An-Najah National University

Faculty of Graduate Studies

Utilization Landfill Gas from ZF Landfill for Electricity Generation

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This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Electrical Power Engineering, Faculty of Graduate Studies, An-Najah National University, Nablus, Palestine.

2019

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This thesis was defended successfully on 24/12/2019 and approved by:

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DEDICATION

To our prophet Mohammed

Blessings and Peace be upon him

To my father

To my mother

To my husband Sajed

To my sons (Mahdi & Mohammad), and daughter (Leen)

To my brothers, and sisters especially Madlin& Hadeel with all of love

To Dr Sae'd Abu Hijleh with all respect &appreciation

To my big family

To my teachers

To all friends and colleagues

To all of them,

I dedicate this work

ACKNOWLEDGMENT

To begin with, acclaim is to Allah for helping me in making this thesis possible.

I might want to express my honest gratitude to my supervisor Dr. Mutasim Baba, for his direction, motivation, support and giving me trust to complete the research.

I also express my deep gratitude to Dr. Sae'd Abu Hijleh from all my heart For his support in all stages of my study.

My parents, husband, brother, sisters, friends, and all my family thank you for being a wellspring of support and motivation. I am appreciative to every one of you for your love, and support.

My thanks and respects go to the staff of Electric Power Engineering Master Program at An-Najah National University, especially Dr Maher Khammash.

Finally, I might want to thank, everyone who was vital to the successful realization of the thesis, as well as expressing my apology that I could not mention personally one by one.

الاقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Utilization landfill gas from ZF landfill for electricity generation

أقر بأن ما اشتملت عليه هذه الرسالة انما هي نتاج جهدي الخاص، باستثناء ما تمت الإشارة اليه حيثما ورد، وأن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل أي درجة علمية أو بحث علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

DECLARATION

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student Name: **اسم الطالبة: أحلام انويف صنوبر**

Signature: **التوقيع:**

Date: **التاريخ:**

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Abstract

In this research, we have studied the feasibility of using anaerobic digestion technology of Municipality Solid Waste to produce biogas and generate electricity at Zahrat Al-Finjan Landfill in northern Palestine.

Solid waste is one of the environmental problems in urban areas of Palestine. Municipal Solid Waste Reduction, Reuse and Recycling (MSW) are technologies for dealing with household solid waste but are not being used effectively in our country. Since MSW is very rich in energy, its use as a renewable energy source is one of the most important economic projects that the Palestinian Authority seeks to implement if its economic viability is proven and the financial resources will be available.

The investigation results of energy efficiency and environmental impact of biogas utilization in ZF landfill are satisfactory enough both for electric energy production and for its contribution to greenhouse gas mitigation.

This thesis has two main objectives. First, to determine whether active extraction of Zahrat Al- Finjan landfill gas would produce adequate electric power for utilization and grid connection. The second objective is to estimate the reduction of greenhouse gas emissions. However, to

optimize the designing of a plant fed by biogas, it was very essential to quantify biogas production over several years.

This research found that the average biogas production per year at Zahrat Al- Finjan landfill is more than 13 million cubic meters, enough to run 3.9 MW plants, and annual energy production of more than 34 GWh/year, and around 18 thousand tons of CO_2 reduction per year.

CHAPTER ONE

INTRODUCTION

1.1 SOLID WASTE PROBLEM

The methods of managing the solid waste are among the issues of major concern in protecting and preserving the environment.

All countries in the world are facing the problem of municipal solid waste management. It is considered as one of the most serious environmental and social problems challenging municipal authorities in developing countries[1].

Municipal and industrial waste have always been a prominent problem, and the growing number of humans makes this problem more serious year after year. Having a practical solution became an urgent necessity for all civilized societies in this world.

Municipal waste has increased sharply as a result of high population growth rate and increase in per income, thus posing a danger to environmental quality and human health[2].

Improper management of solid waste may impose different types of risks such as fire hazards, diseases, atmospheric and water pollution, aesthetic nuisance and economic losses[3].

In modern and developed countries, different strategies were adopted for dealing with all types of wastes. These include recycling and waste to energy generation. Each one of these countries created different public and private bodies for dealing with this problem. However, developing countries just began to establish such agencies and institutions to take care of this important challenge [4].

1.2 SOLID WASTE PROBLEM IN PALESTINE

On the Palestinian side, the years of conflict have made a large challenge to the Palestinian efforts to effectively control the environmental situation. Management of solid waste in Palestine has never been achieved on an environmentally sound basis.

Palestine suffers from great negligence during the Israeli occupation when the Israeli Civil Administration was responsible for providing the Palestinian Territories with basic infrastructure services. During that time, the policy of the Israeli occupation authorities aimed at serving their interests without giving any attention to both the environment and the quality of services provided to the Palestinians[5].

The peace negotiations between the Palestinians and Israelis led to a mutual recognition of the Palestinians need to protect the environment and benefit natural resources on a sustainable basis. This has led to the transfer of some powers and responsibilities to the Palestinian Authority in this field.

Both sides agreed as well to cooperate and share the responsibility of preventing damage to the environment[5].

In 1994, the Palestinian National Authority (PNA) established the Environmental Planning Directorate (EPD) which developed the Palestinian Environmental Strategy (PES).

In the (PES), wastewater and solid waste management were the most important environmental priority elements that need to be addressed in order to resolve the pressing environmental problems. Also in Palestine, the new style of life and the rapid growth of population have taken a big participation in the production of Municipal solid waste. Waste collection methods are very poor, the solid waste is used to be thrown outside garbage containers and to the sides of streets. This bad waste management in our country cause many health effect like diseases, environmental impacts and many disadvantages. At the same time, some people use to burn the garbage containers with the waste inside them that causes harmful emissions, generate waste leachate that pollute groundwater, insects, and fauna.(United Nation for Development programs, [UNDP, 2006] [6].

In addition, Landfilling and open burning method of solid waste were the main techniques of waste disposal in Palestine for many years. Despite the negative effects on the environment, the same techniques are still in use.

1.3 PROBLEM STATEMENT

Cities and villages generate large quantities of solid waste, which creates a huge environmental responsibility. Waste must be temporarily stored and then transported and ultimately disposed of - regardless of whether it will be reused, recycled, landfilled or burned. This requires vehicles, tools, labor, storage space, time, and financing to achieve it. Municipal solid waste is buried in landfills or burned out. Landfills require a large area of land, generate leachate and may cause environmental hazard for the area. Open burning can expose humans to dangerous air emissions and increase air pollutant.

Technical solutions for solid waste management in small and medium-sized cities must be mobile, scalable, durable and easy to operate.

1.4 RESEARCH GOAL AND OBJECTIVES

The research goal of this research is to investigate the feasibility of producing electricity using landfill gas at Zahrat Al-Finjan Landfill. Anaerobic digestion is the proper technology for waste to energy project

The study has the following objectives:

1. To provide a comprehensive literature review on Waste to Energy technologies used in different location in the world.
2. To investigate the technologies that can be applied in Palestine in general and in ZF landfill in specific.
3. To confirm the technical feasibility of using the anaerobic digestion to produce landfill gas capable of running engines to produce electricity.

4. To perform a full analysis to evaluate the quantities of produced landfill gas for at least two decades and the amount of electricity that can be generated using that gas.

1.5 Research Questions and Hypothesis

Based on the problem statement, the following research questions will be addressed in this research.

Main problems:

Is it feasible to produce electricity from municipal waste landfills in Palestine and what is the most suitable technology for that?

Sub-problems:

What are the other impacts of converting waste to energy on the environment?

Will this kind of projects help in reducing the emissions of greenhouse gases such as CO2 and CH4?

Can we consider Municipal wastes as a renewable source of energy in Palestine?

Hypothesis:

It is hypothesized that Municipal solid waste (MSW) can be used to produce energy at waste-to-energy plants and at landfills in the Palestine.

Converting landfill gases to energy can also reduce sharply the bad effects of these gases on the environment and human health.

1.6 RESEARCH METHODOLOGY

The analytical method is adopted in this study. The methods include investigating all possible technologies to convert waste into energy and the feasibility of using them in Palestine. Simulation software will be used to estimate the amount of landfill gases that will be produced in our case of study at Zahrat Al-Finjan Landfill. Data will be collected from different sources and references to estimate the amounts and composition of waste dumped at ZF landfill. Collected data in addition to simulation results will be used to estimate the amounts of electricity that can be produced and its economic feasibility.

1.7 RESEARCH SIGNIFICANCE AND RELEVANCE

This research is very important for all parties interested in waste management, circular economy, renewable energy and environmental protection. The importance of this research stems from the great benefits that can be accessed if the economic, environmental and health feasibility of the project of converting solid waste into energy in Palestine is proven. The success of such projects opens the door to developing a circular economy in Palestine not only as a source of income and a sustainable source of energy, but also as a solution to a complex environmental problem in solid waste management. The result of this study will be valuable to the government and to local investors as well.

CHAPTER TWO

SOLID WASTE MANAGEMENT IN PALESTINE

2.1 GENERATION OF MSW IN WEST BANK

Generation of SW in the West Bank varies from one governorate to another; Table (2.1) presents the amount of SW generated in different governorates. The last column of the table is the calculated per capita generation.

The average per capita generation of SW per day in the governorates of the West Bank is about 0.85 kg. Hebron governorates comprise the highest per capita generation of SW which is around 1.0 kg/c/d, while Salfit comprises the least per capita generation of SW which is almost 0.82 kg/c/d. This research focuses on Nablus, where the per capita generation is 0.92 kg/c/d.

Table 2.1 Solid Municipal Waste generated in different governorates

Governorate	Population (2011)	Total SW generation (ton/day)	Total MSW generation (kg/capita/day)
Jenin	281,156	255.5	0.91
Tubas	56,642	54.2	0.96
Tulkarm	168,973	162.9	0.96
Nablus	348,023	319.1	0.92
Qalqilya	100,012	90.2	0.90
Salfit city	64,614	53.0	0.82
Bireh & Ramallah	310,218	276.1	0.89
Jordan valley & Jericho	46,718	44.8	0.96
East Jerusalem	144,740	127.2	0.88
Bethlehem	194,095	186.3	0.96
Hebron	620,418	615.3	0.99
West Bank	**2,580,167**	**2,184.6**	**0.85**

Source: [7]

Any observer can notice that solid waste is used to be thrown outside everywhere the dumps sites, at the sides of streets in all places, and around the garbage containers. The ineffective way of waste collection and disposal cause bad effects to the public health and environment. Burning of solid waste causes harmful smoke emissions, waste leachate that pollute groundwater, insects, birds, and rodents, which are diseases vectors [8].

The recommendation of “The Solid Waste and Environmental Management Project” (SWEMP) was to construct three different landfills in Palestine. One serves the southern region of Palestine, one for the middle region, and the other for the northern region, which is called Zahrat Al-Finjan (ZF) landfill. This was reported in different studies, reports and projects including: Environmental Resources Management, (ERM), (1998).

West Bank and Gaza Solid Waste and Environmental Management Project (SWEMP), and the Solid Waste Management Study [8].

2.2 WASTE COLLECTION IN WEST BANK

Municipalities and village councils do solid waste collection in West Bank. The employees of the local communities collect the solid waste from the buildings. Some local communities are very far from the public services; the people dump their solid waste outside their houses with no matter to how it will be removed. There are above 166 local communities that do not have any solid waste collection services, which represent around 27.8% from the total local communities where as 78.5% of the local communities have collection service. There are 129 local communities in the West Bank collect their solid waste daily. In 266 of the local communities, the solid waste is collected more than once a week [8].

In the year 2010, a committee from several Palestinian ministries submitted the National Strategy for Solid Waste Management in Palestine (NSSWM) for the period 2010-2018.

The NSSWM put several policies for preventing the random land filling and adopting the use of three regional landfills to serve all Palestinian communities in the west bank (Figure 2.1) and one of the Gaza strip [9].

These are:

1- ZF (in the north)

2- Rammoun (in the middle)

3- Al Minya (in the south) of west bank.

ZF landfill currently receives around 400 ton of waste each day coming from Jenin, Tubas, Nablus and some villages of Tulkarem governorate [8].

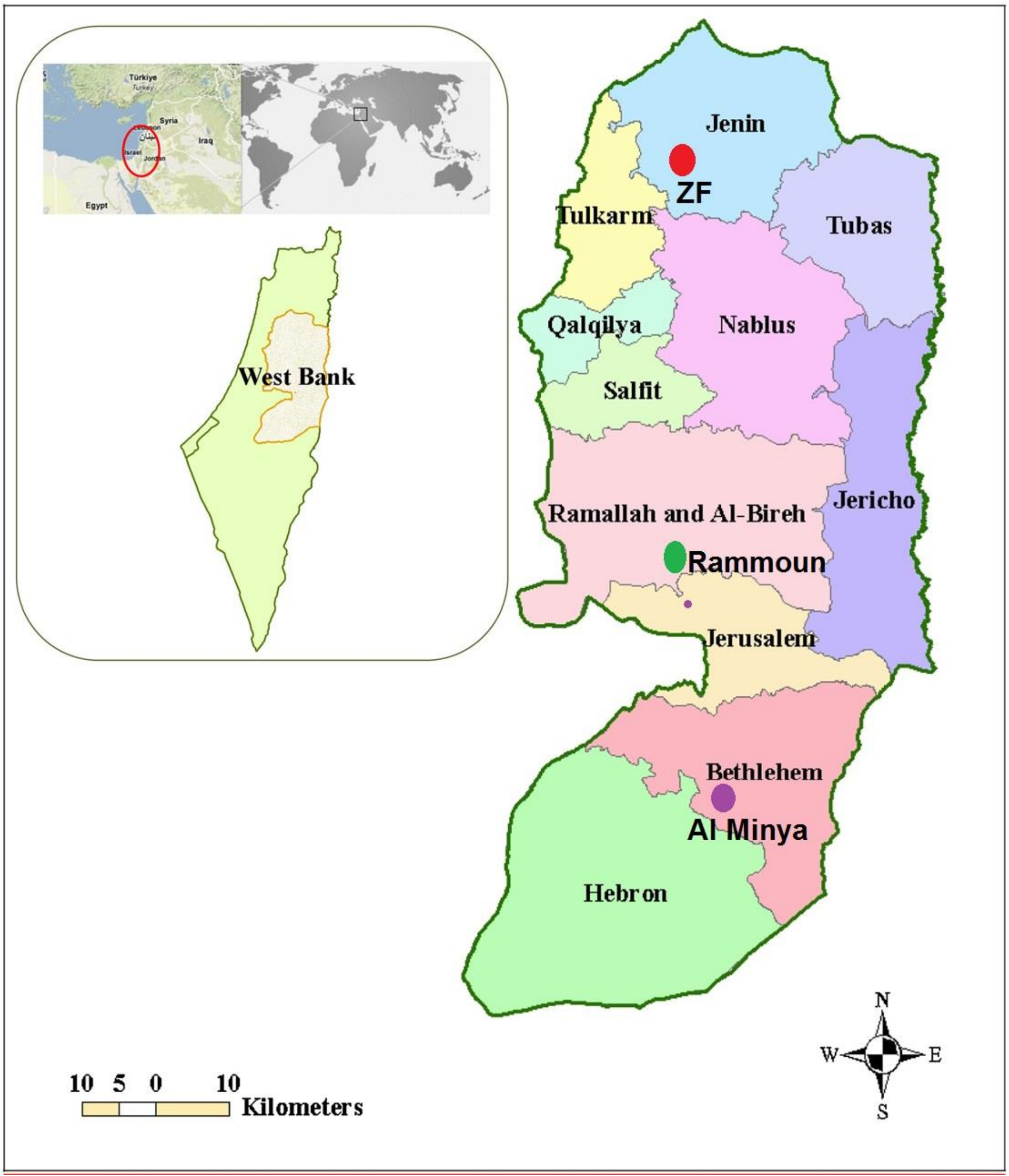

Figure 2.1: Location map of Zahrat Al Finjan landfill site, Al-Minya landfill site, Rammoun landfill site, districts of West Bank, Palestine

2.3 Case Study: Zahrat Al-Finjan Landfill:

Zahrat A-Finjan landfill (ZF) is located in Jenin governorate in Wadi Ali between Arrabeh and A'jja. It is 18 km south of Jenin City, 26 km west of Tubas, 23 km north of Nablus through Jenin-Nablus road, 24 km east of Tulkarem and 50 km northeast of Qalqilia.

Figure 2.2 illustrates the location of ZF landfill within Jenin Governorate between Arrabeh and A’jja villages. ZF landfill is located 1.5 km from A'jja village and 2.5 km form Arrabeh Village.

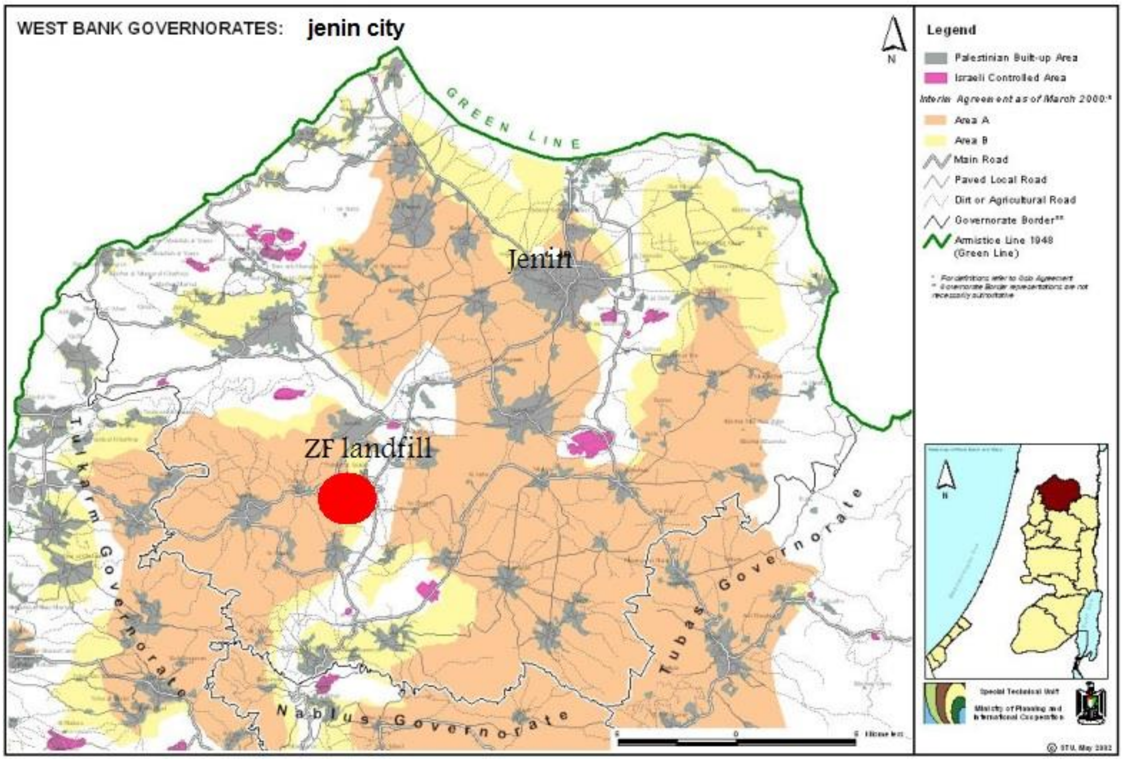

Fig 2.2: location of ZF landfill [8].

