FEASIBILITY STUDY FOR THE UNIVERSITY OF TWENTE CAMPUS CLOSED WATER CYCLE

SECTION: FEASIBILITY STUDY FOR USE OF SUSTAINABLE ENERGY FROM WASTEWATER SLUDGE AND POSSIBILITIES OF WASTEWATER SLUDGE REUSE

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Summary

This study is focused on application routes of biogas from anaerobic fermentation of the wastewater flow from the University of Twente in an up-flow anaerobic sludge blanket (UASB) reactor. Approximate biogas production per day is calculated and suggestion on needed UASB reactor set is provided.

The biogas application routes via boilers, fuel cell unit, combined heat and power unit are assessed, as well as possibilities of the biogas injection to existing natural gas supplying grid. Digested sludge treatment possibilities are also observed. Price comparison of different ways of the biogas application is made and best solutions are indicated.

Educational possibilities over the project are indicated as well.

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CHAPTER 1 Project short description

The University of Twente together with Waterschap Regge & Dinkel intends to assess the feasibility of closing the water cycle of the campus of the University. The reason is the high energy costs for pumping the wastewater from the campus to the off-site wastewater treatment plant. Moreover, a possibility to generate sustainable energy inside the campus from the wastewater is of interest now. Three potential scenarios were developed during the quick scan by DHV [1]:

- In 1st scenario, the current situation of water treatment is considered to stay the same with consideration of water consumption reduction measures and rain water lock-in in the campus, and the balance point between replacement and maintenance of the existing pumping station of Regge & Dinkel to maintain the current situation.

- In 2nd scenario the wastewater treatment plant, consisting of an anaerobic reactor (UASB) and membrane reactor MBR, is aimed to be located in the campus of the University in order to reduce the costs of pumping the wastewater to the Regge & Dinkel treatment plant located nearby. Annual savings on pumping costs are estimated to be € 180 000/year.

- In 3d scenario (till 2030) the wastewater treatment plant with an anaerobic reactor (UASB) is planned to be located in the campus as well, with aim to make a positive contribution to human health and the environment. Here the waste separation is very important, where the nutrients and phosphates are recovered from liquid wastes, and energy produced from ammonia through the Fuel Cell unit, as well as biogas produced after the treatment of the black water in the UASB. This will allow reduction of the energy costs on pumping to the Regge & Dinkel treatment plant, as well as, possibly, produce electrical energy from fuel cell unit, and thermal energy for domestic needs in the campus.

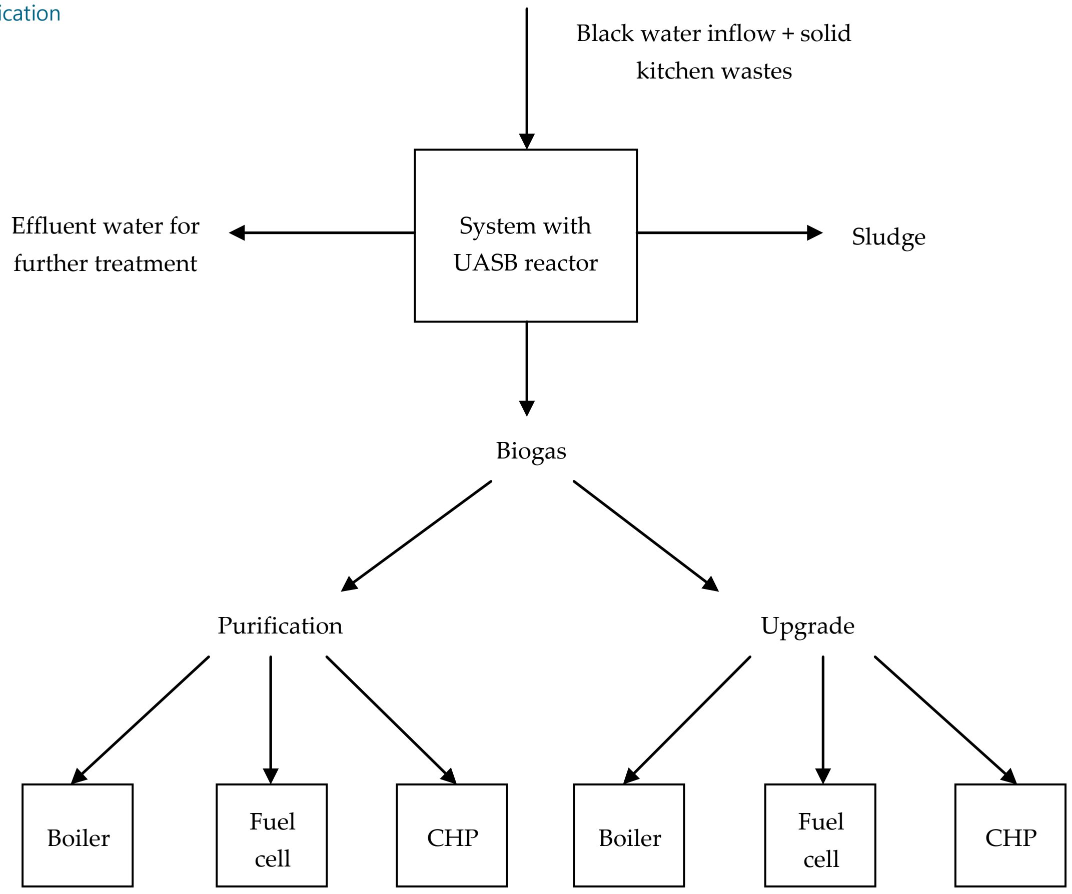
This study assesses the feasibility of sustainable energy generation from the biomass of the black water, as well as possibilities of utilization of the wastewater products, such as digested sludge. The study includes different steps from 2nd and 3d scenarios for biogas application, produced from the black water.

1.1 CURRENT STUDY RESEARCH TOPICS

Current study focuses on application routes of the biogas produced from anaerobic digestion of concentrated black water in a system using UASB reactor.

Generalized flow chart of the wastewater treatment plant is shown on Figure 1.1.

Figure 1.1
Generalized scheme of the waste water treatment plant with biogas application routes



The UASB reactor is constructed with 3-phase separation system, which allows to separate output products into digested sludge, effluent water and biogas. Effluent water is then must be treated further in order to obtain clean water for reuse and also to extract valuable nutrients from it. Current study does not focus on effluent water, but focuses on biogas application routes and sludge disposal. Biogas produced has to be studied from different perspectives of application and best feasible option has to be indicated. Based on this, current study includes several research questions:

- Produced biogas from the sludge of the waste water has to be studied as an energy source for the operation of the waste water treatment plant itself.

Approach and explanation: As it is proposed by the scenarios 2 and 3 of the DHV quick scan, UASB reactor is an option to consider for horizon model till 2030. Produced biogas in this study has to be studied as a source of heat supply to the reactor in order to reduce energy consumption of the whole plant, since the reactor, depending on weather conditions, needs additional heat to be supplied to maintain digestion temperatures.

- Biogas purification methods and biogas upgrade till natural gas quality has to be overviewed for application in different appliances.

  Approach and explanation: produced biogas from anaerobic digestion contain some impurities which can harm metal appliances and reduce calorific value of the biogas. Different methods of biogas purification and upgrade has to be overviewed and best option among them has to be indicated in this study.

- Produced biogas will be studied as an option for heating facilities in the University with application of gas-fired boilers.

  Approach and explanation: Gas-fired boilers will be reviewed in order to suggest the type of the boiler to produce certain amount of heat from available biogas from the treatment plant. Currently, biogas applied a lot in applicable boilers and the heat produced can be properly utilized in space heating facilities or hot water supply facilities. In case of the University of Twente, heat produced from the biogas application in boilers can be utilized directly on campus buildings or student houses and bring additional capital savings with this.

- Possibilities of supplying of produced biogas to the existing grid of pipelines (with possible upgrade to natural gas quality).

  Approach and explanation: Biogas injection to the natural gas supplying pipe to the University is desired to be overviewed as an option to reduce natural gas consumption by the University. Biogas has to be upgraded till pure methane content for injection possibility.

- Possibilities of electricity generation on site from the fuel cell unit operating on biogas/methane.

  Approach and explanation: Produced biogas can be utilized in certain types of fuel cells and electricity production is possible in this case. This electricity can be then utilized on site in campus. Observation of the type of fuel cells operating on biogas/methane will be done, as well as its operational condition and amount of electricity possible to produce from certain amount of biogas supplied.

- Electricity and heat generation via combined heat and power (CHP) generation units will be studied as well, as produced biogas could be an option to run such CHP units. Produced electricity and heat can be utilized in the University, or supplied to existing grid.

  Approach and explanation: current energy market offers modern CHP units which can operate on biogas or methane, in the output electricity and heat are possible to obtain. CHP units operating on biogas have to be assessed. Produced electricity and heat will be utilized on site in campus to cover a part of existing electrical and heat energy consumption.

- Processed sludge after biogas production will be studied on possibilities of being composted for use on site.

  Approach and explanation: Studies on the possibilities of the sludge, remaining at the treatment plant after biogas production, of being converted (composted) for use as an addition to fertilizers, will be evaluated for use in the campus or for sale. The sludge most of the time incinerated, however it could be a valuable by-product of the treatment process and there may be other ways of sludge treatment or disposal.

