DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

ENERGY BASED APPROACHES TO INTEGRATED WASTE MANAGEMENT

by

Antonina GÖKSEL

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IZMIR

ENERGY BASED APPROACHES TO INTEGRATED WASTE MANAGEMENT

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MS. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled "**ENERGY BASED APPROACHES TO INTEGRATED WASTE MANAGEMENT**" completed by **ANTONİNA GÖKSEL** under supervision of **PROF.DR.NECDET ALPASLAN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ENERGY BASED APPROACHES TO INTEGRATED WASTE MANAGEMENT

ABSTRACT

The fast and unrestrained growth of population and the changes in the life style of people have brought problems. Economic progress causes intensification of energy demand, and increase of population provokes boost of waste amount. As a result, complications in energy supply, waste management sector are commenced.

Waste is a significant source of energy. Here we should take into account that composition of waste plays a significant role in energy recovery potential. Recapture of energy from waste creates important advantages as electricity, heat or power by using various techniques. It is necessary to mentioned that for all of these activities accurate planning, financing, collection and transportation are asset.

Current waste management practices in Turkey mainly consider environmentally acceptable disposal of solid waste as a priority issue. Solid waste is generally disposed of by landfilling after a partial recycling. Energy recovery from solid waste is not applied widely. Hence, there is a great potential for waste-to-energy recovery projects in Turkey.

With considering the potential and the needs in waste-to-energy recovery sector in Turkey, this study aims to define the principals of waste-to-energy recovery methods (i.e. gasification, incineration, pyrolysis and landfill), to evaluate and compare these methods in terms of technical applicability and financial feasibility and to conduct a baseline study for the assessment of waste-to-energy recovery method applicable in Turkey’s conditions. It also aims to develop waste management approach to integrated waste management systems.

It was determined that difference in electric energy generation during waste-to-energy recovery processes (pyrolysis, incineration, gasification and landfilling) is not substantial; and characteristic such as economical and ecological constrains, land availability, political and cultural views may influence energy recovery option. The significant uncertainty in results for landfill gas recovery potential was found. The results for waste-to-electricity projects for Canakkale and Kusadasi sites are significantly fluctuated as compared to LFG potential results based on literature information and models approaches. Waste- to-electricity projects for Canakkale and Kusadasi sites can be reliable as electricity generated within them is enough to cover user's needs for Canakkale or Aydin provinces. Moreover, Canakkale and Kusadasi projects are comparable with renewable energy assignments within country.

Keywords: Waste, energy recovery, waste management approach, waste-to-electricity

ENTEGRE KATI ATIK YÖNETİMİNE ENERJİ DAYALI YAKLAŞIM

ÖZ

Dünya nüfusunun hızlı ve denetimsiz bir şekilde artması ve ekonomik büyüme ile refah düzeyindeki iyileşme ve insanların yaşam tarzındaki değişiklikler, önemli sorunları da beraberinde getirmiştir. Sürekli artan ekonomik büyüme, enerji talebinin artmasına neden olmuş; ancak mevcut yenilenemeyen enerji kaynakları hedeflenen ekonomik büyümenin sağlanmasında yetersiz kaldığı için dünyanın pek çok ülkesinde enerji sıkıntı ortaya çıkmıştır. Özellikle kentsel yerleşimlerde, nüfus ve tüketimdeki artış gerek toplam gerekse kişi başına oluşan atık miktarını ciddi düzeyde artmıştır. Enerji teminindeki sıkıntılar ve gün geçtikçe daha ciddi bir sorun haline gelen katı atıkların bertarafı bugün katı atıklardan enerji geri kazanımını önemli bir yenilenebilir enerji kaynağı haline getirmiştir.

Katı atıklar, yüksek kalorifik değere sahip organik madde içerikleri nedeniyle önemli bir enerji kaynağıdır. Organik madde içeriği ve nem düzeyi katı atıkların enerji potansiyelini ciddi düzeye etkilediği için enerji geri kazanımında katı atık bileşimi ve su içeriği önemli parametrelerdir. Katı atıklardan enerji geri kazanımı kapsamında değişik tekniklerle elektrik veya ısı elde edilebilir. Tüm enerji geri kazanımı yöntemleri için doğru planlama, finansman, toplama ve taşıma gereklidir.

Türkiye’de hâlihazır atık yönetimi uygulamaları katı atıkların çevresel olarak uygun şekilde bertaraf edilmesini öncelikli olarak hedeflemektedir. Bu kapsamda, katı atıklar genellikle kısmi geri kazanım sonrasında arazide depolama yoluyla bertaraf edilmektedir. Katı atıklardan enerji geri kazanımı yaygın olarak uygulanmamaktadır. Bu açıdan değerlendirildiğinde, atıktan enerji geri kazanımı projeleri için ülkemizde büyük bir potansiyel bulunmaktadır.

Türkiye’de atıktan enerji geri kazanımı konusunda mevcut potansiyel ve ihtiyaçlar dikkate alınarak, bu çalışmada, atıktan enerji geri kazanımı yöntemlerinin ortaya konması, bu yöntemlerin teknik ve finansal açıdan değerlendirilmesi, yöntemlerin avantaj ve dezavantajları ile uygulanabilirlik açısından kıyaslanması ve Türkiye koşullarında uygulanabilir enerji geri kazanımı yönteminin / yöntemlerinin tespitine ışık tutulması amaçlanmıştır. Ayrıca, Kuşadası Katı Atık Düzenli Depolama Tesisi ve Çanakkale Bölgesel Katı Atık Projesi ile atık yönetimi yaklaşımı geliştirmek.

Çalışma kapsamında, atıktan enerji geri kazanımı yöntemlerinin (piroliz, yakma, gazlaştırma ve depolama) uygulanmasıyla elde edilen enerji üretimindeki farkın önemli olmadığı tespit edilmiştir. Ekonomik ve çevresel kısıtlar, arazi mevcudiyeti, siyasi ve kültürel görüşler gibi karakteristikler enerji geri kazanım seçeneğini etkileyebilir. Depo gazı geri kazanımı potansiyeli sonuçlarında önemli bir belirsizlik bulundu. Çanakkale ve Kuşadası atıktan enerji geri kazanımı projeleri sonuçları literatür değerleri ve model yaklaşımları ile kıyaslandığında önemli bir dalgalanma göstermiştir. Çanakkale ve Kuşadası tesislerinde üretilen elektrik enerjisi Çanakkale ve Aydın illeri enerji ihtiyacını karşılayabilecek düzeydedir ve enerji temini açısından bu tesisler güvenilebilirdir.

Anahtar sözcükler: Atık, enerji geri kazanımı, atık yönetimi yaklaşımı, atıktan enerji elde edinimi

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CHAPTER ONE
INTRODUCTION

An exhaustive waste avoidance, reuse, recycling, energy/material recovery and disposal as a last option are the main components of integrated waste management system. Waste reduction approach lowers amount of waste being produced. Environmental benefits include reduction of greenhouse gas production and waste volume, energy and resources savings.

Waste is a significant source of energy. Material mix and moisture content play an important role in the energy composition of waste. (Shah, 2000) .Recovery of energy from the refuse supposes the creation of valuable benefits in the form of electricity or heat/power by using different techniques. For each of these activities careful planning, financing, collection and transportation are necessary. The evaluation of energy potential is crucial from the environmental and economical points of view. The main purposes of it are utilization of waste, elimination of its pollution potential and development of renewable energy system. Energy recovery provides the highest beneficial use to society by creating electricity, heat and power, enhances recovery of metals and decreases the volume of material for disposal. Economic benefits include electrical sales revenue, capacity payments from the energy company and revenue from recycling.

For Turkey, economic growth causes intensification of energy demand. On the other hand, growth of population provokes increase of waste amount. So, if mentioned above issues are merged, arise complications in energy supply, ecological sphere and as a result in waste management sector. According invest.gov.tr, “currently Turkey's waste management infrastructure is not sufficient to cover the country's needs.” The greater number of waste is stored in municipal waste storage facilities and landfills. So, there is great potential for waste-to-energy projects. (invest.gov.tr).

Extraction of useful energy from the waste accommodates a sophisticated range of options such as incineration, gasification, pyrolysis and landfill gas treatment. The objective of the study is to discuss energy processing techniques, compare and contrast them, evaluate recovery options according specific parameters. Furthermore, the purpose is to develop waste management approach to Kusadasi Solid Waste Landfill facility and Canakkale Solid Waste Regional Project, evaluate results of the research.

To undertake these tasks, the related literature and various information sources were reviewed and analysed in details. Different types of gasification, pyrolysis are considered, operational features of landfilling and incineration are discussed; energy recovery potentials and optimization of energy recovery, economics of these processes are explained. Moreover, for Canakkale and Kusadasi facilities solid waste amount is estimated based on population projection, landfill gas potential is determined with respect to literature information, Tabasaran/Rettenberger, LandGem and School-Canyon models. What is more, gas-to-energy analysis is made as a result of electricity generation from landfill gas. Comparison is made for available electricity generation results from landfill gas with electricity available from alternative sources.

After necessary research and projections were concluded, next results were achieved. First of all, there is a widespread uncertainty in results for landfill gas potential. Dissimilarity of results is a issue of several components such as chosen parameters, models and literature information assumptions. Electricity generation projects for Canakkale and Kusadasi facilities are comparable with renewable energy assignments. Finally, in case of projects applicability, electricity generated from landfill gas will cover electricity consumptions by users for Canakkale or Aydin provinces and will make valuable contribution to country electricity generation. It is emphasized at the end of the thesis that energy generation from waste will contribute both the electricity production as well as environmental protection.

In the presentation of the research landfilling is treated as a separate issue rather than pyrolysis, gasification and incineration. In fact, landfilling is more natural process and primary depends on biological reactions, whereas pyrolysis, gasification and incineration is mainly mechanical.

CHAPTER TWO

ENERGY PROCESSING TECHNIQUES

2.1 Strategic Management Approach for Appropriate Methods of Energy Recovery

The strategic management approach for appropriate methods of energy recovery is a new emerging issue. Strategic approach comprise of evaluation; collecting data and deriving information from it; analysis of local environment economic situation; achievement of agreement; identification of options for action and acceptance of priorities; implementation; measurement of goals/achievements; evaluation. It should be analysed and evaluated if minimum conditions for successful implementation of energy recovery approach are met. Political aspects and support of council should be taken into account.

Collecting data/deriving information: waste profile: types of waste, amount of waste, composition, composition by source, estimation of waste volume in the future (for example-increase of population, GDP….); existing waste infrastructure-presence of techniques for energy recovery (landfill, incineration, gasification, pyrolysis anaerobic digestion for example); availability of land; technical constrains; population development indicators.

Analysis of local environment economic situation: availability of potential funding sources; financial constraints; employment/unemployment, min wages.

Achievement of agreement: public awareness; choose of technique for energy recovery; agreement in financial considerations and budget; location, contractor, time limit; identification of possible problems.

Identification options for action and acceptance of priorities: prepare list of actions to implement chosen energy recovery technique (include design, utility arrangements and procurement actions, other steps which is necessary to achieve implementation); *Plan the objectives of technique implementation*; describe the possible scenarios of implementation of chosen energy recovery technique; understand the priorities of implementation, including list of actions in case of emergency situation.

Implementation: realisation of prepared list of actions; actions according ready scenarios; in case of emergency acting strictly according list of actions in case of emergency situation.

Measurement of goals/achievements: monitoring if implementing the chosen technique achieves the expected energy outcomes; efficient cost recovery; measurement if costs of cleaning pollution from finished cycle of energy recovery system is relatively comparable with overall economic benefits; monitoring if chosen technique achieves the overall expected outcomes.

The process of priorities selection may consists of several steps. First of all, we should select the criteria, after that setting up system to measure criteria by their importance. Also we may need the scoring system to evaluate criteria by quantitive measurements, and ask for interested parties to evaluate criteria according importance and quantitive scores. The interesting parties here is specialists, politics, government and private organizations dealing with the implementation of energy recovery project, public which is related to project. To ensure correct selection of priorities it is important to have dispassion and clearness in the process.

2.2 Landfilling

2.2.1 Landfill Site

Initially, landfills are the most common method of organising waste disposal and the oldest form of waste management. Landfill site is a place where wastes are disposed by dumping. Nowadays, it is carefully designed and well –engineered facilities built into or on top of the ground; trash in this case isolated from the environment (Williams, 2002). Surface impoundment, waste pile and land treatment unit, well and soil amendments are not included in landfill (calrecycle.ca.gov). The landfill is detached into disposal cells; and here should be noticed that only one cell is open at a time to accept waste (pollutionissues.com). According Williams (2002), there are “three different types of landfills: landfills for hazardous waste; landfills for non-hazardous waste; and landfills for inert waste.” Each type of landfill accepts only appropriate type of waste (Williams, 2002). It is important to take into account that for the landfill to be secured essential next elements- a bottom liner, a leachate collection system, a cover, and natural hydrogeologic settings. (epa.gov). Contemporary landfill is alienated with a layer of clay and protective plastic to prevent the waste and leachate from moving into groundwater (pollutionissues.com). In other words, a bottom liner is one or more levels of clay or synthetic membrane. It also can be a combination of these materials. The main purpose of liner is to protect ground and groundwater from leachate linking (epa.gov). Leachate is a liquid, which passing through waste and extracts solutes, suspended solids or other components of the waste. It is contaminated by contacting waste and linked into the bottom of landfill. Vesilind (2002) stated, “Leachate is directed to low points at the bottom of landfill through the use of an efficient drainage layer composed of sand, gravel, or geosynthetic material.” Pipes are placed at lowest point to collect leachate and sloped what allows moisture to leave landfill (Vesilind, 2002). A cover helps to prevent leachate formation by keeping water out. It may comprise of several layers. To decrease the option of waste escaping to groundwater the natural setting should be carefully selected. Other elements have to be engineered (epa.gov).

The major components of landfill are shown on Figure 2.1

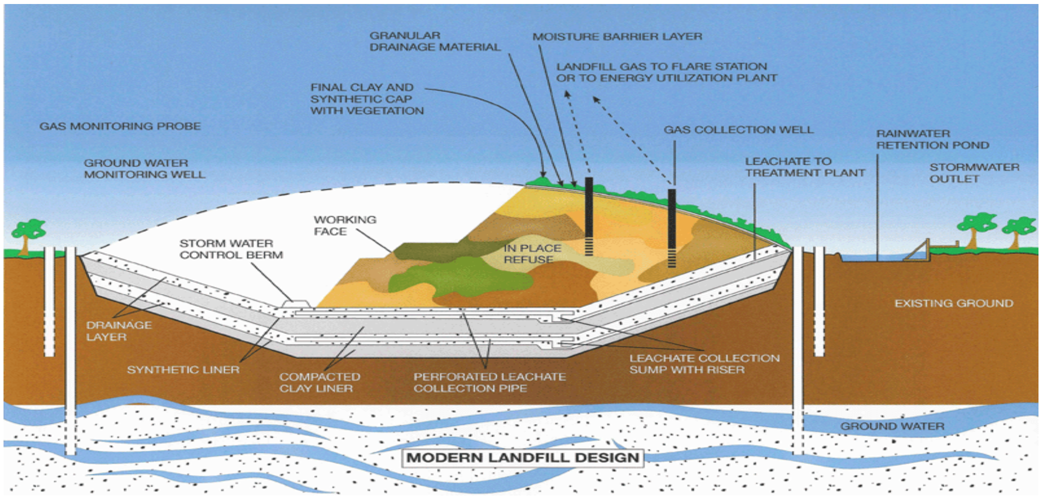
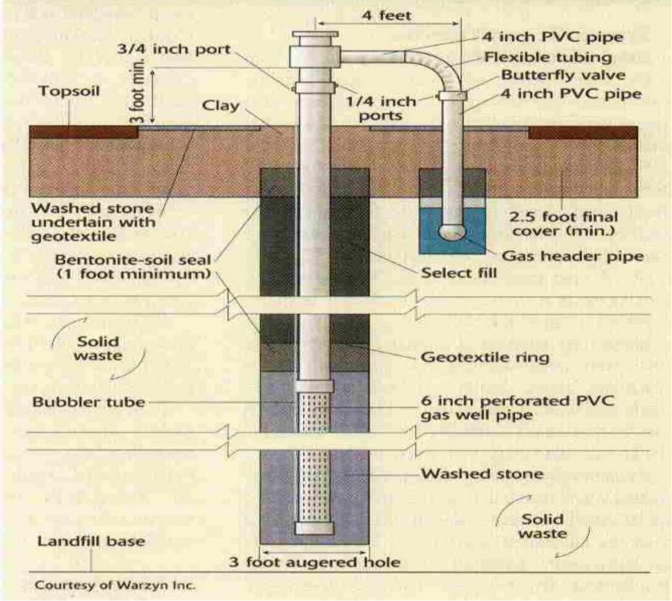


Figure 2.1 The major component of landfill (RUNCO Environmental Inc. ,2011

2.2.2 Reaction Taking Place in the Landfill Site. Gas Collection Systems

At the outset, waste disposed on the landfill site is approximately 75% organic matter, comprised generally of proteins, lipids, carbohydrates and lignins. As Vesilind (2002) stated, “approximately two-thirds of this material is biodegradable, one third is recalcitrant.” The stabilisation of waste continues in five phases; and during these phases the rate of produced leachate and generated gas is dissimilar (Vesilind, 2002). On first stage of aerobic degradation reactions occur in the presence of oxygen. Micro-organisms are of the aerobic type; and they metabolise oxygen and organic fraction of the waste produce hydrocarbons, carbon dioxide, water and heat. The temperature increases to up to 70-90C. If availability of oxygen is less, achieved temperatures are less mentioned level. The aerobic stage is lasts from a couple of days to weeks depending of oxygen availability. Second phase is hydrolysis and fermentation. The facultative anaerobes became dominant after first stage. Organics are hydrolysed and decomposed through deamidisation to form ammonia, carboxylic acids and carbon dioxide. The derived leachate consists of ammoniacal nitrogen in high concentration. The formation of organic acids depends on the decomposition of the initial waste material. The temperatures drop to 30-50 C. Landfill gas concentrations rise up to 80% of carbon dioxide and 20% hydrogen. On the third acetogenesis stage the organic acids from the stage two are converted by acetogen micro-orgnisms to acetic acid and its derivatives, carbon dioxide and hydrogen under anaerobic conditions. Hydrogen and carbon dioxide levels start to drop during this stage. In opposite, metal concentration in leachate is increasing due to acidic conditions. The pH level is dropping to 4 or less. The next methanogenesis stage is the main landfill gas generation stage (Williams,2002). The reactions during this stage are slow and take several years to complete. Methanogens organisms need low levels of hydrogen to form methane. In addition methane may also form from the micro-organism conversion of hydrogen and carbon dioxide. Here, hydrogen concentrations decrease. On this stage the mesophilic bacteria active at the range of temperatures from 30C to 35C and the thermophilic bacteria at 45-65C. So, methane gas is generated at 30-65 C with the optimum temperature in the range 30-45 C. According Williams (2002), substantial concentrations of methane are generated between 3 and 12 month depending on anaerobic microorganisms and waste degradation products. At the last oxidation stage the waste degradation results from the end of the degradation reactions. New micro-organisms slowly replace the anaerobic forms and re-establish aerobic conditions. Gas production substantially decreases (Williams, 2002).

For collection and migration control of landfill gas passive and active systems are used. Passive system relay on natural pressure and convection to move the gas into atmosphere. Natural vents may use flare to burn the gas. This type of collection does not give insurance that the landfill gas will be collected properly and in full amount (O’Leary,P.,Walsh,P., 2002). As Vesilind (2002) stated, that “passive vents may reach only a few feet below the gap or may reach up to 75% of the landfill depth.” In contrast, active collection system is working under a vacuum; the gas is pumped out of the ground. They provide migration control and available remove methane for energy recovery purposes. Gas recovery well is shown on Figure 2.2.



Courtesy of Warzyn Inc.

Figure 2.2 Gas recovery well (O’Leary,P.,Walsh,P.,2002)

The negative pressure in the pipe network should be established. Wells may be placed in the waste or in the soil formation. The location depends on site access (O’Leary,P.,Walsh,P., 2002).

2.2.3 Information About Landfill Gas

Landfill gas is a complicated mixture of gases developed by the cooperation of microorganisms within the landfill site (O’Leary,P.,Walsh,P., 2002).Typical landfill gas composition is introduced on Table 2.1.

Table 2.1 Typical composition of landfill gas (Source: O’Leary,P.,Walsh,P., 2002)

Methane	50-60%
Carbon dioxide	47%
Nitrogen	4%
Oxygen	0,8%
Aromatic-cyclic hydrocarbons	0,2%
Paraffin hydrocarbons	0,1%
Hydrogen	0,1%

Carbon monoxide	0,1%
Hydrogen sulphide	0,01%
Trace components	0,5%

The composition of landfill gas is important for energy producers. As Vesilind (2002) mentioned, "in theory the biological decomposition of one ton of MSW produces 15,600 ft^3 (442 m^3) of landfill gas containing 55% methane (CH_4) and heat value of 530 Btu/ ft^3 (19,730 kJ/m^3). If to take into consideration that not all waste converts to methane due to moisture limitation, the actual methane yield is closer to 3,900 ft^3/ton (100 m^3/ton) of MSW (Vesilind, 2002). It is known that 1 m^3 of landfill gas contains 20 MJ of calorific energy (electrigaz.com). The calorific value of the gas depends on the percentage composition of gases such as methane and non- combustible gases such as carbon dioxide (Williams, 2002). In addition, next information should be taken into account- 1 m^3 of gas may produce 1,7 kWh of electricity and 7,7 MJ of heat (agric.gov.ab.ca).

When anticipated landfill gas yield is actuated a model should be selected to describe gas trends for the future. Mathematical and computer models for anticipating gas yields relay on population, per capita waste generation (Vesilind, 2002).

In the same line, Williams (2002) stated, "the accurate assessment of landfill gas generation from a site is a major factor in deciding whether the site will be developed for the recovery of energy via landfill gas." It is also a base for the financial investment in a landfill gas utilisation project. The assessment includes computer modelling and the physical site assessments. Heterogeneous nature of waste and poor records of the waste emplaced makes difficulties for the physical assessment. To estimate the landfill gas production the rate and duration of the gas production should be taken into consideration. Modelling techniques are based on assumption that particular amount of biodegradable waste will produce the certain amount of gas.

The Figure 2.3 represents the most commonly applied equation to describe the rate of landfill gas generation (Williams, 2002).

Figure 2.3 Landfill gas generation rate (Source: Williams, 2002)

Rate = kL_0e^{-kt}
Rate=rate of landfill gas production
k-rate constant, represents the decay value or half life of the waste
L_0-ultimate yield of landfill gas
t-time

According H.J. Themelis,”at least 50% of the “latent” methane in MSW can be generated within one year of residence time in landfill”.(Themelis,N.J., Ulloa, P.A., 2005). Gas migration rate is actively influenced by weather conditions. With the fall of barometric pressure gas is forced out of landfill site (O’Leary,P.,Walsh,P., 2002).

2.2.4 Bioreactor approach

We can consider modern landfill sites as a “bio-reactor”, which is used to stabilised and produce landfill gas for energy recovery. They are designed to be secure areas for public and nature. Gas balance is executed from microbial reaction in products (O’Leary, P., Walsh,P., 2002). As S.A.Elagroudy stated, “a bioreactor landfill is a landfill that uses enhanced microbiological processes to transform and stabilize the readily and moderately biodegradable organic waste constituents”. The bioreactor is a new and complete approach to waste disposal with energy recovery (Elagroudy, A.S., Abdel-Razik, M.H., Warith, M.A. & Ghobrial, F.H., 2007). Development of landfill bioreactor approach has purposes to optimize landfill as biological treatment system and reduce the landfill stabilization time. R. Eymard (2007) stated that “fast degradation rate in bioreactor landfill in an attractive feature of this innovative technology.” MSW biodegradation in landfills is a complex and changeable process. Microbial ecosystem in landfill has different decomposition points. During the period of steadily growth the methane production reaches maximum value. Augmentation of the biodegradation is accomplished by the recirculation of the leachate collected from the bottom of the landfill. Here, wet environment and supply of necessary nutrients for biodegradation are important. The thermal conductivity, heat capacity of the waste and the initial values of biological parameters are the main aspects having attention on the thermo-biological behaviour of landfill (Gholamifard, S., Eymard, R. &Duquennoi, C., 2008). Specially designed bioreactor landfills maximize the infiltration of rainwater and snowmelt into the waste under controlled conditions. Minimization of leachate migration and maximization of LFG generation are the main points when consider such system. Improvement of solid waste degradation is leading to increase of methane production, acceleration of subsidence and solid waste decomposition. Shredding, leachate recirculation and the addition of nutrients, control of temperature and moisture content are the techniques to accelerate biological degradation of the waste. Moreover, landfill sites with bioreactor approach may provide more controlled options what results in emission reduction.

As Mostafa Warith from Ryerson Polytechnic University stated “A bioreactor landfill is a sanitary landfill site that uses enhanced microbiological processes to transform and stabilize the readily and moderately decomposable organic waste constituents within 5–8 years of bioreactor process implementation.” In contrast to traditional landfill sites, bioreactor landfills enlarge decomposition of organic waste and conversion rates of complex organic compounds. Measurement parameters remain on all the same steady level. At the same time bioreactor landfills require specific management activities and operational modifications, for example liquid addition and the development and implementation of focused operational and development plants. There is no substantial quantity of leachate to support bioreactor needs. In this case water and other non-toxic and non-hazardous liquids can be used to supplement the leachate (Warith, M., 2000). An example of complete bioreactor experimental cell configuration is shown in Figure 2.4.

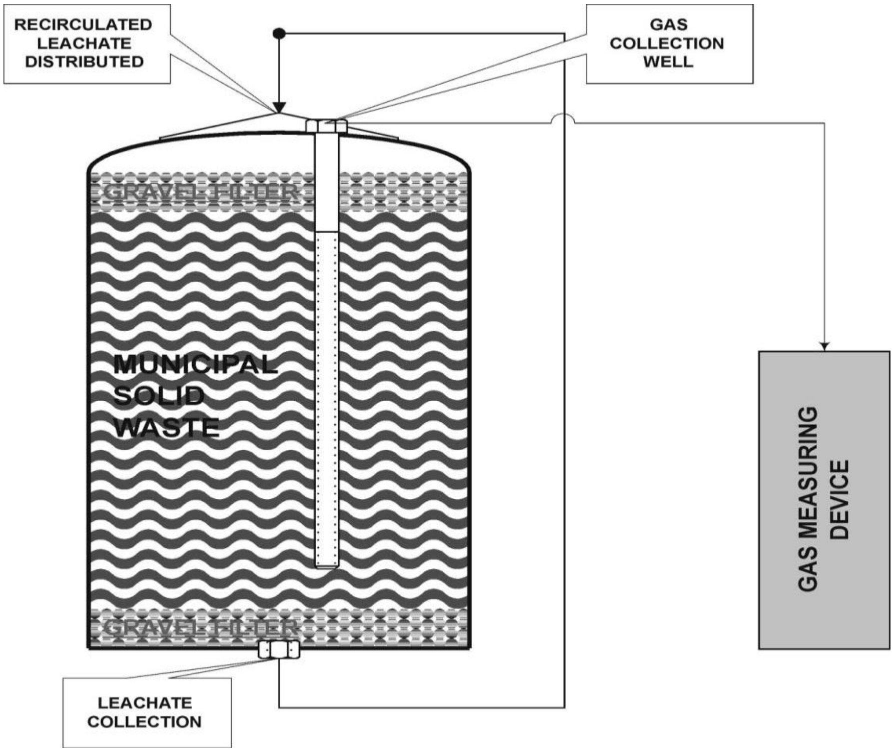


Figure 2.4 An example of complete bioreactor experimental cell configuration (Waste Management [e-journal], 22, 2002)

There are several operational mode available for bioreactor landfills: aerobic bioreactors, anaerobic biocells and cells operating aerobically followed by anaerobically (Elagroudy, A.S. et.al, 2007).

2.2.5 Utilization of Landfill Gas

To anticipate the quality and quantity of landfill gas before construction of energy recovery system various tests should be conducted. It is very important as gas generation rates are different and landfill gases may have different chemical composition (O'Leary,P. & Walsh,P., 2002). Energy recovery can be achieved through different practices. One of them is direct combustion in heaters or furnaces. Also chemical energy storage as a result of conversion into bio-diesel, methanol can be employed. Another practices is when gas clean up and introduced into the national natural gas grid; electric energy generation (Bove,R. & Lunghi,P.,2004). In early energy recovery schemes landfill gas were used as a fuel for kilns, boilers and furnaces located close to the landfill site. The disadvantage is that a suitable end-user should be located close to the landfill area. Gas-power engines which are used to provide power and electricity were developed in later schemes (Williams, 2002). The energy recovery system are depends on the economic markets. From one point of view, it may be practical to pipe gas directly to a boiler. This is possible if factory or large building is near landfill site. Also landfill gas may be passed through filters to remove moisture and possible hydrogen sulphide. The one of the simplest ways to use LFG is boiler fuel. So, availability of a boiler is important. Here we should take into consideration, that the cost of constructing a pipeline between the site and boiler should be compared with the gas value. From other side the gas can be directed to engine-generator system for energy recovery-electricity production. In this case gas does not need as much treatment to be used as fuel in turbine. Methane content in the gas is affecting turbine performance, so gas collection system should be strongly regulated (O'Leary,P. & Walsh,P., 2002). Premium electricity prices and obligations to the non- fossil fuel forced the energy recovery from the landfill sites. The use of the waste heat from the power generation phase to produce combined heat and power system is a further development (Bove,R. & Lunghi,P.,2004).

