Energy Extraction from Horse Manure
Biogas plant vs. Heating Plant

A Case Study in Wången

By: Amitis Moazedian

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Department of Engineering and Sustainable Development
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Abstract

Wången is a trotting school located in Alsen region in Mid Sweden. Currently they keep almost 105 horses in their premises, which produce 2 400 m$^3$ of stall waste per year. Stall waste has always been a concern for those who keep animals, and though composting has been a viable solution to this problem for quite some time, it is no longer the only solution. Stall waste can be converted to energy and there are different techniques and approaches to do so.

In this study the writer compares the viability of two possible techniques (Biogas and heating plant) by collecting data from two existing biogas and heating plant providers for Wången trotting school. The results show that with almost same amount of investment on the reactors, a heating plant can meet 85% of Wången heating demand while Biogas plant could only meet 10 % of Wången’s heating consumption.

On the other hand, as a result of nitrogen bound compound existence in horse manure, burning stall waste in the heating plant showed a more acidifying potential compared to the biogas plant.
List of words and Abbreviations

**Manure**: animal feces and urine

**Bedding material**: material which absorb the liquid portion of manure

**Wood shaving**: a fibrous material used as bedding

**Stall waste**: a mixture of manure and bedding material

**AD**: Anaerobic Digestion (in the absence of oxygen)

**Digestate**: the solid residues of AD

**Biogas**: gas composed of CO2 –CH4 resulted from AD

**CHP**: Combined Heat and Power plant

**Ash**: combustion byproduct

**SRT**: The Solids Retention Time is the average time the activated-sludge solids are in the system. The SRT is an important design and operating parameter for the activated-sludge process and is usually expressed in days (Asano, 2007, p 591).

**TS**: Total Solid

**VS**: Volatile Solid

**Energy density**: the amount of energy stored in a unit of volume

**Nm³**: normal cubic meter used in the industry for gas emission and exchange

**WID**: Waste Incineration Directive
1 Introduction

Today’s increasing need for energy has resulted in using non-renewable fossil fuel in a high pace. Burning fossil fuels has brought about many environmental problems such as global warming. During the burning process, Carbon, stored in the fossil fuels for millions of years, finds its way out to the atmosphere in the form of carbon dioxide. Carbon dioxide is a powerful greenhouse gas, which causes a warming effect by capturing the converted heat from the reflected UV-radiation from the earth surface.

Energy crisis in 1979 along with an increasing desire to have a better environment caused industrial countries like European states to try to find other alternatives for fossil fuels. During these years with heavy invention in the search for alternative energy sources, Sweden has been in the front line between all those countries (Swedish Institute, 2011). According to Swedish institute, 45 percent of Sweden’s energy supply, such as electricity, district heating and fuel, comes from renewable energy, and Sweden has aimed to increase its share of renewable energy to 50 percent by 2020 (2011).

This determination to find renewable sources of energy is even noticeable between companies and small entities in Sweden. Conducting environmental activities is now a natural part of many companies and organizations in Sweden, so is for Wången trotting school.

This quotation in Wången environmental handbook is noteworthy:

“Wången will work for a reduced impact on global warming by working towards reducing energy consumption and greenhouse gas emissions. “(van den Brink, 2012a)

In accordance with their environmental policy, Wången trotting school is moving toward reduction in waste, emissions and energy consumption (van den Brink, 2012b).

To achieve an economically and environmentally sustainable energy system, Wången is looking for alternative ways to provide their energy needs. In this study, the writer will investigate the potential of having a heating plant vs. a biogas plant as an alternative energy source for Wången trotting school.

Scope and boundaries

The scope of this work comprises an investigation on Wången’s current energy situation and conditions, which are necessary to establish a heating and an anaerobic digestion plant plus a partial study of requirements to implement and manage such establishments.

Calculations in this thesis study for evaluating the best possible option1 for biogas and heating plant installation relies heavily on the facts and figures gathered by Lena van den Brink for Wången AB, also on the ones collected from contact and interviews with responsible bodies in Wången AB, and from people, who have relative knowledge about alternative energy sources.

Only a mixture of horse manure and wood shaving as bedding material have been studied as substrate.

1 From environmental, economic perspective and energy provision perspective (described in section bellow)
In this thesis work, the writer will investigate the feasibility of constructing a biogas plant vs. a heating plant for Wången’s manure problem from environmental and economic points of view.

**Environmental point of view**

Environmental issues investigated in this study:

- Global warming potential resulting from greenhouse gas emission during reactors operation time
- Acidification potential caused by emissions to the air during the boilers’ operation time

**Economic point of view**

Microeconomic is the subject of the analysis in this study for economic issues, and related subjects to be discussed are:

- Initial investment
- Operating costs
- Pay-back period

In this section, it is assumed that the company provides itself with the total initial capital. No possibility for getting incentives or loan has been studied here.

**Energy provisioning**

In this section, the amount of energy, which both reactors can create for Wången, will be discussed and compared.

At the end a quick comparison will be made based on:

- The reactors byproduct from quantity, applicability and characteristics
- Horse manure as a substrate for both systems

**Purpose**

The aim of this study is to discover alternative sources of energy for Wången trotting school to pursue the best total solution from a sustainability and economic perspective.

**Goal**

The goal of this study is investigating Wångens conditions for establishing a heating furnace for heating purposes vs. a biogas plant for biogas production from horse manure.

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2 Both boilers need to work 24 hours 7 days per week, and stall waste is available for nine months of the year; therefore, all calculations are made accordingly. Emissions from the heating plant are collected from Swebo Bioenergy pilot boiler, located at Swebo Bioenergy’s premises in Boden with a nominal load of 250 kW (“Emissions do not change drastically as the power of the heating plant increases” stated M. Jansson from SWEBO on an email on 1st May 2013).
Assessing these conditions, result in finding corresponding factors that are crucial for the implementation and a successful establishment of either a heating or a biogas plant.

Contribution of those two boilers (during operation time) to global warming, acidification and the amount of produced energy will be compared and in the end the amount of capital needed to establish for each one of the boilers, operation costs and the possibility of being energy self-sufficient will be discussed.

The work done through this thesis together with gathering and providing more information would help Wången AB to make a decision to solve their manure problem in a more efficient way.

2 Methods

Based on the study of literature reports, the requirements for implementing a successful establishment of both a biogas and a heating plant using horse dung have been investigated.

To provide data for essential calculations, two existing reactor generators have been contacted BioEnergy, a heating plant generator, and SWaB Energy, anaerobic digester producer. These selections have been based on the size of the stall waste in Wången trotting school, and the companies’ experience to deal with horse manure as a substrate alone.

After adopting the collected emission data for Wången’s case study (based on the manure quantity), the data have been processed with GWP 100 years (kg CO₂ e/kg) and acidification (g SO₂ e/g) characterization indicators (Baumann and Tillman, 2004). Then the result is compared to reach a conclusion.

Economic data, such as initial capital; operation costs; etc. has been provided by reactor generators for the right reactor size in case of Wången stall waste. These values are then compared and discussed during the following chapters.

3 About Wången

Wången is a national educational trotting center in Sweden. It is one of the three national equestrian sports centers, whose main task is to educate professional equestrians in the field of modern horse industry, specializing in horses for sport and leisure.

Wången is located in the picturesque Alsen³ region between Åre and Östersund (50 kilometers from Östersund). Horses have been important to this region for over 100 years.

Wången offers education and research

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³ Alsen is located in Mid Sweden, where average lowest temperature reportedly is “-9.6 °C”, in January (Weather statistics for Åre, Jämtland (Sweden), n.d).
opportunities along with conference facilities and an inn with varied accommodations. Formerly a stud-farm, Wången is now the national center for Swedish harness racing, and it offers a wide variety of educational courses in harness racing and Icelandic horse riding. These activities are held in close co-operation with the sports’ respective organizations (Wången, n.d).

