



## **Al-Najah National University**

Faculty of Engineering

Energy Engineering Department

Graduation Project Report 2

### ***“Waste to Energy: A case study for North and North-West of Jerusalem Municipalities”***

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**List of abbreviations:**

|        |                                                        |
|--------|--------------------------------------------------------|
| WTE    | Waste-To-Energy                                        |
| OECD   | Organization For Economic Co-operation And Development |
| AFR    | sub-Saharan Africa Region                              |
| SAR    | South Asia Region                                      |
| BFB    | Bubbling Fluidized Bed                                 |
| MENA   | Middle East and North Africa                           |
| ECA    | Eastern and Central Asia                               |
| LAC    | Latin America and the Caribbean                        |
| EAP    | East Asia and the Pacific Region                       |
| SW     | Solid Waste                                            |
| SWM    | Solid Waste Management                                 |
| GS     | Gaza Strip                                             |
| WTE-T  | Waste-To-Energy Technologies                           |
| ISWM-S | Integrated Solid Waste Management Systems              |
| MSW    | Municipal Solid Waste                                  |
| STMR   | steam-to-MSW ratio                                     |
| NCV    | Net Calorific Value                                    |
| SW     | Solid Waste                                            |
| COD    | Chemical Oxygen Demand                                 |
| TS     | Total Solid                                            |
| VS     | Volatile Solid                                         |
| MSWLF  | Municipal Solid Waste Landfill                         |
| EPA's  | Environmental Protection Agency                        |
| N & NW | North and north west                                   |
| CFB    | Circulating Fluidized Bed                              |
| RDF    | Refuse-Derived Fuel                                    |

## **Abstract**

Our developing world faces many problems; one of these is waste problem. There are huge quantities of waste produced each year and can't find a place to go. In conjunction with that, energy sector suffers a lot from lack of resources and increasing in the demand. Fortunately, we can catch two birds with one stone which is Energy recovery from waste.

Palestine is facing the problem of SW like any country in the world due to increase of the population, the lack of appropriate places for the wastes and shortage of sanitary landfills. Also, there are a lot of challenges facing the Palestinian energy sector. The complications of the current political situation add their own challenges to the environment. There is limited Palestinian control over land and resources. Area C is one of the most affected places, building and administrative restrictions imposed by the Israeli authorities on the development and implementation of waste management infrastructure projects in these places. So, we take the North and North West of Jerusalem as a case study which are 16 Local Authorities consisting of 5 municipalities and 11 councils that are largely neglected by the authorities and are oppressed by the occupation and its barbaric-actions .

The scope of this research is to achieve an effective waste to energy technology. This study assessed the municipal solid waste as a valuable renewable energy resource and as worldwide opportunity of energy recovery by using waste to energy technologies. In this study, the generation of municipal solid waste was assessed to estimate the energy generation potential in the N & NW of Jerusalem. In this study three scenarios were following. The first scenario was without sorting, incineration or gasification for all amounts of MSW. The second scenario was with sorting, centralized bio-digestion or decentralized bio-digestion for organic of MSW and pyrolysis for plastic of MSW. The third scenario was with sorting, centralized bio-digestion or decentralized bio-digestion for organic of MSW and incineration or gasification for plastic, paper and others.

Calculations clearly illustrated that by the thermo chemical process, the electrical energy from the incineration of MSW technology without sorting was estimated 112 MWh/day and with sorting was 42.4 MWh/day. And the electrical energy from the gasification of MSW technology without sorting was estimated 64.9 MWh/day and with sorting was 24.4 MWh/day, but from Pyrolysis of plastic was 16.11 MWh/day. By using biochemical processes, the electrical energy from the centralized bio-digestion was estimated 22.4 MWh/day.

The economic analysis of each WtE technology for each scenario in this study has shown that in scenario one of the first year the incineration of MSW has a larger capital cost and revenues than gasification \$ 26.7 million and 3.3 million \$/yr respectively. But, it has lower running cost of \$1.88 million. The gasification capital cost was \$ 21.6 million and the running cost was \$ 2.3 million with revenues reaches 0.72 million \$/yr. In scenario two, the centralized bio-digestion has a total cost at first year, \$ 2.8 million and revenues was 0.66 \$/yr. However, the investment cost for the pyrolysis of plastic was \$ 5.7 million and operating costs was 0.33 million \$/yr with revenues of 0.47 million \$/yr. In scenario three, at the first year the incineration of MSW has a larger capital cost and revenues than others \$ 10.9 million and 1.2 million \$/yr respectively with the lowest running cost 0.35 million \$/yr.

But, centralized bio-digestion has the lowest total cost and revenues was \$ 2.8 million and 0.66 million \$/yr. And the gasification capital cost was \$ 9.0 million and running cost was \$ 0.87 million with revenues reaches 0.72 million \$/yr.

According to decentralized bio-digestion in scenario one and two, the costs of the home biogas digester for houses with the availability of a garden were \$ 159,144 and with agricultural activity was \$ 156,315. And the costs for the houses with rearing of livestock \$ 65,07. But, the costs for all numbers of housing unit were \$ 1,850,315.

The recommendation of this study is choosing the best scenario with less of environmental or economic aspects. According to the environmental aspect, the gasification and pyrolysis are environmentally friendly with low harmful gases if suitable treatment systems followed. In Anaerobic Digestion can avoid environmental hazard if the correct operation assured and leakage avoided. But, the incineration has the very bad effect on the environment.

According to economic aspects and without considering the capital cost of each technology, the incineration is recommended with the largest revenues and less running cost. Also the centralized bio-digestion and pyrolysis is good economically, but with fewer revenues. And the gasification is the largest running cost, but reasonable revenues. So, the decision is related to stakeholders in determining their priorities and possibilities by referring to the detailed study that be introduced.

## **Constraints:**

The constraints for development of WTE technologies in N & NW of Jerusalem:

### **Political status:**

- A clear comprehensive and general energy policy at a national level is still absent; neither for development of renewable resources nor for energy efficiency. This is due to the continuous Israeli occupation.
- The occupation imposed dominance and full control over all sectors in this region
- Disability to import the products due to absence of import's regulations, restrictions and obstacles imposed by Israelis.
- Furthermore, trade and industry of RE technologies in Palestine is strongly affected by the Israeli market due to the occupation and Israeli monopolizing practices on the trade movements across the borders and obstacles on import/ export of material and products. This affects the machinery and equipment needed for these technologies.

### **Technical:**

- Lack of professional technical handbook for sizing, design, installations of RE technologies.
- Lack of professional training on new applications & designs.
- Lack of regulations & provisions to implement standards or control quality.
- Lack of professional labs, testing & certification facilities.
- Lack of pilot projects and expertise especially for new applications of different types of RE.

### **Economical:**

- WTE involves a large capital investment and high operating costs
- Small scale of national projects due to the nature of small region. Unfortunately, this is usually out of concern of the regional supporting programs.
- Municipal authorities are responsible for managing MSW but have budgets that are insufficient to cover the costs associated with developing proper waste collection, storage, treatment and disposal.
- The lack of strategic government finance regulatory framework.

## **Chapter one:**

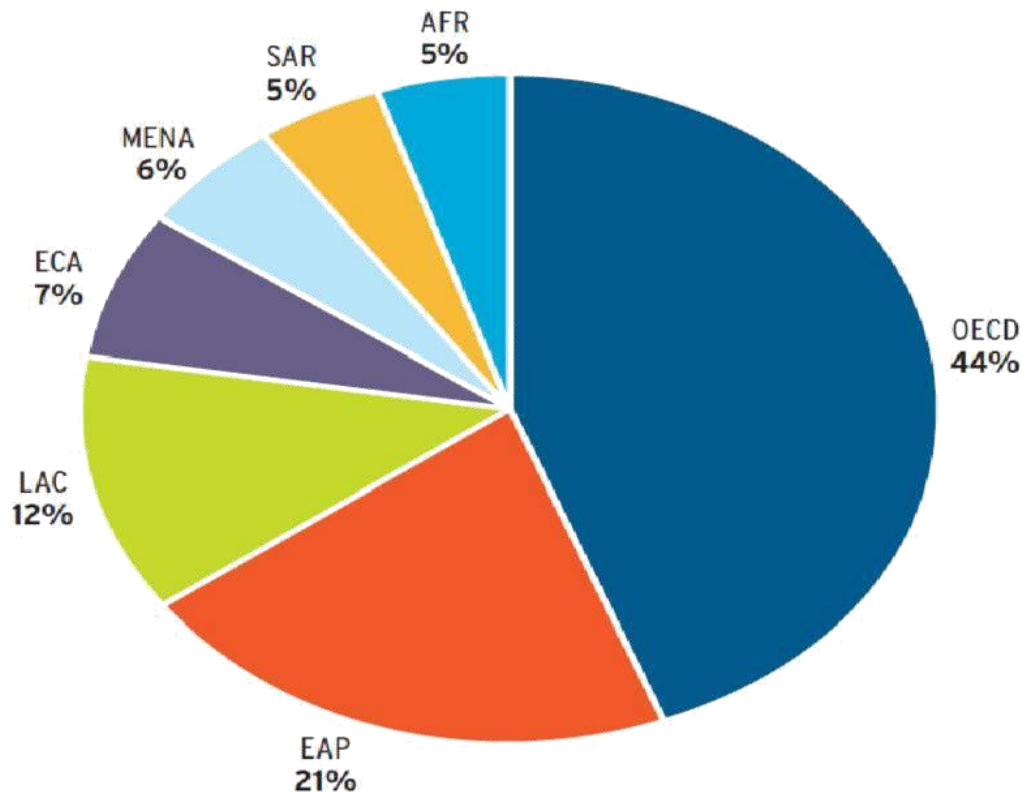
### **Introduction**

Waste is an inevitable product of society, and one of the greatest challenges for future generation is to understand how to manage large quantities of waste in a sustainable way. One approach has been to minimize the amount of waste produced, and to recycle larger fractions of waste materials. However, there still is a considerable part of undesired end products that must be taken care of, and a more suitable solution than simple land filling needs to be found.

The waste management sector faces a problem that it cannot solve on its own. The energy sector, however, is considered to be a perfect match, because of its need to continuously meet a growing energy demand. Waste is now not only an undesired product of society, but a valuable energy resource as well. Energy recovery from waste can solve two problems at once: treating non-recyclable and non-reusable amounts of waste; and generating a significant amount of energy which can be included in the energy production mix in order to satisfy the consumers' needs.

The interaction between waste management solutions and energy production technologies can vary significantly, depending on multiple factors. Different countries across the world choose to adopt different strategies, depending on social, economic and environmental criteria and constraints. These decisions can have an impact on energy security, energy equity and environmental sustainability when looking at the future of the energy sector. If waste-to-energy (WtE) technologies are developed and implemented, while following sustainability principles, then a correct waste treatment strategy and an environment friendly energy production can be achieved at the same time, solving challenges in both the waste management and energy sectors.

A World Bank report estimates that 1.3 billion tons of waste is currently being generated annually. Around the world; by 2025 this will increase to 2.2 billion tons annually. This represents a significant increase in per capita waste generation rates from 1.2 to 1.42 kg per person per day in the next 15 years. These data appear to be urgent. Need strategies to address the increase in the rate of municipal solid waste generation worldwide. However, although in developed countries waste is used by a resource to produce energy, heat, fuel and compost, in developing countries collection, transport and disposal of waste are current issues. In general, cities are unable to manage municipal solid waste effectively and are rarely able to manage more demanding services such as electricity, health, education or transportation [1]. Figure 1 illustrates global waste generation per region, where The Organization for Economic Co-operation and Development (OECD) countries make up almost half.



**Figure 1: Global waste generation per region**

Waste is a big problem in Palestine. It is facing the problem of SW like any country in the world due to increase of the population, the lack of appropriate places for the wastes and shortage of sanitary landfills. Major sources of pollution are urban wastewater, municipal SW and industrial emissions [2]. SWM is a crucial issue for life development in Palestine. In Palestine, the population growth, which is approximately 3% [3] and the development of lifestyle have resulted in an increase in the amount of the SW being generated.

Generation rate per capita was estimated to be 0.94 kg/day, in Gaza Strip (GS) at 1.045kg/day, and in the West Bank at 0.939kg/day. It is estimated that waste generation rate per year increases by 4%; where 3% is increase due to natural population growth, and 1% is due to increase in generation rate per capita. Per capita waste Generation in rural communities (very small villages) was observed to be between 0.35kg/day to 0.6 kg/day; in the big urban areas ranges from (0.9 to 2.05kg/day), while in middle size towns from 0.6kg/day to 0.9kg/day (according to Palestinian Central Bureau of Statistics (PCBS), most of these middle size towns are classified as urban areas).

The complications of the current political situation add their own challenges to the environment. There is limited Palestinian control over land and resources and there is in addition to that a disposal of Israeli waste (including hazardous waste) in the occupied Palestinian land. The implementation of sound and integrated SWM in Palestine is confronted with several challenges at the environmental, legislative, organizational, technical, and financial levels. This situation is further complicated by the lack of accurate statistical data needed for planning, decision making, and monitoring operations [4].

Solid waste disposal in sanitary landfills makes only 33% of the waste. The rest is disposed of in random dumpsites and/or burned. In the West Bank, 44% of the waste is disposed of in the two sanitary landfills of Jenin Zahrat al Finjan and Jericho, while 22% of waste in Gaza is disposed of in the sanitary landfill in Deir al Balah. There are 53 open random disposal sites in Palestine, of which more than half are not in use, however not rehabilitated yet [5]. Three sites are controlled, which means they apply daily cover, however no leachate collection, nor gas collection; while the remaining sites are active.

The construction of the West Bank Barrier and its physical structure negatively impacts the management of waste disposal in Palestinian communities located along its route. Over 20 per cent of the surveyed communities reported that the Barrier either affected their solid waste or their sewage disposal system. Limited access to sanitary waste disposal services exposes the affected Palestinian population to health risks and places a greater financial burden on them [6].

Furthermore, building and administrative restrictions imposed by the Israeli authorities on the development and implementation of waste management infrastructure projects in Area C (over 60 per cent of the West Bank), impedes the establishment of new solid and sewage waste facilities to help to alleviate waste disposal issues. In Barrier-affected areas, solid waste disposal has become a serious problem for many communities along its route [6].

With waste disposal sites behind or close to the Barrier now being rendered inaccessible, many communities are unable to dispose of their solid waste as they used to. Affected communities must either transport their waste to distant sites, at their own cost, or burn the garbage within their residential areas, releasing toxic emissions into the air and leachate into soil and groundwater. Due to increased transportation costs, villages such as Qatanna, Jerusalem, with a population of 6,458 (81 per cent of whom are Palestine refugees) have little choice but to burn their garbage within the community [6].

So we take the north and North West of Jerusalem as a case study because they are one of the most affected places by the humiliations of occupation. They are 16 Local Authorities consisting of 5 municipalities and 11 councils, We aim to design and implement short and long term strategic plans to develop an integrated solid waste management system, and to achieve effective and integrated treatment of solid waste by establishing treatment and recycling facilities for waste. Also, Launching environmental awareness campaigns that enhance the role of the community in solid waste management in collaboration with bodies local government.

The most promising solution is to get rid of waste problem is Energy-from-waste that provides: safe and economic waste disposal, greenhouse gas reduction and renewable energy. In waste management there are several methods (compositing, reuse, waste minimization, landfill, recycling). The best method is making energy from waste. In general it is a process of creating energy in the form of electricity and heat from waste.

