EPS group, which led to the study of their report. In addition, the project-scope included the search for so far unutilized substrates. This initial study led to some possible suggestions for substrates mixtures in order to examine their bio methane potential.

Within following sessions of experimental occupation in a laboratory of Technobothnia this specific characteristic were determined. The actual first testing-mixtures came up during the initial study due to suggestions found in appropriate literature. The suggestions for subsequent tested mixtures in session two and three were already based on the results of the first experiments.

A final analysis combines both the results of the experimental determinations of the bio methane potential and the availability of the utilized substrates in the region of Ostrobothnia. The suggestion for an ideal mixture for biogas production in this specific area is therefore based on this data. The conclusion again contains information about possible subsequent work to examine a broader field of utilization for the maximum available substrates in the region.

Abbreviations

The following list includes every abbreviation used inside the text. The authors explained an abbreviation the first time the term was used inside the text. For this reason the following list is for look-up for abbreviations used subsequently.

AMPTS	… Automatic Methane Potential Testing System
BMP	… Bio methane potential
C/N	… Ratio between carbon and nitrogen
CMS	… Content management system
CH_4	… Methane
CO_2	… Carbon dioxide
DS	… Dry substance
EPS	… European Project Semester
EU	… European Union
H_2O	… Water (vapour)
H_2S	… Hydrogen sulphide
HTML	… Hypertext markup language
LNG	… Liquefied natural gas
NaOH	… Sodium hydroxide
NH3	… Ammoniac
O_2	… oxygen
PHP	… **P**HP: **H**ypertext **P**reprocessor
R&D	… Research and Development
RM	… Raw material
SQL	… Structured query language
SWOT	… Strengths, Weaknesses, Opportunities, Threats
UAS	… University of Applied Sciences
UNECO	… United Nations Educational, Scientific and Cultural Organisation
VS	… Volatile substance
WBS	… Work Breakdown Structure

Table of Content

1. Introduction

"Biogas is produced in biogas plants by the bacterial degradation of biomass under anaerobic conditions." [Wellinger a.o., 2013, p1]

The certainty of having biomass available at every region people are living, working and operating is the basis for local production of biogas. This fact is the major impulse behind the project carried out by the team "Wasteconverters" during the European Project Semester in spring 2016 at Novia University of Applied Sciences Vasa in Finland.

Finland's natural gas import of 4.7 billion cubic metres in 2010 represents a number of crucial disadvantages compared to countries having own natural gas occurrences [Fatih, 2016]. The prevention of creating a necessity of those imports in contrast creates several benefits. In particular, the substitution of imported energy with domestic production generates additional creation [Schneider a.o., 2016, p14] of value and is therefore a serious economical reason for politics to legislate supportingly. In addition the combustion of the entire imported natural gas produces at least 9.2 million tonnes CO_2-emissions annually[1] under ideal conditions, whose avoidance assists climate protection goals.

Biogas is a convenient substitution technology for natural gas, which is able to achieve both objectives. The relocation of gas production to Finland means to generate employments both in engineering and constructing as well as in operating those plants, which is a valuable contribution to Finland's economy. Additionally the origin of CO_2 from combusted biogas is biological and therefore not contributory to climate change and this again is the bigger part of Finland's liable emission-reduction. Those facts indicate the necessity of increasing the biogas production within Finland gradually.

An increase of the domestic biogas production is achievable by installing a number of appropriate plants. In addition the yield of those plants is significantly influenceable by the exact biomass used within the fermenter. This fact initiates the necessity of the execution of the project.

Since Vasa is the capital of the region of Ostrobothnia, it is centre of industry in the region as well. For this reason the local energy demand has a hotspot here and locally produced Biogas would assist the autarchy exceedingly. The right mixture of ingredients for the production process would minimize the necessary engineering expenditure and maximize the possible yield of local biogas plants.

[1] The amount of emission results from the stoichiometric correlation $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ and characterises on this account the ideal combustion of methane.

1.1. Participants

An EPS-team has to be:

- multi-national
- multi-disciplinary
- consisting of from 3 to 6 members

On this account the EPS-Coordinator of the Novia University of Applied Sciences Vaasa formed the team Waste Converters based on origin and study in order to form the team consisting of the following members from six different countries as well as five different universities with five contrary backgrounds. Since the main aim of the project is to convert waste into a resource, hence the name "Wasteconverters".

Achraf Azzouani
The Netherlands / Morocco
Home institution:
The Hague University of Applied Sciences
Degree program:
Process & Food Technology

Figure 1: Portrait Achraf Azzouani

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Urban Renewable Energy Technologies

Figure 2: Portrait Alexander Hofer

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Energy and Environmental Engineering

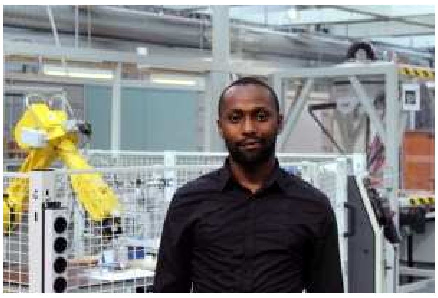

Figure 3: Portrait Mwangi Magana

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Figure 4: Portrait Mateusz Pawlowski

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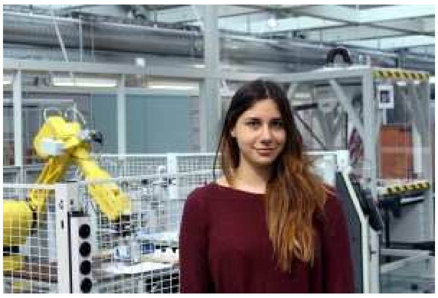
Figure 5: Portrait Andrea Pusineri

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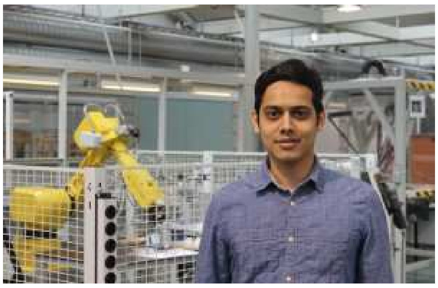
Figure 6: Portrait Shiva Sharma

1.2. Brand identity

We decide to call our team "Waste Converters" because we are working to convert different kinds of waste into biogas. Waste in particular ranges from domestic household waste to industrial waste.
When designing a logo, nothing is casual: every word, every colour, every line and every font has a precise meaning. The logo is an important part of a company because it identifies the brand. It is the first approach with people and needs to show clear links with the theme with which the company works.
We decide to insert two leaves to link the logo to the concept of production of gas from organic materials, something natural, and to do that we choose to simplify the leaves of the birch tree as shown in Figure 7. It is a typical tree in Finland and very common in the region of Ostrobothnia.

Figure 7: Inspiration for the leaf in the logo

The choice of the colours is due in part to the link with the leaf of the birch tree (C 62, M 0, Y 82, K0 – see Figure 8), we tried to recall the colour the leaf of the birch in spring, on the other side is linked to the colour that we commonly associate to petrol and hydrocarbons in general (C 87, M 34, Y 60, K 27).

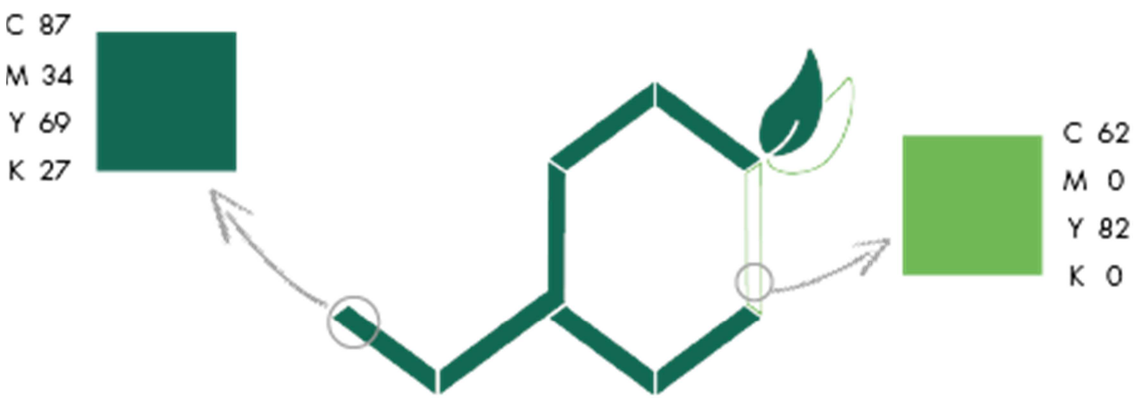

Figure 8: Choice of the colour for the logo

The "C" resembles a graphite structure which is a form of carbon. It symbolizes energy, since carbon can be a source of energy. Then the leaf is placed on top to represent care for the nature. This is in line with our project objective which is to produce green energy (biogas) from organic waste.
We tried to realize something simple and effective that could remind people about chemistry, biogas production and also nature.

1.3. Tasks

During this three month the team has done research about the possibility of producing biogas, adequate materials and technical reducibility. Since the participants had different study origins, the acclimatisation phases lasted for different durations.

Biogas is produced as a result of biochemical conversion of substrates by microorganisms during anaerobic conditions. Substrates like for instance animal manure, food waste and sludge are the basis for the production process.

In particular we engaged to do a mapping of the different substrates available in the region around the city of Vasa utilisable for producing biogas. As a result we collected different kinds of waste: from residues of the bakers, the fish and meat leftovers, the scraps of cucumbers plantations, potatoes peel, biowaste, waste from breweries and pigs manure.

Besides many physical characteristics each substrate has its own bio methane potential (BMP), which means how many cubic meter methane can be fetched from one tonne substrate. Materials containing a high filamentary ratio like cellulose, respectively, wooden proportion of lignocellulose are non-qualified for biogas production whereas a high proportion of protein, fat and carbohydrate results in a high yield of biogas. Analysing and doing researches about these materials we found suggestions about mixtures to do with these materials to optimize the biogas production.

In the next step an experimentally evaluation of the biodegradability of the mixtures through was carried out in a series of experiments in the chemistry laboratory.

The aim of the project on this account is to find the ideal composition of substrates based on availability, logistics and efficiency suitable for biogas production plants in the region of Ostrobothnia in Western Finland.

1.4. Website

Since one of the demands of the project observer was an appropriative way of presenting the project work as a matter of progress of both team-work-skills of the members and topic related activities the team decided to set up a website.

The website contains the following information:

- About the project
  This section is to describe especially the aim of the project. The information provided relates to the core function of the European Project Semester as well as the topic of the project work. On this account the content is about task, environment, resources, stakeholders and progress of the project.
- About the team members
  Since the members of the team are an aim of the project as well this section informs about the background of everybody.

- News/Blog
  The visit of a website is directly related to its topicality. For this reason the section News is updated at least twice a week and informs about the progress of the project work. It contains small reports about the activities carried out by the team-members related to the project work.
- Contact
  This section provides a form to contact the team for suggestions, requests and claims.
- Downloads
  Every protocol, respectively, report produced is provided in this section for interested visitors as a download.

The website is organized as a Content Management System (CMS) and therefore updateable by every team-member using the password to enter the section *Internal*. Since most of the web browsers currently understand the HTML5-standard this website is viewable for most of the users and provides a maximum of availability. Purchasing the domain www.wasteconverters.net supported the claim of the project-team of a convenient way for the online appearance of the project. Figure 9 shows an example of the website.