- Approximate costs of each of the options will be estimated. Based on the results obtained, proposals on most feasible option will be generated for further development.

Depending on uncertainties and needs which may occur during the study of described options, the approach to solve the questions can be changed during the study.

1.2 EXPECTED OUTCOMES

The report includes:

- Options of utilization of the biogas for supplying heat to the UASB reactor of the wastewater treatment plant on the campus.
- Options of utilization of the biogas for heating systems on campus.
- Feasibility of upgrading and supply of the biogas to the grid.
- Applicability of a fuel cell unit running on biogas/methane.
- Electricity and heat generation possibility via CHP unit and electricity supply.
- Rough costs of each of the options above are calculated.

In addition to the current report, Microsoft Excel general table was organized for different technical applications for biogas utilization, overviewed in this study. Depending on certain variables, like number of residents, power outputs of different appliances, other end values are changed. The table is provided in separate file with this report.

CHAPTER 2 UASB reactor for black water treatment

By the general data for the wastewater flows in urban residential areas, the rough average daily wastewater flow per capita is estimated to be 365 liters/day [2]. Assuming that there are 4000 residents in the University at the same time during the day [1], wastewater flow in the University is estimated to be about 1 460 000 liters/day (1460 m^3/day). However, according to DHV quickscan report, average wastewater flow pumped from the campus to the Regge& Dinkel treatment plant is 800 m^3/day. This means that average combined wastewater flow (grey, black and rain water) in the campus is around 200 l/p/d. This can be explained that there are mostly student houses with several students living in the same house and the water consumption in this case is less than if one student would live in one house.

Up-flow anaerobic sludge blanket (UASB) reactor technology is considered as a possible option for application in the wastewater treatment plant on the campus of the University of Twente in the future [1]. It is also considered to be one of the most economic options for anaerobic fermentation of the wastewater [3].

Advantages of the UASB reactors over normal anaerobic digesters are stated as following: low energy requirement for operation, low maintenance and operation costs, lower skills required for control and supervision of operation, less sludge production, possibility of resource recovery in the form of methane-reach biogas and stabilized sludge production [3].

For the estimation of the biogas production from the UASB reactor and its constant yield, it is first necessary to indicate that the wastewater flow should be separated to black and grey water. The black water is then fed into the UASB reactor for treatment. Currently, the wastewater flow in the University is a mix of grey, black and rain water, and is not prepared for separated treatment. However, for consideration in the future scenarios, all new constructing/renovating buildings on the campus have to be designed with black and grey water separation facilities, like vacuum toilets and separated piping systems. In the long term, wastewater separation systems has to be implemented in all buildings in the campus.

However, current black water concentrations in the Netherlands are appeared to be low for efficient treatment in UASB reactors, which makes UASB technology not yet suitable enough for broad applications in the Netherlands. With this perspective, and also due to small projected wastewater flow in the campus only, possibilities of additional wastewater suppliers attraction has to be considered. Relatively small amount of biogas production comes from low volumes of the black water supplied to the UASB reactor. Such actors like FC Twente located on South-West from the University, and Companies and Organizations located in the Business and Science Park of Twente, restaurants with kitchen wastes, can be considered as wastewater and solid kitchen refuses contributors for future wastewater treatment plant in the University. These actors could treat their wastewaters, and the University would gain additional benefit from processing of increased volumes of grey and black water.

2.1 APPROXIMATE BIOGAS PRODUCTION YIELD, REACTOR VOLUME AND PRICE

Based on the related study [4], the approximation to a given state of the biogas production from the domestic wastewater treatment in the UASB reactor was done. The reactor operation was observed on treatment of the average domestic concentrated black water at 25 ^{0}C and under 8.7 days of hydraulic retention time (HRT), and with long solid retention time SRT of 254 days [4].

The volume of the reactor was estimated to be about 63 l/p for black water, amount of methane content in the biogas produced is estimated to be 25 l/p/d (roughly 0.025 m^3/p/d) under the condition that black water was produced at 5 l/p/d and solid kitchen refuse is included, concluding in total 140 gCOD/p/d [4], [5].

Knowing that there are 4000 people residing in the campus, it is possible to estimate that methane production on campus would result in approximately 100 m^3/d [4]. The total biogas production is equivalent to 166.6 m^3/day.

Volume of the reactor depends on the HRT value, number of people contributing to the black water inflow and production of the black water per person.

The volume of the reactor can be calculated using the following general formula:

$V_{reactor} = HRT * Q_{person} * N_{persons}$;

where:

HRT - hydraulic retention time (8.7 days);

Q_{person} – black water flow per person per day (5 l/p/d);

$N_{persons}$ – number of person (4000).

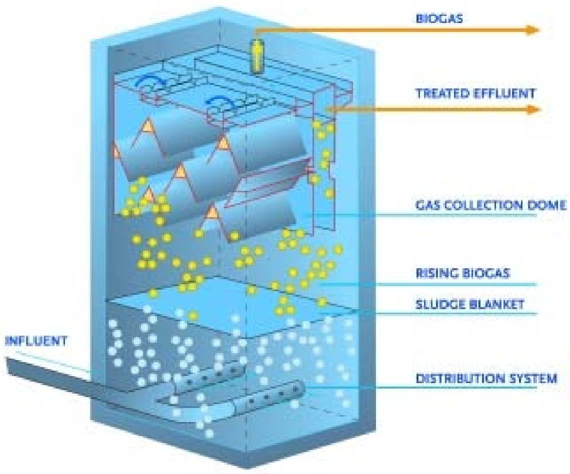
Thus, the reactor volume is calculated to be about 174 m^3.

Current costs of UASB reactor depends on many factors. The PAQUES company (www.paques.nl) was contacted for negotiations about the volume, conditions, insulation and the preliminary price calculations for the needed UASB set.

The set consisting of the BIOPAQ UASB reactor with gas-tight roof, 3 phase separator for sludge, effluent and biogas separation, influent distribution piping, 1kW recycle pump and pipes, control valves and flowmeter, has been estimated to cost 220 000 Euro, whereas the UASB reactor itself will cost approximately 200 000 Euro. General view of the UASB reactor with 3 phase separation system for sludge is shown on Figure 2.1.

Figure 2.1

General scheme of the UASB reactor with three phase separation system (www.paques.nl)



Insulation thickness of the UASB reactor from the PAQUES company can be designed to be thick enough, up to 20 cm, and this insulation is, in most cases, enough to maintain mesophilic temperature of the wastewater in the reactor in weather conditions of the Netherlands. If the inflowing wastewater is heated up before entering the reactor, this is stated to be enough for the heat supply to the UASB reactor only.

2.2 CHAPTER SHORT OVERVIEW

Current wastewater flow from the campus has to be separated to black, grey and rain waters for effective treatment. Black water is then can be treated in the anaerobic reactor to extract additional sustainable energy out of it in the form of methane-rich biogas, as well as effluent liquid and processed sludge.

For an anaerobic treatment of the black water, the UASB reactor is considered as one of the best solutions at present. The PAQUES Company in the Netherlands can provide such UASB reactor for installation in the University.

Table 2.2 shows basic data about the black water production and biogas production considering 4000 people contributing the black water in the University campus to the UASB reactor. The reactor volume is calculated and shown, as well as approximate price for such reactor set.

Table 2.2
General data of biogas production in the UASB reactor

Main input data			UASB reactor				
Black water, l/p/d	**COD with kitchen wastes, g/p/d**	**Number of people**	**Reactor volume, m^3**	**Total biogas yield, m^3/d**	**CH_4 content, %**	**CO_2 content, %**	**Reactor set price, €**
5	140	4000	174	166.6	60	40	220000

Application of the UASB reactor for black water treatment gives a possibility to obtain methane-rich biogas out of it and does not require additional energy (heat) supply to the reactor to maintain mesophilic temperatures of digestion process in the reactor. The only requirement is good insulation of the reactor tank and preheating of the inflowing black water to the reactor.

CHAPTER 3 Biogas treatment

Biogas, extracted from the anaerobic treatment of wastewater contains methane in approximately 60% share, carbon dioxide in 40% share, and has certain harmful contaminants in its content such, as hydrogen sulfide in almost negligible share [4], however it can vary from 10-500 ppm [6].

In order to utilize the biogas in energy generation appliances, such as gas-fired boilers, CHP units, fuel cells, the H_2S content of the biogas have to be removed in order to prevent corrosion of metallic elements and chocking. This way is considered as a purification of the biogas.

Some advanced boilers (steam generators), high efficiency CHP units require the biogas to be treated to methane-rich gas, and the requirement to inject the biogas to natural gas grid states the need in upgrade of the biogas to pure methane content of high calorific value.

Before feeding the upgraded biogas to the natural gas grid, it has to be odorized in order to identify any possible leakage, and, in case if it's needed, liquefied petroleum gas (LPG) or propane has to be added for enrichment of its calorific value [8]. Biogas upgrade for feeding to the existing gas grid of the University of Twente might be feasible in the future as well.

Currently, a lot of researches are conducted in the field of hydrogen sulfide and carbon dioxide removal with two sets of methods: chemical methods and biotechnological methods. Biotechnological methods, like biofilters, bioscrubbers and biotrickling filters are considered to be more effective, need less investment costs, allow higher energy savings, avoid catalysts and formation of side contaminants after the treatment [7]. For example, biotrickling filter concept includes usage of microorganisms like bacteria genus Thiobacillus to degrade H_2S contaminants in the biogas. This bacteria does not oxidize CH_4 and uses CO_2 as a carbon source for feeding themselves [7]. However, these technologies has to be deeply assessed since they are not broadly used as best solutions for biogas purification and upgrade.