The challenges facing the Palestinian energy sector, and evaluate the renewable energy potential in meeting part of the energy demand. In Palestine 100% of the fossil fuels and 89% of the electricity supply comes from Israel, resulting in a demand increase for both countries [7]. The conversion of agricultural waste into biodiesel can reduce diesel imports by 5%; the conversion of animal waste into biogas has the potential to replace 1.6% of the imported LPG [8].

### **Objectives for our research:**

- 1- Study the N & NW of Jerusalem area according to its location, quantity and quality of the MSW produced, the possibility of generating energy from MSW, and economic feasibility.
- 2- Encourage the exploiting the waste to energy technology and choose the suitable technology for the N & NW of Jerusalem economically and environmentally.
- 3- Production of electricity and heat from MSW and using it thus relieving mitigating waste amounts and energy reduction problems.
- 4- To create an efficient and sustainable method for MSW disposal.

## **Chapter two**

### **Waste to energy technologies**

Energy conversion from waste can be obtained by utilizing different technologies. Each one of these waste to energy (WtE) solutions has specific characteristics, and can be more or less feasible depending on many parameters. This includes the type and composition of waste, its energy content, the desired final energy form, the thermodynamic and chemical conditions in which a WtE plant can operate, and the overall energy efficiency [9].

Waste-to-energy technologies (WTE-T) are promising technologies, especially for developing countries, to turn waste into a useable form of energy. In the developed world, WTW-T is being part of their Integrated Solid Waste Management Systems (ISWM-S) to not only produce other by-products but also to address global warming and climate change. Globally, WTE-T plays a vital role for sustainable waste management and mitigation of environmental issues. These technologies are generally classified as biological treatment technologies (or Biochemical process) and thermal treatment technologies (or Thermo chemical process) [10] .

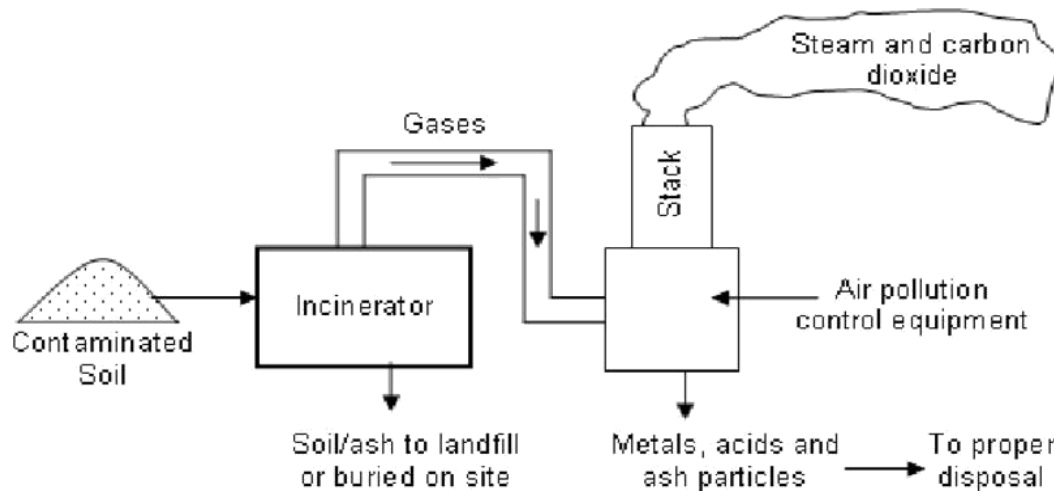
Thermo-chemical conversion methods, such as combustion, gasification and pyrolysis are suited to relative dry woody and herbaceous biomass whereas biochemical technologies, such as anaerobic digestion and alcohol fermentation can also handle biomass with high moisture content [11] .

#### **2.1Thermal treatment technologies:**

The major thermal treatment technologies currently used for municipal solid waste (MSW) treatment include: conventional combustion, gasification and pyrolysis.

##### **2.1.1Conventional combustion:-**

Conventional combustion systems combust mixed (unprocessed or minimally processed) solid waste in an incinerator. While designs vary; a typical system as shown in the graph below involves the transfer of waste by crane from a pit to a moving grate incinerator where combustion takes place. Combustion gases flow through a heat recovery boiler, where water is heated to produce steam. The steam can be used to power a turbine and associated generator, producing electric power that can be provided to the electric power grid. MSW combustion systems will have multiple air pollution control devices to control emissions of sulfur oxides, nitrogen oxides, particulate matter, and other pollutants.



**Figure2. 1: Convectional combustion process**

After combustion, the waste volume is typically reduced by 90% or more. Ash and metals are the primary residual materials. Ferrous metals are typically recovered from the residual material and recycled. Some newer facilities can recover nonferrous metals such as aluminum, copper, bronze, and brass. Ash can be landfilled with other wastes, used as a landfill cover material, or sent to a “monofill,” where only ash is disposed of. The ash may contain heavy metals and other toxic components. However, research is underway to identify beneficial uses for the ash, such as use in road paving materials or construction materials. It may also be possible to recover nonferrous metals from monofilled ash [12].

Advantages of conventional combustion:-

1. Immediate reduction in volume and weight (i.e,by reduction in 90% volume and 75% in weight)
2. Stabilization of waste
3. Energy recovery
4. Sterilization of waste

Disadvantages of conventional combustion:-

1. Not all wastes are incinerated
2. High capital cost
3. Supplemental fuel is required to imitate and at times to maintain the incineration process
4. Air pollution- Dioxins occur in the incineration of chlorine-containing substances

### 2.1.2 Gasification:-

Increasing attention is being paid to the gasification process of MSW, which is considered to be an energy efficient, environmentally friendly, and economically sound technology [13].

Diminishing landfill volume and high costs associated with traditional incineration technologies strongly increase the interest on the application of the gasification process to MSW: the evidence that gas is easier to handle (and to burn) than a solid waste makes it a candidate to become the advanced thermal treatment of the near future, for both the unsorted residual dry fraction left downstream of separate collection and that produced from mechanical treatment of MSW [14].

Gasification is defined as the thermo chemical conversion of carbon-containing materials to syngas through gas-forming reactions in an oxygen-deficient environment, using gasifying agents such as air, hydrogen, steam, and their mixtures [15, 16]. MSW gasification can prevent dioxin formation and reduce acidic gas emission due to the higher temperature and reduction conditions [17]. The products of the gasification of MSW are ash, oils, and gases, which are mainly carbon monoxide, hydrogen, carbon dioxide, and hydrocarbons [15].

Many researchers have investigated this process to evaluate the influences of operating parameters (i.e., temperature, steam-to-MSW ratio (STMR), residence time, feedstock particle size, addition of catalyst, etc.), types of feedstock, and gasifying agents on the gasification performance. In order to develop an efficient and economic MSW gasification process, it is necessary to understand how these factors influence the gasification reactions, which can provide valuable information for the better design of the MSW gasification process.

Gasification has several potential benefits over traditional combustion of solid wastes, mainly related to the possibility of combining the operating conditions (in particular, temperature and equivalence ratio) and the features of the specific reactor (fixed bed, fluidized bed, entrained bed, vertical shaft, moving grate furnace, rotary kiln, plasma reactor) to obtain a syngas suited for use in different applications. It can be utilized as a fuel gas that can be combusted in a conventional burner, connected to a boiler and a steam turbine, or in a more efficient energy conversion device, such as gas reciprocating engines or gas turbines. Its main components, carbon monoxide and hydrogen, can also offer the basic building blocks for producing valuable products as chemicals and fuels [14].

The gasification of a solid waste includes a sequence of successive, endothermic and exothermic, steps described with reference to main reactants and products:-

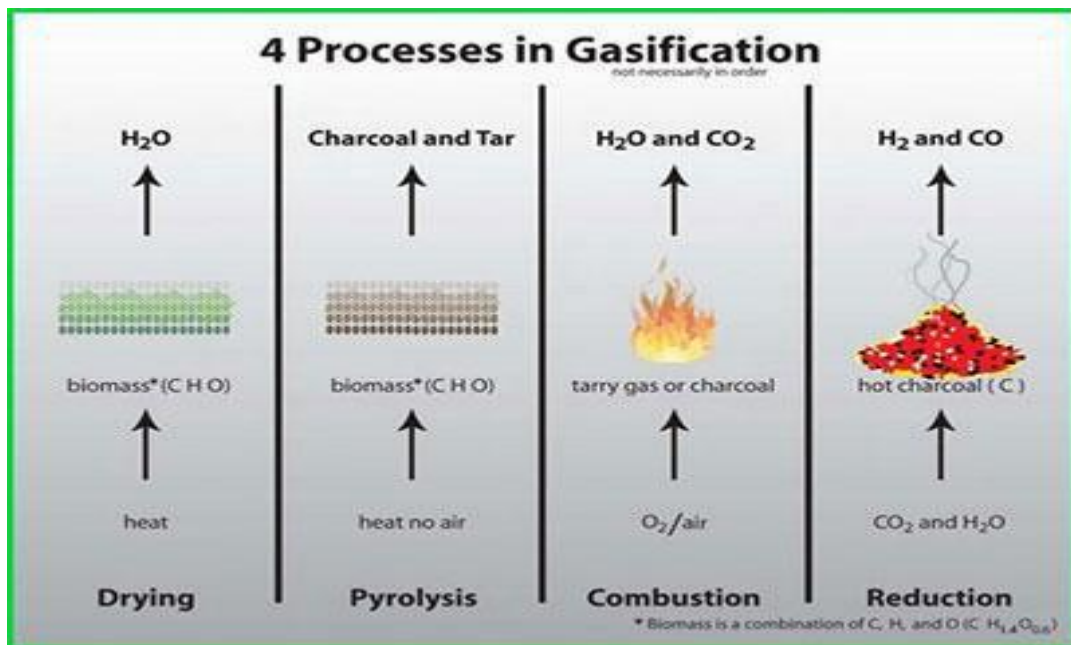


Figure2. 2: Gasification process

- Heating and drying:-that occurs at temperatures up to about 160 C: it is a combination of events that involve liquid water, steam and porous solid phase through which liquid and steam migrate.
- pyrolysis or thermal decomposition:- that occurs at temperatures up to about 700 C, involving thermal cracking reactions and heat and mass transfers and determining the release of light permanent gases (such as  $\text{H}_2$ ,  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{H}_2\text{O}$ ,  $\text{NH}_3$ ), tar (condensable hydrocarbon vapors, that release from solid matrix as gas and liquid in form of mist) and char (the remaining devolatilised solid waste residue).The composition, quantities and characteristics of chemical species released from pyrolysis (not necessarily in a single stage) depend on several factors, mainly original composition and structure of the waste[18], temperature, pressure and composition of waste-involving atmosphere and heating rate imposed by the particular reactor type [19]. It should be emphasized that pyrolysis releases many components, and hydrogen is required for molecular links in several of them: then depletes hydrogen from the original carbonaceous matrix of the waste.
- A number of chemical reactions, that occurs in a reducing environment, i.e. under a presence of oxygen remarkably lower (from 25 to 50%) than that required for a stoichiometric oxidation.

### **Gasifier types:-**

There are several different generic types of gasification technology that have been demonstrated or developed for conversion of biomass feedstock. Most of these have been developed and commercialized for the production of heat and power from the syngas, rather than liquid fuel production. The principal types are shown in the figures below , with the main differences being:

- How the biomass is fed into the gasifier and is moved around within it – biomass is either fed into the top of the gasifier, or into the side, and then is moved around either by gravity or air flows
- Whether oxygen, air or steam is used as an oxidant – using air dilutes the syngas with nitrogen, which adds to the cost of downstream processing. Using oxygen avoids this, but is expensive, and so oxygen enriched air can also be used
- The temperature range in which the gasifier is operated
- Whether the heat for the gasifier is provided by partially combusting some of the biomass in the gasifier (directly heated), or from an external source (indirectly heated), such as circulation of an inert material or steam
- Whether or not the gasifier is operated at above atmospheric pressure – pressurized gasification provides higher throughputs, with larger maximum capacities, promotes hydrogen production and leads to smaller, cheaper downstream cleanup equipment. Furthermore, since no additional compression is required, the syngas temperature can be kept high for downstream operations and liquid fuels catalysis. However, at pressures above 25 – 30bar, costs quickly increase, since gasifiers need to be more robustly engineered, and the required feeding mechanisms involve complex pressurizing steps.

### **The types:-**

#### **1. Updraft fixed bed**

- ✚ The biomass is fed in at the top of the gasifier, and the air,oxygen or steam intake is at the bottom, hence the biomass and gases move in opposite directions
- ✚ Some of the resulting char falls and burns to provide heat
- ✚ The methane and tar-rich gas leaves at the top of the gasifier, and the ash falls from the grate for collection at the bottom of the gasifier

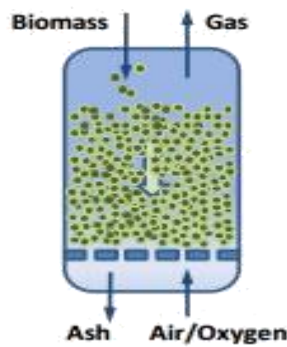


Figure2. 3:Up draft fixed gasifier

## 2. Downdraft fixed bed

- ✚ The biomass is fed in at the top of the gasifier and the air, and oxygen or steam intake is also at the top or from the sides, hence the biomass and gases move in the same direction
- ✚ Some of the biomass is burnt, falling through the gasifier throat to form a bed of hot charcoal which the gases have to pass through (a reaction zone)
- ✚ This ensures a fairly high quality syngas, which leaves at the base of the gasifier, with ash collected under the grate.

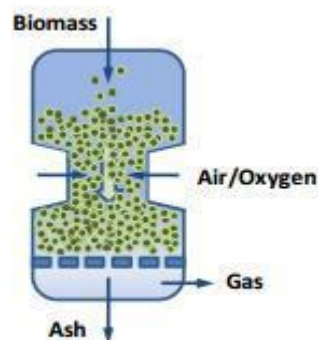


Figure2. 4: Downdraft fixed bed gasifier

## 3. Entrained flow (EF)

- ✚ Powdered biomass is fed into a gasifier with pressurized oxygen and/or steam
- ✚ A turbulent flame at the top of the gasifier burns some of the biomass, providing large amounts of heat, at high temperature (1200-1500°C), for fast conversion of biomass into very high quality syngas.
- ✚ The ash melts onto the gasifier walls, and is discharged as molten slag.

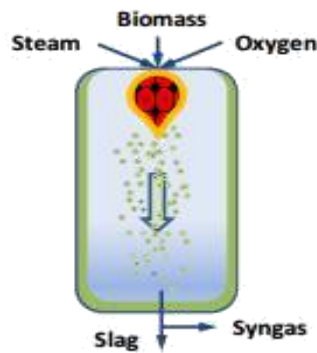


Figure2. 5: Entrained flow gasifier

#### 4. Bubbling fluidized bed (BFB)

- ✚ A bed of fine inert material sits at the gasifier bottom, with air, oxygen or steam being blown upwards through the bed just fast enough (1-3m/s) to agitate the material
- ✚ Biomass is fed in from the side, mixes, and combusts or forms syngas which leaves upwards
- ✚ Operates at temperatures below 900°C to avoid ash melting and sticking. Can be pressurized.