For example, in the USA gas utilisation schemes include electricity generation from gas use in engine, via power generation using gas turbines and direct use. The estimated total electrical output is over 350 MW per year. Moreover, the government regulations encourage the use of landfill gas in energy recovery projects. According Figure 2.5, the energy recovery technology is based on the gas collection system, pre-treatment and power generation technology. The systems for the gas collection (vertical or horizontal) depend on the type of the site, site-filling techniques, depth of waste and leachate level. The gas is collected in a series of perforated gas pipelines connected to a central pipeline. The rate of gas generation plays an important role for the spacing of the wells. Gas temperatures require a condensate removal system. It is used to remove the water vapour. Condensate system both below and above ground may be required to dewater the gas. To remove a particular material from the gas flow the system needs a filter. The following stage may require an additional gas cleaning if corrosive trace gases and vapours are present.

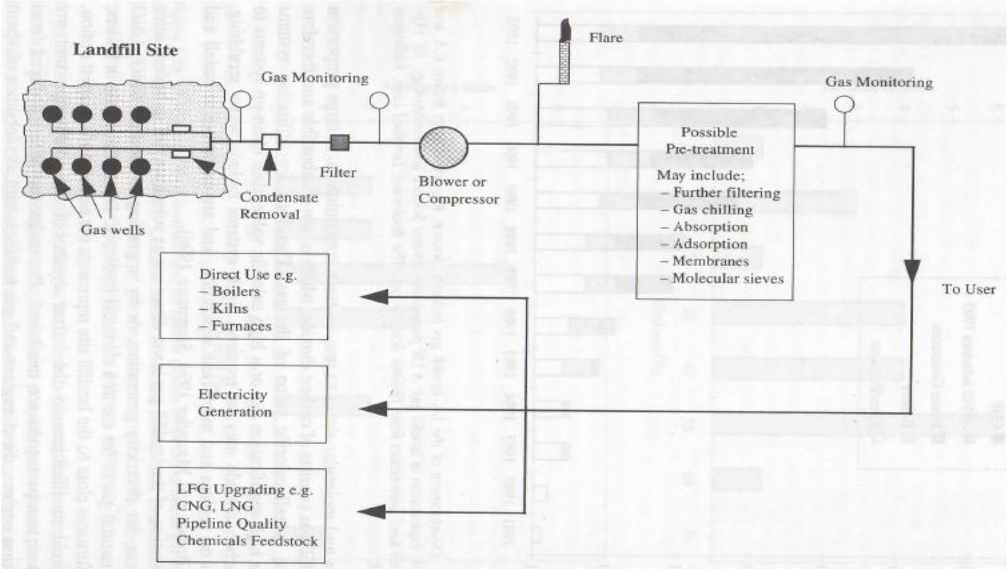


Figure 2.5 Schematic diagram of a landfill gas energy recovery project (Williams, 2002)

It is widely known that large proportion of landfill gas consists of non-combustible carbon dioxide which is reduces the calorific value of the gas. As a result cleaning system may require removal of the carbon dioxide. The negative aspect here is that such systems are expensive to install and maintain. There is several opportunities for the utilisation of the landfill gas: via direct use as a substitute fuel in boilers, kilns and furnaces, for electricity generation, or by upgrading to produce CNG, LNG substitute natural gas or for the use as a chemical feedstock. Direct utilisation can be seeing as a cheapest way since minimal modifications to the burning system of the combustion unit are required and transport costs are minimal. In case of power generation the engines are used with the pure landfill gas or together with natural gas. The presence of carbon dioxide should be taken into consideration as it lowers the calorific value and ignitability of the gas compared to natural gas. The upgrading of the gas to the necessary specifications is needed if to use gas for the vehicles for landfill site. If to use landfill gas as substitute natural gas it should be cleaned up to comply with the gas industry specifications. Here calorific value, fine particulate material, trace components should be taken into consideration. Landfill gas must reach a consistent composition. It is also possible to use gas with the chemical purposes. In this case wide range of products is potentially available from the methane (Williams, 2002).

Electricity can be transported through the national grid, so the most important advantage of electricity generation is that end-users should not be located close to the landfill site. The existence of chlorinated organic compounds in the landfill gas influence the combustion of the gas as here is possible the formation of the dioxin and furans in the exhaust. To minimise the formation of such elements help high combustion temperatures with extended residential time.

Mechanisms and techniques used for landfill gas utilization. Mainly, next mechanisms and techniques are used for landfill gas utilization:

- *boilers* produce thermal energy or heat, and not electricity. They are not sensitive to landfill gas contaminants. Moreover boilers require less cleaning than other methods. Pipelines bring gas to the boilers. Pipelines require cleaning of the gas as gas contains corrosive elements such as hydrogen sulphide (Cheremisinoff, N.P., 2003);

- *reciprocating internal combustion engine (ICE).*It is one of the most often technologies for electric recovery from LFG. The combination of renewed power with the process economy is the main reason of that. ICE is consolidated technology with low economic risks. ICE is condensed and easy to move. R.Bove and P.Lunghi consider that main disadvantage of ICE is high pollution (Bove,R. & Lunghi,P.,2004). The amounts of NOx and CO are very high;

- currently *gas turbine* is less applicable due to electricity losses and relatively low performance. But in contrast to ICE the emissions of this technology are reduced significantly;

- nowadays *the organic rankine cycle* (ORC) is used for geothermal energy conversion. The ORC is an external combustion engine, but if the energy source is LFG no operations alteration is happening;

- *fuel cells* allow to gain energy and heat through reaction of reach hydrogen gas an oxidant. Water occurs as a product. There is no combustion in fuel cells, so as a result pollutants are reduced. Fuel cells are interesting for stationary application as they have high efficiency, and low pollution emissions, and they may realize a combination of heat and power production.

- *molten carbonate fuel cells* (MCFC) operates at high temperatures. Here noble metals are important as catalysts for the electrochemical reaction. And as a result MCFC operates with higher impurities concentrations in compare with low temperature cells. The life cycle assessment for LFG shows an impressive pollution reduction. High energy conversion efficiency obtained together with low noise emissions R. Bove noticed in his article that the main disadvantage of thi technology is high capital costs as MCFC can not be considered a demonstrated and validated technology;

- *solid oxide fuel cells (SOFC)* have operating temperatures between 800-1000 C. This leads to high internal performance, the use of carbon monoxide as a fuel. However, temperature below 800 C decreases cost of production.

According R.Bove and P.Lunghi the internal combustion engine cause the most significant pollution. But emissions from Stirling cycle engines and high temperature cells are very low. We may conclude that high energy conversion efficiency of fuel cells may become more economically competitive (Bove,R. & Lunghi,P.,2004);

- *phosphoric fuel acid cell* is available commercial technology. It is non combustion and consists of landfill gas collection and pre-treatment, fuel cells processing system, fuel cells stacks, and a power conditioning system. Several chemical reactions results in production of water, electricity, heat and waste gases which is devastated in a flare (Cheremisinoff, N.P., 2003).

2.2.6 Landfill Gas Management and Economics

LFG has to be accumulated from all landfills accepting biodegradable waste and also it should be treated and used. In the case when energy can not be collected, LFG must be burned. Collection and burning supports strong reduction of greenhouse effect as a reason of the global warming potential of methane.

We may summarise that some of the management conversion systems are:

- LFG use in reciprocating engine;
- LFG direct use in appropriate fuel sells;
- LFG steam reforming associated with CO2 removal with a purpose to obtain a hydrogen-rich syngas to be fed to fuel sells;
- LFG steam reforming associated with CO2 removal with a purpose to obtain a hydrogen-rich syngas to be fed to fuel sells for vehicle application;

The potential to recover energy with the help of landfill gas combustion is an important factor involved in the assessment of landfill costs. The generation of electricity from landfill gas allows operators to bid for a non-fossil fuel obligation (NFFO) contract, which allows a negotiated fee for the electricity at rates above the general pool price. The generation of the electricity from a landfill site does not guarantee that NFFO contract will be granted, and therefore the general electricity pool price would then be obtained. If NFFO contract will be granted, the cost of landfill would be further reduced. The introduction of the NFFO encourages the development of the renewable energy schemes such as energy from the waste was seen as a method to develop the technologies. Some electricity generation schemes developed outside NFFO scheme. Landfill gas energy recovery projects can have a significant influence on the economics of waste landfills. Direct use of landfill gas in furnaces, boilers and kilns are the lowest cost options since gas transport costs and modifications to the burner of the combustion system are minimal. Electricity generating schemes relying on spark ignition; diesel engines and gas turbine plant require investment in the power plant, generation units and associated electricity (Williams, 2002).

2.3 Gasification

2.3.1 Gasification. Types of Gasification

Gasification is an advanced thermal treatment. Moreover, gasification processes suggest accumulation for recovering value from waste and producing solid residues which are more suitable for reuse. Also, gasification proposes itself as a clean energy recovery technology in compare with incineration and landfill (Yassin,L., Lettieri,P., Simons,S.J.R. & Germana,A., 2007). In a process of gasification oxygen in the form of air, steam or pure oxygen reacted at high temperatures with the available carbon in the waste to produce a gas product, ash and a tar product (Williams, 2002). Gasification can also be defined as a partial oxidation of waste in presence of an oxidant amount lower than that necessary for stoichiometric combustion. This process results in the production of a hot fuel gas or syngas, which contains significant amounts of not completely oxidized products with different calorific values. The organic substance of the waste is mainly converted to carbon monoxide, hydrogen and lower amounts of methane (Arena,U.,2011). If air gasification is used, nitrogen will also occur as a major component (Williams,2002). One more explanation of the process is given by V. Belgiorno from University of Salerno: “Gasification can be broadly defined as the thermochemical conversion of a solid or liquid carbon-based material (feedstock) into a combustible gaseous product (combustible gas) by the supply of a gasification agent (another gaseous compound).”(Belgiorno,V., Feo,G.D., Della Rocca,C. & Napoli, R.M.A., 2002). The thermochemical conversion implies changes into chemical structure of the biomass with the help of high temperature. The agent gives an opportunity to the feedstock to be quickly converted into gas (Belgiorno,V. et. al, 2002).Here, we should take into account that gasification require nearly homogeneous feedstock (Stantec Consulting LTD,2011).

Gasification can be direct and indirect. During direct gasification an oxidant agent is used to partially oxidise the feedstock. The temperature of the process is sup 18 by the oxidation reactions. In contrast indirect oxidation needs an external energy source such as steam (Belgiorno,V. et. al, 2002). The operating temperatures of the gasification process is relatively high- 800-1100C with air gasification, and 1000-1400C with oxygen. Calorific values of the product gas are low for air gasification, in the region of 4-6 MJ/m3, and medium about 10-15 MJ/m3, for oxygen gasification (Mountouris,A.,Voutsas, E. & Tassios,D., 2006). Electricity production is around 0,4-0,8 MWh/annual tonne of MSW and 0,3-0,6 MWh/annual tonne of MSW for plasma gasification (Stantec Consulting LTD,2011). Steam gasification at pressures up to 20 bar and temperatures of between 700 and 900 C, produces a fuel gas of medium calorific value. The heating of the waste produces pyrolytic reactions and methane, and higher molecular hydrocarbons are formed. When air is used the non-combustible nitrogen in the air inevitably reduces the calorific value of the product gas by dilution (Williams, 2002). The energy production depends on moisture content of the feed waste, amount of air/oxygen, the gasification energy, the net thermal energy produced by the process, the heating value of the produced gas, the reactor temperature (Mountouris, A., Voutsas, E. & Tassios,D.,2006). For residual to disposal landfill capacity consumption reduce by 90 to 95%. According information given in report of Stantec Consulting LTD (2011), gasification tends to have high operating and capital costs as a result of waste pre-treatment and complexity of the technology. In addition, relatively high net costs are have place. (scribd.com). As stated in scribd.com, median reported capital costs for gasification system 850$/annual design tonne -/+40% (for plasma gasification this amount increasing to 1300$), median reported operating cost for Europe and Japan- 65$/ tonne -/+ 45% (for plasma gasification-120$).

2.3.2 Gasifier Reactor System Types and Compounds

Basically, a gasification system includes three main elements such as gasifier for production of the combustible gas, the gas cleaning system, and the energy recovery system. In addition gasification system may be completed with technologies to control environmental impacts (Belgiorno,V., Feo,G.D., Della Rocca,C. & Napoli, R.M.A., 2002). Gasifiers primary designed to produce valuable syngas (scribd.com).Table 2.2 shows examples of the gasifier system used for waste gasification.

Table 2.2 The main types of waste gasifier reactor system (Source: Belgiorno,V. et al, 2002)

The main types of waste gasifier reactor system
Updraft gasification Air flows up from the base of the reactor with the waste flowing down counter-current to the air flow. Gasification takes place in a slowly moving "fixed" bed. Because the moisture, tar and gases generated do not pass through a hot bed of char there is less thermal breakdown of the tars and heavy hydrocarbon, and therefore the product gas is relatively high in tar. The tar may be condensed and recycled to increase thermal breakdown of the tars.
Downdraft gasification The air and the waste flow co-currently down the reactor. Gasification takes place in a slowly moving "fixed" bed. There is an increased level of thermal breakdown of the tars and heavy hydrocarbons as they are drawn through the high temperature oxidation zone, producing increased concentrations of hydrogen and light hydrocarbons. The air/steam or oxygen is introduced just above a "throat" or narrow section in the reactor, which influenced the degree of tar cracking
Fluidised bed gasification Waste is fed into the fluidised bed at high temperature. The fluidised bed may be a bubbing bed where the solids are retained in the bed through the gasification process. Alternatively, circulating beds may be used with high fluidising velocities; the solids are elutriated, separated and recycled to the reactor in a high solids/gas ratio, resulting in increased reaction. Twin fluidised-bed reactors may be used where the first bed is used to gasifier the waste, and the char is passed to the separation an then to the second fluidised bed, where the combustion of the char occur to provide heat for the gasifier reactor.

Figure 2.6 introduces updraft and downdraft gasifiers.

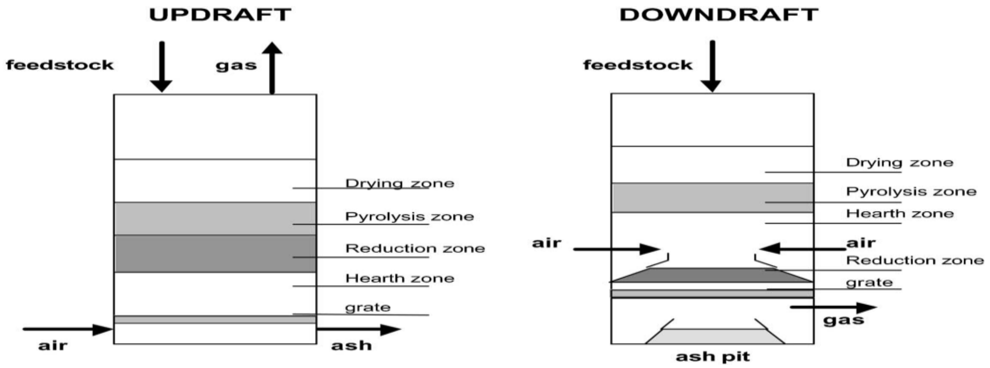


Figure 2.6 Updraft and downdraft gasifiers (Belgiorno,V. et al, 2002)

Fluidised bed gasifiers are shown on Figure 2.7

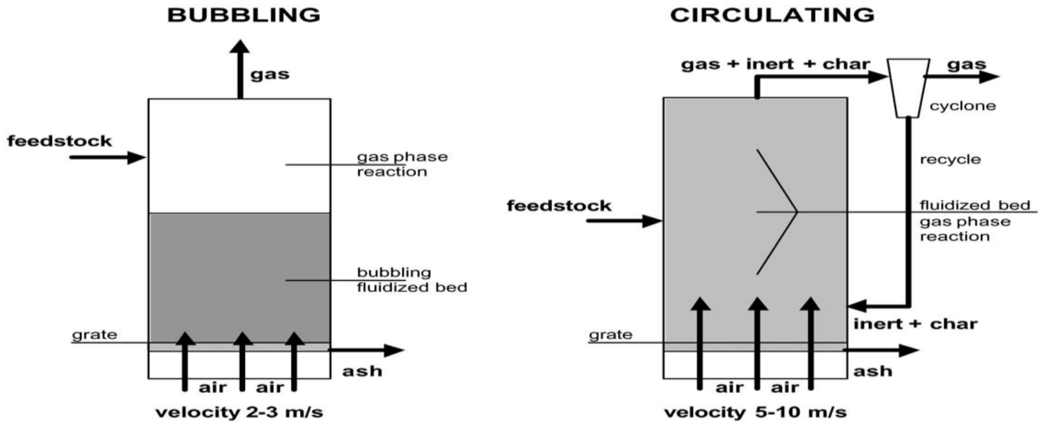


Figure 2.7 Fluidised bed gasifiers (Belgiorno,V. et al, 2002)

The characteristics of the gasifier system, the waste composition and operational conditions can give rise to tars, hydrocarbon gases and char; these are products of the incomplete gasification of the waste. Utilisation of the gaseous product is often by the direct combustion in a boiler or furnace. The heat energy is used for process heat or to produce steam for electricity generation. But the row gas will contain tar, char and hydrocarbon gases, and therefore the boiler or furnace burner system must be able to tolerate these contaminants and not be susceptible to fouling or clogging. Gasification of heterogeneous waste such as municipal solid waste produces a gas which can vary in composition and boiler system of the boiler or furnace should be able to handle a range of gas compositions and calorific values. Where the utilisation of the product gas is into gas turbines or internal combustion engines to generate power or electricity, then the gas has to be cleaned to a higher specification than direct combustion systems. Piping of the gas to the combustion unit requires that it be cooled and cleaned before utilisation to prevent pipe corrosion and deposition of tars and water. Some modern developments in thermochemical processing of waste have utilised both pyrolysis and gasification. Here several systems can be reviewed. These include the combined pyrolysis-combustion system of Siemens, Germany, two-stage pyrolysis by TSK, Japan, the pyrolysis-vitrification system of Proler, USA. Box 1 represents the combined pyrolysis-gasification Noell process developed in Germany (Williams, 2002).

Box 2.1 The Noell Waste Treatment Process

The Noell waste treatment process is based on a combination of pyrolysis and entrained flow gasification. The system is designed to treat domestic waste, sewage sludge, hazardous waste and biomass with throughputs of up to 100 000 tonnes per year. The pyrolysis section consists of an indirectly heated, gas-fired rotary kiln operated under an inert gas atmosphere, the gas being derived from the waste treatment process. Shredded waste is fed into the pyrolysis reactor at approximately 550 °C and solids retention times in the kiln are about 1 hour. The char product is separated, and ferrous and non-ferrous metals are separated from the char. The char is then ground and passed to the entrained flow gasifier. The pyrolysis gases and oil, water and dust carry-over are quenched. The condensed oil, dust carry-over and gas plus the ground char are passed to the gasifier. The gasifier is an entrained flow type where an inert solid material of particle size < 1 mm and reloading of about 350 kg/m3 of solids is fed with the pyrolysis products and oxygen into a burner operating at sub-stoichiometric conditions. High temperatures of the order of 1400 °C are produced in the gasifier. The gasifier reaction under partial oxygenation conditions, i.e. substoichiometric, generates a gas composed of over 80% carbon monoxide and hydrogen. Any solid inert material is converted to an ash slag because of the high temperatures invoke; quenched and granulated. The resultant gas is cooled, scrubbed and utilised for energy recovery. The high gasifier temperatures completely destroy toxic hydrocarbon compounds, and because the operating conditions are reducing the de-novo synthesis of dioxins and furans eliminated, thus reducing the costs of gas clean-up.

Source: Williams, 2002

As stated by Higman, C. and Van der Burgt, M. (2003), “Gasifiers have thermal or cold gas efficiencies between 70% and 93%, with most operating at between 75% and 88%”. The cold gas efficiency may be assign as ration of the energy content of the syngas to the energy content of the waste feedstock. It is known that gasification processes in addition to various configurations apply diverse energy conversion systems (Yassin, L., Lettieri, P., Simons, S.J.R. & Germana, A., 2007). The information given by L. Yassin (2007) shows that gasification system efficiencies raised by 6-10% with the doubling of the plant capacity (Yassin, L. Et.al, 2007). Operational controls for gasification systems depends on particular gasification technology used (scribd.com).

2.3.3 The Classification of Gasification Processes

- *food waste gasification*: For food waste gasification can be used fluidized beds. In this case a feed stoke is allowed to react with water and oxidizer in a fuel-reach environment at elevated temperature. Gasification depends upon adequate residence time of feedstock groups at elevated temperatures and an appropriate mixing. In case when air is used as an oxidizer the end gas product will contain significant amounts of H2O, CO_2 and N_2 in one line with main chemical components such as CH4, CO and H2. According to P.A. Caton, gasification of waste food is limited to fuel-air equivalents ratios up to 2.2 with water context less than 30 % (Caton, P.A., Carr, M.A., Kim, S.S. & Beautyman, M.J., 2009). With increasing water context the equilibrium temperature is decreasing. So, the food waste with higher water context would need significant dehydration before gasification. As were stated by P.A. Caton and M.A. Carr in Energy Conversion and Management Journal (2009), "the presence of CH_4 in the producer gas is nearly independent of the amount of water in the gasifier and increases steadily if the reaction became more fuel-reach." In contrast, the water context and the equilibrium ratio affect the CO context (Caton, P.A., et.al, 2009).

-*atmospheric-pressure gasification process*: The process is used to produce the heat and power generation such as biomass and solid wastes. The gasification increases the electricity output up to 50%. According M. Morris and L. Waldheim (1998), the atmospheric-pressure gasification process is based on atmospheric-pressure circulating fluidized bed gasifier "coupled to a tar-cracking vessel". The technology contains two main steps-the first step includes gasification of a fuel in CFB reactor (circulating fluidized bed), the second-the cleaning of the product gas in two steps: cleaning of the hot and cold product gases. The produced gas is energy rich and can be fired in a gas boiler or gas turbine. There is no comprehensive flue gas cleaning, and economic advantages can be achieved in a short-term by using the cold clean product gas in a gas boiler (Morris, M. & Waldheim, L., 1998).

-carbo-V gasification technology: The Carbo-V gasification technology is a two-step process. In the primary step air-blown gasification of dried and pre-treated waste take place at 300-350C for less than 30 min a a low-temperature reactor. In the second step products are gasified with pre-heated air or oxygen a two-stage reactor at 1400-1500C to ensure ash vitrification. As were mentioned by T. Malkow (2003) in his article for “Waste Management” journal ” the slag flows along the reactor walls and collected in a water bath at the bottom whereas the gas enters the reactor on the top to be partly combusted with the pulverised coke introduced in the second stage”.

The MCV (medium calorific value) gas is tar free and can be used energetically with a electrical efficiency of 25% for 5 MW gas engine. In addition, High Calorific value gas may be yielded converting CO into H2 (Malkow, T., 2003).

-the BCL/FERCO gasification technology: The allothermal two-vessel gasification technology is based on a low inlet velocity high-trough-put atmospheric gasifier and combustor. Gasification of biomass is at 830C in one vessel using steam. Fluidized bed combustion with air takes place in another vessel using sand. But all of the vessels are connected with each other and in this case the hot sand is moving into gasifier. The Medium calorific value gas may be may be utilized in the engine or turbine (Malkow, T., 2003).

- *Krupp-Uhde Pre-Con Process*: It is aimed to treat waste, biomass and/or coal thermally by the mean of modular fluidised bed gasification. Producer gas is utilized in a boiler, gas engine and turbine.

Firstly, fuel is going for screening to remove metal scrup and dried to less than 10 % moisture followed by air or oxygen-blown gasification. Nowadays, a 1tonn/hour atmospheric gasifier is in Germany. The 30t/hr oxygen-blown co-gasification operates in Germany at 950C and 10 bars. It utilised contaminated coke, pre-treated MSW, post-consumer plastics and sewage sludge for methanol production (Malkow, T., 2003).

- *plasma gasification technology*: It is advanced and environmentally friendly method of gasification is used to dispose solid waste and sewage sludge and convert them into usable products. The main idea is to process waste into simple molecules by mean of extremely high temperatures in an oxygen starved environment. The main product is synthesis gas is used to produce energy. The main advantage of the above process is that the most of the carbon converted into fuel gas as a result of waste minimum combustion; substantial potential to convert organic material into electricity. In addition to waste volume reduction plasma gasification eliminates toxic organic compounds and fixes the heavy metals in the inert slug (Mountouris, A., Voutsas, E. & Tassios,D.,2006).

As A. Mountouris noticed in his article for the "Energy Conversion and Management" journal, "The waste feed subsystem is used for pre-treatment of the waste in order to meet the inlet requirements of the plasma furnace. For waste material with high moisture content, a dryer for reducing the moisture content of the sludge will be required with air tight screw feeders being required to drive the sewage sludge into the furnace." The plasma consists of two graphite electrodes which extend into the plasma furnace. Electric is passing these electrodes and generates electric arc between this electrodes and conducting receiver. The gas is moving between two electrodes and "the slug that become plasma can be oxygen" by air. As a result of high temperatures and dissolve reactions organic components and water are transformed into synthesis gas. Inorganic components in this case form an extremely stable form of glass, which later can be used a construction material (Mountouris, A., Voutsas, E. & Tassios, D., 2006).

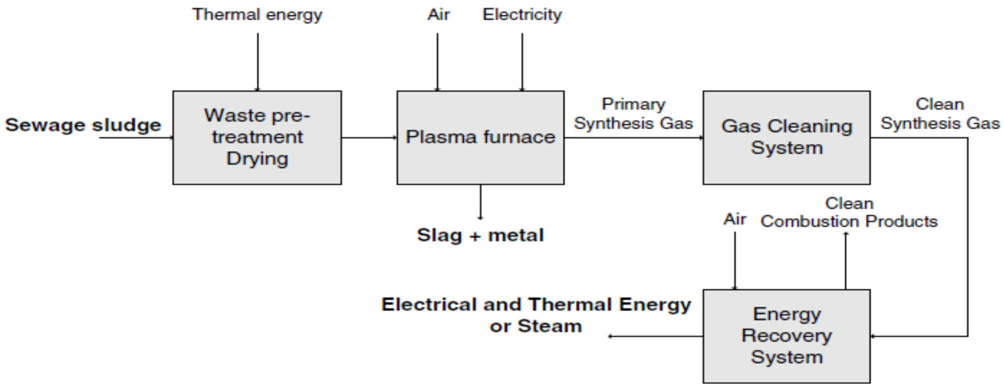


Fig. 1. Block diagram of plasma gasification process.

Figure 2.8 Block diagram of plasma gasification process (Mountouris,A. et al, 2006)

The gas cleaning system is necessary to reach the elimination of acid gases, suspended particulars, heavy metals and dry gas before entering the energy recovery system.

- *plasma Gasification Melting Technology*: High-temperature agent gasification (Hi-TAG) is established as an efficient technology. According Lucas C., "preheating the gasification agent can sharply reduce the air demand in a gasification process, so the concentration of non-combustible gases (N2 and CO2) in the syngas product can be reduced correspondingly." (Lucas C, Szewczyka D, Blasiaka W. & Mochidab S.,2004). Moreover, preheated gasification agent reduces significantly tar yield due to high temperature, and system stability increases. AS Q. Zhang (2010) noticed in his article, the syngas quality improving as a result of decreasing impressionability to variations in particular size and heating value and moisture content of MSW. (Zhang,Q., Dor, L., Fenigshtein, D., Yang, W. & Blasiak, W., 2010).

Most of the alkali and heavy metals, with exception for mercury zinc and lead, are retained in the bottom ash produced during gasification. To anticipate secondary pollution from the bottom products, a melting technology has been widely introduced in MSW gasification plants. Here, the solid residues are melted to form a slag in which heavy metals are locked. The Plasma Gasification Melting technology is a combination of HiTAG and melting technology. The process is shown on Figure 2.9.

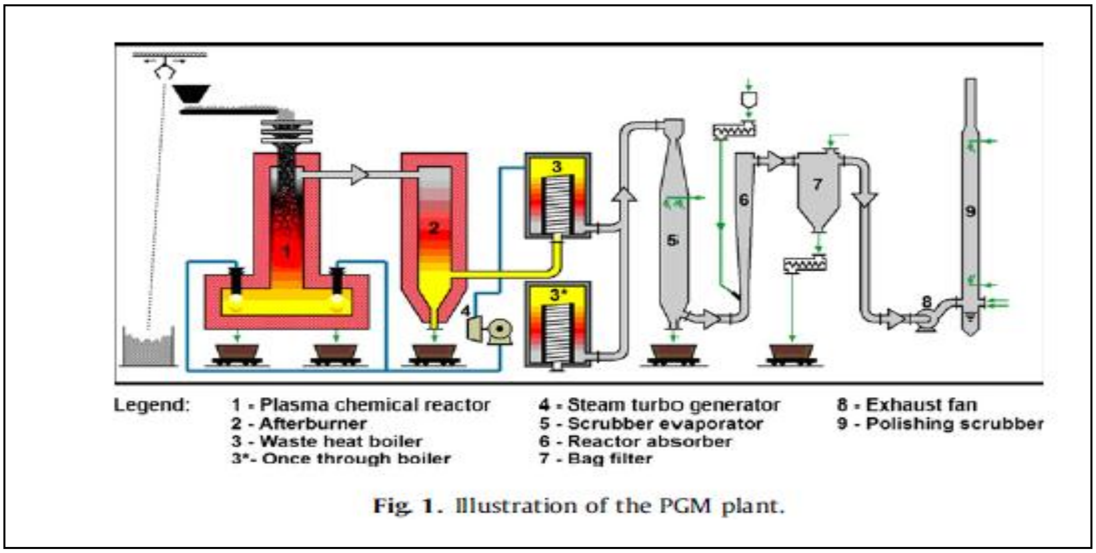


Figure 2.9 The process of gasification melting technology (Zhang,Q. et al., 2010)

The process flow description is given in the article of Q. Zhang and L.Dor (2010), "MSW is fed into the reactor through airtight feeding chambers placed at the upper part of the plasma chemical reactor, wherein gasification reactions occur. Syngas produced from gasification flows into the afterburner and is combusted there. The hot flue gas from combustion is sent to the boiler to produce steam, which drives a steam turbine connected to an electrical generator. The fly ash is removed from the flue gas in the scrubber-evaporator. SOx is absorbed in the reactor absorber and removed using a bag filter. The solid residue from gasification is melted by the plasma jet and collected by the slag collectors." The scheme of the reactor is introduced in the Figure 2.10.