Several studies on currently used purification and upgrade methods of the biogas from anaerobic digestion of organic material were observed [8], [9].

3.1 BIOGAS PURIFICATION AND UPGRADE METHODS

From the observed technologies, high pressure water scrubbing (water wash technology) is sorted to be the most appropriate in terms of energy consumption and prices [8]. However, water scrubbing technology for biogas purification needs high volumes of water, so water regeneration has to be installed with it to reduce water consumption. Adsorption by chemical reaction allows to reduce methane losses within the purification process, but requires large amount of heat for chemical regeneration of the reagent (like alkanolamines) with steam.

The other research, conducted by the Technical University of Eindhoven together with DMT Environmental Technology organization in the Netherlands gives a broad and detailed view on five purification and upgrade technologies of the biogas [10].

All of the observed technology can be adjusted to biogas upgrading needs, which allow to remove CO_2 content as well as harmful contaminants. First four technologies are shown in diminution order over the price per cubic meter of the biogas treated, where are all costs are shown in the Table 3.1 in the end of the Chapter. The fifth technology, as the most expensive and least feasible one is shown in the end.

- Chemical absorption of H_2S content from the biogas into iron-chelated solutions provides very efficient and almost complete removal of the H_2S content, which is converted to elemental sulfur. The advantage of this technology is that, as it was said, the H_2S content is removed almost completely from the biogas and produced sulfur can be sold as a product. A disadvantage of this technology is considered to be that CO_2 content of the biogas cannot be removed and a scrubber is needed therefore [10]. Introduction of a scrubber allows to purify the biogas with high level of H_2S and CO_2 removal.

  However, this technology in its basic application for biogas purification with removal of sulfur content only, can be used to obtain biogas needed for application in boilers, CHP units and fuel cells, which can work on biogas. And this is almost the only technology to obtain needed mixture of carbon dioxide and methane, with sulfur content removal only.

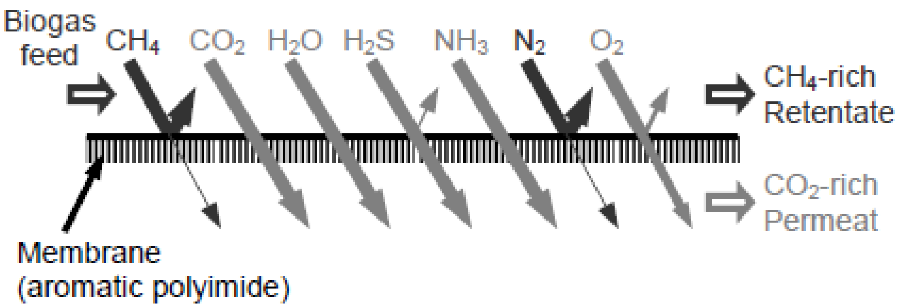
- Pressure swing adsorption (PAS) allows separation of certain gas species from the mixture of gases using high pressure. The separation is done according to the molecular characteristics of the species. The high enrichment of the methane yield is obtained, but the adsorption material adsorbs hydrogen sulfide irreversibly, so separate technology is needed to be applied as an external installation to remove H_2S content of the biogas prior to PSA application.
  The technology requires low power input and has low level of emissions in the end. The gas collected at the top of the last absorber vessel has a reduced value of CO_2 and harmful

contaminants as H_2S are removed. Thus, the methane content is reached to be higher, so higher its calorific value.

- The purification of the biogas using selective membranes allows to separate CO_2 together with H_2S content of the biogas within one separation technique, named Gas Permeation [9]. The technique is easy to control due to its stability in operation, and the whole process of operation is appeared to be very simple and compact. The basic principle of the membrane operation with biogas is shown on the Figure 3.1.1.

  This is also a relatively simple technology because the membrane and compressor are only needed. However, the membrane is currently expensive [10].

Figure 3.1.1
Principle of gas separation using the membrane technique Gas Permeation (9)

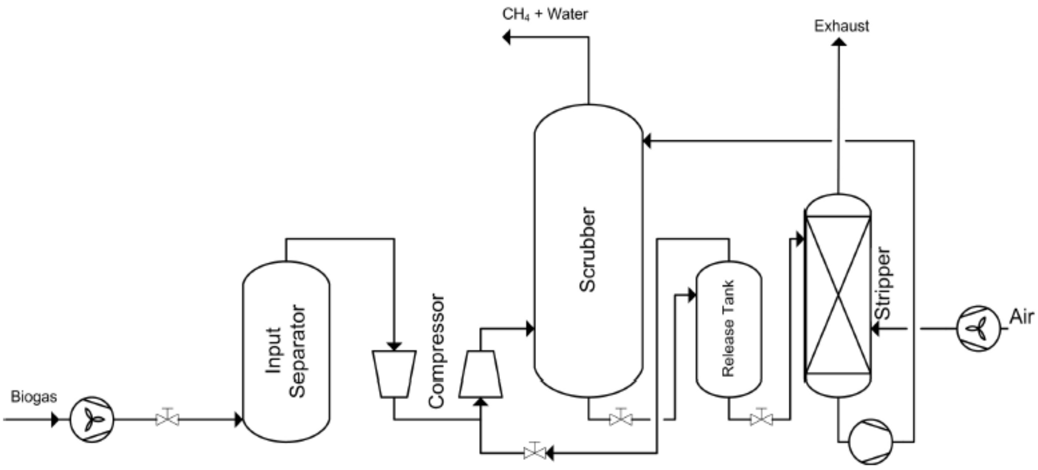


The membrane is a polyimide membrane with different solubilities and diffusivities for various composites of the biogas feed [9], [10]. Due to the differences in the phase pressures on the sides of the membrane, the permeation and separation occurs. Here only nitrogen shows similar behavior as methane, and can remain in the product gas. Other contaminants, including CO_2, are transported to a low pressure permeate side of the membrane. It is obvious, that gas quality and quantity is very much dependent on sufficient membrane area. Depending on the sizes of membrane stack and membranes size themselves, it is possible to treat the CH_4-rich gas on the outlet of one membrane to remove other contaminants which can be still present in the gas. Main advantages of the technology are: compactness and light weight construction, low labor intensity, no moving parts require low maintenance time and cost, low energy requirements. The disadvantages are: expensiveness of the membrane used, harmfulness of certain solvents and colloidal solids for the membranes so biogas content should be carefully investigated prior.

Thus, this technology is relatively new and expensive and needs some further research for final statement of its application.

- High pressure water scrubbing is based on the physical dissolving of the gases in liquids. The difference in solubility of methane and carbon dioxide allows the latter, as well as hydrogen sulfide, to dissolve into the water in a scrubber. This makes the technology relatively simple in operation.
  Under high pressure the gas enters the scrubber, and then the water is sprayed from the top of the scrubber and flows down in counter-current direction to the gas. Then, after the drying step the pure methane is obtained in 98% of purity [10]. The H_2S and CO_2 are solved in water. Exhausts are left after separation in the stripper with air and the water is supplied back to the scrubber column. The process diagram is shown on Figure 3.1.2.
  The high pressure water scrubbing technology requires a large amount of water, which is a disadvantage of this technology, but the water can be reused where there are no H2S and CO2 contaminants in it. So the main focus nowadays is on the water regenerative adsorption within this technology. And the dissolubility of contaminants like H_2S and CO_2 increases with increasing pressure.

Figure 3.1.2
Flow diagram of high pressure water scrubbing process (10)



The technology allows to remove carbon dioxide content together with harmful contaminants and obtain a very high quality gas (upgraded to 98% pure methane) [10], which can be then considered to use in high efficient boilers, CHP units, fuel cells and for injection to the natural gas grid after needed odorizing and propane/LPG addition. Furthermore, this technology appeared to have least capital costs among all technologies per cubic meter of treated biogas.

- The cryogenic separation technology of the components in the biogas applies liquefaction of different chemicals in the biogas at different temperatures and pressure domains. Normally, temperature of -170 ^{0}C [10] and a pressure of 80 bar is applied. Main advantages are: large quantities of highly purified biogas, use no chemicals in the process. The disadvantages are: requirement of number of devices and special equipment like compressors, heat exchangers, insulators, turbines, distillation columns etc. This requires high capital costs and can be economically feasible only if a large amount of biogas is processed [10].

Based on the study [10], the comparison of prices, and purity of described technologies was done, as it is shown in the table below.

Table 3.1

Prices and purity of obtained methane using different purification technologies

Technology	Price per Nm^3 of biogas treated, €	End purity %
Chemical adsorption	0.28	up to 98
Pressure swing adsorption	0.26	up to 98
Membrane separation	0.22	up to 89
High pressure water scrubbing	0.15	up to 98
Cryogenic separation (least feasible)	0.4	up to 91

Thus, it can be concluded that high pressure water scrubbing technology allows to purify and upgrade the biogas with lowest price per cubic meter of the biogas treated and under high purity. Only the treatment process of 166.6 m^3/day of the biogas produced would cost around 25 Euro/day, or 9125 Euro/year.

