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FEASIBILITY STUDY IN SEWAGE TREATMENT PLANT PROJECT, UTILIZATION OF BIOGAS PRODUCED IN AN ANAEROBIC DIGESTER

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Abstract

This thesis is concerned with the utilization of biogas produced in an anaerobic digester and will include a feasibility study with the following elements.

Design requirements for a biogas utilization project such as space availability population data, amount of waste, location, thermal interface and gas cleanup requirements.

Different technologies will be surveyed for their applicability to the project: fuel cells, reciprocating engines and micro turbines.

Life cycle cost analysis: Different biogas utilization options will be modelled to determine their technical and economic performance. A life cycle cost analysis (including a sensitivity analysis of essential variables) will determine each option's net present value.

Environmental Analysis: The potential impact on greenhouse gas and criteria pollutant emissions was determined for each of the biogas utilization scenarios. An environmental valuation was performed to provide an economic metric to determine environmental benefit of each option.

Chapter 1

INTRODUCTION

Around the world, pollution of the air and water from municipal, industrial and agricultural operations continues to grow. Governments and industries are constantly on the lookout for technologies that will allow for more efficient and cost - effective waste treatment. One technology that can successfully treat the organic fraction of wastes, is anaerobic digestion (AD). When used in a fully-engineered system, AD not only provides pollution prevention, but also allows for sustainable energy, compost and nutrient recovery. Thus, AD can convert a disposal problem into a profit center. As the technology continues to mature, AD is becoming a key method for both waste reduction and recovery of a renewable fuel and other valuable co-products.

This study provides an outline of the status of AD as the most promising method of treating the organic fraction, municipal solid waste (MSW), and other wastes.

1.1 Introduction To Anaerobic Digestion

Biogas is formed solely through the activity of bacteria, unlike composting in which fungi and lower creatures are also involved in the degradation process. Microbial growth and biogas production are very slow at ambient temperatures. They tend to occur naturally wherever high concentrations of wet organic matter accumulate in the absence of dissolved oxygen, most commonly in the bottom sediments of lakes and ponds, in swamps, peat bogs, intestines of animals, and in the anaerobic interiors of landfill sites.

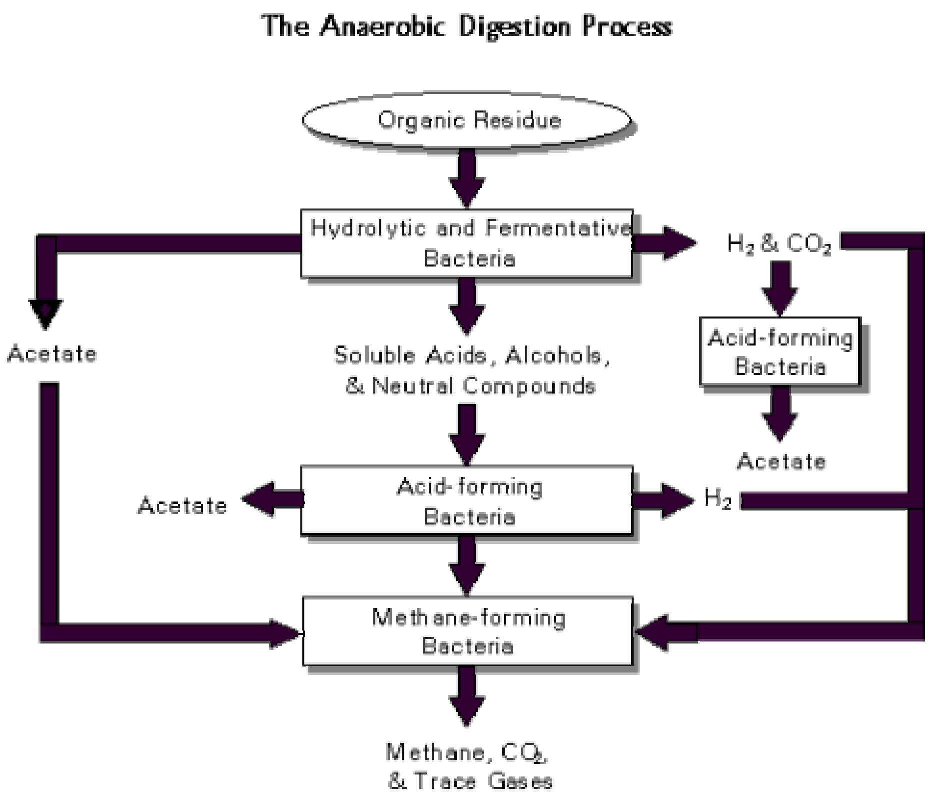


***figure 1**. Anaerobic digestion process*

As shown in the figure 1, the overall process of AD occurs through the symbiotic action of a complex consortium of bacteria. Hydrolytic micro organisms, including common food spoilage bacteria, break down complex organic wastes. These subunits are then fermented into short-chain fatty acids, carbon dioxide, and hydrogen gases.

Syntrophic micro organisms then convert the complex mixture of short-chain fatty acids to acetic acid with the release of more carbon dioxide, and hydrogen gases. Finally, methanogenesis produces biogas from the acetic acid, hydrogen and carbon dioxide. Biogas is a mixture of methane, carbon dioxide, and numerous trace elements. According to some, the two key biological issues are determining the most favourable conditions for each process stage and how non-optimal circumstances affect each process stage as a whole, and the governing role of hydrogen generation and consumption.

Sulphate-reducing bacteria, which reduce sulphates and other sulphur compounds to hydrogen sulphide, are also present during the process. Most of the hydrogen sulphide reacts with iron and other heavy metal salts to form insoluble sulphides, but there will always be some hydrogen sulphide in the biogas.

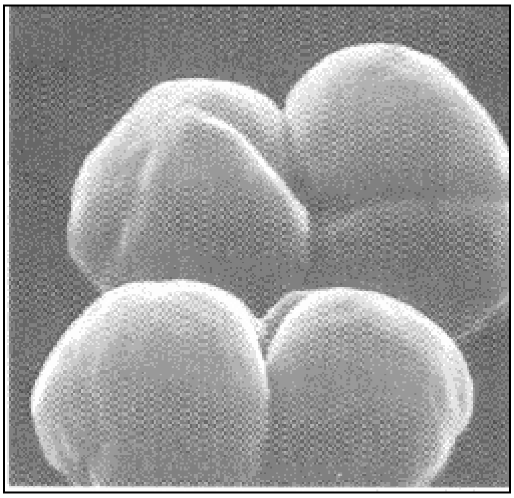


figure 2.Methanogenic Bacteria

The widespread natural occurrence of methane bacteria demonstrates that AD can take place over a wide temperature range from 4,5 ^{o}C(40°F) to more than 100 ^{o}C (212°F) and at a variety of moisture contents from around 60% to more than 99%. This distinguishes the methane bacteria favorably from most aerobic microorganisms involved in the composting process.

AD occurs in the psychrophilic temperature range 5-15^{0}C (less than 68°F), and is routinely observed in marsh gas and in the ambient temperature lagoons used for livestock. Conventional anaerobic digesters, as will be explained in greater detail, are commonly designed to operate in either the mesophilic temperature range 25-45^{0}C (95°-115°F) or thermophilic temperature range 55-70^{0}C (130°-160°F).

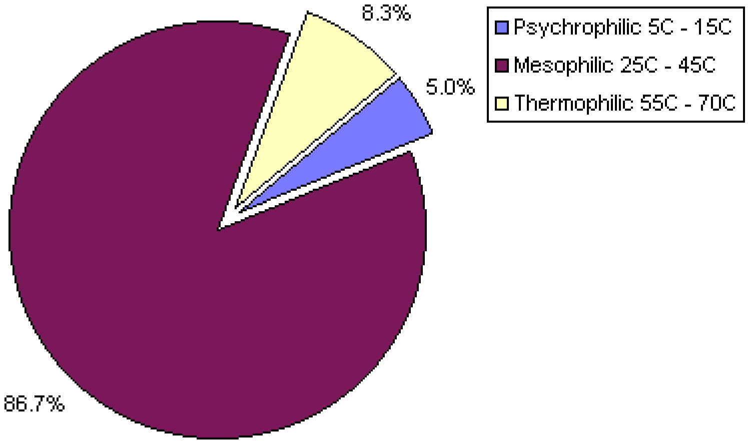


figure 3. Temperature Range - all digestors

There are usually two reasons why the mesophilic and thermophilic temperatures are preferred. First, a higher loading rate of organic materials can be processed and, because a shorter hydraulic retention time (HRT) is associated with higher temperatures, increased outputs for a given digester capacity result. Second, as will be discussed in more detail, higher temperatures increase the destruction of pathogens present in raw manure.

1.2 What is anaerobic Digestion?

Bacteria play a vital role in converting waste to energy. The same bacteria that produce methane at the landfill are used in the anaerobic treatment process to treat wastewater. Sadly, only a few thrifty municipal treatment plants are converting their digester gas (biogas containing 65-70% methane) into energy. Those that do are typically reducing their total wastewater treatment plant energy costs by one third to one half. But this only represents but the tip of the iceberg.

Traditional anaerobic treatment, frequently referred to as conventional high rate (CHR) treatment, is extremely inefficient at producing methane gas. It consists of a single vessel suspended growth digester at about 35 ^{0}C (95 F).

The operation of anaerobic digesters requires very close attention as the continuing adjustment of pH and alkalinity is process demanding. This is because two independent biological steps, or phases, are occurring simultaneously within a single fermentation or digestion vessel.

In the first phase *hydrolytic* and *acidogenic* bacteria convert dispersed and dissolved organics into aldehydes, alcohols, acids, and carbon dioxide (acetogenesis). In the second phase, methanogenic bacteria convert the 1st phase intermediates into mostly methane gas (methanogenesis). Sulfur compounds, if present, are reduced to hydrogen sulfide gas.

1.3 Different phases of anaerobic digestion.

The first phase biological digestion is optimized in a pH range of 5.0 to 6.0 at an ORP (oxidation/reduction potential) of -200 to -300mV whereas the second phase is optimized in a pH range of 7.2 to 8.2 at an ORP of -400 to -450mV. When both phases occur in a single vessel at a single pH and ORP an anaerobic reactor always operates way below process efficiency.

1.3.1 Improvements to the old procedure.

By isolating the independent biological phases, resulting process efficiency will enhance overall system performance and reduce the total size of the anaerobic digestion equipment.

Other significant improvements available are:

- Utilizing attached growth rather than suspended growth bacteria. This modification greatly decreases the total reactor size because of the inherent ability to accommodate up to a five-fold increase in active bacteria.

- Employing thermophilic bacteria at 59°C (138.2°F) metabolizes organics at four times the rate of mesophilic bacteria, permitting a further size reduction in digestion equipment as well as the associated HRT (hydraulic residence time).
- Staged treatment that increases process efficiency.
- Flow recirculation to further increase process efficiency by reducing the size of the required reactor vessel.
- Process controls and instrumentation to achieve environmental conditions that permit the several biological reactions to be optimized rather than obstructed, and
- The addition of essential micronutrients to permit the sophisticated anaerobic biology to reach its ultimate and remarkable effectiveness.

Conventional anaerobic treatment has been commercially practiced for the last sixty years. Process improvements have been slow to develop and unimpressive. Researchers and anaerobic treatment equipment manufacturers worldwide have been consistently troubled by the complexity of the biology as several reactions always occur simultaneously.

Research reports frequently cite plant start-up problems associated with the lowering of the pH so as to diminish methane production. The remedy was always to raise the pH to favor the methanogenic methane producing biology. In so doing, the higher pH also suppressed the performance of the several acidogenic reactions.

1.3.2 Phase Isolation for Efficiency

Both reactions work entirely without restraint when they are separated from each other and permitted to function at their individually preferred pH and ORP. This method is referred to as **two-phase treatment** and looks to rapidly become the dominant process of anaerobic treatment.

Although process refinement is far from over, most existing CHR plants can be upgraded to take advantage of the several process improvements available to achieve levels of treatment efficiency thought unattainable until now.

Therefore, although energy from waste can indeed be achieved using CHR technology, any such program would likely be as unsuccessful as the landfill methane gas-to-energy or municipal-solid-waste-to-energy efforts.

Elevating waste-to-energy technology to a successful commercial operation with a positive return on investment is, however, now possible. Anaerobic treatment digesters that capitalize on the process improvements available are capable of treating five to ten times more wastes, on an organic loading basis, than a usual CHR vessel.

1.4 A Short History Of Anaerobic Digestion

Anecdotal evidence indicates that biogas was used for heating bath water in Assyria during the 10^{th} century BC and in Persia during the 16^{th} century. Jan Baptita Van Helmont first determined in 17^{th} century that flammable gases could evolve from decaying organic matter. Count Alessandro Volta concluded in 1776 that there was a direct correlation between the amount of decaying organic matter and the amount of flammable gas produced. In 1808, Sir Humphry Davy determined that methane was present in the gases produced during the AD of cattle manure.

The first digestion plant was built at a leper colony in Bombay, India in 1859. AD reached England in 1895 when biogas was recovered from a “carefully designed” sewage treatment facility and used to fuel street lamps in Exeter. The development of microbiology as a science led to research by Buswell and others in the 1930s to identify anaerobic bacteria and the conditions that promote methane production.