The website was coded dynamically with PHP (version 4) and the usage MySQL-databases for the CMS of the website by the team. The technical requirement was essential for choosing an appropriate server.

Figure 9: Project-website

1.5. European Project Semester

European Project Semester (EPS) is a program offered by sixteen European universities in twelve countries throughout Europe to students, who have completed at least two years of their particular studies.

EPS is primarily provided for engineering students. However, students of other studies can participate as well in order to support the project with their specific knowledge.

Furthermore EPS was launched to address the design requirements of the degree and prepare engineering students with all additional necessary skills to face the challenges of today's world economy. It is a mixture of "project-related" courses and project organized/problem based learning.

Students work in international and interdisciplinary teams of three to six students on their multidisciplinary projects. Some of these projects are performed in cooperation with commercial businesses and industries whereas others are academic.

A main aim is that students learn to take responsibility for their studies and their work. In addition the development of their individual intercultural competences, communication skills and interpersonal skills is essence of EPS. The language for all oral and written communication during the semester primarily is English.

EPS is an experience, which helps students to grow up as engineers but as individual as well. Changing the personal approach to projects, the way of team-working and the mentality of working at all should be the outcome of the project semester.

Taking part in this program means that students need to be determined to pursue their goals to grow up on the level of career and collaborate in teams with people from all over the world: knowing different countries as well as people and create links, respectively, collaborations between schools, students, professors and everyone, who's providing a constructive experience to the own work.

EPS is a unique way of growing up together and to improve the continuous exchange of ideas and knowledge with people of different cultures, backgrounds and languages.

2. Project Management

In order to achieve our goal in this project, a comprehensive project management plan is necessary. The plan will incorporate all the necessary parts required to ensure we work efficiently and timely since we are working on a fixed timeline.

The project development is divided into phases from limited information to an increasing more knowledgeable area. The development of the project is a continuous process where as more information is gathered, we review all the issues in the new context.

The overall activities can be divided into three main phases:

- Phase 1 – Initiation: This is mainly familiarization with the project and team building. This typically consists of resource planning, building technical competences and gathering information.
- Phase 2 – Project development: Developing the specifications of the project (choice of substrates, scope), making a testing plan and documentation.
- Phase 3 – Practical work: Laboratory work, analysis of results and project completion.

2.1. Project Description

There has been an increase in the demand for methane as a transport gas in the EU. Finland does not have any source of LNG (methane). Currently Vaasa is looking into increased biogas production which can be upgraded to bio-LNG. In order to facilitate future increased biogas production in Ostrobothnia based on co-digestion, the following tasks have to be carried out:

1. Mapping substrates available in the region
2. Suggesting suitable substrate mixtures
3. Evaluating experimentally the biodegradability of the mixtures

The aim of the project on this account is to find the ideal composition of substrates based on availability, logistics and efficiency suitable for biogas production plants in the region of Ostrobothnia in Western Finland.

2.2. Project Objectives

As stated in the description the mapping of substrates has already been covered. For our project we have to:

- Suggest suitable mixtures – This will be based on the experiments we carry out for the different substrates.

- Make informed recommendations – Based on the outcome of our experiments.

2.3. Project Deliverables

At the end of the project we will have:

1. A document containing substrate mixtures and their cogeneration potential.
2. Dedicated website for our team waste converters where all our research will be uploaded.
3. A PowerPoint document summarizing our project from start to finish.

2.4. Project Time Management

The project schedule is contained in the Gantt chart shown in Figure 10.

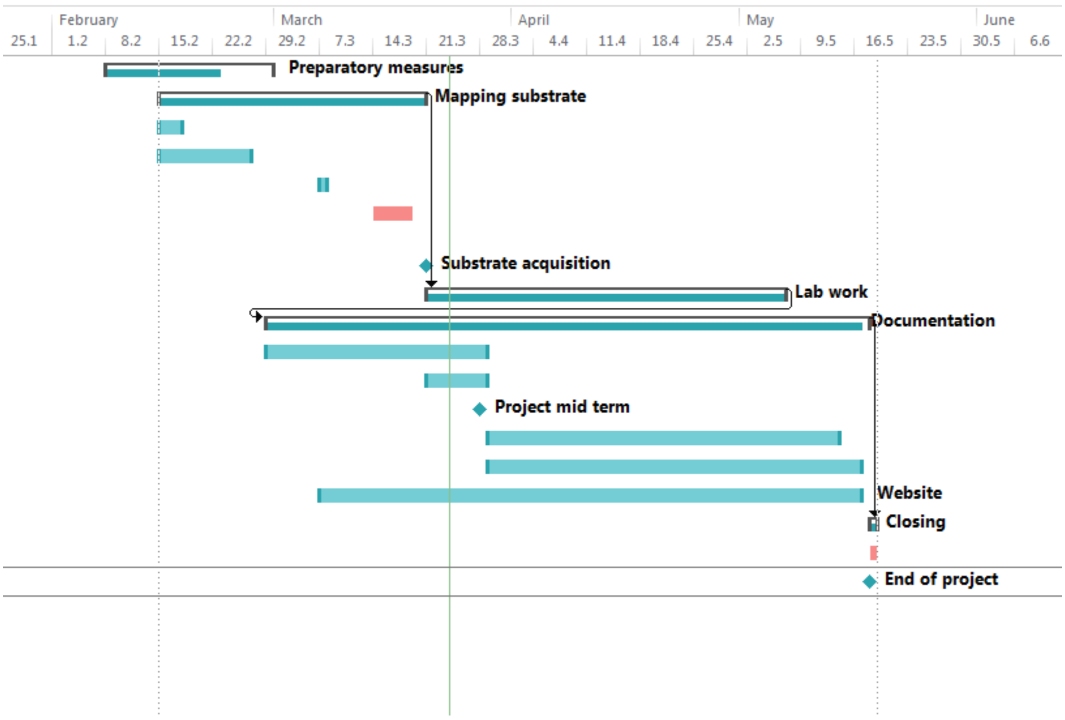

Figure 10: Gantt chart for the project

The schedule is continuously updated as we gather more information about the project. The labels highlight some of the most important tasks in our project. The milestones are marked with a blue diamond. The detailed Gantt chart can be found in Appendix 4.

2.4.1. Project Milestones

These are the key accomplishments and they are:

- 21/3/16 Determining mixtures – It will be the end of the research and the beginning of the practical work.

- 24/3/16 Starting lab work – This will mark the beginning of the experiments.
- 30/3/16 Mid-term – This will be the reflection of all the work we have done so far and focusing our energy on the remaining part of the project.
- 26/4/16 Obtaining first results – We will be able to see if the experiment went according to plan.
- 17/5/16 Hand over – The end of the project.

2.4.2. Work Breakdown Structure

The work breakdown structure for the project basically is the tasks we plan to carry out. At the beginning of the project, not all the information is provided hence the need to update the WBS as the project progresses.

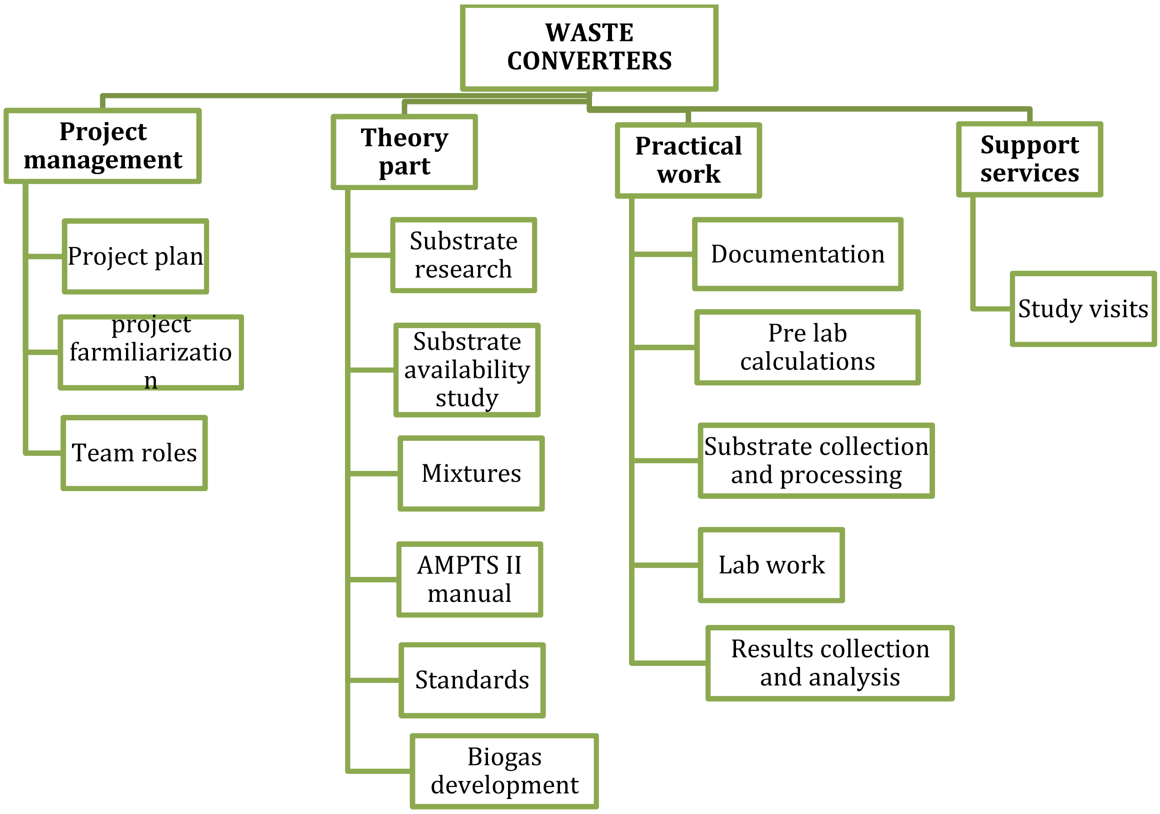

Figure 11: Work Breakdown Structure (WBS)

Our team decided on dividing the tasks based on the type of work for each task. For the case of our project the main work was:

- Project management – which was a necessity due to the fact that it is a project and also because we were working as a team.
- Theory part – The project is about biogas which is subject-specific for energy or environmental field of study. Since members had different background studies they needed to familiarise themselves with the topic.

- Practical work – This involves documentation, actual lab work and all the physical activities we did during the project.
- Support services – These were tasks we carried out just to help us gain further understanding of the biogas production in Ostrobothnia.

Figure 11 for this reason shows the work breakdown structure with some of the main tasks. The detailed tasks with their description can be found in the Appendix 5.

2.5. Project Roles

The project as mentioned before is of interest to many people in Finland and Vaasa in Finland who need the biogas. The stakeholders in this project are as listed below:

i. EPS energy R&D department – The research will be used to further investigate possibilities of increasing biogas production which is in line with the EU promotion of greener energy.
ii. EPS Waste Converters team.
iii. Ab Stormossen Oy – they are a waste management company who plan to increase their biogas production.
iv. City of Vaasa – They are rolling out an ambitious program where all the buses in the city will run on biogas to reduce pollution.
v. Other potential clients looking into increasing biogas production.

2.5.1. Responsibilities

The responsibility matrix contains the information about the different steps of the project in order to bring it to an appropriate end. Table 1 on this account shows this responsibility matrix.