2.4 SERVICE AREA OF ZF

ZF receives waste from different cities and villages in north area of the West Bank. This includes Jenin, Tubas, Nablus, and some villages in Tulkarem Governorate. The expected lifetime of the landfill is 15 years. For the nearest future, there is a plan to receive waste from Qalqilia, Salfeet, Tulkarem, and some villages in Tulkarem and Nablus area. That will reduce the lifetime of the landfill to 10 years. The whole capacity of the landfill is 2.25 million tons of waste [8].

The composition of Municipal Solid Waste is an important issue. The components of MSW determines the density of waste, the percentage of recycling and reusing, and the best technique to extract energy from MSW.

Waste composition differs according to national income, socioeconomic conditions, and social development and culture. Accordingly, it is important to obtain the data for each source separately[10].

The landfill is composed of many zones according to the locality of provenience, the distance between the landfill and the zone as shown in the table below:

Table (2.2) Composition of MSW in ZF Landfill

Material	**Zone 1+2**	**Zone 3+4**	**Zone 5**	**Average**
	% Weight	**% Weight**	**% Weight**	**% Weight**
Plastic	12.4	11.2	12.5	12.03
Metal	3.3	2	3.3	2.87
Glass	2.8	4.2	4.2	3.73
Paper & Card	16	10.3	13.8	13.37
Organic	51	62.2	49.1	54.10
Textile	8.6	7.6	11.9	9.37
Others	5.9	2.5	5.2	4.53
	100	100	100	100

Source: [8]

The reuse and recycle strategies will help prolong the lifetime of ZF landfill like. Also, converting solid waste to energy will make the landfill usable for decades.

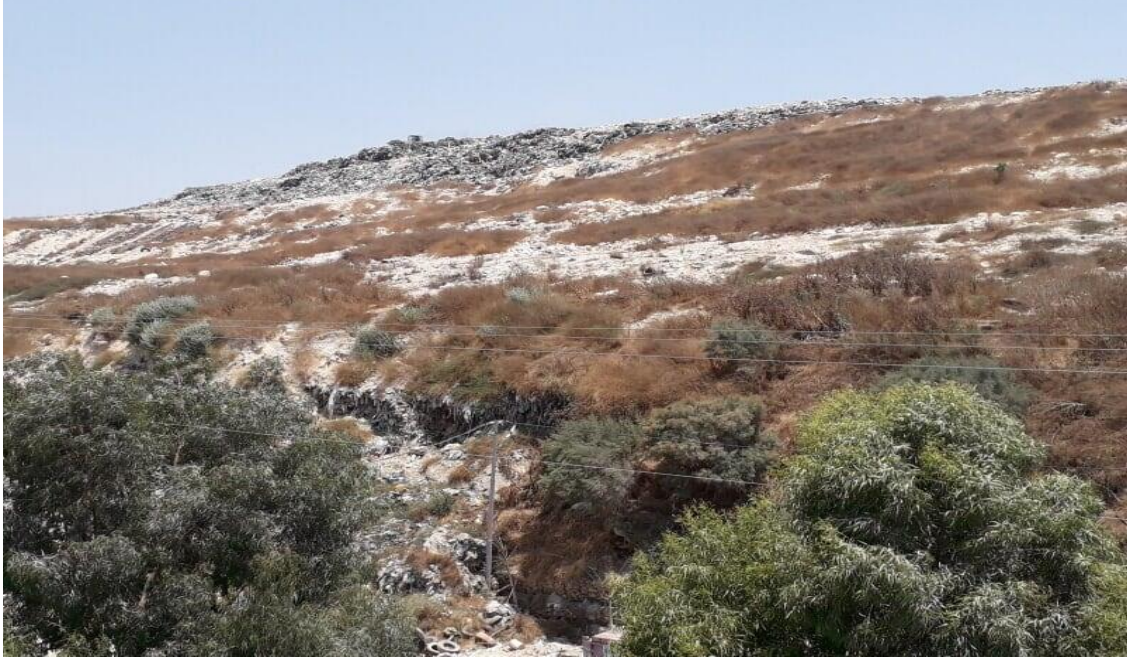

Figure 2.3: ZF landfill 2019 (My personal visit to ZF 24-6-2019)

2.5 WASTE COLLECTION AND TRANSFER TO ZF LANDFILL

Zahrat Alfinjan landfill (ZF) is the first stationary landfill, which was constructed in Jenin area to serve northern part of the West Bank. The waste is dumped there as mixed municipal waste and is covered with soil daily [8].

Waste composition information, and the quantities generated are basic needs for managing the SWRR system. The waste consisting of limited list of waste components, such as paper, glass, metal, plastic and organic materials, into which municipal waste may conveniently be separated [11].

2.6 WASTE COLLECTION IN NABLUS

The Joint Services Council for Solid Waste Management was established in Nablus with the aim of improving environmental quality, the quality of services provided to citizens in the solid waste management sector from all regions, and its final safe disposal. The Council was established on 15/11/2007 by a decision of the Minister of Local Government to include all the municipalities and village councils in Nablus governorate with 58 local councils. These councils signed a memorandum of understanding to form this council. The board of directors for this council is composed of the heads of a number of local councils that are appointed by the members of the public body headed by Mayor of Nablus municipality. The Council is subject to the supervision of the Joint Services Council of the Ministry of Local Government

The Joint Services Council for Solid Waste Management in Nablus Governorate is the responsible body for securing these services for the province despite the great difficulties facing this sector. These difficulties include waste collection process from residential communities, transferring them to the assembly points and then shipment to Zahra al-Finjan (official landfill in the North). The total number of member councils in Nablus Governorate is 61 with total population of 373,274 persons (as of 2007) and produce approximately 340 tons/day of municipal waste.

Due to the lack of necessary resources and the lack of adequate machinery, waste containers and other equipment, the Joint Services Board currently serves 21 of the 61 local councils only.

Table 2.3 Village and municipal councils served directly by the Joint Services Council / Nablus

Serial	Council	Population	Waste volume (ton / day)
1-	Nablus Southern part	50000	40
2-	Awarta	6531	4.4
3-	Salem	5879	3.7
4-	Tell	5045	3.1
5-	Beit Eiba	3658	3.4
6-	Oreef	3393	2.2
7-	Yutma	3314	2.1
8-	Azmoot	3078	1.8
9-	Sarrah	2976	2.1
10-	Deir SHaraf	2857	2
11-	Kofor Kalleil	2847	1.6
12-	Karyoot	2696	1.5
13-	Deir Alhatab	2570	1.5
14-	Zawata	2178	1.8
15-	Quseen	1985	1
16-	Jureesh	1626	0.9
17-	Odala	1318	0.8
18-	Beit Wazan	1228	0.9
19-	Iraq Borein	892	0.5
20-	The Samaritan community	598	1
21-	Galood	539	0.5
Summation		**105,208**	**76.8**

Source: (Nablus Municipality health Director- personal interview 2018)

In addition to these councils, the Joint Services Council provides services to other neighborhoods of Nablus where about 50,000 people are served and the amount of collected waste is estimated at 40 tons/day.

The Joint Services Board for Solid Waste Management in Nablus Governorate collects and transfers solid waste to a terminal in Nablus, and then transferred to by a private contractor to Zahra al-Finjan landfill in Jenin governorate.

In addition to the Joint Services Council, there are other bodies who provide the service for collecting and transferring the solid waste from the governorate. The major bodies are:

Municipality of Nablus

Service Councils of Refugee Camps in Nablus Area

The Municipality of Nablus is responsible for more than 70% of waste collection and shipment from the city and surrounding camps to the Zahrat al-Finjan landfill by assembling them at the point of deportation east of the city, sorting out some plastic, cardboard, nylon and scrap in the site and then a special contractor transfer them to Zahra al-Finjan.

Table 2.4 Nablus city and surrounding camps

Serial	Council	Population	Waste volume (ton / day)
1-	Nablus	146,493	162.2
2-	Balata Camp	17,708	24.4
3-	Askar Camp	13,481	18.6
4-	Ein Beit Elma Camp	4,621	6.4
Summation		**182303**	**211.6**

Source: Nablus Municipality health Director- personal interview 2018

1- Joint Services Council for the Governorate of Jericho and the Jordan Valley

This council covers the service of 6 local councils and the transfer of waste collected to the Jericho landfill. Table 1.5 contains a list of served councils, their population and produced waste.

Table 2.5 Councils served by the Joint Services Council for the Governorate of Jericho and the Jordan Valley

Serial	Council	Population	Waste volume (ton / day)
1-	Alnassaryyah	1,841	1.2
2-	Beit Hasssan	1,302	0.8
3-	Alaqrabanyyah	1,163	0.8
4-	Froush Beit Dagan	893	0.3
5-	Ein Shibly	389	0.3
6-	Alnawagy	99	0.1
Summation		**5687**	**3.8**

Source: Nablus Municipality health Director - personal interview 2018

2- Joint Services Council for Tubas:

This Council shall cover the service of one local council and transfer the waste it collects to the Zahrat Al-Finjan dump

Table 2.6 Councils served by the Joint Services Council for Tubas

Serial	Council	Population	Waste volume (ton / day)
1-	Albathan	2,974	2

Nablus Municipality health Director - personal interview 2018

3- Joint Services Council for Jenin:

This council serves 9 local councils and is responsible for collecting solid waste and transferring it to the Zahrat al-Finjan landfill.

Table 2.7 Councils served by the Joint Services Council for Jenin

Serial	Council	Population	Waste volume (ton / day)
1-	Tallozah	2,758	1.5
2-	Yaseed	2,420	1
3-	Beit Mreen	3,276	2
4-	Alnaqoorah	1,794	1
5-	Sabastyah	3,036	2.5
6-	Bezzaryah	2,616	1.5
7-	Ignesenyyah	587	0.5
8-	Half Gubeil	458	0.5
9-	Borqa	4,262	2.5
Summation		**21,207**	**13**

Nablus Municipality health Director - personal interview 2018

4- Local councils that provide the service for their communities using their own cars.

These include 13 local councils who provide the service for their own communities and transfer the waste to random dumps.

Table 2.8 Councils with own collection system

Serial	Council	Population	Waste volume (ton / day)
1-	Beit Fourik	12,008	20
2-	Aseera Alshamalyah	8,776	8.5
3-	Roogeep	4,880	4
4-	Qabalan	8,281	10
5-	Howwarah	6,469	10
6-	Beita	10,545	15
7-	Beit Dagan	4,048	3
8-	Madama	2,037	2
9-	Aseerah Alqeplyyah	2,748	2
10-	Bourein	2,682	2
11-	Aqrabah	9,500	7
12-	Osarein	1,872	1.5
13-	Magdal Bani Fadel	2,767	2
Summation		**76,613**	**87**

Nablus Municipality health Director- personal interview 2018

5- Local councils covering the service within their communities by a private contractor:

Private contractors provide the service for 5 local councils and transfer the collected waste to random dumps. These councils are listed in table 1.9.

Table 2.9 Councils served by contractors for waste collection

Serial	Council	Population	Waste volume (ton / day)
1-	Doomah	2,438	1.7
2-	Qusrah	5,084	3.7
3-	Ein Aboos	2,718	1.9
4-	Zeeta Gemmaeen	2,456	1.7
5-	Gemmaeen	7,230	6.7
Summation		**19,926**	**15.7**

Nablus Municipality health Director -personal interview 2018

The Joint Services Board for Solid Waste Management owns a number of waste collection vehicles as shown in fig (2.4)

Figure 2.4: Car garbage collection 2018, Source: Nablus Municipality health director- personal interview 2018.

The types, number, source, capacity and condition of these vehicles are summarized in table 2.10.

Table 2.10 Collection vehicles owned by Nablus Municipality

Type of vehicle and model	No	grant source	Year of receipt	Capacity	Car status assessment
EFCCO waste compactor 2009	2	Bethlehem Council of Services	2010	12 cube	Medium
Volvo waste compactor	3	EU grant 2011	2012	8 cube	Medium
Graple Grane Dumpsters	1	EU grant 2011	2012	10 cube	Good
Large container crane	1	EU grant 2011	2012	10 cube	Good
Large Container Crane EFCCO 2009	1	From the Salfit Services Council	2010	20 cube	Good

Source: Nablus Municipality health director - personal interview 2018

2.7 COMPOSITION OF NABLUS SOLID WASTE

Solid waste in Nablus Governorate is composed of different materials as shown in the table 2.10 and figure 2.5. Based on the study carried out in 2012 at the Sarafi station for solid waste migration, the collected waste consists of different materials with high variety resulting from the diversity of human activities. However, these materials can be limited to two types; organic components which can be rot in different forms such as food residues, plant and animal residues and inorganic materials such as plastics, Glass and metal.

Table 2.11 Composition of Nablus Solid Waste

Number	Solid waste type	Percentage
1-	Organic materials	53.3%
2-	Paper and Cartoon	20%
3-	Plastic	10%
4-	Metals	3%
5-	Glass	2%
6-	Wood	2%
7-	Rubber	2%
8-	Other	7,7%
Summation		100%

Source: Nablus Municipality health director - personal interview 2018

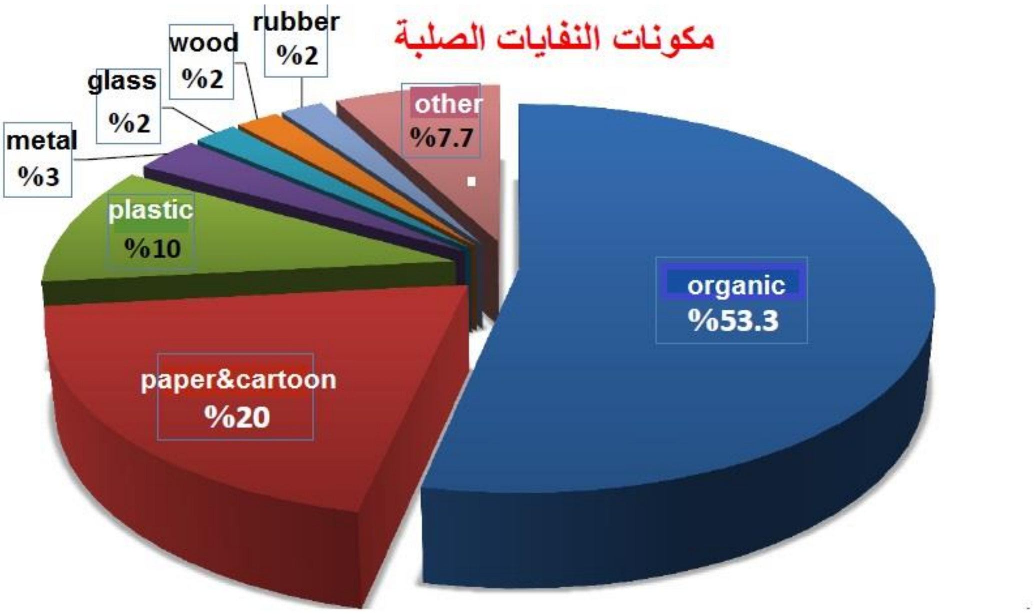

Figure 2.5: Composition of Nablus Solid Waste, Source: Nablus Municipality health director - personal interview 2018.

CHAPTER THREE

WASTE TO ENERGY TECHNOLOGIES

3.1 TECHNOLOGIES FOR CONVERTING SOLID WASTE TO ENERGY

Waste-to-Energy is a modern technology used to recover energy from municipal solid wastes and convert it to other forms such as steam, heat or electricity. In addition to its benefits of producing energy, this technology has another positive impact in reducing the volume of the solid waste by 90% approximately, and the remaining part (10%) will be in the form of ash or digested organic compounds. Figure (3.1) shows the main steps, for converting the waste into energy. Waste-to-Energy is one method of solid waste management and it refers to any type of waste treatment that generate energy in the form of electricity or heat from a waste source rather than dumping it in a landfill. Other advance processes may result a fuel commodity, such as ethanol or hydrogen, in addition to a good fertilizer at the end of each process.

The design of a power plant in a landfill requires accurate data about the quantity and composition of generated solid waste every day. In this research, possible technologies for converting solid waste into energy will be studied for selecting the suitable one for Palestine and Zahrat Al-Finjan landfill.

Figure 3.1 is overview of MSW material flow and its different utilization and treatment options. Collection of separated waste streams makes the utilization of different treatments more viable.