In the world of AD technology, farm-based facilities are perhaps the most common. Six to eight million family-sized, low-technology digesters are used to provide biogas for cooking and lighting fuels with varying degrees of success. In China and India, there is a trend toward using larger, more sophisticated systems with better process control that generate electricity.

In Europe, AD facilities generally have had a good record in treating the spectrum of suitable farm, industrial, and municipal wastes. The process was used quite extensively when energy supplies were reduced during and after World War II. Some AD facilities in Europe have been in operation for more than 20 years. More than 600 farm-based digesters operate in Europe, where the key factor found in the successful facilities is their design simplicity. Around 250 of these systems have been installed in Germany alone in the past 5 years.

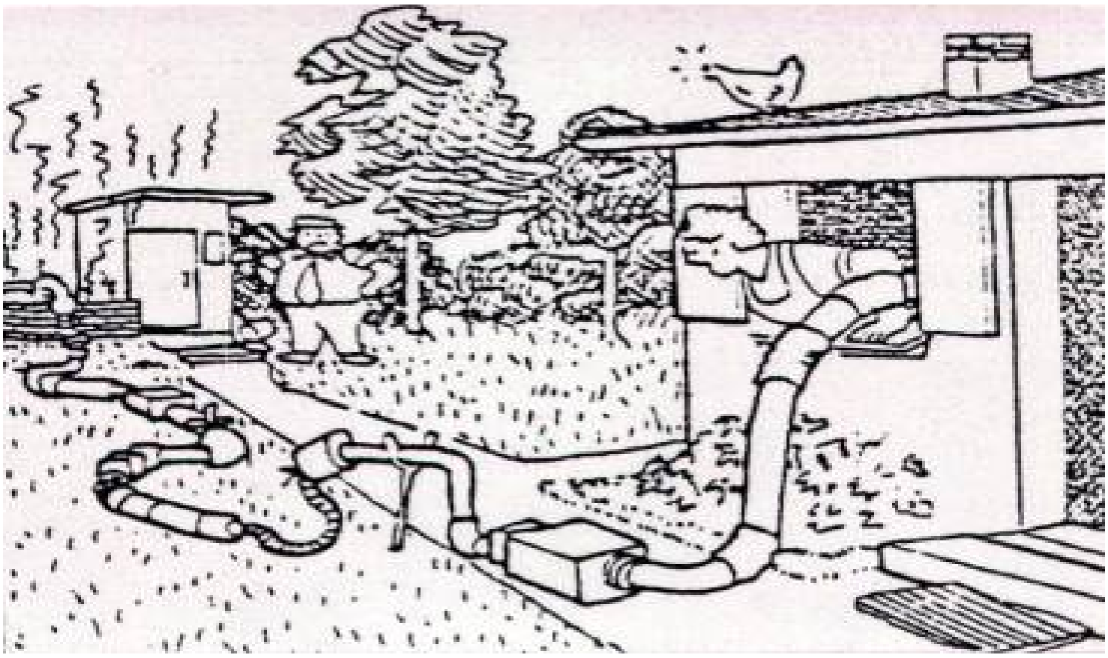


figure 4. *“There is enough for only one pancake and we have five people to feed!” dates from World War II when energy supplies for private use were drastically reduced"*

Other factors influencing success have been local environmental regulations and other policies governing land use and waste disposal. Because of these environmental pressures, many nations have implemented or are considering methods to reduce the environmental impacts of waste disposal.

The country with the greatest experience using large-scale digestion facilities has been Denmark, where 18 large centralized plants are now in operation. In many cases these facilities co-digest manure, clean organic industrial wastes, and source-separated municipal solid waste (MSW).

Denmark’s commitment to AD increased with an energy initiative that will triple it by the year 2005. One of the key policy tools used to encourage technology deployment is “green pricing,” i.e., allowing manufacturers of biogas-generated electricity to sell their product at a premium. Interestingly, the sales of co generated hot water to specially-built district heating systems is becoming an important source of revenue for project developers.

The use of the AD process for treating industrial wastewaters has grown tremendously during the past decade. Worldwide, more than 1,000 vendor supplied systems now operate or are under construction. It is estimated that European plants comprise 44% of the installed base. Only 14% of the systems are located in North America. A considerable number of the systems are located in South America, primarily Brazil, where they are used to treat the vinasse co product from sugar cane-based ethanol production.

figure 5. *A digester treating dilute wastewater at a fuel ethanol production plant in Brazil*

More than 35 example industries that use digesters have been identified, including processors of chemicals, fiber, food, meat, milk, and pharmaceuticals. Many use AD as a pretreatment step that lowers sludge disposal costs, controls odors, and reduces the costs of final treatment at a municipal wastewater treatment facility. From the perspective of the municipal facility, pretreatment effectively expands treatment capacity.

MSW digestion poses many technical problems, including an increase in HRT. High-solid digestion (HSD) systems have been developed with the potential to improve the economic performance of MSW systems by reducing digester volume and the parasitic energy required for the AD process. Several alternative HSD designs have been developed that operate with total solids (TS) concentrations greater than 30%. These designs employ either external or internal mixing, using biogas or mechanical stirrers.

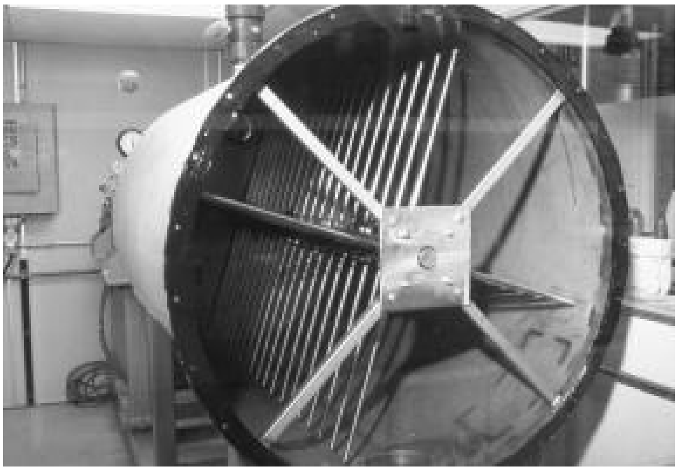


figure 6. Prototype HSD system developed in the United States uses equipment adapted from the mining industry(photo credit: Pinnacle Biotechnologies)

Chapter 2

Energy and Anaerobic Digestion

Processes such as AD and composting offer the only biological route for recycling matter and nutrients from the organic fraction of MSW. Composting is an energy-consuming process, requiring 50-75 kWh of electricity per ton of MSW input. Composting technology for MSW is commercially available and in use, but its further application is limited mainly by environmental aspects and process economics. AD is a net energy-producing process, with around 75-150 kWh of electricity created per ton of MSW input. MSW digestion technology is now being demonstrated and fully commercialized.

The theoretical methane yield can be shown to be 5.6 ft^3/lb (0.35m^3/kg) of chemical oxygen demand converted, but the exact recoverable yield depends on a number of environmental conditions. The ultimate yield of biogas depends on the composition and biodegradability of the organic feedstock, but its production rate will depend on the population of microorganisms, their growth conditions, and fermentation temperature.

2.1 Methane and Natural gas

Methane produced by the AD process is quite similar to “natural” gas that is extracted from the wellhead. However, natural gas contains a variety of hydrocarbons other than methane, such as ethane, propane, and butane. As a result, natural gas will always have a higher calorific value than pure methane. Depending on the digestion process, the methane content of is biogas generally between 55%-80%. The remaining composition is primarily carbon dioxide, with trace quantities (0-15,000 ppm) of corrosive hydrogen sulfide and water.

The average expected energy content of pure methane is 500-700 Btu/ft^3 (1Btu/ft^3 = 37,26KJ/m^3), natural gas has an energy content about 20% higher because of added gas liquids like butane. However, the particular characteristics of methane, the simplest of the hydrocarbons, make it an excellent fuel for certain uses. With some equipment modifications to account for its lower energy content and other constituent components, biogas can be used in all energy-consuming applications designed for natural gas.

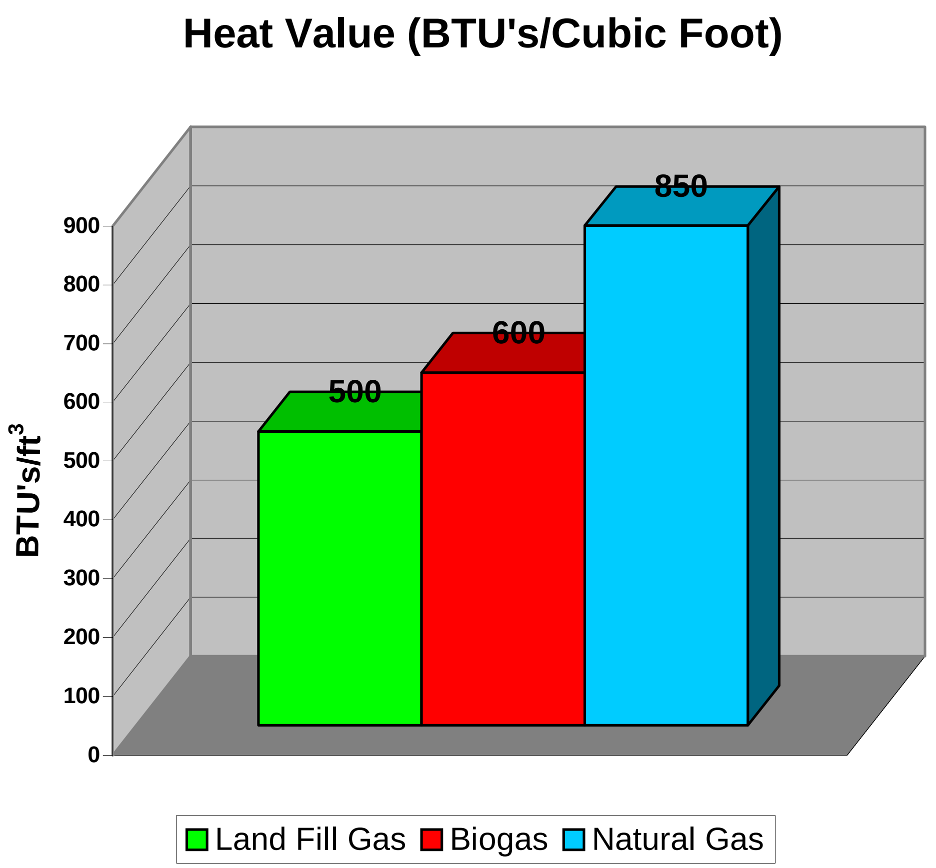


figure 7. Heat values (1Btu/ft^3 = 37,26KJ/m^3).

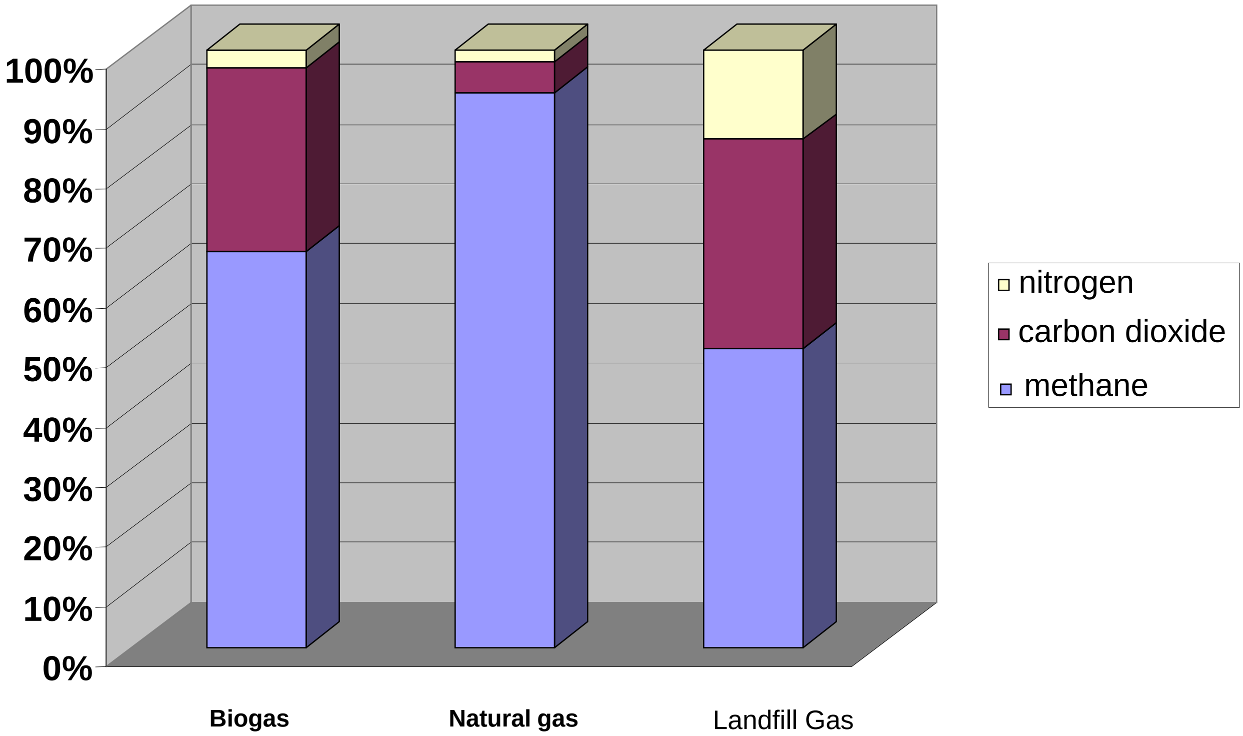


***figure 8*.**Composition of different gases.

2.2 End-Use of Biogas

Today, biogas it is commonly burned in internal combustion engines to generate electricity. Practical experience with small-scale internal combustion engines with a rated capacity of less than 200-kW indicate an electrical conversion efficiency of less than 25%. Larger engines can have a greater conversion efficiency. One engine supplier claims to have an engine with an electrical conversion efficiency that averages 38% for engines in the 600-1000 kW range.

figure 9.Biogas use in internal combustion engine

When biogas is used to produce electricity, there is the added potential for harvesting hot water and steam from the engine's exhaust and cooling systems. Combining hot water and steam recovery with electricity generation may provide an overall conversion efficiency of 80% or more. Biogas is also burned in boilers to produce hot water and steam used for heating and sanitary washing.