Task Name Note: R =responsible ; S =support	Achraf	Alex	Mwangi	Mateusz	Andrea	Shiva
Preparatory measures						
Kick-off	R	R	R	R	R	R
Assign duties	R	S	S	S	S	S
Project familiarization	R	R	R	R	R	R
Mapping substrate						
Reading EPS report	R	R	R	R	R	R
Research about substrate	R	S	S	R	S	S
Practical work planning	S	R	S	S	S	S
Substrate collection and storage	S	R	R	S	R	R
Lab work						
Plan experiment	R	R	S	R	R	R
Lab introduction	R	R	R	R	R	R

Pre lab						
Substrate co digestion testing	R	R	R	R	R	R
Result collection	R	R	R	R	R	R
Result analysis	R	R	R	R	R	R
Documentation						
Mid-term report	R	R	R	R	R	R
Mid-term presentation	R	R	R	R	R	R
Project mid term	R	R	R	R	R	R
Final report	R	R	R	R	R	R
Final presentation	R	R	R	R	R	R
Website	S	R	S	S	R	S
Closing						
Hand over	R	R	R	R	R	R
End of project	R	R	R	R	R	R

Table 1: Responsibilities

2.6. Project Risk Management

For any project undertaken it is vital to have a risk management plan. The reasoning being even the simplest activity has a chance of going wrong. Our biogas project is quite complex from a risk point of view because there is the theory and the practical part.

The risk management plan contains the risks identified which is a continuous process covering the whole project life cycle. Then there is the risk assessment which contains the threat level to the project and mitigation to avoid or reduce the likelihood of the project failure.

2.7. Risk Identification

The risk identification was addressed from the very beginning of the project. Some risks were quite obvious that we identified them before starting the project. Others will be identified as the project commences. We agreed the project risks can be identified by anyone associated with the project in order to make a comprehensive risk list.

Risks that we identified were through brainstorming, SWOT Analysis and interviewing people familiar with biogas testing in the lab.

2.7.1. Risk Responsibilities

The responsibility for managing risk is shared amongst all the waste converter team. However, key decisions and especially those that cost or require resources lie with the Project Supervisor who is responsible for resource mobilization.

The list below highlights the responsibilities of the project team in different aspects of team management:

- Risk Identification: All project stakeholders
- Risk Assessment: All project stakeholders
- Risk Response: All project stakeholders
- Risk Response Approval: Project supervisor (Emelia)
- Risk Response Management; Project Manager
- Risk Reporting; All project stakeholders

2.8. Risk Assessment

Risk assessment involves two factors. First is the likelihood of it to occur and the second part is determining the effect on the project and mitigation plans as well as severity to the project. The probability of the risk occurring is based on a scale of 1-5 with 1 being least and 5 the most. The probability scale is then incorporated to the risk register (see Appendix 3) to be able to identify the risks that need to be monitored more.

Apart from the probability, the impact is also given a value between 1 -5 where 1 is low and 5 is high. Using these two parameters, a value is calculated to differentiate between the important and not important risks. On this account risks valued with a high number should be considered rather accurate whereas risks valued with a low number have less influence on the project. Figure 12 shows the risk in descending order.

Key	Risk	Probability	Impact	Value
R1	Fire	5	5	25
R2	Computer failure	5	5	25
R3	Biohazard	4	5	20
R4	Team problems	4	4	16
R5	Lab preparation	4	4	16
R6	Substrate quality	3	5	15
R7	Making wrong mixtures	5	3	15
R8	Bacteria doesn't work	3	5	15
R9	Lack of information	3	5	10
R10	Lacking a laboratory technician	3	3	9
R11	No biogas produced	3	3	9
R12	Lack of information on substrates	3	2	6
R13	Project failure to take-off	1	3	3
R14	Not getting substrates	2	1	2
R15	No results from the experiments	2	1	2
R16	Lack of report	2	1	2
R17	Not completing project	2	1	2
R18	Picking wrong substrates	1	1	1
R19	Website problem	1	1	1

Figure 12: Risk analysis

Using the key, we obtain a chart that shows how the risk is distributed as depicted in Figure 13. The risks falling in the red zone are the most critical to our project and proper mitigation measures should be put in place.

The yellow region is for risks which can affect the project but not necessarily bring it to a halt. The green region represents risks that have minimal effect to the project.

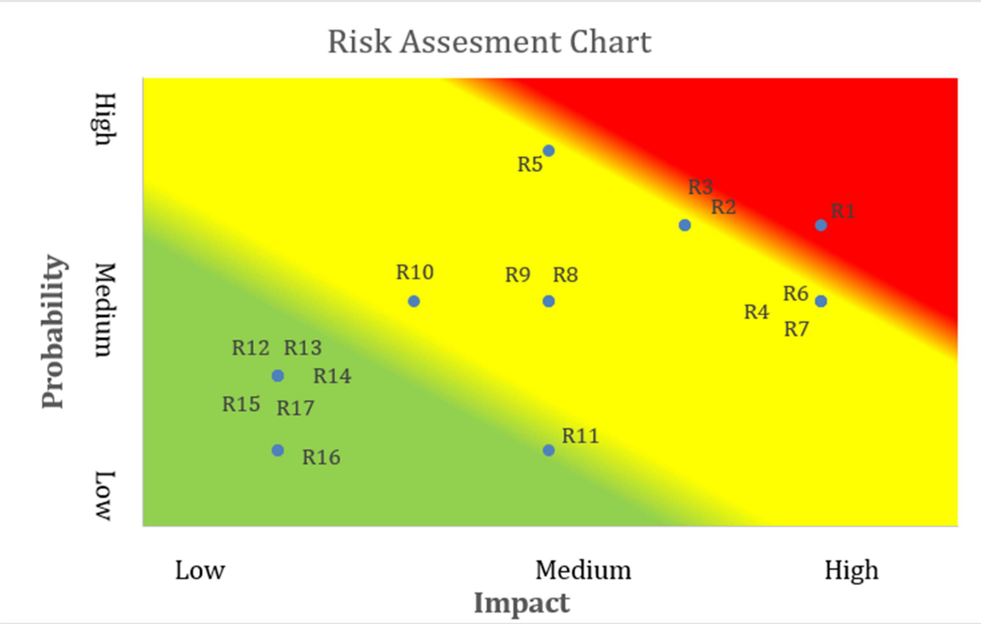

Figure 13: Risk chart

2.9. Cost management Plan

The Cost Management Plan purpose is to show the costs estimates of the project. Moreover it identifies factors that can increase the project cost.

2.9.1. Major cost

Table 2 provides the major cost of the project whereupon the biggest share of the total sum is the labour of the team members.

Category	Hours	Cost
Direct labour	809h @ €20/h	16,180 €
Indirect labour	60	1200 €
Total labour	869	17,380 €
Substrate		0 €
Software		0 €
Lab facility		0 €
Consulting		0 €
Web development		0 €
Travel and living		600 €
Total project		17,980 €

Table 2: Project cost

2.9.2. Potential Causes of Increases in Cost

The cost of the project is dependent on many factors although as can be seen in the project cost table the budget is made up of labour and travel expenses. As we become more familiar with the project, the cost might change.

Below is a cost increase analysis for the project.

2.9.3. Labour costs

- Project activities require more effort than planned; this will result to in increased labour costs.
- Unplanned or paid overtime is required to complete the activities on the WBS.
- More staff is assigned to the project.

2.9.4. Travel and living Costs

- Depending on the substrate availability longer distance means more expensive.
- Number of study visits and their locations.
- Other expenses associated with living expenses for the project.

2.9.5. Other Costs

- Consulting costs if needed.
- More effort is needed.
- Other unforeseen costs.

3. Subject-specific

3.1. Biogas fundamentals

The expression *Biogas* stands for a mixture of different types of gas, which are "[…] produced by anaerobic fermentation of organic material […]" [Paul a.o., 1982, p1]. Thus the process has to occur without the presence of oxygen.
Since the aim of biogas is the utilization of renewable resources, a major claim for the commercial production in many cases is sustainability. For this reason the used substrates for the process are mostly any kind of biogenic garbage, respectively, renewable raw material as well as process supportive additives.
Biogenic garbage in this matter is the most broadly based substrate because it includes bio-waste from domestic households as well as remnants in wastewater treatment plants, waste in food production processes and any kind of manure for instance. Common renewable raw materials in this context are energy crops, which are any kind of sugary, starchy or oleaginous plants.

Produced types of gasses contain:

- 50-75% Methane – CH_4
- 25-50% Carbon dioxide – CO_2
- 0-5% Water vapour – H_2O
- 0-3% Ammoniac – NH_3
- 0-3% Hydrogen sulphide – H_2S

Since Methane is a flammable gas with a significant heating value it is the main product within biogas. Due to the biogenic source in this context it is also called *bio methane*. There is no difference in chemical characteristics between methane as a part of natural gas and bio methane obtained from biogenic resources [cp. Breuer, 2016]. Besides its commercial usage for combustion methane has a 21 times higher global warming potential than carbon dioxide if escaped to the atmosphere [cp. Figueres, 2016], which is the main reason for necessary carefulness.

Pure carbon dioxide is a non-flammable gas and as a natural resource component of the air [cp. Breuer, 2016]. The increasing occurrence of carbon dioxide in the atmosphere supports the effects of climate change because it is a crucial greenhouse gas. Considering the energetic characteristics carbon dioxide is the most oxidized carbon compound, from which no energy is obtainable. For this reason it decreases the heating value of raw biogas. In contrast to carbon dioxide emitted by combusting mineral oil products, carbon dioxide emitted in-/directly by combusting/producing bio methane was retained within plants and comparable previously. In spite of carbon dioxides presence within biogas, it is said to be a CO_2-neutral energy resource because of the biogenic cycle [cp. Wilkie, 2016].

Anaerobic digestion means also to heat up the substrate mixture. The water inside the mixture evaporates and is therefore also a component of biogas. For this reason biogas has to be dried before the usage to avoid damages due to condensed water inside the machines on the one hand and to increase the heating value on the other hand.

Ammonia is an undesired component of biogas as well as hydrogen sulphide. They are aggressive chemical compounds, which lead to corrosion within technical equipment, and accrue depending on the used substrates for the production process [cp. Breuer, 2016]. Due to ammonia's water solubility it is removed by drying the gas during the conditioning process of biogas. The desulphurization is often done in two steps – a chemical vapour deposition technique is used in the first step followed by activated carbon filter. Most of biogas' applications have defined upper limits of these two harmful raw components.

3.1.1. Formation of biogas

The production process of biogas by using anaerobic digestion follows the general equation (1) and is a result of adding any kind of biomass ($C_cH_hO_oN_nS_s$) with a necessary amount of water (y H_2O).

$$C_cH_hO_oN_nS_s + yH_2O \rightarrow xCH_4 + nNH_3 + sH_2S + (c-x)CO_2 \tag{1}$$

According to equation (1) the constants c, h, o, n, s and x depend on the used substrate for the process. For this reason the composition of substrates used is essential for designing the conditioning process before the usage of the biogas. Furthermore it can now be seen that it depends also on the used substrate how much of ammonia and hydrogen sulphur contains the primarily produced biogas.

The stoichiometric formula (2) shows for this reason the essential components carbon, hydrogen and oxygen with its necessary amount of water added to predict the amount of biogas produced [Wellinger a.o., 2013, p112].

$$C_nH_aO_b + \left(n - \frac{a}{4} - \frac{b}{2}\right) H_2O \rightarrow \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right) CH_4 + \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right) CO_2 \tag{2}$$

Catalyst for this reaction are different bacteria, which are added to the substrate mixture, respectively, are already inside the digester in a continuous commercial process.