However, to obtain precise calculation on amount of investment needed to technically build up the whole technology set for the wastewater treatment plant in the University of Twente, more detailed observation has to be executed, since the design of the scrubber and the system itself must be carefully projected. Furthermore, it may be needed to conduct observations on the environmental impact of each of the method in order to suggest on certain technology application feasibility with consideration of price and possible pollution level.

In practice, investment volume into the purification plant is proportional to price of cubic meter of biogas treated [10], so the least costs of cubic meter of biogas treated shows the least capital investments to the purification plant.

3.2 CHAPTER SHORT OVERVIEW

Produced biogas, besides methane and carbon dioxide, contains hydrogen sulfide and sometimes other contaminants in a very small share, which has to be removed in order not to damage most technical appliances. However, for certain advanced boilers and CHP units, the biogas has to be upgraded to pure methane.

Table 3.2
Main technologies for biogas purification and upgrade

Technology	Price per Nm^3 of biogas treated, €	End purity %	Advantages	Disadvantages
Chemical adsorption	0.28	up to 98	Almost complete H_2S removal	Removal of only one component in column, scrubber is needed; Expensive catalyst
Pressure swing adsorption	0.26	up to 98	Low power demand; Low emissions level; N_2 and O_2 adsorption;	Additional complex H_2S removal step needed
Membrane separation	0.22	up to 89	Compact, simple and light weight; Low maintenance and energy requirements; Very promising technology	Relatively low CH_4 purity and yield; Expensive and easy to damage membrane
High pressure water scrubbing	0.15	up to 98	Lowest capital investments High purity, good yield; No chemicals used; Simple technique; Neutralization of corrosive gases	Requires a lot of water, even with regeneration; H_2S damages purification equipment if not removed
Cryogenic separation (least feasible)	0.4	up to 91	Production of large volumes and high purity CH_4; No chemical used; Easy to scale up	Complex process, a lot of equipment, high capital investment

Main purification and upgrade technologies are observed in the Table 3.2.

Here the high pressure water scrubbing is seen as the best technology to use for purification and upgrade of the biogas, where the price per m^3 of biogas treated is the lowest.

Chemical adsorption, however, in its basic application for biogas purification with removal of sulfur content only, allows to obtain needed mixture of carbon dioxide and methane and run specific boilers, CHP units and fuel cells.

Purification of the biogas using selective membranes is a very promising technology at present time and will be researched intensively in the coming future.

CHAPTER 4 Boilers. Produced power and prices

Produced biogas can be burnt in gas-fired boilers for hot water production, or in steam generating boilers running on methane-rich biogas.

4.1 STEAM GENERATING BOILERS

Steam generating boiler with production capacity of 80 kg of steam per hour can be installed for heat production on site in campus. Dutch company Scharff Techniek BV offers full boiler sets from Certuss company, which produces several types of steam boilers and offers a certain boiler type Junior SC (http://www.scharfftechniek.nl/junior.htm) with consumption of 5.8 m^3/h of natural gas, which basically can be replaced with pure methane gas [11]. The methane extracted from the anaerobic digestion of concentrated black water (bio-methane) has a calorific value around 35.6 MJ/m^3 [4] and this value is considered to be enough for application in the mentioned steam generating boiler, though the methane consumption to produce 80 kg of steam per hour could be a bit higher due to possible lower obtained calorific value of the methane from the biogas in comparison to natural gas.

Power output of the produced steam by the mentioned boiler is stated to be 53 kW at 80 kg/h of steam at 180 ^{0}C. Taking into account, that heating of 10 m^2 of living area with height under 3 m needs roughly 1.1kW of heating power [12], including 10% extend for the compensation due to insulation efficiency of the rooms, the power output of the boiler corresponds with approximately 481 m^2 of living space to be heated.

For application on site in the campus this would mean that the boiler can produce 80 kg/h of steam for approximately 16.5 hours per day, and for this period the living area of 482 m^2 can be heated on campus. Taking into account area of typical student room on campus, 20 rooms could be heated for 16.5 hours a day using bio-methane from the wastewater treatment plant on campus.

However, produced heat is most efficiently can be utilized during cold season of a year, so the consideration of production of hot water is also included as water can be heated up with the steam produced via hot water tanks for water heating. In the summer period hot water can be produced for use in showers and kitchens by need. For efficient utilization of heat and hot water, and switch time between them in certain period of a year, a research can be run on campus in order to identify heat and hot water production best periods in seasons of a year.

The Scharff Techniek BV company was contacted on some details about the Junior SC boiler with production capacity of 80 kg/h of steam. The full set, which includes fuel pump, heat exchanger, pipings, thermal water storage etc., and warranty, costs 25 308 Euro as a base price. The life time of the boiler set is estimated to be 25 years.

Steam produced can be used not only for heating purposes via heat exchangers and hot water tanks, but also as a pressurized steam supplied to the steam turbines. There is the TECHNOPA Engineering GmbH Company in Germany (www.technopa.eu), which developed and manufactures S2E Steam Microturbines currently with power ranges of 50-250 kWe [13]. One of the features of these turbines is that they can operate on saturated (wet) steam, and the risk of the blades to be damaged is minimized in this case. Such kind of turbines can be considered in the future if the biogas produced in larger volumes and the possibility to generate steam in steam generators can reach value of 1.5 t/hour [13].

4.2 BOILERS FOR HEATING AND HOT WATER PRODUCTION

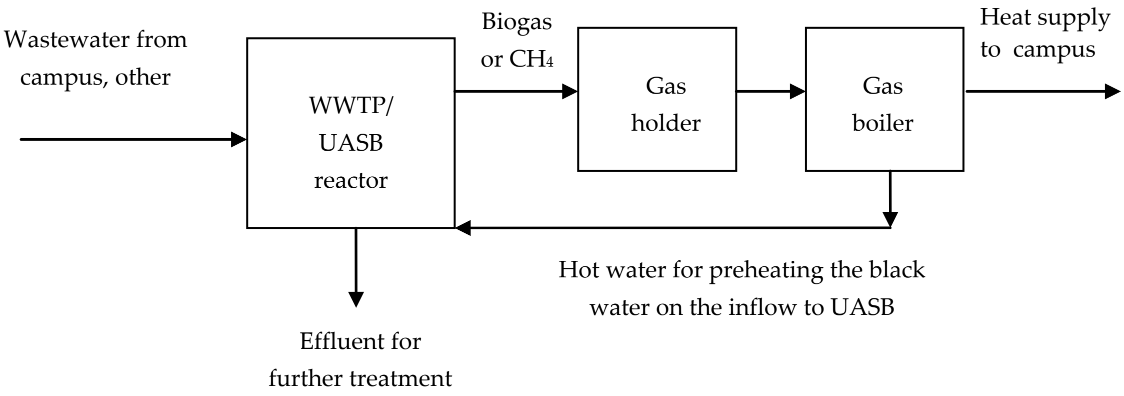
Another option is considered to be the boiler for hot water production for direct heating facilities. The Nefit B.V. company in the Netherlands offers the biogas burning boiler from Buderus Company, Logano G215-58 with the needed operation module and gas burner, which operates on the biogas consisting of methane (60%) and carbon dioxide (40%) with calorific value of 21.6 – 25.2 MJ/m^3. [14].

The output power of the boiler is 58 kW of heat produced (92% efficiency) at the biogas consumption rate of 10.3 m^3/h [14].

In case of the application on campus, this would give approximately 58 kWh for 16.1 hours a day with utilization of 166.6 m^3 of the biogas produced. By this amount of heating power, knowing that 1.1 kW is needed to heat up 10 m^2, it could be possible to provide heat for 16.1 hours a day to approximately 527 m^2 of living area, or about 22 student rooms on campus, and/or to constantly preheat the inflowing black water to the UASB reactor via heat exchanger of the UASB set, as shown on Figure 4.2.

Figure 4.2

Generalized scheme of the waste water treatment plant with gas boiler application



The set consisting of the boiler Logano G215-58 with the gas burner Dreizer M06 2-95, suited for bio-methane and biogas, and necessary operating module costs 8925 Euro [14]. The price excludes installation and maintenance cost of the complete boiler set. Electrical energy must be supplied in the value of 270 Wh to the motor of the gas burner.

Possibilities for application of the extracted methane from the biogas for the use in existing boilers on campus has to be overviewed on site, after detailed look at current boilers age, materials used, load, overall condition.

4.3 CHAPTER SHORT OVERVIEW

Two types of boilers are overviewed and are shown in the Table 4.3.

Table 4.3

Boilers overview

Boiler set	Power, kW	Biogas purity	Gas use, m^3/h	Hours/day operation	Heated area, m^2	Price, €	Distributing company
Certuss Junior SC 80 steam generator	53	CH_4	5.8	16.5	482	25308	Scharff Techniek B.V.
Buderus Logano G215	58	CH_4+CO_2	10.3	16.1	527	8925	Nefit B.V.

Produced biogas can be effectively utilized in biogas fired boilers. For observed steam generating boiler, it is needed to upgrade the biogas to its methane content and then supply it to the steam generating boiler.