Figure 2.10 Typical schematic of a PGM gasifier (Zhang,Q. et al., 2010)

Air demand for gasification may be reduced with feeding of high-temperature steam. The energy efficiency of air and steam gasification is more sophisticated than simple air gasification. Main energy loss in this system is because of tar formation (Zhang, Q. et al., 2010).

-the gasification of waste containing PVH: If the waste contains Polyvinyl Chloride recycle problems may occur as a result of thermal treatment- PVH gives an important contribution due to its high chlorine context. There is an opportunity for PVH to be recycled in two-stage reactor. Here PVH is blended with RDF and other chlorine-reacted substances. RDF should be ground and mixed to obtain homogeneous mixture. The scheme of gasification process is introduced on Figure 2.11.

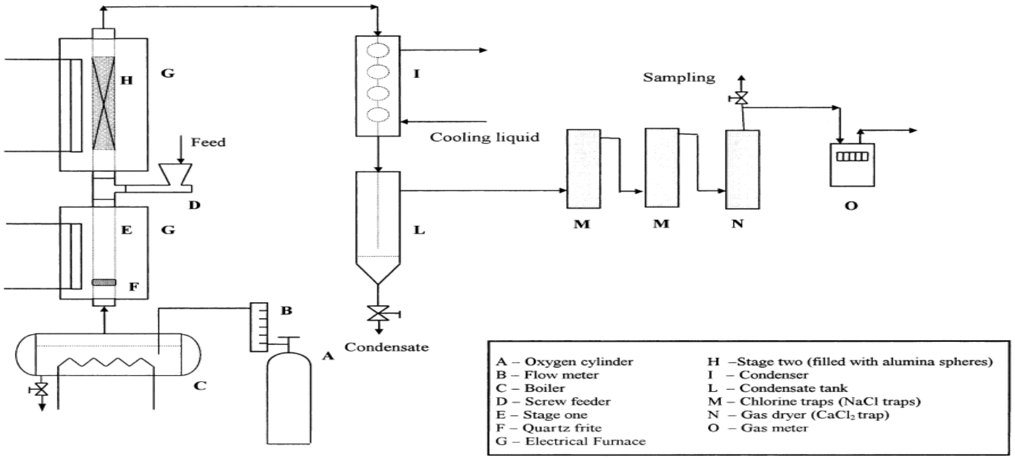


Fig. 1. Schematic diagram of the bench scale gasification unit.

Figure 2.11 The scheme of gasification process of waste containing PVH (Borgianni, C. et al, 2001)

It is possible to see two main section-reaction and product collection. The reaction section consists of two vertical stages. Once the RDF is introduced into reactor is immediately pyrolysed, and due to gravity char is goes to the bottom of stage one and meets gasifying mixture. This mixture is flows to the stage two. In this stage tar, liquid and heavy hydrocarbons is packed increase there residence time. This allows to complete gasification. The cooled off-gas from the stage two is passing through sodium hydroxide traps in order to collect all the chlorine. According information given by Borgianni, C. and other authors in there article for “ Fuel” journal, the next operative conditions are selected for the gasification of the RDF-PVC blend:

1. Steam flow-rate 160 L_{stp}/h,
2. Injected oxygen 0,116 g O_2/g of charge fed,
3. total oxygen 0,41 g O_2/g of blend, considering that 0,29 g O_2/g of blend are already in the sample,
4. First stage temperature 600C
5. Second stage temperature 1000C

It is possible to indicate that temperature on the stage one, oxygen/charge ratio and Na2CO3 addition act positively on the unburned char amount. 1000 C is a sufficient temperature to avoid tar in the syngas. Here, if stimulate this process thermodynamically its leads to the same results (Borgianni, C., Filippis, P.D., Pochetti, F. & Paolucci, M.,2001).

2.4 Pyrolysis

2.4.1 The Process of Pyrolysis.

Nowadays pyrolysis is seems to be an alternative technology which has minimal environmental impact with an image of energy recovery (Shah, 2000). The application of the pyrolysis to the waste management is relatively resent development (Williams, 2002). Pyrolysis is a thermal degradation of organic waste in the absence of oxygen to produce a carbonaceous char, oils and combustible gases. Relatively low temperatures are used, in the range 400-800C (Williams, 2002). Pyrolysis is a reaction in which heat must be supplied for the reaction to occur (endothermic), whereas in incineration, heat is produced (exothermic). A typical pyrolytic reaction using cellulose is

$C_6H_{10}O_5=CH_4+2CO+3H_2O+3C$

Here, gas contains methane, carbon monoxide, and moisture. The $_{CO}$ and $_{CH4}$ are combustible, providing the produced gas with a positive heating value. The carbon residual (3C), a char, also has a heating value. The char is a carbon-rich solid (Shah, 2000).

Pyrolysis requires waste preparation and pre-processing and have a difficulties in accepting variable waste streams (scribd.com). The composition and yield of the products of pyrolysis can be varied by controlling the operating parameters (pressure, temperature, time, feedstock size, auxiliary fuels) (Shah, 2000). Pyrolysis temperature and heating rates has the most significant influence on the product distribution. According Williams (2002), "pyrolysis produces char, gas and oil, the relatively proportions of which are dictated by the pyrolysis technology." Moderate heating rates in the range about 20C/min to 100C/min and max temperature 600C gives almost an equal distribution of oils, char and gases. Very high heating rates about 100C/min to 1000C/min and temperature less than 650C mainly lead to the formation of liquid. But high heating rates and high temperatures are force to develop gas products. Pyrolysis condition can be optimized to produce necessary product. Table 2.3 represents the typical characteristics of different types of pyrolysis.

Table 2.3 Typical characteristics of different types of pyrolysis (Source: Williams, 2002)

Pyrolysis	Heating rate	Reaction environment	Pressure (bar)	Temperature (C)	Major products
Carbonization	Very low	Combustion products	1	400	Charcoal
Conventional	Low-moderate	Primary/secondary products	1	Less 600	Char, gas, liquid
Flash-liqiud	High	Primary products	1	Less 600	Liquid
Flash-gas	High	Primary products	1	More 700	gas
Ultra	Very high	Primary products	1	1000	Gas, chemicals
Vacuum	medium	Vacuum	Less 0,1	400	Liquid
Hydropyrolysis	High	H2+primary	20	Less 500	Liquid, chemicals
Methanolysis	High	CH4+primary	3	1050	Benzene, toulene

The advantages of producing an oil product from the waste are that the oil can be transported away from the pyrolysis plant, may be used directly as a fuel and the energy supply. The oil also has significant calorific values. The gases produced from the process are mainly carbon dioxide, carbon monoxide, hydrogen, methane. The gases have a significant calorific value about 40MJ/m^3. The calorific value is due to high concentration of hydrogen and other hydrocarbons. The calorific value of the pyrolysis gases gives an opportunity to used gas to meet energy requirements for the pyrolysis production plant.(Williams2002). Potential for electricity production is around 0, 5-0, 8 MWh/annual tonne of MSW. (scribd.com). The chars produced may be used directly as fuel to meet energy requirements, upgraded to produce a higher grade activated carbon, or mixed with the pyrolysis oil products to produce slurry for combustion. A wide range of technologies are used for the pyrolysis of waste material. The design is dictated by the type of pyrolysis being undertaking (Williams, 2002). As s result of pyrolysis technologies for residual to disposal landfill capacity consumption reduced up to 90% (scribd.com).

2.4.2 The Classification of Pyrolysis Processes

-the pyrolysis of MSW in the form of RDF. First, we should consider the pyrolysis of MSW in the form of RDF (refused derived solids). In this case recyclable components such as glass and metals are detached. According information represented by Buah K., Cunliffe A.M.& Williams, P.T. (2007) “ refuse derive fuel involves a process, where the main end product is the production of a fuel in the form of the combustible fraction of municipal solid waste.” Consolidation of the combustible materials may be reached by the elimination of the non-combustible materials, removal of low-calorific value materials (putrescibles). The major steps in producing RDF are preliminary liberation, size screening, magnetic separation, coarse shredding and series of processes to control physical characteristics of the fuel. Results of the process conducted by the W Buah K., Cunliffe A.M.& Williams, P.T (2007), shows that “ thermal decomposition of the RDF is dependent on particle size; the major weight loses of the cellulosic matter occurred

between 250-400 C; the thermal degradation of the polystyrene, polypropylene, low density polyethylene and occurred between 350-500 C."

The main characteristics of the char product:

-the low pyrolysis temperatures force the formation of the harder chars;
-the specific surface areas of the chars from the RDF pyrolysis increase with increasing temperature from 400 C to 700 C;
-the moisture retention ability of the chars samples decline with rise of the temperature;
-the properties of the derived chars are dependant on particle size;

The main characteristics of the gaseous products:

-the main gases are CO_2, CO, H_2, CH_4, C_2H_6 and C_3H_8 with lower concentration of other hydrocarbon gases;
-higher gas yield depends on time spending by the pyrolysis products in the hot zone of the reactor, occur in temperatures more than 750 C;
-in contrast to CO_2, the percentage configuration of H_2, CH_4 and CO increases in the range of temperatures 400-700C, the increase in the percentage of hydrocarbon is up to 600C;
-the high concentration of CO_2 and CO in the product gases is established from the oxygenated structures in the original material;

The main characteristics of the oil/wax products:

-after separation of water the calorific value of the products is independent of pyrolysis temperatures;
-high oxygen content in the product oils/waxes resulting in a lower calorific value;
-biomass and MSW pyrolysis oils can be viscous, highly acidic and readily polymerize;
-products chemically very heterogeneous and highly oxygenated;
(Buah, K., Cunliffe, A.M. & Williams, P.T., 2007).

Anh N. Phan from the University of Sheffield concluded that the char from slow pyrolysis of segregated waste contains 38-55% of the energy content of the original materials, the liquids-20-30%. With the increase of the temperature char gain more calorific value, but the energy yields decrease. The calorific value of pyrolysis liquids is about 10–12 MJ/kg. The heavy oil fraction had a H/C ratio such as alkenes/cycloalkanes. With the increase of the temperature more than 600C the liquid yield is droping. The heating value of dry gases at 700C is 13–16 MJ/N m3. (Phan, A.N.,Ryu, C., Sharifi, V.N. & Swithenbank, J., 2007).

As noticed by Shah (2000), "municipal solid waste has a high heating value, with a range of 10-12 million Btu per ton". Such waste is not only heterogeneous but may differ greatly from one batch to the next. So, considerable research and pilot work are needed before pyrolysis can be applied as an efficient process to recover energy from solid waste. Figure 6 illustrates an experimental unit that uses the pyrolysis process from the Battelle Northwest final report. Solid waste is shredded to a size of less than 4 in. and is passed through a magnetic separator. It is then fed into the reactor. As it enters the reactor, the waste passes through the drying zone, the pyrolysis zone, the char gasification zone, and then settles in the ash bed in the bottom. A mechanism removes the ash from the reactor, passes it through a crusher, and then loads it onto tracks for landfill. The air-and-steam mizture injected into the bottom of the reactor reacts with the char residue to produce the heat required to pyrolyze the incoming waste. Half the steam decomposes during the reaction; the other half heats the solid waste stream. Water from the condensed steam is then piped for treatment, and the gas from the reactor is compressed and piped to a turbine for power generation (Shah, 2000).

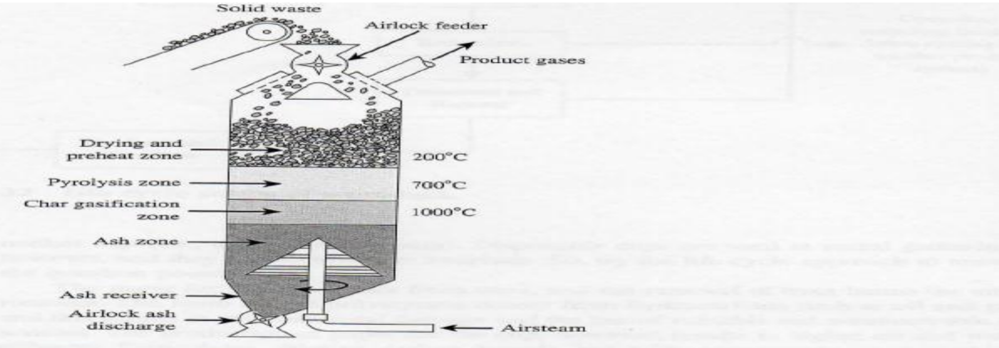


Figure 13–31 Battelle pyrolysis reactor.
(From U.S. Environmental Protection Agency. Battelle Northwest Final Report, City of Kennewick, Washington. *Washington, D.C.: U.S. Govt. Printing Office, 1972; with permission.)*

Figure 2.12 Battelle pyrolysis reactor (Shah, 2000)

- *Pyrolysis of hardware components.* Hardware components wasters are mainly composed of computer and television components. Pyrolysis of such elements should be performed under nitrogen. The degradation products are separated in three division- solid, liquid and gaseous. Two different types of components can be used: white or green, with or without microchip. According paper, presented by Carlo Mazzocchia and others in the Journal of Analytical and Applied pyrolysis (2002),” the solid phases obtained from the pyrolysis of hardware components were oxidised using the air/N2 mixture.” The overall process scheme presented in the Figure 2.13.

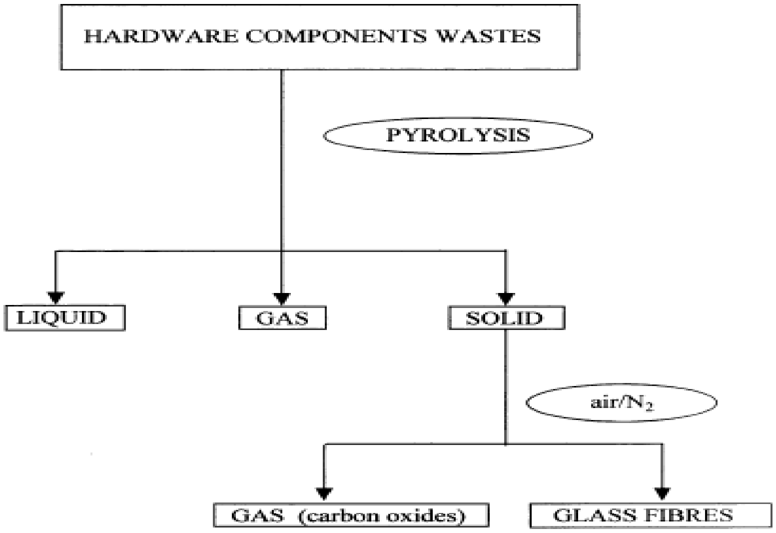


Figure 2.13 Overall process scheme (Mazzocchia, C., et. all, 2002)

The solid part captured after carbon abolishment mainly presented by glass fibres. Different metals such as copper, gold, stannous, aluminium, lead, silver were presented in the solid residue. In order to remove copper and distinguish these metals from the residue it should be washed with ammonium carbonate. The rest of the metal can be removed by using aqua regia and/or thiourea. The recovered glass fibres are able to be used as row material or recycled in products, for example hardware components (Mazzocchia, C., Kaddouri, A., Modica, G., Nannicini,R., Audisio, G., Barbieri, C. & Bertini, F.,2002)

As were noticed by the specialists, working in Milano, Italy, " the gas phase obtained by pyrolysis of hardware components was found to be about 4-7 wt.% of the total weight. This phase consists principally of light hydrocarbons C1-C4 and hydrogen." Moreover, changes in gas product composition are caused by modification of the temperature. During these changes increases the amounts of methane and hydrogen. The liquid part was discovered to be about 1/5 of the total weight. Two phases of the liquid presented by a brown viscous and less viscous white participate. Depending from the type of hardware the presence of phenol in the liquid phase varies from 40 to 60%.

As proposed by Blazso, components presented in above table "are formed through the cleavage of phenolic resin chain" (Mazzocchia, C., et al., 2002).

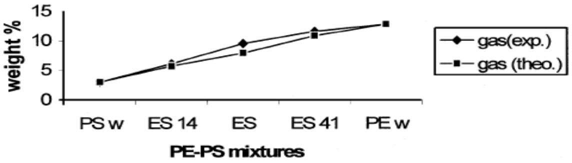
It is noticeable that the concentration of isopropyl-phenol is significant in compare with other components. Also a substantial amount of brominated products are presented in the liquid fraction, around 7-15 wt. %. Therefore, the formation of hydrogen bromide and possibility to form toxic polybrominated dibenzo-dioxins and furans are the main disadvantages in the use of brominated flame retardant. According Carlo Mazzocchia and other authors, the temperature between 430-460C is the most optimal for the process; "the gas obtained are highly calorific and may serve as heating gas for energetic purposes."(Mazzocchia, C., et. al., 2002)

- *pyrolysis of waste tyres.* Lower emissions of nitrogen oxide and sulphur oxide in compare with other thermal processes shows that pyrolysis is an attractive method of reducing waste tyres. Information given by the V.K. Sharma in Applied Energy journal (2000), shows that "product of pyrolysis represents about 50% of the initial volume of the organic matter and they call be converted into energy to either sustain the process or produce excess power." The process usually starts with the preheating of the shredded materials. Following further heating to the required temperature lead to gas production. The gas has to be clean by the liquid separators to remove oil or tars. In contrast to the gaseous fraction, which is consists of non-condensable organic, H2, H2S,CH4, CO, NH3, the oil fraction mainly consists of olephinic and aromatic hydrocarbons. The composition of both fraction relay on operating condition, but in general can be presented as follows:

Char fraction-33%
Oil residue-35%
Metallic fraction-12%
Gas-20%
(Sharma,V.K., Fortuna, F., Mincarini,, M., Berillo, M. & Cornacchia, G., 2000).

- *pyrolysis of plastics.* As N. Kiran (2000) supposed in his paper, "the products obtained from the pyrolysis of plastics depend on the type of plastics, feeding arrangements, residence time, temperatures employed, reactor type and condensation arrangement." At a low temperature liquid products are dominant. In contrast, at a high temperatures gas fraction is the mainly presented. The amounts of the gaseous and liquid fraction and residue, adjusted from the pyrolysis of the polyethylene (PE) and polystyrene (PS) are presented in the Figure 2.14, where PSw, ES14, ES, ES41 and PEw are mixtures of polyethylene and polystyrene in gaseous and liquid phases.

(a) gas products



(b) liquid products

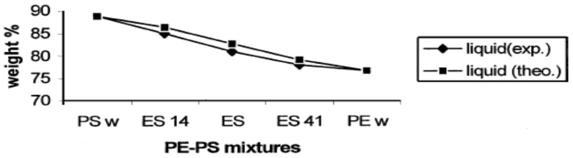


Figure 2.14 The amounts of the gaseous and liquid products (Kiran, N., Ekinci, E. & Snape, C.E., 2000)

The pyrolysis of the PE gives the two main products: green wax and gas, whereas the pyrolysis of the PS gives one-brown coloured oil with small fractions of gas. Usually pyrolysis is taking place at a low temperature. As it is possible to see on the Figure the total oil production decreases with the increase of the PE content of the feed, but the gas production is increased. The different mixing ratios of PE and PS almost have no influence on residual char. As it was concluded by N. Kiran (2000),” liquid yield of PS was found to be higher that waste PE. The dominant product of waste PS was styrene monomer with a percentage of 37% followed by toluene, naphthalene and xylene. The pyrolysate of PE mainly consisted of propenylbenzene followed by butenylbenzene.” In addition we can notice, that gas production is higher in the case of PE pyrolysis. The information presented in the Resources Conservation and Recycling journal, shows that “the mono-aromatic products, which are economically valuable, were less in the pyrolysis of PE than that of PS.”(Kiran, N., Ekinci, E. & Snape, C.E., 2000)

- t*hermal plasma pyrolysis*. Thermal plasma pyrolysis of organic waste, including plastic, tyres, medical waste and agricultural residue is supposed to be a useful way of waste management for energy and material recovery.

Description given by the H. Huang and L. Tang (2006) tells, that thermal plasma pyrolysis is “the process of reacting a carbonaceous solid with limited amounts of oxygen at high temperature to produce gas and solid products.” There are a lot of electrons, ions and excited molecules in a highly reactive plasma zone. Also here exists high energy radiation. When carbonaceous particles are in the plasma, they become heated very rapidly. As a result of this process, the volatile matter is released and bursted; hydrogen and light hydrocarbons such as methane and acetylene are increased. Allocation of pyrolysis products depends on plasma input power. Gas and carbonaceous residue are the two stream products available. In contrast to conventional pyrolysis of tyres, where amount of gas is 10-50 % of the feed, thermal plasma pyrolysis enlarges this matter to 70-80%.

The main characteristics of gas product:

- substantial quantities of combustible gases such as H_2, CO, C_2H_2, CH_4, C_2H_4 are produced;
- parameters;
- the product gas may be utilized in syngas application;

The main characteristics of char:

- the char fraction may contain inorganic materials, any unconverted solid additives, carbonaceous residues, depending on operating conditions;
- heating values of the char allows to use it directly as solid fuel;
- the solid residue mixture is only useful as a low-grade semi-reinforcing filler for non-tire application;
  (Huang,H. & Tang,L. ,2006)

- *fast pyrolysis of biomass-the RTI process***.** During the pyrolysis of biomass charcoal, liquid and fuel gas fuels are available. The transformation to liquid receives most appreciations as a liquid fuels appear to have the largest general applicability as an alternative energy source. To achieve maximum yield of organic fuels certain conditions have to be followed by: atmospheric pressure, temperature interval 450-550C, apparent volatiles residence time less than 1 c, very fast heating rate of biomass. The outstanding feature of the liquids obtained from these conditions is high content of some rare chemicals such as glycolaldehyde, levoglucosan and acetol. These liquids can be used not only as an alternative fuels, but also be a feedstock for recovery some unique organic chemicals. The RTI process in a bubbling fluid bed reactor is an improved version of “fast” pyrolytic technology allowing to receive such components. Relatively low temperatures (360-490C) and gas residence time greater than 5c result in liquid rates similar to those obtained at 550C. In combination with the fine sand used a as bed heat carrier, and indirect heat supply appears improved thermal efficiency (Scott, D.S., Majerski, P., Piskorz, J. & Radlein, D., 1998). The thermal efficiency is an important factor as a process is used to produce alternative fuels and energy.

Separately collected chars can be used as a source of process heat without ash contamination. As were mentioned in the Journal of Analytical and Applied Pyrolysis (1999), RTI process “with its lower pyrolysis temperatures, deep fluidized bed and long gas residence times facilitates the use of heat exchangers and economizers to provide an independent heat supply to the pyrolyzer, which is made more favourable by the larger available temperature differential and the greater bed volume.” Thus we may conclude that high temperatures of the flue gas make him available for gasification to provide gas for process heating and biomass drying. Table 2.4 introduces some results from RTI pyrolysis reactor.

Table 2.4 Results from RTI pyrolysis reactor

Process	Experimental yields (wt.%) mf hardwood sawdust feed			
	Temperature (°C)	Char	Bio-oil	Gas
RTI process	430	12,5	74,3	10,1
RTI process char converter@800°C	430	4,5	73	19

Source: Scott, D.S., et all., 1999

From the point of energy efficiency the liquid yields of the process are improved (Scott, D.S. et.al., 1998).

- *the pyrolysis innovative system.* The next pyrolysis innovative system uses a combine cycle engine to produce electricity.

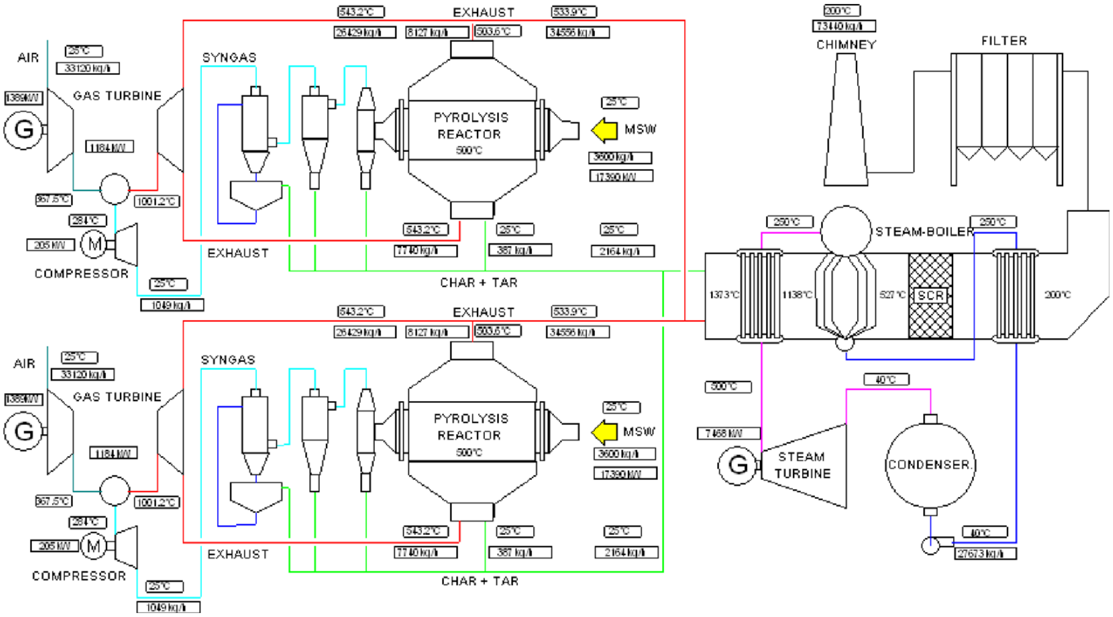


Figure 2.15. Schematic diagram of an innovative system for municipal solid waste (MSW) pyrolysis (Baggio, P., Baratieri, M., Gasparella, A. & Longo, G.A., 2006).

The system consists of two pyrolysis lines which feed two gas turbines. The exhaust from gas turbines drives a steam turbine. The MSW after the rotary klin produces char, tar and syngas and also ash. The syngas is purified in a cyclone and scrubber to remove particulars and condense humidity and heavy hydrocarbons vapours. After compression the syngas is injected into the combustion chamber of the gas turbines. As were noticed by Paolo Baggio (2006),” the gas exhaust from the gas turbines may be used as reactant in the recovery boiler for the combustion of char and tar in order to drive the steam turbine”. Before discharge the flue gas is processed in a selective catalytic reduction unit.

The innovative aspects such as application of combine cycle engine allow rational use of different products resulting from the pyrolysis. The other advantages of this system are high flexibility, reliability and low polluting emissions. Production of syngas, tar and char depends upon operating temperature, residence time and heating rate. The heating value of char fraction is comparable with lignite and coke. The heating value of tar fraction is comparable with oxygenated fuels; the syngas- with coal gas which is much lower than natural gas heating value. According information given by P. Baggio and other authors , "the system is fed with 34.8 MWt of MSW and produces 9.84 MWe of electric power with a global efficiency of 28.3%. The steam turbine provides 7.47 MWe (76%) with efficiency around 29.5%, whereas the gas turbines provide 2.36 MWe (24%) with efficiency around 18.6%" (Baggio, P., Baratieri,M., Gasparella,A. & Longo,G.A., 2006).

- *pyrolysis technology based on conventional principle.* The new pyrolysis technology based on conventional principle was developed in China to process municipal and medical waste. In one line with composting it also contains coke oxygenation, carbon dioxide revivification and water gas reaction. The burning is reduced to 900C; and there I no fast cooling and the main heat come from the waste itself.

The waste is pyrolysed under the high temperature, low oxygen and pressure in a heat –reactor to allow chemical bonds to be disrupted. The surface water, carbon dioxide and methane generate mixture of gases with a methane as main component. So, the main waste is changed into coke (carbon). According Z. Yufeng (2002), some of waste is used for combustion reaction support what allow to produce heat to support other reactions; "the rest is used to react with the mixed gases." The clean energy produced is used to maintain the reaction temperature of the equipment and for consumer consumption. The whole process includes next stages-pyrolysis of the waste, heat-disposing the mixture gas and purifying the fire gas. The results shows that if the waste contains more than 85% of food waste than calorific value of 100-120 m^3 of is about 13,585–14,630 kJ/m^3. To compare, if the waste contain more than 40% of plactic, the calorific value of 150-

180 m^3 of fuel gas is16,000–20,000 kJ/m^3.(Yufeng,Z., Na, D., Jihong, L. & Changzhong, X., 2002).

2.4.3 Energy Potential Analysis

As were mentioned above, conditions of organic waste in the form of RDF may be optimized to produce solid char, gas or oil products (Buah, W.K., Cunliffe, A.M., & Williams, P.T., 2007). The solid char may be used as a solid fuel or as slurry for the fuel. In the same way the oil can be used directly as a fuel, added to petroleum refinery stocks, upgraded using catalysts. It is known then oil has a high energy density than waste, what can be an additional benefit for recycling RDF. The calorific values of generated gas is sufficient to support energy requirements of the pyrolysis plant(Buah, W.K., Cunliffe, A.M., & Williams, P.T., 2007). During the pyrolysis process of hardware components burning of material generates heat and steam. Moreover highly calorific gas fraction may serve as a heating gas. According information given in Journal of Analytical and Applied Pyrolysis (2003), " in order to perform an energy recovery evaluation" theoretical calculation should be made using combustion heat value of gases "which compose gaseous effluents obtained from hardware material pyrolysis." The evolution of combustion heat is presented in the Figure 2.16.