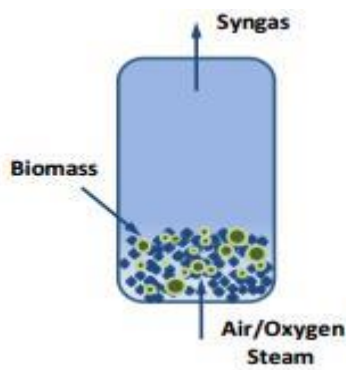


Figure2. 6: Bubbling fluidized bed gasifier

#### 5. Circulating fluidized bed (CFB)

- ✚ A bed of fine inert material has air, oxygen or steam blown upwards through it fast enough (5-10m/s) to suspend material throughout the gasifier
- ✚ Biomass is fed in from the side, is suspended, and combusts providing heat, or reacts to form syngas
- ✚ The mixture of syngas and particles are separated using a cyclone, with material returned into the base of the gasifier
- ✚ Operates at temperatures below 900°C to avoid ash melting and sticking. Can be pressurized.

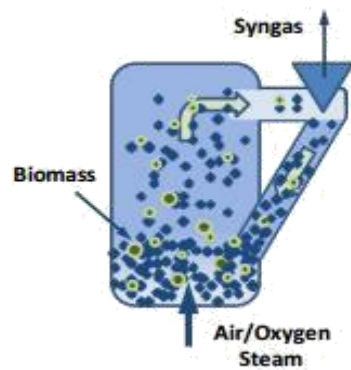


Figure2. 7: Circulating bed gasifier

## 6. Dual fluidized bed (Dual FB)

- ✚ This system has two chambers – a gasifier and a combustor
- ✚ Biomass is fed into the CFB / BFB gasification chamber, and converted to nitrogen-free syngas and char using steam
- ✚ The char is burnt in air in the CFB / BFB combustion chamber, heating the accompanying bed particles
- ✚ This hot bed material is then fed back into the gasification chamber, providing the indirect reaction heat
- ✚ Cyclones remove any CFB chamber syngas or flue gas
- ✚ Operates at temperatures below 900°C to avoid as melting and sticking. Could be pressurized.

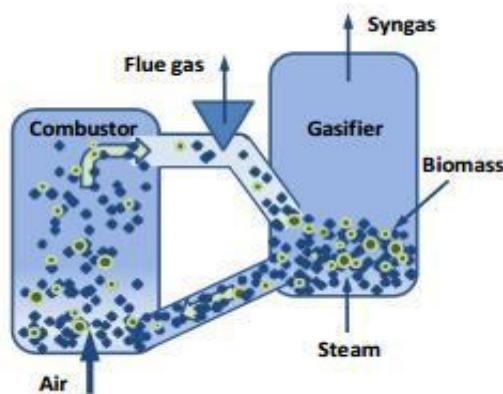
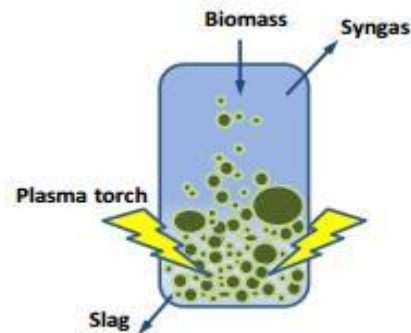


Figure2. 8: Dual fluidized bed gasifier

## 7. Plasma

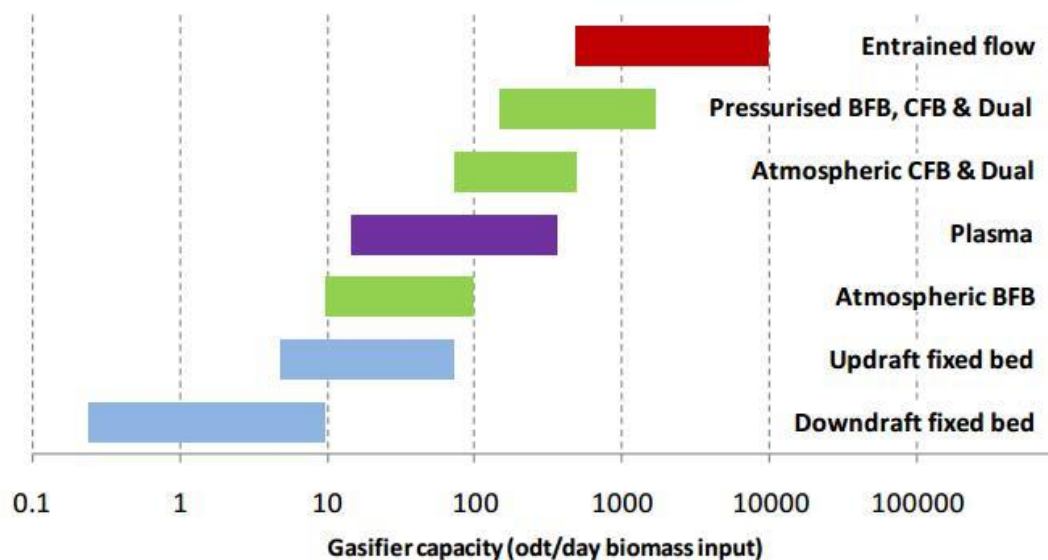
- ✚ Untreated biomass is dropped into the gasifier, coming into contact with an electrically generated plasma, usually at atmospheric pressure and temperatures of 1,500-5,000°C
- ✚ Organic matter is converted into very high quality syngas, and inorganic matter is vitrified into inert slag

- Note that plasma gasification uses plasma torches. It is also possible to use plasma arcs in a subsequent process step for syngas clean-up.



**Figure2. 9: Plasma gasifier**

Figure below shows the likely scale of operation of different gasifier types [20].

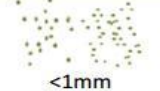
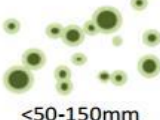
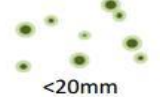


**Figure2. 10: Scale of operation for gasifier types**

- Note: **-odt** is Oven dry tonne, a unit to express the dried weight of an agricultural commodity such as biomass that contained significant water weight when harvested.
- The requirements of different gasifier types vary considerably: from EF gasifiers requiring small particle sizes, an optimal moisture content and a consistent composition over time, to plasma gasification which can accept nearly all biomass feedstock's with minimal or no pre-treatment. CFB and BFB, and Dual systems have intermediate feedstock requirements, being able to accept larger particle sizes and a wider range of moisture contents than EF, but also requiring care over the use of feedstock's with low ash melting temperatures, such as agricultural

residues. The feedstock requirements for each gasifier type are summarized in Table below

**Tabel2. 1: Feedstock requirements for gasifier types**

| Gasifier                            | Size                                                                                               | Moisture      | Composition                                                                       | Other                                                    |
|-------------------------------------|----------------------------------------------------------------------------------------------------|---------------|-----------------------------------------------------------------------------------|----------------------------------------------------------|
| EF                                  | <br><1mm          | 15%           | Should not change over time. Limited proportion of high-ash agricultural residues | Pre-treatment steps being used                           |
| BFB<br>(and Dual with BFB gasifier) | <br><50-150mm     | 10-55%        | Can change over time<br>Care needed with some agricultural residues               |                                                          |
| CFB<br>(and Dual with CFB gasifier) | <br><20mm         | 5-60%         | Can change over time<br>Care needed with some agricultural residues               |                                                          |
| Plasma                              | <br>Not important | Not important | Not important, can change over time. Higher energy content feedstocks preferred   | Used for a variety of different wastes, gate fees common |

As gasification evolves as an industry there are several key areas that could potentially reduce capital and operating expenses and further reduce environmental impact. The most obvious way is to improve removal of the harmful constituents of the synthesis gas. Better catalysts and system designs that more thoroughly eliminate tars in the product gas will have several advantages. It will allow more reliability and longer operational ability of gasifiers and turbines. Furthermore, it will enable high temperature gas clean-up technologies that offer the benefit of increased chemical to electricity efficiencies, and result in increased energy revenues. Alternatively, high temperature gas cleaning technologies, such as improved alkali “getter beds” and more durable filters that can more readily tolerate tars in the product gas stream will also improve operational efficiencies [21].

Another area that would increase the viability of waste gasification is the improvement of waste sorting and pre-treatment methods. Processing of raw MSW to a more homogeneous RDF (refuse-derived fuel) fuel with a lower non-combustible component permits a decrease in the overall bed air-to-fuel ratio below the stoichiometric point, lowering the bed temperature. Under these conditions, a very large fraction of the organic refuse component breaks down into volatile components maximizing energy production [22].

Creating a true RDF cost effectively remains one of the most difficult tasks in thermo chemical conversion of solid waste. It involves a large amount of mechanical processing and close supervision, which greatly impact operating costs and can account for as much as 40% of the total plant capital costs. If too much metal and glass are allowed to pass through into the gasifier, the heating value of the (RDF) decreases and there can be constant operational problems and plant shutdowns making the plants costly and unreliable.

If shredding and sorting of the waste can be made simpler and more effective, gasification would become even more advantageous [22]. Similarly, waste gasification will be most successful in communities where there is good recycling practice. A better job of recycling glass and food wastes by city residents will improve the gasification reactions. It should be noted that energy recovery from waste is not in competition with recycling, but rather its complement in a sound waste management plan.

In the future, gasification with pure oxygen or pure hydrogen (hydro gasification) may provide better alternatives to the air blown or indirectly heated gasification systems. This depends greatly on reducing the costs associated with oxygen and hydrogen production and improvements in refractory linings in order to handle higher temperatures. Pure oxygen could be used to generate higher temperatures, and thus promote thermal catalytic destruction of organics within the fuel gas [23].

 As a final result, summary of advantages, disadvantages and applications for gasification process as shown below:-

#### Advantages

- High efficiency at small scale
- Flexible in capacity
- Low investment

#### Disadvantages

- Complex equipment
- High maintenance cost

#### Applications

- Medium and small system
- Combined cycles, which combine gas turbines and steam turbines to produce electricity

### 2.1.3 Pyrolysis:

Pyrolysis is the thermal degradation of a substance in the absence of oxygen which makes it mostly endothermic process that ensures high energy content in the products received. Pyro means heat, lysis means breakdown into parts as in Greek symbols. This process requires an external heat source to maintain the temperature required. Typically, relatively low temperatures of between 300°C to 800°C are used during pyrolysis of materials such as MSW. The products produced from pyrolyzing materials are a solid residue and a synthetic gas (syngas). The solid residue (sometimes described as a

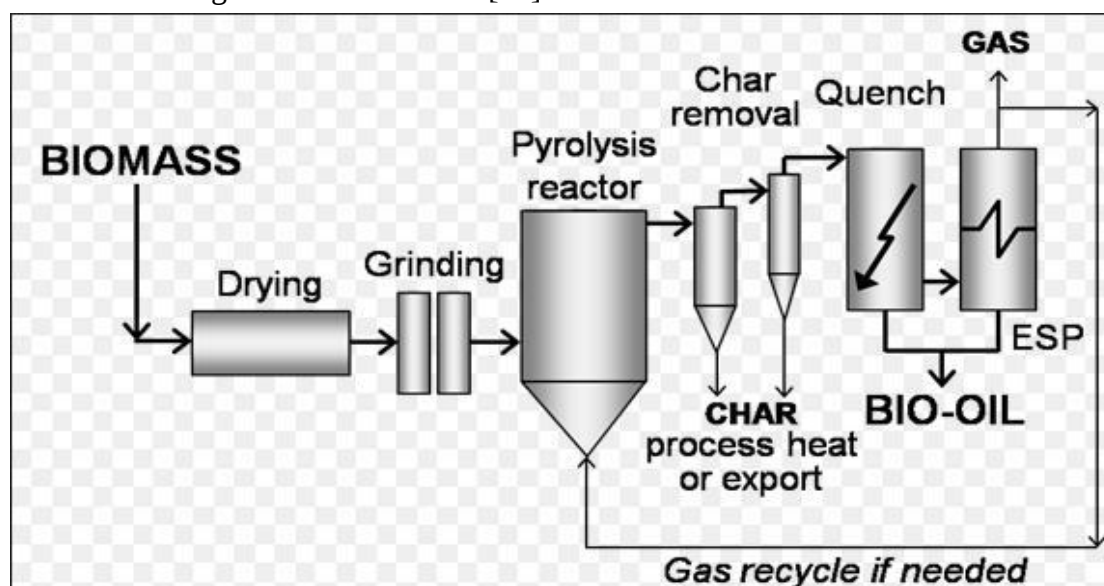
char) is a combination of noncombustible materials and carbon. The syngas is a mixture of gases (combustible constituents include carbon monoxide, hydrogen, methane and a broad range of other volatile organic compounds). A proportion of these can be condensed to produce oils, waxes and tars. The syngas typically has a net calorific value (NCV) of between 10 and 20 MJ/Nm<sup>3</sup>. If required, the condensable fraction can be collected by cooling the syngas, potentially for use as a liquid fuel [24].

The initial steps of conventional pyrolysis are usually drying and milling. From milling, raw material enters the pyrolysis chamber, where temperature is high. Condensable volatile gases (heavy hydrocarbons) are recovered and condensed after separation step. Solid products (charcoal) and liquid tar are separated for further treatment and utilization [25].

During the pyrolysis, a particle of material is heated up from the ambient to defined temperature. The material remains inside the pyrolysis unit and is transported by screw conveyor at defined speed, until the completion of the process. Chosen temperature of pyrolysis defines the composition and yields of products (pyrolysis oil, syngas and char).

#### Schematic of pyrolysis (char and Bio-oil)

Installation of a pyrolysis plant as shown in graph below starts with determining the amounts and properties of feedstock, so the circumstances, catalysts, reactor size etc. can be considered. Also it is good to define desired end product, which can be gas, charcoal or bio-oil, so operating temperatures, residence time, product yield and heating rate can be thought out. In addition, raw material suppliers are essential to find and make agreements with them [25].



**Figure2. 12: Pyrolysis process**

### **Feedstock for Pyrolysis:**

 **Moisture content of feedstock:** A wide range of biomass feedstock can be used in pyrolysis processes; process is very dependent on the moisture content of the feedstock, which should be around 10% [26].

- ✓ At higher moisture content ,high levels of water are produced and at lower levels there is a risk that the process only produces dust instead of oil
- ✓ High-moisture waste streams, such sludge and meat processing waste, require drying before subjecting to pyrolysis.

 **Particle size of feedstock:** most of pyrolysis technologies can only process small particles to a maximum of 2mm keeping in view the need for rapid heat transfer through the particle and hence demand for small particle size means that the feedstock has to be size-reduced before being used for pyrolysis [26].