Wången and environment

Wången trotting school is concerned about environmental problems. Their environmental work is characterized by continuous improvement of environmental performance which is achieved by:

- Environmental and cyclical thinking
- Providing employees and students training and information; creating conditions so that everyone can perform applying a better management concerning the environment
- Reducing waste, emissions and energy consumption by educating all the people involved, such as employees, students, trainees, guests, suppliers and other stakeholders, in order to minimize wasting natural resources. (van den Brink, 2012b)

Wången’s map

Figure bellow shows different areas of the Wången trotting school.

![Figure 2. Wången's map (van den Brink)](image-url)
Energy consumption and costs

Today, Wången is equipped with geothermal heat pumps and photovoltaic panels, which provide the school with warm water and heat. Almost 60% of warm water and space heating comes from geothermal during winter. The solar panels only supply one stable and the pupils’ homes with warm water for 60% during summer time. The rest of the warm water during summer for the entire Wången comes from geothermal heating (L. Van den Brink, personal communication, 20 May 2013).

Figure (4) illustrates Wången energy consumption since 2006. Except for 2010, the rate of energy usage remains the same. Therefore, energy consumption of the year 2009 is used as a sample for the calculations. See Appendix 1.

![Energy consumption kWh](image)

Figure (4). Wången energy consumption from 2006 (van den Brink, 2013a)

Figure (5) shows Wången energy consumption in 2009. Based on the chart, the lowest energy consumption happens in July and the highest in January, and the big share of energy consumption for heating in winter is noticeable. See Appendix2.

Wången spent about 1 752 000 SEK in 2009 to purchase electricity. This high figure pinpoints the importance of finding other alternative energy sources for Wången School to help decreasing its energy costs.

4 The exact amount of the energy, which is provided through geothermal is not available.
5 Wången experienced a cold winter in 2010.
4 Horse manure

The horse manure consists of about 60% of solids and 40% of liquids portion. In order to keep a hygienic environment both for workers and horses, bedding materials used in the stall boxes to absorb the liquid part, are exchanged regularly. A mixture of manure, urine and bedding material is therefore, the component of stall boxes’ waste.

There are several different types of bedding materials. Wood shavings, sawdust, straw and peat or paper pieces are the most common of them. Choosing a bedding material is strongly dependent on the availability of that material at low cost. In northern Sweden, wood-shavings are generally used due to its great accessibility (Lundgren and Pettersson, 2009). The fraction of bedding material in stall wastes varies significantly based on how careful stall keepers are in cleaning the stables.

Wången’s horse manure problem

In case of an arable land existence in the vicinity of the stable, horse manure composting can be used as soil enrichment; otherwise costly removal and transportation of large waste volumes would be required, which many horse owners cannot afford (Lundgren and Pettersson, 2009).

Wången owns 105 horses currently (C. Erlandsson, Wången, personal communication, 24 April 2013), which spend almost 18 hours per day in stables except during June to August, when they are moving freely in pastures (L. van den Brink, Personal communication 15 April 2013).

About 2400 m³ (2012) manure along with bedding material is produced annually from Wången stables. This Manure has to be handled in an environmentally satisfactory way and...
at an affordable/reasonable cost. So far, the manure has been used as fertilizer for crops in a nearby field. But the manure is mixed with bedding material resulting in the farmers’ gradual refusal of the mixture (L. van den Brink, personal communication 15 April 2013). Therefore, Wången has to find another solution in a most efficient way to deal with their horse manure.

5 Possible solutions for producing usable energy from horse manure

Dealing with stall wastes has always been a concern for horse owners. Composting manure in order to produce organic rich soil is an applicable way to deal with the stall wastes. No longer, however, is it the only solution.

Converting horse manure into energy is now another alternative for horse owners of all sizes, and different technologies are available for this conversion, including:

- Incineration
- Anaerobic digestion
- Heat extraction
- Gasification

Traditionally, the cost-effectiveness of these technologies has largely been dependent on the size of the horse farm operation. In general, the larger the operation, the more cost-effective these options are. However, technology development has made several of these options feasible for small horse farms, as well (Sustainable Stables, 2012).

In the following part, the first two alternatives will be discussed for Wången’s manure problem.

6 Results

Incineration

Burning manure to produce heat is not a new trend. For ages, man has burned animal waste to obtain heat (Combs, n.d.), and is still a common practice around the world especially in traditional and developing countries, such as India. In those regions, dried cow dung is being burned for heating and cooking purposes (Chopp, 2013).

According to Lundgren and Pettersson (2009), the largest part of the horse manure is recycled for agricultural purposes. Combustion and other usages such as soil production for lawns were of small importance.

6.1.1 Legislation

According to the Waste Combustion Directive (WID 2000/76/EC), all the European Union members, should determine if manure is considered as a waste or a renewable fuel for heat production. If it follows the Waste Combustion Directive, the plant owner has to fulfill regulations concerning:

- permission for a new plant
- operation conditions
- emissions to air
water discharges from the cleaning of exhaust gases
ash handling
controlling and monitoring system
measurement requirements
access to information and public participation

Some countries do not have any actual requirements for small scale biofuel plants, while some countries require exhaust gas emissions, thermal efficiency and supervision programs. If heat production from manure is considered to be a biofuel plant, there is no EU directive for the plant to fulfill.

Combustion of manure in Sweden is included in WID. In spite of the fact that horse manure is a waste, it can be burned without fulfilling WID requirement due to the fact that the horse manure contains a lot of grass and bedding material as opposed to usual poultry, cow and pig manure (Edström et al., 2011, P.8).

However, the remained ash can only be used as fertilizer if it passes the regulations regarding cadmium content.

### 6.1.2 Problems regarding the choice of an incineration plant

Inconsistency in horse manure compound is perhaps the biggest challenge in manure combustion. Changes in the size of the fuel particles (such as in bedding material), difference in ash composition or amount, as well as content moisture difference could cause mechanical problems or may require changes in operation, which may not be possible with the actual plant design.

To solve these issues, there are two possibilities:
- Designing a facility with the ability to modify itself according to the fuel quality variation.
- Providing a standardized input fuel (requires a much higher technical and economical effort on fuel preparation) (Edström et al., 2011).

### 6.1.3 Selection of an incineration plant for Wången

A 300-500 kW (M. Jansson, SWEBO, personal communication 25 April 2013) Swebo Biotherm Gen 3 with Power and emission control system (EKS) and adjustable to the fuel quality is chosen as heating plant to study the Wången’s case. Swebo Biotherm Gen 3 can handle manure with moisture content up to 50% and an energy content of about 1700kWh / ton. In cases of higher moisture content or long maintained manure, the EKS program (or pallet booster) in a matter of 30-60 seconds activates to avoid decreasing power and increasing emissions. This system causes the wooden pellets which are stored in a cylinder near the heating plant, to be injected directly into the fireplace and in this way the combustion process is regulated. This system is also activated when the requirements for combustion are not maintained due to the poor quality of fuel, or if a higher power than the original fuel is needed (BIOTHERM, 2012, P.8). It is also equipped a cyclone to reduce dust emission. Swebo Biotherm Gen 3 is illustrated in figure (6).

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6 All the mentioned problems, which can occur while dealing with horse manure, can be avoided with this selection.
6.1.4 System description

Figure (7) shows different parts of the heating plant. The process begins with placing the horse manure in the combustion chamber. Then, the manure is burned at about 850 °C. Flue gases resulted from burning the manure at high temperature are then transported to the boiler unit, which is used to heat water. The hot water can be used as warm water, or be run through a network of pipes to provide space heating. The byproduct of this process is ash, and it can be removed from the storage chamber, which is usually placed outside the installation for easy cleaning. This ash is high in phosphorus and potassium and can be used as forest fertilizer if the cadmium content is lower than the prevailing regulations (Sustainable Stables, 2012, Lundgren and Pettersson, 2009). The heating plant itself consumes 10 kW energy.
6.1.5 Fuel options for SWEBO Biotherm

SWEBO BioTherm is not designed solely for horse owners. It is also ideal to be used by slaughterhouse owners, animal breeders, chicken manures and in the forestry industry (BIOTHERM, 2012).