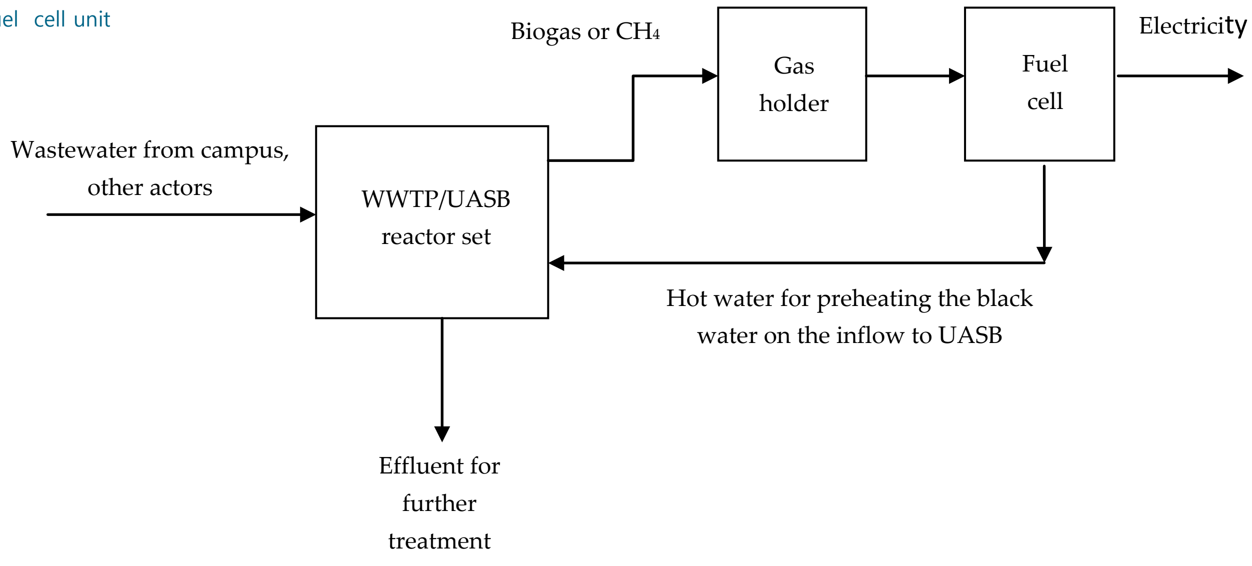
Furthermore, observed boiler Buderus Logano G215-58 can operate on purified biogas, if hydrogen sulfide is removed only. This appeared to be a better solution and produced biogas can be utilized to provide 58 kWh of heat for 16 hours a day for lower price, and/or to heat up the inflowing black water to the UASB set, to maintain its mesophilic temperatures.

During summer period the boiler can be used for water heating purposes for showers and kitchens.

CHAPTER 5 Fuel Cells running on biogas

The biogas produced through anaerobic fermentation consists of methane with approximately 60% share, carbon dioxide 40%, and some minor shares of impurities, such as hydrogen sulfide, ammonia and hydrogen chloride [15]. The impurities, such as hydrogen sulfide, have to be removed from the gas in order not to damage the catalyst and electrodes in the fuel cells [16], so the biogas pretreatment is needed before using it as a fuel feed to the fuel cells. The biogas upgrade method has to be chosen based on study of different upgrading technologies, described in Chapter 3 of current report.

Figure 5.1
Generalized scheme of the waste water treatment plant with fuel cell unit



Currently, Phosphoric Acid Fuel Cells (PAFC) has no alternatives on the market of fuel cells working on methane. If there is a need for a commercial system running stable and reliable, the PAFC stated to be the most appropriate for now. [15], [17], [18].

Quick look on the phosphoric-acid fuel cell from Fuji Electric Company [15], [18] shows that biogas and bio-methane operated PAFC with 100 kW output power consumes 45m^3/h of the biogas. This would result in 3.7 h/d of operation of this 100kW PAFC unit with produced biogas volume on campus from the wastewater treatment plant with UASB reactor. Furthermore, 50kW of thermal power is produced with hot water output of 90^0 C [18].

Thus, obtained volume of biogas produced can give around 370 kWh/d of electrical energy from the PAFC unit described in [15], [18]. Thermal energy produced from the fuel cell unit, under 90 ^{0}C hot water for 3.7 h/d of operation, concluded in 185 kWh and can be used for preheating of the black water inflow to its mesophilic temperatures before being supplied to the UASB reactor, as well as for other heating purposes, as shown on Figure 5.1.

General appearance of the PAFC 100 kW fuel cell unit from Fuji Electric Company is shown on Figure 5.2. Amount of produced hot water per hour has to be studied in order to conclude on its best route of application.

Figure 5.2
Appearance of PAFC FP100 (100 kW) fuel cell from Fuji Electric Company (Phosphoric Acid Fuel Cell (PAFC) presentation, September 2010, Fuji Electric Co.

Cost of installed kW is 3600 USD/kW for the fuel cell itself, and the cost of such PA fuel cell from Fuji Electric Company will approximately be 360 000 USD [17], or about 261 000 Euro at the exchange rate of 1.38 EUR/USD.

However, depending on the infrastructural complexity of gas supply, special requirements on site of installation, the total system price of the 100 kW PAFC unit can cost till 700 000 Euro, including guarantee on the whole life time of the unit, and all certifications. Thus, the price for 1 kW installed of the full PAFC unit is estimated to be 7000 Euro.

The system lifetime is 15 years with one replacement of stack and reformer after 7.5 years. The company N2telligence (http://www.n2telligence.com/) was contacted as the official distributor in Europe for PAFC for negotiations on price and other conditions.

Furthermore, for operation of the described fuel cell units, carbon dioxide removal is considered to be unnecessary, just hydrogen sulfide, other sulfur compounds, nitrogen content in the biogas have to be reduced or removed completely. However, for stable operation of the fuel cell, it has to function ceaseless, without often shut-offs, so the biogas supplied to the fuel cell has to be produced in larger volumes.

5.1 CHAPTER SHORT OVERVIEW

The PAFC fuel cell appeared to be one of the best fuel cells working on biogas from anaerobic digestion of wastewater. Fuji Electric PAFC FP-100 was observed and energy output was calculated (Table 5.1) based on the fuel cell operation on obtained volume of the biogas from the UASB reactor.

Table 5.1
Energy outputs and operation time of the PAFC form Fuji Electric Company

Fuel Cell unit	Electric output, kW	Thermal output, kW	Biogas purity	Gas use, m³/h	Hours/day operation	Price, €	Distributing company
Fuji Electric PAFC FP-100	100	50	CH_4+CO_2	45	3.7	700000	N2telligence

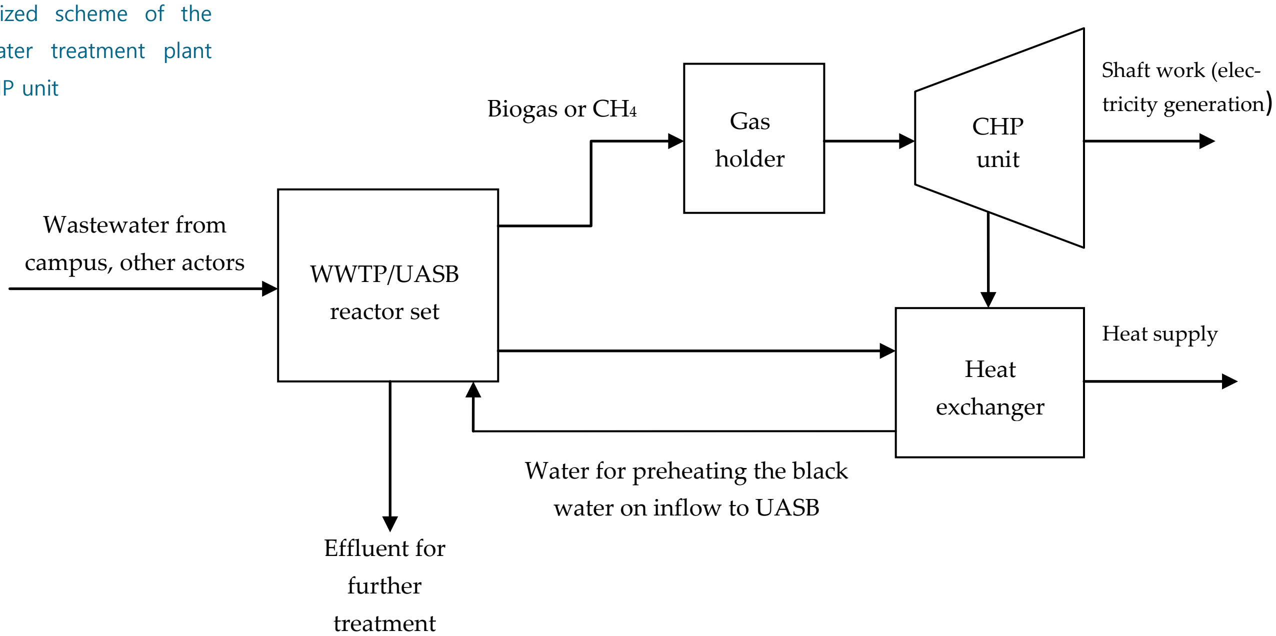
Observed fuel cell can generate 100 kWh of electric and 50 kWh of thermal energies for 3.7 hours a day, using available biogas from the UASB reactor set. High costs of the fuel cell, and this can be applied to any other fuel cell currently, is the main disadvantage and makes it unattractive from economical point of view at present time.

Moreover, it is not recommended to often turn on and off the fuel cell unit, which is an issue with observed relatively low volumes of biogas production.