3.1.2. Production phases

"Biogas is produced by anaerobic bacteria that degrade organic material to biogas in four steps: hydrolysis, acidification, production of acetic acid and production of methane." Different phases are carried out by different microorganisms in order to produce biogas [Wellinger a.o., 2013, p2f]. Figure 14 shows the whole process graphically.

1. **Hydrolysis**

Making the large organic polymers of biomass available for the bacteria means to break them down in a first step. This is done in hydrolysis. Compounds soluble in water are decomposed. Long-chain carbohydrates are broken down into short-chain sugars, proteins into amino acids and fats into fatty acids and glycerine. The hydrolysis takes a few days. During this process phase oxygen is used up, allowing the following anaerobic process by microorganisms. [Deublein a.o., 2008, p99f]

2. Acidogenic phase

In the Acidogenic phase the products of hydrolysis are degraded by anaerobic bacteria to short-chain organic acids, C_1-C_5 molecules, alcohols, nitrogen oxide, hydrogen sulphide, hydrogen and carbon dioxide. "This Acidogenic (fermentative) biological reaction is like the process of milk going sour." [Marchenko, 2008, p1]

Carbohydrates are decomposed to pyruvate, which is then converted to lactic acid and to ethanol. In this reaction the main part plays the microorganisms: Lactobacillales, Propionibacteria and Capstridia.

Fatty acids are degraded by e.g. Acerobacter in β-oxidation. The fatty acid is bound by coenzyme A and is then oxidised through removal of carbon.

Amino acids are degraded by Clostridium botulinum through Stickland reaction. Two amino acids react; the products of the reaction are acetate, ammonia and CO_2. [Deublein a.o., 2008, p99f]

3. Acetogenic phase

The products of earlier stages are further digested by acetogens to produce acetic acids, carbon dioxide and hydrogen. Homoacetogenic microorganisms reduce hydrogen and carbon dioxide to acetic acid. Acetogenic bacteria are crucial hydrogen producers. The formation of acetate is thermodynamically possible only when the hydrogen partial pressure is low. To ensure that, acetogenic bacteria are symbiotic with microorganism that produce methane, which can only work when the hydrogen partial pressure is high. [Deublein a.o., 2008, p99f]

4. Methanogenic phase

The intermediate products are converted into mostly methane, carbon dioxide and water by methanogens (cp. Table 3). After this last phase of the biogas production process the remaining material is indigestible and constitutes among other things all dead bacteria. [Deublein a.o., 2008, p99f]

CO2- type	$4H_2 + HCO_3^- + H^+ \rightarrow CH_4 + 3H_2O$
	$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$
	$4HCOO^- + H_2O + H^+ \rightarrow CH_4 + HCO_3^-$
Acetate type	$3H_3COO^- + H_2O \rightarrow CH_4 + HCO_3^-$
Methyl type	$4CH_3OH \rightarrow 3CH_4 + HCO_3^- + H^+ + H_2O$
	$4CH_3OH + H_2 \rightarrow CH_4 + H_2O$

Table 3: Methanogenic degradation [Deublein a.o., 2008, p99f]

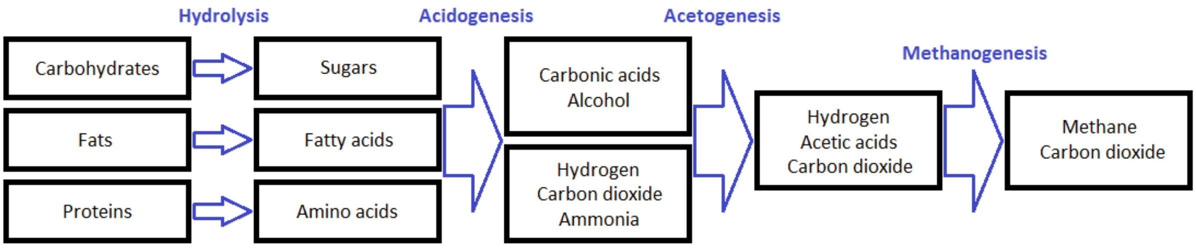

Figure 14: Production phases

3.1.3. Process parameters

The methane production in anaerobic digestion is dependent on many parameters. Inappropriate conditions can decrease or even totally stop the production process of biogas. According to the Biogas Handbook (UNESCO, 1982) the following parameters are essential:

- Airtightness
  Since the breakdown of organic material in the presence of oxygen (O_2) produces carbon dioxide (CO_2) its absence must be ensured to initiate the anaerobic digesting process.
- Temperature
  "Anaerobic digestion […] takes place within three temperature ranges:
  - Thermophilic, 55-60°C
  - Mesophilic, 35-40°C
  - Psychrophilic, <20°C" [Wellinger a.o., 2013, p115]

  Depending on the temperature range the bacteria occur to produce biogas diversifies. On this account a constant temperature level has to be ensured within the fermenter.
- PH-level
  The microorganisms require a neutral or mildly alkaline environment. Ideal pH values are between 6.5 and 8.5. Values outside this range are probably detrimental for the bacteria.
- Solid contents
  "Suitable solid contents of raw materials are 7-9%. Dilutions should be in the ratio of 4:5 or equal proportion." Since Stormossen mentioned during the study visit there to use 5% of solid contents, this was also chosen for the experiments within the project.
- C/N ratio
  The mixtures used for producing biogas must ensure a ratio of carbon (C) to nitrogen (N) between 25:1 and 30:1 in order to provide ideal conditions.

- Water contents
  Both equation (1) and (2) show the necessity of water for the production process of biogas. On this account it is recommended to ensure a water content of around 90% of the weight of the total contents. If too much water is used for the process the production per unit volume decreases, which means to use the fermenter inefficiently. Contrarily the usage of too less water means that "[…] acetic acid will accumulate, inhibiting the fermentation process and hence production […]" of biogas within the fermenter.
- Nature of used materials
  "Materials rich in cellulose and hemi-cellulose with sufficient protenaceous substance produce more gas […]" whereas ligneous substances produce little quantity of gas. Complex polysaccharides are one of the most favourable substances for the formation of methane.
- Supplementary nutrients
  On the market various supplementary nutrients are available. Depending on the substrate mixture used within the fermenter the likeliness for the production of ammonia for instance is much higher, which is avoidable by adding suitable nutrients. Other manufactures offers products, which raises the demand of methane produced.
- Reaction period
  "Under optimum conditions 80-90% of total gas production is obtained within a period of 3-4 weeks. The size of the fermentation tank also decides the reaction period."
- Presence of harmful materials
  Sulphates, Copper and Chromium are examples for harmful materials affecting the microorganisms negatively. There are upper limits defined for the presence of different harmful materials, up to which the production of biogas is said to be unaffected by these materials.

Besides the parameters excerpted from the Biogas Handbook (UNESO, 1982) other the pre-treatment of the substrates affects the actual output of gas as well [Wellinger a.o., 2013, p90f]:

- Physical pre-treatment
  - Mechanical pre-treatment
    In order to make the biogas-relevant material inside the substrates available for the bacteria especially solid substrates have to be cut into smaller pieces. "A particle size of 1-2mm is recommended for effective hydrolysis […]", which leads to 20 – 25 % higher gas yield.

  - Thermal pre-treatment
    Substrates as for instance brewers' spent grains needs thermal pre-treatment in order to generate significant yields. There are different technologies available. In many cases the substrates are heated up to 220 °C under pressures up to 30 bars. This process disrupts the hydrogen bonds as well as hemicellulose.
- Chemical Pre-treatment
  - Alkali pre-treatment
    Since "[…] lignocellulosic materials are resistant to hydrolysis […]", a removal of acetate groups from hemicellulose makes them "[…] accessible to hydrolytic enzymes […]". Sodium hydroxide (NaOH) for instance is commonly used.
- Biological Pre-treatment
  - Microbiological pre-treatment
    This form of pre-treatment means the physical separation of hydrolysis/acidogenesis from acetogenesis/methanogenesis, which necessitates a two-stage digestion system. The first stage has to be carried out with a lower pH-level in order to increase the H_2 production, which leads to a higher methane concentration at the end of the production process.
  - Enzyme addition
    Enzymes are added in order to assist the break-down of complex polymers within the substrate.

A combination of those pre-treatment methods is used commonly and has to be reconsidered for every mixture of substrate.

Other parameters are mentioned by Deublein (a.o, 2008):

- Brightness
  Light inhibits the methanation, so the digestion should take place in total darkness.
- Concentration of microorganisms
  Since methanogenic microorganisms regenerate slowly, even up to 10 days, the process must be performed in a way that prohibits washing away of them.
- Redox potential
  "In the bioreactor, low redox potentials are necessary (…) In order to maintain a low redox potential, few oxidizing agents should be supplied, for example, no oxygen, sulphates, nitrates, or nitrites."

- Biogas removal
  Gas is removed from the substrate, affecting the process. The microorganism concentration is increased, which cause improved metabolism.
- Foaming and scum formation
  During biological reactions foam and scum may be produced. They block the discharge of biogas, which then inhibits the process. There are few ways of dealing with that problem. Firs mechanical foam breakers can be installed, the scum can be also removed mechanically. Another way is adding precipitating agents that destabilize the foam.
- Fermenter technology
  As a matter of fact cultivation, mixing and volume load within the fermenter affects the production of biogas essentially.

3.2. Substrates

"The process inside the fermenter is comparable to the process within alimentary tracts of ruminant animals." [FNR, 2006, p27] On the account of in chapter 3.1.1 mentioned equation, substrates within the meaning of biogas production are digestible substances with a significant component of proteins, fats or carbohydrates. According to the "profession agency renewable raw material" (ger. "Fachagentur Nachwachsende Rohstoffe" – see references) the survival of the bacteria producing methane guarantees the occurrence of components like for instance iron, nickel and cobalt. This requirement leads therefore to the conclusion that there are substrates highly potent for the production of biogas whereas others are unfit.

According to the objective of the project substrates available in the region of Ostrobothnia have to be considered for utilization. The further EPS project [Ajaokorie a.o., 2015, p16f] was taken into account as well as own investigations. The following substrates were determined to be utilized.

3.2.1. Mink manure

Mink manure is known for its high nutrient value. Therefore it is used as a fertilizer. One ton mink manure consists of 25.3 kg phosphorus, 6.6 kg of ammonium and 3.4 kg of potassium [Fewer, 2016]. The reason for these high nutrient values is that minks are carnivores. Their diet ensures that their manure contains sulphur.

According to Turkistieto there exist 2 million minks within Ostrobothnia whereas 19 kg annually of manure are produced per animal [Kauppi a.o., 1990, p32]. Thus there are 38,000 tons annually available.

3.2.2. *Fox manure*

Fox manure has a high content of nitrogen. An average fox produces 0.12 kg manure per day. The amount of nitrogen annually is 1.5 kg per fox. The manure has low moisture content and is therefore firmly hard. [Kauppi a.o., 1990, p32]

According to Turkistieto there exist 2.1 million foxes within Ostrobothnia, which makes about 92,000 tons annually of fox manure.