Around one mile from Wången, locates Pelle & Lisa, an egg producer. It has around 18,000 chickens that provide around 60 liters of manure per hen per year. This manure can be also burned with stall wastes. During contact with a responsible representative of Pelle & Lisa, (U.Hallberg, Pelle & Lisa, personal communication, April 29 2013), Pelle & Lisa expressed their interest to cooperate with Wången regarding the project. There is possibility for further studies to investigate the effects of mixing chicken manure with stall waste. This study only focuses on using horse manure and bedding material for biogas production.

Organic residues can also be burned with stall waste to produce energy. Currently, Wärdhus (number 9 in Figure (2)) produces about 100 liters of organic waste every week, which can be added to stall waste in furnace. This amount of organic waste is now composted at the facility (C. Erlandsson, Wången, personal communication, 24 April 2013). Examining the effect of mixing these residues with biogas production is out of the scope of this study.
6.1.6 Heating plant and the environment

Same as with other organic compounds, burning horse manure results in formation of CO$_2$ and water. Horse manure contains considerably more fuel-bound nitrogen compared to other organic materials such as wood-chips. This results in formation of NOx (Lundgren and Pettersson, 2009). Nitric oxide and Nitrogen dioxide (NOx) will be produced during combustion of nitrogen and oxygen at high temperatures. NOx contributes to smog and acidic rain formation.

6.1.6.1 Global warming potential

No greenhouse gas emission has been reported during the furnace operating time (See Appendix 4).

6.1.6.2 Acidification

As mentioned, as a result of Nitrogen compound existence in horse manure, NOx will be emitted. NOx emission has an acidification effect. HCL and SO$_2$ are other byproducts of horse manure burning with acidifying potential. Amongst the emissions, NO$_2$ contributes the most to the acidification (See Appendix 6).

6.1.7 Energy usage

Wången had 1 812 939 kWh of total energy consumption in 2009. The lowest consumption was reported in July of this year, with 52 206 kWh while the highest was reported in January with 257 321.

To calculate the percentage of energy used for heat consumption compared to the total purchased electricity, the total energy consumption in July is assumed to be default energy usage for any other purposes except heating for all the months. The difference between the total energy consumption and the default amount is meant to be the electricity usage for heating purposes, such as space heating and water heating (see Appendix 2). Thus heating usage consumes 65 % of all purchased energy in Wången.
6.1.8 Calculated heat production

Mikael Jansson (Swab Energy, personal communication, 25 April 2013) states that the horse manure varies in quality, but based on his experience working with already delivered systems, he evaluates that one ton of manure with moisture content of 45-50% occupies between 3-5 cubic meters of space. He also mentions that depending on the quality of the manure, the heating value can vary between 900 kWh / ton to up to 2000 kWh / ton.

In this study, horse manure’s moisture content, density and heating average values are assumed to be 45-50%, 350 kg/m3 and 1.45 kWh/kg respectively (To see the heating value of some common fuels see Appendix 0). The system is modulating down to around 20% of the energy capacity.

Since stall waste is only available for nine months (September till May), energy consumption in June, July and August has been deducted from total energy consumption. With 20% modulating down in the furnace, total amount of 108 267 kWh energy, in the form of heat, is expected to be obtained from the furnace each month.

The total heat surplus in April, May, September and October is calculated to be 145 152 kWh. As table (1) shows the gained heat from the stall waste combustion cannot meet the Wången’s heating demand during the other months. Minus signs in the table below shows the amount of extra heat which is needed to be met during those months.

<table>
<thead>
<tr>
<th>Month</th>
<th>Energy consumption kWh</th>
<th>Energy for heating and warm water kWh</th>
<th>Energy for other purposes than heating kWh</th>
<th>Gained energy from horses with modulation kWh</th>
<th>Heat need kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>257 321</td>
<td>205 115</td>
<td>52 206</td>
<td>108 267</td>
<td>-96 848</td>
</tr>
<tr>
<td>Feb</td>
<td>251 000</td>
<td>198 794</td>
<td>52 206</td>
<td>108 267</td>
<td>-90 527</td>
</tr>
<tr>
<td>Mars</td>
<td>189 472</td>
<td>137 266</td>
<td>52 206</td>
<td>108 267</td>
<td>-28 999</td>
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<td>April</td>
<td>139 135</td>
<td>86 929</td>
<td>52 206</td>
<td>108 267</td>
<td>21 338</td>
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<tr>
<td>May</td>
<td>104 652</td>
<td>52 446</td>
<td>52 206</td>
<td>108 267</td>
<td>55 821</td>
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<td>September</td>
<td>98 515</td>
<td>46 309</td>
<td>52 206</td>
<td>108 267</td>
<td>61 958</td>
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<td>October</td>
<td>154 437</td>
<td>102 231</td>
<td>52 206</td>
<td>108 267</td>
<td>6 036</td>
</tr>
<tr>
<td>November</td>
<td>167 239</td>
<td>115 033</td>
<td>52 206</td>
<td>108 267</td>
<td>-6 766</td>
</tr>
<tr>
<td>December</td>
<td>251 038</td>
<td>198 832</td>
<td>52 206</td>
<td>108 267</td>
<td>-90 565</td>
</tr>
<tr>
<td>Total</td>
<td>1 612 809</td>
<td>1 142 955</td>
<td>469 854</td>
<td>974 400</td>
<td>-168 555</td>
</tr>
</tbody>
</table>

Table (1). Calculated heat gain and need in Wången

With a good management of stall wastes during the months with surplus heat, Wången only needs to provide around 200 000 kWh for their heating demand during nine months (more description is provided under the chapter ‘Suggestion to Wången school’).

6.1.9 Economy

As Table (2) shows, the total capital costs are evaluated to be around 4 million SEK. This includes the inspection fee, which varies between 10-20000SEK (depending on the size of stall waste) and the cost for issuing a guarantee from Inspecta or other similar companies, after installation.

---

7 Equivalent of 100 105 kg or 286 m³ stall waste
8 The cost for issuing a guarantee from Inspecta or other similar companies, after installation
the boiler) (M. Jansson, SWEBO, personal communication 13 May 2013). The average electricity price assumed to be one SEK. The operational costs consist of the total electricity consumption costs for the furnace.

To make the calculations easy, the costs of building a boiler room and labor costs are excluded here.

Based on the calculations here, it is expected that Wången would pay off the initial capital in about 5 years. Then, Wången would purchase around 770 400 kWh less electricity for heating purposes (about 800 000 SEK per year (1 SEK per kWh)).

<table>
<thead>
<tr>
<th></th>
<th>Total costs (SEK)</th>
<th>kWh</th>
<th>Electricity price SEK/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating plant+ installation+ shipping</td>
<td>3 758 250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspection fee</td>
<td>20 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total capital</strong></td>
<td>3 778 250</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total operating costs</strong></td>
<td>64 800</td>
<td>64800</td>
<td>1</td>
</tr>
<tr>
<td><strong>Energy purchase avoidance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat</td>
<td>835 200</td>
<td></td>
<td><strong>835200</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>835 200</td>
<td></td>
<td><strong>835200</strong></td>
</tr>
<tr>
<td><strong>Electricity purchased</strong></td>
<td>1 752 868</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pay off period (YEAR)</strong></td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

Table (2). A summary of investment and operational costs for heating plant

**Anaerobic digestion**

Anaerobic Digestion (AD) in a biogas plant is a natural process in which organic matter is broken down in the absence of oxygen. A wide range of raw material such as manure, food waste, sewage, organic wastes and energy crops can be used for an anaerobic digestion (Lantz et al., 2007).