### **Types of pyrolysis process:-**

It divided to four groups depend on oven temperature and residence time: Flash, fast, mild and slow pyrolysis. The table below summarizes the differences of temperature conditions, particle size and other properties between the types:-

**Tabel2. 2: Differences between pyrolysis types**

| Process         | Oven temperature<br>residence time<br>pressure | Particle size                              | Heat rate                                        | Main products             | Heating value of products | Application area                                                                            |
|-----------------|------------------------------------------------|--------------------------------------------|--------------------------------------------------|---------------------------|---------------------------|---------------------------------------------------------------------------------------------|
| Flash pyrolysis | 800 °C – 1000 °C<br>< 0.5 sec<br>1-5 bar       | < 0.2 mm<br>Biomass supply in form of dust | Very fast heating rate<br>> 1 °C/s               | Tar products<br>Bio - Oil | -                         | Power plants, diesel, boiler, resin, fertilizer, fine chemicals, transport fuels, emulsions |
| Fast Pyrolysis  | 500 °C - 600 °C<br>~ < 2 second<br>1-5 bar     | < 1 mm                                     | High heating rate<br>>100 °C/min                 | Tar products<br>Bio - oil | 17 MJ/kg                  | Power plants, diesel, boiler, resin, fertilizer, fine chemicals, transport fuels, emulsions |
| Mild Pyrolysis  | 315 °C – 450 °C<br>10-20 second<br>1-5 bar     | 5-50 mm                                    | Controlled heating rate to control tar formation | Char<br>Bio - coal        | 19 – 24 MJ/kg             | Filtration (water and air), soil improvement, power plant, pharmaceuticals                  |
| Slow Pyrolysis  | 200 °C - 300 °C<br>30 minute / days<br>1-5 bar | 5-50 mm                                    | 0.1 – 0.2 °C/sec                                 | charcoal                  | 25 - 37 MJ/kg             | Char coal (lump)                                                                            |

### ✚ Products:-

✚ Depending on the thermal environment and the final temperature ,pyrolysis will yield:-

- ✓ Mainly biochar at low temperatures, less than 450 degree Celsius, when the heating rate is quite slow.
- ✓ Mainly gases at high temperatures, greater than 800 ,with rapid heating rates.
- ✓ At an intermediate temperature and under relatively high heating rates ,the main product is bio-oil

✚ This graph Illustrates all the possible outputs from pyrolysis process:-

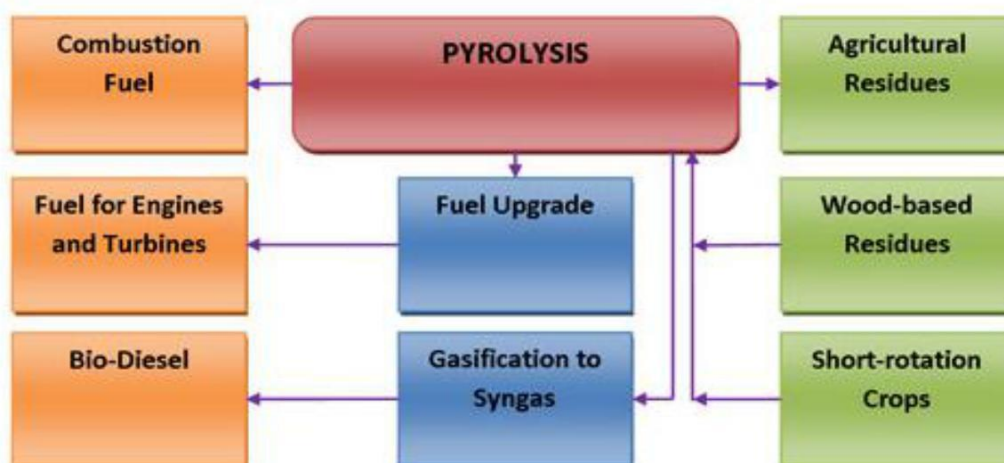


Figure2. 13: Outputs from pyrolysis process

### ✚ Bio-oil (pyrolysis-oil):-

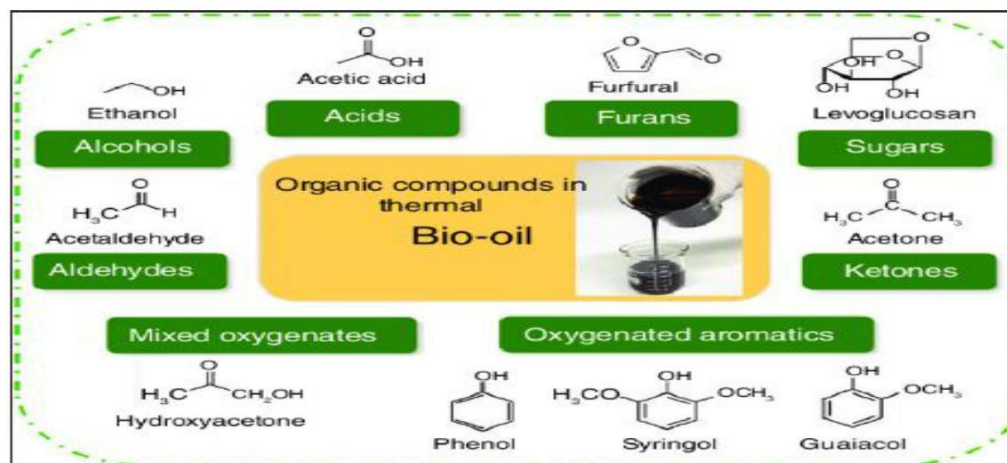


Figure2. 14: Organic compounds of Bio-oil

- ✓ Dark brown liquid
- ✓ Has a similar composition to biomass
- ✓ Much higher density than woody materials which reduces storage and transport costs.

Advantages:

- Particularly attractive for co-firing because it can be more readily handled and burned than solid fuel and is cheaper to transport and store
- Can offer major advantages over solid biomass and gasification due to the ease of handling storage and combustion in an existing power station when special start up procedures are not necessary
- In addition, bio-oil is also a vital source for a wide range of organic compounds and specialty chemicals

Disadvantages:

- Not suitable for direct use in standard internal combustion engines

 **Typical industrial applications of pyrolysis oil as a fuel:-**

Pyrolysis oil is widely used as industrial fuel to substitute furnace oil or industrial diesel.

Other uses:-

- ✓ Boilers
- ✓ Furnaces
- ✓ Hot water generator
- ✓ Thermal fluid heater

Environmental permit for the pyrolysis plant is compulsory, due to its potential environmental hazards. Environmental Impact Assessment is necessary to compose, and regulations and legislative systems related to waste streams are taken into account. Also the collection and transportation of waste is regulated. These regulations vary also from country to country [27].

The pyrolysis process is producing and handling hazardous compounds, such as Co, H<sub>2</sub> and hydrocarbons. Carbon monoxide is very toxic compound; it can cause dizziness and even in low. For the possible leaks of Co, a ventilation system and a Co detection device are necessary. Furthermore, glowing particles can ignite or cause an explosion, if there is a source for ignition presents [28].

Malfunction in the process, for example electrical malfunction, or inadequate activity of boiler can cause hazards. In addition, boiler feed-water and steam loss can cause boiler malfunctions. Electrical malfunction can cause problems with control systems, with severe consequences. Finally, the bio-oil and charcoal have be stored, handled and transported properly to prevent any safety and health hazards [25].

 Advantages of waste pyrolysis

Better control and optimization of pyrolysis process:

- conditions of thermal decomposition (temperature and pressure),
- conditions of pyrolysis products burning,
- conditions of pyrolysis products conversion,

- pollutant emissions (gaseous and dust)
  - ✚ Disadvantages of waste pyrolysis
- The waste incineration installations based on pyrolysis process has several disadvantages in comparison to the combustion processes:
- less capacity,
  - less efficiency,
  - more sophisticated,
  - more expensive.

## **2.2Biological treatment technologies:-**

### **2.2.1Anaerobic digestion:-**

Large amount of biomass waste is generating every year from agricultural, forestry, food, and other industries. As a result, there is an opportunity to improve the sustainability of energy production by converting this locally abundant biomass waste into bioenergy products using anaerobic digestion [29].

Anaerobic digestion is extensively acceptable as an efficient process to treat and utilize food waste because it has proven to be promising method for waste reduction and energy recycling [30]. Landfilling is a dangerous process because the leachate containing organic and inorganic contaminants poses a risk of ground water contamination. This leachate problems calls for leachate management and treatment facility. Green house gasses must be collected. Facing this problem, many countries all over the world started recycling the waste and developed management infrastructure programs [31].

Anaerobic digestion is the biological process in which the biodegradation and stabilization of complex organic matter in the absence of oxygen with a consortium of microbes lead to the formation of energy-rich biogas. It is used to replace fossil fuel. The residues of anaerobic digestion process are nutrient-rich, used as soil amendment [32].

Food waste not only contains molecular organic matter, but also contains various trace elements. Currently, anaerobic digestion process has become an intensive field of research, since the organic matter in the food waste is suited for anaerobic microbial growth. During anaerobic digestion process, organic waste is biologically degraded and converted into clean gas. In most of the studies, anaerobic digestion process is mainly divided into four steps as shown below: hydrolysis, acidogenesis, acetogenesis, and methanogenesis [33].

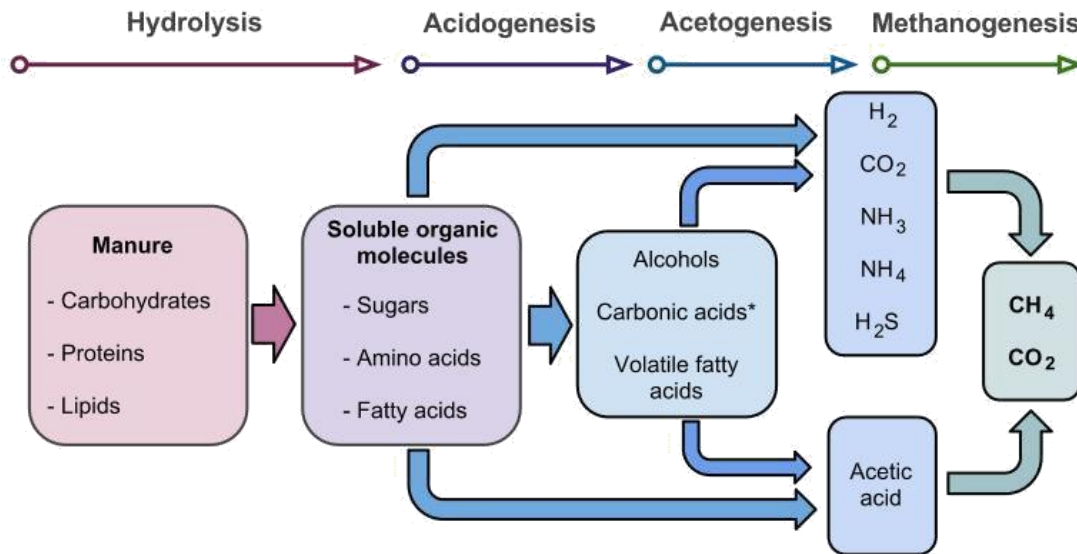
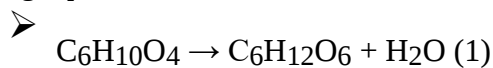


Figure2. 16: Anaerobic digestion process

#### Hydrolysis:-

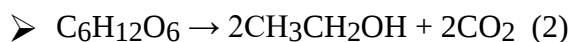
Complex organic molecules like proteins, polysaccharides, and fat are converted into simpler ones like peptides, saccharides, and fatty acids (Figure, stage-1) by exoenzymes like cellulase, protease, and lipase produced by hydrolytic and fermentative bacteria [34]. End products are soluble sugars, amino acids, and glycerol and long-chain carboxylic acids [35]. Overall reactions (1) are represented by the following equations



Hydrolysis is a relatively slow process and generally limits overall reaction. The overall conversion of polymers into soluble monomers is catalyzed by enzymes known as hydrolases or lyase like esterase, glycosidase, or peptidase [34].

#### Acidogenesis:-

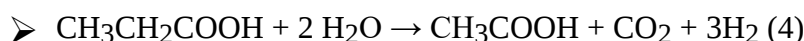
In acidogenesis, the product of hydrolysis peptides, saccharides, and fatty acids are converted into simpler molecules having low molecular weight like organic acids alcohols, carbon dioxide, hydrogen, and ammonium. The existence of oxygen and nitrates is considered toxic and inhibits the anaerobic process. So, the presence of oxygen removing bacteria is vital to remove the oxygen and facilitate anaerobic conditions. During acidification process, pH reduces to 4 [36]. Byproducts like ammonia and hydrogen sulfide are also produced (Figure, stage-2). Overall reaction is represented by the following Equations (2 and 3) [37].



The acid-phase bacteria belonging to facultative anaerobes use oxygen accidentally introduced into the process, creating favorable conditions for the development of obligatory anaerobes of the following genera: Pseudomonas, Bacillus, clostridium, Micrococcus, or Flavobacterium [38].

#### **Acetogenesis:-**

In acetogenesis, the product of acidogenesis is converted into acetic acid, hydrogen, and carbon dioxide by acetate bacteria (Figure, stage-3). Before methanogenesis acetic acid is formed. Homoautotrophic acetogenesis is produced by acetate from hydrogen and carbon dioxide. Overall reactions (4), (5), and (6) [39] are shown as:

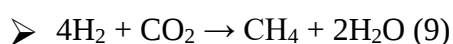
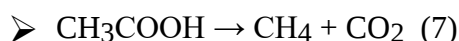


The first three steps are together known as acid fermentation. In this process, no organic matter is removed from liquid phase but converted to as substrate for further process of methanogenesis [36].

#### **Methanogenesis:-**

In this final step of anaerobic digestion, the products of the acetogenesis are converted into methane gas by two groups of microbes known as acetoclastic and hydrogen-utilizing methanogens (Figure, stage-4). The acetoclastic methanogens convert acetate into carbon dioxide and methane. Hydrogen-utilizing methanogens reduce hydrogen and carbon dioxide into methane. The former process is dominant producing about 70% of methane in anaerobic digestion because hydrogen is limited in anaerobic process [40].

The overall reaction (7), (8), and (9); [41] of methane production is described by the following chemical reactions



#### **General Characteristics:-**

The composition of food waste depends upon eating habitats, cultivation, and availability. The food waste mainly comprises rice, vegetables, meat, egg, bread, meat, etc. The presence of high moisture content in food waste indicates the high biodegradability [42]. The characterization of substrate and inoculate is vital before feeding the digester. TS (total solid) and VS (volatile solid) are mostly measured according to the Standard Methods [43], pH is determined using a pH meter.

#### ✚ Waste particle size

Particle size directly affects the decomposition, calls for particle reduction by crushing, gridding, and shredding. It increases surface area action for microbes, ultimately improves the efficiency of digester.

✚ C/N ratio the ratio of C and N plays a crucial role in anaerobic digestion. The carbon acts as energy source and nitrogen serves to enhance the microbial growth. These two nutrients often act as limiting factor. Optimum ratio is between 20 and 30 [44]. The gas production is low due to high C/N ratio by rapid consumption of nitrogen. On the other hand, low C/N ratio causes ammonia accumulation. PH value exceeds 8.5 that is toxic to methanogenesis. Optimum C/N ratio can be achieved by mixing substrate of low and high C/N ratio [45]. It has been found that conversion of carbon to nitrogen in digestion process is 30–35 times faster, so ratio of C/N should be 30:1 in raw substrate. Nitrogen is considered as limiting factor and nitrogen sources like urea, bio-solids, and manure could be used as supplements' C/N ratio between 20 and 30 provide sufficient nitrogen for anaerobic process. C/N between 22 and 25 is best for anaerobic digestion of fruit and vegetable wastes [46].

#### ✚ Comparative properties and composition of biogas

Before loading the digester, food waste must undergo pretreatment. After this the digester is fed with substrate and gas is produced by systematic reactions. The gas produced is known as gobar gas or digestion gas, or natural gas sewage gas. Depending upon the existing condition. The gas is colorless, odorless, and flammable having calorific value between 4500–5000 kcal/m<sup>3</sup> and burns with blue flame if methane content is present [47].