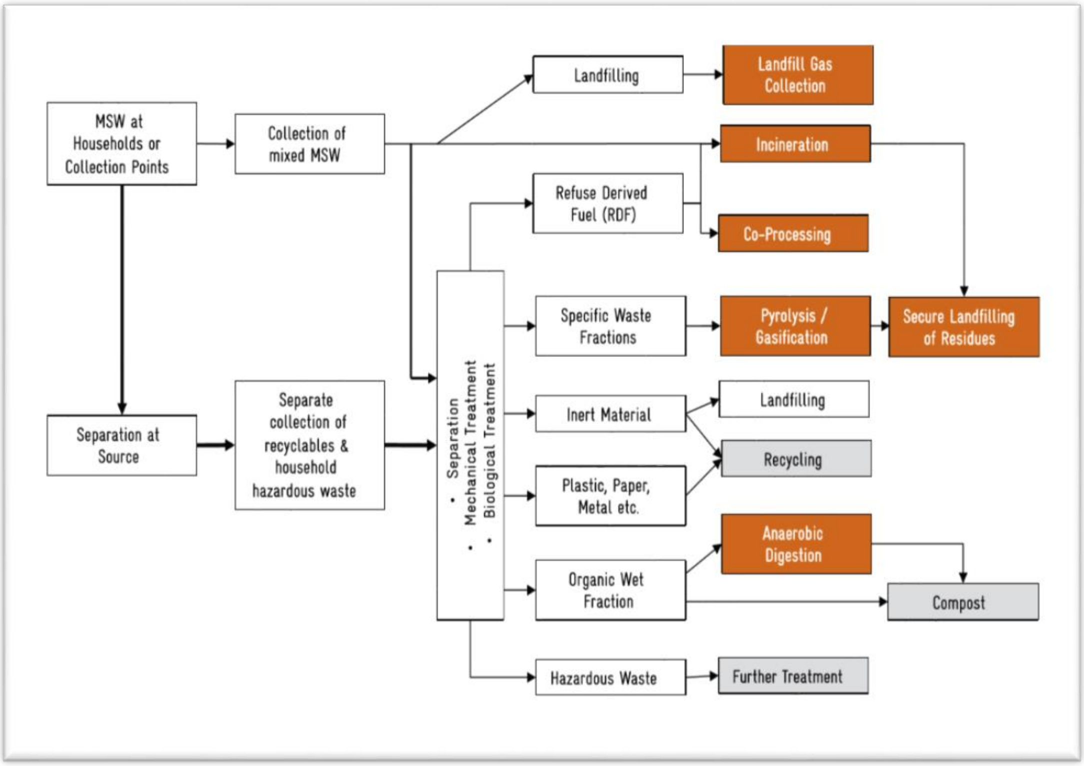

Fig 3.1: Energy from waste

The literature review shows that there are five emerging solid waste to energy technologies. These technologies are:

1- Incineration or Direct combustion

Incineration (direct burning) is a simple and traditional method for converting waste into heat to generate steam and/or electricity.

In the incineration method, waste is burned in boilers to produce high-pressure steam. This steam will be transferred in tubes to rotate turbine-connected generators that produce electricity. There are hundreds of incineration plant all over the world, which use direct combustion to generate electricity, and the steam from the plants is also used for industrial processes to heat water or to heat buildings. Such plants are usually known as co-generation facilities. Incineration plants usually achieve thermal efficiencies of approximately 20%. Higher efficiencies can be achieved through co-generation as shown in figure (3.2) below:

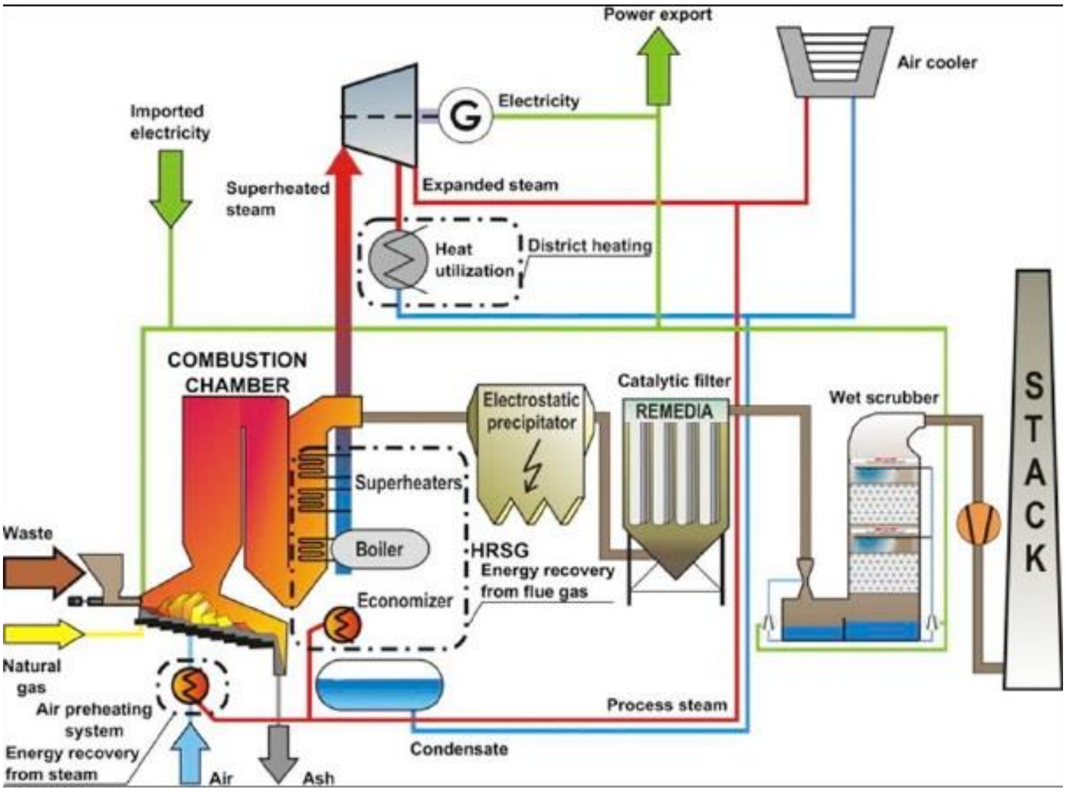

Figure 3.2: Incineration plant to produce electricity and heat from MSW [12]

2- Co-firing

In the Co-firing process, solid waste is mixed with coal and burned jointly in traditional power plant boilers. This technology can be considered as one of the most economical methods to produce energy as electricity from waste because we do not need to build a new power plant and existing power plant equipment can be used without major adjustment.

In most industrial countries, some coal-fired power plants use co-firing not only to lower coal consumption but also to decrease production of Sulfur dioxide, Carbon dioxide, and Nitrogen oxide emissions. Co-firing increases the efficiency for waste conversion to electricity to 33% and up to 37% in some cases. This process is illustrated in figure (3.3).

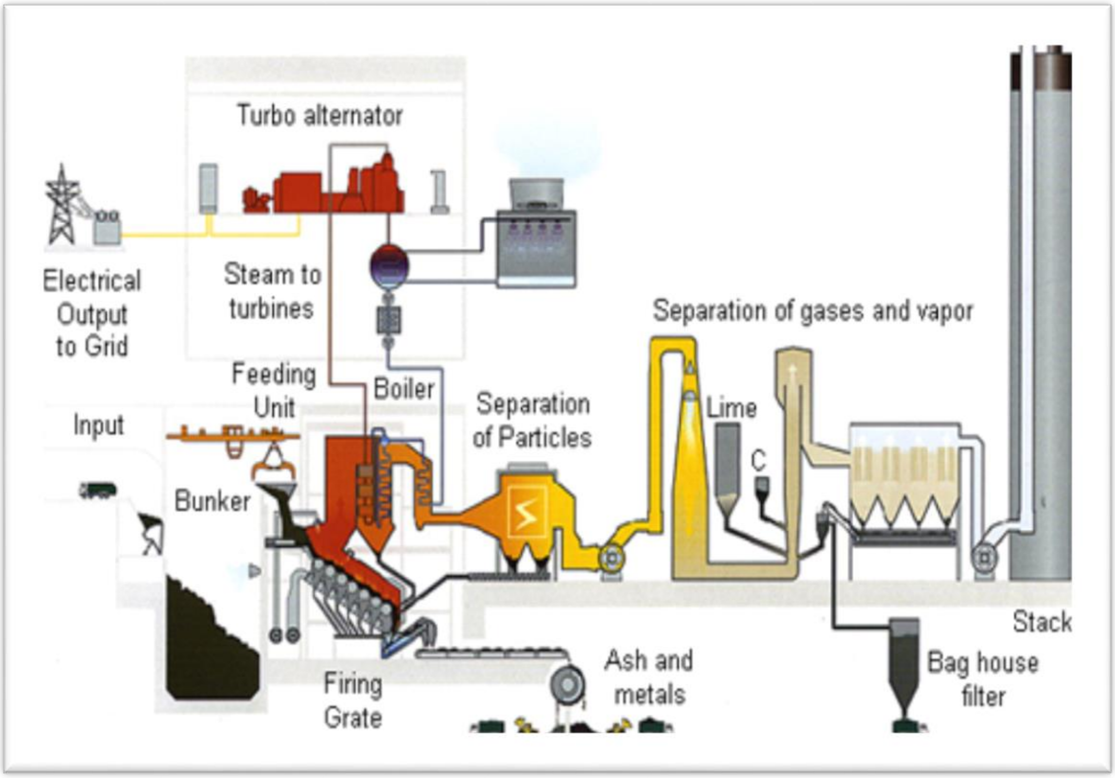

Figure 3.3: Co-Firing Process [13]

3-Gasification

Gasification is a process that uses high temperatures (without combustion) to decompose materials to produce a synthetic gas. The so-called "syngas" obtained by gasification has several applications. It can be utilized as a gas fuel for combustion in conventional burners or in a gas engine to run generators to produce electricity. Synthetic gas can be used to produce synthetic diesel. This liquid form of synthetic gas is cleaner and more efficient than many alternative liquid fuels.

Compared to the Incineration process, gasification greatly reduces air emissions and produces a product with a higher thermal efficiency.

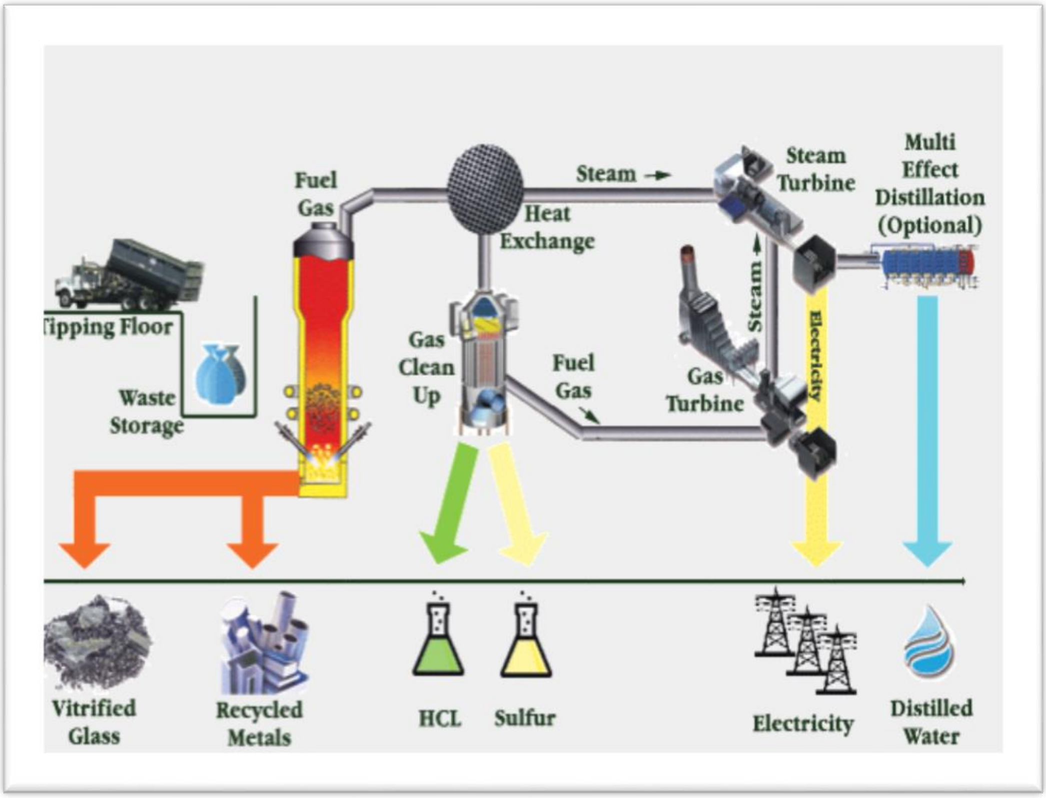

Figure 3.4: Gasification Process [14]

4- Pyrolysis

Pyrolysis means a process of thermal degradation of kinds of the waste in absence of air that produces char, oil/wax and gases. Pyrolysis has been used to produce charcoal from biomass for many years. When used to waste management, MSW can be turned to fuel and char, and the pyrolysis process conditions can be used to produce either a solid char, gas or liquid (oil product). A pyrolysis reactor acts as an effective waste-to-energy convertor [18]

The produced bio-oil of the pyrolysis process is very similar to petroleum types, which can be burned to generate electricity while the char can be used for heating as illustrated in figure (3.5) bellow:

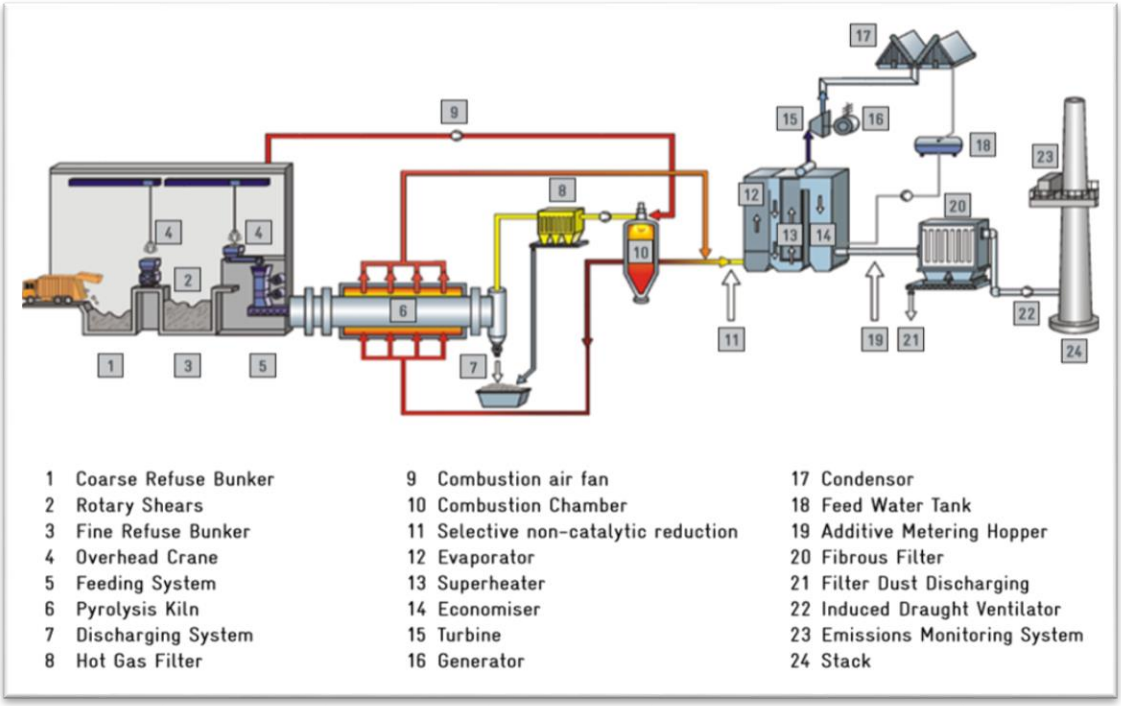

Figure 3.5: Solid waste pyrolysis process of solid waste [15]

5- Anaerobic Digestion

The "Anaerobic Digestion Process" is a technology used to transform solid waste with a relatively high moisture content into biogas. Certain kinds of bacteria are used to break down the organic content of the waste in the absence of oxygen that will generate "biogas". Anaerobic digestion is a natural process, which can be harnessed to treat organic material such as solid or liquid wastes, crops residues, and wastes from agricultural processes and municipal waste streams. When we burry municipal solid waste materials in landfills then bacteria will digest them resulting in biogas (landfill gas) that is very rich in methane. This gas we can use it to run engines, heat buildings, and generate electricity as shown in figure (3.6) below:

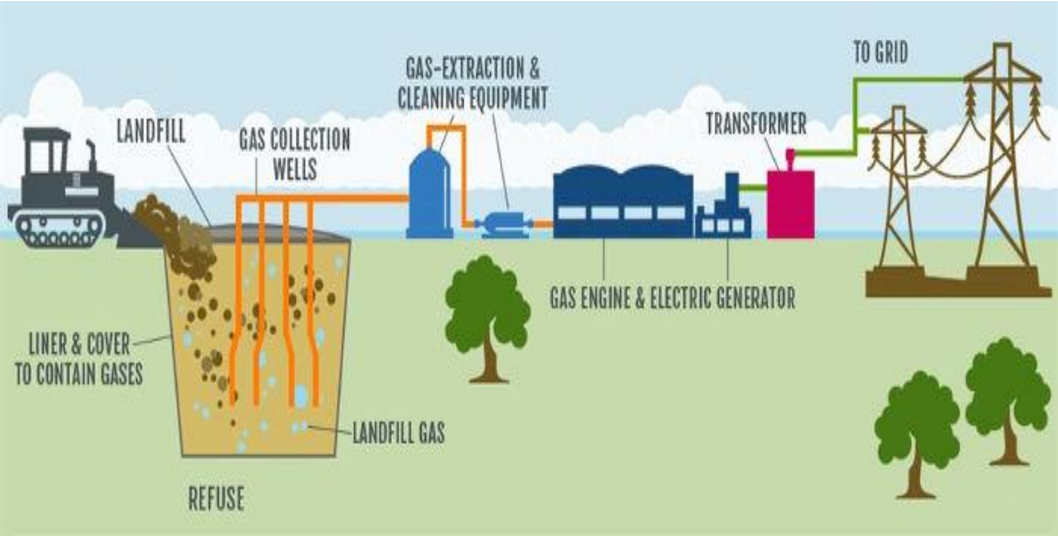

Figure 3.6: Anaerobic digestion process in landfills [16]

3.2 SELECTION OF TECHNOLOGY FOR ZF LANDFILL

From the previous discussion about the possible technologies for converting Waste to Energy, we can conclude that anaerobic technology is the best because this process has a high efficiency and results in fewer particulate matter emission and greenhouse gases. In addition, this technology is considered cheaper and requires less time for installation, taking into account that we have different landfills in Palestine.