There are some terminologies in anaerobic digestion, which need to be explained:

**Total solid (TS)** refers to the weight of the remaining sample after drying at 105 °C for a minimum of twelve hours compared with the total weight of the sample before drying. The water content of natural feed materials varies; therefore, for scientific calculations, the solid or dry matter of the feed is used. **Volatile solid (VS)** is the weight loss of the sample weighed before and after burning the sample at 550 °C for at least 6 hours. Organic or volatile material of the feed are the only parts important for the digestion process. Therefore, only the organic part of the dry matter is considered in calculations here. The final ash left is equal to the sample mineral content (Yohaness, 2010, Sasse, 1988).

---

9 Energy crops are plants grown and harvested with the specific intent to use them as fuel (What are energy crops?, 2013)
Digestion Techniques are divided into Wet and Dry Digestion Process (Liss, 2008). When the dry matter content of the feedstock is below 15%, the AD process is called ‘Wet Digestion’, or ‘Wet Fermentation’; when it is above 15%; the process is referred to as ‘Dry Digestion’ (Lukehurst et al., 2010, p. 5).

The overall division of different digestion techniques is often linked to the solids’ content (TS content) in the digester. The Wet process generally refers to anaerobic digestion of liquid and pumpable substrate when TS content in the digester is about 2-10 weight percent. Dry process generally refers to digestion by stackable substrate mixtures, where TS content in the digester is about 20-35 weight percent (Norberg and Norberg, 2007). Figure (10) shows the TS range of different substrates and suitable digestion types for them.

Figure (10). Classification of different substrates by TS content (Norberg and Norberg, 2007)

Existence of several inorganic ingredients, such as salts (eg, ammonium); chloride; peroxides; and organic ingredients such as solvent halogenated aromatics, etc., can also have inhibitory effect on the microorganisms.

A balanced, stable pH level is important for the functioning process. Optimum pH for the anaerobic digestion process is between 6.5 and 7.5. Alkalinity is a measure of the buffering capacity and thus ability resist rapid pH changes should be at least 1000-5000 mg / liter (Norberg and Norberg, 2007, p.10-15).

Digesters’ content temperature is approximately the temperature of its surrounding environment and varies from season to season. Different anaerobic microorganisms are active at different temperature ranges. Based on the sludge temperature, sludge digestion and methane production are divided into three groups of mesophilic, thermophilic and psychrophilic. Table below shows temperature range and some characteristics of each one of these digestions (Gerardi, 2003).
Decomposition takes place faster at higher temperatures, nevertheless requires more energy to keep the temperature up (Liss, 2008, p.10).

Temperature is carefully regulated during the digestion process to keep the mesophilic or thermophilic bacteria alive (Anaerobic Digesters, n.d). Consequently, added energy is required to keep the precise temperature. So, a portion of the recovered gas can be used for this purpose. (Jarvis, 2003)

Anaerobic Digestion Process can be Batch or Continuous:

- In a Batch system substrate is added at once into the reactor and then the reactor is sealed for a certain period (retention time). Methane production starts and ends through each loading and unloading. Thus, to sustain the operation and to have a constant flow of biogas for commercial operation, it is necessary to have several reactors. If a batch reactor is opened and emptied before the process is well completed, odor issue is inevitable.

- In Continuous digestion system, substrates are constantly loaded into the digester and at the same time digestate is unloaded. This guarantees a steady biogas output. In a continuous system drastic changes in input composition should be avoided. Applying continuous digesters are better when a large scale of organic matter is aimed to be treated for biogas production (Kusch et al., 2011, p.118).

Biogas and digestate are the two valuable products resulted from an anaerobic digestion. Figure 11 shows the anaerobic digestion process.

<table>
<thead>
<tr>
<th>Type of digestion</th>
<th>Temperature (° C)</th>
<th>SRT(Days)</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesospheric</td>
<td>30–35°C</td>
<td>&gt;20</td>
<td>Municipal and industrial wastewater treatment process</td>
</tr>
<tr>
<td>Thermophilic</td>
<td>50–60°C</td>
<td>&gt;8</td>
<td>Industrial wastewater treatment plants</td>
</tr>
<tr>
<td>Psychrophilic</td>
<td>5–20°C</td>
<td>~100</td>
<td>Small-scale operations</td>
</tr>
</tbody>
</table>

Table (3). Mesophilic, Thermophilic and Psychrophilic AD (Sasse, 1988)
Biogas

Biogas consists of methane (50%–80%), carbon dioxide (20%–50%) and traces of other gases. For example, hydrogen sulphide (0–0.4%) is a useful and renewable source of energy, which can be utilized for various energy usages such as heat, combined heat and power, or as a vehicle fuel (Lantz et al., 2007). Usage of biogas derived from waste is not new. It traces back to UK’s early experiments both inside England and in its colonies. The first biogas plant was built in 1859 in India – Bombay to handle human sewage. Later on, in 1895, in Exeter, England gas was produced using sewage. The treatment facility was used to turn the street lights on. During the energy shortages in World War II, biogas was used extensively in Europe (Combs, n.d.).

The total biogas production in Sweden, in 2005 was estimated to have been about 219 million normal-cubic meters (MN m$^3$). This is Corresponding to 1286 GWh electricity. The largest amount of this biogas was produced on treatment plants and landfills. Co-digestion plants digested total of 228 167 tones substrates, of which 97 750 tons were slaughterhouse waste (42%). The remaining amount was made up of 68 149 tons of manure (30%), 34 700 tons of food waste (15%) and 27 568 tons of a variety bio waste sources (12%).

The total anaerobic digester volume was 44 500 m$^3$, and more than half of the gas produced was used by vehicle industry, while the rest was mainly used to produce heat. Biogas plants in agriculture treated a total of about 34 930 tones substrate. The majority of which (87%) consisted of manure, 30 430 tons. These plants also reportedly treated 3 500 tons of slaughterhouse waste, 600 tons of sewage sludge and 400 tons source separated bio waste (Norberg and Norberg, 2007).

Today, there is no digestion plant in Sweden that would only digest horse manure for biogas production (James Bonet, Jordbruksverket, personal communication, 2013). Horse manure is relatively untapped in Sweden and unused as a sole feedstock for anaerobic digestion. The theoretical potential to produce energy through anaerobic digestion from horse manure in Sweden is estimated to be 450 GWh per year (Liss, 2008, p.14).

6.1.10 Anaerobic digestion - Microbiology

Anerobic digestion happens through three various stages. Different types of bacteria work one after another to produce methane. The first stage is hydrolysis and acidogenesis. Polymers are converted into monomers such as glucose and amino acids through hydrolytic bacteria. These monomers are transformed into fatty acids and alcohol via acid-producing bacteria. In the second stage, Acetate-forming bacteria transform these fatty acids into hydrogen (H$_2$), CO$_2$, and acetic acid. Methanogenesis is the final stage, where methane-forming bacteria use H$_2$, CO$_2$ and acetate to generate biogas (Gerardi, 2003, p.154).

Digestate

AD feedstock contains nutrients. These nutrients are essential for plants, animals and bacterial life. These nutrients are not absorbed efficiently in animals and most of them gets excreted. The amount of nutrients in the feedstock doesn’t change after Anaerobic Digestion process.

During AD, bio-chemical changes result in altering nutrients to a more available form for the crops. For example, a part of the organic nitrogen supplied with the feedstock is converted to ammonium, although the total nitrogen content in digestate remains the same as in the
feedstock. As a result, digestate has a great potential to be used as a bio-fertilizer (Lukehurst et al., 2010, p.8). Due to organic substance degradation in the digester, the remaining digestate does not create odor.