3.2.3. *Pig manure*

Pig manure can be divided into two categories. Liquid pig manure and pig manure with litter. For the experiments pig manure with litter has been used. Research showed that pig manure with litter has a higher yield instead of pig manure without litter. Liquid pig manure has a biogas yield of about 20 m^3_{CH4}/t_{RM} and the manure with litter has a yield of about 74 m^3_{CH4}/t_{RM}. Pig manure has a very low nutrient content in comparison to other animal manure and is therefore not used as a fertilizer. Not only does it have low nutrient value, it also often carries parasites like roundworms [Christensen, 2016]. Pig manure has an average density of 800 kg/m^3 and a nitrogen value of 0.4 % (low nutrient value) [Teira-Esmatges, 2013]. In the Ostrobothnia region, the estimated amount of pig manure is 715,733 m^3 annually (672,000 tonnes) [Ajaokorie, 2015].

3.2.4. *Slaughter house waste*

Slaughter waste is the waste that comes from slaughter houses and is therefore different in its characteristics depending where it is from. Slaughter waste of pigs, has different characteristics than slaughter waste from chickens or cows. But on average, there are some comparisons. Slaughter waste consists of animal bones, skulls, intestines, blood, fat and a small amount of meat. Slaughter wastes are a potential reservoir of bacteria that are harmful to people and animals and need to be disposed as quickly as possible. Slaughter waste has high energy content and consists of proteins, nucleic acids, carbohydrates and lipids. These high lipid and protein concentrations can cause a high ammonia production and therefore need to be controlled [Franke-Whittle, 2016].
According to Luke (Natural Resource Institute Finland) there are 46,000 tons of beef and pork meat produced in Ostrobothnia. Besides there are 1.7 kg of Waste for each ton meat produced [FOC, 2016]. Thus there is about 78 tons of Slaughter house waste produced within Ostrobothnia annually.

3.2.5. Fish processing waste

Fish waste is the parts of the fish that are not consumed. This can be the heads, bones, organs and fins. The composition of the waste differs every time depending on what kind of fish is used. But the average waste composition consists of fats, proteins, enzymes, moisture and ash. The fat content rises when fat fish like salmon are used. Fish waste is mostly used in animal food. They use the organs and produce them into food for pets. Since the region of Ostrobothnian is located at the west coast of Finland, there are many fish farms. In 2009 there were 13 fish farms and all of them within the Ostrobothnian Centre for Economic Development, Transport and the Environment area. The total production of these farms was 800 tons in 2009 [Haglund, p23]. The estimation of 20 per cent of waste makes therefore around 160 tonnes annually of waste available.

3.2.6. Domestic bio-waste

Bio waste is a short term for biodegradable waste and consists of organic matter. Organic matters are substances that can be broken down into smaller compounds like carbon dioxide, water, methane and simple organic molecules. Because of the fact that bio waste consists of a lot of different things and in different ratios as well, there is no average composition which can define bio waste. Bio waste can consist of human waste, animal manure, food waste, green waste, paper or sewage for instance.

According to the Worldbank report [Hornweg a.o., 2012, p19] and StatisticsFinland it can be estimated that within the region on Ostrobothnia there is 20,000 tonnes of domestic households available.

3.2.7. Cucumber plants

Cucumber plants are creeping vines with large hairy leaves that bear cucumbers. Likewise as the cucumber themselves, the plant consists of high liquid content. The plants have an optimum growth in soil, which has a pH between 5.5 and 7.0 and need sufficient nutrients like phosphorus and magnesium [Valenzuela, 2012]. Cucumber plants are considered green waste and are usually decomposed. Most of the cucumbers that are produced in Finland are grown in southern part of Ostrobothnia in a city called Narpes. This small city is known for its greenhouses and produced 14.4 million kg of cucumbers in 2013. This is 40 % of the total amount of Finland's cucumber production. [Jussila, 2016]

According to farmers, the proportion of left-over cucumber plants to the fruit is around 1:7. For this reason there are around 2,000 tons of left-over cucumber plants annually.

3.2.8. *Potato peels*

Potato is the third largest food crop in the world. For this reason it is an excellent way to use the peels for the biogas industry. The composition of the peels depends on several factors like plant species, soil and climate conditions, fertilisation and time. On average, potato peels have a high moisture content of around 83g per 100g. The composition of roughly 100 grams of potato peel pulp consists of 83.29 grams of water, 2.57 grams of protein, 0.1 grams of lipids, 1.61 grams of ash, 2.5 grams of fibre and 12.44 grams of carbohydrates [Lucas, 2014]. The Ostrobothnia region produces an amount of 6400 tonnes potato waste annually.

3.2.9. *Brewer grains*

Beer is produced in a multi-staged production process by adding water, barley, malt and hop, respectively, wheat in some cases. Depending on the actual type of beer brewed the ratios of those ingredients vary partly significantly.

Brewer grains are the leached residues after the beer production process with a common dry substance content of about 22 per cent. According to ForFarmers (see references) the contained sugar and starch in the ingredients are consumed by the final beer product. For this reason the brewer grains contain no mentionable sugars or starch. However, the substrate is high in protein as well as fat. Hitherto brewer grains were used for the animal feed industry because of its positive effects on the milk production and meat quality.

Since the substrate is high in protein, it was considered for utilisation as a substrate for the biogas production. An expectable yield of 122 m^3_{CH4}/t_{RM}[2] leads to an utilisation as a substrate for co-digestion combined with other substrates [Nacke, 2016].

On average there accrue 200 gram of wet brewer grains per litre beer produced [Kaltschmitt, 2016, p312]. Inside Ostrobothnia is currently a single commercial brewery located, which is Bock's Corner Brewery in Vasa. Another start-up company, located in Jakobstad, currently initiate first brewing experiments. According to the brewery master of Bock there will be around 150,000 litres produced in 2016. This leads to 30 tonnes brewer grains available annually – upward trend.

3.2.10. *Bakery waste*

Bakery waste is the waste that is obtained from bakeries. This waste consists of doughnuts, bread, cookies, cake etc. Bakery waste contains a lot of fat, sugars and fibres and is mostly used as cattle feed. Bakery waste can be divided into two

[2] The abbreviation means cubic meter methane per tonne of raw material.

categories. The dry baking category which consists of bread, bun and roll baking and the second category is the one which consists of pies, cakes, doughnuts etc. Bakery waste can produce around 650 m^3_{CH4}/t_{RM} with a methane percentage of 52 %. The estimation of the bakery waste in the Ostrobothnian region is between 21-25 million kg annually. [K. Silvennoinen, 2012, p12f]

3.2.11. Used oil

Substrates which have a positive influence on biogas production are grease and oil. Grease and oils have high energy value content and are already used for biogas production. For the experiments used sunflower oil is used. Sunflower oil has a biogas yield of 1222 m^3_{CH4}/t_{RM}. This is a really high number and therefore sometimes used as an alternative when the biogas production is not good. Sunflower oil has a density of 918.8 kg/m3 and a caloric value of 884 kcal per 100 grams [Irina Nita, 2016]. Annually the grease waste of Ostrobothnia is estimated to be 5.4kg/capita.

3.3. Examined mixtures

Co-digestion is a method to combine positive characteristics of different types of substrates in order to produce biogas with a high percentage of CH_4. Since estimated 13 billion tons of animal manure annually worldwide is available, these are often used as feedstock for biogas plants [Wellinger a.o., 2013, p22f]. The biogas potential of this substrate is relatively high but average high moisture contents decreases the specific biogas yield per unit manure. However, using manure as the basic feedstock within a digester creates the necessary liquidity. In addition substrates with much more biogas production per unit are added in order to create a potent mixture. The final mixture is practicable for the equipment of the biogas plant and produces an adequate yield of biogas.

The difficulty is to find the ideal combination of substrates in order to create above mentioned benefits. According to "Jeppo biogas" most of the biogas plants use their fixed substrate mixture during the whole lifecycle-process of the plant. Re-evaluations are uncommon. In addition also "Stormossen" pointed out that there is not the ideal mixture of substrates. The challenge is mostly to find another local available mixture of substrates – the main aim of this project.

On this account a lot of research is needed in order to gain viable substrate-combinations because biogas production is still under way. Therefore is not much information obtainable, thus many of the chosen combinations are based on "educated guesses" (Quotation of the project-observer). The basic objective is for this reason to examine the biogas potentials of different mixtures in order to exclude corrupt mixtures and recommend viable mixtures. The following comments were the basis for the upcoming suggestions:

1. Slaughter waste and potato peels
   Slaughter waste is very potent and has a high caloric value. The biogas yield contains excessive ammonia, which is highly undesirable (see chapter 3.1). Therefore it is combined with crops. The addition of crops results in balance of carbon/nitrogen-value and decreases the risk of ammonia inhibition.
2. Pig manure and cucumber plants
   Since pig manure is very potent but has a high moisture content, cucumber plants were added in order to increase the specific yield per unit.
3. Bio-waste and grease
   Municipal bio-waste differs regularly in its composition. This unsteady composition changes a lot and needs to be re-arranged sometimes. When the bio-waste has a low caloric value, grease should be added. It is proven that, when grease is added to bio-waste, good results will be get. Grease improves the quality of the gas.
4. Fish and Bakery waste
   The digestion of fish produces too many gases and therefore it should be mixed with bakery waste. This way, the gases are not extreme and can be controlled by balancing the ratio of the fish and bakery waste.
5. Pig manure with Brewers' grain
   See Combination one and two.
6. Slaughter waste and Bio-waste
   As mentioned before, slaughter waste is able to produce large quantities of ammonia and therefore it should be mixed with something else. In this combination it is mixed with bio-waste. The reason for this is, that bio-waste contains practically everything and therefore also plants and vegetables. This will reduce the ammonia production and might improve the CH_4 production.

3.4. Experiment description

Regarding the realisation of the experimentally verification of biogas potential for different mixtures of substrates a various number of steps are necessary in order to produce reliable results.

The basis for the search of suitable substrates was the further EPS-project *Biomap*. In this report many available substrates in the region of Ostrobothnia are enlisted as well as many facts like their biogas-potential. In addition to this report own studies of the team-members were considered in order to choose out of a broad spectrum of available substrates for the mixtures.

After this first step of decisions the substrates were collected as shorthanded and logistically possible in order to guarantee the freshness. Fresh substrates again guarantee accurate testing results of the potential of each substrate.

3.4.1. Experiment preparation

Once the fresh wanted substrates are available in the laboratory a number of testing have to be done:

1. Examination of the dry substance
2. Examination of the volatile substance
3. Calculation for filling up the bioreactor

According to the study visit to Stormorssen the experiment-mixture has to consist of defined moisture content. It is necessary to know before carrying out the experiments with the bioreactor how much moisture the used substances contain in order to calculate the amount of wet substrate needed for each mixture. A European standard (EN 14774-3:2009) refers to this type of examination for the testing of solid biofuels.

The examination of the volatile substance of the substrates is necessary in order to analyse the biogas potential of the following mixtures [Wilkie, 2016]. As described above the major elements carbon, hydrogen, oxygen, nitrogen and sulphur inside the substrates are responsible for the chemical process for producing biogas. The ash content is excluded from this process. A final analysis of the biogas potential should consider the result of this test, which accords to a European standard as well.

In sequence there are the following standards to consider:

3.4.1.1. Dry Substance (DS)

The standard EN 14774-3:2009 "Solid biofuels: Determination of moisture content. Oven dry method. Part 3: Moisture in general analysis sample" is a European standard and therefore obligatory within the European Union.