In practical application, the anaerobic process can be done in phases, which means that solid waste will be collected in a specified location for a specified period of time (several years), then this location will be closed and capped and a new location will be selected for a new phase for a new period. As gas generation of the first phase decreases by time, we will move to the second phase, third phase and so on.

The anaerobic process can produce 368 kW–770 kW per ton of processed MSW [16]. The processed waste is a separated one where recyclable materials such as metals, glass and some chemicals are taken from the municipal waste. For that, the treatment of waste through good capping can be a feasible technique for producing electric power from MSW through anaerobic digestion as long as the process of capping is executed through simple steps and at low cost. With the good capping of organic materials in the landfill, in addition to doubling the amount of energy produced by the landfill gas, it is also possible to make organic matter available for bio digestion or processes for production of gases with high value .[19]

CHAPTER FOUR

LANDFILL GAS POTENTIALS OF ZF LANDFILL

In this research, we have selected Zahrat Al-Finjan landfill (ZF) as a case study. Comparing the five technologies of Waste to Energy, we can conclude that Anaerobic Digestion is the most practical technology for this landfill. Anaerobic digestion and landfill gas system requires relatively small investment and short time for installation. Millions of tons of municipal solid wastes have been buried in the last decade. Incineration requires large investment and many years of installation and cannot deal with buried waste. The co-firing requires the existence of a thermal power plant that uses coal as a fuel, which does not exist in the area or anywhere else in our country. Pyrolysis and Gasification techniques are very complicated and require high capital costs in infrastructure for the generation of an auxiliary substance that will be used later as a fuel for the power plant. Gasification can produce the gas more quickly than landfill but it has a number of disadvantages of implementation, namely it is only suitable for organic wastes; all other materials must be removed of course.

In this chapter, the Anaerobic technique will be discussed in details to understand the procedures used in it and how it can be implemented in ZF landfill.

4.1 PROCESS OF MSW ANAEROBIC TECHNIQUE

The buried solid waste in the Anaerobic Process has a life cycle in the landfills. In this cycle it has five phases of waste decomposition is illustrated in figure 4.1.

In each one of these phases, leachate and landfill gas are produced at different rates and different qualities. The production rate has a peak value after capping the landfill for one or two years, then these quantities will decrease by time. The following section will describe these five phases:

Phase I: (lag phase) which is the period of acclimation. At this phase, the aerobic bacteria (bacteria that live only in the presence of oxygen) begins to consume the amount of oxygen, which is trapped in newly deposited solid waste and moisture begins to accumulate.

Nitrogen content is expected to be high in this phase, but it will decline by time as the landfill moves through the five phases.

This phase may last for days or months depending on the amount of oxygen, that is present at the time of waste disposal in the landfill.

Phase II: (transition phase): As oxygen decreases to a very low level in the landfill, anaerobic bacteria will replace the aerobic bacterial. This will result in an increase in moisture content of the waste.

In this phase, anaerobic bacteria will increase its activity due to the increase in the chemical oxygen demand (COD) of the leachate, and due to detectable levels of total volatile acids (TVA).

Phase III: (acid phase) in this phase, acidogenic bacteria convert the waste to total volatile acids which results in a decrease in leachate pH level. This stage is the primary hydrolysis where the biodegradable organic material easily dispose in the leachate liquid. The pH becomes more acidic (low pH) due to the formation of organic acids and rapid deterioration.

Volatile Organic Compounds (VOCs or solvents) and Heavy Metals are mobilized due to acidity high level (low pH). The highest levels of COD and BOD (Biochemical Oxygen Demand) in leachate occurs in this phase.

In addition, small amounts of H_2 will be produced in phase III.

Phase IV: Methanogen becomes more predominant; it includes the period in which previously produced acidic compounds are converted to methane (CH4) and carbon dioxide (CO2) by methanogen bacteria**.**

Phase IV causes to return to more neutral environment and from acidic conditions to neutral pH conditions and a corresponding reduction in the metals and VOC concentrations in leachate. The landfill gas production and COD/BOD cycle follow similar first order bio-decay constants.

Landfill gas production reaches its peak in this phase.

Phase V: (final phase) in the last stage most of the biodegradable matter and nutrients will be consumed and their content will decrease to very low levels. This will lead to a decrease in landfill gas production, constant concentrations of leachate constituents, and a relatively slow deterioration of organic matter at this stage.

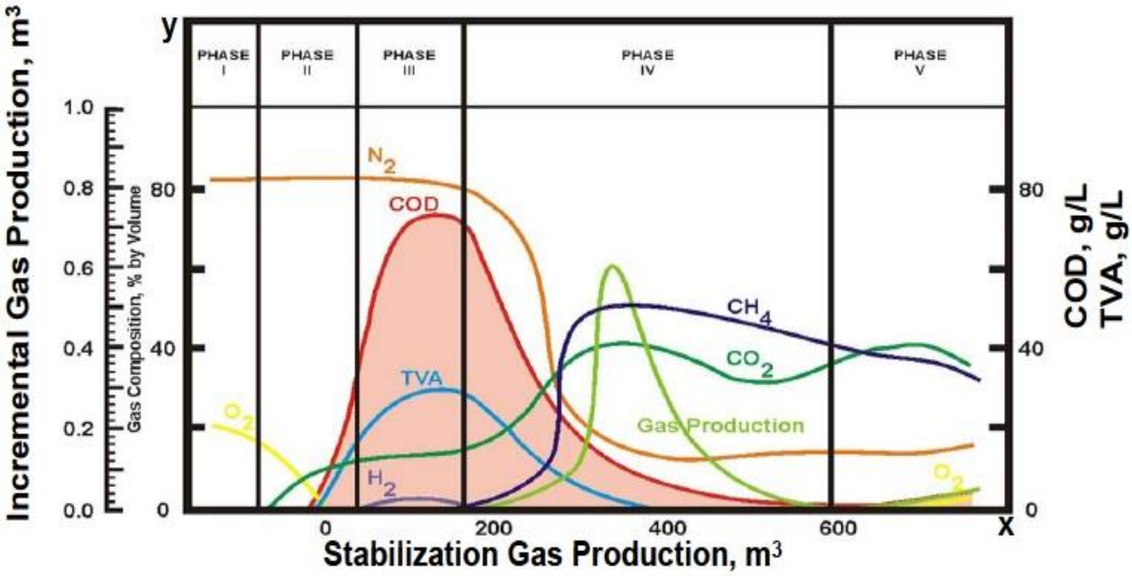

Figure 4.1: Five phases of waste decomposition, Source: [20]

As landfills often receives waste gradually for many years, so we expect to have several phases of decomposition in the same landfill at the same time. In other words, waste buried several years ago in a specific area is expected to be in a different phase of decomposition than recently buried waste in the same or in another area of the landfill.

4.2. FACTORS AFFECTING GAS GENERATION IN LANDFILLS

The rate of landfill gas generated at any landfill depends on the composition of the waste and different environmental factors such as temperature, moisture, pH level and atmospheric conditions. These factors are summarized in Figure 4.2

1. **Waste Composition**. The main nutrients (macronutrients) essentially needed for bacterial growth in a landfill are oxygen, nitrogen, carbon, hydrogen, and phosphorus. Other elements (micronutrients) such as calcium, sulfur, sodium, potassium, and magnesium are also required for bacterial growth but at smaller quantities. The existence of such macronutrients in the waste of the specified landfill affects both the composition of the produced gases and the volume of leachate generated from microbial processes. Landfills, which are used to dump municipal wastes generally, have a high percentage of organic content and supply for most microbial processes to proceed. As shown in table 1.10, organic content of Nablus Municipal Waste exceeds 53%. This percentage will increase sharply after separation of metals, glass, plastic and other recyclable materials from the waste.

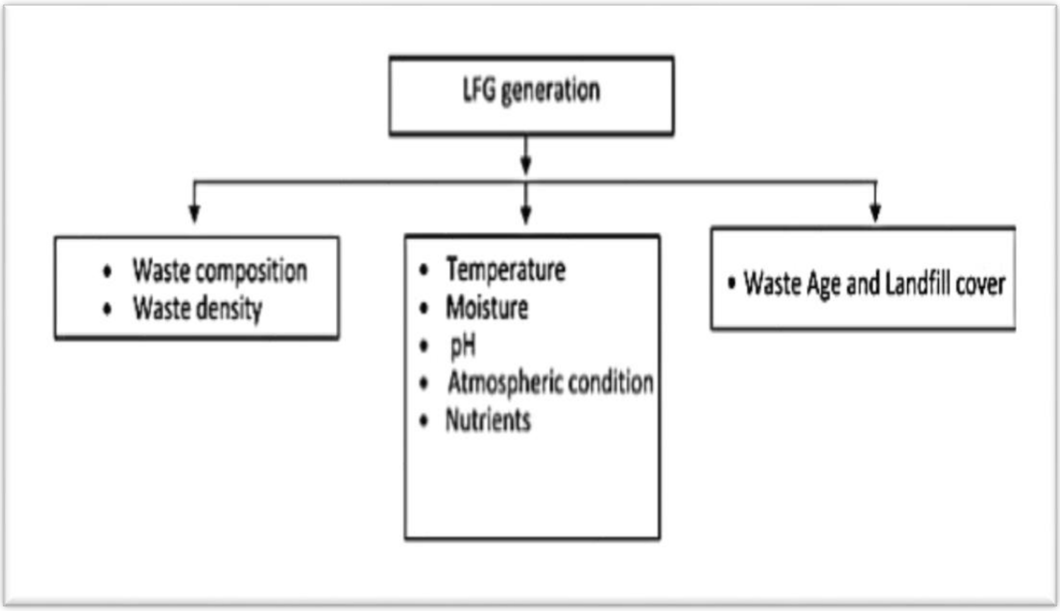

Figure 4.2: Factors Affecting LFG generation. [21]

2- Environmental factors

A- Temperature. Aerobic decomposition of waste (with oxygen) occurs mostly at temperature ranges between 54 and 71ºC, while the most suitable temperature range for anaerobic bacteria (for digestion without oxygen) is 30 to 41ºC. When we have temperatures below 10ºC then a dramatic drop in activity of anaerobic bacteria is expected.

B- Moisture. Moisture is another important factor for biological decomposition of waste. In most cases, the moisture content of Municipal Solid Waste in Palestine ranges between 15% to 40% with an average of 25%. However, we can find a great variation in the moisture content in different locations of the landfill. Decomposition of waste decreases sharply at very low moisture content, which will limit gas production. The optimum moisture content for maximum gas production is in the 50 to 60 percent range.

C- pH (acidity or alkalinity). The pH level of leachate depends heavily on materials placed in a landfill can vary within the landfill widely. Usually the leachate has a pH level that ranges between 5 and 9. However, the pH during CH_4 formation occurs at pH levels in the range of 6.5 to 8.0. If the leachate within the landfill exhibits a low pH, then metals will mobilize and may leach out of the landfill, or they may become toxic to the bacteria generating the gas.

D- Weather Conditions. Weather conditions such as temperature, pressure, and moisture will affect the contents within a landfill. Good capping of the landfill can provide an isolation for the waste from weather conditions by limiting oxygen intrusion, reducing water infiltration of precipitation, and buffering the effects of temperature changes.

a. **Ambient Temperature**. Cold ambient temperature has negative impacts on biological activity in the outmost layers of the landfill, and may result in the reduction in the volume of gas generated. In the lower layers of the waste, the heat generated by biological activity may overcome the effects of cold weathers. In general, the temperature inside the landfill is affected by different factors such as microbial activity, waste depth, compacted density, chemical reactions and water content.

b. **Atmospheric Pressure**. The impact of atmospheric pressure on the rate of landfill gas released to the atmosphere is considered as a minor one. However, the atmospheric pressure may influence the operation of gas extraction systems. An increase in barometric pressure will cause LFG flow to temporarily decrease, and a decrease in barometric pressure may cause a temporary increase in (LFG) flow. This is because the changes in pressure within the landfill are at a slower rate than the changes in atmospheric pressure. This will develop a temporary pressure gradient between the inside and outside of the landfill until these pressures equalize.

c. **Precipitation**. Rainwater has a great impact on gas production in the landfill. Precipitation will supply water to the biological process and will carry out dissolve oxygen in the waste. If rain rate is very high, then there is a great danger of flooding in sections of the landfill and this may cause sharp reduction in as generation. Good capping of the landfill can prevent some of these negative impacts on the system.

E- Density of the Waste. The density and compaction of waste in the landfills are highly variable in most cases. An estimation of waste density of that landfill is required for estimating gas generation rates in a landfill.

F- Age of Waste. Tests of existing landfills in the world have shown that gas production at significant rate may last for 10 to 20 years after establishing the anaerobic conditions. After that period, we expect a sharp reduction in biological decomposition in Landfills as most of the of organic component of the waste will have already been consumed [22].

4.3. LFG TRANSPORT MECHANISMS

Diffusion and advection are the principal Transport methods of landfill gas. Transport conditions both surrounding the landfill and within the landfill must be considered[22].

1. Diffusion. In conditions with concentration difference between two different locations then molecular diffusion will occurs in the system. The gas diffusive flow will be in the direction where its concentration decreases. The concentration of the volatile component in LFG will be higher than that of the surrounding atmosphere, so the components tend to migrate to the atmosphere

The concentration gradient between the surface and the interior of the landfill is highly affected by wind speed. High wind speeds tend to keep the surface concentration at or near zero. This will promote the migration of vapors to the surface[22].

2. Advection. Advective flow (horizontal flow of gas) occurs when we have a pressure gradient. The rate of movement of gas is usually faster advection than for diffusion. The gas will flow from high pressure to low pressure areas. In landfills, advective forces result from the production of vapors from biodegradation, chemical reactions, compression, or the active LFG extraction system. Variations in water-table levels can create small pressure gradients that either push out gases or pull gases in. The gas flow of LFG gases is also affected by changes in atmospheric pressure on the surface[22]**.**

4.4. LFG MIGRATION AND EMISSIONS IMPACTS:

Different environmental impacts may occur as a result of the migration and emission of LFG. These impacts are summarized in table 4.1 and illustrated in figure 4.3.

Table 4.1 Impacts of LFG migration and emission

Migration	Emissions
• LFG migrates horizontally and vertically from landfills. • LFG follows the path of least resistance • LFG cannot penetrate water **Impacts:** - Low groundwater quality - Entry within tight spaces - GHG - Fire, explosion	• Landfill gases rises through over soil **impacts:** - odors - vegetative stressing - fire ,explosions - health and safty risks -Vegetative stressing

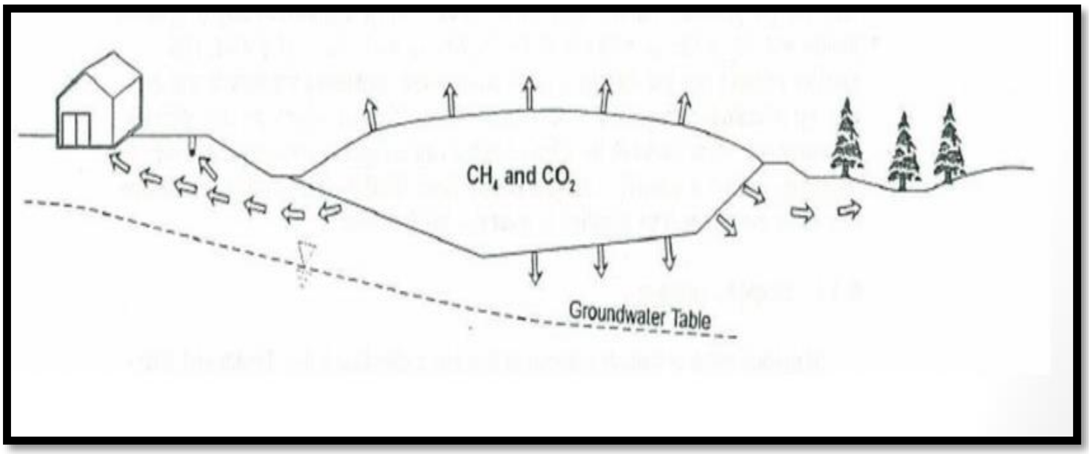

Figure 4.3: LFG Migration and Emissions

4.5 Composition of LFG gas in ZF landfill

Before we perform the calculation of expected amount of landfill gas from Zahrat al Finjan landfill, we have to understand important characteristics related to gas production, which is the composition of generated Gas. The components of LFG are listed in the following table (table 4.2).

Table (4.2): Composition of biogas

Biogas component	Concentration (%)
CH_4	40-58
CO_2	30-45
O_2	0-2
N_2	0-3
H_2S	Trace level
Non-methane Organic compound	0- .25
VOC	0 - .1
CO	0 - .2
Moisture	Up to 14

Source: [23]

CHAPTER FIVE

ELECTRICITY GENERATION FROM MSW

5.1 INTRODUCTION

Production of energy from landfill gas can be a feasible option at Zahrat Al-Finjan (ZF) landfill site subject to corrections on some site conditions. The most important correction action needed is to cap the landfill to minimize gas leakage to lowest possible rate.

With available data on quantities, type and composition of waste in a site, it is possible to calculate a theoretical gas production curve for the life of the site. Landfill gas generation has been modelled using the "GasSim" software, which is suitable for these aims and has been used to predict gas generation along the life of the site. The rate of generation will depend on many factors, but In particular:

1- Waste composition

2- Waste quantity

3- Moisture content

4- The exclusion of air from the site

Leachate levels within the landfill are increased up to a visually estimated 10 meters depth, with what appears to be perching and very poor control. These high levels might prevent landfill gas abstraction rates.

When associated with the absence of a relatively impervious capping layer, this will seriously impact the quantities of gas produced and collected. Over the whole life cycle of the site at all, the quantity of gas produced will be constant, but control of gas production and the possibility for electricity generation will be made more difficult unless correlated measures are implemented by reducing leachate levels and capping the site.

The design of the gas collection system requires the capping of the site and its external flanks with HDPE and soil to prevent air ingress and to increase gas collection efficiency. It will also need the reduction of leachate levels to eliminate saturated conditions, which will after that increase gas recovery effectiveness and improve the stability of the site too. Under these conditions, the capping process may present a high danger, as it would need the use of heavy machinery on potentially unstable slopes.