6.1.11 Legislation

In Sweden, substrates for biogas generation are divided into three categories in Sweden. There are some special laws regarding the ways to deal with each category. Animal manure and digestate are classified under category 2. To reduce the risk of spreading seriously transmitted diseases, the basic requirement for category 2 materials is a heat treatment at 70 °C for 60 minutes. Other methods that provide an equivalent level of hygienic end product can be approved by the Board of Agriculture. If the digest undergoes this treatment it can be used as fertilizer in Sweden (Jordbruksverket, 2013).

6.1.12 Problems regarding the choice of an anaerobic digester

Operational conditions (gas composition, hydraulic retention time (HRT), oxidation-reduction potential (ORP), and volatile acid concentration) in the digester should be controlled and maintained carefully within optimum ranges, as Methane- forming bacteria are very sensitive to changes in alkalinity, pH, and temperature (Gerardi, 2003). Having a liable substrate is of a great importance when it comes to anaerobic digestion. In case of having no substrate to feed the digesters, anaerobic bacteria will die (A.Ricketts, Swab Energy, personal communication, 30 April 2013).

6.1.13 Selection of anaerobic digestion plant for Wången

As it is shown in figure 10, dry anaerobic digestion is suitable for almost all residues from farms, such as manure, crop residues and household organic wastes. So a dry anaerobic digester can be used for horse manure. Regarding the large volume of waste, a continuous dry fermentation is preferable.

SEaB Energy supplies compact and easy to install turnkey continuous anaerobic digesters (AD), which can process between 200 and 1000 tons of food and bio waste per year. The system is known as MUCKBUSTER and SEaB MB400 in the food processing and on-site catering and accommodation sectors.

In the agricultural and rural sectors, the system generates energy and can create new income. It is designed to produce between 8kWe - 55kWe electricity via a combined heat and power unit (CHPs). The system also provides PAS110 pasteurization, so that residual organic digestates can be sold as fertilizer or mulch (SWabEnergy).

The system is designed to be fully automated; it feeds itself as long as the hopper is filled. If pH dosing is required, the system will add the mix to fix it. In case of using horse manure no pH dosing is required because horse manure is neither pH acidic nor. Digester has remote dial in equipment that provides controllers with pressures, temperatures and levels (A.Ricketts, Swab energy, personal communication, 4 May 2013). Therefore, in case any problem arises, the system can adjust itself.

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10 This legislation only applies if the substrate originates from more than three different farms.
Two anaerobic digesters with 240 m$^3$ reactor capacity are needed to handle the manure in Wången case. These two digesters are then need to be connected to a 40 kW CHP plant which can provide the school with both heat and electricity.

### 6.1.14 System description

Different parts of Muckbuster anaerobic digester is shown in figure (12). As the figure shows, section (1) is first fed with the horse manure and bedding material, where they can be chopped and mixed for a better fermentation effect. During the next stage, manure paste transfers to section (2) to pasteurize. Pasteurization is part of the process creating a good methane quality at a fast rate and providing the user with a certified$^{11}$ fertilizer and mulch. This sector consumes 65%-75% of all the heat produced in the process and 5%-10% of the produced electricity.

During the next stage, substrate fills section (3), where Mesospheric methane forming bacteria turns organic matter to methane at a constant temperature of 35°C. Once the operation starts, it takes two days to generate the first gas production. The methane formation process takes place in a continuous mode. The produced biogas will be burned in a CHP plant (Combined Heat and Power Plant), to generate heat and electricity. The remained pasteurized mulch is then loaded to the section five, where it leaves$^{12}$ the machine constantly via the dewatering device. A collection hopper is needed to sit in front of the outlet pipe to collect the mulch, which is ready to be used as soil amendment after a certain period of time$^{13}$.

![Figure (12). Anaerobic digester technical details (SWabEnergy)](image_url)

### 6.1.15 Horse manure as raw material in AD

According to M. Liss’ report (2008), Steineck et al. (2001) present data from their experiment with composting horse manure, which was conducted in Wången during October 1998 - May 1999. The composting experiments included manure, and wood shavings and hay as bedding material. The manure had a TS + content of 32% and a carbon / nitrogen ratio of 59.

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$^{11}$ Regarding category 3 regulation

$^{12}$ It takes 15 days since the loading date

$^{13}$ Depending of different regulations in different countries
Today, Wången uses wood shavings as bedding material (L. van den Brink, personal communication, 15 April 2013). Moreover, each manure heap can vary in characteristics based on the amount of bedding material in the pile. The figures from this experiment cannot be applied completely but give a general idea about the characteristics of the product.

6.1.16 Calculated gas production

The methane gain depends on several factors such as the digestion time and degradation kinetics (influenced by substrate characteristics and process conditions). The total methane potential G\textsubscript{pot} can be determined by optimized batch testing, which should include extrapolation of the experimental findings (Kusch et al., 2011). In order to reach this, the amount of TS and VS of horse manure should be determined in laboratory. Since there was no possibility to do an experiment on stall waste composition in Wången to obtain the TS and VS value, these values are adopted from other studies (30% TS and 75% VS of TS%).

Horse manure often consists of very long straw that is difficult to manage, resulting in a rather low biogas output. Kreuger et al. (2006) presents such attempt where the biogas yield for horse manure was 120 Nm\textsuperscript{3} CH\textsubscript{4}/ton VS laboratory scale, but only 50 Nm\textsuperscript{3} CH\textsubscript{4} in hydrolysis reactor in pilot scale. The low biogas yield in pilot scale is thought to be due to the manure possibly stored for long time without coverage and existence of long straw.

Experiments in hydrolysis reactor laboratory scale, which gave 146 Nm\textsuperscript{3} per tons dry mater in 42 days of anaerobic digestion (Kusch, 2008), is consistent with the approximately 150 Nm\textsuperscript{3} CH\textsubscript{4} / ton TS at 40 days reported by Nilsson (2000), while indicates Kusch (2008) the yield after 100 days on a laboratory scale was as high as 247 Nm\textsuperscript{3} CH\textsubscript{4} / ton TS.

To get a more accurate result for methane gas yield, sample digestion from Wångens horse manure should be examined. Based on Norberg and Norberg, 2007, Rylander and Wiqvist, 2008 report, a simple calculation can be made to estimate the amount of methane production. The results are shown in the table below. A reasonable methane yield based on the horse manure, stored uncovered and not atomized before digestion, is considered to be 120 N m\textsuperscript{3} CH\textsubscript{4} /ton TS (Rylander and Wiqvist, 2008). However, according to A. Ricketts (personal communication, 5 May 2013), the biogas yield of 2400 m\textsuperscript{3} horse manure and bedding material would be around 17.5 m\textsuperscript{3} per hour, which is producing an annual yield of 113 400 m\textsuperscript{3} biogas per annum (73 710 m\textsuperscript{3} methane at 65 % methane share in biogas). This yield can only be possible with 386 m\textsuperscript{3} CH\textsubscript{4} / ton VS, which is a quite high number. This value couldn’t be found in any experimental studies\textsuperscript{14}.

<table>
<thead>
<tr>
<th>Substrate volume(m3)</th>
<th>Substrate density(kg/m3)</th>
<th>Total substrate weight(tone)</th>
<th>TS %</th>
<th>VS of TS %</th>
<th>VS (tone)</th>
<th>Methane production Nm\textsuperscript{3}/ton VS</th>
<th>Methane yield m\textsuperscript{3}</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 400</td>
<td>350</td>
<td>840</td>
<td>30</td>
<td>75</td>
<td>189</td>
<td>120</td>
<td>22 680\textsuperscript{14}</td>
</tr>
<tr>
<td>2 400</td>
<td>350</td>
<td>840</td>
<td>30</td>
<td>75</td>
<td>189</td>
<td>390</td>
<td>73 710\textsuperscript{2}</td>
</tr>
</tbody>
</table>

\textsuperscript{14} From now on only the provided value by the company is used.