The main aim of this standard is to harmonize the procedure for determining the moisture content of any sample of solid biofuels. It must be pointed out that small sized biofuels are very hygroscopic, which means that they change their moisture proportionally to the

Figure 15: Preparation for the experiments

change of humidity of the atmosphere surrounding them. In order to avoid abnormalities the determination of the moisture of the sample should be made simultaneously with all the other necessary measurements on the sample.

The determination of the moisture content has to be carried out as following:

1. Dry an empty weighting dish with its lid at (105 ± 2) °C until constant in mass and cool it to room temperature in a desiccator.
2. Weigh the weighing dish.
3. Add minimum 1 g of the analysis sample into the weighing dish in an even layer and weight the dish plus sample.
4. Dry the dish with the sample until constant in mass.
5. Cap the weighting dish while it's still in the oven and transfer it to a desiccator in order to cool it to room temperature.
6. Weigh the dish plus sample rapidly without its capping to avoid hygroscopic reactions.

Besides this procedure it has to be considered that the used scale's accuracy must be under 0.1 g, different substrates need various durations in order to dry and a minimum of two determinations of each sample have to be carried out.

As a result of these measurements the moisture content is calculable by using formula (2).

$$M_{ad} = \frac{(m_2 - m_3)}{(m_2 - m_1)} * 100\% \qquad (2)$$

m_1 … mass of the empty dish; $[m_1]$ =g
m_2 … mass of the dish plus sample before drying; $[m_2]$ = g
m_3 … mass of the dish plus sample after drying; $[m_3]$ = g
M_{ad} … moisture content; $[M_{ad}]$ = %

The report – according to the standard – has to include at least the following information:

a. Identification of the laboratory and the testing date
b. Identification of the sample tested
c. Reference to the standard
d. Any deviation from the standard
e. The used drying atmosphere
f. Test results expressed with relevant symbols and on an analysed basis (mean of the determinations to the nearest 0.1 %)
g. Conditions and observations

3.4.1.2. Volatile Substance (VS)

The standard EN 14775:2009 "Solid biofuels: Determination of ash content" is a European standard as well and therefore obligatory.

The main aim of this standard is to harmonize the procedure for determining the ash content of any sample of solid biofuels. It must be pointed out that the ventilation rate through the furnace should be such that no lack of oxygen for combustion arises during the heating procedure. The problem of hygroscope is the same as of the determination of DS.

The determination of the ash content has to be carried out as following (as far as the determination of the moisture content has been carried out directly prior to this measurement):

1. Heat an empty dish at (550 ± 10) °C for at least 60 min. After cooling down to ambient temperature weigh it to the nearest 0.1 mg and record the mass.
2. Add minimum 1 g of the analysis sample into the dish in an even layer, weight the dish plus sample and place it in a cold furnace.
3. Raise the temperature evenly to 250 °C over 30 to 50 min to allow the volatiles to leave the sample before ignition.
4. Continue to raise the temperature evenly to maximum temperature over a period of 30 min. Maintain at this level for at least 120 min.
5. Remove the dish from the furnace and allow it to cool down inside a desiccator.
6. Weigh the dish with its content to the nearest 0.1 mg.
7. Calculate the ash content with the following formula.

Besides this procedure it has to be considered that the used scale's accuracy must be under 0.1 g and a minimum of two determinations of each sample have to be carried out.

As a result of these measurements the moisture content is calculable by using formula (3).

$$A_d = \frac{(m_3 - m_1)}{(m_2 - m_1)} * 100\% * \frac{100\%}{100\% - M_{ad}} \tag{3}$$

m_1 … mass of the empty dish; $[m_1]$ =g
m_2 … mass of the dish plus sample; $[m_2]$ = g
m_3 … mass of the dish plus ash; $[m_3]$ = g
A_d … ash content; $[A_d]$ = %

The report – according to the standard – has to include at least the following information:

a. Identification of the laboratory and the testing date
b. Identification of the sample tested
c. Reference to the standard
d. Any deviation from the standard
e. The test result on dry basis
f. Conditions and observations

3.4.2. Experiment execution

The experiments for this project have to be carried out with the ”Automatic Methane Potential Test System (AMPTS II)” by ”bioprocess control”. Before the execution of the experiments with this equipment the experimental preparation have to be done to ensure the accuracy of especially the DS-value. The knowledge of each DS-value of every used substrate mixture is obsolete.

3.4.2.1. AMPTS II

This equipment consists of different parts interacting with each other. An example can be seen in Figure 16. For the realisation of the determination itself the following core parts are necessary:

- Sample incubation unit
  These small containers (15 vials in total) contain the substrates mixed with anaerobic inoculum at a desired temperature. The contents are mixed by a slow agitator during the whole testing duration.
- CO_2-fixing unit
  The biogas produced in each container passes through individual vials containing NaOH. CO_2 and H_2S are retained by a chemical interaction. Only CH_4 passes through to the bio methane gas monitoring unit. In addition a pH indicator is added into each vial for controlling the acid binding capacity.
- Gas volume measuring device
  CH_4 released by the CO_2-fixing unit is measured using a wet gas flow measuring device individually. An integrated embedded data acquisition system is used to record, display and analyse results.

Figure 16: AMPTS II equipment (Source: bioprocess control)

The whole system is connected to any appropriative device using Ethernet. Usually simple notebooks, respectively, personal computers can be used for executing the software delivered with the equipment.

This software is used to execute record and analyse the experiments in particular.

3.4.2.2. Execution

According to the biogas production facility of Stormossen the testing reactors have to contain 5 per cent of dry substance. On this account it is inevitable to know the DS-value of each of the substrates before executing the experiments. Since the liquid containing the anaerobic inoculum was picked up at the facility of Stormossen it contains 5 per cent of dry substance and is mixable with every other liquid with the same DS-value without altering it.

The instruction was that the whole 450 ml of each of the containers have to be filled with 50 ml of the liquid containing the anaerobic inoculum. The remaining 400 ml have to be filled with the substrate mixture. The following formula (4) leads to the necessary amount of each substrate in every mixture:

$$m_i = s_i * \frac{20g}{\sum_j [(1-M_{adj}) * s_j]} \qquad (4)$$

m_i … mass of every substrate within the mixture; $[m_i]$ =g

s_i … share of every substrate within the mixture; $[s_i]$ = 1

M_{ad} … moisture content of every substrate within the mixture; $[M_{ad}]$ = 1

Since 5 per cent of 400 ml are 20 ml and the density of water is 1 kg/m³ the weight of solid substance within the mixture has to be 20 grams, which is the reason for the formula above.

The following approach has to be carried out:

1. Wash and dry all sample incubation units needed for the experiment.
2. Weigh the units and note the value.

3. Fill in every substrate needed according to formula (4).
4. Fill the container up to 400 ml volume with water.
5. Measure the pH level and note the value.
6. Preheat the mixture to a temperature about 50 to 55 °C.
7. Add the liquid containing the bacteria.
8. Close every container according to the manual of AMPTS II.
9. Execute the experiments by keep the temperature around the above mentioned level in order to prevent the bacteria from dying.

Since the used equipment is an automatic testing system any further step has to be done while the testing is executed. The system itself will notify as far as the maximum amount of bio methane is produced inside each container individually.

On this account the number of tested mixtures carried out depends on the individual experiment duration of each mixture tested.

3.4.2.3. Subsequent work

After carrying out every possible, respectively, necessary and logical mixture of substrate the results have to be analysed. It is necessary to involve facts like availability and logistics into the analysis to recommend the ideal mixture for a biogas facility located in the region of Ostrobothnia.

3.5. Laboratory

According to the in chapter 3.4 specified sequence of laboratory work several sessions of working phases inside the laboratory were necessary in order to produce the results. The following section is a summary of all the sessions within the laboratory arranged according to the sequence of steps.

3.5.1. Dry/Volatile Substance

The measured data prepared for calculating the final DS/VS-values of the substrates in Table 4 is collected in Appendix 1.

Substrate	**DS-value** [DS] = %	**VS-value** [VS] = %
Slaughter house waste	77.2	-
Pig manure	10.7	89.0
Cucumber plants	8.9	68.7
Domestic bio-waste	26.2	95.1
Barley malt	19.6	93.8

Bakery waste	78.5	93.8
Fish waste	33.0	90.0
Used oil	99.6	-
Potato peels	12.7	92.4
Mink Manure	28.0	74.1
Fox Manure	47.1	61.7

Table 4: Summary of DS/VS-testing

Since the determination of the ash content requires an ignition of the substrate in an oven at a temperature of 500 °C a problem came up during the first season of experiments. A laboratory staff-member opened the oven when the formation of smoke was extraordinarily high, which was probably caused by too low ventilation. The outcome of this was the stop of this experimental season and the reason for a lack of information regarding two VS-values in Table 4.
Some of the determinations were repeated according to the data in the Appendices.

3.5.2. Bioreactor content

A number of fourteen different mixtures were carried out during the duration of the project. A first session of experiments led to promising results and further to other ratios of already tested mixtures. On this account Table 5 shows the tested mixtures of substrates including the initial and final measurements.

No.	**Substrates**	**Ratios** [r] = %	**Content** [c] = g	**Initial pH-level**	**Final pH-level**	**BMP** [BMP] = Nm^3/t_{RM}
1	Slaughter waste Potato peels	40 60	21.1 31.1	5.9	6.6 (7.5, 5.7)	8.9*
2	Pig manure Cucumber pl.	60 40	121.2 81.0	7.5	7.6	18.6 16.3
3	Fish waste Bakery waste	50 50	18.1 18.5	6.3	3.8	10.9 10.8
4	Pig manure Barley malt	70 30	105.1 45.1	7.3	5.9	3.1
5	D. Bio-waste Used Oil	80 20	39.1 10.1	5.5	5.2 (5.0, 5.4)	11.7*
6	D. Bio-waste	70	34.1	5.5	5.1	10.5

	Slaughter waste	30	14.2			14.2
7	Used Oil Mink Manure	20 80	10.1 38.5	8.1 (7.9, 8.3)	6.7	33.5
8	Cucumber plants Fox manure	40 60	25.4 38.7	8.2	7.5	61.8 57.8
9	Pig manure Cucumber plants	80 20	157.9 40.7	7.8	7.4	25.6 27.0
10	D. Bio-waste Slaughter waste	30 70	10.4 23.3	5.3	5.5 (5.2, 5.8)	11.2 14.5
11	D. Bio-waste Used oil	70 30	29.1 12.1	4.8	4.9	12.6 8.9
12	Mink manure Fish waste	60 40	40.4 27.5	8.2	6.3	19.3 13.0
13	Fox manure Fish waste	60 40	29.1 19.2	7.9	6.6	6.5
14	Fish waste Cucumber pl.	70 30	54.2 23.2	7.1	6.7	7.5 9.7

Table 5: Analysed mixtures of substrates

Since all the experiments were carried out in two parallel bioreactors the measurements correlate to the average of the measurements of both samples. In case of potently different pH-level measurements the actual results are written in brackets. The BMPs are written as a single number if both reactors produced the same amount of methane. In the case of different results both results are written. Results marked with a [*] mean that one of the parallel experiments didn't deliver any results.

A full overview of the whole result report is included in the Appendices.

3.6. Analysis

The objective of this project was not only to analyse the bio methane potential of different substrates mixtures. It was also necessary to take the local availability into account. For this reason the used ratios (Table 5) were transferred to the available amount of substrates (see 3.2) in order to calculate an estimated methane yield from these particular mixtures. The exploitable substrates as well as the producible yields are shown in Table 6.