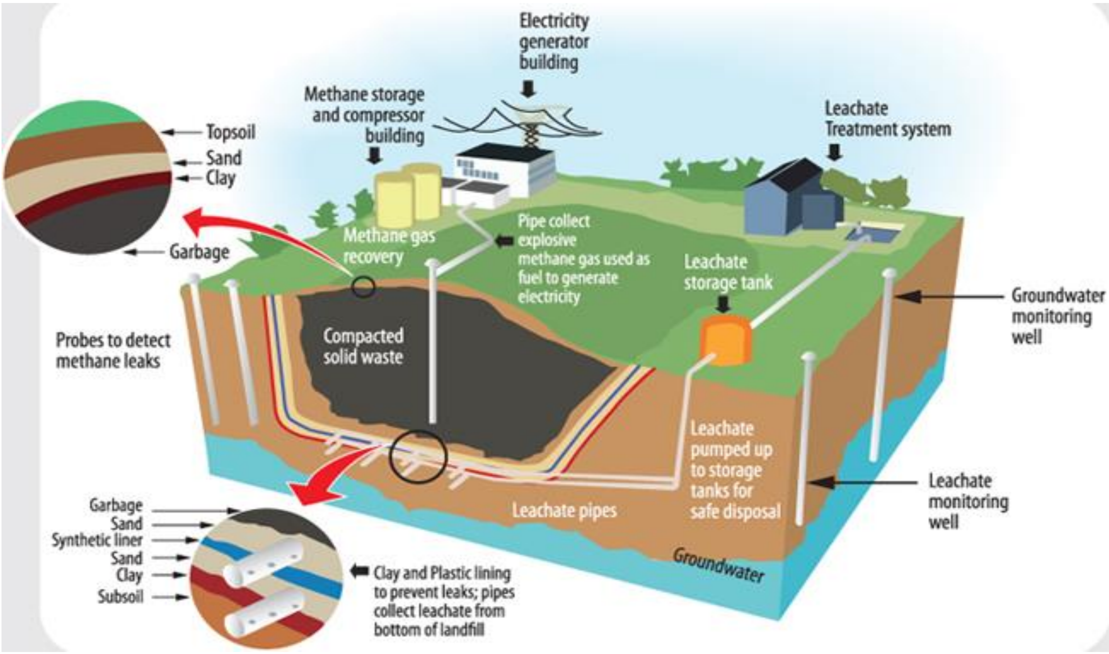

Figure 5.1: Diagram showing landfill prepared for gas collection, Source: [28]

5.2 RESOURCE ANALYSIS

5.2.1 Waste Quantities by Available Data and Personal Interviews

Waste input to the ZF site has been growing continuously. Inputs are shown as in Table 5.1.

Table 5.1: Recorded Waste Inputs from 2007 to 2018

year	Tones
2007	30,000
2008	126,112
2009	134,758
2010	182,476
2011	260,837
2012	306,135
2013	337,500
2014	352,460
2015	371,215
2016	389,045
2017	402,501
2018	423,415

A regression graph shows the rate of growth in Figure 4.1:

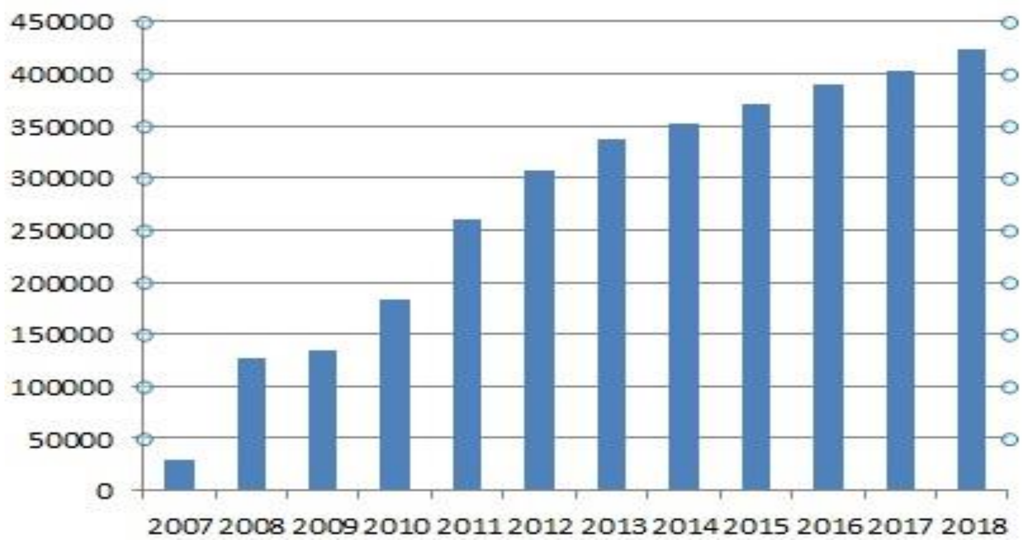

Figure 5.2: Growth Rate of Waste Input at ZF landfill

Suppose that continued growth will be sustained and suggest that the input may level off at around 450,000 tons per year.

5.3 Waste Composition

In 2013, different donors employed an international firm (Integrated Skills) to study ZF landfill. Because it is important to know waste components in order to project gas generation, it was very essential to carry a detailed waste composition analysis. Integrated Skills has conducted an activity for this purpose in June of 2013 [29]. Training was provided to six employees at the ZF landfill and provided with following equipments:

1- Four sorting tables fabricated in metal and designed to be enable them to be folded for ease of transportation.

2- Two weighing scales

3- Fifty plastic boxes for segregating the components of the waste.

The results reported by Integrated Skills in 2014 is shown in Table 5.2 .

Table 5.2: Combined weight and Assay % for the 17 samples

Primary category	Sub-categories	Weight (kg)		Assay %	
Paper Card	Recyclable paper	61.30	146.10	2.93	6.99
	Other paper	84.80		4.06	
	Corrugated card	147.75	199.30	7.07	9.53
	Thin card	51.55		2.47	
Plastic film	All film	316.35	316.35	15.13	15.13
Dense plastic	Plastic packaging	120.35	165.40	5.76	7.91
	Other dense plastic	45.05		2.16	
Textiles	All textiles	193.15	193.15	9.24	9.24
Miscellaneous combustible	Untreated wood/cork	9.65	127.65	0.46	6.11
	Treated wood	9.35		0.45	
	Carpet/flooring	1.40		0.07	
	Nappies and sanitary	98.95		4.73	
	Other misc. combustible	8.30		0.40	
Misc. non-combustible	Construction/demolition waste	22.75	35.10	1.09	1.68
	Other misc. non-combustible	12.35		0.59	
Glass	Glass bottles and jars	28.75	36.05	1.38	1.72
	Other glass	7.30		0.35	
Ferrous metals	Ferrous cans	17.95	28.85	0.86	1.38
	Other ferrous	10.90		0.52	
Non-ferrous metals	Non-ferrous cans	15.10	19.75	0.72	0.94
	Other non-ferrous	4.65		0.22	
Putrescible	Food	568.43	686.71	27.19	32.85
	Garden type vegetation	54.30		2.60	
	Soil	20.93		1.00	
	Pet excrement and bedding	43.05		2.06	
Fines	<10mm	93.75	93.75	4.48	4.48
Hazardous wastes	Mainly from hospitals	38.65	38.65	1.85	1.85
Electrical/electronic		3.65	3.65	0.17	0.17
Total		**2090.46**	**2090.46**	**100.0**	**100.0**

Source: [29]

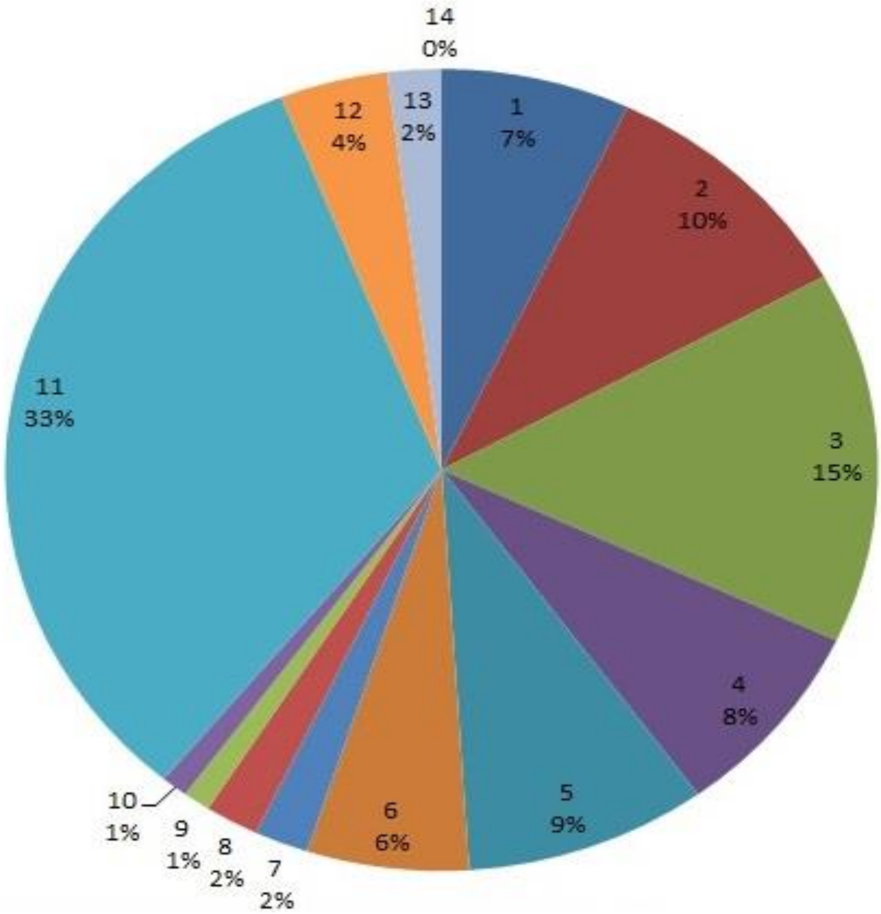

Figure 5.3: Combined weight and Assay % for the 17 samples from ZF landfill, Source: [29]

5.4 GAS SAMPLING

Experts from Integrated Skills company have studied the site carefully and made some tests. One of these tests was "gas sampling". A gas sampling point was installed within waste that was 2 years old only. This sampling point was tight at the surface with aluminum tape and the surface waste compacted to decrease permeability as shown in figures 5.4 and 5.5 After about twenty minutes a landfill gas smelling was detected coming from the monitoring point, indicating a pressure build up. This was left to stabilize for two days and was then sampled after that.

The monitoring point was rated using a Sabre portable gas monitor for Hydrogen Sulphide and carbon monoxide with concentrations found to be 16 ppm Hydrogen Sulphide and 10 ppm carbon monoxide only [29]. These concentrations are within an anticipated range for landfill gas. The carbon monoxide value indicates the waste is unlikely to be on fire at the sample location anyway. The Hydrogen Sulphide concentration is within a range approximately where continued exposure should be discouraged as it presents a health risk of course. The hydrogen sulphide concentrations at the ramified before flaring and energy production at an engine will be much larger as a result of applied suction.

Figure 5.4: Trial pit excavation before sampling point installation, Source: [29]

The analysis results showed that trace components contain halogenated and organo-sulphur compounds that could cause engine erosion. Siloxanes, organo-silicon compounds cause engine damage and distortion of cylinder heads due to build-up all of siliceous deposits after combustion. This can be a serious problem leading to very high maintenance costs after that. Analysis discovered concentrations of trace components and siloxanes are approximately low and at this stage would not indicate a need for additional treatment such as carbon filtration after that.

Figure 5.5: Sampling point installation, Source: [29]

Analysis results also indicate concentrations of trace components and siloxanes at low levels and would not indicate a need for additional treatment such as carbon filtration. However, it is important that the sampling preoceedure must be repeated on a regular basis when a gas collection/combustion system is introduced in order to rate for changes and control gas into engines.

5.5 SITE PREPARATION

Construction of landfill components is an integral part of site development. Detailed engineering construction plans and technical specifications must be prepared prior to beginning construction of Gasification system at ZF landfill. The extent of preparatory works is site specific and should be determined during the investigation stage. The preparatory works will include the stripping/filling of soil to formation level for the:

- lining system for cell/phase construction;
- leachate and gas management facilities;
- groundwater and surface water systems;
- landscaping and screening; and
- Gas collection system.

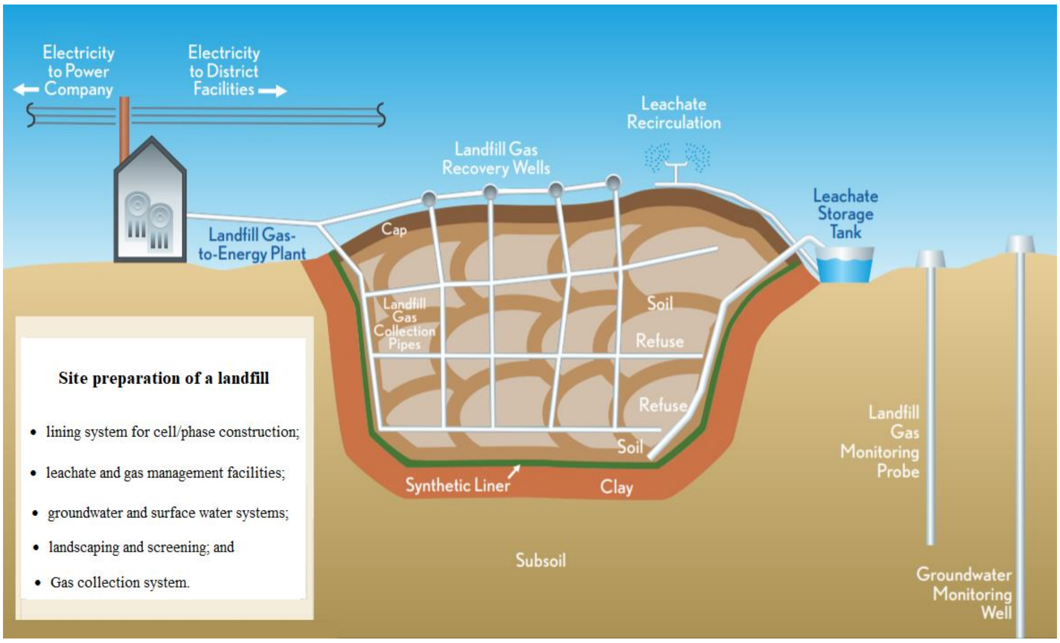

Figure 5.6: Site preparation of a landfill, Source: [30]

1- Lining system for cell/phase construction: The landfill liner system at ZF Landfill must meet the international standards. The landfill liner system consists of multiple layers.

2- Leachate management: Leachate is liquid, primarily rainwater, which passes through the waste. The leachate collection system usually comprised of a leachate drainage layer installed on the floor and side slopes of the lined landfill cells. This is essentially an area where the leachate collects and Gathering at the base of the landfill, after which it is pumped out from a sump into a holding lake and then under the road for treatment in a leachate lagoon.

Figure 5.7: Leachate holding lagoon at ZF landfill, Source: [29]

3- Groundwater and surface water are major natural resources of both ecological and economic value and their protection is of prime importance. It is therefore essential that a landfill design must include provisions for the management and protection of both these entities.

Landscaping: The landfill should present a clean and well-managed appearance to the public. Provision of a buffer zone with landscaped berms and other tree planting may lessen the environmental impact. The development sequence should allow for early screening of the landfill and this may warrant construction and planting of screening bunds around the landfill perimeter at the beginning of the project.

The designer should take into account the proposed end use of the site after work completion, as this to some degree will dictate the final landform. This final landform should fit in with the surrounding environment.

4- Gas Collection system: Gas Collection and Control Systems (GCCS) are a common and major component of landfills. They are designed to help control odors, minimize non-methanogen organic compound releases to the atmosphere, and increase safety by controlling migration. A properly designed and constructed GCCS will operate for many years without major problems, but every system requires periodic and continuous maintenance. A GCCS is often installed in landfills where waste filling has concluded; however, the landfill will continue to undergo changes that affect the rate of gas production and the ability of the GCCS to collect gas efficiently.

Figure 5.8: Landscaping at ZF landfill, Source: [29]

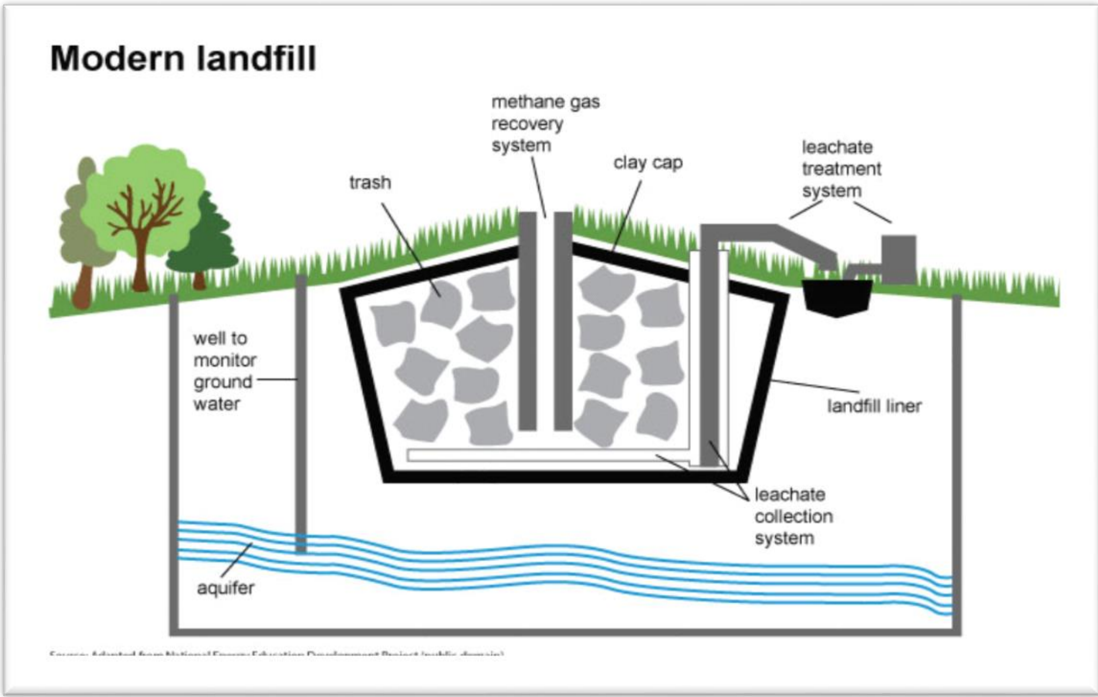

Figure 5.9: Prepared landfill for gas collection, Source: [31]

Figure 5.10: Landfill gas collection system, Source: [32]

5.6 FINAL MODEL OF WASTE TO ENERGY FACILITY

The final design of the facility is shown in figure 5.11. The main units of the facility are:

1- Gas collection lines,

2- Gas processing skid,

3- Internal combustion engine, and generator, and

4- Power transfer and high tension lines.