---

\textsuperscript{1} Methane yield base on Rylander and Wiqvist (2008)
\textsuperscript{2} Methane yield predicted by SWab Energy (A.Ricketts, Swab Energy, personal communication, 30 April 2013)
6.1.17 Calculated heat and power production

Biogas comprises two main compositions, Carbon dioxide and Methane. The percentage of carbon dioxide and methane vary based on the substrate contents. During anaerobic digestion, a large part of the energy contained in the biomass is transformed into methane, an energy carrier, which has a wide variety of possible applications. The most common usages are listed below (Kusch et al., 2011, p. 116):

- Cooking and lighting purposes (small-scale AD plants at household level, common in rural areas in developing countries)
- Heat generation
- Electricity generation which is often accompanied by heat generation in combined heat and power plants/ CHP)
- Fuel for cars/vehicles
- Feeding into the natural gas grid (it needs upgrading to natural gas quality)

The most efficient and possible usage of biogas for Wången seems to be heat and power generation in a CHP plant.

In Sweden, biogas, which is used for energy generation in combined heat and power plants, provides 1/3 electricity and 2/3 of the thermal energy (Liss, 2008, p. 16).

With 9.97kWh/ Nm$^3$ (Basic data on Biogas, 2012) methane energy density (the energy content of upgraded methane based on the calculated proportion of methane in biogas), it is expected to gain 23 833 kWh per month in the form of electricity and 13 241 kWh in the form of thermal energy\textsuperscript{15}.

Biogas combustion can only meet 10 % of the heating demand and 46% of the Wången’s other energy demands during the nine months of operation (see Appendix 7).

<table>
<thead>
<tr>
<th>Methane yield /month</th>
<th>Methane energy content kWh/m3</th>
<th>Total gained energy kWh</th>
<th>Gained electricity</th>
<th>Gained heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 190</td>
<td>~10</td>
<td>79 443</td>
<td>23 833</td>
<td>13 241</td>
</tr>
</tbody>
</table>

Table (5). Calculated CHP gain heat and electricity of burning biogas in each month

6.1.18 Anaerobic digestion and the environment

Anaerobic digestion provides renewable energy and contributes to the sustainable management of waste through the ability of utilizing organic waste and transforming it into a source of energy.

Production of biogas can help to reduce greenhouse gases. This is partly because fossil fuels are replaced with biogas\textsuperscript{16} and also because the spontaneous methane emission from conventional methods for manure gathering will be reduced (Jordbruksverket, 2013).

\textsuperscript{15} 65%-75% heat and 5%-10% electricity deduction (reactor energy consumption) is calculated here.

\textsuperscript{16} combustion of biogas produces no net addition of carbon dioxide to the atmosphere, due to the fact that carbon content in the biogas originating from atmospheric carbon dioxide

If remained sludge, which is enriched with nutrients, is in conformation with the regulations regarding sanitation of the digest in Sweden, it can be used as soil amendments in farms.

According to Schäfer et al. (2006), storage of solid manure heaps can result in nitrous oxide and methane emissions. Anaerobic digestion of daily produced solid manure would reduce these emissions.

6.1.18.1 Global warming potential

NO\textsubscript{X} and CO are the two main emissions resulted from biogas burning in a CHP plant (see Appendix 5). None of these gases have a global warming potential. CO\textsubscript{2} is filtered during the process. And in case of release, it would not contribute to the global warming due to the carbon content in the biogas originating from atmospheric carbon dioxide.

However, we can say that biogas production in some way, with capturing the methane can mitigate global warming. This methane could be emitted to atmosphere if the manure left untreated.

6.1.18.2 Acidification

At 5% oxygen, only 500mg/Nm\textsuperscript{3} of NO\textsubscript{X} (acidifying gas) is emitted from biogas combustion in a CHP plant. This amount compared to the acidifying gas emissions from a bio burner is trivial.

![](image)

**Figure (13).** Biogas CHP plant acidification potential in gSO\textsubscript{2} eqv / year
6.1.19 Digestate usage

Depending on the volume of wood bedding used, the manure will be reduced to 20%-30% of its original volume. The bedding volume will not be reduced (A. Ricketts, Swab Energy, personal communication, 2013).

As mentioned in previous sections, digestate is rich in nutrient and can be used as fertilizer. Nevertheless, like other crop fertilizers, if it is applied during autumn and winter when there is little plant uptake, nutrient leaching and runoff into the ground and surfacewaters is inevitable. Digestate must therefore be stored until the right time for application.

Each country has set some regulating limits to adjust nitrogen loading on farmlands. In Sweden, required storage time for digestate is 6–10 months (Lukehurst et al., 2010, p.9-11).

Storing digestates, such as manure, in open tanks, can result in ammonia and methane emission. Therefor by covering the surface of digestate in a storage tank using protective layers such as plastic pieces, clay pebbles or chopped straw, etc., these emissions can be reduced (Lukehurst et al., 2010, p.9-11).

In an email on 29 April 2013 A. Ricketts stated that the digestate also can be used as bedding material if it is left to dry up. However, the feasibility of using digestate as bedding material according to Swedish regulations has not been studied here.

6.1.20 Economy

Total capital cost for starting a biogas plant, including shipping and application fee, is evaluated to be about 4 million SEK, which can be paid off in almost 24 years.

Full operating cost, including parts and labor for anaerobic digesters for one year, is estimated to be 263 219 SEK by the company. Since labor cost for the heating plant has been excluded in this study, to have a more reliable comparison between two systems, half of the estimated operating cost is used for calculation. Since reactor energy demand is provided by its own energy generation (5%-10% electricity and 65%-75% heat), the energy consumption has already been deducted from the generated energy. The provided figures are the expected captured heat and electricity.

After the pay-off period, Wången purchased a total of 306 180 kWh less energy annually (about 300 000 SEK less per year).

17 This value is equivalent to 26 000 GBP.
Total costs (SEK) | kWh | Electricity price SEK/kWh
---|---|---
**Capital costs**
AD plant + CHP plant | 4 043 928 | 5 kWh per kWh
Application fee | 9 000 | 6 kWh per kWh
Shipping | 141 537 | 7 kWh per kWh
**Total capital costs** | 4 194 465 | 4 kWh per kWh

**Operating costs SEK/ year**
AD plant + CHP plant (full service including parts) | 131 609 | 1 kWh per kWh
**Total operating costs** | 131 609 | 1 kWh per kWh

Energy purchase avoidance

<table>
<thead>
<tr>
<th>kWh energy in the form of heat (kWh)</th>
<th>kWh energy consumption in Wängen for heating purposes</th>
<th>kWh electricity consumption in Wängen</th>
<th>kWh heat deficiency</th>
<th>kWh el deficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>119 165</td>
<td>333 661</td>
<td>-168 555</td>
<td>-469 854</td>
</tr>
<tr>
<td>Electricity</td>
<td>214 496</td>
<td>1 752 868</td>
<td>-1 023 791</td>
<td>-255 358</td>
</tr>
</tbody>
</table>

**Payoff period (years)**
21

Table (6). Capital and operating cost for biogas plant

7 Discussion

Heat and electricity generation comparison

As Table (7) shows horse dung and bedding material have a potential to produce 974 400 kWh and 119 165 kWh of heat in an incineration and a biogas plant, respectively.