While operating at a technology level requiring specially trained maintenance personnel, a promising near-term application for biogas-fueled electricity generation is the use of gas turbines. For larger-scale systems, combined cycle power stations consist of gas turbines, steam turbines, and waste heat recovery boilers, all working together to produce electricity. Modern gas turbine plants are small, environmentally friendly, and visually unobtrusive. Units as small as 200-kW are available but their electrical efficiency is quite low, around 16-18%. Only at scales of greater than 800kW does the heat rate equal or surpass an engine-based system. However, the use of a gas turbine allows a greater fraction of the waste heat to be recovered as potentially more valuable steam. Overall gas turbine efficiency can be greater than 70%.

Biogas is also successfully compressed for use as an alternative transportation fuel in light and heavy-duty vehicles. To obtain usable methane, the biogas is scrubbed of its carbon dioxide, hydrogen sulfide, and water.

figure 10. A compact unit that scrubs and compresses biogas for use in alternative motor fuel

After scrubbing, the technique of fueling with biogas is basically the same as that used for compressed natural gas (CNG) vehicles. Although only a few thousand vehicles are using biogas, it is estimated that worldwide around one million vehicles are now using CNG as a transportation fuel.

The change to CNG operation means that a vehicle is converted or that a new one is specially built. Vehicles can operate in three different modes: as a dedicated CNG; as a bi-fuel on either gas or gasoline; or as a simultaneous dual-fuel on gas and diesel fuel. The CNG is stored in a number of tank cylinders made of steel or fiberglass that are filled with gas to a high pressure. The normal number of tank cylinders will provide enough capacity to cover 150-175 miles. Fleet vehicles that are parked overnight, such as buses, are fueled slowly for 5-8 hours. Quick filling takes about 2-5 minutes, and is used for vehicles in constant use such as service vans. Because methane burns very cleanly, many fleet operators have reported savings of 40%-50% in vehicle maintenance costs. In many countries, biogas is viewed as an environmentally attractive alternative to diesel and gasoline for operating buses and other local transport vehicles. The level of sound generated by methane-powered engines is generally lower than that generated by diesel engines, which is a positive aspect, particularly in an urban environment. Exhaust fume emissions are considerably lower than the emissions from diesel engines, and the emission of nitrogen oxides is very low.

2.3 Why Anaerobic Digestion(AD) ?

There are a number of benefits resulting from the use of AD technology.

2.3.1 Waste Treatment Benefits

Natural waste treatment process.

Requires less land than aerobic composting or landfilling.

Reduces disposed waste volume and weight to be landfilled.

Reduces concentrations of leachates.

2.3.2 Energy Benefits

Net energy producing process.

Generates a high-quality renewable fuel.

Biogas proven in numerous end-use applications.

2.3.3 Environmental Benefits

Significantly reduces carbon dioxide and methane emissions.

Eliminates odors.

Produces a sanitized compost and nutrient-rich fertilizer.

Maximizes recycling benefits.

2.3.4 Economic Benefits

Is more cost-effective than other treatment options from a **life-cycle** perspective.

2.4 Description Of A Successful Digestion System

An anaerobic digester is a completely closed (oxygen free) system that receives and biologically treats manure with naturally occurring organism. A successful system is easy to operate, is cost effective and characterized by consistent and significant: reduction in total solids, production of methane rich biogas, and effluent with less odor, reduction of pathogenic organisms and weed seeds than was present in the incoming waste. In a successful system no additives or additional organisms are required. Anaerobic digestion systems may have biogas capture and utilization for production of power and/or heat. The system may have solids recovery.

2.4.1 Economic

Digestion systems may both directly and indirectly enhance revenues of the production facility.

2.4.2 Direct Economic Benefits

Several ways a digestion system may directly impact the facility are:

A system, which includes equipment to convert biogas to electricity, and hot water, may sell electricity directly to utilities; gas or hot water may also be sold.

A system, which includes equipment to remove suspended solids from the liquid, may sell digested fiber.

Digestion systems will greatly reduce the viability of seeds found in the waste stream. Consequently, there is the potential less herbicide will need to be purchased.

Though the market is not developed to date, there is speculation that waste managers treating certain waste streams may eventually be able to sell pollution credits; current discussion focuses on sale of CO_2 credits associated with combustion of manure derived methane which would otherwise have been emitted to the atmosphere.

Through the assistance of a tax specialist system ownership may be structured to permit sale of certain tax benefits associated with system installation.

2.4.3 Indirect Economic Benefits

The greatest potential indirect economic benefit is the reduction in risk of the facility being subject to legal action and forced outright closure. Digestion systems, properly designed and operated, significantly reduce the odors associated with manure management.

Even if electricity or hot water are not directly sold:

Digestion systems with biogas conversion equipment (boilers, engine generator sets) have the potential to replace purchased electricity and fuel.

Recovered digested solids may be used for animal bedding, offsetting the cost of bedding purchase.

System using solids separation equipment will reduce lagoon or storage cleaning costs.

Because digested manure is biologically stable, the design size (and capital cost) of the storage facility will correspondingly be greatly reduced.

Research in many countries indicates manure stream nutrient availability and plant uptake may be improved with digestion. Fertilizer purchases are expected to be reduced and crop yields possibly improved.

The pumpability of digested liquid is greatly improved.

2.4.4 Non-Economic

Staff as well as neighbors would prefer to not deal with odors associated with manure management. In digestion, compounds, which usually produce odors, are greatly reduced. Pathogenic organism are greatly reduced, most more than 90%, many more than 95%, a few only 50% or more (note: they are not to be considered eliminated).

2.5 A Brief Environmental Analysis

The inclusion of methane, the primary component in natural gas and biogas, in emission strategies is key to curbing global warming, according to a team of atmospheric scientists, economists and emissions experts. The scientists found that by including methane in abatement strategies, the costs of meeting the global emission-reduction targets could be lowered.

It has been estimated that for short-term targets, methane can offset carbon dioxide reductions and reduce global. abatement costs by more than 25 percent compared to strategies involving carbon dioxide alone.

Because methane remains in the atmosphere about 12 years, a short time compared to other greenhouse gases, concentrations will respond quickly to emission reductions, producing an immediate and significant impact on climate change. It takes carbon dioxide, the top human-caused greenhouse gas, anywhere from 50 to 200 years to disappear from the atmosphere. Methane is the second-most important greenhouse gas. Together, methane and other non-carbon dioxide gases are currently responsible for about 40 percent of the global warming problem. However, reducing carbon dioxide emissions is still the primary means of achieving significant long-term mitigation of climate change. Over the last two centuries, methane concentrations in the atmosphere have more than doubled, largely due to human-related activities.

2.5.1 Kyoto Protocol

World leaders established the Kyoto Protocol in 1997 to create standards to stabilize six greenhouse gases in order to lessen global climate warming. Members of the industrialized world committed to improving emissions based on a five-year budget period from 2008 to 2012. The targets cover emissions from carbon dioxide (CO_2), methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride.

2.5.2 Methane Emission

Methane is naturally occurring, but human-related activities such as landfills, coal mining, livestock, manure and the production and transmission of natural gas are the five major sources of human-produced methane all over the world. Methane's natural sources include wetlands, natural gas and permafrost.

A significant amount of these emissions can be reduced by applying available and economically worthwhile options such as capturing the methane and recovering the cost of the emission-reduction technology by selling the gas or using it to substitute for other energy inputs, according to the scientists.

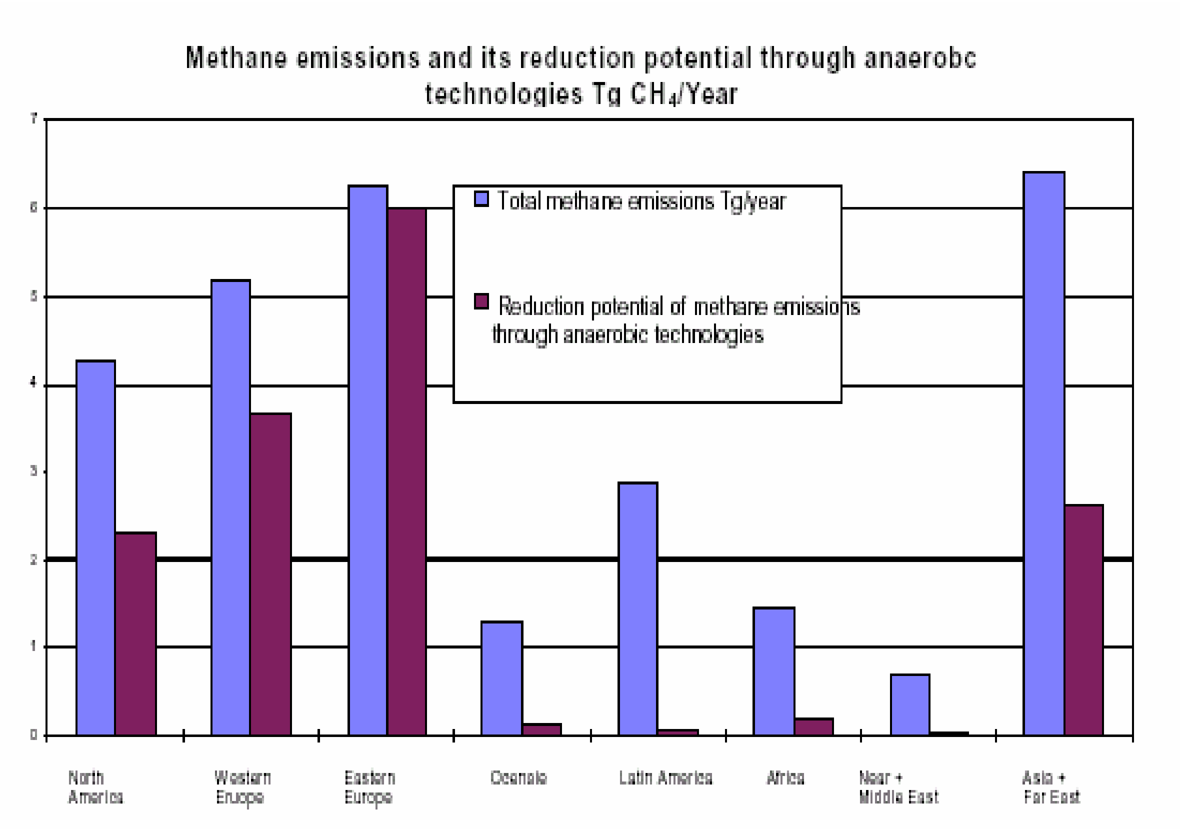


figure 11. Methane reduction potential through anaerobic technologies

Methane is produced by several sources where gas can be contained and measures can be taken to prevent it from being released to the atmosphere. For example, cattle manure can be collected and placed in a digester. As anaerobic decay occurs, methane is produced. This methane can be removed from the digester and used to generate electricity. By capturing methane lost during normal operations, companies can benefit by using this fuel source onsite, selling it to utilities, or selling it directly to end users while benefiting the environment.

Chapter 3

Design requirements for our case study

Anaerobic digester system costs vary widely. Systems can be put together using off-the-shelf materials. There are also a few companies that build system components. Sophisticated systems have been designed by professionals whose major focus is research, not low cost. Factors to consider when building a digester are cost, size, the local climate, and the availability and type of organic feedstock material.

The availability of inexpensive fossil fuels has limited the use of digesters solely for biogas production. However, the waste treatment and odour reduction benefits of controlled anaerobic digestion are receiving increasing interest. Where costs are high for sewage, agricultural, or animal waste disposal, and the effluent has economic value, anaerobic digestion and biogas production can reduce overall operating costs.

3.1 Project Background

3.1.1 Purpose

- To determine the economic and technological feasibility of using digester gas for onsite power and process heat.
- Basic information of the technologies that utilize biogas a fuel.
- Three Technology options and a base case (status quo) were studied.
- Evaluation Criteria were established to meet the specific need of the plant.
- Greenhouse Gases reduction is a requirement.

3.1.2 Evaluation Criteria

Location.

Population data.

Energy produced.

Energy Utilization.

Thermal / Heat Recovery Interface.

Gas Clean-up/Sequestration Options.

Determine the advantages and disadvantages of each option and to quantify the economics of the best performer.

3.2 Location

Our feasibility study will take place in an small island in Greece. We assume that the present status is the disposal of wastes into a swamp without any further process. This of course causes extra odours and affects the local environment.