**Tabel2. 3: Bio gas composition [48]**

| Gas               | CH <sub>4</sub> | CO <sub>2</sub> | N <sub>2</sub> | H <sub>2</sub> | H <sub>2</sub> S | O <sub>2</sub> | C <sub>x</sub> H <sub>y</sub> | NH <sub>3</sub> | R <sub>2</sub> SiO |
|-------------------|-----------------|-----------------|----------------|----------------|------------------|----------------|-------------------------------|-----------------|--------------------|
| Concentration (%) | 50–70           | 25–30           | 0–10           | 0–5            | 0–3              | 0–3            | 0–1                           | 0–0.5           | 0–50               |

✚ **Contaminants can cause damage to AD equipment.** Components not suitable for AD treatment plant include:

- Inorganic materials (e.g., glass, plastics, metals and sand)
- Wood wastes
- Bone from food wastes
- Soil
- Disinfectant, pesticides and antibiotics in feedstock'

 **Scale of AD:-**

**Tabel2. 4: Differences between scales of AD**

| <b>Size</b> | <b>Approximate tonnage</b> | <b>Approximate energy production</b> | <b>Typical Applications</b>                                               |
|-------------|----------------------------|--------------------------------------|---------------------------------------------------------------------------|
| Small       | up to 7,500                | 25 – 250 kW(e)                       | Household or farm                                                         |
| Medium      | 7,500 – 30,000             | 250kW – 1MW(e)                       | Farm or manufacturing facilities producing digestible waste               |
| Large       | 30,000 or more             | >1 MW(e)                             | Centralized, mixed feedstock sources (municipal, commercial & industrial) |

 **Differences Between AD Size:-**

**Tabel2. 5: Differences between small and large scale AD**

| <b>Small-Scale AD</b>                   | <b>Large-Scale AD</b>                             |
|-----------------------------------------|---------------------------------------------------|
| On-site waste management                | Multiple sources of feedstock                     |
| Low to no transport cost                | Feedstock delivered to site as a source of income |
| Rural locations                         | Centralized facilities                            |
| Can attract higher subsidies            | Subsidies may be available                        |
| Can offer simple design and maintenance | More complex design and maintenance               |

AD processes are characterized by the following:

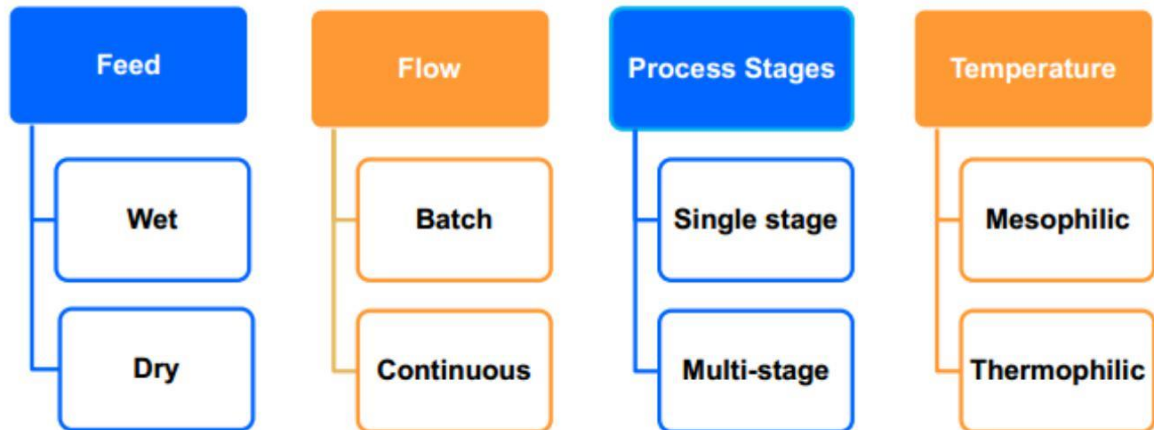


Figure2. 17: AD process characterization

➤ **Feed:**

**Wet**

- <15% dry solids
- Waste is macerated prior to processing
- Examples include food waste, manure, slurry

**Dry**

- Higher dry solid content 15-40%
- No water addition
- Less mechanical treatment
- Examples include green wastes and energy crops

Figure2. 18: Differences between wet and dry feed to AD

➤ **Flow:-**

**Batch**

- The digestion process, or a stage of the digestion process, is allowed to start and finish in a single vessel.
- Once complete the vessel is emptied and the process is restarted with new feedstock.
- A series of vessels may be used to overcome peaks and troughs in flows of feedstock and gas production.

**Continuous**

- Feedstock flows through the plant continuously.
- Avoids the need to empty digesters and restart the process – a labour-intensive and time-consuming process.
- Biogas generation tends to be more consistent, although biogas generation rates may be lower than for batch processes.



Figure2. 19: Differences between batch and continuous flow in AD

➤ **Process stages:-**

**Single-stage process**

- Digestion occurs in a single reactor
- The plant design is simpler and more economical
- Produces less biogas
- Feedstock takes longer to digest

**Multi-stage process**

- Two or more reactors to optimize process
- Helps to further degrade feedstock
- Extracts more biogas

---

Figure2. 20: Differences between single and multi stage process in AD

➤ **Temperature:-**

**Mesophilic**

- Operates at 30-40°C
- Stable process
- Suitable for slurries and industrial and commercial food wastes
- Most popular option in developed countries
- Retention time 15-30 days

**Thermophilic**

- Operates at 50-60°C
- More complex & less stable
- Suitable for a wider range of feedstocks
- More expensive due to higher energy input requirement
- Retention time of 12-14 days

---

Figure2. 21: Differences between mesophilic and thermophilic temperatures in AD

➤ Typical Technology Costs as to the figure:-

|              | Capital | Operational |
|--------------|---------|-------------|
| Thermophilic | \$\$\$  | \$\$\$      |
| Mesophilic   | \$      | \$          |
| Wet          | \$      | \$\$\$      |
| Dry          | \$\$\$  | \$          |
| Continuous   | \$\$\$  | \$          |
| Batch        | \$\$\$  | \$          |
| Singe stage  | \$      | \$          |
| Multi stage  | \$\$\$  | \$\$\$      |

\$\$\$ = higher  
\$ = lower

Figure2. 22: Capital and Operational cost for AD Technologies

## Advantages of Anaerobic Digesters

- **Advantages** of anaerobic digesters
  - Methane recovery by most of the microbial biomass produced in aerobic growth (biogas), can be used as alternate fuel source (**green solution**).
  - Reduces production of landfill gas, which when broken down aerobically releases methane into atmosphere (a powerful greenhouse gas).
  - Sludge occupies less volume, easier to dry.
  - Lower operating costs.
  - Odours/flies typically removed from system.
- **Disadvantages** of anaerobic digesters:
  - Accumulation of heavy metals and contaminants in sludge.
  - Narrow temperature control range.
  - Installing and managing an interrelated group of systems to safely handle heating of the tank, hydrogen sulphide reduction, methane transfer, heat production, electrical production, inter connection with the electrical grid and surplus heat management.

Figure2. 23: Advantages and disadvantages of AD

### 2.2.2 Landfill:

Landfills are the physical facilities used for the disposal of residual solid wastes in the surface soils of the earth. In the past, the term sanitary landfill is used to describe a landfill in which the waste placed in the landfill was covered at the end of each day. Today, sanitary landfill refers to an engineered facility for the municipal solid waste designed and operated to minimize public health and environmental impacts [52].

The term *cell* is used to describe the volume of material placed in a landfill during one operating period, usually one day. A cell includes the solid waste deposited and the daily cover material surrounding it. During landfill operations, waste is spread thinly and compacted before it is covered by daily cover. It usually consists of 15.24 cm to 30.48 cm (6 to 12 in) soil or alternative material which is applied to the working faces of the landfill at the end of the each operating period. The purpose of daily cover is to control the infestation of pests, to limit windblown debris, to cover unsightly waste and to prevent infiltration of rain and snow melt into compacted waste.

A *lift* is a complete layer of cells over the active area of the landfill. Typically, landfills consist of a series of lifts. The final lift includes the cover layer. The term bench (or terrace) is commonly used where the height of the landfill will exceed to 15.24 m to 22.86 m (50 to 75 ft). Benches are used to maintain the slope stability of the landfill, for the placement of surface water drainage channels, and for the location of landfill gas recovery piping. The final cover layer is applied to the entire landfill surface after all landfilling operations are finished. It usually consists of multiple layers of soils and geomembrane materials which are designed to enhance surface drainage, intercept percolating water, and support surface vegetation.

*Leachate* is known as the liquid collected at the bottom of the landfill. In general, leachate is a result of the percolation of precipitation, uncontrolled runoff, irrigation water into the landfill, the water initially contained in the waste and also infiltrating groundwater. It contains a variety of chemical constituents derived from the solubilization of the materials deposited in the landfill and from the products of the chemical and biochemical reactions occurring within.

*Landfill gas* is the mixture of gases within a landfill. It mainly consists of methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>). These are the principal products of the anaerobic decomposition of the biodegradable organic fraction of the municipal solid waste in the landfill. Other components of landfill gas include atmospheric nitrogen and oxygen, ammonia, and trace organic compounds.

*Landfill liners* are materials (both natural and manufactured) used to line the bottom area and below grade sides of a landfill. Liners usually consist of layers of compacted clay and geomembrane material designed to prevent migration of landfill leachate and landfill gas [52].

### **Common Land filling methods:-**

The active methods for disposal of municipal solid waste in landfills;

- 1) 1-excavated cell / trench.
- 2) 2-area.
- 3) 3- Canyon.

#### 1-Excavated cell/trench method

The excavated cell/trench method of landfilling is suitable for areas where an adequate depth of cover material is available at the side and where the water table is not near the surface. Typically, solid wastes are placed in cells or trenches excavated in the soil. The excavated soil from the site is used for daily and final cover. The excavated cells or trenches are usually lined with synthetic membrane liners or low permeability clay or a combination of the two to limit the movement of both landfill gases and leachate [52].

A variation of this method is the artesian or zone of saturation landfill. These landfills are constructed below the naturally occurring groundwater table. Special provisions should be made to prevent groundwater from entering the landfill and to control the movement of leachate and gases from completed cells. Usually the site is dewatered, excavated and then lined. The dewatering facilities are continued until the site is filled to avoid the creation of uplift pressures which may cause the liner to heave and rupture [53].

#### 2- Area method

The area method is used when the terrain is unsuitable for the excavation of cells or trenches. High groundwater conditions necessitate the use of the area type landfills. Site preparation includes the installation of a liner and leachate control system. Cover material must be carried by truck or earthmoving equipment from adjacent land or from borrow-pit areas. In locations with limited availability of material compost produced from waste can be used as cover. Other techniques include the use of movable temporary cover materials such as soil and geomembranes. Temporarily placed soil and geomembranes over a completed cell, can be removed before the next lift is begun [52].

#### 3- Canyon/Depression method

In this method, canyons, dry borrow pits, and quarries are used for landfills. The techniques to place and compact solid wastes in canyon/depression landfills vary with the geometry of the site, the characteristics of the available cover material, the hydrology and geology of the site, the type of the leachate and gas control facilities to be used, and the access to the site. Typically, filling for each lift starts at the head end of the canyon and ends at the mouth to prevent the accumulation of water behind the landfill. Canyon/depression sites are filled in multiple lifts, and the method of operation is the same as the area method. If a canyon floor is reasonably flat, the

initial landfilling may be carried out using the excavated cell/trench method. The availability of adequate material to cover the individual lifts and to provide a final cover over the entire landfill is very important. Cover material is excavated from the canyon walls or floor before the liner system is installed. Borrow pits and abandoned quarries may not contain sufficient soil for intermediate cover, so that it may have to be important [52].

**Tabel2. 6: Advantages and disadvantages of landfill**

| <b>LANDFILL ADVANTAGES</b>                                                                                                       | <b>LANDFILL DISADVANTAGES</b>                                                                                                |
|----------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| burying can produce energy and can be obtained by the conversion of landfill gas.                                                | Imported waste Reduction of landfill Lifetime.                                                                               |
| The waste products of landfills can be used as direct fuel for combustion or indirectly they can be processed into another fuel. | The areas surrounding the landfills become heavily polluted.                                                                 |
| The landfill is a specific location for a waste deposition that can be monitored.                                                | The landfill can pollute the air, water and also the soil.                                                                   |
| On completion of the landfill, it can be reclaimed and it can be used as parks or farming land.                                  | In a poorly developed landfill, it is difficult to keep the dangerous chemicals from leaching out into the surrounding area. |
| Disposal strategy up to 30 years                                                                                                 | Dangerous chemicals can seep into the groundwater system.                                                                    |
| In properly designed landfills the waste can be processed and all recyclable materials can be used before closing.               | Many insects and rodents are attracted to landfills and can result in dangerous diseases.                                    |
|                                                                                                                                  | It can cause diseases and illness in the communities living around the landfill.                                             |

## Chapter three

### Study Area

#### 3.1 Location

**Jerusalem** Is a city in the Middle East, **located** is located on coordinates  $31^{\circ}47'N$ ,  $35^{\circ}15'E$ . Jerusalem lies 48 kilometers (30 miles) east of the Mediterranean Sea. It is bordered on the north, south, and east by the West Bank of the Jordan River. it is 757 meters (2,484 feet) above sea level. Our case study as shown in the figure represented by the north and north-south of Jerusalem which are 16 Local Authorities



**Figure3. 1: Map of North and North-west Jerusalem regions**

Consisting of 5 municipalities and 11 councils with population of ( 54,540) According to data provided by the Central Bureau of Statistics and the percentage of population increase. This census was estimated for the period until the data were obtained for the latest census as shown below:

**Tabel3. 1: Population of North and North-west of Jerusalem**

| Population<br>2018 / تعداد 2018 | Population<br>2017 / تعداد 2017 | Population 2016<br>/ تعداد 2016 | Population 2015<br>/ تعداد 2015 | Name / اسم الهيئة المحلية<br>of LGU      |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|------------------------------------------|
| 2872                            | 2824                            | 2775                            | 2727                            | Rafat/ رافات                             |
| 1427                            | 1402                            | 1378                            | 1354                            | Qalandia/ قلنديا                         |
| 1297                            | 1274                            | 1252                            | 1230                            | Beit Hanina/ بيت حنينا                   |
| 2756                            | 2709                            | 2661                            | 2614                            | Al-Jdeerah/ الجديرة                      |
| 5829                            | 5731                            | 5631                            | 5533                            | Nabala Beir/ بير نابلا                   |
| 8226                            | 8087                            | 7947                            | 7809                            | Biddu/ بدو                               |
| 2292                            | 2254                            | 2215                            | 2177                            | Beit Iksa/ بيت اكسا                      |
|                                 |                                 |                                 |                                 | النبى صمونيل / Al-Nabi Sumoa'el          |
| 314                             | 308                             | 302                             | 296                             | Beit Ijza/ بيت اجزا                      |
| 844                             | 830                             | 816                             | 802                             | Beit Sureik/ بيت سوريك                   |
| 4704                            | 4624                            | 4544                            | 4465                            | Beit Duqqu/ بيت دقو                      |
| 1962                            | 1929                            | 1895                            | 1862                            | Beit Duqqu/ بيت دقو                      |
| 5107                            | 5021                            | 4933                            | 4847                            | Al-jeib/ الجيب                           |
| 4817                            | 4735                            | 4653                            | 4572                            | Beit Anan/ بيت عنان                      |
| 3837                            | 3773                            | 3708                            | 3644                            | Alqubaiba/ القبية                        |
| 7814                            | 7684                            | 7550                            | 7418                            | Qatannah/ قطننة                          |
| 438                             | 431                             | 424                             | 417                             | Om Al-Iahem/ ام اللحم                    |
| 54540                           | 53617                           | 52684                           | 51767                           | المجموع الكلي للسكان<br>Total Population |

The amount of waste to be collected in north and north-west of Jerusalem is about 98 tons per day. According to the data in the table below and on the information collected based on the size of the waste vehicles and the number of rounds for each council.