Table (7). A Comparison between heat and electricity generated in two systems in 9 months
Biogas can only meet 10% \(^{18}\) of heat and 46% of electricity consumption in nine months operation, while a heating plant in case of a good management of surplus stall wastes during April-October can cover up to 85% of heating demand (Table 8). This high percentage of heat coverage is of great importance for Wången’s case where 65% of total energy consumption is to fulfill their heating demand. Figures 14 and 15 illustrate the gained energy from both plants and Wången’s energy demand.

\[ 
\text{Biogas} 
\]

![Biogas chart](image1)

Figure(14). Summary of energy production in a CHP plant and Wången energy demand

\[ 
\text{Heating plant} 
\]

![Heating plant chart](image2)

Figure (15). Summary of energy production in a heating plant and Wången energy demand

\(^{18}\) It is mostly due to reactor’s high heat consumption in pasteurization process for a better Methane quality at a fast rate
The percentage of energy usage for heating purposes from June- August is calculated to be 22 % of total energy consumption in that period. See Appendix 8.

Environment

None of these systems showed any greenhouse gas emissions during their operations, although acidifying emissions (mostly NO\textsubscript{X}) have been seen in both systems. Combusting horse manure in the furnace however, showed more NO\textsubscript{X} emissions compared to that of biogas burning in a CHP plant. This created a more acidification potential compared with that of a heating plant (see Appendix 6).

![Acidification potential comparison](image)

**Acidification potential comparison**

The NO\textsubscript{X} emissions from the heating plant can be justified if transporting manure to a heating plant center (as the only remained solution to deal with the manure problem) come into consideration.

Two such facilities can be chosen for this purpose (Jonas Hasselstam, Jämtkraft, personal communication, 3 June 2013).

- **Lungvik heating plant in Östersund**

  Biomass (mostly fleece) is the main burning substrate in this facility. As a result of the high moisture content and different energy capacity (compared to fleece) of horse manure, burning stall waste in this facility has never been practiced. Further study is needed to investigate the feasibility of burning manure in this plant.
• **Korsta Verken plant in Sundsvall**

The possibility of burning manure in this plant is more probable. All the burnable waste in Östersund is transported to Korsta Verken plant to be burned. However burning manure in this facility has never been practiced.

Investigating the contribution of transporting stall waste to these two facilities to global warming and acidification potential is out of the scope of this study.

**Byproducts**

**Digestate**

Digestion process causes the manure volume to be reduced to 20%-30% of its original volume. However, the bedding material volume will not be reduced. Assuming that the substrate has manure and bedding material portion with 2:1 ratio, there is still 4.8 m$^3$ effluents per day or 1296 m$^3$ per annum. Moreover, according to Swedish regulations, digestate needs to rest for a period of 6–10 months to be allowed to be used as fertilizer.

**Ash**

About 2%-4% of the stall waste’s volume turns into ash (M. Jansson, SWEBO, personal communication, 13 May 2013). This provides about 0.36 m$^3$ ash residues per day or 97 m$^3$ per year, which is almost 5% of the waste’s volume. If ash passes the heavy metal prevailing limit in Sweden, it can be used as both forest and farm fertilizer without storage time limitation.

**Manure load as substrate**

Accessible manure for nine month per year (during winter), makes stall wastes a reliable substrate for heating plant. Almost 85% of energy needed for heating purposes can be acquired by burning horse manure and bedding material during winter.

On the other hand, anaerobic digesters need to have a reliable load the whole year; otherwise, microbial activity stops (A. Ricketts, Swab Energy, personal communication, 25 April 2013). A reliable substrate can be obtained by the help of sewage and slurry form toilets in Wången, however, this substrate shift’ compatibility with the Swedish regulations must be studied.

**Economy**

Table (9) shows a comparative summary of economic aspects of the two reactors. The initial capital for system establishment is almost the same. However, the huge difference between the energy outputs of the digesters has resulted in a longer payback period for the biogas reactor and huge difference between the avoided purchased energy.

---

19 Toilete sewage is now stored in tanks with the capacity of 30 m$^3$ outside the Wången, and a company is hired to empty the storage tanks four times per year.
Table 9. Economic comparison heating plant vs. anaerobic digester

<table>
<thead>
<tr>
<th></th>
<th>Initial capital SEK</th>
<th>Payback period (year)</th>
<th>Avoided energy purchased after payback period (kWh)</th>
<th>Operation costs (SEK/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating plant</td>
<td>~4 000 000</td>
<td>5</td>
<td>835 200</td>
<td>64 800</td>
</tr>
<tr>
<td>Biogas</td>
<td>~4 000 000</td>
<td>21</td>
<td>333 661</td>
<td>131 609</td>
</tr>
</tbody>
</table>

8 Conclusion

By investing almost 4 million SEK in a heating plant for combustion of stall waste, Wången trotting school can on one hand meet 85% of their heating demand during the peak need of electricity for heating purposes facilities, and on the other hand, decrease the waste volume to 5% of its original volume. Nonetheless, compared to the biogas plant, the heating plant has more acidification potential.

Wången is located in Mid Sweden, where heat is a valuable product during winter. As mentioned before, Wången uses 65% of the purchased electricity for heating purposes while an anaerobic digester uses 65%-75% of its produced heat for having a better quality Methane yield at a fast rate. This means that an anaerobic digester can provide only 10% of Wången’s heating demand.

Now, the question is whether digestate is valuable enough to compensate the amount of consumed heat after a 6-10 months storage period, or not.20

Due to the fact that Wången is an educational center, having a clean and nice environment is of great importance to Wången. Between these two possible options, heating plant can meet the demand by combusting manure with reducing the effluent volume in a faster and more efficient way.

9 Suggestion to Wången School

Since the heating plant is equipped with a pellet storage, considering wooden pellet burning when there is no access to the accumulated stall waste can be an option to reduce the electricity purchase for heating purposes when it is needed.

Table below shows that about 100 tons of manure need to be stored for Wången to avoid the surplus heat and in April, May, September and October and be able to obtain almost 85% of their heat demand from horse manure. It is also evaluated in case of not using the surplus manure Wången needs to buy 65 tons of pellet during their peak heat consumption, which is estimated to cost 130 869 SEK (Fuel cost per kWh, 2011). This means 182 838 SEK less electricity purchase for heating purposes per year. In case of efficient usage of surplus manure this saving reaches 243 239 SEK per year.

20 Today (2013), Wången has no need for digestate. In case of manure handling by another company, transportation emissions need to be considered.
<table>
<thead>
<tr>
<th>Month</th>
<th>Heat need (Ton)</th>
<th>Pellet need with saved manure (Ton)</th>
<th>SEK</th>
<th>Manure saving (Ton)</th>
<th>SEK</th>
<th>Pellet needed with saved manure (Ton)</th>
<th>SEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>-96 848</td>
<td>20</td>
<td>40 267</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb</td>
<td>-90 527</td>
<td>19</td>
<td>38 254</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>-28 999</td>
<td>6</td>
<td>12 080</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>21 338</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>55 821</td>
<td></td>
<td></td>
<td>38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>September</td>
<td>61 958</td>
<td></td>
<td></td>
<td>43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>October</td>
<td>6 036</td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>November</td>
<td>-6 766</td>
<td>1</td>
<td>2 013</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>-90,565</td>
<td>19</td>
<td>38 254</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-313 707</td>
<td>65</td>
<td>130 869</td>
<td>100</td>
<td>35</td>
<td>70 468</td>
<td></td>
</tr>
</tbody>
</table>

Table (10). Calculated saved manure and pellet need
10 Reference


BIOTHERM, S. 2012. SWEBO BIO THERM - Yesterdays residues are today’s fuel.


SWABENERGY MUCKBUSTER® Brochure.