3.3 Population Data

The regular habitants of the island are approximately 3500 people but during summertime there is an increase in the population of about 2000 people. For our calculations will take an average of 4000 people during a year. That is concluded from the following formula.

$$population\ average = \frac{3500*12+2000*3}{12} = 4000$$

3.4 Methane Yield-Energy Produced

The basic parameters required to determine the methane potential of wastewater are the biochemical oxygen demand (BOD) and an emission factor. The amount of degradable carbon is derived from the BOD. It is the degradable carbon that is potentially available to form methane. The larger the amount of degradable carbon and the more anaerobic the process, the greater the quantity of CH_4 that will be produced.

Data needed are:

Degradable organic component (DC) indicator in kilograms of DC per 1000 persons per year. BOD is the more commonly used DC indicator for municipal wastewater.

Actual capacity of the plant (number of persons) (P)

Fraction of BOD removed as sludge

Methane is obtained from wastewater and from sludge.

The basic equations

$MW = BOD_w \times EF_w$ for wastewater; and

$MSL = BOD_{sl} \times EF_{sl}$ for sludge.

where:

BOD_w is the BOD of wastewater

BOD_{sl} is the BOD of the sludge

EF_w is the methane emission factor for wastewater

EF_{sl} is the methane emission factor for sludge

This means that you need to estimate BOD_w, BOD_{sl}, EF_w and EF_{sl}.

3.4.1 The equation to estimate BODw

$BOD_w = P \times DC_w \times (1 - F_{sl})$

where:

BOD_w is wastewater in kg BOD per year

P is population served (in 1000 persons)

DC_w is kg BOD per 1000 persons per year of wastewater

F_{sl} is fraction of degradable organic component removed as sludge.

3.4.2 The equation to estimate BODsl

$BOD_{sl} = P \times DCw \times F_{sl}$

where:

P is population served (in 1000 persons)

DC_w is kg BOD per 1000 persons per year of wastewater

F_{sl} is fraction of degradable organic component removed as sludge.

3.4.3 Determination of an emission factor (EF) and estimation of a methane conversion factor (MCF).

This is derived by determining:

Maximum methane producing capacity *(M_o or M_{sl}):* The methane producing potential is the maximum amount of CH_4 that can be produced from a given quantity of wastewater or sludge. The methane potential varies by the composition of the wastewater sludge and its degradability. The default value for BOD and COD is 0.25 kilograms of CH_4 per kilogram of BOD or COD. This value can be used for preliminary calculations.

Fraction of wastewater treated by certain handling systems *(F_a and F_{an}):* These are the fractions of wastewater treated by specific handling systems (aerobic (a) or anaerobic (an)). If the system is completely anaerobic then F_{an} equals 1 and F_a equals 0.

Fraction of sludge treated by certain handling systems *(FSL_a and FSL_{an}):* These are the fractions of sludge treated by a specific handling system (aerobic (a) or anaerobic (an)). If the sludge is treated anaerobically to maximise CH_4 production then FSL_{an} equals 1 and FSL_a equals 0.

Methane conversion factor *(MCF_w or MCF_{sl}):* The amount of methane that is actually produced depends on the MCF. The MCF defines the portion of

CH_4 producing potential (M_o or M_{sl}) that is achieved. For a completely anaerobic system the MCF equals 1. This is the value that can be used for these calculations.

The values that are assigned are:

$M_o = M_{sl}$ = 0.25 kg per kg of BOD

$F_a = 0$

$F_{an} = 1$

$FSL_a = 0$

$FSL_{an} = 1$

$MCF_w = 1$

$MCF_{sl} = 1$

3.4.3.1 The emission factor for wastewater

$EF_w = M_o \times Fan \times MCF_w$

$= 0.25 \times 1 \times 1$

3.4.3.2 The emission factor for sludge

$EF_{sl} = M_{sl} \times FSL_{an} \times MCF_{sl}$

$= 0.25 \times 1 \times 1$

3.4.3.3 Methane from wastewater

$MW = BOD_w \times M_o \times F_{an} \times MCF_w$

3.4.3.4 Methane from sludge

$MSL = BOD_{sl} \times M_{sl} \times FSL_{an} \times MCF_{sl}$

Assumptions to estimate the total methane

Assuming that M_o and M_{sl} equal the default value of 0.25 kg per kg of BOD, and that MCF_w and MCF_{sl} equal 1, then:

$EF_w = 0.25$, and

$EF_{sl} = 0.25$.

A straightforward calculation can be undertaken to obtain guidance as to the total quantity of CH_4 that could be produced. Namely:

$$MW = BOD_w \,´\, 0.25$$

$$MSL = BOD_{sl} \,´\, 0.25$$

$$MW + MSL = (BOD_w \times Mo \times F_{an} \times MCF_w) + (BOD_{sl} \times M_{sl} \times FSL_{an} \times MCF_{sl})$$

$$= [P \times DC_w \times (1 - F_{sl}) \times Mo \times F_{an} \times MCF_w] + [P \times DC_w \times F_{sl} \times M_{sl} \times FSL_{an} \times MCF_{sl}]$$

$$= [P \times DC_w \times (1 - F_{sl}) \times 0.25] + [P \times DC_w \times F_{sl} \times 0.25]$$

Data on DC_w should be readily available to wastewater treatment plants as should the fraction of BOD removed as sludge. Once the methane potential has been estimated the plant is in a position to decide whether further investigation is warranted. Energy production can be explored to determine whether it is a viable option. This could include an energy audit of the operations.

The default value that can be used for the preliminary calculation is 18,250 kg per 1000 persons per year. Assume that our plant serves a population of 4000, and that the fraction of BOD removed as sludge is 0.63 (the value used to calculate the national inventory).

Then:

$$MW + MSL = [4 \times 18{,}250 \times (1 - 0.63) \times 0.25] + [4 \times 18{,}250 \times 0.63 \times 0.25]$$

$$= 6752{,}5 + 11497{,}5$$

$$= 18250 \text{ kg of methane}$$

3.5 How much energy?

One cubic metre of CH_4 has a heating value (or energy content) of around 33,810 kilojoules. This implies that 1 kilogram of CH_4 will yield 50,312.5 kJ of energy or equally 1 kg of CH_4 will yield 13.975kWh

. The energy potential of 18250 kg of methane:

= 918,203,125 kJ

= 255,056 kWh

255056/365*24=29kWh

which means that we have an average production of 2 kg of CH_4 per hour.

3.6 Gas cleanup requirements

Upgrade of biogas to natural gas quality

Biogas can be processed to extract a gas that is almost 100 per cent methane, so that the product is chemically equivalent to natural gas. The processing involves removing the carbon dioxide and trace contaminants from Biogas using complex refining systems. Facilities that process Biogas to natural gas quality are rare. One study estimated that in 1994, only 4 per cent of Biogas extracted for energy use in the US was being upgraded to natural gas quality. This approach to energy recovery is expensive. Relatively high processing costs, compared to the cost of extracting natural gas, mean that this application of Biogas has proved to be uneconomic throughout the world. Investment in refining equipment is a key outlay, representing a large fixed cost. This cost can be justified if the price of natural gas sustains a per-unit profit on variable costs that covers the fixed cost. Given a low price of natural gas, a sustainable per-unit profit will be small. This means that upgrading Biogas to natural gas will be economic only at very large projects. One estimate is that a Biogas flow of more than 4,000 m^3/hr is needed for upgrading to be viable.

3.7 Digester Designs

Anaerobic digesters are made out of concrete, steel, brick, or plastic. They are shaped like silos, troughs, basins or ponds, and may be placed underground or on the surface. All designs incorporate the same basic components: a pre-mixing area or tank, a digester vessel(s), a system for using the biogas, and a system for distributing or spreading the effluent (the remaining digested material).

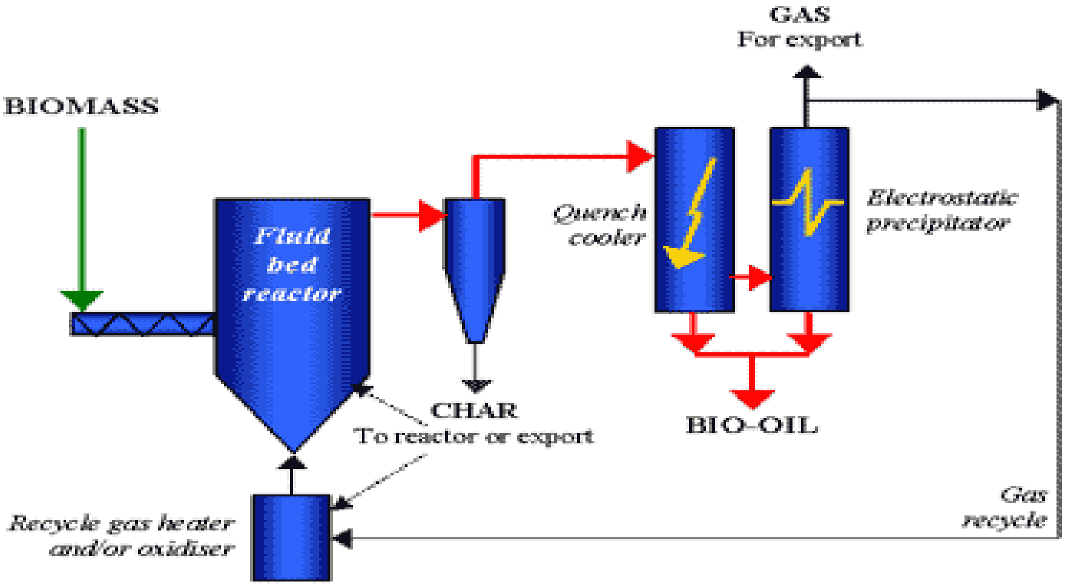


figure 12.Typical biomass plant design

There are two basic types of digesters: batch and continuous.

Batch-type digesters are the simplest to build. Their operation consists of loading the digester with organic materials and allowing it to digest. The retention time depends on temperature and other factors. Once the digestion is complete, the effluent is removed and the process is repeated.

In a continuous digester, organic material is constantly or regularly fed into the digester.

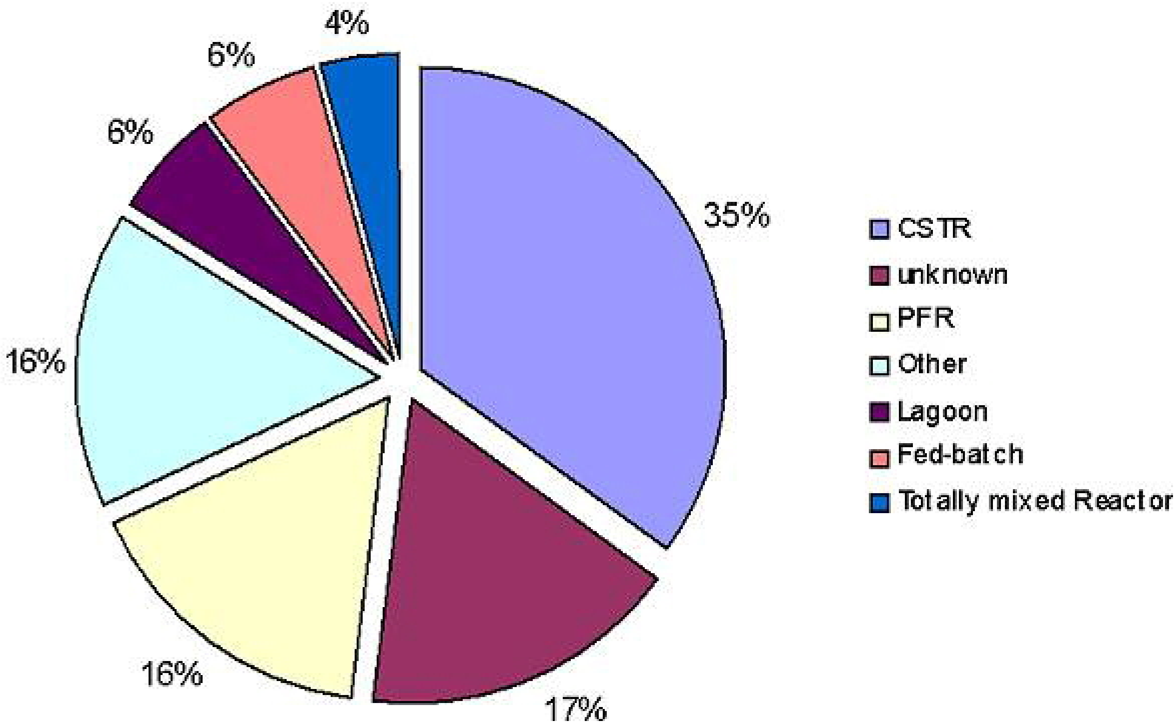


figure 13 .*Different types of digesters*

The material moves through the digester either mechanically or by the force of the new feed pushing out digested material. Unlike batch-type digesters, continuous digesters produce biogas without the interruption of loading material and unloading effluent. They may be better suited for large-scale operations. There are three types of continuous digesters: vertical tank systems, horizontal tank or plug-flow systems, and multiple tank systems. Proper design, operation and maintenance of continuous digesters produce a steady and predictable supply of usable biogas.

The continuous stirred tank reactor (CSTR) is the most common type of technology in use (35%), since it is both comparatively cheap and simple to operate, closely followed by the plugged-flow reactor (PFR) (13%). Unfortunately, some 17% of the technologies still remain unclassified.