The operation of the facility includes three processes. These process are summarized in figure 5.12. These processes are:

1- Process 1: Gas collection

2- Process 2: Treat and transfer the gas to the generation unit where it is used to run the internal combustion engine. This engine drives an electric generator to produce electric power.

3- Process 3: Transfer generated power to customers. This is done by using power transformers to raise the voltage to medium high tension (22 kV or higher), this power will be transferred to the customers using power lines and step down transformers.

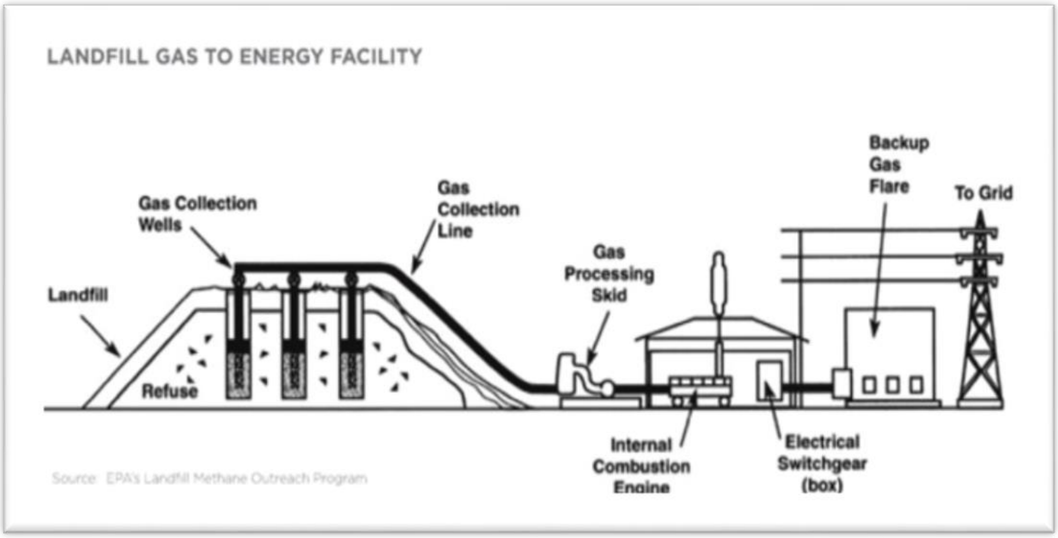

Figure 5.11: Final Waste to Energy Facility Configuration, Source: [33]

If national grid is available, then this power can be injected into the grid and considered as a renewable source of energy.

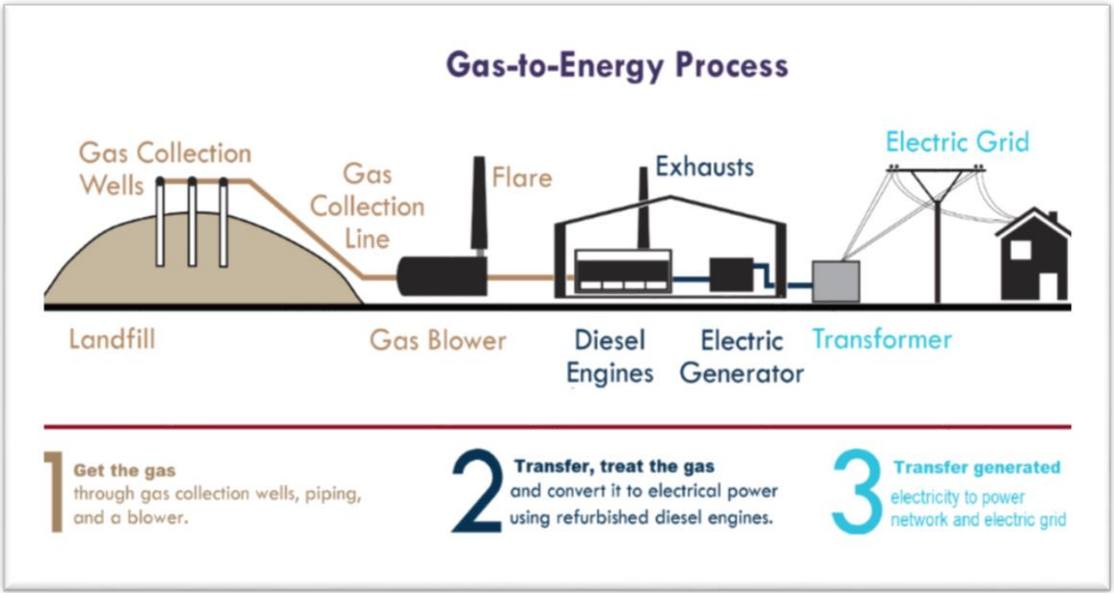

Figure 5.12: Three processes for converting Waste to Energy, Source:[33]

CHAPTER SIX

WASTE TO ENERGY GENERATION AT ZF LANDFILL

6.1 TECHNICAL FEASIBILITY OF GENERATING ELECTRICITY

The theoretical landfill gas generation curve from ZF has been estimated using the GasSim model® software. As discussed in previous chapter, gas collection can be done only after preparing the site and capping the landfill to reduce the amount of escaping gas to the minimum level.

In this research, we assume that ZF landfill to be completed by 2020. By this time, it is most likely that another landfill will be developed on the other side of the main road in the site. This new site should be generating sufficient gas by 2030 so that the decreasing in electricity generation will not actually happen. Indeed the generation potential will then probably increase.

6.2 LANDFILL GAS PRODUCTION

The first step in designing the Waste to Energy plant is to estimate how much gas the site is producing in a specified period of time, so that installations and components can be planned.

Landfill gas, involving mainly methane and carbon dioxide, is produced during the bacteriological breakdown of waste in a landfill under no air conditions. The volume of landfill gas that is produced at the site is dependent on many environmental factors and the quantity of waste the degradable organic carbon content of that waste.

If both the amounts and types of waste deposited at the site are known, the volume of gas that is likely to be produced by a site can be estimated using the GasSim model.

GasSim Model

The GasSim 2.5 model has been used to estimate the gas production levels at Zahrat Al-Finjan landfill. GasSim uses Monte-Carlo simulation and is a potential model which does not dependent on deterministic calculations.

The critical input data in relation to form gas production are.

- Waste input (tons per year)
- Waste components (determines carbon content)
- Moisture content (determines the degradation rate of components)
- The physical characteristics of the landfill of ZF.

Until the end of year 2019, ZF landfill will have accepted more than 4,250,000 tons of waste. The waste components have been described in section 3.6 of this thesis.

Average moisture content is suitable to use at this site because rainfall is within the "average" range used in the model (about 500 mm annually) and the amount of leachate in the site. The site also circulates leachate again. The site has high leachate rates that increases in raining periods. This can significantly decrease the ability to capture landfill gas at depths where the waste is saturated with moisture.

From the gas generation curve generated using GasSim software, we can conclude that in 2020 gas generation will be about 4500 m^3/hour. This is illustrated in Figure 6.1 shown below.

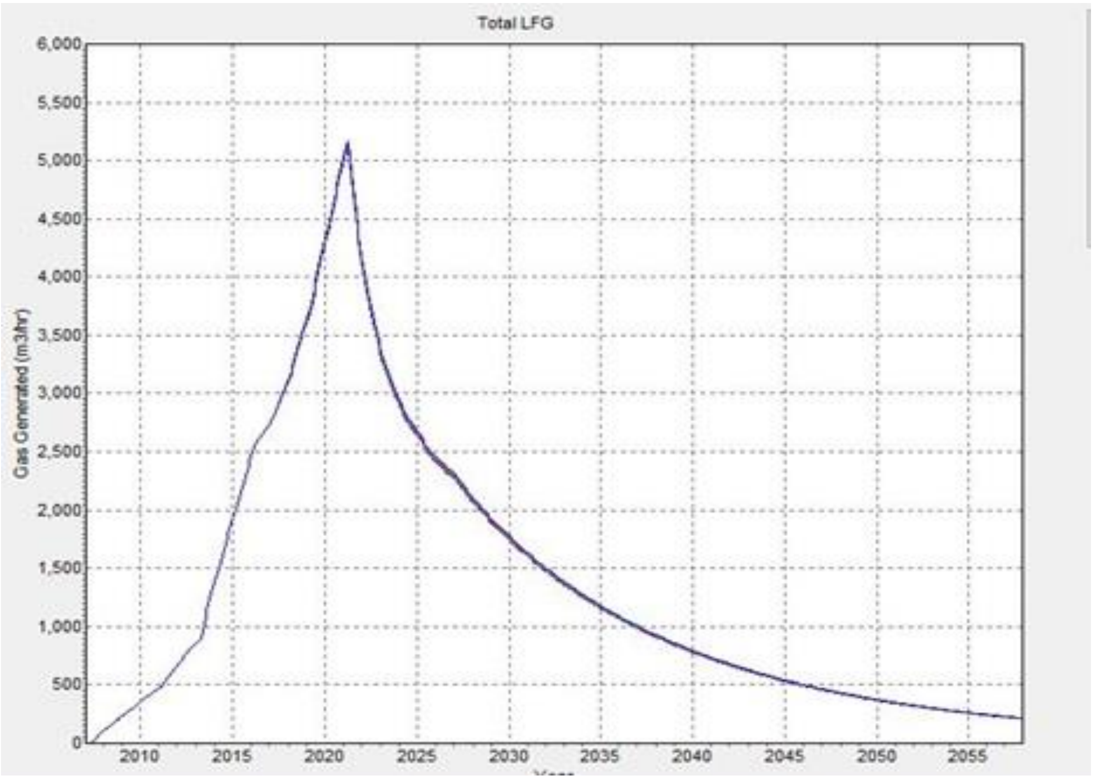

Figure 6.1: Estimated gas production of ZF landfill using GasSim2.5 Model

The GasSim model built with average moisture components predicts that the maximum production of 5200 m^3/h will occur in 2022.

According to “Landfill Gas Technical Guidance Note 03 – Guidance on the control of Landfill Gas” produced for the UK Environment Agency, a benchmark collection efficiency of 85% should be used to Evaluation the made of a gas collection system. This depends on the site being capped and with a gas collection system that provides sufficient overlap between gas wells and might include a partially collection system. According to that, the benchmark collection figure that should be used to Evaluation the potential gas at Zahrat Al-Finjan is

$$4{,}500*.85= 3{,}825 \text{ m}^3\text{/h} \quad \text{in the year 2020.}$$

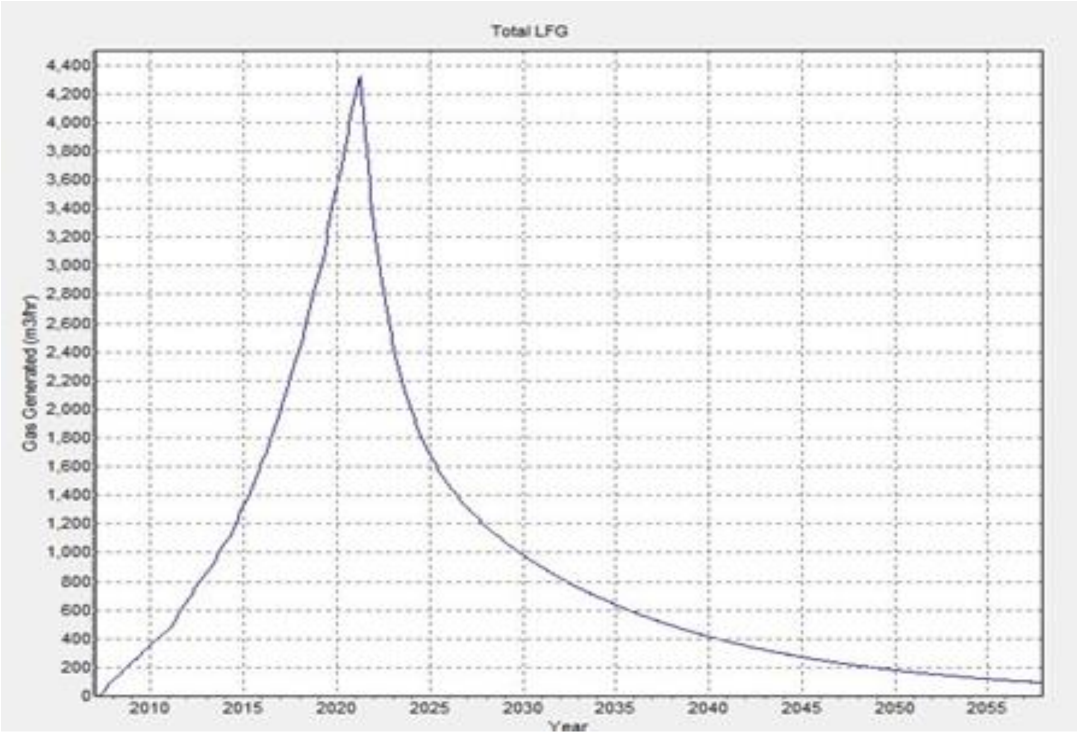

Figure 6.2: Predicted Gas collectable of capped ZF landfill from 2007-2055

The ZF site now has no capping and it has exposed flanks along the tipping face and along the road adjacent to the site compound. Both of these flank areas have high potential for gas escaping to the atmosphere. A site that has no capping could be expected to make sure achieve a maximum collection figure of 65% only, which would imply gas capture will be reduced to 2,486 m^3/h in 2020 and a peak of 2,873 m^3/h in 2022. Accordingly, the methane concentration in the gas will be very much lower and air is likely to exist (see figure 6.3). Consequently, the potential for power generation will be lower, while the danger of fire will be much higher.

This fact demonstrates the importance of capping ZF landfill and the need for phased capping and the need for gas collection at an early stage.

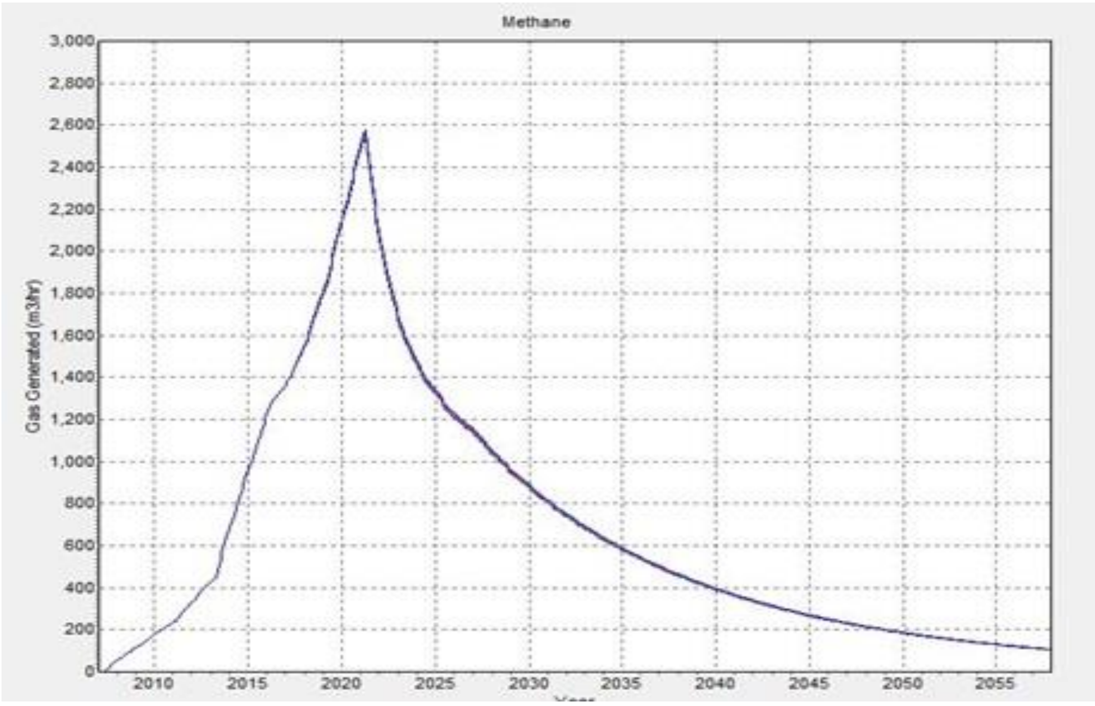

Figure 6.3: Zahrat Al-Finjan landfill – Predicted CH4 gas generation.

We should note that the GasSim model assumes the yield will contain 50% methane levels and 50% carbon dioxide levels. The model does not account for conditions that may grow because of re-circulation of acidic leachate in the existence of calcareous rocks, which could generate additional carbon dioxide levels.

Table 6.1: Gas production and collection rates at ZF Landfill

	Capped m^3/hour	**Uncapped** m^3/hour
Estimated volume of gas generated in 2020	4,500	4,500
Estimated volume of gas generated at peak production in 2022	5,200	5,200
Estimated volume of gas collectable in 2020 (85%)	3,825	2,486
Estimated volume of gas collectable at peak production in 2022 (85%)	4,420	2,875

(The data calculated for average moisture content of 50% in all conditions)

Carbon dioxide concentrations within the gas may change as a result of chemical reactions and this can change the calorific value of the landfill gas. For this matter, bulk gas samples must be taken and analyzed to evaluate this issue frequently.

One of the most important factors that affect the quantity of collected gas is the number of wells and the distance between them. Our survey for existing project in different countries shows that each well is usually capable of collecting 30 m^3/hour of LFG. This parameter is used in the industry as a realistic magnitude of the gas that can be collected from a well. In the case of ZF landfill, as we estimate peak collected gas to be around 2,875 m^3/hr (in 2022), then there is a need for at least 93 gas wells that could be drilled.