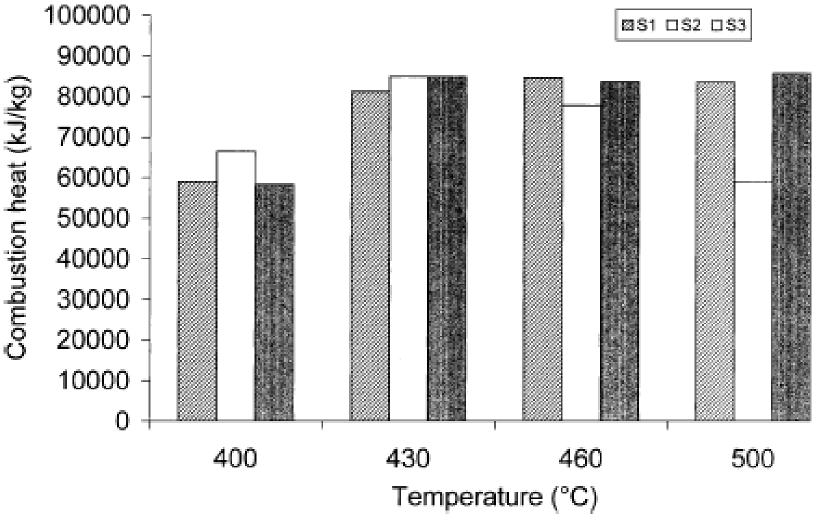


Figure 2.16 The evolution of combustion heat (Mazzocchia, C. et.al, 2003)

It is possible to observe that in the range of temperature between 430-460C the combustion heat is almost constant. Thus, we can make conclusion that chemical composition of the gases during this interval is almost constant also. The combustion of carbon residue deposited on glass fibres can generation extra energy. In general, energy obtained from the process may support pyrolysis system and allow it to be self-efficient.

As were mentioned above, the products of pyrolysis of waste tyres can be converted into energy. As in case of hardware components pyrolysis, pyrolysis of waste tyres has a high energy potential and allow system to sustain and what is more- to produce excess power. The oil and gas fractions can be used as a fuel.

Pyrolysis of plastic wastes for the simultaneous generation of oil and gases is convenient to generate energy. Utilisation of energy from the high calorific plastic products may bring additional economical and environmental benefits.

Thermal plasma pyrolysis technology replies the resent interests in energy recovery. The properties of the process products are suitable for energy recycling. The combustion heat value of the gas product 4-9 MJ/Nm^3 allows it to be used directly as a fuel in different energy applications. As mentioned by H. Huang and L. Tang, (2007) “heating values of the chars obtained from plasma pyrolysis are usually comparable with those of lignite and coke and can be used as a solid fuel directly.” The process is energy self-sufficient.

2.5 Incineration

2.5.1 The Incineration Process

Mainly, waste incineration is decomposition of materials in the waste that can be burned to provide heat or power (ec.europa.eu). It is known that waste is highly heterogeneous, and the main components of it are organic, minerals, metals and water.

Fuel gases as result of incineration process contain the majority of the fuel energy as heat. When the essential temperature is achieved the organics in the waste is burned in contact with oxygen. Combustion is a gas stage process, which releases energy where calorific value of the waste when oxygen accumulation is acceptable.

The major phrases of incineration are:

1. Condense and removal of dissolve gases from the waste- at the range of temperatures from 100 to 300 C, do not need oxidising agent and depends upon supplied heat.

2. Pyrolysis and gasification-later decomposition of organics at the range of temperature 250-700 C. Here, Gasification is the reaction of the residue with water vapour and CO2 at temperatures from 500 to 1000C generally. But in some cases the temperature range may exceed up to 1600 C.

3. During oxidation the combustible gases created and flue-gas temperature usually in the range 800-1500C (ec.europa.eu)

For incineration of hazardous waste special treatment techniques are required. Flue gas emissions from the incinerators require expensive clean-up using a variety of systems to remove potentially highly toxic pollutants. Rotary kilns are the preferred design for the hazardous waste incinerators (Williams, 2002). It should be taken into account that conditions for the incineration of medical waste should be the best currently available. In opposite, the incineration is dangerous due to release of unwanted components in extremely high concentrations (pops.int)**.**

2.5.2 Operational Features and Boiler Configuration

Operational controls are developed to reduce release of unwanted components and increase potential of energy recovery. Accumulation of energy capture requires efficient combustion. Thus, for example, waste streams should match with particular amount of oxygen (scribd.com).

The combustion gases should be cooled before discharged through the flue gas cleaning system. It is known that gas cleaning system required temperature of the gases to be below 250-300 C. So the temperature of the gases, equal 800-1100 C is too high for the direct discharge. Cooling can be assessed by the integral boiler and boiler chamber system. The boiler consists of banks of steel tubes through which water flows to generate steam from the heat generated in the furnace. As Williams mentioned in his book (2002), “the integral part of water-wall boilers are constructed around and integrated with the combustion chamber, the main boiler is located in the separate boiler chamber above the combustion chamber and the tubes are heated by the hot flue gases.” One of the options-after the boiler there may be a heat exchange system to produce hot water from the flue gases before they enter the flue gas cleaning system. The hot water or steam produced in the boiler may also be used to provide power and space heating. The boiler should be designed to ensure good heat transfer with the optimum circulation of the water (Williams, 2002)

The major factor in the efficient operation of the boiler is that tubes should not be fouled with deposits from the flue gases as they stick to the boiler tubes and reduce the transfer of the heat. Corrosion is also important in the design and operation of the incinerator boilers (Williams, 2002).

If a boiler is having operational problem, that lead to the next consequences for energy recovery. First of all, it is the drop of heat exchange coefficients what reduces the heat recovery. Second, it is the great possibility of blocking up the heat-exchange bundles, and as a result closing of the whole plant. We should notice that the proper boiler must have a necessary heat-exchange surface and have a suitable geometric design.(ec.europa.eu)

By the way that waste is moving through different zones in the combustion chamber various grate incineration system are recognized. These systems are applied for incineration of MSW. Here air feeding, conveying velocity and raking combustion of solids are important as well as mixing of the waste. For incineration of hazardous wastes is more efficient to use rotary kilns. For this type of system cylindrical vessel inclined on its horizontal axis. The vessel is located on rollers, what allow the klin to rotate or oscillate around its axis. The waste is moving through the klin with the help of gravity. If to take into attention only finely divided and pre-treated wastes, fluidised b incinerators should be applied in this case (Autret, E., Berthier, B., Luszezanec, A. & Nicolas, F., 2006).

2.5.3 Energy Recovery Potential and Features

Incineration facilities have reasonably good energy efficiency. It can be up to 30% for electricity and 60% for combined heat and power or just heat recovery system (scribd.com). Incineration is one of available instruments in integrated waste management system; can treat substantial amounts and kinds of wastes. According information given in Journal of Hazardous materials, “Incinerators, designed and constructed under the latest European standards and especially the 2000/76/EC incineration European Directive, fully respect the environment and human health at an acceptable price” (Autret, E., et.al, 2006) . Moreover, Mario Grosso et. all says that “ the incineration of waste is a treatment operation widely applied all around Europe to recover the energy content of residual waste” (Grosso, M., Motta, & Rigamonti, E., L.,2010)

Incineration is a process that consumes and produces energy at the same time. And energetic value of the waste is exceeded the process requirements, what results in the energy export. Valuably, the waste incineration proposes a substantial source of energy. Also, according information given in (ec.europa.eu), “ energy inputs to the incineration process can include: waste; support fuel such as diesel and natural gas for start-up and shutdown, to maintain required temperatures, for flue-gas reheating; imported electricity for start-up and shutdown phases when all lines are stopped and for plants without electricity generation.” Energy production during incineration includes electricity and heat. Here, the efficient energy recovery from the waste is a key issue (ec.europa.eu).

From one point of view, the demand for energy has a fluctuation character. So in an incineration plant waste is burned at a more or less constant rate and generally near design capacity. And the output of energy cannot be varied to meet demand. If to look on space or district heating, the utilisation of this energy may also be a problem. But electricity generated may be sold to the mains grids. If continuous output of heat is required, a back-up surface is required with additional investment. Similarly, the alternative users of the heat or cooling system for the gas is required if heat demand is reduced

*Energy recovery via District Heating and Electricity Generation***.** As were mentioned above, waste incinerators produce and consume energy; and net export of energy is available because in most cases the energetic value of the wastes exceeds the process requirements. Three ways of recovering energy include electric, thermal and combination of heat and power (Autret, E. et.al, 2006). Electricity production for older incineration sites is 0,5-0,6 MWh/annual tonne of MSW and 0,75-0,85 MWh/annual tonne of MSW for new facilities (scribd.com). We should also take into account that energy recovered from biomass fraction of the waste may contribute to a reduction in the carbon dioxide emission from energy production. Here energy can be considered as substitution for fossil fuel (Autret, E., et.al, 2006). The modern municipal waste incinerator produces steam for electricity generation or district heating, what done to ensure the cost-effectiveness of the process. Electricity generation and district heating may also be combined as heat and power systems. Electricity is generated from the steam produced in the boilers through a steam-condensing turbine. The steam with the high pressure and temperature enters and passes though the different stages of the turbine. High velocity of the steam is turning the blades of the turbine and hence the turbine shaft, which generates the electricity. If district heating is the objective, the high temperature and pressure steam passes through heat exchanges which generate hot water under pressure ready for distribution. Heat and power systems would use a different type of steam turbine which generates a lower amount of electricity, but the steam fluent from the turbine will be at a higher temperature, what allows district heating to be incorporated. Evaluation of options is a site-specific issue. All contracts obligations for the electricity generation and waste plants should be secured. It is important to notice that recycling schemes do not influence variations in the calorific value on a significant scale. It is also makes a little difference to the energy recovery performance of a solid waste incinerator (Williams, 2002).

Thermally integrated incineration should give prominence to operational flexibility. It is substantial to accomplish pollutants demolition and compensation of thermal demand in spite of turbulence in the waste steam and heat load. A proper exact state model, which is related to the process variables, is developed by the R.S. Ettouney, M.A. El-Rifai and S.A. El-Behairy. It is based on extensive heat balance computation for an industrial unit. As authors stated in their work, “systems exploiting the thermal energy generated through incineration of wastes in complementing the heat requirements of other processing units should enable sufficient flexibility to accommodate the variable supply of combustible wastes and the variable demand on the heat contained in the resulting flue gases.” The major considerations are to make sure that complete waste destruction is applied, to prevent of soot deposition in the waste heat recovery unit and abstain extremely high temperatures beyond the incinerator. Prevention of soot deposition is achieved by supplying for ample combustion air and for a residence time between 2 and 5 s at 1473K. If system has a proper design , the incinerator and post incineration quench dust are size to apply sufficient residence time and gas mixing with maximum flow conditions. Moreover, the design of the waste heat recovery unit should consider necessary heat transfer surface. This is important to allow operation at a maximum heat load. According the R.S. Ettouney (2004), “the operation of such systems consists of controlling the incineration and quenched flue gas temperatures within narrow limits while responding to the variable demand on the thermal energy and variable supply of the combustible pollutants.” Here, the constant heat balance of the unit is very important. (Ettouney, R.S., El-Rifai, M.A. & El-Behairy, S.A., 2004)

Optimization of energy recovery. The optimization of energy recovery during incineration is optimization of the whole process, what includes decreasing the losses and limiting the process usage, reducing the losses and limiting the process consumption. The ideal energy efficiency techniques depend on particular location and on operational factors. According information given on ec.europa.eu, the next examples of factors should be taken into consideration while consider energy output: location, demand for energy recovered and variability of demand. Moreover, for the optimization of energy techniques it is necessary for the incineration plant to meet the demand requirements of the energy user. For example, plants that can supply only electricity should have different design from those which may supply electricity, heat and power. As were noticed on ec.europa.eu, “ increasing the recovery and effective supply/use of the energy value of the waste replaces the need for the external generation of this energy, resulting both in a saving of the resources and in avoiding the emissions and consumptions of the avoided external energy generation plant.” The quantity of energy that is available to be recovered from the waste depends on the calorific value of the waste.

Amount of generated electricity depends upon steam quantity and its parameters, plant size and steam utilization potential. The energy recovery has to be combined with the safe destruction of the waste. For example, steam conditions may discrete plant accessibility. All cautions should be taken into account. In the same way market availability for heat power and electricity should be considered. If there are no consumers for electricity, the only option is to generate heat or power. Increase of steam parameters improves electricity output (ec.europa.eu).

Reduction of flue-gas temperatures after the boiler can donate to energy recovery improvement. Supplementary heat-exchange capacity in the boiler can progress possibilities for use of that heat. There are several points to be consider when the purpose to reduce temperature at the end of the boiler. First of all, if the temperature is below 180 there is a risk of oxidation. Second, if the heat in the flue-gases is necessary for the operation of subsequent flue-gas cleaning equipment. Moreover, if additional heat recovered at low temperatures will be useful. According information given on ec.europa.eu, “the key temperature to consider in term of corrosion risk is not the temperature of the flue-gas but the (lower) surface temperature of the (cooled) metal tubes of the exchanger (which is necessarily colder than the flue-gas).” (ec.europa.eu.) So, the conclusion can be made that heat-exchangers should be from special materials to decrease low temperature corrosion problems.

The benefit of the process is that recovered heat may be used for heating purposes or for pre-heating water at the boiler. But we should take into account that any removed heat has to be added on a later stage. Probably this will result in supplementary consumptions of primary fuels. When temperature of flue-gas is decreasing acid dew point is important. However, as stated on ec.europa.eu, reduction of temperature is applicative if the het recovered is for the useful purpose and flue-gas cleaning system are not unfavourably affected.

Use of flue-gas condensation scrubbers includes the use of chilled scrubber that abbreviates water vapour from the flue-gas systems as extremity end solution. The cooling is accommodated by heat exchange with the returned district heating water. This technique allows to extract the additional energy from the gases. Here the result (amount of recovered energy) depends upon the return water temperature in the district heating system. System is applicable where district system has a low temperature feedback and prices for the additional energy is comparable with capital investment. Moreover, all waste types may be used here.

To improve heat recovery heat pumps may be used. As stated on ec.europa.eu,“ heat pumps provide a means of uniting various relatively low temperature heat and cooling sources to provide a stream at an upgraded temperature level.” As a result the additional energy is recovered with the help of condensing scrubbers. The improvement may be up to 25% when there is a combination of absorption heat pumps and condensing scrubbers. However, we should notice that heat pumps need energy to work. This technique is applicable where district heating uses most of the available heat and there is low temperature return. Also the possibility of using such technique is decreasing if there is no user for additional recovered energy. It can be applied to any type of waste, to the new and existing processes. Additional heat sales and income are the driving force for implementation (ec.europa.eu).

Flue-gas losses as energy loss reduction. When the flue-gas is decreasing it is the heat leaving the plant at the boiler stage. The real loss is generally depends upon flue-gas flow and temperature. According ec.europa.eu, there are some possible techniques to decline these losses: "reduce the flue-gas flow; to achieve this several options are possible- reduce excess air e.g. improve primary and/or secondary air distribution, recycle flue-gas, i.e. replace a part of the secondary air by flue-gas, enrich the combustion air in O2, i.e. increase the proportion of O2 and decrease the one of N2 by O2 injection ,reduce the flue-gas temperature, e.g. by using flue-gas condensation or by decreasing the temperature at the boiler exit" (ec.europa.eu).

Reduction of overall process energy consumption. There is a need in energy supply for incineration process. The process may be self-sufficient and supply necessary energy by itself. The quantity of energy depends upon the type of burned waste and plant design considerations. Effective incineration should be in balance with installations energy requirements. As stated on ec.europa.eu, " the following techniques and measures can reduce process energy demand" and by this increase energy output: "avoiding the use of unnecessary equipment, using an integrated approach to target overall installation energy optimisation rather than optimising each separate process unit ,placing high temperature equipment upstream of lower temperature or high temperature drop equipment." Also the use of controlled rotating equipment will reduce average energy consumption as a result of pressure variations (ec.europa.eu). The progress in incineration technology activates movements in construction of new plants. These plants also benefit from energy recovery results as decreasing dependency from fossil fuels (Grosso, M., Motta, & Rigamonti, E., L., 2010).

2.5.4 The Environmental Impact of Incineration Process

The environmental impact of municipal solid waste incineration has increasingly become the subject of public debate. Critics assert that incineration is no longer acceptable for ecological reasons. Furthermore, in view of the main goal of incineration-namely, to destroy the organic pollutants and to reduce the volume and quantity of non-avoidable and non-recyclable waste-energy utilization is increasingly being discussed as merely a secondary effect. Over the long term, however, waste incineration can only continue to be an accepted waste management technique if further progress is made in advancing its strong points, i.e. manageability of the treatment process, the extensive reduction of the hazard potential posed by waste and the controllability of the emissions. Furthermore, in addition to adhering to the progressive standard in treatment and flue gas cleaning technology, an importance prerequisite for improving public acceptance is that care is taken to ensure that only residual waste deemed unavoidable and non-recyclable is subjected to thermal treatment and that thermal treatment plants are a part of integrated waste management schemes.

CHAPTER THREE
WASTE MANAGEMENT APROACHES TO REAL PLACES

3.1 Introduction

The purpose of this chapter is the analysis of availability for gas-to-energy recovery projects on the base of two landfill areas: Kusadasi Solis waste Landfill facility and Canakkale Solid waste Regional Management Project; give examples what energy recovery results can be for gasification, pyrolysis and incineration.

Kusadasi Solid Waste Landfill Facility located in 6,5 km from Kusadasi city centre and accepts waste from Kusadasi, Davutlar, Soke, Guzelcamli regions. Kusadasi Solid Waste Landfill Facility built according European Union standards and its integrated plan consists from the following components: landfills, gas collection and flare unit, leachate treatment plant, medical waste sterilization unit and social facilities. Solid waste landfill area about 1.5*106 m^3 capacity and the facility is planned to serve for a period of 20 years. Storage space is composed of 3 cells. (Kusadasi Kirazli Duzenli Depolama Isletme Plani, 2011)

Canakkale facility is located in quarry of Kemel village in Canakkale municipality. Selected site is located on the northeast of Canakkale city center and the distance from city center to the area is 17 km. Landfill accepts waste from 50 villages in Çanakkale, 40 villages in Lapseki, Kepez, Umurbey, Çardak, Erenköy and Kumkale. Facilities build according European Union standards. (Kavcar, A., 2006)

Currently both sites do not have energy recovery facilities. To examine availability for gas-to energy projects will be complete next actions: projection of solid waste amount, determination of landfill gas potential based on literature information, estimation of landfill gas generation potential based on Tabasaran/Rettenberger, LandGem and School-Canyon models, analyzing dissimilarity of received results, Gas-to –Energy economic analysis of results , comparison of available energy generation results from landfill gas with the energy available from alternative sources. Projection of solid waste amount is based on Iller Bankasi population estimation method and produced waste Ca/day for areas supplying waste to Canakkale and Kusadasi facilities.

For determination of landfill gas potential based on literature information 3 meanings are used- minimum 50 m^3 of LDG per 1 ton of waste, middle-200 m^3 of LFG /ton of waste and maximum 400 m^3 of LFG /ton of waste. Dissimilarity of received results is analyzed with respect to models transparency, organic context and composition of the waste, methods of LFG collection.

3.2 Estimation of Solid Waste Amount

3.2.1 Population Projection

According tuikapp.tuik.gov.tr, the population of areas supplying waste for Kusadasi facility in 1965 was 88462 Ca, for Canakkale site – is 68026 Ca. Information given on turkstat.gov.tr shows that population of areas which accommodate waste for Kusadasi facility increased to 153342 Ca by 2011 and by 137768 Ca by 2011 for Canakkale site.

So, $N_p=N_{last}*(1+p)^{\Delta t}$, where

$$p=\sqrt[a]{\frac{N_2}{N_1}}-1,$$

$a=t_2-t_1$ and $\Delta t=t_p-t_2$;

For Kusadasi facility:

$a=t_2-t_1=2011-1965=46$,

$$p=\sqrt[46]{\frac{153342}{88462}}-1=0{,}012$$

1. For the projection year 2029 $\Delta t=t_p-t_2=2029-2011=18$

$$N_p=153342*(1+0{,}012)^{18}=190069\,\text{Ca}$$

2. For the projection year 2028 $\Delta t=t_p-t_2=2028-2011=17$

$$N_p = 153342 * (1 + 0{,}012)^{17} = 187815 \text{ Ca}$$

3. For the projection year 2027 $\Delta t = t_p - t_2 = 2027 - 2011 = 16$

$$N_p = 153342 * (1 + 0{,}012)^{16} = 185588 \text{ Ca}$$

4. For the projection year 2026 $\Delta t = t_p - t_2 = 2026 - 2011 = 15$

$$N_p = 153342 * (1 + 0{,}012)^{15} = 183387 \text{ Ca}$$

5. For the projection year 2025 $\Delta t = t_p - t_2 = 2025 - 2011 = 14$

$$N_p = 153342 * (1 + 0{,}012)^{14} = 181213 \text{ Ca/year}$$

In the same way calculations are made for the years 2012-2024. Results are introduced in the Table 3.1.

Table 3.1 Population projection results

Projection year	P	a	Δt	N_p, Ca
2012	0,012	46	1	155182
2013			2	157044
2014			3	158929
2015			4	160836
2016			5	162766
2017			6	164719
2018			7	166696
2019			8	168696
2020			9	170721
2021			10	172769
2022			11	174842
2023			12	176941
2024			13	179064
2025			14	181213
2026			15	183387
2027			16	185588
2028			17	187815
2029			18	190069

Projections for Canakkale site:

a=t_2-t_1=2011-1965=46,

$$p = \sqrt[a]{\frac{N_2}{N_1}} - 1 = \sqrt[46]{\frac{137768}{68026}} - 1 = 0{,}015$$

1.For the projection year 2029 Δt=t_p-t_2=2029-2011=18

$$N_p = 137768 * (1 + 0{,}015)^{18} = 180110 \text{ Ca}$$

2.For the projection year 2028 Δt=t_p-t_2=2028-2011=17

$$N_p = 137768 * (1 + 0{,}015)^{17} = 177448 \text{ Ca}$$

3.For the projection year 2027 Δt=t_p-t_2=2027-2011=16

$$N_p = 137768 * (1 + 0{,}015)^{16} = 174826 \text{ Ca}$$

4.For the projection year 2026 Δt=t_p-t_2=2026-2011=15

$$N_p = 137768 * (1 + 0{,}015)^{15} = 172242 \text{ Ca}$$

5.For the projection year 2025 Δt=t_p-t_2=2025-2011=14

$$N_p = 137768 * (1 + 0{,}015)^{14} = 169697 \text{ Ca}$$

In the same line projections are made for the period from 2012 to 2024. The results are shown in the Table 3.2.

Table 3.2 Population projection results for Canakkale site

Projection year	A	Δt		Np, Ca
2012	46	1	0,015	139835
2013		2		141932
2014		3		144061
2015		4		146222
2016		5		148415
2017		6		150642
2018		7		152901
2019		8		155195
2020		9		157523
2021		10		159885

Table 3.2 continue

2022		11		162284
2023		12		164718
2024		13		167189
2025		14		169697
2026		15		172242
2027		16		174826
2028		17		177448
2029		18		180110

The projected results of both sites are expressed in Figure 3.1, where it is possible to see main tendency and differences in population growth.

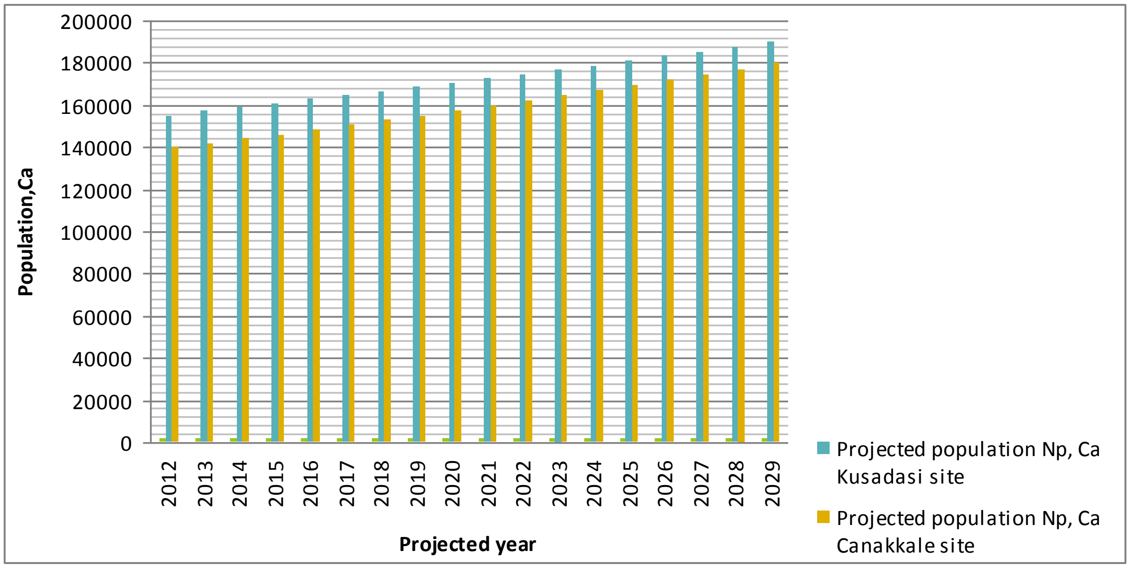


Figure3.1 Population projection for Kusadasi and Canakkale sites

3.2.2 Waste Projection

According information given in tuikapp.tuik.gov.tr, the amount of waste produced in areas supplying waste for Kusadasi facility is equal 1,28 kg/Ca-day, for Canakkale site – is 1,31 kg/Ca-day. On the base of this information and population projection we will determine amount of waste, entering facilities in the period from 2012 to 2029. The received results are introduced in next table and bar chart.

Table 3.3 The projected amounts of waste entering Kusadasi and Canakkale facilities from 2012 to 2029

Projected year	Amount of waste, tonnes/year	
	Kusadasi	Canakkale
2012	72,501.03	66,862.11
2013	73,370.96	67,864.79
2014	74,251.63	68,882.77
2015	75,142.58	69,916.05
2016	76,044.28	70,964.73
2017	76,956.72	72,029.47
2018	77,880.37	73,109.61
2019	78,814.77	74,206.49
2020	79,760.85	75,319.62
2021	80,717.68	76,449.01
2022	81,686.18	77,596.09
2023	82,666.84	78,759.91
2024	83,658.7	79,941.52
2025	84,662.81	81,140.62
2026	85,678.41	82,357.51
2027	86,706.71	83,593.05
2028	87,747.17	84,846.76
2029	88,800.24	86,119.6

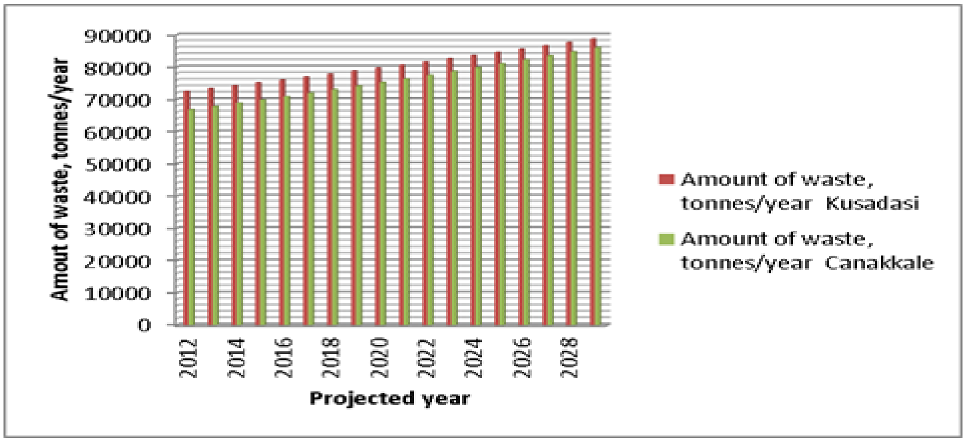


Figure 3.2 The waste projection results for Kusadasi and Canakkale sites

3.3 Determination of Landfill Gas Potential with Various Approaches

3.3.1 Determination of Landfill Gas Potential with Respect to Literature Information

The amount of potential landfill gas generation for the years 2012-2029 is calculated based on projected population Ca, for 2009 to 2011 on given information. For Kusadasi facility the amount of received waste from period 2009 to 2029 is 1612121 tonnes.

$50\,m^3/tonne*1612121$ tonnes=80,606,050 m^3 of LFG is produced during 20 years of operation.

$200\,m^3/tonne*1612121$ tonnes = 322,424,200 m^3 is produced during 20 years of operation.

$400\,m^3/tonne*1612121$ tonnes=644,848,400 m^3 is produced during 20 years of operation.

For Canakkale (CAKAB) site, the amount of waste supplied in the period from 2009 to 2029 is 1512133 tonnes.

$50\,m^3/tonne*1512133$ tonnes=75,606,650 m^3 of LFG produced during 20 years of operation.

$200\,m^3/tonne*1512133$ tonnes=3,024,266,600 m^3 of LFG produced for 20 years.

$400\,m^3/tonne*1512133$ tonnes=604,853,200 m^3 of LFG produced during 20 years.