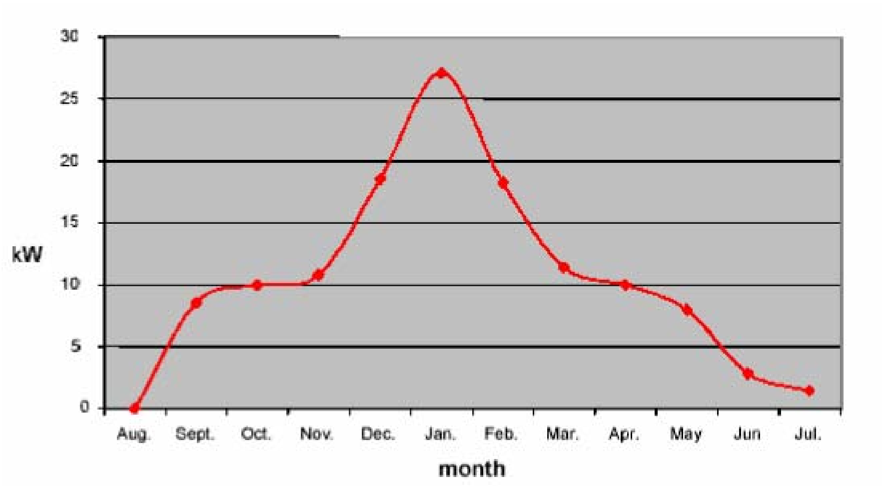


figure 14.**Heat demand for the sewage treatment digester**

Our choice of the anaerobic digester will be a batch type digester because it's the best choice for the volume of our wastes and the scale of the expected biogas production, it is simpler to build and easier to operate, it is also cheaper and with lower maintenance cost. The heat demand for the type and the size of our digester is presented in figure 14. We see that the biogas produced in our case study can fully satisfy the heat demand of our digester.

Chapter 4

Technology Survey

Technology Options

- Internal Combustion Engine.
- Fuel Cell.
- Microturbines.

4.1 Reciprocating Engines

Technology is readily available and accepted throughout industry

- Electrical efficiencies near 40%.
- Improvement in noise and emissions reduction.
- Retooling for fewer moving parts has led to reduced routine maintenance expenses.
- Engines are mostly designed for liquid fuels - models at this project scale are not available.

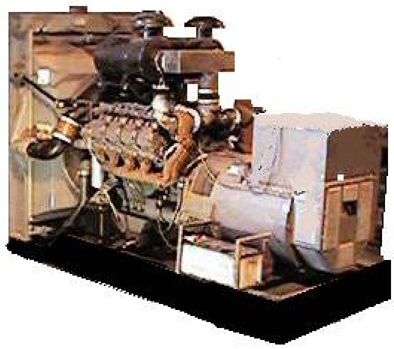


***figure 15**. Internal combustion Engine*

- Most sewage gas engines (> 300 kw range) too large for this project (< 30 kW of gas available).
- Engine this size would replace approximately 80%-90% of the power presently supplied to the entire plant on a daily basis.

- Cost of € 360,000 or €120/kW for a 300kW unit would be expected for this scale.
- Operation and maintenance (O&M) costs for units will be very high.

4.2 Fuel Cells

- Rapidly developing distributed resource technology option.
- High initial cost - as high as €3000/kW.
- Selection of this technology limited by the unavailability of a unit for our scale of operation.
- Residential units with a 7-10/kW range and a capital cost of €8,000 to €12,000 are in operation from the end of 2000.
- Units could meet the energy and heating needs of our case study . A "stack " of two or three fuel cells could utilize all the digester gas produced and supply approximately 30kW of electricity.
- Clean supply of gas is required to produce the hydrogen used in the reaction to produce electricity.
- Sewage digester gas contaminated with other chemical components (H_2S, CO_2, etc.) that can damage the fuel cell equipment.
- Utilization of the digester gas would require a clean-up step.
- Gas cleanup stage to remove Hydrogen Sulfide (H_2S) could add an additional €40,000 to €60,000 to the initial cost and add around €10,000 annually for maintenance.
- Commercial fuel cell in the range of 30/kW would cost €90,000 at present pricing.

figure 16 **.** *Fuel Cells*

- Fuel cell availability for this size (30kW) is very low in general the industry is working on residential (7-10KW), portable and large-scale utility (>1MW) type products.

4.3 Microturbines

- Microturbines have been demonstrated to operate on various fuels and to produce low emissions.
- Efficiencies of 25%-30% have been reported. This efficiency can be increased with exhaust-heat recovery to produce area space heating, process heat or even process steam.
- Microturbines reported with 10,000 hours of operation with only routine shut downs for scheduled maintenance.

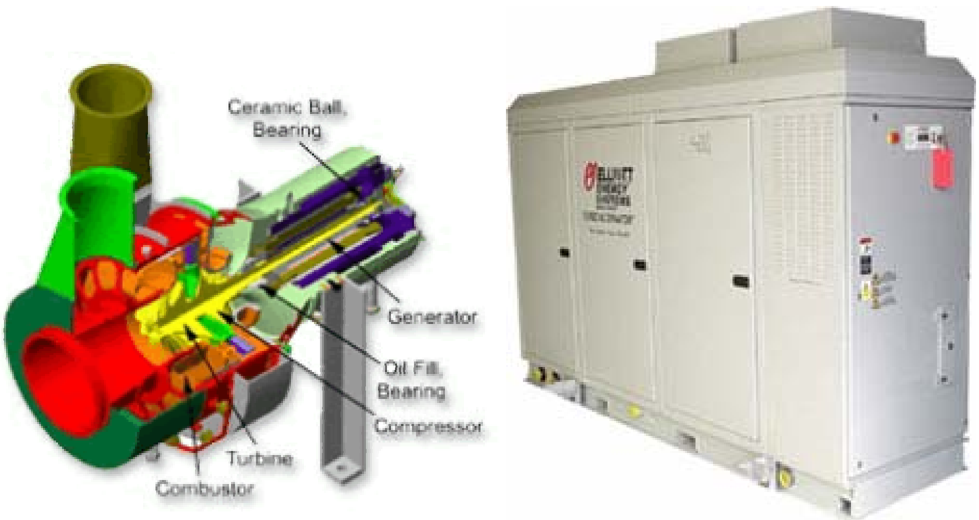


figure 17. Microturbines

- Microturbine features only one moving part, is air cooled, is designed with an air bearing that is reported to eliminate the need for lubricants and coolant. Requires very little routine maintenance.
- Recent tests have proven reduced hydrocarbon emissions and a reduction of NO_x emissions (a smog precursor, ground-level ozone) from 30 ppm (flare levels) to 1.9 ppm.
- Operated on untreated gas mixture (~50% CH4, ~50% CO2) for more than 1300 hours with minimal problems.
- The quantity of gas produced in our case study will be sufficient to operate a 30/kW unit for a period of at least 12 hours a day.
- Microturbine can handle up to 7.0% H_2S which is 14 times the concentration of the plant digester gas.

4.4 Conclusions

The microturbine appears to be a good fit for the needs of our case study . It's use will meet most of the established requirements. The choice of a 30/kW unit will use all of the digester gas produced.

The small size of these packaged units will allow for installation almost anywhere, it would be better a location close to the existing swamp (where the wastes are end up). A small concrete pad and maybe a shed are all that is needed for this area. The exhaust from the turbine will be used to improve the heating capabilities of the sludge heating boiler.

Chapter 5

Life cycle Cost Analyses of selected Biogas Utilization Option .

5.1 Purpose of Life Cycle Cost Analysis

- Which biogas utilization project is the best investment?
- How could this project investment compare with some other investment (of the same duration and risk) ?

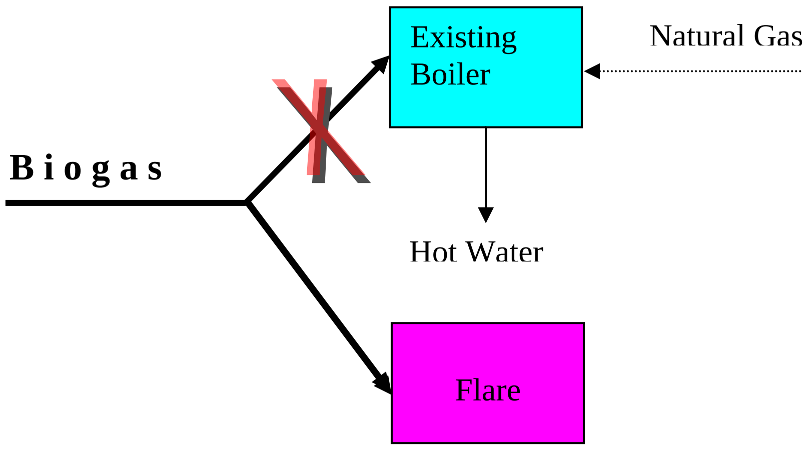
What if

- o The capital cost estimate is too low
- o Energy prices change
- o Biogas production decreases?
- o Equipment performance is worse than expected

our case study will include 4 different cases. We consider the first case as the Status Quo where no biogas is combusted to the boiler and all the produced quantity of biogas is flared, the energy needs for our plant are covered from the use of natural gas.

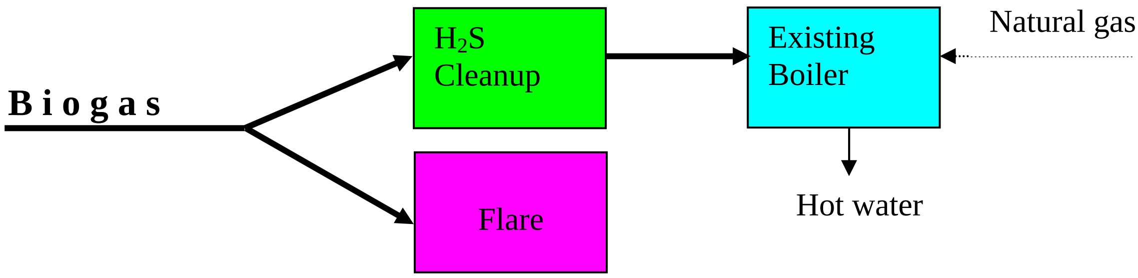
5.2 Case 0:Status Quo

No Biogas is combusted in boiler due to black powder formation. All Biogas is flared



5.3 Case 1:H_2S Removal

Biogas is stripped of H_2S and burned in boiler to heat water. Excess biogas is flared. If there is a need for extra energy we use Natural gas.



5.4 Case 2:Microturbine With heat Recovery

Raw Biogas is burned in turbine to produce power. Excess biogas is flared. Turbine exhaust heat recovered to heat water.

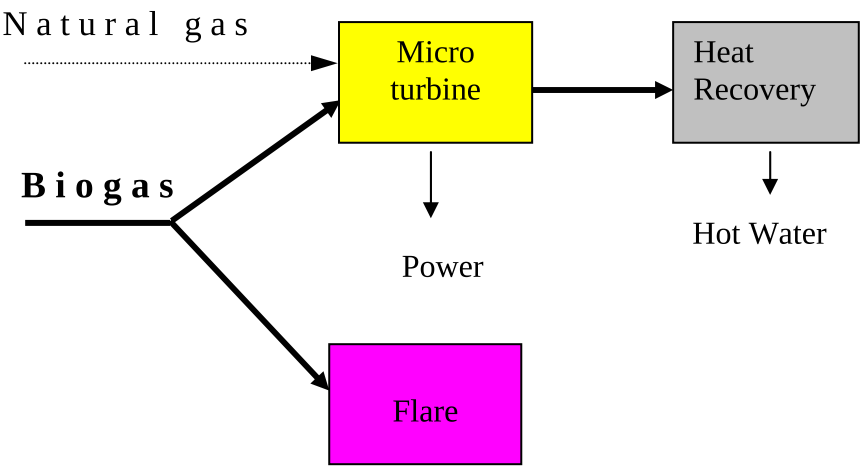


figure 18 . Case 2:Microturbine With heat Recovery

5.5 Case 3:H_2S Removal and Microturbine with Heat Recovery

Biogas is stripped of H_2S and burned in microturbine, producing power and hot water. Excess biogas is burned in boiler to heat water

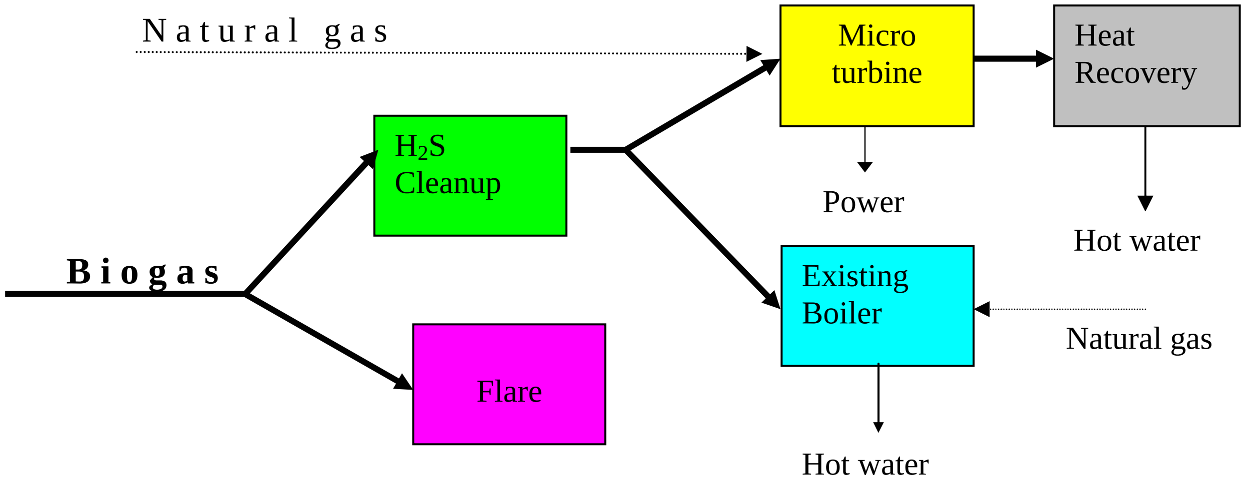


figure 19 . Case 3:H_2S Removal and Microturbine with Heat Recovery

5.6 LCC Analysis Overview

- Costs & savings occur throughout a project's life.
  - Capital costs.
  - O&M, equipment refurbishment and avoided utility costs.
  - Salvage costs.
- LCC analysis combines these cash flows into an estimate of the project's net worth by discounting them to their <u>present</u> values.
- This Net Present Value (NPV) is the difference in today's Euros ,between:
  - The net return you would obtain from investing in the proposed project.
  - The interest you would earn by investing the same Euros at the chosen discount rate.
  - A positive NPV means the project is a better investment.
- Future cash flows are estimated in current Euros and discounted using a nominal discount rate, i.e one that includes both
  - The general inflation rate (the change in a Euros's purchasing power).
  - The time –value of money (a Euro's earning power).
- The nominal discount rate.
  - Should be equivalent to the investor's minimum acceptable rate of return for investments of equivalent risk and duration.
  - Is usually based on market interests rates, which include the investor's expectation of general inflation.