6.3 CO_2 GAS EMISSIONS

CO_2 will be generated at huge quantities in the landfill during the biological cycle. The predicted amount of CO_2 generation is almost 50% of the bulk gas generation (GasSim estimates). Other emissions are expected as a result of burning LFG in generation engines and in the flares.

Figure 6.4 shows the emissions that would be expected from combusted landfill gas from flares and engines at ZF site. The GasSim model for this site has been configured at first to use engines and then a flare when there is a small magnitude of gas for an engine. These results were made on the assumption that the project will not start operation until 2020.

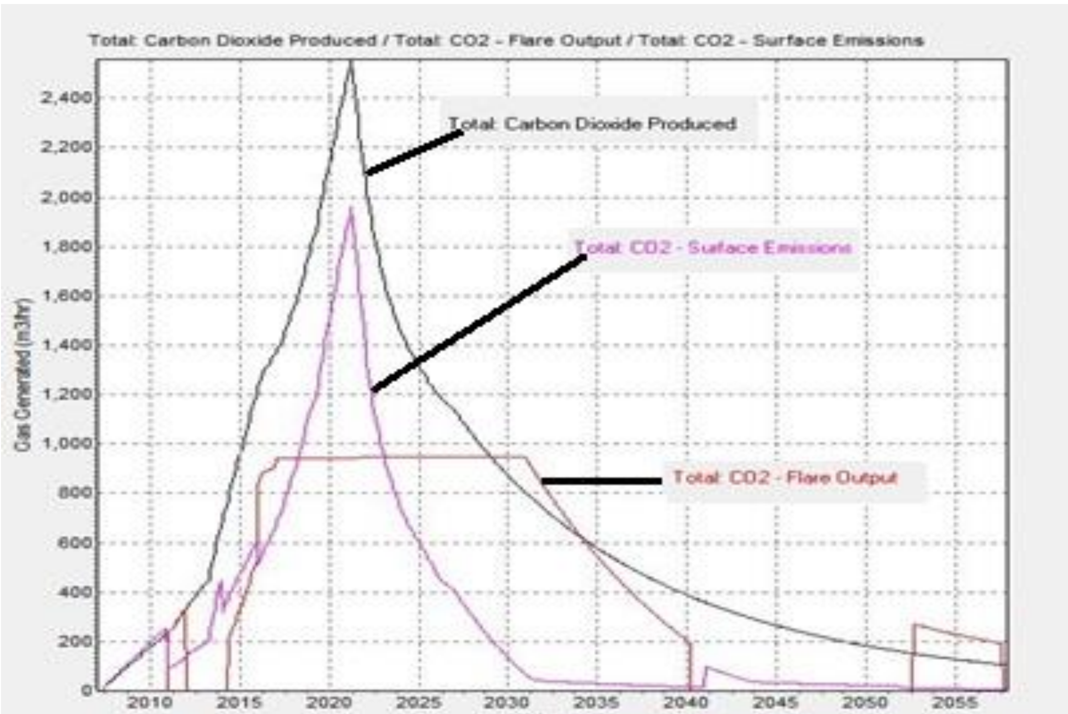

Figure 6.4: Total CO_2 emissions, surface emissions and flare emissions (using GasSim)

6.4 GAS UTILIZATION SYSTEM OVERVIEW

The gas utilization system (sometimes named a gas treatment system) will comprise a concrete fenced and lockable gas compound containing gas engines with generating sets and a flare to treat any excess gas. Dryer is used to reduce the moisture content of the gas which it will be transmitted after that to the generation engine using a blower. The dryer is also used to extract the H_2S gas that may exist. The schematic diagram of the gas treatment system is illustrated in figure 6.5

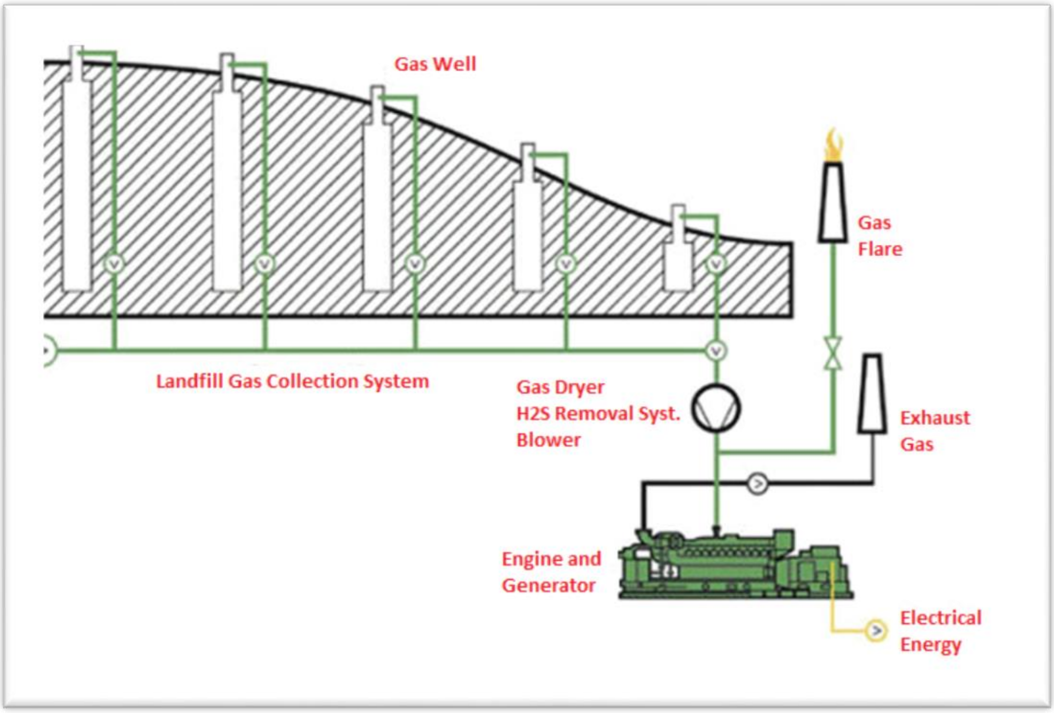

Figure 6.5: Schematic diagram of gas treatment system of the landfill

Gas Engines

The gas compound should be able to include at least two gas engines with a potential total built generating capacity in the order of 1.5 MW each. This capacity is based on hourly peak gas generation estimated using GasSim Software.

Gas Flares

The gas compound needs an elevated a flare with a maximum capacity of $1000m^3$/hour. On European landfill sites are strictly controlled and excess gases are flared using ground flare technology there. The reasons for this are partly due to the existence of heavily populated areas close to landfill sites and very strict air quality standards. In the case of ZF these standards are not considered suitable as the nearest population is far enough from the site. Furthermore, the introduction of the planned landfill gas control system will improve local air quality by collecting gas that is now escaping to atmosphere. Also, gas not used by the engines should be sent to the flare by automatic valves.

Figure 6.6: Landfill Gas Flare, Source: [34]

Gas Boosters

The gas booster is a rotating machine that makes the suction of gas in each well. On the other side to the booster the constant pressure is negative and depends on the quantity of gas being produced at the wells. This negative constant pressure is accounted for in the gas system design by considering loss of pressure along the gas pipes. If the pressure loss along the gas lines surpasses the suction at the booster, there will be areas of the site that do not have gas collection. Gas suction at each well will normally be in the region of about less than 5 m^3 during early phases of gas production, this is because gas is being generated under positive pressure to the well. As gas generation levels decrease, more suction is need to collect the gas, this may mean about 40mb (or more) suction is required. The suction at the booster always generally needs to be equal to or above than the drop in pressures in the pipework that result from frictional forces plus the maximum amount of suction need at the well with the highest potential pressure loss between that well and the booster there. At the outlet of the fan, the gas is increased to produce the pressure needed to operate the engines and flare.

The gas booster at ZF should have about 300mb total pressure uplift and 2,200 m^3/hour capacity which should be suitable for the current and peak gas production rates.

6.5: QUANTITIES OF MSW DUMPED IN ZF LANDFILL:

The amounts of dumped municipal wastes dumped in ZF landfill increases every year. The average daily MSW recorded and disposed in Zahret Alfinjan landfill between 2007 and 2015 is shown in figure 3.4 [24].

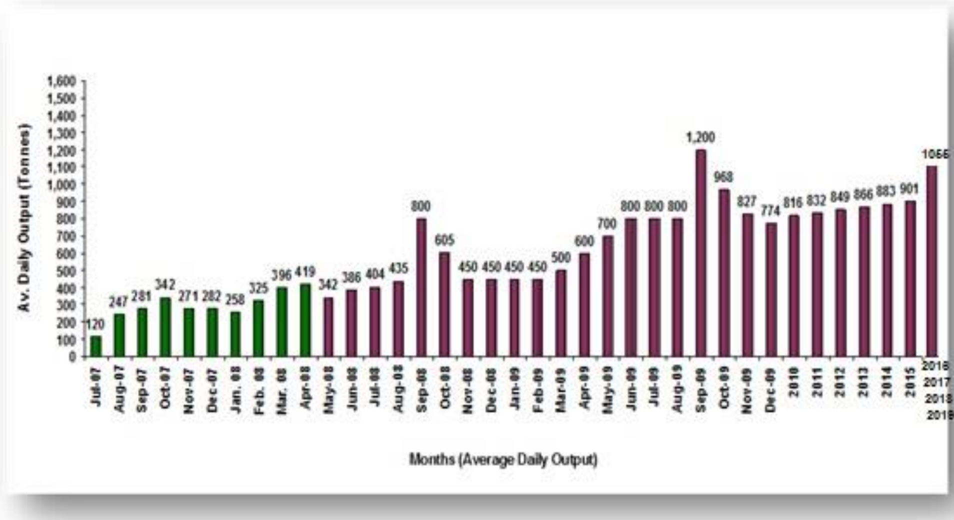

Figure 6.7: MSW per day in Zahret Alfinjan landfill [25] , & self-interview with ZF staff

6.6 Composition of the waste in ZF landfill:

There has been different attempts to analyze the municipal waste sent to ZF landfill. We found that the most accurate and precise one is reported by the Palestinian Energy and Environment Research Center (PEC) in their report of 2012. From this report, it is clear that the organic matter represents a high percentage (more than 60%) of the composition of the waste.

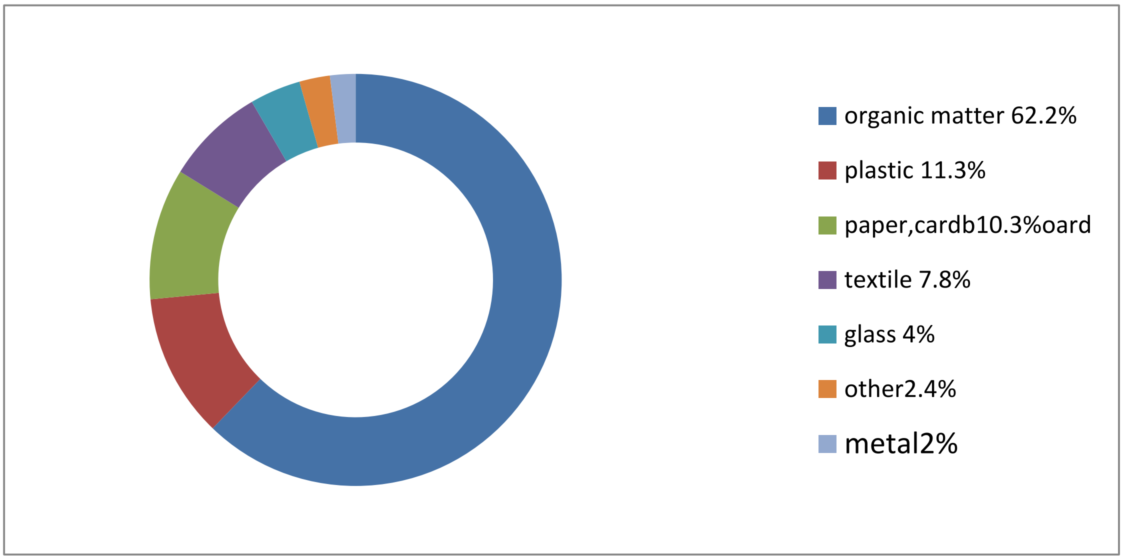

Figure 6.8: Composition of the waste [25]

6.7 Landfill Gas Energy Recovery in ZF

In general, the landfill gas generation can be calculated using the following equation which we can apply to the case of ZF landfill: [26]

$$LFG_t = L_0 . \mathrm{R}\left(\mathrm{e}^{-\mathrm{kc}} - \mathrm{e}^{-\mathrm{kt}}\right)$$

Where:

Lo: Total LFG yield per kg of municipal solid waste in m^3/kg

R: Filling rate in kg/yr

t: number of years since landfill opened

c: number of years since landfill closure

k: Annual rate of LFG generation = 1/years

The value of **c is zero** if the landfill is still accepting waste. The value of "e" is based on the Napierian or natural logarithm (approximately 2.718). Lo is estimated from waste composition and degradable organic content which values can be extracted from figure 3.5. According to Vogt, Peyser, and Peterson (1996), total LFG yield per kilogram MSW is 0.17 m^3/kg (AGO, 1997). [26]

If we assume that the average daily rate of filling ranges between 901 ton/day in 2013 and 1215 ton/day in 2019, the average value of daily filling will be around **1050** tons/day and working days = 330 days/year.

If we can consider that only 62.2% (organic materials) of the shipped MSW will be dumped in the landfill after separation of recyclable materials. Then we can estimate R as follows:

*R =1050 tons/day * 365 day/year * 62.2% = 238.4 million Kg/year*

k = 0.05/years

t=13 years (2007-2020)

We can estimate the average biogas production per year of the considered landfill is :

$$LFG_t = L_0 . \mathrm{R} \left(\mathrm{e}^{-\mathrm{kc}} - \mathrm{e}^{-\mathrm{kt}}\right)$$

$= 0.17\ m^3/kg \times 238.4$ million kg/yr $[e^{(-0.05x0)} - e^{(-0.05x13)}]$

LFGt = 19.37 million m^3/year.

This result is close to the value generated by GasSim Software, where the estimation was 2,486 m^3/hr (19.69 million m3/yr based on 330 working days per year)

<u>Power produced equal to :</u>

Q= m.C.V = (19,370,000 m^3 * 0.3 * 21.4 MJ/m^3) =124,355,400 MJ/year

(With thermal efficiency C = 30 %)

and Calorific value V= 21.4 MJ/m^3

So, the estimated average power of the power plant (P) with Conversion factor=0.277kw/MJ will be as follows:

P = Q\ t = (124,355,40 * 0.277 kW/MJ) / (8760 h)

= 3,932 kW

= 3.9 MW

❖ **<u>The annual energy production will be</u>:**

E= p * t = 3.9 MW * 8760h = **34,446** MWh/year

(With 30% thermal efficiency).

In Palestine, the cost of electricity from the source = 0.45 NIS/kWh, so the estimated savings are:

<u>Cost savings</u> = 0.45 NIS * 34,446,000 kWh / year

= **15,500,000** NIS per year

= US $ 4.3 million/ year (approximately)

These results are reflected at the following table for the case study of the Zahret Alfinjan landfill:

Table (6.2): Zahret Alfinjan MSW potential biogas production Starting year 2020

Plant	Waste	Average filling (ton/day)	Rate of organic waste	Biogas production (m^3/year)	Calorific value (MJ/m3)	Potential of MWh/yr	Total price saving NIS/year
ZF Land fill	MSW	1055	62.2%	19,370,000	21.4	**34,446**	15,500,000

Based on the assumption that power generation will start in 2020

6.8. EMISSIONS OF CO2

To calculate the amount of CO_2 cut down by utilization of landfill gas project connected with electric network, we have to:

1- find the amount of CO_2 resulting from generating 1 Kwh in conventional power plants run by coal-assuming all consumption come from coal power plant,

2- Then find out the power of landfill gas project and then calculate the amount of electricity in Kwh, which generate as an alternative to that amount coming from conventional power plants.

3- Based on this amount we can find the amount of CO_2 that has been cut down

The following table (6.3) shows the amount of CO_2 emissions resulted from generating 1 Kwh for different fuels:

Table (6.3): CO_2 Emissions in gram/Kwh

Fuel	emitted CO_2 (g/KWh)
Diesel or coal	800-1050
Natural gas (combined cycle)	on average 340
Hydroelectric	4
Nuclear	6
Wood	1500
Wind power	3-22

Source: [27]

The amount of CO_2 would be reduced if we assume that the consumption of electricity in Palestine comes from a power plant runs by coal:

= amount of Kwh/year (E) * Avg. grams of CO_2/Kwh

= 34,446,000 Kwh * (800+1050)/2

= 31,862,550 ton CO_2 per Year

6.9 Comparing the Results with Amount of Energy Consumed in Palestine:

The average demand of electricity in the West Bank is approximated at 600 MW, which is equivalent to 5,256,000 MWh per year. **[16]**

The price rate for electric companies is around 0.45 NIS/kWh, so the total cost of electricity consumed is equal to:

0.45*5,256,000*1,000/1000,000 = 2,365.2 million NIS per year

Which means that we can save

(15,500,000 /2,365,200,000) x 100% = 6.55%

If we assume that the total consumption of electricity came from a power plant runs by coal, then the amount of CO_2 would be:

= amount of Kwh/year * Avg. grams of fuel/Kwh

= 5,256,000,000 Kwh *(800+1050)/2 =48,618,000 ton CO_2 per Year.

6.10 Gas Utilization Capacity and Size Options

Usually, the plant size would be selected to maximize the amount of electric power that can be generated. When the project starts in 2020, about 3.9 MW can be generated as calculated in section 5.7 of this report. This will increase to 4.5 MW in 2022 before falling again. For the sake of flexibility, our recommended sizes of generators:

- 1 x 1.5 MW gas engine.
- 1 x 3.0 MW gas engine.

If we use two 2.25 MW engines then this choice will endure higher capital costs but will give more flexibility, especially during maintenance periods.

6.11 ELECTRICAL CONNECTION

The best position of the gas compound is at the entrance to the landfill in nearly to the power line system.