CHAPTER 6 Combined Heat and Power (CHP) generation units

Combined heat and power unit can be considered as an option where the produced biogas or methane can be applied. The biogas from the wastewater treatment plant has to be purified till methane with carbon dioxide to eliminate corrosion risks. However, in some cases it is needed to obtain constant quality of the gas, so methane has to be extracted only. The mechanical energy extracted from the combustion engine where the biogas is combusted is then transferred to electrical energy via electrical generator and exhaust heat produced by the engine is then used to create heat in special heat exchangers. Figure 6.1 shows the general scheme of wastewater treatment plant and CHP unit application.

Figure 6.1
Generalized scheme of the wastewater treatment plant with CHP unit



All described CHP units below are assumed to operate under their 100% output.

The CHP unit Cento T80 from Czech company TEDOM, working on biogas, has an electric output of 77 kW and heat output of 112 kW under biogas consumption of 35.7 m^3/h [19]. Assuming biogas application as the gas feed to the mentioned CHP unit, the production of electricity and heat would conclude in 77 kWh and in 112 kWh correspondingly for 4.6 hours a day.

Tedom CHP units working on biogas require removal of hydrogen sulfide and other sulfur compounds from the biogas, but the carbon dioxide content can be left in the product gas.

TEDOM company was contacted for costs calculations. The cost of the Cento T80 CHP unit is calculated to be 93 875 Euro, with 1000 Euro for transportation and 29 600 Euro for installation and maintenance costs. Overall cost is approximated to be 124 475 Euro.

Another option could be the use of Micro T-30 CHP unit from TEDOM, which works on biogas as a feed fuel. The unit operates with 10.6 m^3/h of biogas under 100% output and produces 21 kW of electrical and 43.5 kW of thermal power [19]. With the utilization of 166 m^3 of biogas in the Micro T-30 under 100% of its output, the unit would work for approximately 15.7 hours a day and produce electrical and heat energies in approximately 330 kWh/day and 683.8 kWh/day correspondingly.

The cost of the Micro T30 CHP unit is calculated to be 38040 Euro, with 1000 Euro for transportation and 11412 Euro for installation and maintenance costs. Overall cost is approximated to be 50452 Euro.

Ecopower Micro CHP units from the company PowerPlus Technologies GmbH are balanced for off-grid operation and full control on consumed electricity. It is possible to operate several Micro CHP units simultaneously, and connect such a system directly to the local grid. The output electronic devices of the unit provide grid-synchronized, three phase alternating current, and, if necessary, feed the unused power back into the grid. Controlling this extra power via energy meter allows the owner of the CHP unit to get reward for the supplied power from the local grid operating authority [20].

Combination of several Ecopower Micro CHP e4.7 is possible in case of pure and constant methane supply as an energy source for needed amount of hours on Campus of the UT. These Micro CHP units have overall efficiency of 90%, where 65% comes for heat and 25% for electrical output, and only 10% is lost into the atmosphere as waste heat [20].

Single Ecopower Micro CHP e4.7 produces 4.7 kW of electric power and 12.5 kW of thermal power under 100% output [19]. Gas consumption rate by the unit is 2 m^3/h [20]. With the given amount of bio-methane produced, each CHP e4.7 unit can produce 112.8 kWh/day of electric and 300 kWh/day of thermal energies per day, resulting in 226 kWh/day (9.4 kWh) of electric and 602 kWh/day (25 kWh) of thermal energies for two CHP units combined in one system.

The system with two e4.7 CHP units is possible to setup for a single generating unit and is considered for 24 hours work per day with available methane production. General appearance of single Ecopower Micro CHP is shown on Figure 6.2.

Figure 6.2
Appearance of Ecopower Micro CHP e4.7 (www.ecopower.de)

PowerPlus Technologies GmbH was contacted for price per unit of Micro CHP e 4.7 and maintenance cost.

One single Ecopower Micro CHP e4.7 unit with complete set of thermal storage, switch cabinet, smartload unit, pipings etc, costs 16 700 Euro [20], and for two units it is 33 400 Euro correspondingly.

Additional cost can be applied in amount of 950 Euro per unit per year. This additional cost includes yearly maintenance, replacement of damaged parts of the unit, warranty etc. The prices are given for installation in Germany. Local taxation has to be considered over the price of each CHP unit, as well as negotiations over installation and transportation costs. All provided prices are pure prices from the producers of the CHP units, not including any governmental subsidies or feed-in tariffs for purchasing CHP units.

6.1 CHAPTER SHORT OVERVIEW

Currently CHP units can provide a feature to supply generated and unused electricity to the local grid via electronic synchronizing equipment in the set of the CHP units and get reward from local electricity distributing authorities for supplied electricity.

Observed CHP units are divided for biogas operated and methane operated, as shown in the Table 6.1.

Table 6.1
CHP Units. Energy outputs and operation time

CHP unit	Electric output, kW	Thermal output, kW	Biogas purity	Gas use, m^3/h	Hours/day operation	Price, €	Distributing company
TEDOM T-30	21	43.5	CH_4+CO_2	10.6	15.7	50452	TEDOM
Ecopower Micro e4.7, 2 unit system	9.4	25	CH_4	4.15	24	33400	PowerPlus Technologies GmbH

Micro CHP unit Tedom T-30, running on biogas, is can provide 21 kWh of electrical and 43.5 kWh of thermal energies for 15.7 hours a day utilizing produced biogas from the UASB. Hydrogen sulfide removal is needed only as a requirement for biogas purity. This makes this micro CHP unit attractive for application with biogas produced from wastewater.

Ecopower Micro e 4.7 unit can be organized in a system with two and more units, and scaled up further to the needed power range. 9.4 kWh of electrical and 25 kWh of thermal energies can be constantly generated for 24 hours if the gas supply is constant. The disadvantage is the requirement for the gas supplied, which has to have a calorific value close to natural gas.

CHAPTER 7 Biogas injection to the local natural gas grid

The calorific value of the natural gas in the distribution grid in the Netherlands has a reference value of 35.17 MJ/m^3 [21]. The pure methane produced from the anaerobic digestion of the wastewater has an average calorific value from 35 up to 35.9 MJ/m^3 [4], [5], [22], thus the specific additional upgrade of the methane obtained is not crucial for the case of its injection to the natural gas grid. However, if the biogas from anaerobic digestion is not upgraded to pure methane, then the calorific value of the biogas consisting of methane and carbon dioxide varies significantly and is not high enough for supplying the biogas to the natural gas grids, so the upgrade is necessary.

Furthermore, the volumes of the biogas produced are not high enough for the companies to consider its injection into their NG grids due to high costs and risks associated with pressurizing the gas and injection itself.

CHAPTER 8 Energy consumption of the University of Twente

Electrical energy and gas consumption rate of the campus of the University of Twente was analyzed at condition of 2009. However, depending on installed boilers types, sizes and overall system efficiency in the campus, precise thermal energy production from utilization of the natural gas can be obtained.

Annual electrical energy consumption for the campus is 28 270 MWh, thermal energy consumption of 116.91 TJ (32 475 MWh) and natural gas consumption is 185 144 Nm^3. The data is provided by Energy coordinator facility of the University of Twente (Energiecoördinator Facilitair Bedrijf Universiteit Twente). Roughly, electrical energy consumption per day is calculated to be 97.5 MWh, including high decrease in consumption during holidays periods and weekends.

CHAPTER 9 Price comparison of the biogas application routes

Cost calculation and comparison can be done for described technologies of biogas application. Costs of the UASB reactor unit approximated to be 220 000 Euro.

Cheapest biogas purification and upgrade technology is chosen to be high pressure water scrubbing. Treatment process of 166.6 m^3/d of the biogas produced costs approximately 25 Euro/d, or 9125 Euro/y. Research is needed on input investment volumes to the purification plant.

Approximate costs for different solutions of biogas application are shown below.

Table 9.1
Cost and energy output comparison for different systems of biogas application

Application	Electrical energy output, kW	Thermal energy output, kW	Hours/day operation	Biogas treatment	Cost, €
Buderus Logano G215-58 boiler set	-	58	16.1	Purification/ H_2S removal	8 925
Fuji Electric PAFC FP-100 unit	100	50	3.7	Purification/ H_2S removal	700 000
TEDOM micro CHP T-30 unit	21	43.5	15.7	Purification/ H_2S removal	50 452
Ecopower Micro CHP e4.7 two units	9.4	25	24	Upgrade to bio-methane	33 400

Comparing these different routes, energy output analysis shows that:

- Boiler setup produces 933.8 kWh of thermal energy per day.
- PAFC produces 370 kWh of electrical and 185 kWh of thermal energies per day.

- TEDOM T-30 Micro CHP produces 330 kWh of electrical and 683.8 kWh of thermal energy per day.
- Ecopower Micro CHP e4.7 two units system produces 226 kWh of electric and 602 kWh of thermal energy per day. However, the CHP unit requires pure methane supply, extracted from the biogas.

These CHP units are balanced for operation autonomously or with connection to existing electrical grid, and allow to control the consumption of electricity. Electronic grid synchronizing devices allows to feed electrical energy to the grid as well in case if it's been unused locally. These controlling devices with energy meters give a possibility to get reward for supplied energy from local authorities who operate local electrical grids.