**Tabel3. 2: Information about numbers of collected waste in study area**

| موقع التخلص النهائي    | عدد النفايات بالاسبوع | تكرار الجمع     | مناطق الجمع                                                     |
|------------------------|-----------------------|-----------------|-----------------------------------------------------------------|
| مكب بيت عنان الصحي     | 6                     | 6 ايام بالاسبوع | بدو                                                             |
| مكب بيت عنان الصحي     | 8                     | 6 ايام بالاسبوع | القبية + بيت عنان                                               |
| مكب بيت عنان الصحي     | 6                     | 6 ايام بالاسبوع | مجلس مشترك شمال القدس (رافات، الجديرة، بيت حنينا، قلنديا البلد) |
| مكب بيت عنان الصحي     | 6                     | 3 ايام بالاسبوع | الجيب                                                           |
| مكب بيت عنان الصحي     | 5                     | 5 ايام بالاسبوع | قطننة                                                           |
| مكب بيت عنان الصحي     | 1                     | 2 يوم بالاسبوع  | بيت اكسا                                                        |
| مكب بيت عنان الصحي     | 1                     | 1 يوم/الاسبوع   | خربة ام اللحم                                                   |
| مكب بيت عنان الصحي     | 0.5                   | 1 يوم / اسبوعين | النبى صمونيل                                                    |
| مكب بيت سوريك العشوائي | 9                     | 3 ايام بالاسبوع | بيت سوريك                                                       |
| مكب بير نابلا العشوائي |                       | 2 يوم بالاسبوع  | بير نابلا                                                       |

In the current situation, waste is collected by tracks and tours that have been designed by local authorities using waste collection vehicles designated for them.

### 3.2 Problems related to region:-

There are 16 population gatherings in the north and northwest of Jerusalem, which touch the geographical borders of occupied Jerusalem and the Palestinian coast, where the historic Jerusalem Street of Jaffa. The second group includes nine villages: Badu, Beit Ijsa, Beit Diku, Beit Surik, Beit Iksa, Nabi Samuel, Qubeiba, Qatneh, and the villages of Rafat, Bir Nabala, Jadira, , Beit Anan, and an isolated area called "the ruin of the flesh" from the territory of Qutna, adjacent to the village of Abu Ghosh inside the Green Line (occupied Palestinian territory). In the area, after the Israeli occupation authorities closed the only landfill located on the land of Beit Anan village. And the closure of the main road leading to the landfill in Beit Anan, and prevented the use of villages in the area of the landfill. These villages were placed in front of a difficult option after the construction of the Apartheid Wall as shown below



**Figure3.2: Apartheid wall**

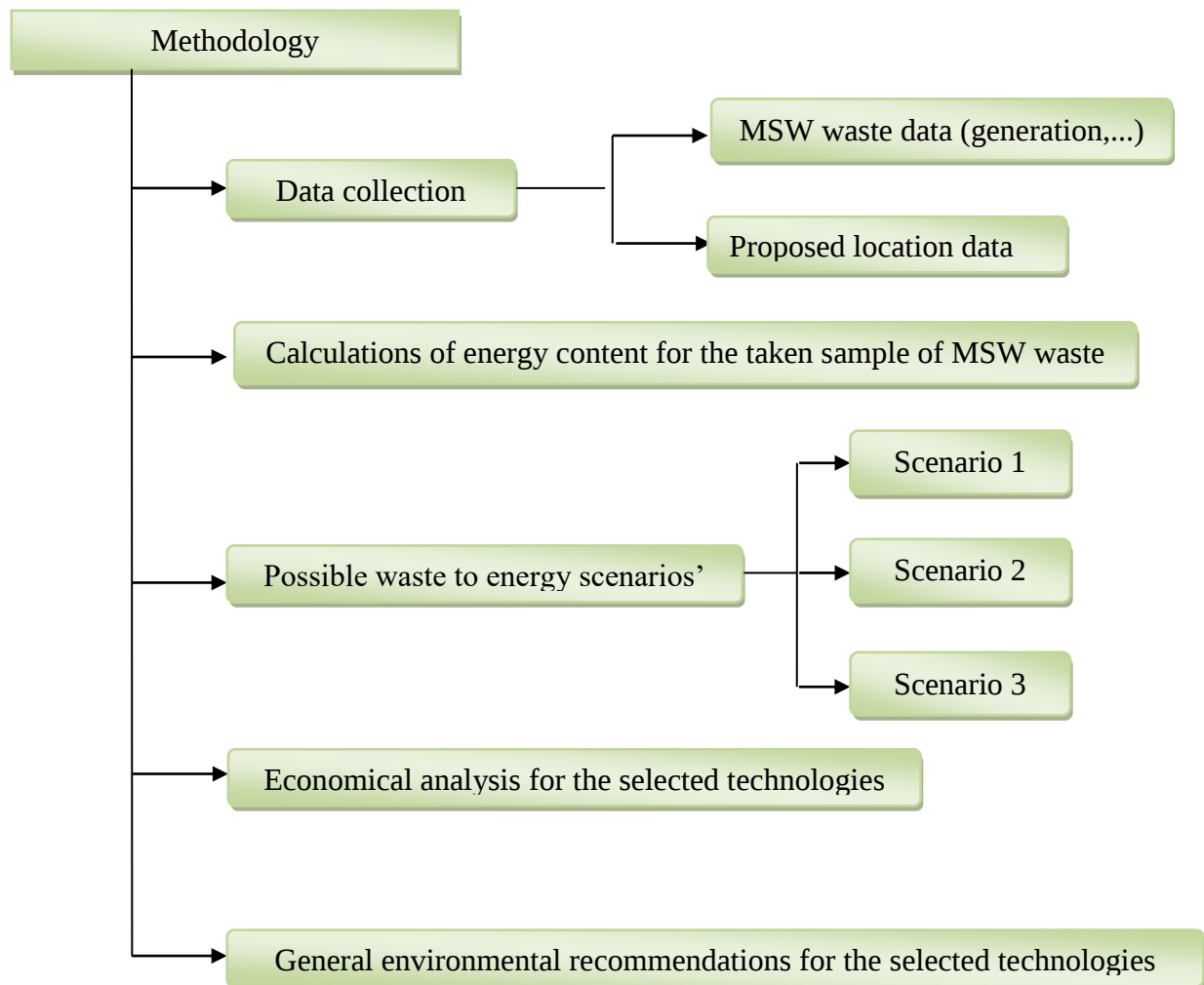
, which claimed the largest part of the lands of most of these villages. About 70 per cent of the land of the village of Jib, 80 per cent of the land of Beit Iksa, 50 per cent of the land of Beit Iksa, one of the villages completely isolated by the Wall, which forced many of its inhabitants to leave, as well as the village of the Prophet Samuel. Which forced the implementation of a joint project cost of thousands of dollars is a dump of waste on the remote lands of the village of Beit Annan, but the occupation authorities closed the main street will be opened wide doors to the spread of epidemics and diseases, and the environmental threat to the entire region .

## **Chapter four**

### **Methodology**

The scope of this work is to find an effective and integrated treatment process for the conversion of municipal solid waste to energy for the North and North West of Jerusalem.

To achieve this scope, strategies as followed in the flow chart below were followed. At first, specified data about the MSW related to generation, collection, composition and moisture content were be determined. Also, we collected data about the proposed location for chosen technology. Then, the calculations of energy content of MSW were made to see how much energy we can get from the selected quantity of MSW waste. Moreover, we suggested the possible waste to energy scenarios' to achieve the greatest possible benefit, and to confirm this more precisely, Economical analysis is made for the selected technologies. At last, as the environment plays an important part in waste to energy technologies and projects, General environmental recommendations for the selected technologies were made.



## **Chapter five**

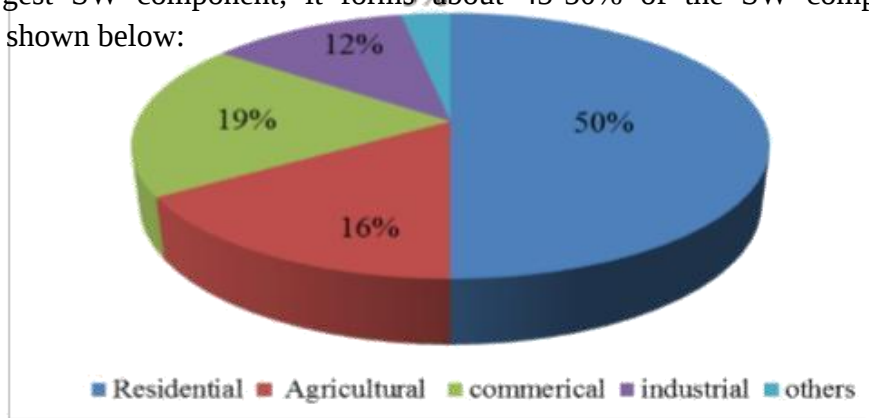
### **.Results and discussion:**

#### **5.1 Data collection**

##### **5.1.1Municipal solid waste (MSW):**

Municipal solid waste MSW (also called trash or garbage) is defined at the national level as wastes consisting of everyday items such as product packaging, grass clippings, furniture, clothing, bottles and cans, food scraps, newspapers, appliances, consumer electronics, and batteries. These wastes come from homes; institutions such as schools and hospitals; and commercial sources such as restaurants and small businesses. EPA's definition of municipal solid waste (MSW) does not include municipal wastewater treatment sludge's, industrial process wastes, automobile bodies, combustion ash, or construction and demolition debris [54].

The amount of MSW is affected by many factors such as a number of populations, income level, political, and natural. There is an important to know the components of MSW to choose the best method to deal with it. Household waste is the most important and the largest SW component; it forms about 45-50% of the SW components in Palestine as shown below:



**Figure5.1: percentages of solid waste resources in Palestine**

Residential and commercial are composed primarily of organic waste such as leftovers food, as well as the inorganic such as paper, plastic, glass, iron, scrap and clothing worn components [54].

##### **MSW Generation:**

The amount of waste that can be collected, processed and disposed (or converted to energy) in North and North West of Jerusalem, is about 98 tons per day. This amount was recently sent to the landfill.

### MSW Collection:

The waste is collected according to the tours that were previously designed by the bodies and waste collection policies as shown in table 3.2 above. In which there is no perfect path to waste collection. Therefore, the Council will do the of work and we will take the waste directly from assembly places.

### MSW Composition:

Figure1 shows the composition of waste of municipalities of the study area. Organic wastes were the most abundant ones sharing 59.1 % of total, while plastics and papers shared 14.2% and 10.1%. All other wastes shared only 11.5% of total waste.

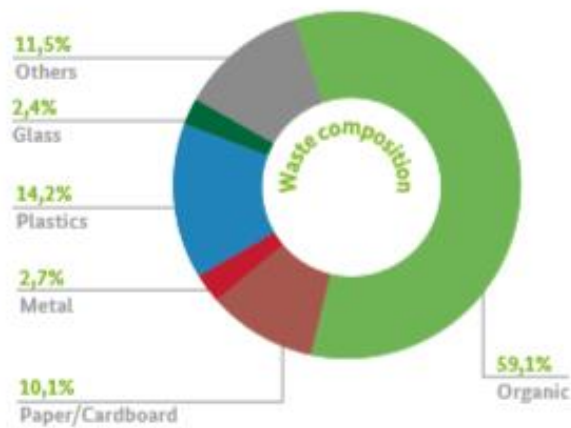


Figure5.2: Percentage share of total waste of municipalities of study area

### Moisture Content of the MSW:

The MSW is categorized into four strata: organic wastes, paper wastes, plastics wastes and other wastes (contained textile wastes, dusts, and electronic wastes). Table5.1 shows the percentage of moisture content and dry weight for the four strata of MSW [55].

The moisture content for the use of these MSW into waste to energy conversion system is important because moisture content is an important determinant factor in the energy content of waste substance [55]. Moisture content of MSW for this study was calculated and was 47.62 %.

Table5. 1: Percentage of moisture content of MSW

| Type of waste | Quantity of waste(kg) | Moisture content (percentage) | Dry weight (percentage) |
|---------------|-----------------------|-------------------------------|-------------------------|
| Organic       | 1                     | 70                            | 30                      |
| Plastic       | 1                     | 05                            | 95                      |
| Paper         | 1                     | 20                            | 80                      |
| Other         | 1                     | 10                            | 90                      |

The total weights of moisture content of municipal solid waste of study area are given in the Table 5.2.

**Table5. 2: Total weight of moisture content in MSW**

| Type of waste | Total municipal waste (ton) | Moisture weight (ton) | Dry weight (ton) |
|---------------|-----------------------------|-----------------------|------------------|
| Organic       | 58.0                        | 40.6                  | 17.4             |
| Plastic       | 14.0                        | 00.7                  | 13.3             |
| Paper         | 10.0                        | 2.00                  | 8.0              |
| Other         | 11.3                        | 1.13                  | 10.2             |
| Total         | 93.3                        | 44.43                 | 48.9             |

### Energy Evaluation of Waste

The average energy content of these wastes [55] is presented in Table 5.3. Among all categories, plastics have highest energy content and category organic has second most energy content in the waste stream. Paper and organic wastes have similar energy content per kg; however, high volume in the waste composition for organic waste has more contribution in energy content of overall MSW.

**Table5. 3: Total energy content of MSW**

| Type of waste | Dry weight (ton) | MJ of energy per( ton) | Total energy of MSW(GJ) |
|---------------|------------------|------------------------|-------------------------|
| Organic       | 17.4             | 15680                  | 272.8                   |
| Plastic       | 13.3             | 40610                  | 540.1                   |
| Paper         | 8.0              | 15640                  | 125.1                   |
| Other         | 10.2             | 17550                  | 179.0                   |
| Total         | 48.9             |                        | 1117                    |

Gross total energy (Gte) in the municipal solid waste was found to be 1117 GJ. But this did not consider the heat required to convert moisture content in the waste to gas, i.e. Ed. Because, during conversion of waste to energy, all the wastes are accepted in the wet state and there is certain energy required to dry out that moisture from the waste to be able to accept as fuel. Thus, it is needed to subtract latent heat of vaporization from the gross total energy. This is also called as Net total energy (Ne) [55].

### Solid waste management

Management of solid waste reduces or eliminates adverse impacts on the environment and human health and supports economic development and improved quality of life. A number of processes are involved in effectively managing waste for a municipality. These include monitoring, collection, transport, processing, recycling and disposal.