Calculated above information is summarised in the Table 3.4 and Figure 3.3

Table 3.4 The amount of LFG produced and collected on Kusadasi and Canakkale facilities with respect to literature information

	Canakkale	Kusadasi
	LFG produced,m3	LFG produced,m3
50m3/tonne	75,606,650	80,606,050
200m3/tonne	302,426,600	322,424,200
400m3/tonne	604,853,200	644,848,400

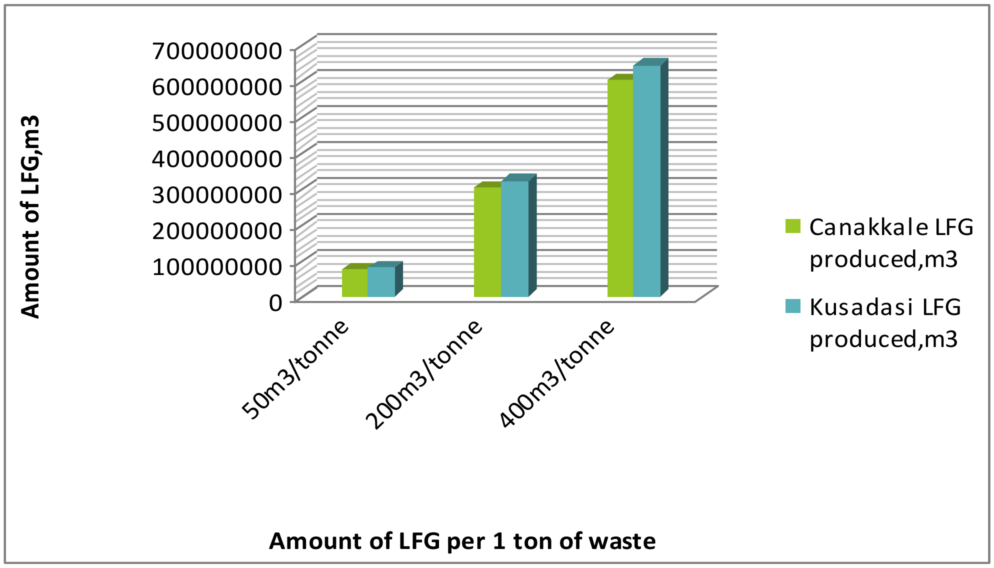


Figure 3.3 The produced amount of LFG for Canakkale and Kusadasi facility

3.3.2 Determination of Landfill Gas Generation Potential Based on Tabasaran/Rettenberger, LandGem and School-Canyon Models.

3.3.2.1 School-Canyon Methane Formation Model

According information given in report of Ministry of Environment, the model accounts for the main factors responsible for LFG generation and at the same time provides matrix approach what allows users to input site specific information (regarding climate conditions, precipitation for example). In addition, the model allows to characterize waste into a number of fractions and to account for landfill management practices as they related to water filtration.

School- Canyon Methane Formation Model for Kusadasi Facility

The model equation is:

$Q=k*L_0*R*e^{-kt}$, where:

Q- annual amount of methane gas, $m^3/year$,

L_0- methane generation capacity, $m^3/year$,

R- annual quantity of waste disposal, $tonnes / year$,

k- landfill gas generation rate, $year^{-1}$,

t- time,

In the period from 2009 to 2029 the amount of waste entered and projected for Kusadasi facility is 1612121 tonnes. The waste composition data will be used to determine the “relatively inert”, “moderately decomposable” and “decomposable” fractions of mixed solid waste collected at the landfill.

Table 3.5 Composition of waste that has been stored at Kusadasi facility

Type of waste	**percentage**	
paper	6,5%	28%
carton	3,5%	
bulky cardboard	0,5%	
plastic	9,0%	
glass	5,5%	
metal	2,5%	
bulky metal waste	0,5%	
food waste	52,5%	55,0%
park-garden waste	2,5%	
other burnable wastes	4,0%	6,0%
other combustible waste volume	2,0%	
other non-combustible wastes	8,0%	10,0%
other non-combustible waste volume	2,0%	
household hazardous waste	0,5%	0,5%
electric and electronic wastes	0,5%	0,5%
Toplam	100%	100%

Percentage household hazardous waste is not taken into account for calculations. Each category of waste has a different methane generation capacity. Values of methane generation capacity is determined in Section 5.2 of Landfill Gas Generation assessment Procedure Guidelines and introduced in Table 3.6 (env.gov.bc.ca).

Table 3.6 Methane generation capacity values (Source:env.gov.bc.ca)

Waste Category	Methane generation capacity (Lo)
Relatively inert	20 m3 methane/tonne
Moderately Decomposable	120 m3 methane/tonne
Decomposable	160 m3 methane/tonne

Each type of waste has its own landfill gas generation rate (constant) k, which is depends on average annual precipitation data and water management. The annual average precipitation for Kusadasi facility is 609, 3 mm (Kusadasi Kirazli Duzenli Depolama Sahasi Isletme Plani, 2011). The landfill gas generation rate k is provided in section 5.3 of Landfill Gas Generation assessment Procedure Guidelines. The prescribed k for each category of waste in Kusadasi facility is introduced in Table 3.7.

Table 3.7 Value of landfill gas generation rate k for each waste category

Waste Category	Landfill gas generation rate k
Relatively inert	0,02
Moderately Decomposable	0,04
Decomposable	0,09

K values are based on waste category and average annual precipitation. Landfill gas generation rate should be adjusted to water addition factor, which is for Kusadasi facility is equal 0, 9 according information in Kusadasi Kirazli Duzenli Depolama Sahasi Isletme Plani. This meaning is multiplied with meaning of k to use in final calculations.

1. Calculation of the amount of waste taking into account waste composition

For paper: x=6.5%*1612121 tonnes/100%=104,787.9 tonnes,
carton: x=3,5%*1612121 tonnes/100%=56,424.24 tonnes,
bulky cardboard: x=0,5%*1612121 tonnes/100%=8,060.605 tonnes,

plastic: x=9%*1612121 tonnes/100%=145,090.9 tonnes,
glass: x=5.5%*1612121 tonnes/100%=88,666.66 tonnes,
metal: x=2,5%*1612121 tonnes/100%=40,303.03 tonnes,
bulky metal: x=0,5%*16121211 tonnes/100%= 8,060.605 tonnes,
food waste: x=52,5%*1612121 tonnes/100%= 846,363.5 tonnes,
park-garden waste: x=2,5%*1612121 tonnes/100%= 40,303.03 tonnes,
other burnable waste: x=4%*1612121 tonnes/100%=64,484.84 tonnes,
other combustible waste volume: x=2%*1612121 tonnes/100%=32,242.42 tonnes,
other non- combustible wastes: x=8%*1612121 tonnes/100%= 128,969.7 tonnes,
other non-combustible waste volume: x=2%*1612121 tonnes/100%= 32,242.42 tonnes,
electric and electronic wastes: x=0,5%*1612121 tonnes/100%=8,060.605 tonnes

2. Value of k including water addition factor:

for relatively inert waste k*0,9=0,02*0,9=0,018;
for moderately decomposable waste: k*0,9=0,04*0,9=0,036,
for decomposable waste: k*0,9=0,09*0,9=0,081

3. The summarised information is shown in next table

Table 3.8 The summarised information for Kusadasi facility

Type of waste		**Percentage**	Amount, tonnes	Lo	k
moderately decomposable	paper	6,5%	104,787.9	120	0,036
	carton	3,5%	56,424.24	120	0,036
	bulky cardboard	0,5%	8,060.605	120	0,036
relatively inert	plastic	9,0%	145,090.9	20	0,018
	glass	5,5%	88,666.66	20	0,018
	metal	2,5%	40,303.03	20	0,018
	bulky metal waste	0,5%	8,060.605	20	0,018

Table 3.8 continue

decomposable	food waste	52,5%	846,363.5	160	0,081
	park-garden waste	2,5%	40,303.03	160	0,081
	other burnable wastes	4,0%	64,484.84	160	0,081
	other combustible waste volume	2,0%	32,242.42	160	0,081
relatively inert	other non-combustible wastes	8,0%	128,969.7	20	0,018
	other non-combustible waste volume	2,0%	32,242.42	20	0,018
	electric and electronic wastes	0,5%	8,060.605	20	0,018

4. Final calculations by taking into account model equation.

For paper: $Q=0{,}036*120*104787{,}9*e^{-0{,}036*20}=221815 m^3$,

carton: $Q=0{,}036*120*56424{,}24*e^{-0{,}036*20}=119438{,}8\ m^3$,

bulky cardboard: $Q=0{,}036*120*8060{,}605*e^{-0{,}036*20}=17062{,}69\ m^3$,

plastic: $Q=0{,}018*20*145090{,}9*e^{-0{,}018*20}=36458{,}44\ m^3$,

glass: $Q=0{,}018*20*88666{,}66*e^{-0{,}018*20}=22280{,}16\ m^3$,

metal: $Q = 0{,}018*20*40303{,}03*e^{-0{,}018*20} = 10127{,}34\ \text{m}^3$,

bulky metal: $Q = 0{,}018*20*8060{,}605*e^{-0{,}018*20} = 2025{,}469\ \text{m}^3$,

food waste : $Q = 0{,}081*160*846363{,}5*e^{-0{,}081*20} = 2171837\ \text{m}^3$,

park-garden waste: $Q = 0{,}081*160*40303{,}03*e^{-0{,}081*20} = 103420{,}8\ \text{m}^3$,

other burnable waste: $Q = 0{,}081*160*64484{,}84*e^{-0{,}081*20} = 165473{,}3\ \text{m}^3$,

other combustible waste volume: $Q = 0{,}081*160*32242{,}42*e^{-0{,}081*20} = 82736{,}63\ \text{m}^3$,

other non-combustible waste: $Q = 0{,}018*20*128969{,}7*e^{-0{,}018*20} = 32407{,}5\ \text{m}^3$, other on-combustible waste volume: $Q = 0{,}018 * 20 * 32242{,}42 * e^{-0{,}018*20} = 32407{,}5 \text{ m}^3$,

electric and electronic wastes: $Q = 0{,}018 * 20 * 8060{,}605 * e^{-0{,}018*20} = 2025{,}469 \text{ m}^3$

The amount of methane for 20 years of operation: Q= 221,815+119,438.8+17,062.69+36,458.44+22,280.16+10,127.34+2,025.469+2,171,837 + 103420,8+165473,3+82736,63+32407,5+8,101.875+2,025.469= 2,995,210 m3

On the base that landfill gas contains 55% of methane the amount of LFG is 5,445,836.36 m^3.

School- Canyon Methane Formation Model for Canakkale Facility

$Q=k*L_0*R*e^{-kt}$, where:

Q- annual amount of methane gas, $m^3/year$,

L_0- methane generation capacity, $m^3/year$,

R- annual quantity of waste disposal, $tonnes / year$,

k- landfill gas generation rate, $year^{-1}$,

t- time,

In the period from 2009 to 2029 the amount of waste entered and projected for Canakkale facility is 1512133 tonnes. A solid waste characterization study has been carried out during the planning of ÇAKAB Landfill Site. The result of the study is given in the following table.

Table 3.9 The results of study for CAKAB Landfill site

Waste Type	**Percent (%)**	**Amount of waste, tonnes**
Organic Waste	44.50	672,899.2
Plastic	11.67	176,465.9
Metal	2.80	42,339.72
Glass	2.67	40,373.95
Paper – Cardboard	15.15	229,088.1
Composit	0.16	2,419.413
Others	23.05	355,351.3

Each category of waste has a different methane generation capacity. Values of methane generation capacity is determine in Section 5.2 of Landfill Gas Generation Assessment Procedure Guidelines and introduced in Table 3.10

Table 3.10 Methane generation capacity values (Source: env.gov.bc.ca)

Waste Category	Methane generation capacity (Lo)
Relatively inert	20 m3 methane/tonne
Moderately Decomposable	120 m3 methane/tonne
Decomposable	160 m3 methane/tonne

The annual precipitation for Canakkale region is 447.54 mm (tutiempo.net). The landfill gas generation rate k is provided in section 5.3 of Landfill Gas Generation Assessment Procedure Guidelines. The prescribed k for each category of waste is introduced in next Table.

Table 3.11 Value of landfill gas generation rate k for each waste category

Waste Category	Landfill gas generation rate k
Relatively inert	0,01
Moderately Decomposable	0,02
Decomposable	0,05

K values are based on waste category and average annual precipitation. Landfill gas generation rate should be adjusted to water addition factor, which is for Canakkale is equal 0, 9 according information in presentation on Canakkale regional Solid Waste Management project. This meaning is multiplied with meaning of k to use in final calculations.

Value of k including water addition factor:

For relatively inert waste k*0,9=0,01*0,9=0.009;
for moderately decomposable waste: k*0,9=0,02*0,9=0.018,

for decomposable waste: k*0,9=0,05*0,9=0.045;

The summarised information introduced in Table 3.12.

Table 3.12 The summarised information for Canakkale facility

Waste Type		**Amount of waste, tonnes**	**Lo**	**K**
Decomposable	Organic Waste	672,899.2	160 m3 methane/tonne	0.045
Relatively inert	Plastic	176,465.9	20 m3 methane/tonne	0.009
	Metal	42,339.72	20 m3 methane/tonne	0.009
	Glass	40,373.95	20 m3 methane/tonne	0.009
Moderately decomposable	Paper - Cardboard	229,088.1	120 m3 methane/tonne	0.018
Decomposable	Compost	2,419.413	160 m3 methane/tonne	0.045
Moderately decomposable	Others	355,351.3	120 m3 methane/tonne	0.018

Final calculations by taking into account model formula:

For organic waste : $Q = 0{,}045 * 160 * 672899{,}2 * e^{-0{,}045 * 20} = 1986398 \ m^3$,

Plastic : $Q = 0{,}009 * 20 * 176465{,}9 * e^{-0{,}009 * 20} = 26681{,}65 \ m^3$,

Metal : $Q = 0{,}009 * 20 * 42339{,}72 * e^{-0{,}009 * 20} = 6401{,}766 \ m^3$,

Glass: $Q = 0{,}009 * 20 * 40373{,}95 * e^{-0{,}009 * 20} = 6104{,}541 \ m^3$,

Paper/cardboard: $Q = 0{,}018 * 120 * 229088{,}1 * e^{-0{,}018 * 20} = 345391{,}6 \ m^3$,

Compost: $Q = 0{,}045 * 160 * 2419{,}413 * e^{-0{,}045 * 20} = 7142{,}107 \ m^3$,

Others: $Q = 0{,}018 * 120 * 355351{,}3 * e^{-0{,}018 * 20} = 535756 \ m^3$,

The amount of methane for 20 years is $2913876\,m^3$. If to take into account landfill gas contains 55% of methane, the amount of LFG is 5297956, $36\,m^3$. The summarised information for Kusadasi and Canakkale facilities is in the next table.

Table 3.13 The summarised information for Kusadasi and Canakkale facilities

	Facility	
	Kusadasi	Canakkale
Amount of methane,m3	2,995,210	2,913,876
Amount of LFG,m3	5,445,836	5,297,956

3.3.2.2 LandGem Model Approach

LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste (MSW) landfills. The software provides a relatively simple approach to estimating landfill gas emissions. It is important to mention that field test data can also be used in place of model defaults when available. LandGEM is based on the gas generated from anaerobic decomposition of landfilled waste which has a methane content between 40 and 60 percent (epa.gov).

As stated in epa.gov, “LandGEM is an automated tool for estimating emission rates for total landfill gas, methane, carbon dioxide, nonmethane organic compounds (NMOCs), and individual air pollutants from MSW landfills.” LandGEM can use site-specific data to estimate emissions ,if no site-specific data are available -default parameters. According epa.gov, LandGem uses first-order decomposition rate equation:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0,1}^{1} k L_0 \left(\frac{M_i}{10} \right) e \; -kt_{ij}$$,where

Q_{CH4}= annual methane generation in the year of the calculation (m3/year);

i = 1-year time increment;

M_i = mass of waste accepted in the ith year (Mg);

n = (year of the calculation) - (initial year of waste acceptance);

t_{ij} = age of the j_{th} section of waste mass Mi accepted in the ith year (decimal years, e.g., 3.2 years) ;

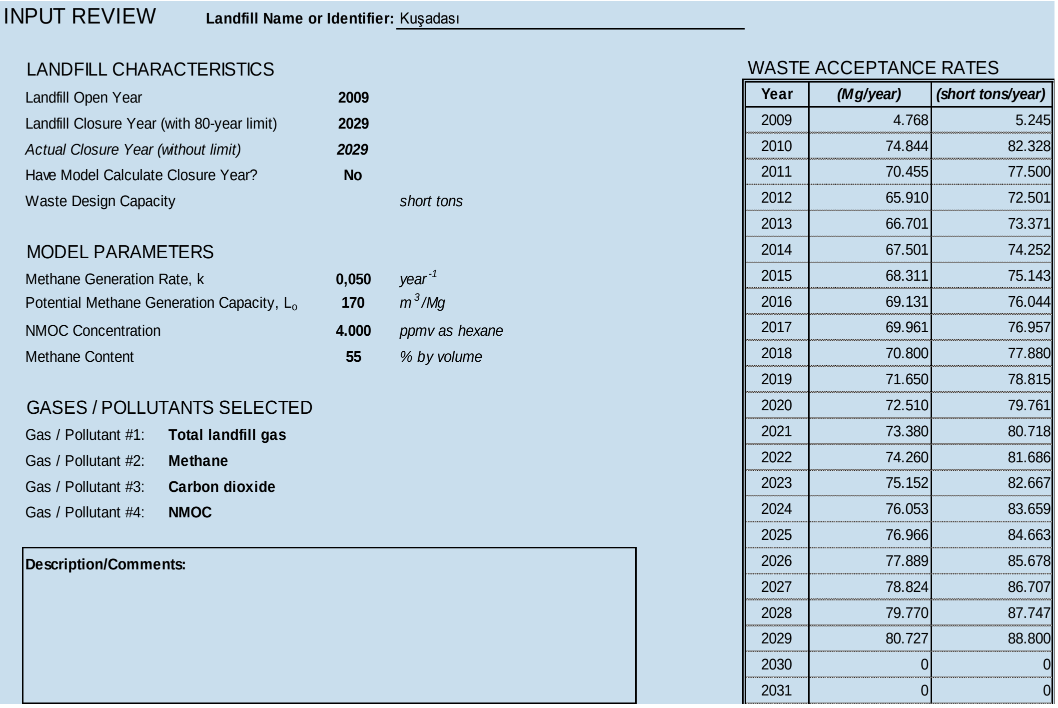
j = 0.1-year time increment;

k = methane generation rate (year-1) ;

Lo = potential methane generation capacity (m^3/Mg).

LandGem Model for Kusadasi Facility

Next field characteristics are provided: landfill open and closure years; model parameters: methane generation rate for CAA (Clean air act) conventional default, potential methane generation capacity for CAA conventional, methane context-specified value 55%,waste acceptance rates. The screenshot of the input review and results is presented in this chapter below.



INPUT REVIEW **Landfill Name or Identifier:** Kuşadası

LANDFILL CHARACTERISTICS

Landfill Open Year **2009**

Landfill Closure Year (with 80-year limit) **2029**

Actual Closure Year (without limit) ***2029***

Have Model Calculate Closure Year? **No**

Waste Design Capacity *short tons*

MODEL PARAMETERS

Methane Generation Rate, k **0,050** *year^{-1}*

Potential Methane Generation Capacity, L_o **170** *m^3/Mg*

NMOC Concentration **4.000** *ppmv as hexane*

Methane Content **55** *% by volume*

GASES / POLLUTANTS SELECTED

Gas / Pollutant #1: **Total landfill gas**

Gas / Pollutant #2: **Methane**

Gas / Pollutant #3: **Carbon dioxide**

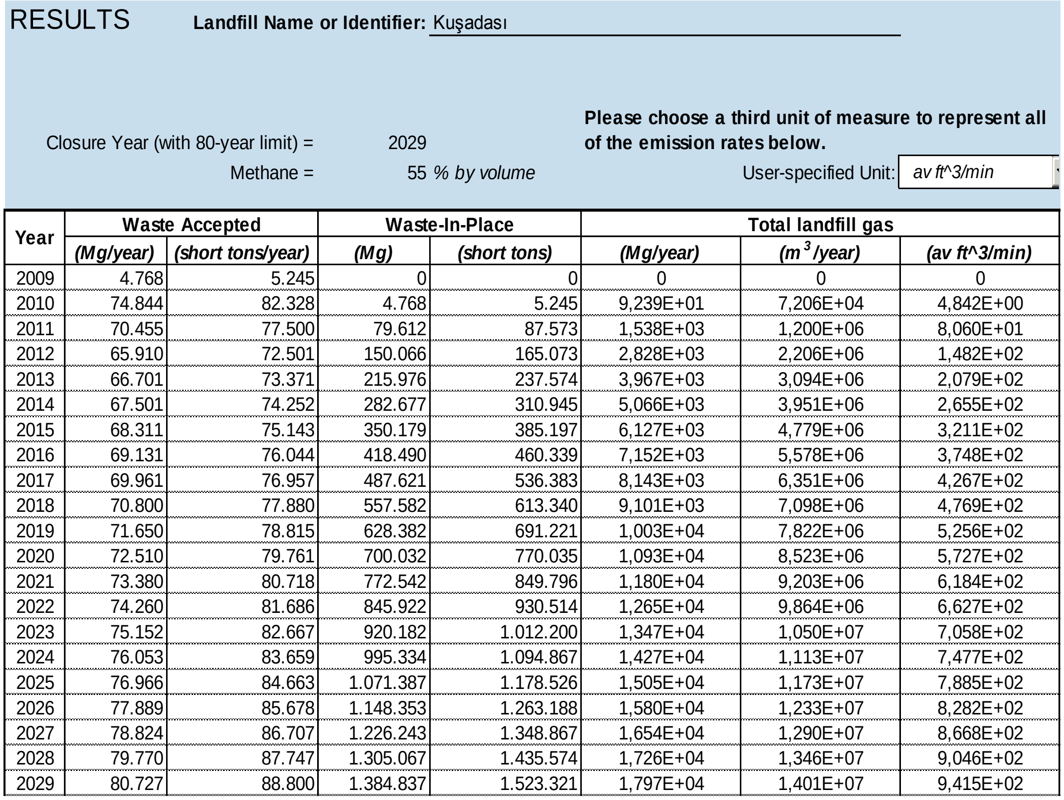
Gas / Pollutant #4: **NMOC**

Description/Comments:

WASTE ACCEPTANCE RATES

Year	*(Mg/year)*	*(short tons/year)*
2009	4.768	5.245
2010	74.844	82.328
2011	70.455	77.500
2012	65.910	72.501
2013	66.701	73.371
2014	67.501	74.252
2015	68.311	75.143
2016	69.131	76.044
2017	69.961	76.957
2018	70.800	77.880
2019	71.650	78.815
2020	72.510	79.761
2021	73.380	80.718
2022	74.260	81.686
2023	75.152	82.667
2024	76.053	83.659
2025	76.966	84.663
2026	77.889	85.678
2027	78.824	86.707
2028	79.770	87.747
2029	80.727	88.800
2030	0	0
2031	0	0

Figure 3.4 Screenshot of LandGem model input review for Kusadasi facility



RESULTS **Landfill Name or Identifier:** Kuşadası

Closure Year (with 80-year limit) = 2029

Methane = 55 *% by volume*

Please choose a third unit of measure to represent all of the emission rates below.

User-specified Unit: *av ft^3/min*

Year	Waste Accepted		Waste-In-Place		Total landfill gas		
	(Mg/year)	*(short tons/year)*	*(Mg)*	*(short tons)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2009	4.768	5.245	0	0	0	0	0
2010	74.844	82.328	4.768	5.245	9,239E+01	7,206E+04	4,842E+00
2011	70.455	77.500	79.612	87.573	1,538E+03	1,200E+06	8,060E+01
2012	65.910	72.501	150.066	165.073	2,828E+03	2,206E+06	1,482E+02
2013	66.701	73.371	215.976	237.574	3,967E+03	3,094E+06	2,079E+02
2014	67.501	74.252	282.677	310.945	5,066E+03	3,951E+06	2,655E+02
2015	68.311	75.143	350.179	385.197	6,127E+03	4,779E+06	3,211E+02
2016	69.131	76.044	418.490	460.339	7,152E+03	5,578E+06	3,748E+02
2017	69.961	76.957	487.621	536.383	8,143E+03	6,351E+06	4,267E+02
2018	70.800	77.880	557.582	613.340	9,101E+03	7,098E+06	4,769E+02
2019	71.650	78.815	628.382	691.221	1,003E+04	7,822E+06	5,256E+02
2020	72.510	79.761	700.032	770.035	1,093E+04	8,523E+06	5,727E+02
2021	73.380	80.718	772.542	849.796	1,180E+04	9,203E+06	6,184E+02
2022	74.260	81.686	845.922	930.514	1,265E+04	9,864E+06	6,627E+02
2023	75.152	82.667	920.182	1.012.200	1,347E+04	1,050E+07	7,058E+02
2024	76.053	83.659	995.334	1.094.867	1,427E+04	1,113E+07	7,477E+02
2025	76.966	84.663	1.071.387	1.178.526	1,505E+04	1,173E+07	7,885E+02
2026	77.889	85.678	1.148.353	1.263.188	1,580E+04	1,233E+07	8,282E+02
2027	78.824	86.707	1.226.243	1.348.867	1,654E+04	1,290E+07	8,668E+02
2028	79.770	87.747	1.305.067	1.435.574	1,726E+04	1,346E+07	9,046E+02
2029	80.727	88.800	1.384.837	1.523.321	1,797E+04	1,401E+07	9,415E+02

Figure 3.5 Screenshot of LandGem model results for Kusadasi facility

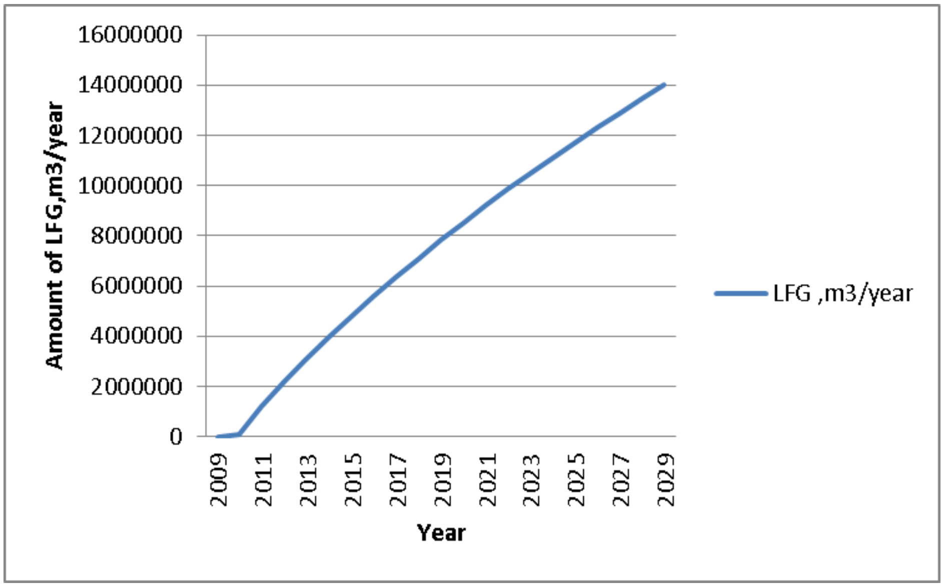
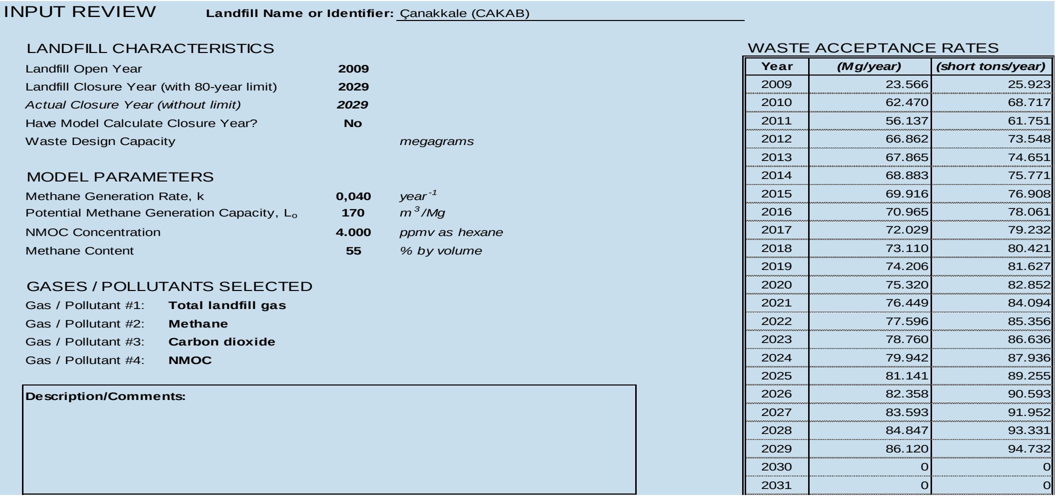


Figure 3.6 Screenshot of LandGem model graph for Kusadası facility

LandGem Model for Canakkale Site

Next field characteristics are provided: landfill open and closure years; model parameters: methane generation rate for is site-specific data, potential methane generation capacity, methane context-specified value 55%, waste acceptance rates. The screenshot of the input review and results are presented in this chapter below.