No.	Substrates	Availability [a] = t/y	Usability [u] = t/y	Bio methane [m] = Nm³
1	Slaughter waste Potato peels	78 6,400	78 117	1,740
2	Pig manure Cucumber pl.	572,000 2,000	3,000 2,000	87,250
3	Fish waste Bakery waste	160 700	160 160	3,472
4	Pig manure Barley malt	572,000 30	70 30	310
5	D. Bio-waste Used Oil	20,000 970	3,880 970	56,750
6	D. Bio-waste Slaughter waste	20,000 78	182 78	3,210
7	Used Oil Mink Manure	970 38,000	970 3,880	162,480
8	Cucumber plants Fox manure	2,000 92,000	2,000 3,000	299,000
9	Pig manure Cucumber plants	572,000 2,000	8,000 2,000	263,000
10	D. Bio-waste Slaughter waste	20,000 78	33 78	1,430
11	D. Bio-waste Used oil	20,000 90	210 90	3,230
12	Mink manure Fish waste	38,000 160	240 160	6,460
13	Fox manure Fish waste	92,000 160	240 160	2,600
14	Fish waste Cucumber pl.	150 2,000	150 65	1,850

Table 6: Estimated Bio methane production

4. Discussion, Conclusion and Suggestion

4.1. Discussion and Conclusion

According to the experiments carried out within this project the most potent mixture is cucumber plants and fox manure (mixture no. 8) with almost 300,000 cubic metre of methane produced, which correlated to about 2.4 GWh[3] of energy. Besides this composition there are yet other potent mixtures (see Table 6), which produces quite similar amounts of methane. Pig manure and cucumber plants produces about 2.1 GWh and used oil mixed with mink manure produces about 1.3 GWh of energy. Considering that the available amount of cucumber plants is only usable for one of those above mentioned mixtures, a possible parallel production of bio methane (mixtures 8 and 7) would lead to 3.7 GWh.

Due to the tested ratios of the substrates it can be seen in Table 6 that in almost every mixture it was never possible to consume the whole available amount of the specific substrate within the region of Ostrobothnia (e.g. mixture no. 4 pig manure). For this reason it would have been effective to examine the availability of the utilized substrates before starting the experiments. This determination would have led to a more sufficient exploitation of the available ingredients and maximised possibly the predicable amount of bio methane within the region.

Considering these factors different ratios of the used substrates may have led to a higher yield of bio methane implicated the availability as well. According to Wellinger there is often used liquid manure as a basic feedstock combined with very potent substrates. Since pig manure is the most available substrate in Ostrobothnia, a combination of this with any other substrate would have generated more broad results. Considering the BMP (see Table 5) every mixture with fox, respectively, mink manure was very potent too. Thus a combination of different sorts of manures would have been recommendable. As a lack of data during the project such a combination of substrates was not carried out.

According to biteco pig manure normally produces around 45 cubic metre bio methane per ton substrate. Barley malt contrarily produces around 72 cubic metre bio methane. However, the generated BMP of a mixture of those substrates led to 3.1 cubic metre bio methane. A comparison of all the BMPs of the tested mixtures showed that every generated result was lower than expectable. For this reason an investigation for the reason of these lowered BMPs led to findings in chapter 3.2. Considering the characteristics of the chosen substrates before carrying out the

[3] Since methane has a density of 0.72 kg/Nm³ and a heating value of 39.82 MJ/kg, for 300,000 Nm³ of methane follows about 8,601.12 GJ. This correlates to 2.3892 GWh.

experiments would have possibly avoided lowered BMPs in the results. A particular reason might have been dying bacteria during the production process due to a lack of components necessary for the survival of the bacteria.

As a matter of fact decreased yields of bio methane draw through the whole experimental session. However, considering that an ideal environment for the bacteria has a pH value between 6.5 and 8.5 (see chapter 3.1.3), Table 5 contains possible causes during the experiments. Those results with appropriate pH values during the whole duration of testing have significant higher BMPs than those with pH values beyond this particular range (compare mixtures no. 1, 3, 4, 5, 6, 10, 11). On this account an alteration of the pH value by adding different kind of nutrients may affect the BMPs. In addition some kind of substrates need appropriate pre-treatment (see chapter 3.2), which was not carried out during the experiments due to an unavailability of required equipment.

The inoculum (bacteria added to the mixtures) was obtained from Stormossen. Another possibility of decreased yields, respectively, no produced biogas at all might also be a failure in the handling of the bacteria. The bacteria were picked up from Stormossen before every experiment. A lowered temperature may have caused the death of the bacteria, which means usually no biogas production within the bioreactors. Since there no testing of the inoculum was done, an analysis of data about this cause is yet not possible.

Another issue depends on the calculated available substrates. Most of the availability-data shown in Table 6 rely in some cases on calculations from different sources to generate the required information. For instance, the amount of slaughter house waste was generated out of the total amount of meat production in Ostrobothnia combined with an article showing an average amount of waste for slaughtering animals. For this reason a specific study has to be carried out in order to generate more accurate data in some cases.

4.2. Suggestion

Since not a single member of the team has ever dealt with biogas before, the duration of getting in touch with this topic was rather short. Due to different communication problems some delays were not avoidable. After all, the experiments run on slowly at the beginning of March. On the one hand it was important to start the experiments by then, because their durations were hardly predictable. On the other hand profound knowledge about several things depending on the project came in mind later on and therefore too late for implementing it into the experiments.

On this account we would like to give some hints for following groups in this specific field.

- An imprudent variation of mixtures leads to hardly comparable results. Due to information in chapter 3.2 and **Fehler! Verweisquelle konnte nicht gefunden werden.** it is rather advisable to choose an appropriate basic raw material in order to make several experiments with different co-digesting substrates.
    - A common basic raw material is pig manure. Mixing this substrate with high potent substrates may generate an even higher yield.
    - Fox and mink manure are also very present in Ostrobothnia. Since both have a high dry content, it has to be mixtures with more liquid substrates. The results seem very potent.
- The research for the availability of the used substrates showed that substrates may differ in their characteristics depending on their origin. For this reason it seems recommendable to experiment with substrates from different sites in order to compare the results.
- An initiation of the experiments as soon as possible is still recommendable due to their duration. However, since it is common that students working on this project are not familiar with this topic, lectures are very recommendable at the beginning of the project.

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6. Registers

6.1. Table-Register

6.2. Figure-Register

7. Appendices

7.1. Appendix 1 – Examination of dry and volatile substance

DS - according to EN 14774-3
VS - according to EN 14775

Sample Nr.	Weighting before drying	Weighting after	Drying duration	Weighting after burning	Burning duration	Laboratory
1-27	21.03.16	23.03.16	45 hours	23.03.16	2 hours	Biolab
28-36	05.04.16	07.04.16	43 hours	07.04.16	2 hours	Biolab

No.	Sample	Dry dish weight	Burn dish weight	Wet sample weight	Dried sample weight (1)	Dried sample weight (2)	Burnt sample weight	Moisture content	Ash content	DS-value	VS-value
-	-	$[m_1] = g$		$[m_2] = g$	$[m_3] = g$			$[M_{ad}] = \%$		[DS] = %	[VS] = %
1	Slaughter 1	2.52		13.61	10.43			23.4%			
2	Slaughter 2	2.52		10.42	7.81			25.0%			
3	Slaughter 3	2.51		10.28	8.23			19.9%		77.2%	
4	Pig manure 1	2.52	26.73	14.71	1.43	1.38	0.17	90.3%	11.9%		
5	Pig manure 2	2.50	28.75	11.78	1.27	1.22	0.13	89.2%	10.2%		
6	Pig manure 3	2.50	29.44	18.46	2.13	1.98	0.23	88.5%	10.8%	10.7%	89.0%
7	Cucumber 1	2.53	21.73	17.22	1.51	1.52	0.49	91.2%	32.5%		
8	Cucumber 2	2.53	21.79	13.79	1.21	1.21	0.37	91.2%	30.6%		
9	Cucumber 3	2.51	16.80	15.69	1.43	1.41	0.44	90.9%	30.8%	8.9%	68.7%
10	Biowaste 1	2.52	28.49	14.44	3.78	3.78	0.14	73.8%	3.7%		
11	Biowaste 2	2.52	26.70	16.74	4.39	4.39	0.27	73.8%	6.2%		
12	Biowaste 3	2.51		16.39	4.30			73.8%		26.2%	95.1%
13	Barley 1	2.50	24.08	16.21	3.31	3.31	0.17	79.6%	5.1%		
14	Barley 2	2.53	26.54	17.04	3.21	3.23	0.19	81.2%	5.9%		
15	Barley 3	2.53	24.48	20.66	4.03	4.04	0.31	80.5%	7.7%	19.6%	93.8%
16	Bakery 1	2.53	26.19	10.52	8.26	8.22	0.35	21.5%	4.2%		
17	Bakery 2	2.53	26.54	11.56	9.07	3.23	0.91	21.5%	10.0%		
18	Bakery 3	2.53	24.48	12.34	9.69	4.04	0.41	21.5%	4.2%	78.5%	93.8%
19	Fish 1	2.50	29.79	17.07	5.47	5.41	0.54	68.0%	9.9%		
20	Fish 2	2.51	22.59	20.38	6.88	6.76	0.70	66.2%	10.2%		
21	Fish 3	2.53	26.31	21.31	7.06	7.00	0.70	66.9%	9.9%	33.0%	90.0%

22	Oil 1	2.52		9.60	9.64			-0.4%			
23	Oil 2	2.50		7.30	7.09			2.9%			
24	Oil 3	2.50		7.91	8.01			-1.3%		99.6%	
25	Potatopeel 1	2.51		11.22	1.42			87.3%			
26	Potatopeel 2	2.52		16.65	2.08			87.5%			
27	Potatopeel 3	2.50		7.79	1.00			87.2%		12.7%	
28	Potatopeel 1	2.52	29.45	10.04	1.33	1.33	0.15	86.8%	11.3%		
29	Potatopeel 2	2.51	28.75	8.78	1.12	1.11	0.13	87.2%	11.6%		
30	Potatopeel 3	2.52	26.71	9.73	1.11	1.07	0.00	88.6%	0.0%	12.5%	92.4%
31	Mink Man. 1	2.52	26.54	15.86	4.35	4.35	1.15	72.6%	26.4%		
32	Mink Man. 2	2.52	28.48	15.67	4.40	4.40	1.10	71.9%	25.0%		
33	Mink Man. 3	2.53	24.49	13.65	3.87	3.87	1.02	71.6%	26.4%	28.0%	74.1%
34	Fox Man. 1	2.53	28.35	17.08	9.67	9.67	3.75	43.4%	38.8%		
35	Fox Man. 2	2.52	26.73	13.30	5.43	5.43	2.00	59.2%	36.8%		
36	Fox Man. 3	2.53	28.79	13.67	6.00	6.00	2.35	56.1%	39.2%	47.1%	61.7%

Here is shown every measurement made for the calculation of the DS-VS whereas the results are also shown in Table 4 as a summary.

7.2. Appendix 2 – Working time

In Figure 17 the graph shows the trend and the final amount of hours, from each of the team members, spent on European Project Semester during their studies at Novia University of Applied Sciences Vasa.