From these numbers and the costs showed above, the most competitive from price-performance perspective is appeared to be the boiler set Buderus Logano G215-58 and the TEDOM T-30 Micro CHP unit, considering that the University pays 0.45 Euro/m^3 of natural gas consumed, amount of heat produced from 1 m^3 of natural gas is roughly 9.8 kW under calorific value of 35.17 MJ/m^3, for electrical energy consumed the price is 0.9 Euro/kWh.

Amount of heat produced from the boiler set Buderus Logano G215-58 is calculated to be 933.8 kWh/d under 16.1 hours of operation and 100% output (ideal case), and it saves around 95.3 m^3 of natural gas consumed per day (42.8 Euro/d). With the ideal case, the biogas production and supply must be constant and purification of the biogas has to be as efficient as possible, heat supply infrastructure has to have no leakages and the boiler should be placed as close as possible to the heated area.

Thus, the pure price of the Buderus Logano G215-58 boiler of 8 925 Euro can be paid off in roughly 1 year in this ideal case. Considering price for the biogas purification of 0.15 €/m^3 (25 €/day) by high pressure water scrubbing, the boiler can be paid off in approximately 2 years.

The price of 50 452 Euro for Micro CHP T-30 from TEDOM company can be paid off in 6-7 months under 100% output (ideal case) and complete utilization of 330 kWh/d and 683.8 kWh/d of electrical and thermal energies produced, saving 297 Euro/day on electrical energy and 31.3 Euro/d on natural gas (69.7 m^3/d). Payback period with consideration of biogas purification price of 0.15 €/m^3 (25 €/day), would be approximately 7-8 months.

Fuji Electric PAFC FP-100 unit can be paid off at least in 7 years in the ideal case, which is just the period of the Fuel Cell reformer stack replacement. Payback period of the FC with consideration of 0.15 €/m^3 (25 €/day) for biogas purification, would be approximately 7.5 - 8 years.

This appears to be the most undesired solution among the others in terms of cost-performance index.

CHAPTER 10 Digested sludge treatment

The solid sludge, resulted after the wastewater treatment in the UASB reactor may contain certain concentration of the contaminants from the original wastewater itself. Considering the protection of the environment, this resultant sludge must be properly disposed or, if possible, reused or recycled as a product. Normally, sludge has to be treated to reduce water content in it, fermentation propensity or presence of pathogens, before being disposed or reused. This can be achieved by dewatering, stabilization and disinfection, thermal drying and combination of these methods [23]. Application of each treatment methods has to be studied with specific sludge sample.

There are three main methods for sludge disposal [23]: recycling to agriculture (landspreading), incineration or landfilling. Also, there are some other methods used, like land reclamation, wet oxidation, pyrolysis and gasification, but they are less developed nowadays and rarely considered. Each disposal method has specific conditions of implementation, outcome and environmental impact.

Landspreading of sludge, or product of composting the digested sludge can partially replace the conventional fertilizer because it contains some organic matter valuable in agricultural application. However, there are harmful pollutants in the digested sludge which can penetrate to the soil and undergo some transformation processes in there. The resultant poisoning of groundwater, microbal transformation, volatilization can allow the microbes penetration into the air and water, and in the end to the food products [23].

Incineration, or combustion of the processed sludge. Here the output of the combustion is the flue gases, ashes and wastewater. So, burning of the sludge produces some amount of emissions to the air (particularly, acid gases, heavy metals, greenhouse gases etc), soil (ashes disposal and flue gases residues landfilling), and water (wet processes for flue gas treatment). Emissions content and concentration after incineration process can vary depending on the sludge content. However, energy produced can be used for sludge drying. Sludge, dried by heat application is considered to be safe for different routes of application due to bacteria elimination under heat application.

Landfilling of digested sludge needs some inputs like electricity, in some cases fuel for vehicles, treating materials to close leachate on site. Emissions to the air (as greenhouse gases), soil and water (heavy metals, organic compounds and micro-organisms in the leachate) are registered with landfilling process. There are accidents published in the United Stated mentioning human and cattle diseases after digested sludge buried in the land in farming areas in the region of San Francisco [24].

Digested sludge can be composted and used together with fertilizer, but cannot replace it completely, or it has to be fortified with mixture of other chemical ingredients. Composting is the aerobic thermophilic decomposition of organic waste to a condition of stable humus [23]. Good compost is valuable product for its nutrient content, but also for its humus forming and moisture retaining properties [23], [26], [27].

Composted sludge is considered to be a positive addition for soil fertilizer, which improves soil structure, especially in old, depleted and heavy soils, and provides useful minerals to the soil.

However, to compost the digested sludge, several important criteria has to be met: complete mixing of organic solids, uniform particle sizes, proper moisture content, adequate aeration, needed temperature and pH condition, proper carbon-nitrogen ratio in the raw solids.

All of these steps have to be deeply studied before advising on certain way of digested sludge application, produced from the waste water treatment plant in the University of Twente. Sludge samples have to be studied on site first. A lot of uncertainties are still involved in this topic and it is rather difficult to propose certain solution [23].

Described ways of sludge treatment also depend on the amount of sludge produced per hour. One study shows, that the amount of sludge applicable for feasible incineration have to reach the value of 0.25-3 t/h [25], which is far too more than the sludge production which can be forecasted for the future wastewater treatment plant. Incineration is mechanically and financially extensive process [25], and relatively large amounts of sludge have to be considered.

One of the recent studies on wastewater sludge compost and cost analysis in Korea shows that composting the sludge after deep content exploration is possible and even economically feasible [26]. There the cost of 1 ton of composted sludge produced is reported to be 52 USD, where as the most inexpensive fertilizer of compost form for landscape architecture with identical chemical content reported to cost 250 USD per ton [26]. So, total capital savings by using sewage sludge in composted form are stated to be 198 USD per ton.

Although, this case is applicable for Korean market only, but it shows that the composting of sludge is possible after certain exploration of its content and large production volumes.

For case of Western Europe, the price for normal compost used in agriculture approximated to be 12.72 Euro/t [27]. However, the report of European Sludge Network shows that there is no realistic scenario on the way of sewage sludge composting possibilities or further treatment is established yet [27].

The information was received that Wageningen University and Research Center (WUR) will soon start up researches on wastewater digested sludge content and routes of it applications in conditions of the Netherlands.

10.1 CHAPTER SHORT OVERVIEW

Currently, sludge treatment is divided to three main techniques: landspreading, incineration and landfilling.

Landspreading is one of the most interesting at present time, since it can provide a valuable product after sludge composting as an addition for agricultural fertilizers.

However, the process can be harmful from environmental and human health point of view. Sludge content has to be studied in details and researches have to be conducted on site in order to suggest on the best way of sludge treatment and needed investment volumes.

CHAPTER 11 Conclusions

Application of the anaerobic digestion of the wastewater with good biogas production yield requires separation of the wastewater flow to grey and black water in the University of Twente in the future, where as all new constructing or renovating buildings in the campus now have to be designed with black and grey water separation facilities. Black water is then treated in the UASB reactor under the temperature of 25 ^{0}C.

The UASB reactor is one of the best solutions for anaerobic digestion of sewage water nowadays. The calculations showed that the volume of the UASB reactor needed to treat the concentrated black water generated by 4000 residents in the campus of the University is 174 m^3, cost of the needed UASB reactor set from the PAQUES company is approximated to be 220 000 Euro. Insulation thickness can be designed to be up to 20 cm for maintaining mesophilic temperatures of the wastewater in the reactor. The only requirement is constant preheating of the inflowing wastewater before entering the reactor. Biogas production yield from this UASB reactor is estimated to be around 166.6 m^3/day with methane content around 100 m^3 (60% share).

The flow rate of the black water from the campus is appeared to be low enough with considered number of people for high rate of biogas production and its broad application in energy generating facilities. Thus, the suggestion can be made to attract external actors for treatment of their wastewaters in the future wastewater treatment plant in the University of Twente. FC Twente located nearby the University, Companies and Organizations located in the Business and Science Park of Twente, local restaurants could be considered as an external actors, and who eventually could be the investors to the project as well. This action would allow to increase the volume of the biogas produced.

The biogas produced has to be purified for application in most of the available appliances on market. Hydrogen sulfide content and other sulfur compounds, if they are present, have to be removed always in order to prevent corrosion of metal elements of any system. For application in some appliances like high quality steam producing generators and several types of fuel cells and CHP units, the CO_2 content has to be removed as well. For injection of the biogas to the natural gas grids, the biogas has to be upgraded to methane in order to obtain required heating value of 35 MJ/m^3. For application in most of the boilers for hot water supply and suited for operation on biogas, the hydrogen sulfide has to be removed only.

The best technology for biogas purification and upgrade appears to be the high pressure water scrubbing. The disadvantage of this technology is the large amount of water used, so the water regeneration has to be included within the technology application. Relevant studies state the price of 0.15 Euro per m^3 of the biogas treated.

Boilers running on biogas are appeared to be a good option as a solution for the biogas application. Boiler set Buderus Logano G215-58 with output power of 58 kW can work on biogas with carbon dioxide presence as 40% share, and produces up to 933.8 kWh/d of thermal energy in ideal case under 16.1 h/d of operation and 100% output. It allows to save around 95.3 m^3 of natural gas per day, and costs 8925 Euro for the boiler set itself, which can be paid off in about 1 year under the ideal case, or in 2 years considering the cheapest price for biogas purification. Part of the hot water produced can be used as a heating medium via heat exchanger for preheating of the inflowing black water entering the UASB reactor to mesophilic temperatures.