LCA is a popular tool widely used to assess the environmental impact of waste management systems

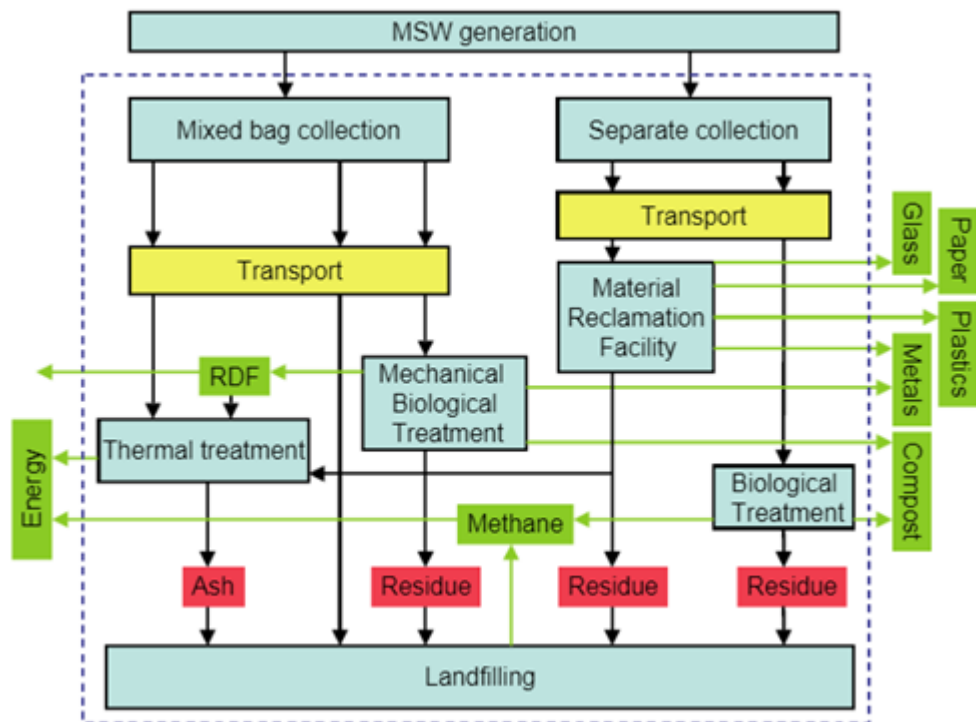


Figure5.3: The complete life cycle of MSW

There are two different strategies for conversion the MSW to energy:

- **Without sorting**: to take all waste together without any separations.
- **With sorting**: to separate the waste into organic waste, plastic, metals, glass and residue and handle each part individually. The sorting can be centralized which performed by the municipality at a suitable site (i.e. within plant) or be decentralized just done for organic waste using home biogas digester at the source (i.e. within the household).

#### 5.1.2. Proposed Location for chosen technology:

Selection of the appropriate location for MSW fueled Power Plant is subject to certain sources which include the distance from population localities, accessibility from the localities, distance from nearest power hub (grid station) etc. The proposed site for Power Plant is shown in Fig. 1 by the help of Gemology site and is about 1 km away from Biet Liqya, and 2.03 km away from Biet Anan.



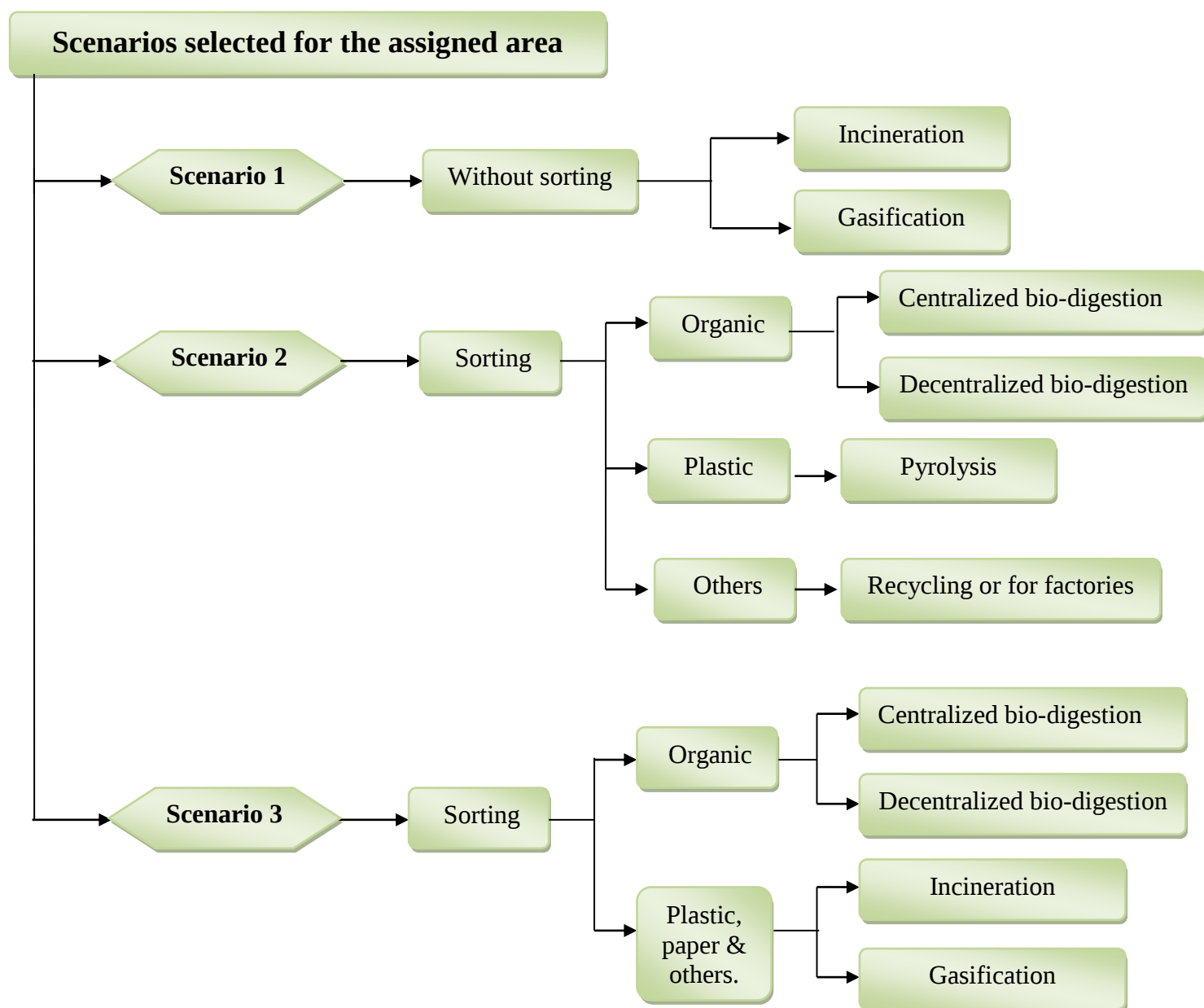
Figure5.4: Proposed area on Gemology



Figure5.5: Proposed area on Gemology with distance from nearest residential area

## 5.2. Scenarios':

The diagram below shows all the scenarios identified and evaluated in this study:



### 5.2.1. Scenario 1:

In this scenario, all collected waste is taken and either incinerated or gasified.

#### **1. Incineration:**

Combustion of MSW is the complete oxidation of MSW (unprocessed or minimally processed) in an incinerator.

Heating value is the amount of heat produced by a complete combustion of fuel and it is measured as a unit of energy per unit mass or volume of substance. Considering Literature Review and taking percentage by Mass theoretical calculations are as follows  $C=48.9$ ,  $H=6$ ,  $O=33.9$ ,  $S=0.3$  where  $C$ ,  $H$ ,  $O$  and  $S$  are the % of these elements on dry ash free basis [56]. Applying to formulae:

$$HV (kJ/kg) = 338.2 \cdot C + 1442.8 \cdot (H - O/8) + 94.2 \cdot S \quad [56].$$

We get Heat Energy Generated = 19.1 MJ/kg.

First, heat energy generated is used to calculate steam energy which is 70% [56] of heat energy and was calculated 13.4 MJ/kg.

Above calculated steam energy is used to run the turbines, these turbines are coupled with generators which produces electricity.

Considering the conversion efficiency of 31.6% [56] in a power plant heat input of 11.4 MJ/kWh is required.

So electric power generation = Steam energy  $\div$  11.4  
= 1.2 kWh/kg.

Total weight of MSW collected from study area 93.3 tons/day which equal 93300 kg/day.

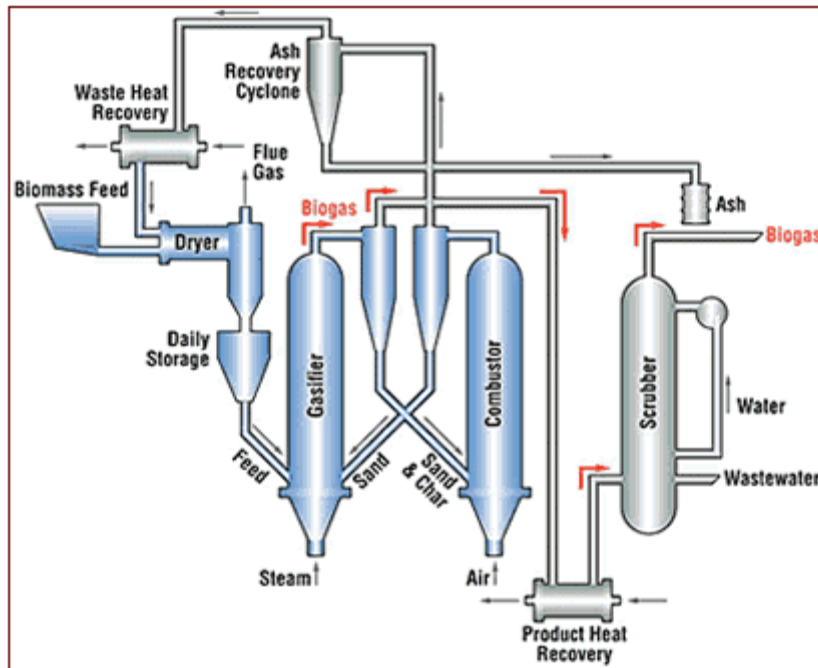
Total electric power generation is 112 MWh/day.

#### **2. Gasification**

MSW gasification is defined as the thermo chemical conversion of carbon-containing materials to syngas through gas-forming reactions in an oxygen-deficient environment, using gasifying agents such as air, hydrogen, steam, and their mixtures. The products of the gasification of MSW are ash, oils, and gases, which are mainly carbon monoxide, hydrogen, carbon dioxide, and hydrocarbons.

In this study we choose the medium heating value gasification system developed by Battelle and licensed to Future Energy Resources Corporation (FERCO) [57].

This technology utilizes a circulating fluidized bed gasification reactor, operating at about 850 C and near atmospheric pressure. This process uses two physically separate reactors: (1) a gasification reactor in which the MSW is converted into a medium-heating value gas and residual char, and (2) a combustion reactor that burns the residual char to provide heat for gasification. Heat transfer between reactors is accomplished by circulating sand between the gasifier and the combustor [3]. Flow sheet of the the Battelle gasification process circulating fluidized bed gasifier are shown in Figure 5.6.



**Figure5.6: Flow sheet of Battelle steam-reforming gasifier [57].**

The product gas composition for gasification results for the 45.25% moisture content for MSW that syngas composition shows 25-30% CO, 20-35% H<sub>2</sub>, and 22-40% CO<sub>2</sub> [58].

Battelle has experimented with a MSW feedstock in their Process Research Unit (PRU) and this pilot plant was concluded from these studies that throughputs of about 396.5 cubic meter per ton MSW of product gas with 0.0186 GJ HHV of product gas per cubic meter as shown in table 5.4 [57]. So the electric power generation from 93.3 ton/day of MSW is 60.3 MWh/day with electrical efficiency gasification 34% [59] as shown in table 5.4.

**Table5. 4: Calculation of gasification process with capacity of 34054.5 ton/year**

|                                                 |         |
|-------------------------------------------------|---------|
| MSW capacity (ton/year)                         | 34054.5 |
| Volume of product gas (m <sup>3</sup> /ton MSW) | 396.5   |
| Volume of product gas (Mm <sup>3</sup> /year)   | 13.5    |
| HHV of product gas (MJ/ m <sup>3</sup> )        | 18.6    |
| HHV of product gas (TJ/ year)                   | 251     |
| Electrical efficiency gasification(%)           | 34      |
| Electrical production from MSW (TJ/year)        | 85.3    |
| Electrical production from MSW (GWh/year)       | 23.7    |
| Total electric power generation (MWh/day)       | 64.9    |

### 5.2.2 Scenario 2:

In this scenario, organic waste was separated from the total waste and two paths were suggested either to be centralized or decentralized and the details were shown below, Also plastic was separated and treated by pyrolysis. What remains It was suggested to go for recycling.

- **1. Sorting the organic waste** at centralized which performed by the municipality at a suitable site (i.e. within plant) or be decentralized just done for organic waste using home biogas digester at the source (i.e. within the household).

#### Anaerobic digestion of the organic part:

Anaerobic digestion is the biological process in which the biodegradation and stabilization of complex organic matter in the absence of oxygen with a consortium of microbes lead to the formation of energy-rich biogas. It is used to replace fossil fuel.

##### 1.1 Organic → centralized bio-digestion:

Total waste quantity organic in MSW in this study is 58 ton/day.

Few assumptions are made,

Organic biodegradable fraction (33%) [6] = 19.1 ton/day. Typical digestion efficiency (60%) = 11.5 ton/day.

Typical biogas efficiency(0.8) [60] =  $0.8 \times 11500 \text{ kg} = 9200 \text{ m}^3/\text{day}$

Typical biogas efficiency (80%) we get  $9200 \text{ m}^3/\text{day}$ .

Net Calorific value (C.V) of biogas =  $5000 \text{ Kcal/m}^3$  [60].

Energy recovery potential =  $\text{NCV} \times 9200 \times 1.16 \times 10^{-3} = 53,360 \text{ kWh/day}$ .

The Electrical energy production with generator efficiency 42% is 22.4 MWh/day.

##### 1,2 Organic → decentralized bio-digestion:

The sorting is at household only for organic waste and converts it into clean biogas and liquid fertilizer in the backyard of the house.

Home biogas is a user-friendly appliance that utilizes naturally-occurring bacteria to transform all organic waste into clean, renewable cooking gas and liquid fertilizer. It is compatible with both rural and peri-urban lifestyles. The appliance is ideal for families who live in a warm climate area in a detached or a semi-detached home with a garden [61]

Home biogas is an off-grid system that generates clean energy without any electricity and allows to properly treating the household waste. The system produces up to 2 hours of cooking gas every day solely from food scraps or animal waste. Using home biogas for one year will reduce your carbon emissions by 6 tons, making it a must-have for anyone aiming to transition to a more sustainable lifestyle. Everything you need arrives in a small box; it only takes 1 hour to install [61].

The maximum amount can feed home biogas daily is 12 liters ( $0.012 \text{ m}^3$ ) of food waste mixed with water or 40 liters ( $0.400 \text{ m}^3$ ) of animal manure mixed with water and it can accept all food, including meat, fish, oil and fats [61].

Every liter of food waste put into the appliance produces about 200 liters of gas, the amount needed to cooking for one hour over a high flame. On average, home biogas produces up to 3 hours of cooking gas each day – the perfect amount for a family [61].



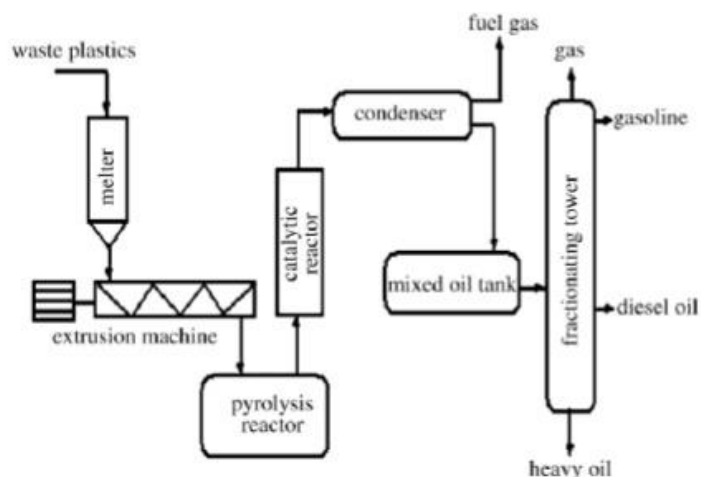
**Figure5.7: Home biogas digester [61].**

## 2. Sorting → Plastic

### Pyrolysis

Pyrolysis of MSW is defined as a thermo-chemical decomposition of MSW at elevated temperatures, approximately between 500 °C and 800 °C, in the absence of air and it converts MSW into gas (syngas), liquid (tar) and solid products (char). Figure 6 shows the plastic waste to pyrolysis fuel.