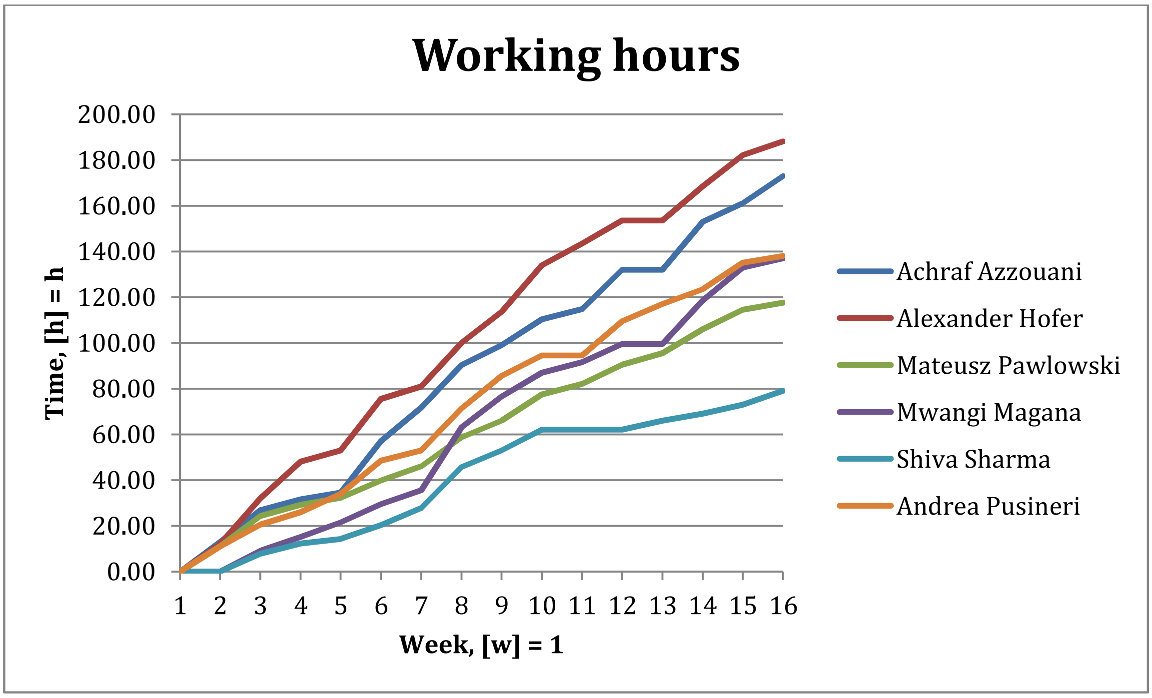

Figure 17: Working hours

7.3. Appendix 3 – Risk management

This Appendix shows all the risks identified correlating to their particular mitigation.

Risk	Mitigation
Preparatory measures	
Lack of enough information	• Asking supervisor for more information. • Carrying out independent research and information from other stakeholders
Team problems	• Making a team charter, which all members are obliged to sign and abide by the rules. • Having regular meetings and communication to reduce misunderstandings.
Take-off failure	• Gathering information as project progresses.

Mapping substrate	
Lack of information on substrates	• Researching previous studies on substrate mapping in Vaasa. • Independent literature and internet research.
Not getting substrates	• Doing an investigative study on substrate availability before choosing the final substrate list
Picking the wrong substrates	• This is a positive risk since the scope does not limit the substrate types.
Substrate-quality deteriorates before testing	• Picking the substrates close to the day for starting experiments. • Freezing the substrates immediately after collection.
Lab work	
Lab preparation not adequate	• Seek help from the library staff and supervisor. • Consult informed people (e.g. Evelyn)
Lacking a lab technician	• Contact supervisor if problem arises.
Making wrong mixtures	• Making calculations before making the mixtures. • Researching similar experiments and possible outcomes. • Consulting before making the mixtures in the lab.
Fire	• Taking all the precautions in working in the lab. • Using the oven under supervision by the laboratory-technician.
Biohazard from handling the waste	• Ensuring all the necessary health measures is taken. • Using protective gear for the experiments. • Maintaining high hygiene standards (washing hands frequently and using disinfectant).
Computer failure (AMPTS software)	• Take the IT support contact. • Testing the software before actual lab work.
Bacteria does not work	• Contact the supplier (e.g. Stormossen)

No biogas produced	• Check calculations. • Check the laboratory plan. • Ask other people in this field.
No results to analyse	• Analyse the results from lab even if it does not give expected outcome.
Documentation and closing	
Make an incomplete report	• Writing the report in parallel with the project so as not to delay the writing.
Not finishing the website	• Website development continuous at the same time with the project.
The project is incomplete	• Stick to the project plan. • In case of changes, managing them so there is no big impact on the schedule.

7.4. Appendix 4 – Gantt chart

EPS project.mpp

ID	Task Mode	Task Name	Duration	Start	Finish	Half 1, 2016
1	✓	**Preparatory measures**	**11 days**	**Mon 8.2.16**	**Mon 22.2.16**	
2	✓	Kick-off	1 day	Mon 8.2.16	Mon 8.2.16	100%
3	✓	Team building	5 days	Mon 8.2.16	Fri 12.2.16	100%
4	✓	Assign duties	3 days	Mon 8.2.16	Wed 10.2.16	100%
5	✓	Project farmiliarization	11 days	Mon 8.2.16	Mon 22.2.16	100%
6	✓	**Mapping substrate**	**25 days**	**Mon 15.2.16**	**Mon 21.3.16**	
7	✓	Reading about biogas	6 days	Mon 15.2.16	Sun 21.2.16	100%
8	✓	Reading EPS report	3 days	Mon 15.2.16	Wed 17.2.16	100%
9	✓	Research about substrate	10 days	Mon 15.2.16	Fri 26.2.16	100%
10	✓	Practical work planning	1 day	Mon 7.3.16	Mon 7.3.16	100%
11	✓	Substrate collection and storage	5 days	Mon 14.3.16	Fri 18.3.16	100%
12	✓	Determining mixtures	0 days	Mon 21.3.16	Mon 21.3.16	21.3
13	✓	**Study visits**	**29 days**	**Wed 24.2.16**	**Mon 4.4.16**	
14	✓	Visit to Stromossen	1 day	Wed 24.2.16	Wed 24.2.16	100%
15	✓	Visit to Jeppo biogas	1 day	Mon 4.4.16	Mon 4.4.16	100%
16		**Lab work**	**36 days**	**Mon 21.3.16**	**Sun 8.5.16**	
17		**Plan experiment**	**4 days**	**Mon 21.3.16**	**Thu 24.3.16**	
18	✓	Lab introduction	1 day	Tue 22.3.16	Tue 22.3.16	100%
19	✓	Pre lab calculations	2 days	Tue 22.3.16	Wed 23.3.16	100%
20	✓	Familiarization of lab procedures and standards	1 day	Tue 22.3.16	Tue 22.3.16	100%
21		Start lab	0 days	Thu 24.3.16	Thu 24.3.16	24.3
22	✓	**Measuring substrate moisture content and volatile matter**	**2 days**	**Thu 24.3.16**	**Fri 25.3.16**	

Critical, Critical Split, Critical Progress, Task, Split, Task Progress, Manual Task, Start-only, Finish-only, Duration-only, Baseline, Baseline Split, Baseline Milestone, Milestone, Summary Progress, Summary, Manual Summary, Project Summary, External Tasks, External Milestone, Inactive Task, Inactive Milestone, Inactive Summary, Deadline

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EPS project.mpp

ID	Info	Task Name	Duration	Start	Finish	Half 1, 2016 (J F M A M J)
23	✓	Determining DS	1 day	Thu 24.3.16	Thu 24.3.16	100%
24	✓	Determining VS	1 day	Fri 25.3.16	Fri 25.3.16	100%
25	✓	**Codigestion**	**31 days**	**Fri 25.3.16**	**Fri 6.5.16**	
26	✓	PH measurement	2 days	Tue 26.4.16	Wed 27.4.16	100%
27		**Results**	**10 days**	**Tue 26.4.16**	**Sun 8.5.16**	
28		obtaining results	0 days	Tue 26.4.16	Tue 26.4.16	26.4
29	✓	Result collection	9 days	Tue 26.4.16	Fri 6.5.16	100%
30	✓	Result analysis	2 days	Fri 6.5.16	Sun 8.5.16	100%
31		**Documentation**	**66 days**	**Mon 15.2.16**	**Mon 16.5.16**	
32		Mid term	0 days	Wed 30.3.16	Wed 30.3.16	30.3
33	✓	Mid term report	31 days	Mon 15.2.16	Mon 28.3.16	100%
34	✓	Mid term presentation	4 days	Thu 24.3.16	Tue 29.3.16	100%
35		Final report	34 days	Tue 29.3.16	Fri 13.5.16	75%
36		Final presentation	35 days	Tue 29.3.16	Mon 16.5.16	50%
37	✓	Website	51 days	Mon 7.3.16	Mon 16.5.16	100%
38		**Closing**	**1 day**	**Tue 17.5.16**	**Tue 17.5.16**	0%
39		Hand over	0 days	Tue 17.5.16	Tue 17.5.16	17.5
40		Lessons learnt	1 day	Tue 17.5.16	Tue 17.5.16	0%

Critical	Manual Task	Baseline Milestone	External Tasks
Critical Split	Start-only	Milestone	External Milestone
Critical Progress	Finish-only	Summary Progress	Inactive Task
Task	Duration-only	Summary	Inactive Milestone
Split	Baseline	Manual Summary	Inactive Summary
Task Progress	Baseline Split	Project Summary	Deadline

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7.5. Appendix 5 – Work Breakdown Structure

Task group	***Task***	***Description***
Preparatory measures	Kick off	Project introduction
	project familiarization	Reading and understanding biogas and co-digestion
	Team building	Developing a team spirit and communication
	Assign duty	Dividing duties according to strengths and weaknesses
Mapping substrates	Reading about substrates	Determining what is a substrate and basic qualities
	Reading EPS report	Biomap EPS group did a substrate mapping project for Ostrobothnia. This was the starting point in determining substrates
	Substrate research	Finding out more information on the substrates available
	Substrate collection and storage	Searching for the substrates and collecting them and freezing them
	Determining mixtures	Based on the substrates collected, researching on the effects of mixing different substrates
Study Visits	Visit to Stormossen	Stormossen is the biggest biogas producer in Ostrobothnia. Aim of the visit was to learn more about biogas production
	Visit to Jeppo biogas	Learning more about biogas production
Lab work	Plan experiment	Developing a plan for conducting the experiments including how to prepare substrates before the experiment
	Lab introduction	Visiting the lab and getting more information on equipment, safety measures and how to carry out the experiment
	Pre lab calculations	Making an excel file with all the necessary formulas which will be used in the experiment.
	Determining DS	Measuring the dry content of the substrates
	Determining VS	Determining the ash content of the substrates
	Co-Digestion	Making the mixtures and running the experiments. The inoculum is added at this stage
	PH measurement	Determining the pH after biogas production since it's important for the microorganisms during biogas production
	Result collection	The results are obtained from the AMPTS II software both data and graphs
	Result analysis	Determining if the results obtained reflect the theoretical expectations
Documentation	Mid-term report and presentation	Making a preliminary report based on the progress
	Final project report and presentation	Making a final report including all the work carried the entire project
	Website	Developing a platform for showcasing our work
Closing	Hand over	Handing over our report to the EPS management
	Lessons learnt	Reflecting on the EPS experience as a whole and what we learned about the project