5.7 Operation Strategies for Process Models

Four process models were prepaired in Ms Excel

- Case 1 :H_2S removal

    -All biogas is burned in existing boiler

- Case 2a:Microturbine

    -Biogas not needed by turbine is stored or flared (none is used in boiler)

    -If biogas is not sufficient for turbine, the fuel supply is supplemented with natural gas

- Case 2b:Microturbine + Heat recovery

    -Biogas not needed by turbine is stored or flared (none is used in boiler).

    -If biogas is not sufficient for turbine, the fuel supply is supplemented with natural gas.

    -We take advantage of heat recovery.

- Case 3: H_2S removal + Microturbine + Heat recovery

    --Biogas not needed by turbine is stored or flared (none is used in boiler) .

    -If biogas is not sufficient for turbine, the fuel supply is supplemented with natural gas .

    -We take advantage of heat recovery

    - because of the H_2S removal excess biogas is burned in existing boiler.

5.8 Economic inputs

Economic Inputs	
Annual Nominal Discount Rates	8 %
Annual General Inflation Rate	4 %
First Year Marginal Utility Rates	
Natural Gas ,€ / MMBtu (1MMBtu =293 kWh)	7.58
Electricity Demand ,€ / kW - month	4.69
Electricity Energy Rate ,€ / kW	0.037
Avg Annual NOMINAL Escalation Rates for Delivered Energy costs	
Natural Gas	5.3 %
Electricity	3.3 %

table 1 . Economic inputs

- Discount and inflation rates were estimated.
- Utility rates are our project's current marginal rates.
- Energy cost escalation rates are the average annual rates from the relevant ministry in Greece.
- Project life is 10 years.

5.9 Equipment Performance & Operational Data

Equipment Performance & Operational Data	
Existing Hot Water Boiler (Sludge Heater)	
Avg Boiler Efficiency on Natural Gas , LHV*	0.8
Avg Boiler Efficiency on Digestor Gas , LHV*	0.75
Treatment Plant System Data	
Average Digestor GasFlow Rate,CF/day	18000
Average Digestor Gas LHV,Btu/CF (Btu/ft^3=37,26KJ/m^3)	600

table 2 . Equipment Performance & Operational Data

-Boiler efficiencies were estimated.

-Biogas flow rate and heating value based on 3 days sampling and analysis in August 2000.

* **Lower heating value** or **LHV** , is the heating value of the fuel when the water in the combustion gases is a vapour . Efficiencies of cars and jet engines are normally based on lower heating values since water normally leaves as a vapour in the exhaust gases, and it is not practical to try to recuperate the heat of vaporization.

5.10 Base case 1:Input Values - H_2S Removal

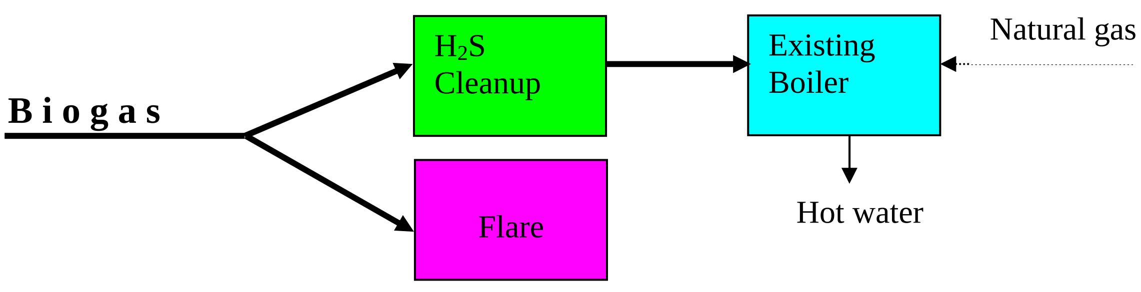


table 3 . Capital ,Maintenance and Salvage Costs,(in 1st Years,€)

5.10.1 Base case 1:Output Values-- H_2S Removal

Disposition of Digester Gas ,Annual Totals , MMBtu (1MMBtu =293 kWh)	
Total produced Combusted in boiler Combusted in flare	3942 3942 0
First-Year Avoided Energy Costs	
Natural gas via combustion in boiler,€	28013
First –year Capital and O&M Costs	
Total capital cost Total annual maintenance,€	60000 9000
Economic Evaluations	
Simple Payback Period Net Present Value,1st –year €	3.2 120197

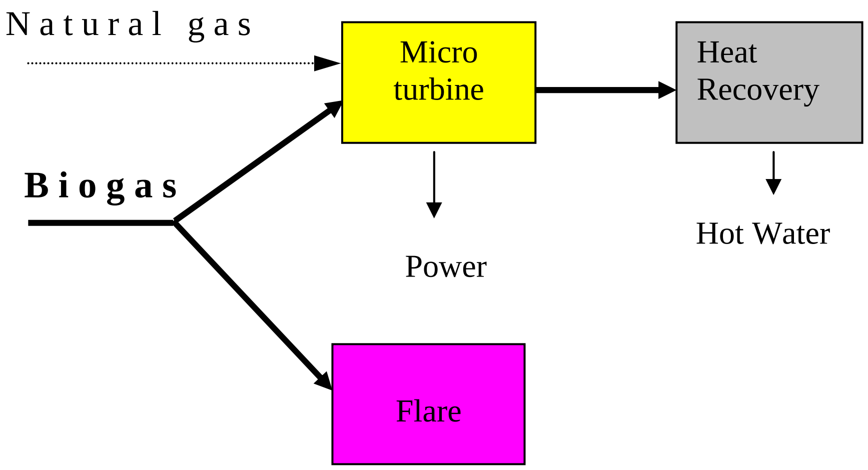
Capital ,Maintenance and Salvage Costs,(in 1st Years,€)	
Hydrogen Sulfide Removal System	
installed Capital Cost,€	60000
Annual Maintenance cost,€/year	9000
Salvage Value (Residual + Disposal)	0

table 4 . Base case 1:Output Values-- H2S Removal

NPV = € 120 K

5.11 Base Case 2b :Input Values

Microturbine + Heat Recovery



Capital ,Maintenance and Salvage Costs,(in 1st –Year Euros)	
Heat Recovery System	
Equipment Cost,€	7224
Installation Cost,€	5418
Total Installed Capital Cost,€	12642
Annual Maintenance Cost,€/kWh	0.001
Salvage Value (Residual + Disposal)	0
Equipment Performance & Operational Data	
Heat Recovery System	
Average Efficiency,LHV(fraction of waste energy from power generation system that is transferred to hot water in sludge boiler	0.7

table 5 .Base case 2b,Capital Maintenance and Salvage Costs

5.11.1 Base Case 2b :Output Values

Microturbine + Heat Recovery

Disposition of Digestor Gas,Annual Totals,MMBtu (1MMBtu =293 kWh)	
Totals Produced	3942
Combusted in power generation system	3014
Combusted in flare	928
First-Year Avoided Energy Costs	
Electric energy (kWh savings),€	7348
Electric demand (kW savings),€	1055
Natural gas via heat recovey,€	14991
Total first year avoided costs	23394
First-Year Capital and O&M Costs	
Total capital cost	74052
Supplemental natural gas for power gen system,€	0
Total annual maintenance,€	2428
Economics Evaluations	
Simple payback period	3.5
Net Present Value,1st-year €	98453

table 6 . Base Case 2b,Output Values

NPV=€98K

5.12 Summary of Base Cases

- Case 1:H_2S Removal;Combustion in Boiler

  -NPV = € 120 K
- Case 2a:Microturbine Alone

  -NPV = € 22 K

  -this case can be excluded in favor of Case 2b
- Case 2b:Microturbine with Heat Recovery

  -NPV = € 98 K
- Case 3:Microturbine+Heat recovery + H_2S Removal/Combustion in Boiler

  -NVP = € 26 K

  -this case can be excluded in favor of Cases 1 or 2b

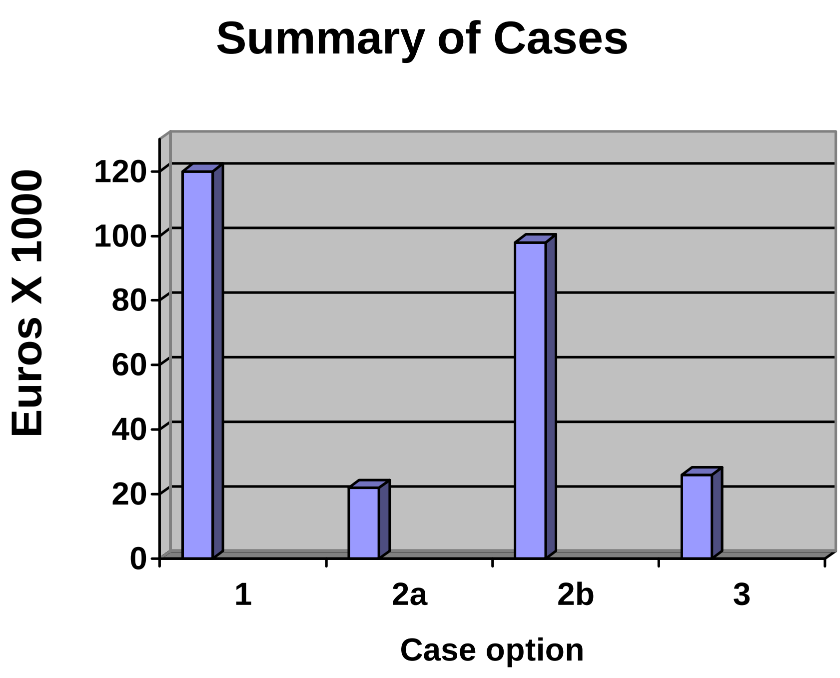


figure 20. Summary of Cases (NPV)

Chapter 6

Environmental Analysis

6.1 Estimated Emissions Reduction of selected Biogas Utilization Options

Gas Composition

- Natural Gas

  -83%Methane

  -16%Ethane

  -0.8%Nitrogen

  -Heat Value:850 BTU/CF (31671 KJ/m^3)

- Biogas

  -65% Methane

  -30% Carbon Dioxide

  -1% Oxygen

  -3% Nitrogen

  -0.5% Hydrogen Sulfide

  -Heat Value : 600 BTU / CF(22356 KJ/m^3)

6.2 Pollutant Emissions

- Greenhouse Gases from sewage

  -Carbon Dioxide,CO_2

  -Methane,CH_4

  -Nitrous Oxide,N_2O

- Combustion Products from Natural Gas or Biogas Burning

  -Carbon Dioxide,CO_2

  -Sulfur Oxides,SO_x

  -Nitrogen Oxides,NO_x

6.3 Environmental Value of Reduction

Methane is the main greenhouse gas resulting from the anaerobic degradation of organic waste. It has a 100 year global warming potential of 21, which means that 1 tonne of methane has the same impact on global warming over 100 years as does 21 tonnes of carbon dioxide (CO_2).