INPUT REVIEW **Landfill Name or Identifier:** Çanakkale (CAKAB)

LANDFILL CHARACTERISTICS

Landfill Open Year	**2009**	
Landfill Closure Year (with 80-year limit)	**2029**	
Actual Closure Year (without limit)	***2029***	
Have Model Calculate Closure Year?	**No**	
Waste Design Capacity		*megagrams*

MODEL PARAMETERS

Methane Generation Rate, k	**0,040**	*year^{-1}*
Potential Methane Generation Capacity, L_o	**170**	*m^3/Mg*
NMOC Concentration	**4.000**	*ppmv as hexane*
Methane Content	**55**	*% by volume*

GASES / POLLUTANTS SELECTED

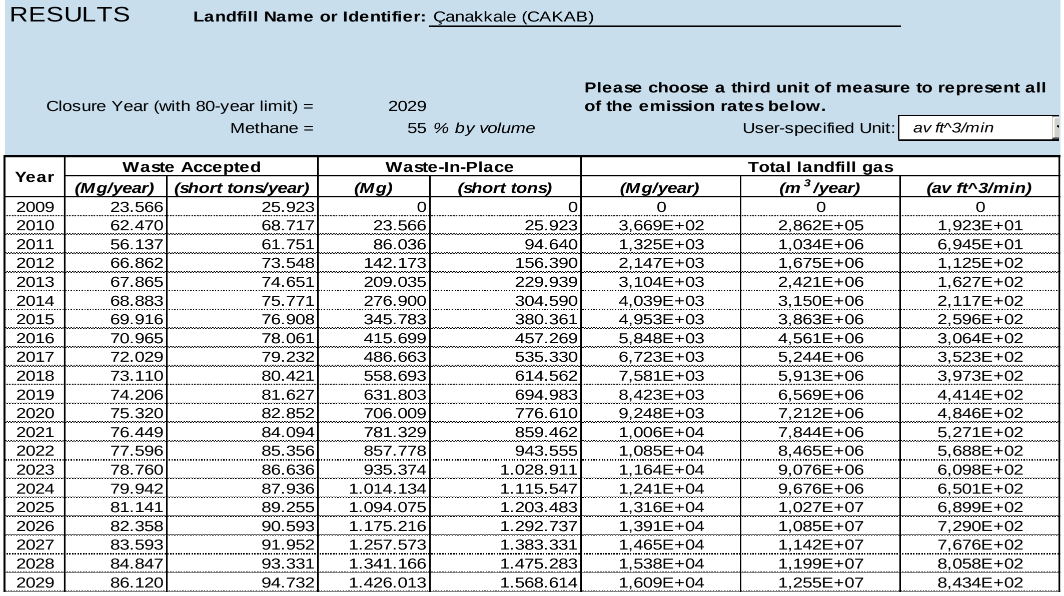
Gas / Pollutant #1:	**Total landfill gas**
Gas / Pollutant #2:	**Methane**
Gas / Pollutant #3:	**Carbon dioxide**
Gas / Pollutant #4:	**NMOC**

Description/Comments:

WASTE ACCEPTANCE RATES

Year	*(Mg/year)*	*(short tons/year)*
2009	23.566	25.923
2010	62.470	68.717
2011	56.137	61.751
2012	66.862	73.548
2013	67.865	74.651
2014	68.883	75.771
2015	69.916	76.908
2016	70.965	78.061
2017	72.029	79.232
2018	73.110	80.421
2019	74.206	81.627
2020	75.320	82.852
2021	76.449	84.094
2022	77.596	85.356
2023	78.760	86.636
2024	79.942	87.936
2025	81.141	89.255
2026	82.358	90.593
2027	83.593	91.952
2028	84.847	93.331
2029	86.120	94.732
2030	0	0
2031	0	0

Figure 3.7 Screenshot of LandGem model input review for Canakkale facility



RESULTS **Landfill Name or Identifier:** Çanakkale (CAKAB)

Closure Year (with 80-year limit) = 2029

Methane = 55 *% by volume*

Please choose a third unit of measure to represent all of the emission rates below.

User-specified Unit: *av ft^3/min*

Year	**Waste Accepted**		**Waste-In-Place**		**Total landfill gas**		
	(Mg/year)	***(short tons/year)***	***(Mg)***	***(short tons)***	***(Mg/year)***	***(m^3/year)***	***(av ft^3/min)***
2009	23.566	25.923	0	0	0	0	0
2010	62.470	68.717	23.566	25.923	3,669E+02	2,862E+05	1,923E+01
2011	56.137	61.751	86.036	94.640	1,325E+03	1,034E+06	6,945E+01
2012	66.862	73.548	142.173	156.390	2,147E+03	1,675E+06	1,125E+02
2013	67.865	74.651	209.035	229.939	3,104E+03	2,421E+06	1,627E+02
2014	68.883	75.771	276.900	304.590	4,039E+03	3,150E+06	2,117E+02
2015	69.916	76.908	345.783	380.361	4,953E+03	3,863E+06	2,596E+02
2016	70.965	78.061	415.699	457.269	5,848E+03	4,561E+06	3,064E+02
2017	72.029	79.232	486.663	535.330	6,723E+03	5,244E+06	3,523E+02
2018	73.110	80.421	558.693	614.562	7,581E+03	5,913E+06	3,973E+02
2019	74.206	81.627	631.803	694.983	8,423E+03	6,569E+06	4,414E+02
2020	75.320	82.852	706.009	776.610	9,248E+03	7,212E+06	4,846E+02
2021	76.449	84.094	781.329	859.462	1,006E+04	7,844E+06	5,271E+02
2022	77.596	85.356	857.778	943.555	1,085E+04	8,465E+06	5,688E+02
2023	78.760	86.636	935.374	1.028.911	1,164E+04	9,076E+06	6,098E+02
2024	79.942	87.936	1.014.134	1.115.547	1,241E+04	9,676E+06	6,501E+02
2025	81.141	89.255	1.094.075	1.203.483	1,316E+04	1,027E+07	6,899E+02
2026	82.358	90.593	1.175.216	1.292.737	1,391E+04	1,085E+07	7,290E+02
2027	83.593	91.952	1.257.573	1.383.331	1,465E+04	1,142E+07	7,676E+02
2028	84.847	93.331	1.341.166	1.475.283	1,538E+04	1,199E+07	8,058E+02
2029	86.120	94.732	1.426.013	1.568.614	1,609E+04	1,255E+07	8,434E+02

Figure 3.8 Screenshot of LandGem model results for Canakkale facility

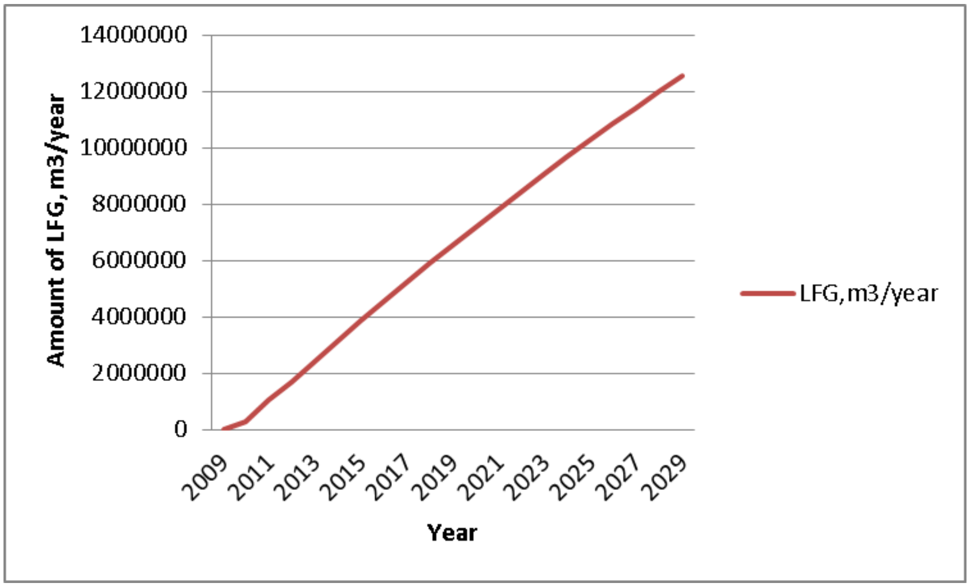


Figure 3.9 Screenshot of LandGem model graph for Canakkale facility

3.3.2.3 Tabasaran/Rettenberger Model Approach

Tabasaran/Rettenberger model is mathematical model developed to determine the amount of gas produced during certain time. The most important issue in the implementation of the model is that variables determine acceptances. Model parameters were determined in Germany and the same conditions are applied to the proposed variables. The decision support system is used for model calibration and verification must carry out (Oonk, H., 2010). The equation for Tabasaran/Rettenberger model is:

$G_t = 1{,}868 \, . \, C_{org}. \, (0{,}014T+0{,}28) \, (1- 10\text{-}kt).M_t$, where

G_t-the amount of gas produced up to the year t (m3);

C_{org}- organic carbon content (kg/tonne of waste);

T-temperature (C);

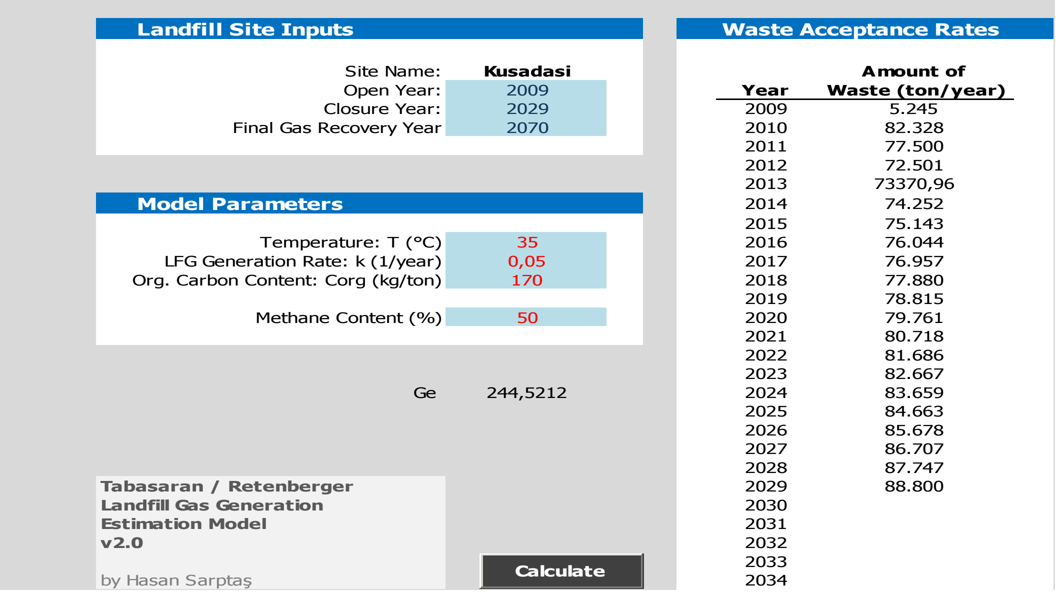
t-the time from the year of operation;

k- landfill gas production coefficient (1/year);

Mt- the amount of waste stored in the year t.

Tabasaran/Rettenberger Model for Kusadasi Facility

Next information is provided- the site open and closure year, final gas recovery year; parameters such as temperature, LFG generation rate and organic carbon content; waste acceptance rates. The screenshot of input characteristics, results and graph are provided below.



Landfill Site Inputs

Site Name: **Kusadasi**
Open Year: 2009
Closure Year: 2029
Final Gas Recovery Year 2070

Model Parameters

Temperature: T (°C) 35
LFG Generation Rate: k (1/year) 0,05
Org. Carbon Content: Corg (kg/ton) 170

Methane Content (%) 50

Ge 244,5212

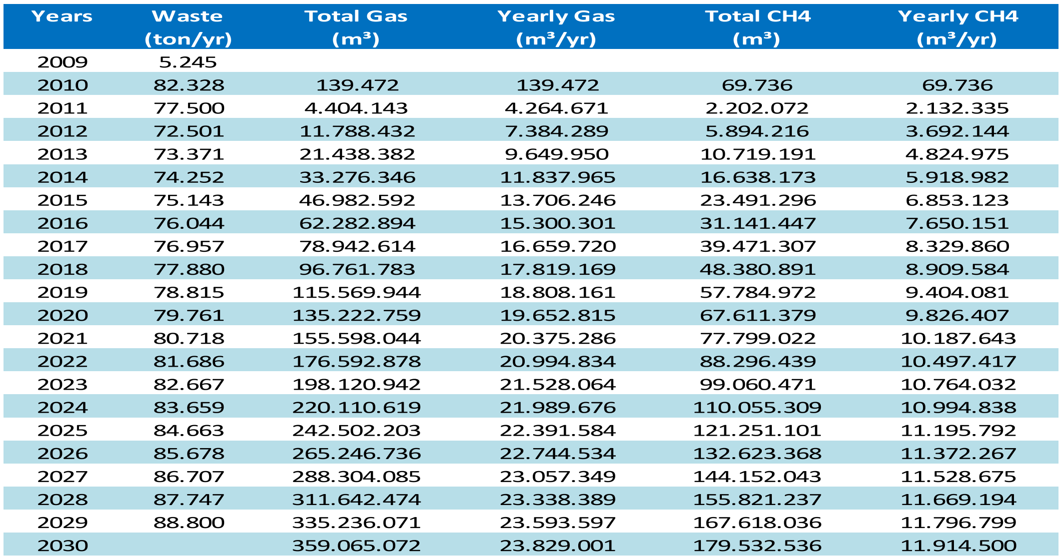
Tabasaran / Retenberger Landfill Gas Generation Estimation Model v2.0

by Hasan Sarptaş

Waste Acceptance Rates

Year	**Amount of Waste (ton/year)**
2009	5.245
2010	82.328
2011	77.500
2012	72.501
2013	73370,96
2014	74.252
2015	75.143
2016	76.044
2017	76.957
2018	77.880
2019	78.815
2020	79.761
2021	80.718
2022	81.686
2023	82.667
2024	83.659
2025	84.663
2026	85.678
2027	86.707
2028	87.747
2029	88.800
2030	
2031	
2032	
2033	
2034	

Figure 3.10 The screenshot of input characteristics of Tabasaran/Rettenberger model for Kusadasi facility



Years	Waste (ton/yr)	Total Gas (m³)	Yearly Gas (m³/yr)	Total CH4 (m³)	Yearly CH4 (m³/yr)
2009	5.245				
2010	82.328	139.472	139.472	69.736	69.736
2011	77.500	4.404.143	4.264.671	2.202.072	2.132.335
2012	72.501	11.788.432	7.384.289	5.894.216	3.692.144
2013	73.371	21.438.382	9.649.950	10.719.191	4.824.975
2014	74.252	33.276.346	11.837.965	16.638.173	5.918.982
2015	75.143	46.982.592	13.706.246	23.491.296	6.853.123
2016	76.044	62.282.894	15.300.301	31.141.447	7.650.151
2017	76.957	78.942.614	16.659.720	39.471.307	8.329.860
2018	77.880	96.761.783	17.819.169	48.380.891	8.909.584
2019	78.815	115.569.944	18.808.161	57.784.972	9.404.081
2020	79.761	135.222.759	19.652.815	67.611.379	9.826.407
2021	80.718	155.598.044	20.375.286	77.799.022	10.187.643
2022	81.686	176.592.878	20.994.834	88.296.439	10.497.417
2023	82.667	198.120.942	21.528.064	99.060.471	10.764.032
2024	83.659	220.110.619	21.989.676	110.055.309	10.994.838
2025	84.663	242.502.203	22.391.584	121.251.101	11.195.792
2026	85.678	265.246.736	22.744.534	132.623.368	11.372.267
2027	86.707	288.304.085	23.057.349	144.152.043	11.528.675
2028	87.747	311.642.474	23.338.389	155.821.237	11.669.194
2029	88.800	335.236.071	23.593.597	167.618.036	11.796.799
2030		359.065.072	23.829.001	179.532.536	11.914.500

Figure 3.11 The screenshot of results of Tabasaran/Rettenberger model for Kusadasi facility

Total and yearly gas generation shown in Figure 3.12 and Figure 3.13

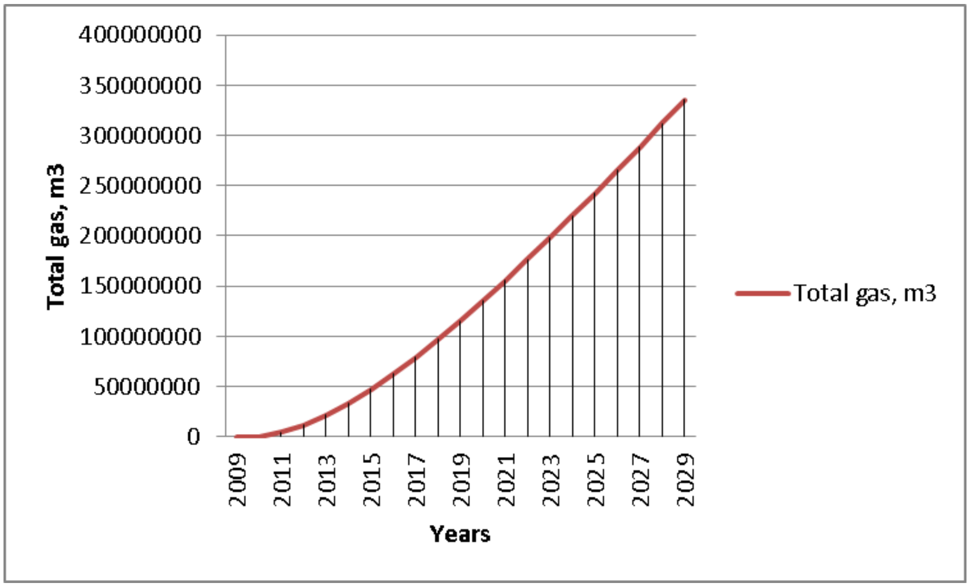


Figure 3.12 Total gas generation for Kusadasi facility with respect to Tabasaran/Rettenberger model

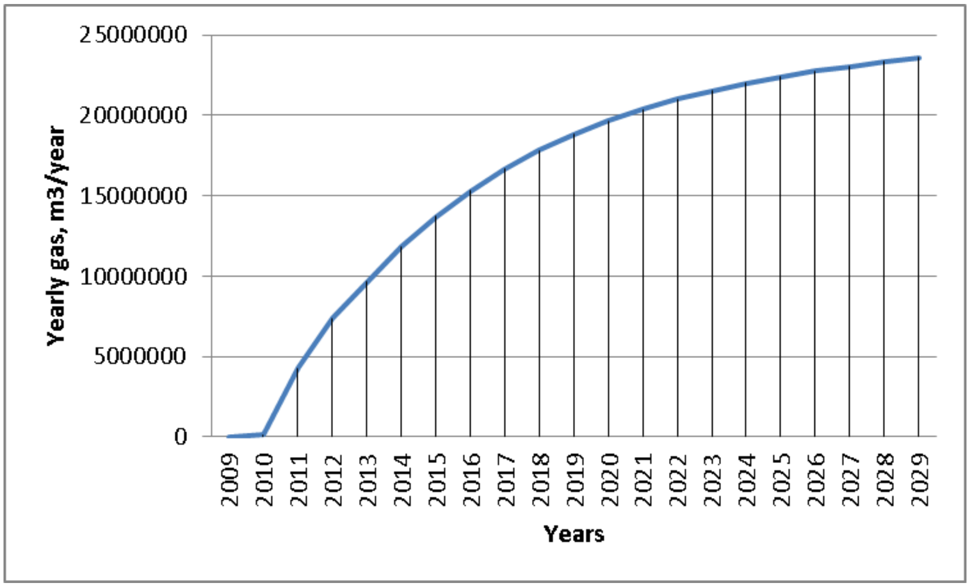
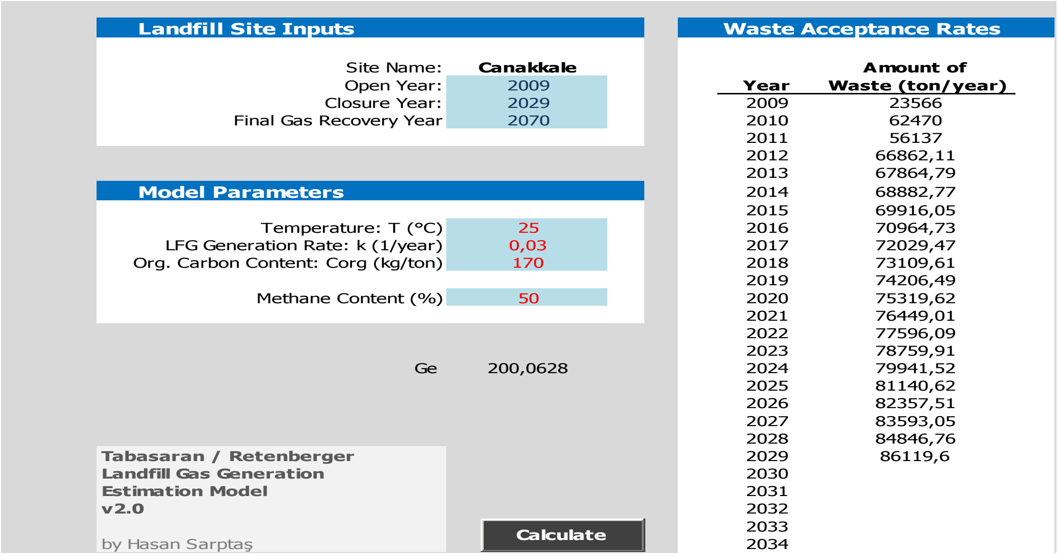


Figure 3.13 Yearly gas generation for kUsadasi facility with respect to tabasaran/Rettenberger model

Tabasaran/Rettenberger Model for Canakkale Facility

Next information is provided- the site open and closure year, final gas recovery year; parameters such as temperature, LFG generation rate and organic carbon content; waste acceptance rates. The screenshot of input characteristics, results and graph are provided below.



Landfill Site Inputs

Site Name: **Canakkale**
Open Year: 2009
Closure Year: 2029
Final Gas Recovery Year 2070

Model Parameters

Temperature: T (°C) 25
LFG Generation Rate: k (1/year) 0,03
Org. Carbon Content: Corg (kg/ton) 170

Methane Content (%) 50

Ge 200,0628

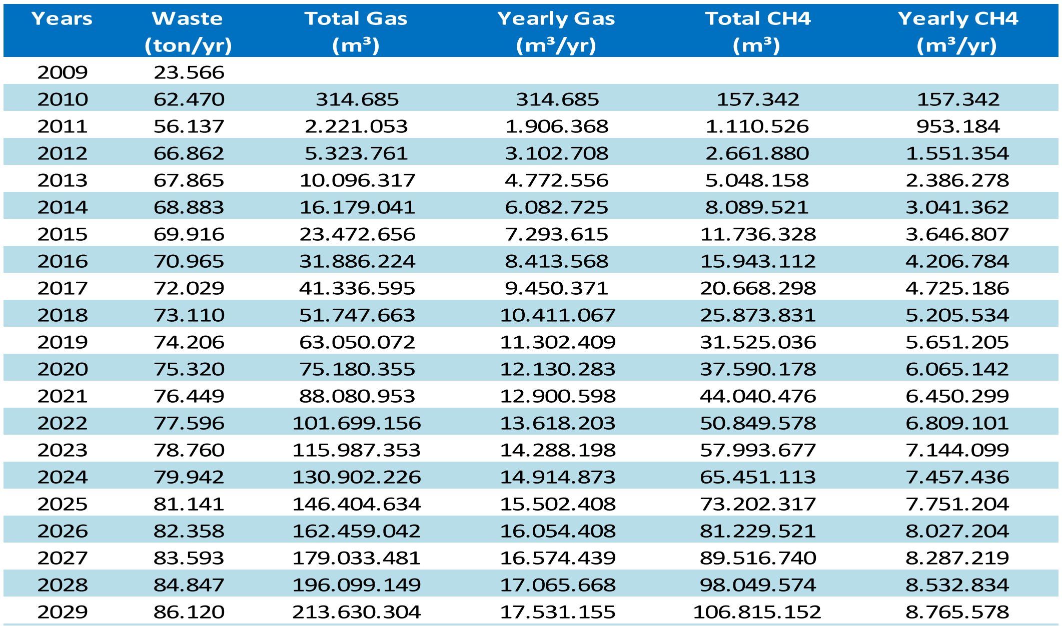
Tabasaran / Retenberger
Landfill Gas Generation
Estimation Model
v2.0

by Hasan Sarptaş

Waste Acceptance Rates

Year	**Amount of Waste (ton/year)**
2009	23566
2010	62470
2011	56137
2012	66862,11
2013	67864,79
2014	68882,77
2015	69916,05
2016	70964,73
2017	72029,47
2018	73109,61
2019	74206,49
2020	75319,62
2021	76449,01
2022	77596,09
2023	78759,91
2024	79941,52
2025	81140,62
2026	82357,51
2027	83593,05
2028	84846,76
2029	86119,6
2030	
2031	
2032	
2033	
2034	

Figure 3.14 The screenshot of input characteristics of Tabasaran/Rettenberger model for Canakkale facility



Years	Waste (ton/yr)	Total Gas (m³)	Yearly Gas (m³/yr)	Total CH4 (m³)	Yearly CH4 (m³/yr)
2009	23.566				
2010	62.470	314.685	314.685	157.342	157.342
2011	56.137	2.221.053	1.906.368	1.110.526	953.184
2012	66.862	5.323.761	3.102.708	2.661.880	1.551.354
2013	67.865	10.096.317	4.772.556	5.048.158	2.386.278
2014	68.883	16.179.041	6.082.725	8.089.521	3.041.362
2015	69.916	23.472.656	7.293.615	11.736.328	3.646.807
2016	70.965	31.886.224	8.413.568	15.943.112	4.206.784
2017	72.029	41.336.595	9.450.371	20.668.298	4.725.186
2018	73.110	51.747.663	10.411.067	25.873.831	5.205.534
2019	74.206	63.050.072	11.302.409	31.525.036	5.651.205
2020	75.320	75.180.355	12.130.283	37.590.178	6.065.142
2021	76.449	88.080.953	12.900.598	44.040.476	6.450.299
2022	77.596	101.699.156	13.618.203	50.849.578	6.809.101
2023	78.760	115.987.353	14.288.198	57.993.677	7.144.099
2024	79.942	130.902.226	14.914.873	65.451.113	7.457.436
2025	81.141	146.404.634	15.502.408	73.202.317	7.751.204
2026	82.358	162.459.042	16.054.408	81.229.521	8.027.204
2027	83.593	179.033.481	16.574.439	89.516.740	8.287.219
2028	84.847	196.099.149	17.065.668	98.049.574	8.532.834
2029	86.120	213.630.304	17.531.155	106.815.152	8.765.578

Figure 3.15 The screenshot of results of Tabasaran/Rettenberger model for Canakkale facility

Total and yearly gas generation is introduced in the Figure 3.16 and Figure 3.17.

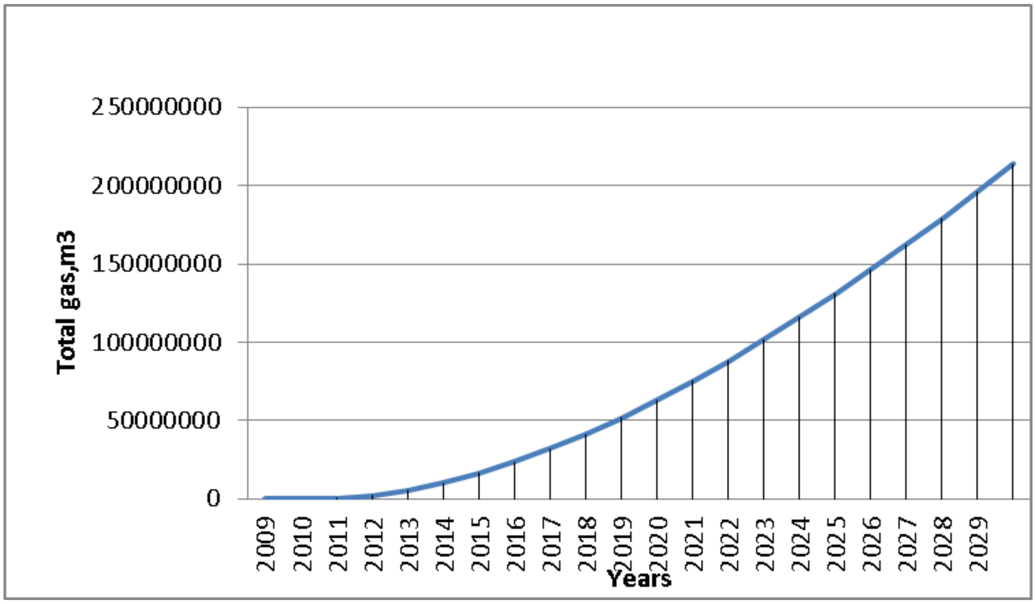


Figure 3.16 Total landfill gas generation for Canakkale facility with respect to Tabasaran/Rettenberger model

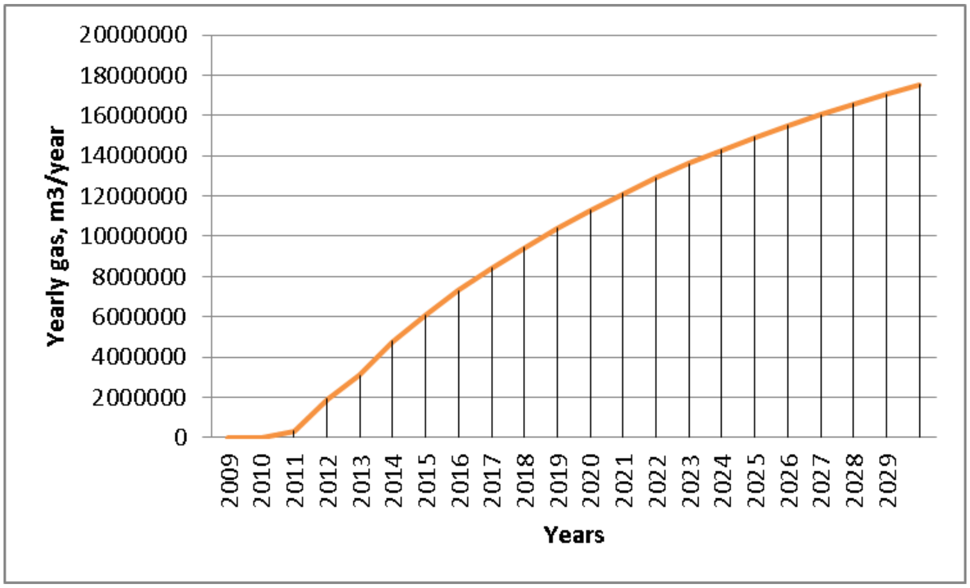


Figure 3.17 Yearly gas generation for Canakkale site with respect to with respect to Tabasaran/Rettenberger model

3.4 Analysis Results Dissimilarity

Landfill gas generation models were applied for two sites within Turkey: Canakkale and Kusadasi facilities. At the outset, substantial difference is noticed between the models, with the highest methane generation in and lowest generation for model. The description of the models, parameters used and assumptions made are resulted in transparency. A Scholl-Canyon model is a simplified first-order model. Disposed waste annual amounts and waste composition are equal throughout the exploitation period. (Oonk, H. 2010)

The LandGem model decreases the discrepancy by application of the conventional model per 1/10th of a year. Due to high k-values encounted the error in the conventional first order model is increased. The input materials are defined in line with the type of information available at the landfill. The model is evaluated in a more positive way. Waste can be specified according its source rather than composition. However, the no evidence that prognosis of LandGem is less accurate than other models. In Land assumed high values of Lo equal 170 and we may conclude that LandGem has a greater probability for overestimation of results.