NEDCO is the electric distribution company in Nablus and Jenin districts. Unfortunately, at this time, NEDCO does not own the high voltage transmission lines yet, which are still in the possession of the Israeli Regional Electricity Company (IREC). Therefore, we can suggest building a 11 kV or 22kV line to Aja, some 2 km distant, which has a need of 3MW in at peak hour. This line will not be connected to the existing high voltage grid. However, NEDCO is negotiating with IREC about taking over the network along the time this project is operational. In any case, it is most likely that NEDCO will manage the network and the power could then be provided to the grid or other villages in the area. Connecting the station to the existing high voltage network will be the most economical solution, as it needs a maximum of about 1 km of high voltage line to the closest connection point.

Electrical output from the engines at the site will be 400V. The two engines will need to be synchronized to each other, using a connection board at a cost around $80,000 according to NEDCO estimation. The local supply is 11KV so a step-up transformers of 4.5MW capacity will be need, costing about $70,000. 1km of overhead high voltage line will then be needed to connect to the grid, at a cost of about $100,000, but if we need to build a direct line to Ajja then the cost will be $200,000 (around 2 to 3 km).

6.12 ELECTRICAL NETWORK

The main parts of the proposed network are:

1- Generation units (400 volts)

2- Synchronizing unit with the Israeli network

3- Step up transformers (400/122 kV)

4- Transmitting lines to load areas.

5- Step down transformers

The main problem now is the fact that the grid in the area is owned by the Israeli network which make the connection to existing network impossible. In this case, we will think of transferring the generated power to the Jalama Substation, which will be responsible for supplying electricity to main loads in Jenin, Nablus and Tulkarem. This illustrated in figures 6.9, 6.10 and 6.10.

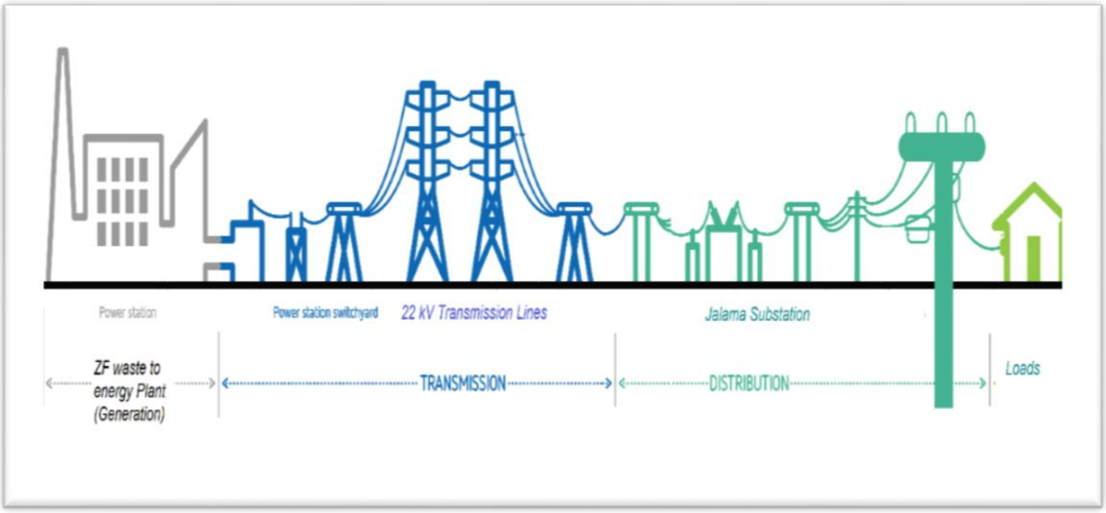

Figure 6.9: Power generation and transmission from ZF plant

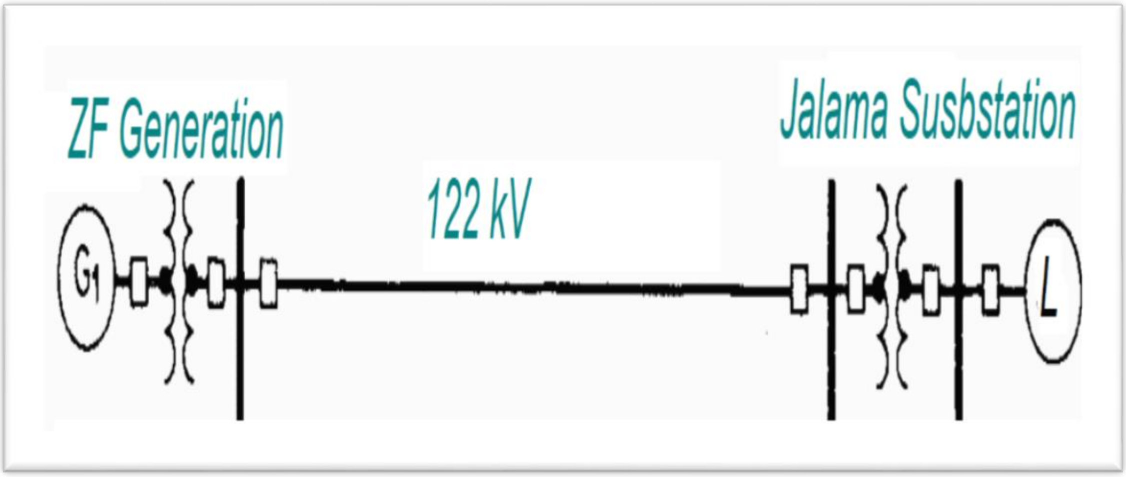

Figure 6.10: Line diagram of power network of ZF project

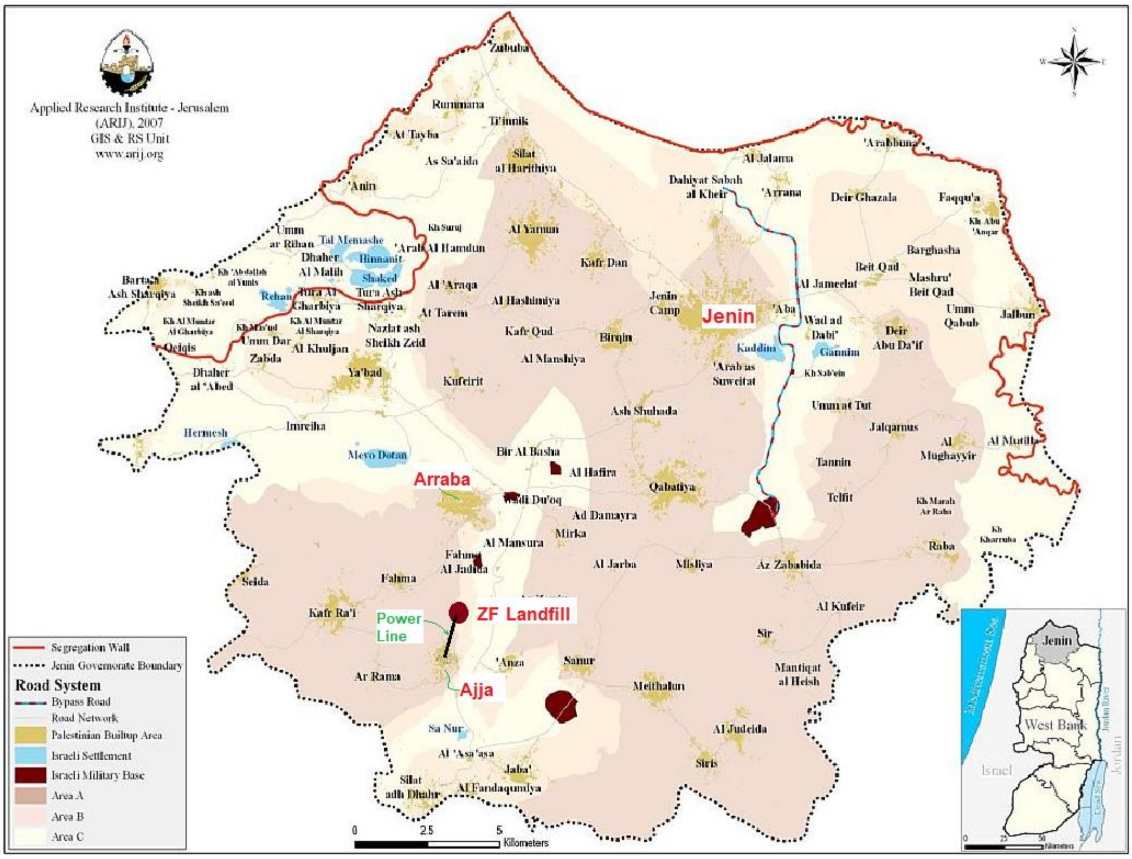

Figure 6.11: Proposed power line to Ajja.

6.13 ESTIMATED COSTS OF LANDFILL GAS TO ENERGY SYSTEM.

The main costs of LFG facility includes capital costs and operational costs. These costs depend heavily on the technology used for converting the landfill gas to energy. The following table summarizes these costs for different technologies.

Table 6.4 Capital and O&M Costs Of LFG Electricity Generation Projects

Technology	Project size (capacity)	Capital costs $/kW	Annual O&M costs $/kW
Microturbine	≤ 1 MW	$ 5,500	$ 380
Small internal combustion engine	≤ 1 MW	$ 2,300	$ 210
Internal Combustion engine	≥ 800 kW	$ 1,700	$180
Gas turbine	≥ 3 MW	$ 1,400	$ 130

Source: US. EPA, 2009.

Capital Costs

The Internal Combustion Engine is the selected technology for ZF landfill. From the table above, the capital cost estimate is $1700 per kW capacity. For the estimated capacity of 3.9 MW, this capital cost will be 6.63 million US dollars. The operational and maintenance costs will be estimated at $180/kW and around 700,000 US dollars per year for the facility.

In this research, we collected some data about the detailed costs of the project. The capital cost of the landfill gas system is seen in Table 5.2.

It should be marked out that the contingency would contain a provision for training on the engineer and manager prior to commencing operations start.

Table 6.5: Capital Costs (USD)

Item	Estimated Cost
Commissioning	$150,000
Pipework and wells	$150,000
Installation costs	$400,000
Drilling (97 wells – cost $3,200/well)	$380,000
Compressor	$20,000
Shipping of equipment	$30,000
Construction of Gas Utilization Compound	$30,000
Ground flare	$20,000
1X 2.5 MW Engin**e**	$2,500,000
1x1.5 MW Engine	$1,500,000
Electrical Connections (see above)	$230,000
Contingency	$78,000
TOTAL	**$5,488,000**

It should be marked out that the site will need to be capped using HDPE, 500 mm of gravel and a geotextile of the ground, plus soils from ground of the site. This is likely to cost at least around $\$40/m^2$ or a total of around **$3,250,000**. We have not counted for this cost as it is needed for environmental protection in any event, even if electricity generation was not considered.

Operating Costs

The annual estimate for operating the facility based on US EPA is $700,000. However, we found that the operating cost of the plant is lower than the previous estimate, because salaries here in Palestine are lower than in the United States. The yearly operating costs are shown in Table 5.6.

Table 6.6: Annual Operating Costs (USD)

Engineer / Manager (including accommodation)	$80,000
Laborer (high quality)	$125,000
Maintenance costs	$150,000
Gas analysis	$20,000
Engine oil analysis	$10,000
Consumables (engine oil etc.)	$20,000
Transport	$15,000
Other overheads (telephone, insurance etc.)	$20,000
TOTAL	**$440,000**

6.14 ECONOMIC ANALYSIS

From previous sections, we found that establishing the Waste to Energy facility at ZF landfill requires a relatively high capital costs in addition to its operational costs. On the other side, generated electricity can save millions of dollars every year.

Total capital costs = $ 3,250,000 (capping) + $5,488,000 (facility)

= US $ 8,743,000

Energy savings = $ 4,300,000 per year

Operational costs = $ 440,000

Nat Annual Savings = 4,300,000 – 440,000 = $ 3,860,000

Payback period = 8.743 M$ /3.860 M$ = 2.26 years

(Note: annual income will decrease at a rate of 10% approximately due to decrease in LFG production after 2023)

6.15 SOCIAL IMPACT OF THE PROJECT

The site location is not far enough from populated areas. There are two small villages approximately 1 kilometer away from the landfill to the northeast; Falima al Jadida and Al Mansura. Also, there is a larger village; Aja, which is approximately 2-3 km to the southwest.

Capping the landfill and collecting the gas will be of great benefit for these villages. At this time, the odor from the site is quite unpleasant for the two small villages if the wind action is in the wrong direction and possibly for Aja as well, as the odor is very strong.

LFG is not collected at this time and it is escaping from different points in the landfill. The risk of fire is very high and imposes great danger on workers in the site. In addition to that, we think there are also some stability problems which put the workforce at danger of injury – although this is not directly relevant to the problem of gas.

CHAPTER SEVEN

CONCLUSIONS

Converting waste into energy is a well-known technology in developed countries. In addition to its benefits in producing electricity and usable heat, the environmental impacts are extremely positive. This includes the reduction of number and areas of landfills and reduction of harmful gas emissions. For our case in Palestine, we found that we it is feasible to apply one of two possible technologies for waste to energy conversion. These two technologies are 1- anaerobic digestion, and 2- incineration (direct burning).

Landfill gas is a sustainable and a renewable solution to replace traditional fuels (coal, oil or natural Gas) for electricity generation. It is not only reducing the emissions of harmful greenhouse gases from fossil fuel power plant but also eliminating fugitive landfill gas. Methane Gas generated in waste landfills is a valuable material that should be recovered for its high energy content.

In this research, we found that more than 1050 tons of MSW are dumped in ZF landfill daily. Our simulation results indicated that this landfill if capped and closed by 2020 then it could produce more than 4000 m^3/hour of landfill gas. As ZF is not capped properly, than we estimate that only 65% of this gas can be collected. In addition, we found that the peak of gas production will be in 2022. LFG production will continue until 2055 with annual drop of 10% approximately in the first 10 years then the drop will be around 5% after that.

To collect the LFG effectively, we need to drill at least 97 wells after capping the landfill. The collected gas can be treated to lower the moisture content and to eliminate the H_2S gas which can damage the engines. The produced landfill gas at ZF landfill can run power generators with peak capacity of 3.9 MW. This produced energy can be transferred to nearby villages or to be transferred to the high voltage grid if NEDCO will take control over the grid.

Our economic analysis showed that this waste to energy project will have a capital cost of almost 5.5 US million dollars and 440 thousands US dollars for annual operation costs. In such case, the payback period will be less than three years.

Improvements on new generator technologies for electricity generation from waste in landfills has evolved in the last two decades. The efficiency of power generator has improved and the same for their environment performance. The new technology, however, still needs to prove the capability to supply energy for a sustainable world. In this research we found that the buried waste in ZF landfill is capable of operating a 3.9 MW power plant by using the landfill gas if properly capped. This gas plant can save more than $4.3 million every year.

Solid Municipal Waste is a sustainable and renewable source of energy. This study proved that the projects of converting waste into energy had an economic and environmental benefit. However, very little attention has been made to this source of energy in Palestine so far. As we know, regulations and set of government incentives have been introduced to enhance power generation from renewable sources. The Palestinian government has supported the development of renewable energy such as PV solar power; however, the government needs to give more attention to the landfill power generation and to learn from other countries experience. Support from government and community for green power will affect investment, improve environment, save valuable resources, which encourages development.

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جامعة النّجاح الوطنيّة

كلية الدراسات العليا

استخدام الغازات الناتجة في مكب نفايات زهرة الفنجان لتوليد الطاقة الكهربائية

إعداد

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إشراف

د. معتصم البعباع

قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة القوى الكهربائية، بكليّة الدراسات العليا، في جامعة النّجاح الوطنيّة، نابلس– فلسطين.

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الملخص

في هذا البحث، قمنا بدراسة جدوى استخدام تقنية الهضم اللاهوائي في النفايات الصلبة البلدية لإنتاج الغاز الحيوي وتوليد الطاقة الكهربائية في مكب زهرة الفنجان في شمال فلسطين.

إدارة النفايات الصلبة تعد واحدة من اهم المشاكل البيئية في المناطق الحضرية في فلسطين. ان استخدام التقنيات المختلفة للحد من النفايات الصلبة وإعادة استخدامها وإعادة تدويرها من اهم طرق حل هذه المشكلة ولكن لا يتم استخدامها بفعالية في بلادنا. نظرًا لأن النفايات المنزلية الصلبة تكون غنية جدًا بالطاقة، فإن استخدامها كمصدر للطاقة المتجددة يعد أحد أهم المشروعات الاقتصادية التي تسعى السلطة الفلسطينية إلى تنفيذها إذا ثبتت جدواها الاقتصادية وتوفرت الموارد المالية اللازمة لذلك.

من هذا البحث وبناء على النتائج التي تم الوصول اليها بخصوص كفاءة الطاقة والتأثير البيئي لاستخدام الغاز الحيوي في مكب زهرة الفنجان في شمال فلسطين كانت مرضية بما يكفي في كل من إنتاج الطاقة الكهربائية وفي المساهمة في التخفيف من الغازات الدفيئة، خاصة غازي الميثان وغاز ثاني أكسيد الكربون.

لقد تم تحديد هدفين رئيسيين لهذه الدراسة وهما: أولاً، تحديد ما إذا كان الاستخراج النشط لغاز مكب زهرة الفنجان من شأنه أن ينتج طاقة كهربائية كافية وبشكل اقتصادي للاستخدام وربطها بالشبكة الكهربائية الموجودة بالمنطقة. والهدف الثاني هو تقدير تخفيض انبعاثات غازات الدفيئة. ولكي نتمكن من اجراء عملية تحليل دقيق لهذه النتائج كان من الضروري اجراء تقدير دقيق لإنتاج الغاز الحيوي على مدى عدة سنوات.

وجد هذا البحث أن متوسط إنتاج الغاز الحيوي سنويًا في مكب زهرة الفنجان يزيد عن 8 ملايين متر مكعب، وهو ما يكفي لتشغيل محطات بقدرة 3.9 ميغاوات، ويقدر إنتاج الطاقة السنوي منها بأكثر من 34 جيجاوات ساعة في السنة، بالإضافة الى تقليل انتاج غاز ثاني أكسيد الكربون بما يقارب 32 ألف طن سنويًا.