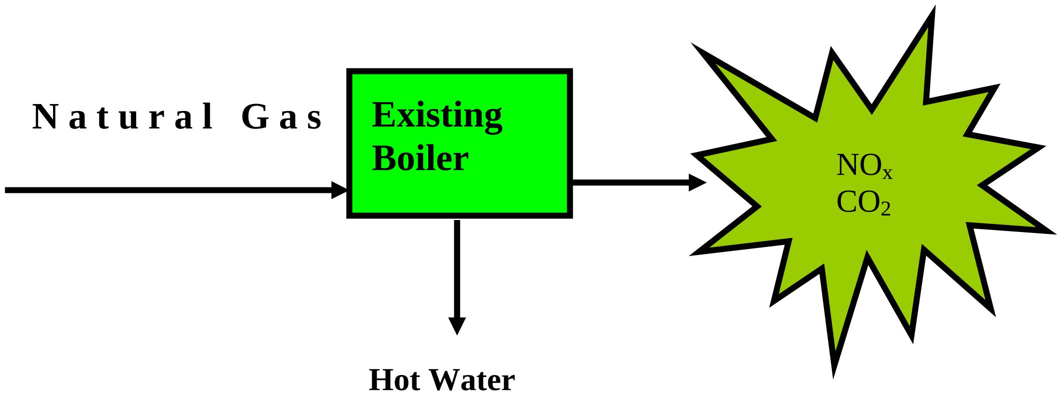
N_2O has a 100 year global warming potential of 310

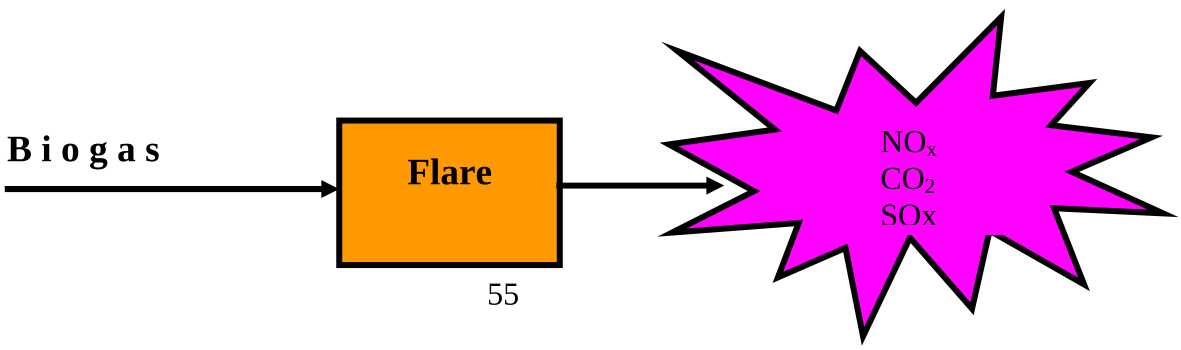
- Reduced Global Warming Effect due to Reduced Greenhouse Gas Emissions

  Global Warming Potential (GWP):
  - CH_4 =21
  - N_2O=310
- Reduced Air Pollution due to Reduced Criteria Pollutant Emissions

6.4 Base Case Emissions

-Average Annually Natural Gas Use: 16.5 million ft^3 / year
-Average Daily Biogas Production:18000 ft^3 / day





	Greenhouse Gas Output mtce / year	Pollutant Output tonnes / year
Boiler emissions		
CO_2	17	0
SO_x	0	0
NO_x	19	0,2
TOTAL	36	0,2
Flare Emissions		
CO_2	5	0
SO_x	0	0,1
NO_x	26	0,3
	31	0,4
Net total	67	0,6

table 7 . Base Case Emissions

6.5 Case 1:Hydrogen Sufide Removal

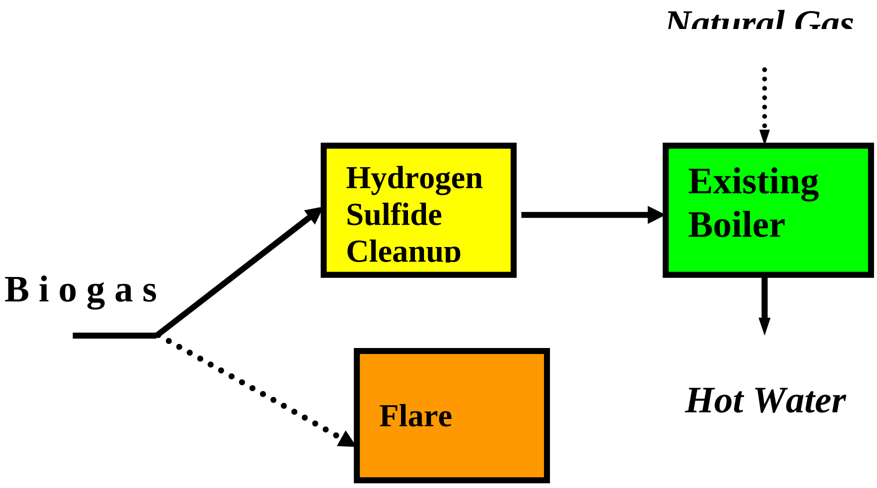
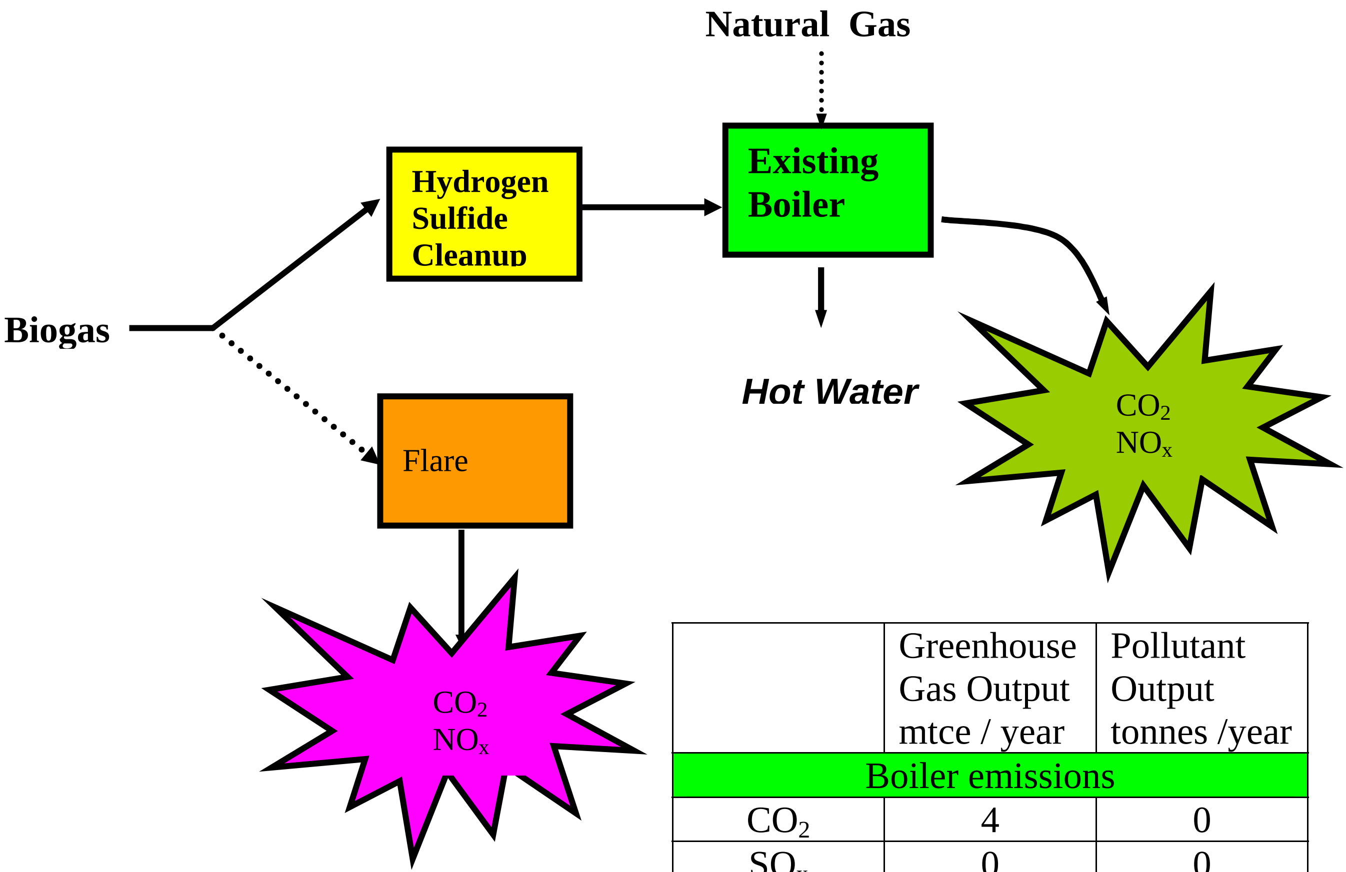


figure 21 . Case1-Hydrogen Sulphide Removal

- Boiler Estimated to be 80% Efficient
- Hydrogen Sulfide Cleanup Estimated 95% Efficient
- Biogas-Boiler System Estimated to Operate 90% of the Year
- Avoided Gas Use: 3696 MMBtu/Year (1MMBtu =293 kWh)

6.5.1 Case 1 Emissions



	Greenhouse Gas Output mtce / year	Pollutant Output tonnes /year
Boiler emissions		
CO_2	4	0
SO_x	0	0
NO_x	19	0,2
TOTAL	23	0,2
Flare Emissions		
CO_2	0,5	0
SO_x	0	0,1
NO_x	2,6	0,03
TOTAL	3,1	0,03
Avoided Natural Gas Emission		
CO_2	**4516**	**0**
SO_x	**0**	**0**
NO_x	**9853**	**120**
TOTAL	**14369**	**64**
NET TOT	**-14342,9**	**-63,77**

table 8 . Case 1 Emissions

6.6 Case 2b:Microturbine with Heat Recovery

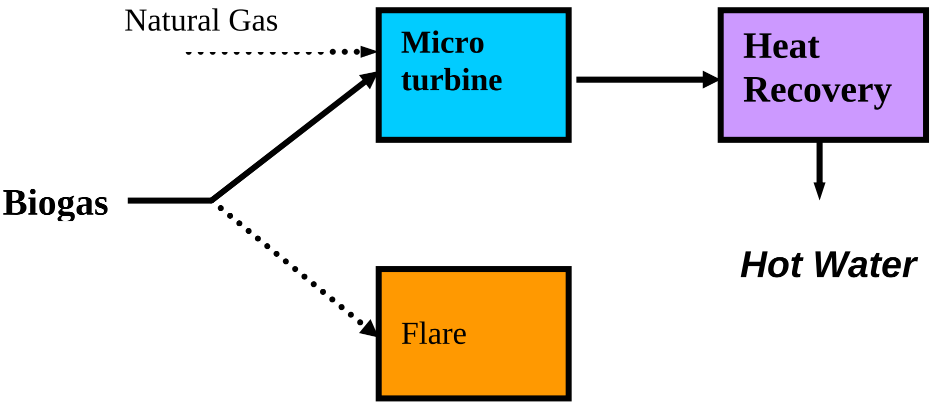


figure 22 . Case 2b:Microturbine with Heat Recovery

-Biogas-Microturbine system assumed to operate 90% of the year
-Avoided Gas Use: 1978 MMBtu/year (1MMBtu =293 kWh)

6.6.1 Case 2b Emissions

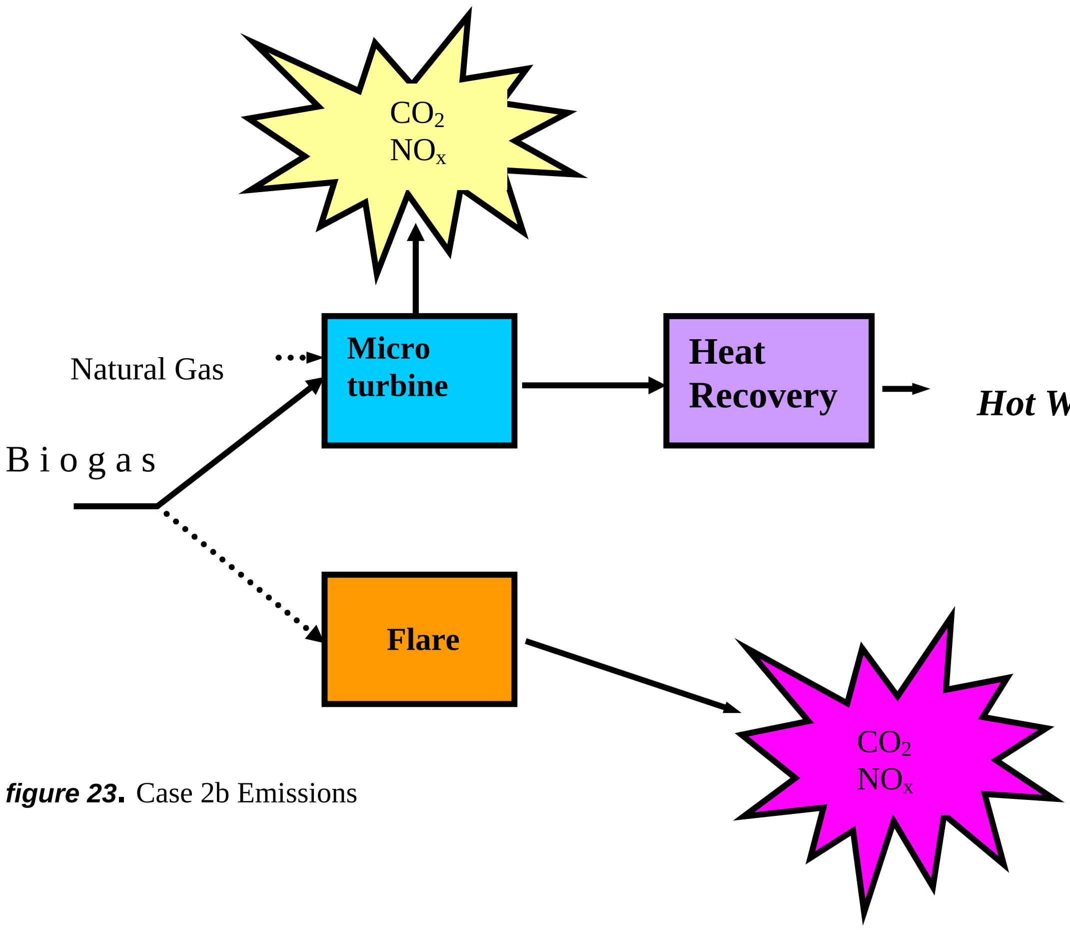


***figure 23*.** Case 2b Emissions

	Greenhouse Gas Output mtce / year	Criteria Pollutant Output tonnes / year
Microturbine Emissions		
CO_2	5	0
SO_X	0	0
NO_X	0	0
TOTAL	5	0
Flare Emissions		
CO_2	1	0
SO_X	0	0,3
NO_X	12	0,2
TOTAL	13	0,5
Avoided Natural Gas Emissions		
CO_2	2420	0
SO_X	0	0
NO_X	5270	64
TOTAL	7690	64
NET TOT	-7672	-63,5