It is important to notice, that the projected energy value of methane produced by the decomposition of organic matter in the waste is one of the most important parameters. Only a part of organic carbon eventually converted into landfill gas as part of it is not convertible under anaerobic conditions. It is generally calculated on the basis of waste composition or from its micro-composition, for example % of paper, textiles. The methane potential depends upon methane concentration in the waste.

Essential fact is what affect amount and energy context of LFG. First of all, landfill gas generation potential and energy context depends upon composition of the waste. Here mainly we should take into account organic fraction of the waste. According this, segregation of waste is consists of next categories: relatively inert, moderately decomposable and decomposable waste. Materials with low and no degradable organic fraction are relatively inert. Waste with a degradable organic carbon which is decomposes at a moderate or slow rate is moderately decomposable. A high degradable organic fraction in the waste is related it to decomposable. (env.gov.bc.ca). Therefore, direct weigh measurements are important to understand the annual mass for each category. Or total mass of the waste can be used for estimation of each type.

If waste characterisation is not available, we may estimate that all waste is decomposable, but this decrease accuracy of calculations for LFG generation. (env.gov.bc.ca)

It is necessary to mention that pre-treatment of waste prior to landfill disposal substantially increases waste stabilisation and by this affects energy performance of the facility. Pre-treatment includes mechanical and biological processes. The amount of received energy depends from the recovered amount of LFG. According (sustainablelandfillfoundation.eu), “gas collection efficiency requires 85 % gas recovery from wastes during the operation of active gas management system.”

A temporary gas collection structure in a landfill which includes horizontal gas wells or pin wells have nearly 50% less efficiency than a correctly engineered gas well. In addition, different cap types have different effect. So the gas collection efficiency reduced with decreased quality of engineered systems. Landfill site should involve different types of landfill gas collection systems to meet a whole site gas collection efficiency and energy recovery. (sustainablelandfillfoundation.eu)

3.5 Gas-to –Energy Economic Analysis of Results

Purpose of calculations is analysis of opportunities of installation of gas recovery systems. Calculation and assumptions made on the base of literature (ftp.ce.cmu.edu). After the annual gas generation is calculated, the gross power generation production in a given year can be calculated:

$$GPGPt=\frac{LFG_T*\eta_{cd}*E_c}{(365)(24)H_r},$$ where

η_{cd} - collection system efficiency, 85%;

E_c - is the energy content of LFG, typically 500 BTU/cf;

H_r - heat rate equipment, given in tables below;

LFG_T - gas production in mmcf per year;

The heat rate equipment for system 3 in Table 2 is accepted (ftp.ce.cmu.edu); 1mmcf=28,320m3. For Kusadasi facility the amount of landfill gas produced for 20 years is equal 175,661,060 m3. So:

$$GPGP_T=\frac{6203*0,85*500}{365*24*20*10246}*1000000=1469KWh;$$

The net power generation potential (NPGP) is then: NPGP=1469*0,98=1440 kWh, where 2%- is the lost energy for IC engines. The annual electricity generated (AEG) is then estimated:

AEG=NPGP*365*20*24*90%, where 90%- assumed average time percentage in a year equipment produce electricity; 24-number of hours in a day; 365- the number of days in a year;20-years of operation;

AEG=1440*24*365*20*0.9=227059200 kWh

For CAKAB (Canakkale) the amount of produced gas for 20 years is 134069200 m3 what is equal 4734,1 mmcf.

$$GPGP_T=\frac{4734,1*0,85*500}{365*24*20*10246}*1000000=1121kWh$$

The net power generation potential (NPGP) is then:

NPGP=1,121*0,98=1,199 kWh. The annual electricity generated (AEG) is then estimated:

AEG=NPGP*365*20*24*90=1,199*24*365*20*0.9=189,058,320 KWh=189, 1 GWh

In the same way gas-to-energy analysis was made for amounts of landfill gas with respect to literature information, Tabasaran/Rettenberger and School-Canyon models. The results are presented in the Table 3.14, Figure 3.18 and Figure 3.19.

Table 3.14 The results of gas-to-energy analysis

	Facility	
	Kusadasi AEG, GWh	Canakkale, AEG, GWh
Literature information		
50m3/tonne	104,1	98
200m3/tonne	417	391
400m3/tonne	833	781,1
School-Canyon model	7,1	6,9
LandGem model	227,1	189,1
Tabasaran/Rettenberger model	433,1	276

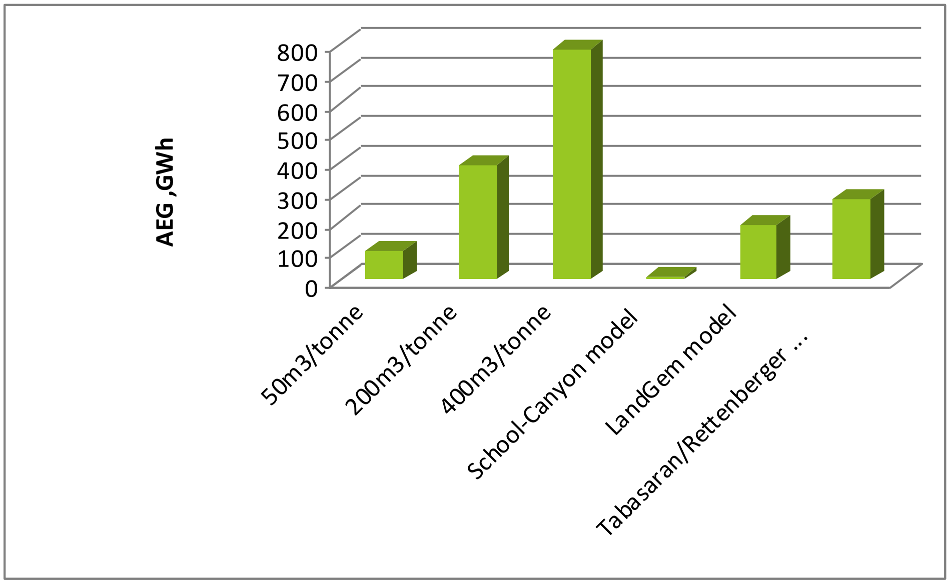


Figure 3.18 Available electricity generation estimation for Canakkale facility with respect to literature information and models approaches

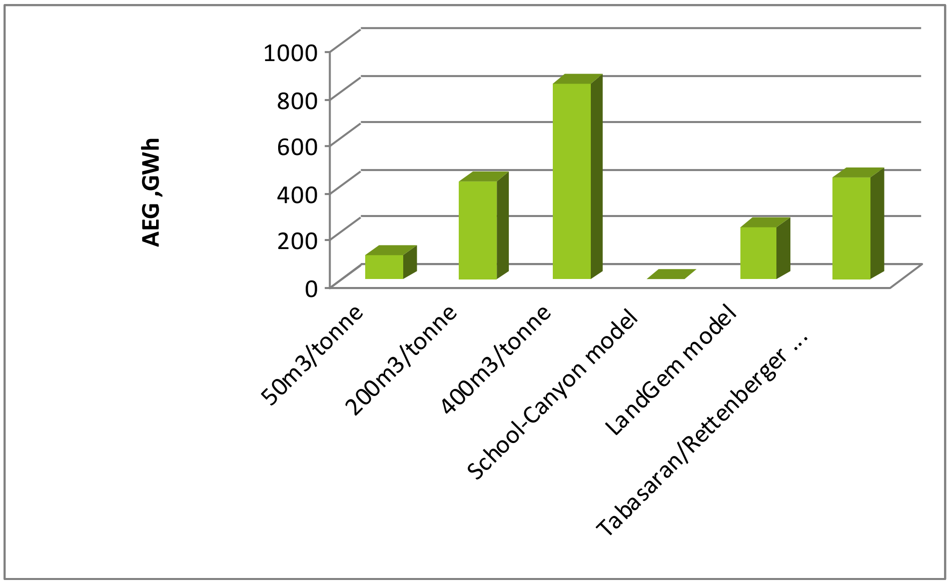


Figure 3.19 Available electricity generation for Kusadasi site with respect to literature information and models approaches

As we may notice the amount of available electricity for Kusadasi and Canakkale facilities with respect to models appriaches differes significantly. For Kusadasi site Tabasaran/Rettenberger model gives result 433,1 GWh, School-Canyon model- 7,1 GWh; for Canakkale facility electricity generation with respect to LandGem model is equal 189,1 GWh, School-Canyon model- 6,9 GWh.

CHAPTER FOUR

ENERGY RECOVERY FROM PYROLYSIS, GASIFICATION AND INCINERATION

At the outset, we should notice that there is no relaible data on energy recovery for gasification and pyrolysis. As were mentioned above, the calorific value of gas during the pyrolysis is 40 MJ/m3 and electricity generation per one annual tonne of waste is 0,5-0,8 MWh. For low-air gasification the calorific value is 4-6 MJ/m^3, for oxygen gasification -10-15 MJ/m3; the electricity generation -0,4-0,8 MWh/annual tonnes of MSW, plasma gasification-0,3-0,6 MWh/annual tonnes of MSW. During incineration 0,5-0,6 MWh of electricity is produced per annual tonne of MSW for old systems and 0,75-0,85MWh/annual tonne of MSW for new facilities. It is known that 1m3 of landfill gas contains 20 MJ of calorific energy. (electrigaz.com) and according agric.gov.ab.ca, 1m3 of gas may produce 1,7 kwh of electricity and 7,7 MJ of heat.

Pyrolysis and gasification technologies are resent development in compare with landfilling and incineration, especially in Turkey. Concret information for energy recovery for gasification and pyrolysis is related to particular system and process. For example, the proposed strategy for integrated waste handling system in Athens,Greece says that gas after gasifier may be burned in a boiler to produce energy with nominal power output 26,5 MW and net electrical efficiency 31% (Morris,M. & Waldheim,L.,1998). Plasma treatment of 250 tonnes/day of high moisture waste will generate 2.85 MW of electricity. Plasma gasification full scale facility in Japan produce 7.9 MW gross electrical energy (4,1 MW net) by treated 183 MSW per day (Mountouris, A.,Voutsas, E. & Tassios,D.,2006).

Nexterra/GE Combined Heat and Power system converts urban wood waste into clean burning, combustible synthetic gas or “syngas” using Nexterra’s proprietary gasification and syngas conditioning technologies. As stated in nexterra.ca, “the syngas will be directly fired into a GE internal combustion engine to produce 2 MW of electricity. Waste heat will be recovered from the engine to produce 9,000 lbs/hour of low pressure steam."

According Baggio,P., et.al, (2006), system based on pyrolysis and combined cycle containes 2 pyrolytic line with 2 gas turbines. The output of 1 turbine is 1389 KWh electricity in case of supply 3600 kg/h of waste.

The GEK Power pallet has an output 10 KWe of electricity with 1 hour biomass consumption 12 kg; an output 20 KWe of electricity with 1 hour biomass consumption 25 kg. Here should be noticed that working day of such system is maximum 6 hours.(gekgasifier.com)

Samra Combined cycle Power Plant (Jordan) is an incineration combined cycle plant with nominal capacity 300MWh and potential electricity generation 400 KWh.(gama.com.tr)

Tuas South Incineration Plant (TSIP) in Singapure can accept 3000 tonnes of refuse per day through the six incinerators and generate 80 MWh of electricity (app.mewr.gov.sg).

Toshima Incineration Plant in Japan may accept up to 400 tonnes/day of waste and generate maximum of 7.8 MW of electricity and 15.5 GJ/h of heat. (ieabioenergytask36.org)

According gipuzkoa.net, "in Austria in all plants there is a power-heat-combination. 116 kWh electricity and 1.920 kWh heat are produced per ton waste input. Thereof 78 kWh electric and 40 kWh thermic are used by the plant itself".

As in case with electricity output, there is no exact information for investment and operational costs for pyrolysis,gasification and incineration. All available information are related to the particular system, process and country. The data varies significantly from one plant to another. For example, McLanaghan reported that capital costs of 11-130 million Euro for 32-360 ktpa gasification and pyrolysis plants in the United Kingdom. To compare in Europe costs are ranges from 13 to 82 million Euro for 20-200 ktpa plants (Yassin, L., Lettieri, P.,Simons, S.J.R. & Germana,A., 2007)

Table 4.1 introduces capital costs for incineration palnts. Here, mass burned well-established incineration are taken into account.

Table 4.1 Capital costs for Europe incineration plants

Plant scale (kpta)	Capital cost (million Euro)
50	18-27
100	35-50
150	53-63
200	56-81
400	102-140

As stated by Yassin, L., Lettieri, P., Simons, S.J.R. & Germana, A. (2007), the operational costs for incineration ranges from 49 to 77 Euro/ ton of waste, and 28-77 Euro/ton of waste for pyrolysis and gasification. For landfilling of non-hazardous waste these costs are 67,2 Euro/ton of waste.

The investment costs for Canakkale CAKAB is 4,325,802.12 Euro; for Kusadasi project- is 5,000,000 Euro. These costs do not include consultancy and project costs.

CHAPTER FIVE
EVALUATION OF RESULTS

5.1 Comparison Of Available Energy Generation Results From Landfill Gas With The Energy Available From Alternative Sources

In this part the available electricity generation will be compared with hydroelectric power plants-Keban dam, Deriner dam, Hacilar HEPP; Soma HEPP and Kizildere GEPP; and analyzed with respect to electricity consumptions.

Keban dam and hydroelectric power plant is a major contributor to the solution of energy proble in Turkey. According ieahydro.org, it is located at north west of Elazığ and upstream of Keban town in Elazığ province. With the capacity of 1,330 MW, power plant is equipped with 8 units, first four of each 157.5 MW and other four units installed later on of each 175 MW capacity. The maximum output is 1330 MW and average energy production 7900 GWh of electricity(ieahydro.org).

Electricity received from landfill gas for Kusadasi is only 1.32% (50m3), 5.3% (200m3), 10,5% (400m3) from this amount. 7,900 GWh is 4.1% of overall grass electricity generation in Turkey for year 2009. (turkstat.gov.tr) To compare, electricity generation for Canakkale site with respect to Tabasaran/Rettenberger model is 0,14%, LandGem model- 0,1%, Scholl-Canyon model – only 0,004% from gross country electricity generation. The analysed information for Kusadasi and Canakkale facilities is introduced in Table 5.1.

Table 5.1 Results of comparison of electricity generation from LFG with respect to electricity generation of Keban dam and gross country electricity generation.

	Facility			
	Kusadasi		Canakkale	
	% in respect to GCEG*	% in respect to KDEG*	% in respect to GCEG	% in respect to KDEG
50m3/tonne	0.05	1.32	0.05	1.24
200m3/tonne	0.2	5.3	0.2	4.95
400m3/tonne	0.43	10.5	0.4	9.89
School-Canyon model	0.004	0.09	0.004	0.088
LandGem model	0.12	2.87	0.1	2.39
Tabasaran/Rettenberger model	0.22	5.5	0.14	3.49

*GCEG- gross country electricity generation;KDEG-Keban Dam electricity generation;

After analysing information presented above conclusion can be made that license for Kusadasi and Canakkale electricity generation projects can be owned by a private company; also projects can be realized on a free market. Here, the amount of generated electricity was taking into account.

Soma Wind Energy Power Plant is located in Manisa provice of Turkey with installed capacity 90 MW for 36 wind turbines. The annual electricity generation is 320 GWh.(bilgin.com.tr) To compare, yearly electricity generation for Kusadasi facility with respect to School-Canyon model is only 7 GWh, for Canakkale facility- 6,9 GWh; electricity generation with respect to literature information (400 m3) for Kusadasi site is 833 GWh, for Canakkale site is 781 GWh- what is more than double amount from electricity generated on Soma WEPP. The main difference in electricity generation from LFG for Canakkale and Kusadasi facilities and electricity generated on Soma WEPP are shown in the Figure 5.1 and Figure 5.2.

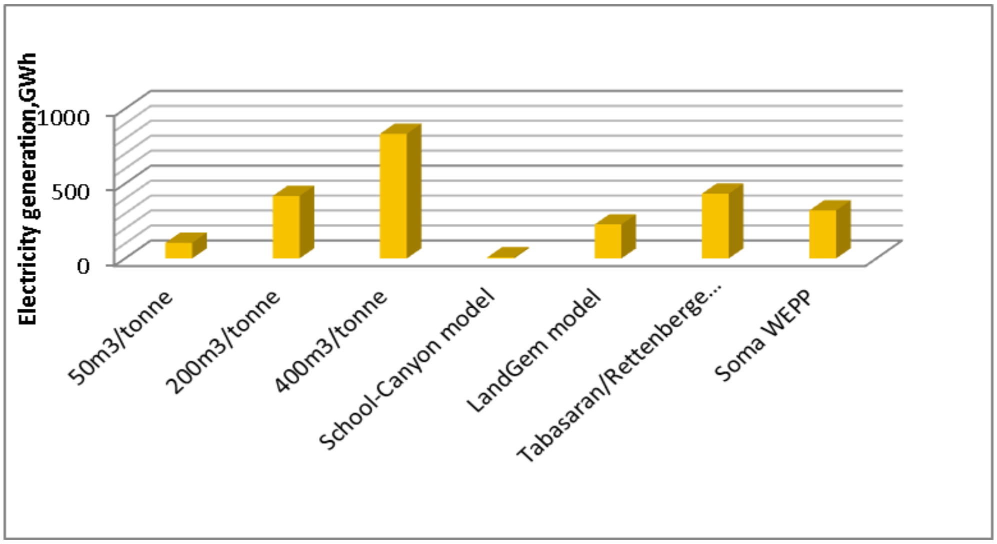


Figure 5.1 Electricity generated on Kusadasi site with respect to literature information and models approaches and Soma WEPP

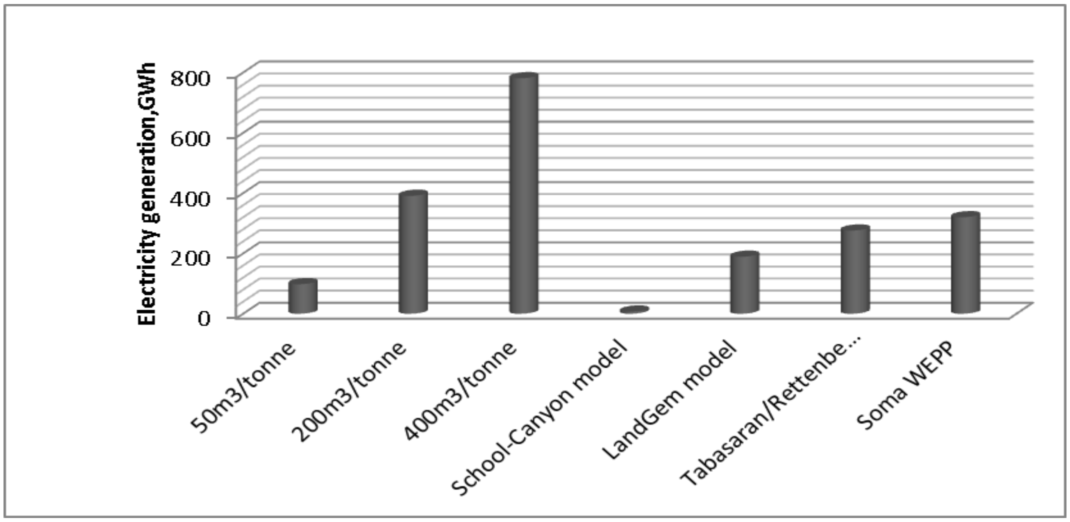


Figure 5.2 Electricity generated on Canakkale site with respect to literature information, models approaches and Soma WEPP

As it is possible to notice that the main differences between electricity generated in Soma WEPP and electricity generated from LFG with respect to literature information (400m3), School-Canyon model.

Kızıldere Geothermal Power Plant is located 40 km west of the city of Denizli, in the eastern part of the Büyük Menderes Graben. The single flash power plant capacity is 20 MW with yearly electricity generation is around 76 GWh. (pangea.stanford.edu, Serpen Ü. and Türkmen N. 2007). In fact, the electricity production from LFG with respect to Tabasaran/Rettenberger model for Kusadasi facility is 433 GWh, for Canakkale facility -276 GWh. The main difference between electricity production on Kizildere GTPP and electricity production based on literature information (400m3). For Kusadasi this difference is equal 757 GWh, for Canakkale site –is 705 GWh. Figure 5.3 and Figure 5.4 represent percentage ratio for electricity generation results based on literature information (400m3), School-Canoyn model and results for Kizildere GTPP.

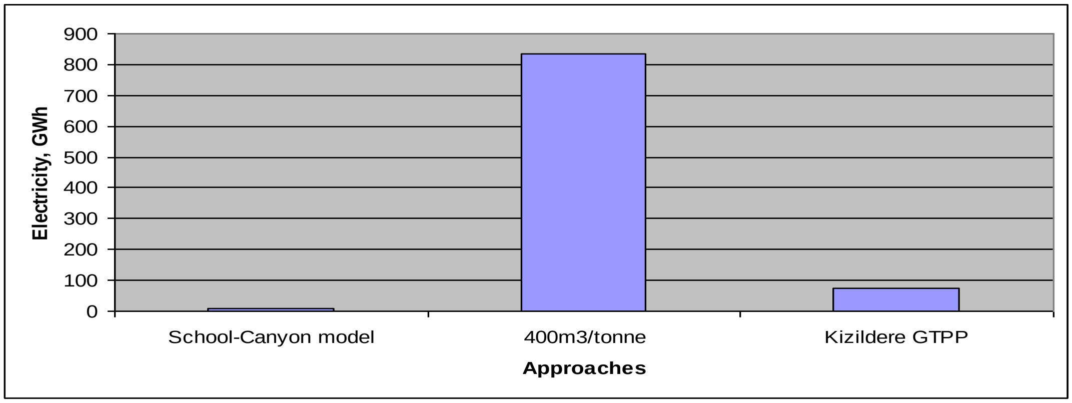


Figure 5.3 Electricity generation results for Kusadasi facility

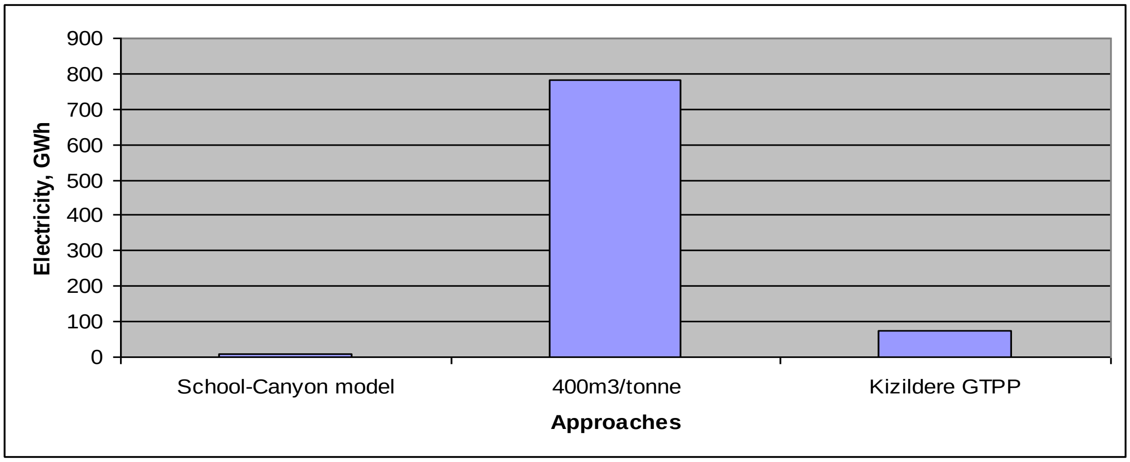


Figure 5.4 Electricity generation results for Canakkale facility

Therefore, the sudstantial difference is noticible between electricity generation from LFG based on School-Canyon model and hydroelectric power plants, Soma WEPP and Kizildere GTPP. Also, electricity generation from LFG based on literature information (400m3) shows the highest results in compare with Soma WEPP, Hacilar HEPP and Kizildere GTPP. In contrast, the electricity production on Keban and Deriner dams is substantially more than electricity production from LFG for both facilities. Figures 5.9 shows comparison of electricity generation for alternative sources and LandGem model results for Kusadasi and Canakkale projects.

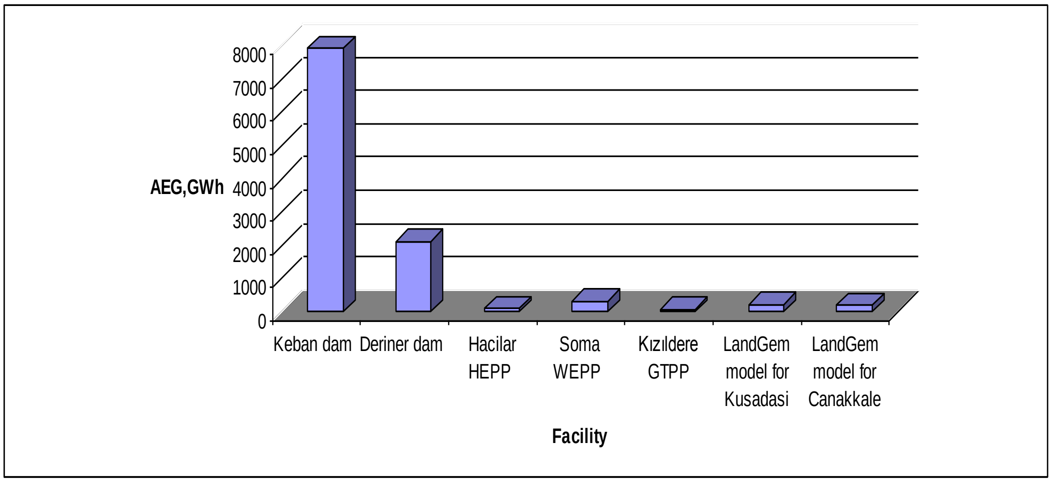


Figure 5.9 Aviable electricity generation results

According tuikapp.tuik.gov.tr, the electricity consumption by users for Canakkale provice in year 2009 was 82700 MWh. It is 85% from amount of electricity generated from LFG with respect to literature information (50m3), 21% (200m3) and 11% (400m3). Forr Aydin provice the electricity consumption for users is 149263 MWh. If to take into account models approaches, it is 66% from electricity generated from LFG with respect to LandGem model, 35%- with pespect to Tabasaran/Rettenberger model. And the amount generated electricity from LFG with respect to School-Canyon model is 5 % from users electricity consumption.

So, electricity generation projects for Kusadasi and Canakkale may significantly contribute in overall electricity comsumption for local users. Assumptions for electricity generation based on literature information and models approaches are substantially ranges. In this case the most relable way in particular situation should be followed, and actual landfill gas measurements will give more clear information.

5.2 General Look to the Countries Available Gross Energy Capacity

The purpose is to estimate landfill gas generation potential on the base of literature information for waste currently disposed into land for several European countries, to analyze the opportunity for installation of gas-to energy systems to evaluate municipal solid waste generation and waste treatment options worldwide, assess and estimate energy recovery options; compare and contrast received results.

In Europe, amount of waste which is deposit into land substantially varies. In next table we can see amount of waste which is landfilled or uncontrolled disposed in several countries.

Table 5.2 Amount of waste disposed into land for several European countries
(Source: epp.eurostat.ec.europa.eu)

Country	**Waste deposit into land, kg per Ca**
Bulgaria	404
Spain	310
Greece	374
Cyprus	610
Malta	485
Turkey	340

To calculate overall waste deposit in presented countries, amount of waste kg per Ca will be multiply with population quantity. The population expanse for the year 2010 is shown in next table.

Table 5.3 The population expanse for the year 2010 (Source:epp.eurostat.ec.europa.eu)

Country	**Population, Ca**
Bulgaria	7,563,710
Spain	45,989,016
Greece	11,305,118
Cyprus	803,147
Malta	414,372
Turkey	72,561,312

The overall amount of waste deposit into land for the year 2010 is introduced in the next table.

Table 5.4 The overall amount of waste deposit into land (Source:epp.eurostat.ec.europa.eu)

Country	**Overall waste amount deposit into land, tones**
Bulgaria	3,055,738.84
Spain	14,256,594.96
Greece	4,228,114.132
Cyprus	489,919.67
Malta	200,970.42
Turkey	24,670,846.08

The landfill gas potential will be determine on the base of literature information. Also it will be assumed that LFG is generated for the amount of waste deposit in year 2010.

For Bulgaria: 50m3/tonne*3,055,738.84 tonnes=152,786,942 m3 of LFG
200 m3/tonne*3,055,738.84 tonnes= 611,147,768 m3 of LFG
400 m3/tonne*3,055,738.84 tonnes= 1,222,295,536 m3 of LFG
For Spain: 50 m3/tonne*14,256,594.96 tonnes=712,829,748 m3 of LFG
200 m3/tonne*14,256,594.96 tonnes=2,851,318,992 m3 of LFG
400 m3/tonne* 14,256,594.96 tonnes=5,702,637,984 m3 of LFG
For Greece: 50 m3/tonne*4,228,114.132 tonnes=211,405,701 m3 of LFG
200 m3/tonne*4,228,114.132 tonnes=845,622,826 m3 of LFG
400 m3/tonne*4,228,114.132 tonnes=1,691,245,653 m3 of LFG

In the same way projections are made for Cyprus, Malta and Turkey. Results are introduced in Table 5.5 and Figure 5.10.