Application of the fuel cell running on biogas is appeared to be possible, however, the biogas volumes are required to be large enough to insure ceaseless operation of the fuel cell without frequent shut downs of the FC system.

Phosphoric acid fuel cell is considered to be one of the best fuel cells running on the biogas obtained from anaerobic digestion of the wastewater. 100kW PAFC from Fuji Electric company can be installed theoretically and operate with the produced biogas, however its price of 700 000 Euro can be paid off only in about 7.5-8 years under ideal case of 100% output of the fuel cell unit. But by that time it would already be needed to replace several parts of the whole system. Some advantage here is that the hot water produced, which can be used via heat exchanger for preheating of the inflowing wastewater before entering the UASB reactor or for space heating, if needed.

The option of FC application appeared to be the most undesirable in terms of cost-performance character, as it was expected.

Combined heat and power units can successfully run on biogas as well, as more relevant products are appearing on the market. Studied Micro CHP unit from TEDOM Company can be applied with produced amount of the biogas site in the campus, and is considered to be a successful option along with Buderus Logano G215-58 boiler.

Micro T-30 CHP unit under 100% output produces 21 kWh of electrical and 43.5 kWh of thermal energy, and, correspondingly, 330 kWh/day and 683.8 kWh/day operating 15.7 hours a day. Under these ideal conditions, the CHP unit, which costs 50452 Euro, can be paid off in about 7-8 months, even with consideration of biogas purification price. Furthermore, there is a possibility to deliver produced and unused electrical power to the local electrical grid and get reward back from it. However, at calculated biogas production rate, power produced by the CHP unit will most probably be totally consumed on site.

Possibilities of injection of the produced biogas to the natural gas distributing grid face certain problems at current stage. First, the amount of the biogas produced is far too low for consideration of its injection to the natural gas grids because of the high costs and risk involved with pressurizing and injection procedures. Another requirement is that the biogas has to be purified and upgraded to methane with high calorific value required in the natural gas grids, but also to eliminate any corrosion possibilities by removal of any sulfur contained compounds in the biogas.

Digested sludge as a solid material resulting from the wastewater treatment process in the UASB can be seen as a valuable byproduct, or at the same time very harmful byproduct for food production, human and animals health. Definite solution for the best way of wastewater sludge treatment is a topic for discussions nowadays. Different ways of disposal of the digested sludge, or its composting and use as an add-on for fertilizer require detailed research on site since the content of the sludge is important to test and study and there is no single best solution yet generated for digested sludge treatment process. In most cases, it is simply incinerated releasing certain amount of emission to the air, soil and water. Relevant research study will soon be started up in the Wageningen University and Research Center.

Summarizing the solutions provided, application of biogas fired boilers for heating purposes and CHP units for electricity and heat production are the two most feasible ways of utilization of the biogas from wastewater treatment process. The CHP units can operate through the whole year and boilers effective application in summer period can be directed for water heating in showers and kitchens.

11.1 RECOMMENDATIONS FOR FURTHER STUDIES

For the current feasibility study of the wastewater treatment plant installation on site in the University of Twente several suggestions for further studies and short term researches could be made:

- Studies on current drainage system of the University, where the possibilities for future separation of the wastewater streams could be observed. The need in separation of black, grey and rain waters is obvious but challenging with current drainage system.
- Concerning UASB reactor application, studies could be run, of course, on the ways of treatment and further reuse of effluent water (liquids) and nutrients, phosphates extraction techniques from it.

- Other reactors, suited for wastewater digestion have to be overviewed and analyzed as well. For example, the ECO Vortex company, located in Twello town in the Netherlands, produces special types of Eco-Vortex Ultra Compact Fermenter reactors operating with different biomass inputs, as well as wastewater. The reactor is positioned as a very compact and efficient biogas producing unit. The price indicated for the reactor can vary, of course, but is stated to be competitive and even less than prices for other relative digesters due its compactness etc.
- Sampling studies on sludge composition and sludge best treatment and disposal ways. Here the optimization and certain process of addition of solid kitchen wastes to the main waste stream is important. The University of Twente can be involved in these studies as well. Related researches on sludge are conducted by such companies as KWR and Wetsus in the Netherlands. And the University has already established cooperation with these organizations, at least the Membrane Science and Technology department is involved from the University.
- Short term studies on the best location on campus to place the wastewater treatment plant with UASB reactor, gas holder and piping systems. Location of the end appliance for biogas application (boiler, fuel cell, CHP unit etc) is also important.
- Precise and deeper studies in the field of biogas purification and upgrade techniques would be helpful in order to propose on total investments volume to the biogas purification and upgrade plant. Especially, feasibility studies on membrane application would be of interest. These studies can be run in cooperation with the Membrane Science and Technology department of the University of Twente since they have significant experience and lab facilities to conduct the studies.
- Carbon dioxide mixture with other contaminants after purification process should be studied in order to suggest on feasibility of carbon dioxide extraction to supply (sell) for use in greenhouses. However, this might be feasible only if biogas is produced in larger volumes, since carbon dioxide content is about 40% of total biogas production on site.
- Observation of current boilers condition, loads and applicability to burn purified biogas for heat production and distribution on campus is important, since it may be possible to use current boilers for these purposes instead of buying new ones.
- Generated heat and electrical energy via different appliances could be studied for other application possibilities on campus.
- Studies on how to attract possible stakeholders to treat their wastewaters in the planning wastewater treatment plant in the University. This would also bring clear view on the possibility to expand capacity of the treatment plant and biogas yield increase.

11.2 EDUCATIONAL POSSIBILITIES

In addition to what was said in the previous subchapter, the University can run certain study projects based on the installed wastewater treatment plant.

Studies and short term researches can be followed in different directions.

First of all, wastewater, especially black water, particular content and concentration has to be studied on site in order to obtain precise data on organic content of the wastewater and COD. This can be done via short and mid-term studies for PhD and master students of the University of Twente as their internship and graduation projects.

Prior to this, studies on current drainage system and its separation for different streams of black, grey and rain waters would bring more value to specific studies on each of the streams.

These studies would bring additional benefit for the University as applied test researches on site, as well as it will help to test and optimize the operation conditions of the wastewater treatment plant itself.

Studies related to pretreatment of the wastewater before digestion can be also studied in such departments of the University as Membrane Science and Technology. The department was contacted on researches possibilities and general interests in biogas purification and membrane development, and they showed a big interest in biogas upgrade processes. They obtained vast experience (on a lab scale) of removal CO_2 for artificial feed gas mixture upgrade. The test facilities on site using biogas would be of great interest both from an academic and application point of view, because they could run test researches on site of the University, which currently missing the link between the academic researches and real application. Possibilities to run researches on SOx, H_2S, NOx removal would be of high priority for the department in coming future.

Produced biogas from anaerobic digestion of the wastewater can be studied with the Fuel cells groups in the University in order to suggest or approve application of other certain types of fuel cells optimized to work on biogas.

These types of studies on site would bring financial benefit in a matter that costs on contracting external companies on studies over membranes, biogas purification in general, fuel cells application could be reduced due to research capabilities of the University itself.

For attraction of external stakeholders to treat their wastewaters in the treatment plant in the University of Twente, some educational activities could be run. For example, to conduct series of workshops and presentations with topics on why the treatment plant in the University would be the best location for these stakeholders to treat their wastewater and what would be the benefits for them.

Furthermore, it has to be insured that local stakeholders in the region of Twente understand that wastewater treatment plant will bring additional benefit as study and research possibilities for the

University, and that their possible investments in the project would not be aimed only on economical and environmental aspects, but will also create education possibilities.

Explanatory advertisement of water consumption reduction and environmental benefit of the wastewater treatment plant could be spread out among possible and chosen external stakeholders. This would help them to get familiar with the project, and be prepared for series of presentations and educational meetings in the University about the wastewater treatment plant.

Preparedness of stakeholders for promotional activities of the University would create effective communication between all stakeholders and the University, since each party will be able to share thoughts, ideas, beliefs, views and desires about the project, which were already been shaped with the advertisements and preparation activities. Moreover, effective and reliable communication would bring a feeling of trust and respect among external stakeholders involved in the project.

To ensure participation of each of the desired stakeholder, the advertising campaign could be aimed in personal to each of the stakeholder. Saying this, areas of interests of each of the stakeholders has to be overviewed, and benefits for them have to be indicated in their personal advertising materials and invitations.

Consideration of the expression of the thoughts and ideas by the stakeholders would allow the University and the management of the project to get important information which, somehow, might not have been forecasted and observed before. This is an additional benefit to be considered by project management since the project is projected for long term future.

All of the potential stakeholders have to be provided with sufficient information about drainage system upgrade possibilities and advantages. Vacuum toilets, water free urinals, water saving showerheads and faucets etc have to be promoted with this information, emphasizing the contribution to water conservation actions as well.

Special attention has to be assigned to restaurants and cafeterias in the area of the University. For them, the paradigm shift in aspect of kitchen waste disposal has to be done. This can be achieved via possible educational workshops in the University on wastes separation and disposal topics. There, the organic content of average kitchen waste can be observed as a valuable input product for the wastewater treatment plant, the solid kitchen waste collecting appliances can be introduced.

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