table 9 . Case 2b Emissions

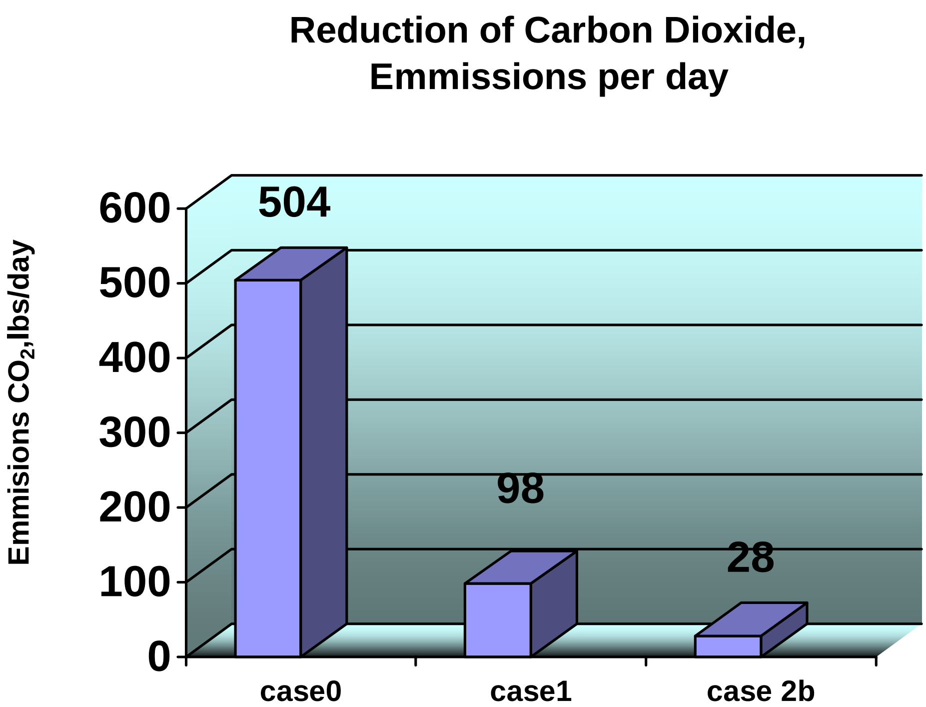


figure 24 . Reduction of CO_2

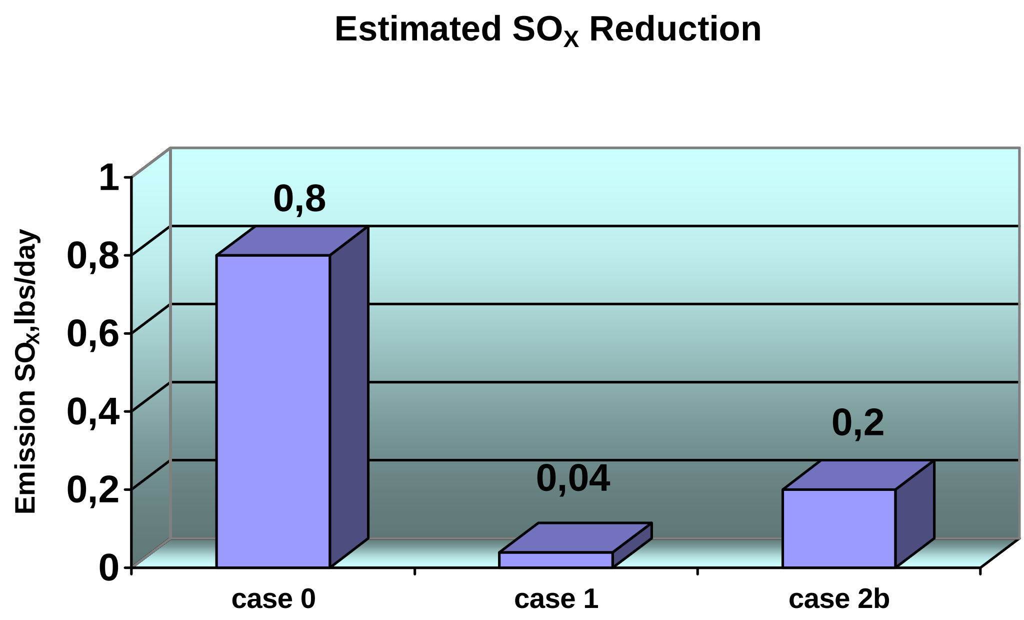


figure 25 . Estimated SOx Reduction

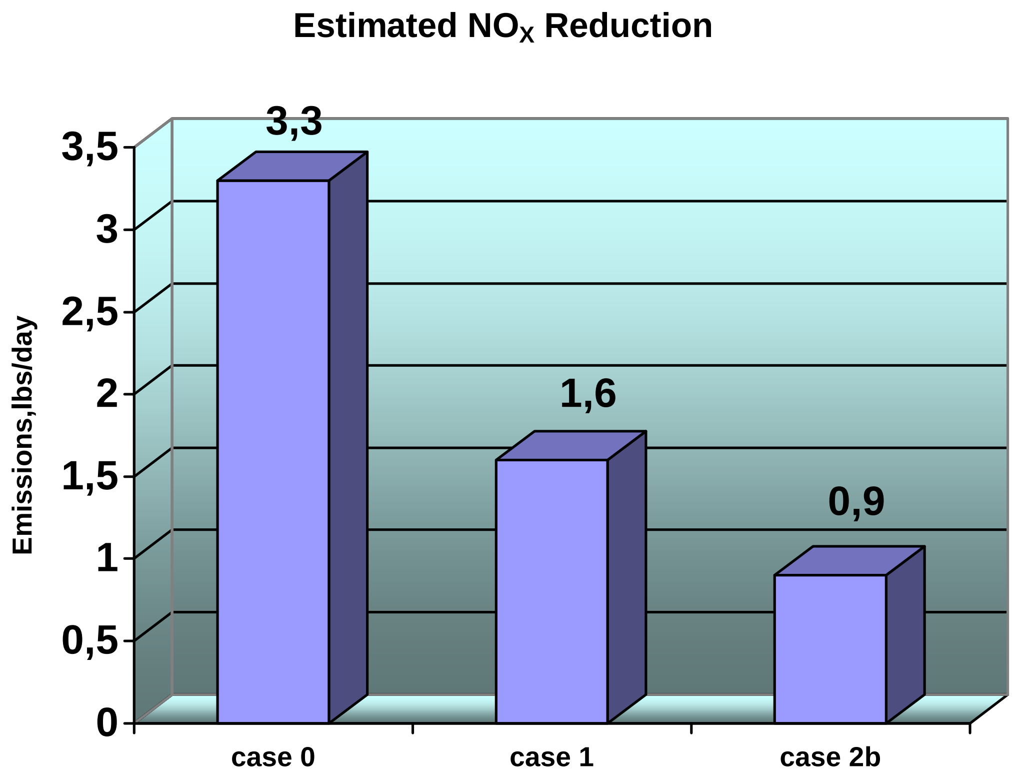


figure 26. Estimated NOx Reduction

Greenhouse Gas	Output Mtce/year	Potential Value (€ / mtce)	Current Potential Value (€)
CO_2	4529,07	14	180,79
NO_x	9850,97	14	-34,49
Greenhouse Gas Total	14380,05		146,31
Criteria Pollutant	**Output Tonnes / year**	**Potential Value (€ / tonne)**	
SO_x	0,13	200	10,81
NO_x	120,40	1200,0	-15,05
Criteria Pollutant Total	120,53		-4,24
Total	14500,58		142,06

table 10 . Case 1-Total Emissions and Valuation

Greenhouse Gas	Output Mtce/year	Potential Value (€ / mtce)	Current Potential Value (€)
CO_2	2428,26	14,0	160,63
NO_x	5279,64	14,0	93,03
Greenhouse Gas Total	7707,91		253,66
Criteria Pollutant	**Output Tonnes / year**	**Potential Value (€ / tonne)**	
SO_x	0,10	200,0	8,70
NO_x	64,53	1200,0	40,61
Criteria Pollutant Total	64,63		49,31
Total	7772,54		302,97

table 11 . Case 2b-Total Emissions and Valuation

Chapter 7

Conclusions of our feasibility study

7.1 Summary and conclusion

Dependent on the treatment process that is used for treating municipal wastewater, there is the potential to exploit energy saving opportunities and to generate energy from biogas. Municipal wastewater treatment plants can produce significant quantities of methane.The question is what kind of treatment would be the most suitable from economic and environmental point of view? The answer to that is "Anaerobic Digestion".

When used in a fully-engineered system, AD not only provides pollution prevention, but also allows for sustainable energy, compost and nutrient recovery. Thus, AD can convert a disposal problem into a profit center. As the technology continues to mature, AD is becoming a key method for both waste reduction and recovery of a renewable fuel and other valuable co-products.

Consequently, a thorough assessment of the treatment process could lead to changes that culminate in energy recovery from biogas, and result in an overall improvement in the efficiency of wastewater treatment. Even though municipal wastewater treatment contributes a relatively small proportion of the total CO_2 equivalent emissions of greenhouse gases, it is a process where the opportunities for reducing this contribution through beneficial use of the methane-containing biogas are likely to be more easily implemented than for other greenhouse gas producing activities.

Sewage treatment plants are unaware of the amount of energy that is being used and the amount of energy that is being wasted, it will also be unaware of the opportunities that exist for offsetting energy use through exploitation of biogas and waste heat recovery. Initially we tried to describe the basics of Anaerobic Digestion and a short history of it. The most important part of the dissertation was the feasibility study where we focused on the following elements.

1. Design Requirements

First of all we decided about the place that our study was going to take place and this was a Greek Island with an average population of 4000 people. Accordingly we estimated the amount of energy we could produce and the result was about 30 KW per day. This amount of energy classifies our study as a small scale or even a micro-scale project. The next step was to determine the best technology solution for our feasibility study.

2. Technology Survey

Three options where surveyed and after a careful consideration we resulted in micro turbines. The micro turbine appeared to be a good fit for the needs of our case study. It's use would meet most of the established requirements. The choice of a 30/kW unit could use all of the digester gas produced.

The small size of these packaged units will allow for installation almost anywhere. The exhaust from the turbine will be used to improve the heating capabilities of the sludge heating boiler.

3. Life Cycle Cost Analysis

We investigated 4 different utilization options (we considered the first one as the Status Quo) to determine their technical and economic performance. A life cycle cost analysis determined each option's net present value with cases 1 and 2b overcome the competition.

4. Environmental Analysis

Finally the potential impact on greenhouse gas and criteria pollutant emissions was determined for each of the biogas utilization scenarios and the tables 10 and 11 present an environmental valuation and provide an economic metric to determine environmental benefit of each option.

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Appendix A

Abbreviations -Glossary

(AD) . . . . anaerobic digestion .

(MSW) . . . . municipal solid waste .

(CHR) . . . . .conventional high rate treatment .

(ORP). . . . . oxidation/reduction potential .

(HRT) . . . . hydraulic residence time.

(HSD) . . . . High-solid digestion .

(CNG) . . . . compressed natural gas vehicles .

(BOD) . . . . Biochemical Oxygen Demand .

(DOC) . . . . Degradable Organic Component .

(EFw) . . . . methane emission factor for wastewater .

(EFsl) . . . . methane emission factor for sludge .

(BOD_w) . . . . is the BOD of wastewater .

(MSL) . . . . municipal sludge .

(BOD_{sl}) . . . . is the BOD of the sludge .

(MCF) . . . . methane conversion factor .

(CSTR) . . . . continuous stirred tank reactor .

(PFR) . . . . plugged-flow reactor .

(O&M) . . . . operation and maintenance .

(BTU) . . . . British Thermal Unit .

(NPV) . . . . Net Present Value .

(LCC) . . . . Life Cycle Cost .

(CF) . . . . Cubic feet .

(AVG) . . . . Average .

(LHV) . . . . Lower Heating Value .

(GWP) . . . . Global Warming Potential .

(Mtce) . . . . Million tonnes of Carbon Equivalent .

(MMBtu). . . . . .Million British Thermal Unit .

Appendix B

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