Table 5.5 Projected amount of LFG

Country	Amount of LFG,m3		
	50m3/tonne	200m3/tonne	400m3/tonne
Bulgaria	152,786,942	611,147,768	1,222,295,536
Spain	712,829,748	2,851,318,992	5,702,637,984
Greece	211,405,707	845,622,826	1,691,245,653
Cyprus	24,495,983.5	97,983,934	195,967,868
Malta	10,048,521	40,194,084	80,388,168
Turkey	1,233,542,304	4,934,169,216	9,868,338,432

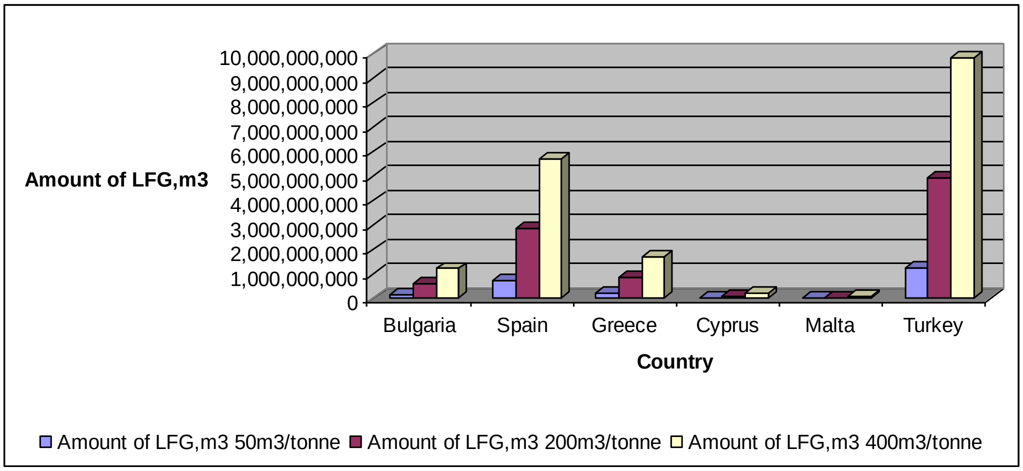


Figure 5.10 Projected amount of LFG

Estimations are made for several countries in Europe based on information waste disposed into land, population Ca and literature approach. As we can see that results are significantly fluctuated. Here, other options of treatment for presented countries are not taken into account.

$$GPGPt=\frac{LFG_T{*}\eta_{cd}{*}E_c}{(365)(24)H_r},$$

The heat rate equipment for system 3 in Table 2 is accepted; 1mmcf=28320m3.So, for Bulgaria:

$$GPGP_T=\frac{5{,}395.02*0{,}85*500}{365*24**10246}*1000000=25{,}546.03KWh$$

The net power generation potential (NPGP) is then:

NPGP=25,546.03KWh-2%=25,035.11KWh, where 2%- is the lost energy for IC engines. The annual electricity generated (AEG) is then estimated:

AEG=25,035.11*24*365*0.9=197,375,940 KWh=197,4 GWh

200 m3: $GPGP_T=\frac{21{,}580.1*0{,}85*500}{365*24**10246}*1000000=102184{,}13KWh$

The net power generation potential (NPGP) is then:

NPGP=102,184.13KWh-2%=100,140.45 KWh, where 2%- is the lost energy for IC engines. The annual electricity generated (AEG) is then estimated:

AEG=100,140.45*24*365*0.9=789,507,307.8 KWh= 790 GWh

400 m3: $$GPGP_T = \frac{43160{,}2*0{,}85*500}{365*24**10246}*1000000 = 204{,}368.3KWh$$

The net power generation potential (NPGP) is then:

NPGP=204,368.3KWh-2%=200,280.9 KWh, where 2%- is the lost energy for IC engines. The annual electricity generated (AEG) is then estimated:

AEG=200,280.9*24*365*0.9=1,579,014,615.6 KWh=1579 GWh

In the same line calculations are made for rest of the countries and results are introduced in Table 5.6

Table 5.6 Available electricity generation for chosen countries

Country	AEG, GWh		
	50m3/tonne	200m3/tonne	400m3/tonne
Bulgaria	197.4	790	1579
Spain	921	3,553.5	7367
Greece	273	1,092.4	2185
Cyprus	31.7	126.6	253.2
Malta	13	52	104
Turkey	1594	6,374.2	12,748

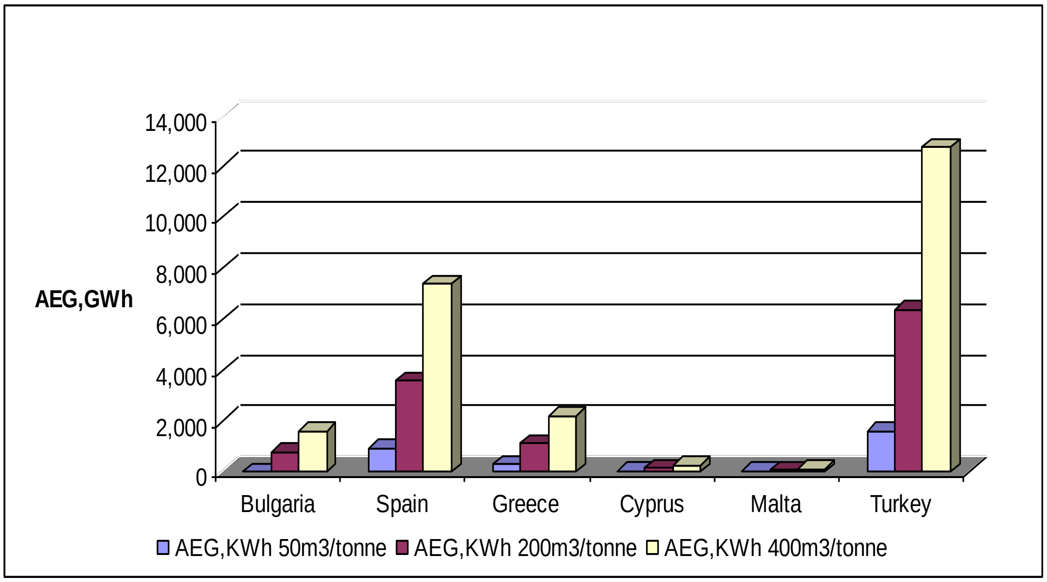


Figure 5.11 Available electricity generation for chosen countries

Thus, if to take into account available amount of landfill gas, the electricity generation for Turkey and Spain, Greece may bring substantial benefits to countries electricity production.

It is clear from next table that % of waste for energy recovery from total waste treatment amount is in direct relationship with country's GDP level. With GDP growth amount of recovered energy is increasing. Exemptions are only UK and Slovenia. In UK the percentage value of waste for energy recovery is substantially less and equal to 0,54%; in Slovenia is more and equal 5,99%. For France, UK and Turkey the quantity of disposal waste is considerably more than amount of waste for energy recovery. But here we should take into consideration that disposal waste has a great potential for recovery of energy –LFG produced in disposal sites.

Table 5.7 The dependence of energy recovery from total waste treatment and country's GDP level

	GDP per capita	**Total waste treatment (tonnes)**	**Amount of waste for energy recovery (tonnes)**	**% of waste for energy recovery from total waste treatment amount**	**Disposal (tonnes)**
Denmark	63,003$	14636000	3320000	22,68	1034000
Germany	44,556$	367256000	23316000	6,35	74708000
Belgium	48,110$	28731000	4453000	15,5	3050000
France	44,401$	322629000	12056000	3,74	107424000
UK	39,604$	316991000	171000	0,054	168178000
Spain	33,298$	137687000	2552000	1,85	64291000
Slovenia	25,939$	5242000	314000	5,99	1873000
Turkey	10,576$	60236000	143000	0,24	45380000
Italy	37,046$	127894000	2459000	1,92	32452000

To investigate energy recovery potential of disposal option the different approach can be applied. Next assumptions are made:

1.Total amount of waste for disposal (tones) contains 70% of biomass, which include the moisture contained and dirt particles; and 15% of petrochemicals wastes;

2.The rest of the landfill waste includes inorganic components.

According reported data of anaerobic digestion in the literature, the simplest reaction of anaerobic decomposition:

$C_6H_{10}O_4 + 1.5H_2O = 3{,}25CH_4 + 2{,}75CO_2$ **(1)**

We may assume that dry organic content of the waste is 60%, and this result in 417 (2, 86 mol) of C6H10O4 per tonne of total MSW. It is known that 1 kmol of CH4 is equal 22,4 Nm3), so taking into consideration balance (1), we may conclude that 1 tonne of MSW is equal to 0,149 tonne or 64Nm3 of methane (Themelis,N.J. & Ulloa,P.A., 2005).

So, in Denmark 1034000 tones of waste are landfilled, from which 258500 tones are inorganic components.

1034000/100*75(60% of biomass+15% of petrochemicals)= 775500 tonnes.

1034000-775500=258500 tonnes

Assuming medium amount of 64 Nm3 or 0,149 tonnes of methane generated per 1 tone of waste (Themelis,N.J. & Ulloa,P.A., 2005): 75500 tonnes of landfill waste produce 49632000Nm3 or 115549,5 tonnes of methane. Similar:

- for Germany: 74708000/100*75=56031000 tonnes produce 3585984000 Nm3 or 8348619 tonnes of methane
- for Belgium: 3050000/100*75=2287500 tonnes produce 146400000 Nm3 or 340837,5 tonnes of methane
- for France:107424000/100*75=80568000 tonnes produce 5156352000 Nm3 or 12004632 tonnes of methane
- for UK:168178000/100*75=126133500 tonnes produce 8072544000 Nm3 or 18793891,5 tonnes of methane
- for Spain:64291000/100*75=48218250 tonnes produce 3085968000 Nm3 or 7184519.3 tonnes of methane
- for Slovenia:1873000/100*75=1404750 tonnes produce 89904000 Nm3 or 209307,75 tonnes of methane
- for Turkey:45380000/100*75=34035000 tonnes produce 2178240000 Nm3 or 5071215 tonnes of methane
- for Italy:32452000/100*75=24339000 tonnes produce 1557696000 Nm3 or 3626511 tonnes of methane

Table 5.8 summarises above calculations

Table 5.8 Amount of generated methane and biogas (with respect to organic content of waste)

	Amount of produce methane		Amount of produce biogas	
	Nm3	tonnes	Nm3	tonnes
Denmark	49632000	115550	99264000	231100
Germany	3585984000	8348619	7171968000	16697238
Belgium	146400000	340838	292800000	681676
France	5156352000	12004632	10312704000	24009264
UK	8072544000	18793892	16145088000	37587784
Spain	3085968000	7184520	6171936000	14369040
Slovenia	89904000	209308	179808000	418616
Turkey	2178240000	5071215	4356480000	10142430
Italy	1557696000	3626511	3115392000	7253022

Amount of available biogas calculated on the basis that biogas composition contain 50% of methane (Yadvika, Santosh , Sreekrishnan, T.,R., Kohli, S. & Rana, V. ,2003). It is known that 1m3 of biogas contains 20 MJ of calorific energy. (electrigaz.com) In addition, next assumptions should be taken into consideration- 1m3 of biogas may produce 1,7 kwh of electricity and 7,7 MJ of heat (agric.gov.ab.ca) . Potential amount of electricity and heat produced from biogas can be calculated.

Table 5.9 The potential amount of electricity and heat produced from biogas

	Potential amount of electricity (GWh)	Potential amount of heat (TJ)
Denmark	84	764
Germany	6096	55224
Belgium	249	2255
France	8766	79408
UK	13723	124317
Spain	5246	47524
Slovenia	153	1385
Turkey	3703	33545
Italy	2648	23989

5.3 Comparison of Processes

5.3.1 Landfilling in Contrast to Pyrolysis, Gasification and Incineration

In contrast to gas produced during pyrolysis, gasification and incineration, landfill gas is a product of waste stabilisation which later is utilised for power and heat generation. Formation of landfill gas relies on biodegrable organics. What is more, waste stabilisation stages during landfill gas formation are different from reactions occur in pyrolysis, gasification and incineration processes. Initial landfill gas generation stage is in the presence of oxygen, third is anaerobic and last one returns to aerobic conditions. Range of temperatures is also altered from other mentioned processes. For example, temperature fluctuates from 70-90C on the first stage to 30-50C on the second stage. In the same line, speed of the reactions during waste stabilisation is differs and it is very slow- from a couple of days to several years for completion. The calorific value of landfill gas is equal 17-18 MJ/m3 is relatively low to compare with product gases of pyrolysis and higher to compare with gasification gases. Also, to compare with pyrolysis, gasification and incineration flue gases, composition of landfill gas is predictable and consists mainly of methane and carbon dioxide.

Advantages of incineration, gasification and pyrolysis over landfilling:

-incineration, gasification and pyrolysis are processing waste in order to reduce waste going to landfill;

-have less risk to the environment;

-visually more attractive (ec.europa.eu);

5.3.2 Incineration to Pyrolysis and Gasification

As well as gasification, incineration is one of available instruments of integrated waste management system. In compare with incineration, gasification is time-tested resent development. Combustion reactions during incineration absolve energy as a high temperature product gas. Gasification moves heat into chemical bonds and actuates energy into gaseous fuel. This fuel may be burned in combustion reaction to produce electricity. So conclusion can be made that gasification way to combustion define itself as a two-stage combustion process. If the temperature for incineration is less than 770C that lead to poor combustion, temperatures above 1090C make it difficult for furnace to sustain heat. Operational control for incineration, in contrast to gasification, where it depends from particular technology, insures that waste should match with exact amount of oxygen.

Gasification has several advantages over incineration of waste. It is a result of operating conditions and features of the used reactor which allow to have a syngas which can be applied to various applications as a chemical feedstock or fuel gas to be burned in reciprocating engines or turbines with the purpose to generate electricity In the same line according Umberto Arena, “gasification has several advantages over combustion technology: a limited formation of dioxins and nitrous and sulphur oxides; a reduced amount of secondary and nitrous and sulphur oxides; a reduced amount of secondary wastes, which in some cases are produced in a less hazardous form”, “the production of an energy carrier”, and “ the possibility of applying the process on a smaller scale.” (Arena, U., 2011). In one line with gasification, pyrolysis is the resent development and substantially differs from incineration.

5.3.3 Pyrolysis and Gasification

Pyrolysis and gasification are related technologies that can recover useable products and energy from waste. The processes four stages include separation of glass, greed and metal; heating the remaining waste to produce oil, gas and tare, or gas as a main product for gasification; cleaning the gas to remove unwanted components and use of clean gas for energy recovery purposes. The examples of carbon-based waste are paper and plastics, organic food waste. It is important that operating parameters control distribution of the reaction products. For slow pyrolysis low heating rates and extended residence time increase char yield; for intermediate pyrolysis hot vapour residence time distribute products in the ratio-gas from 15-to25%, 20-30% char and 45-65 %oil ; fast pyrolytic reactions up to 550C maximise production of oil, above 600C- production of gas. As well as for pyrolysis, for gasification process at temperatures less than 600 C the main product is char, above-increasing yield of gas.

Energy production for both pyrolysis and gasification depends on moisture content of the feed waste, the process energy, the net thermal energy produced by the process, the heating value of produced gas and the reactor temperature. But in case of gasification the energy also relies on the amount of air/oxygen. Operational controls for pyrolysis and gasification depend from particular used technology.

As it stated by the Girods,P., Dufour, A., Rogaume, Y., Rogaume, C. & Zoulalian, A. (2008), during thermo-convention of wood waste, “ the way of the gasification gives the best result in term of energy recovery” in compare with pyrolysis. However, the char produced during pyrolysis contains energy. Here, for both processes raising reactor temperature improving combustible gas production and as a result energy recovery. Here, for both processes raising reactor temperature improving combustible gas production and as a result energy recovery. During thermo-convention of wood waste the best temperature for pyrolysis and gasification is the same and equal 1000 C. However in contrast to pyrolysis, the best way for energy recovery is gasification. To compare with gasification pyrolysis is the best way to prevent ammonia formation (Girods, P., et all, 2008).

Table 5.10 Comparison of characteristics of gasification, pyrolysis and incineration processes

Characteristics	Landfilling	Incineration	Pyrolysis	Gasification
Process definition	Landfill site is a place where wastes are disposed by dumping. The landfill is detached into disposal cells	Process of waste decomposition that can be burned to produce power or heat. .	Thermal degradation of organic waste in the absence of oxygen	Partial oxidation of resence of an mount lower than sary for etric combustion
Waste characteristics	No waste pre-treatment, has no difficulties with	Minimum waste pre-treatment; has no difficulties with	Can treat substantial amounts of	Homogeneous ifficulties in variable waste

Table 5.10 continue

	handling variable waste streams; Can treat substantial amounts of waste,	handling variable waste streams; Can treat substantial amounts of waste, relies on carbon-based waste;	waste, relies on carbon-based waste; require certain amounts and type of waste to operate successfully. waste pre-treatment and pre-processing	relies on carbon- ste, can treat al amounts of waste; ubstantial waste on and pre-treatment
Flue-gas composition	CH_4,CO_2,N_2,O_2, H_2,CO	CO_2,H_2O, N_2,O_2,H_2	CH_4,CO,CO_2, N_2, H_2,	CH_4,CO,CO_2 and N_2
Operating temperature	Up to 70-90 C	From 980C to 1090C, but may increase up to 1600C	from 400to 800C	From 800 to 1100C, and for oxygen gasification- from 1000 to 1400C
Oxygen requirements	yes	Yes	Do not require	In the form of air, steam or pure O_2
Electricity generation	0,6-0,7 MWh/annual tonne of MSW	0,5-0,6 MWh/annual tonne of MSW for old systems and 0,75-0,85MWh/annual tonne of MSW for new facilities	Up to 0,5-0,8 MWh/annual tonne of MSW	0,4-0,8 MWh/annual tonne of MSW-for oxygen gasification; 0,3-0,6- for plasma gaification

Emissions	Release of unwanted gases what cause air pollution and contribute to the global warming	More emissions is produced to compare with pyrolysis	Less emissions produced compare with incineration	Proposed itself as a clean and environmentally friendly

From the Figure 5.12 it is possible to see more clearly that calorific value of the gas from above processes is substantially varies from 6 MJ/m3 for low-air gasification to 40 MJ/m3 for pyrolysis.

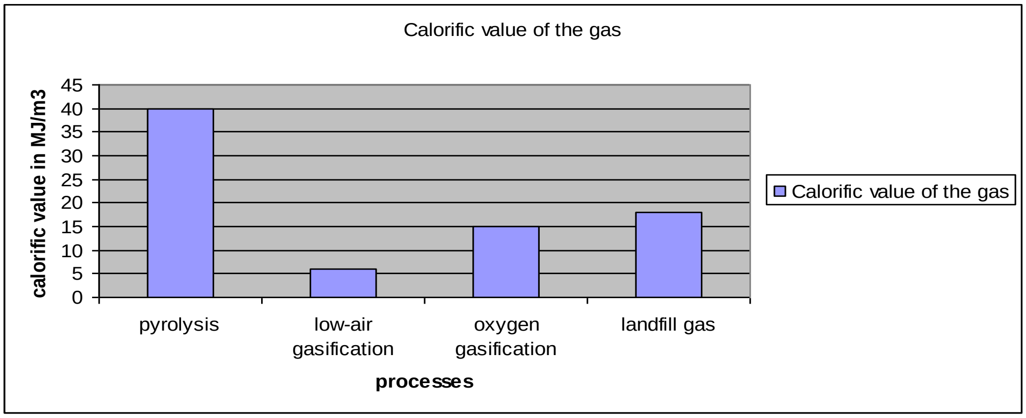


Figure 5.13 Amounts of produced electricity in KWh

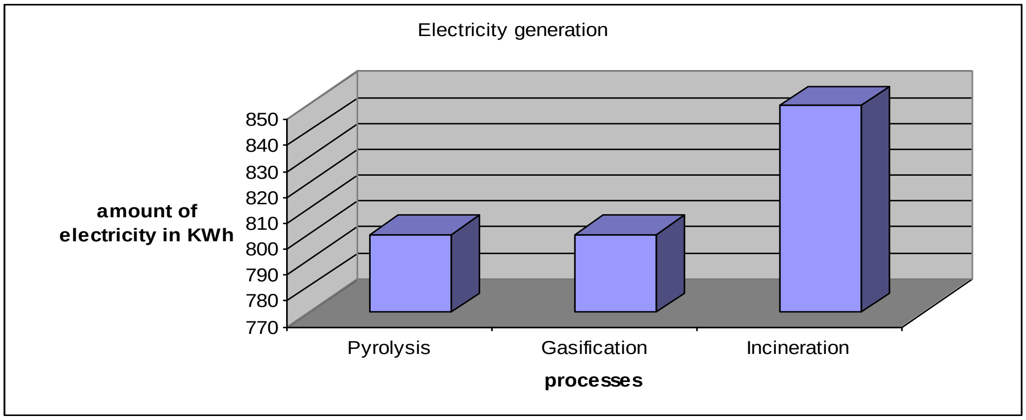


Figure 5.12 Comparison of gas calorific value and amount of electricity production for pyrolysis, gasification, incineration and landfilling

Also the amount of produced electricity is differs; but in contrast to previous figures we can see that new incineration system is available to produce up to 850 KWh electricity.

5.3.4 Evaluation of Technologies- SWOT Analysis

Tables 5.11, 5.12, 5.13 and 5.14 represent strategic evaluation of strengths, weaknesses, opportunities and treats for pyrolysis, incineration, gasification and landfilling.

Table 5.11 SWOT analysis of gasification

Strengths	Opportunities
-advanced thermal treatment proposes itself as a clean technology; -it is a time-tested, reliable and flexible technology; -converts carbon-containing materials, including waste and biomass, into electricity with substantially reduced environmental impact; -can recover energy locked in biomass and waste; -reduces landfill capacity consumption by 90-95%; Table 5.12 continue -produces solid residues which are more suitable for reuse; -can treat substantial amounts of waste; -easy way to modify existing boilers for biomass and/or waste firing;	- improvement in investor confidence; - meet of energy needs around the world; - future reduce of usage of fossil fuels; - increase in electricity production as a result of technology development; - increase of availability of gasification plants; - collaboration in renewable technology research &development;
Weaknesses	Treats
-financial considerations—high capital and operational costs; -require extensive feedstock pre-treatment and pre-processing; -has difficulties with accepting variable waste streams and require nearly homogeneous feedstock;	-difficulties in financial funding; -doubts about plant commercial viability; -poor public perception and difficulties in market penetration; -competition from other technologies-pyrolysis, anaerobic digestion; complex permitting issues as a barrier for

-require syngas cleaning and waste composition and operating conditions give raise to tars and unwanted components; -for plasma gasification – relatively low electricity efficiency; -the raw gas will contain tar, char and hydrocarbon gases, and furnace burner system must be able to tolerate these contaminants and not be susceptible to fouling or clogging;-operational controls depends upon particular used technology;- gasifier characteristics influence quality of the product gas	gasification development

Table 5.12 SWOT analysis of pyrolysis

Strengths	Opportunities
Alternative technology with minimal environmental impact; -useful and cost-effective process with efficient utilisation of waste and production of valuable products; -great source of recovering energy from the waste and produce power, heat and electricity; -the composition and yield of pyrolysis products can be varied by controlling operating parameters; -the pyrolysis plants can be quickly implemented; -for residual to disposal landfill capacity consumption can be reduce up to 90%; -commercial viability on a large-scale commercial plants; -there is wide range of pyrolysis technologies for waste processing; -helps to reduce fossil fuel usage; performance in a relatively small scale in remote locations	-rise to business and investment opportunities; -increase in energy production as a result of technology development and increasing reliability; -technology world expansion; -collaboration in renewable energy technologies research &development
Weaknesses	Treats
-process requires waste preparation and pre-processing; -has difficulties in accepting variable waste streams; -financial considerations-relatively high operating and capital costs;	-facing financial difficulties; -hesitations about commercial pilot scales; -competition from other technologies-pyrolysis, anaerobic digestion;

-limited world-wide applicability of some technologies; -many technical and operational problems should be solved before considering reliability and economics for the market; -disposal of ash and other by-products may be required; reliability and effectiveness of processing mixed MSW is under question; - operational conditions can give rise to tars and unwanted components	-complex permitting issues as a barrier for pyrolysis technology development; -impaired public awareness and problems in market expansion

Table 5.13 SWOT analysis of incineration

Strengths	Opportunities
-minimum waste pre-treatment and pre-processing; can handle substantial amounts and variable waste streams; -for residual to disposal reduces landfill capacity consumption up to 90-95%; -volume of waste is reduced up to 90%; -incineration facilities have reasonable good energy efficiency and can produce electricity up to 0,85 MWh/annual tonne of waste; -can destroy many unwanted components as a result Table 5.14 continue -incineration avoids release of methane and incineration of medical waste produce a non-hazardous end product; -relatively low cost in compare with other technologies; -helps to reduce fossil fuel consumption	-future improvement of poor public image; -developing of the operational control systems which help to reduce release of unwanted components; -technology development and as a result improvement in safety; technology world expansion
Weaknesses	Treats
-release of unwanted components in high concentrations; -flue gases need cleaning; -greater size of incineration plants;	-arising public negative concerns; -competition from other thermo-treatment technologies and difficulties in market penetration; -rise of difficulties in legislation;

-negative public perception; -residue quality and disposal; -poor long-term reliability and size of the plants; -waste incineration process is subject to intensive legislations; - needs of technological attention to continuous monitoring equipment	-complications in investor persuasion and as a result frustration in financial funding;

Table 5.14 SWOT analysis of landfilling

Strengths	Opportunities
-it is a cheap waste disposal options for the local council; -helps to improve local economy; -landfill gives and opportunity to create work places; -the landfill gas collected from the waste stored on landfill can be used in different applications including direct heating applications, electricity generation, purification to pipeline natural gas, -heat recovery from landfill flares; -can accept different kinds and amounts of waste; on the modern landfill sites trash is isolated from the environment	-development of safety technologies for the extraction of gas and pollution prevention; -collaboration in renewable energy research & development policies will help to maintain stable energy production from the LFG; -improvement in public awareness and concerns; - reduction of waste export from the local areas
Weaknesses	Treats
-release of unwanted gases what cause air pollution and contribute to the global warming; -pollution of groundwater as a result of leachate escaping; -landfill needs a complex monitoring even when site is closed; -gas decomposition and as a result essence in local areas; -needs large territories to build up and	-increasing regulations by environmental and planning agencies; -rapid consumption of land; -public negative concerns; -difficulties in market share and competition from recycling processes; complications in legislation

infrastructure damage; -poor reliability; -environmental noise; -recovered amount of LFG rely upon waste composition and other parameters; landfill has capacity that can not be extended	

CHAPTER SIX
CONCLUSION

Integration of waste streams, collection and treatment options in one line with environmental benefits bring economical optimization and societal acceptability for any region. Here, waste management system has to be environmental and economically sustainable; solid waste characteristics should be enriched by applying recycle, reuse and recovery.

Industrial and financial development creates the rise of energy consumption. From this point of view, waste management infrastructure in Turkey must be expanded. To defend country’s energy requirements the substantial number of facilities has to be established. Currently, in Turkey there is not enough waste energy extraction facilities. As were stated before, mainly waste is accommodated in uncontrolled landfill sites and storage areas. However, landfills should be design as reactor in order to obtain energy.

According this, the objective of the study was to discuss energy processing techniques, their applicability, compare and contrast their benefits and negative points, evaluate energy recovery options with respect to particular issues. As a result, gasification, pyrolysis, incineration and landfill options were discussed; landfilling was treated as a separate issue; energy recovery potentials and optimization of energy recovery were appraised. It is important to mention that limited data on energy recovery techniques is available. Information is local and company based, and in some cases is not reliable; data is confidential. The strategic waste management approach for successful implementation of energy recovery techniques was developed, waste management technique for Kusadasi Solid Waste Landfill facility and Canakkale Solid Waste Regional Project was chosen. Here, solid waste amount was estimated based on population projection, and landfill gas potential was valued with respect to information given in literature and Tabasaran/Rettenberger, LandGem and School-Canyon models. On the base of LFG potential results electricity generation for Kusadasi and Canakkale facilities was projected. After, comparable analysis for available electricity generation from landfill gas and electricity available from alternative sources was made.

Thus, we conclude that all processes are not significantly differs one from another in terms of electric energy generation. It varies in the range 0, 3 to 0, 85 MWh/tonne of MSW. So other characteristics may influence the choice of energy recovery option. It can be free land availability, economical and ecological constrains, political and cultural views, possibility to use scientific base. One of the decisive factors is calorific value of product gas which has substantial fluctuations from one energy recovery option to another, and depends from MSW characteristics. Next point is the amount of gas product that can be received, or distribution of products that is necessary to achieve.

The substantial uncertainty in results for landfill gas potential was found. The choice of supplementary components such as parameters, models and literature information assumptions resulted in dissimilarity effect. In LandGem model the input materials are defined in line with the type of information available at the landfill. The k-values and Lo- meanings are default and evaluated in a more positive way. Waste can be specified according its source rather than composition Results for School-Canyon model are too low in compare with LandGem and Tabasaran/Rettenberger models. In School-Canyon model disposed waste annual amounts and waste composition are equal throughout the exploitation period; calculation of biogas potential of various components of the waste, potential biogas amounts for metal, glass and non-combustibles are not reliable. One of the solution of such calculations may be that organics may stick on surface of materials and produce biogas.

The results for waste-to-electricity projects for Canakkale and Kusadasi sites is significantly fluctuated and depends on LFG potential results based on literature information and models approaches. With the maximum 66% (LandGem model result) to 5% (School-Canyon model result) of electricity consumption by users for Aydin province from the amount of generated LFG. Furthermore, electricity consumption by users for Canakkale province is 85% from amount of LFG generated with respect to literature information (50m3), 21% (200m3) and 11% (400m3). This indicates that LandGem model approach is more realistic in compare with Tabasaran/Rettenberger and School- Canyon models. Tabasaran/Rettenberger model gives maximum result whereas School-Canyon model applies pessimistic view.

Waste- to-electricity projects for Canakkale and Kusadasi sites can be reliable as electricity generated within them is enough to cover user’s needs for Canakkale or Aydin provinces. Moreover, Canakkale and Kusadasi projects are comparable with renewable energy assignments within country. Finally, waste-to-electricity enterprises for Kusadasi and Canakkale will contribute to country electricity generation as well as environmental protection.

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