Appendices

Appendix 0: Heating value of some common fuels (Heat Values of various fuels, 2010)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>kWh/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol/gasoline</td>
<td>12.2</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>12.5</td>
</tr>
<tr>
<td>Crude oil</td>
<td>11.6</td>
</tr>
<tr>
<td>Methanol</td>
<td>5.56</td>
</tr>
<tr>
<td>Liquefied Petroleum Gas(LPG)</td>
<td>13.6</td>
</tr>
<tr>
<td>Natural gas(UK,USA, Australia)</td>
<td>10.5</td>
</tr>
<tr>
<td>Fire wood(dry)</td>
<td>4.44</td>
</tr>
</tbody>
</table>

Appendix 1: Wången energy consumption from 2006

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy consumption kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>1 740 201</td>
</tr>
<tr>
<td>2007</td>
<td>1 831 499</td>
</tr>
<tr>
<td>2008</td>
<td>1 808 008</td>
</tr>
<tr>
<td>2009</td>
<td>1 812 939</td>
</tr>
<tr>
<td>2010</td>
<td>2 021 335</td>
</tr>
<tr>
<td>2011</td>
<td>1 646 596</td>
</tr>
<tr>
<td>2012</td>
<td>1 825 540</td>
</tr>
</tbody>
</table>

Appendix 2: Energy consumption in Wången (2009)

<table>
<thead>
<tr>
<th>Month</th>
<th>Energy consumption kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>257 321</td>
</tr>
<tr>
<td>Feb</td>
<td>251 000</td>
</tr>
<tr>
<td>Mars</td>
<td>189 472</td>
</tr>
<tr>
<td>April</td>
<td>139 135</td>
</tr>
<tr>
<td>May</td>
<td>104 652</td>
</tr>
<tr>
<td>June</td>
<td>80 198</td>
</tr>
<tr>
<td>July</td>
<td>52 206</td>
</tr>
<tr>
<td>Agust</td>
<td>67 726</td>
</tr>
<tr>
<td>September</td>
<td>98 515</td>
</tr>
<tr>
<td>October</td>
<td>154 437</td>
</tr>
<tr>
<td>November</td>
<td>167 239</td>
</tr>
</tbody>
</table>
**Appendix 3: Share of electricity usage for heat and other purposes than heating**

<table>
<thead>
<tr>
<th>Month</th>
<th>Energy consumption kWh</th>
<th>Heating kWh</th>
<th>Other kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>257 321</td>
<td>205 115</td>
<td>52 206</td>
</tr>
<tr>
<td>Feb</td>
<td>251 000</td>
<td>198 794</td>
<td>52 206</td>
</tr>
<tr>
<td>Mars</td>
<td>189 472</td>
<td>137 266</td>
<td>52 206</td>
</tr>
<tr>
<td>April</td>
<td>139 135</td>
<td>86 929</td>
<td>52 206</td>
</tr>
<tr>
<td>May</td>
<td>104 652</td>
<td>52 446</td>
<td>52 206</td>
</tr>
<tr>
<td>June</td>
<td>80 198</td>
<td>27 992</td>
<td>52 206</td>
</tr>
<tr>
<td>July</td>
<td>52 206</td>
<td>0</td>
<td>52 206</td>
</tr>
<tr>
<td>August</td>
<td>67 726</td>
<td>15 520</td>
<td>52 206</td>
</tr>
<tr>
<td>September</td>
<td>98 515</td>
<td>46 309</td>
<td>52 206</td>
</tr>
<tr>
<td>October</td>
<td>154 437</td>
<td>102 231</td>
<td>52 206</td>
</tr>
<tr>
<td>November</td>
<td>167 239</td>
<td>115 033</td>
<td>52 206</td>
</tr>
<tr>
<td>December</td>
<td>251 038</td>
<td>198 832</td>
<td>52 206</td>
</tr>
<tr>
<td>Total</td>
<td>1 812 939</td>
<td>1 186 467</td>
<td>626 472</td>
</tr>
</tbody>
</table>

**Appendix 4: Emission during operation of a heating plant**

<table>
<thead>
<tr>
<th>Emission mg/kWh</th>
<th>NOx(as NO\textsubscript{2})</th>
<th>SO\textsubscript{2}</th>
<th>HCL</th>
<th>CO</th>
<th>TOC(total organic carbon)</th>
<th>Dust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating plant</td>
<td>689.29</td>
<td>53.57</td>
<td>89.29</td>
<td>225</td>
<td>1.43</td>
<td>325</td>
</tr>
</tbody>
</table>

**Appendix 5: Emission during operation of a CHP plant**

<table>
<thead>
<tr>
<th>Emission mg/Nm3</th>
<th>NO\textsubscript{x} (as NO\textsubscript{2})</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas CHP plant</td>
<td>500</td>
<td>650</td>
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</tbody>
</table>

**Appendix 6: Acidification potential**

<table>
<thead>
<tr>
<th>Emission ( g SO\textsubscript{2} eqv/year)</th>
<th>SO\textsubscript{2}</th>
<th>HCL</th>
<th>NO\textsubscript{x} (as NO\textsubscript{2})</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating plant</td>
<td>52 200</td>
<td>76 560</td>
<td>470 148</td>
<td>598 908</td>
</tr>
<tr>
<td>Biogas CHP plant</td>
<td>25 799</td>
<td></td>
<td>25 799</td>
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</tr>
</tbody>
</table>
Appendix 7: Energy gain

<table>
<thead>
<tr>
<th></th>
<th>Energy consumption kWh</th>
<th>Energy for heating and warm water kWh</th>
<th>Energy for other purposes than heat kWh</th>
<th>Gained electricity kWh</th>
<th>Gained heat kWh</th>
<th>Electricity need kWh</th>
<th>Heat need kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>25 7321</td>
<td>205 115</td>
<td>52 206</td>
<td>23 833</td>
<td>13 241</td>
<td>-28 373</td>
<td>-191 875</td>
</tr>
<tr>
<td>Feb</td>
<td>251 000</td>
<td>198 794</td>
<td>52 206</td>
<td>23 833</td>
<td>13 241</td>
<td>-28 373</td>
<td>-185 554</td>
</tr>
<tr>
<td>Mars</td>
<td>189 472</td>
<td>137 266</td>
<td>52 206</td>
<td>23 833</td>
<td>13 241</td>
<td>-28 373</td>
<td>-124 026</td>
</tr>
<tr>
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<td>139 135</td>
<td>86 929</td>
<td>52 206</td>
<td>23 833</td>
<td>13 241</td>
<td>-28 373</td>
<td>-73 689</td>
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<td>52 446</td>
<td>52 206</td>
<td>23 833</td>
<td>13 241</td>
<td>-28 373</td>
<td>-39 206</td>
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<td>98 515</td>
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<td>52 206</td>
<td>23 833</td>
<td>13 241</td>
<td>-28 373</td>
<td>-33 069</td>
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<td>October</td>
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<td>-28 373</td>
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<td>November</td>
<td>167 239</td>
<td>115 033</td>
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<td>13 241</td>
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<td>-101 793</td>
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<td>251 038</td>
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<td>52 206</td>
<td>23 833</td>
<td>13 241</td>
<td>-28 373</td>
<td>-185 592</td>
</tr>
<tr>
<td>Total</td>
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<td>1 142 955</td>
<td>469 854</td>
<td>214 496</td>
<td>119 165</td>
<td>-255 358</td>
<td>-1 023 791</td>
</tr>
<tr>
<td>% of total consumption</td>
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<td>10</td>
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</table>

Appendix 8: Energy consumption from June until August

<table>
<thead>
<tr>
<th>Month</th>
<th>Energy consumption kWh</th>
<th>Heat kWh</th>
<th>Electricity kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>80 198</td>
<td>27 992</td>
<td>52 206</td>
</tr>
<tr>
<td>July</td>
<td>52 206</td>
<td>0</td>
<td>52 206</td>
</tr>
<tr>
<td>August</td>
<td>67 726</td>
<td>15 520</td>
<td>52 206</td>
</tr>
<tr>
<td>Total</td>
<td>200 130</td>
<td>43 512</td>
<td>156 618</td>
</tr>
<tr>
<td>% of total consumption</td>
<td>22</td>
<td>78</td>
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</tr>
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</table>