#### Process Flow Diagram of Waste Plastic Pyrolysis



**Figure5.8: Flowchart of pyrolysis process for plastic waste**

Plastic plays a vital role in enhancing the standard lives of human being for more than 50 years. It is a key of innovation of many products in various sectors such as construction, healthcare, electronic, automotive, packaging and others. The demand of commodity plastics has been increased due to the rapid growth of the world population. The global production of plastic has reached about 299 million tons in 2013 and has increased by 4% over 2012 [62].

Plastics may take up to billions of years to degrade naturally. They degrade gradually since the molecular bonds containing hydrogen, carbon and few other elements such as nitrogen, chlorine and others that make plastic very durable. The continuous disposal of plastic in the landfill would definitely cause serious environmental problem.

Pyrolysis is widely seen as a promising technology for converting plastic waste into a oil product which can be used as a heavy fuel oil substitute or as raw material by the petrochemical industry and the obtained gas product runs electric generators.

In our case the total amount of plastic 13.3 ton/day would converted to liquid fuel with thermal efficiency of 70.3% [59] and the energy content of this amount is 540.1 GJ/day so the output energy pyrolysis process is 379.7 GJ/day, while the conversion of liquid fuel to electricity with electric efficiency of 15.25% [59] so the electrical production is 58 GJ/day which 16.11 MWh/day.

### **3. Sorting → others (e.g. paper)**

Recycling refers to the removal of items from the waste stream to be used as raw materials in the manufacture of new products. Thus from this definition recycling occurs in three phases: first the waste is sorted and recyclables collected, the recyclables are used to create raw materials. These raw materials are then used in the `production of new products.

The sorting of recyclables may be done at the source (i.e. within the household or office) for selective collection by the municipality or to be dropped off by the waste producer at a recycling centers. The pre-sorting at the source requires public participation which may not be forthcoming if there are no benefits to be derived. Also a system of selective collection by the government can be costly. It would require more frequent circulation of trucks within a neighborhood or the importation of more vehicles to facilitate the collection.

Another option is to mix the recyclables with the general waste stream for collection and then sorting and recovery of the recyclable materials can be performed by the municipality at a suitable site. The sorting by the municipality has the advantage of eliminating the dependence on the public and ensuring that the recycling does occur. The disadvantage however, is that the value of the recyclable materials is reduced since being mixed in and compacted with other garbage can have adverse effects on the quality of the recyclable material.

Recycling in industrialized countries generally costs much more than disposal to land, but governments are willing to support recycling for environmental reasons. The figure below shows the materials that can be recycled:



Figure 5.9: the waste that can be recycled

### 5.2.3 Scenario 3:

In this scenario, the organic waste was separated and followed the same strategies that done in scenario 2. Then, what remains had two paths either to be incinerated or gasified as elaborated below in details:

#### 1. sorting → organic

The same as in scenario 2 above

#### 2. Sorting → others

##### 2.1. Incineration

Total weight of organic solid waste collected after separated from MSW is 35.3 tons/day which equal 35300 kg/day.

We get Heat Energy Generated = 19.1 MJ/kg.

Steam energy which is 70% [56] of heat energy and was calculated 13.4 MJ/kg.

Above calculated steam energy is used to run the turbines, these turbines are coupled with generators which produces electricity.

With conversion efficiency of 31.6% [56] in a power plant heat input of 11.4 MJ/kWh is required. So electric power generation is 1.2 kWh/kg with 35.3 ton/day

And total electric power generation is 42.4 MWh/day.

## 2.2. Gasification

After separation the moisture and dry of MSW the capacity needs for gasification process is dry MSW 12884.5 ton/year and 396.5 cubic meter per ton MSW of product gas with 0.0186 GJ HHV of product gas per cubic meter [57] with total electric power generation 24.4 GWh/day for 12884.5 ton/year as shown in table 5.5.

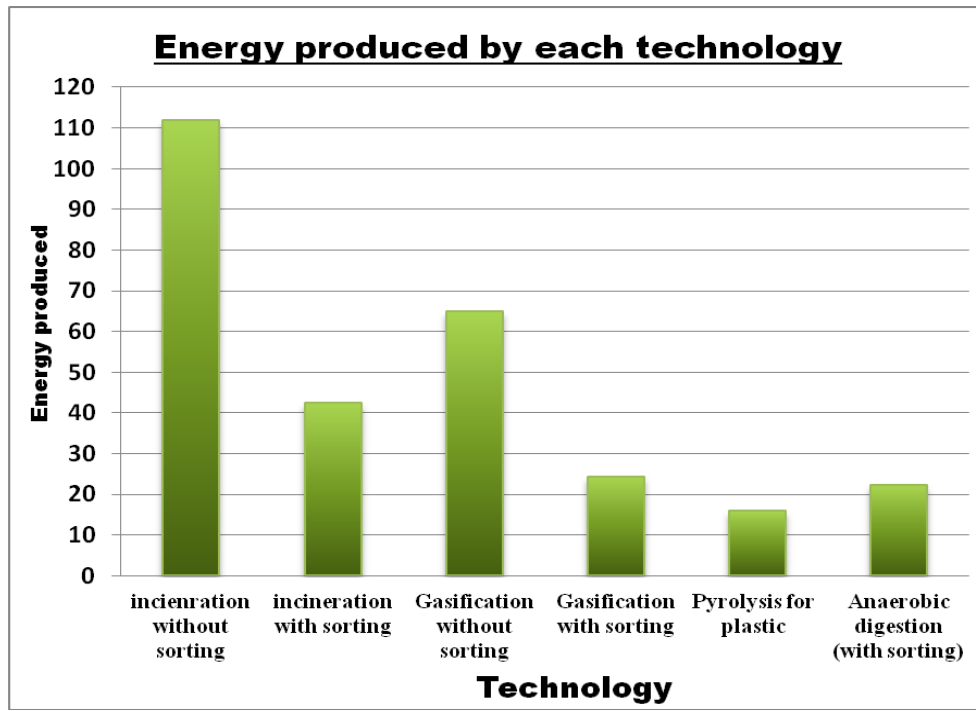
**Table5.5: Calculation of gasification process with capacity of 12884.5 ton /year**

|                                           |         |
|-------------------------------------------|---------|
| MSW capacity (ton/year)                   | 12884.5 |
| Volume of product gas (m3/ton MSW)        | 396.5   |
| Volume of product gas (Mm3/year)          | 5.1     |
| HHV of product gas (MJ/ m3)               | 18.6    |
| HHV of product gas (TJ/ year)             | 95      |
| Electrical efficiency gasification(%)     | 34      |
| Electrical production from MSW (TJ/year)  | 32.3    |
| Electrical production from MSW (GWh/year) | 8.9     |
| Total electric power generation (MWh/day) | 24.4    |

The table below showed a comparison between all selected technologies in terms of components, net electric power generated, products and its uses.

**Table5. 6: the comparison between four technologies**

| Metrics of comparison                   | Incineration                        |                            | Gasification                                    |                            | Pyrolysis (with sorting)                        | Anaerobic digestion(with sorting)    |
|-----------------------------------------|-------------------------------------|----------------------------|-------------------------------------------------|----------------------------|-------------------------------------------------|--------------------------------------|
|                                         | Without sorting                     | sorting                    | Without sorting                                 | sorting                    |                                                 |                                      |
| The component of MSW                    | Organic, Paper, Plastic and others. | Paper, Plastic and others. | Organic , Paper, Plastic and others.            | Paper, Plastic and others. | Plastic.                                        | Organic.                             |
| Net Electric power generation( MWh/day) | 112                                 | 42.4                       | 64.9                                            | 24.4                       | 16.11                                           | 22.4                                 |
| Intermediate product                    | Heat                                |                            | Syngas                                          |                            | Charcoal, Bio-oil and Syngas                    | Biogas                               |
| Final used                              | Electricity and heat                |                            | Electricity, Chemicals, heat and transport fuel |                            | Electricity, Chemicals, heat and transport fuel | Electricity, heat and transport fuel |



### **5.3 Economic feasibility**

Land acquisition cost: is calculated based on the area of the land needed and the current price of the type of land needed. The area of the land needed in this study is estimated to be 58462 m<sup>2</sup>, while the current price of the selected land in N & NW is owned by a country in the JSC and 22,000 NIS (according to an Eng. Mustafa Hammed in Joint Services Council for Solid Waste Management - North and North West Jerusalem) is paid monthly to the municipality)(5888\$/month).

#### **Without sorting**

##### **1. Incineration:**

**Table5.7: Costs of incineration [63]**

| size( t/year) | capital cost (\$/ton/year) | running cost(\$/ton/year) | capital cost (million \$) | running cost(million \$) |
|---------------|----------------------------|---------------------------|---------------------------|--------------------------|
| 34045.5       | 743.02                     | 55.11                     | 26.7                      | 1.88                     |
| 12884.5       | 743.02                     | 27.55                     | 10.9                      | 0.35                     |

The cost of kWh in N & NW of Jerusalem is 0.3 NIS/kWh , so the cost of electrical energy produced from the incineration of 93.3 ton/day of MSW with 112000 kWh/day was 33600 NIS/day and 12.3 million NIS/yr (3.3 million \$/yr).

The cost of electrical energy produced from the incineration of 35.3 ton/day of MSW with 42400 kWh/day was 12720 NIS/day and 4.6 million NIS/yr (1.2 million \$/yr).

##### **2. Gasification**

#### **Has two ways:-**

1) Capital costs of gasification \$ 86,000 per short ton of MSW per day for the Battelle plant [57] for 93.3 ton/day is \$ 8 million and for 35.3 ton/day is \$ 3 million.

- Running Cost \$/t excluding capital cost and energy returns

**Table5.8: costs of gasification [63]**

| size(<br>t/year) | capital cost<br>(\$/ton/year) | running<br>cost(\$/ton/year) | Capital cost<br>(million \$) | Running Cost<br>(million \$) |
|------------------|-------------------------------|------------------------------|------------------------------|------------------------------|
| 34054.5          | 591.73                        | 67.76                        | 21.6                         | 2.3                          |
| 12884.5          | 591.73                        | 67.76                        | 9.0                          | 0.873                        |

The cost of kWh in N & NW of Jerusalem is 0.3 NIS/kWh , so the cost of electrical energy produced from the gasification of 93.3 ton/day of MSW with 64900

kWh/day was 19470 NIS/day and 7.1 million NIS/yr (1.9 million \$/yr).

The cost of electrical energy produced from the gasification of 35.3 ton/day of MSW with 24400 kWh/day was 7320 NIS/day and 2.7 million NIS/yr (0.72 million \$/yr).

### **With sorting**

#### **1. Anaerobic digestion of the organic part:**

### **Have two scenarios:-**

#### **1. Centralized**

Volume and construction of the digester:

The potential of biogas production and the size of digester are essentially depended on the amount of organic waste. The organic waste can be classified to wet matter and dry matter content. So, for calculating the amount of total organic waste it is necessary to take into account the water content that should be added to the substrate of the anaerobic digestion process. The water content in the organic waste of this study is about 70% of the total weight contents and the organic dry matter is about 30% [55].

**Table5. 9: Total organic waste added to the digester**

| Total amount of<br>organic waste<br>(kg/day) | Dry waste amount<br>$m_{dry}$ (kg/day) | Added water<br>amount $m_{water}$<br>(kg/day) | Total organic waste<br>mass added to<br>digester (kg/day) |
|----------------------------------------------|----------------------------------------|-----------------------------------------------|-----------------------------------------------------------|
| 58000                                        | 17400                                  | 116000                                        | 174000                                                    |

The digester volume calculation based on the length of the retention time ( $R_t$ ) which is about 30 days and the amount of organic waste that should added to the digester is 174000 kg/day. It is necessary to take into account the collecting factor ( $f_{col}$ ) of the wastes which is equal to 1.25. The volume of the digester  $V_d$  can be calculated as:

$$V_d (m^3) = m_{tot} \times R_t \times f_{col} [64].$$

So the volume of the digester is 6525  $m^3$ .

The dimensions of digester are Diameter ( $D_d$ ) and Height ( $h_d$ ) was calculated based on the relationship between height and diameter was ( $\frac{H}{D} = 0.5$ ).

**Table5. 10: Dimensions of the digester**

| Diameter (m) | Height (m) |
|--------------|------------|
| 20.3         | 10.15      |

In order to have a suitable design and feasible cost of the digester this scenario are considered to building digester:

Two digesters with each one have a volume equal to 3263 m<sup>3</sup> and height 10.15 m.

**Table5. 11: total costs of centralized bio-digestion system [64]**

| Component                                |                                   | Cost (\$) |
|------------------------------------------|-----------------------------------|-----------|
| Construction                             |                                   | 511,499   |
| Two pumps for pumping the organic matter |                                   | 34,372.92 |
| Two stainless steel heating pipes        |                                   | 3902      |
| Land acquisition (\$/yr)                 |                                   | 70656     |
| Internal combustion engine               | Capital cost (\$)                 | 2,190,455 |
|                                          | Operating and maintenance (\$/yr) | 69857     |

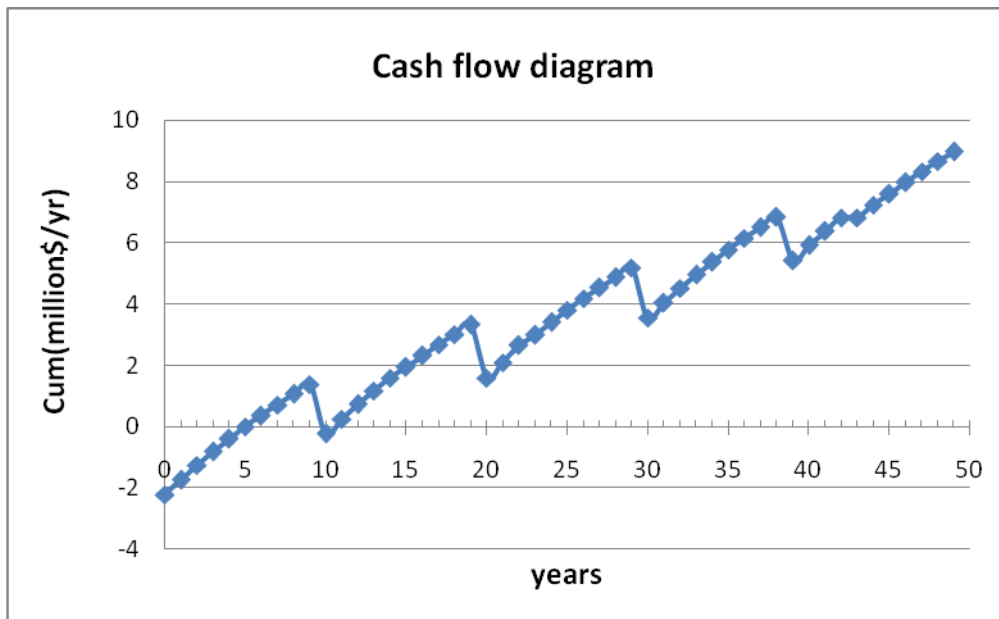
The lifetime of the plant is 50 years and the life time of each component in the plant.

The cost of kWh in N & NW of Jerusalem is 0.3 NIS/kWh, so the cost of electrical energy produced from the plant was 6720 NIS/day and 2,45 NIS/yr (658,83 \$/yr).

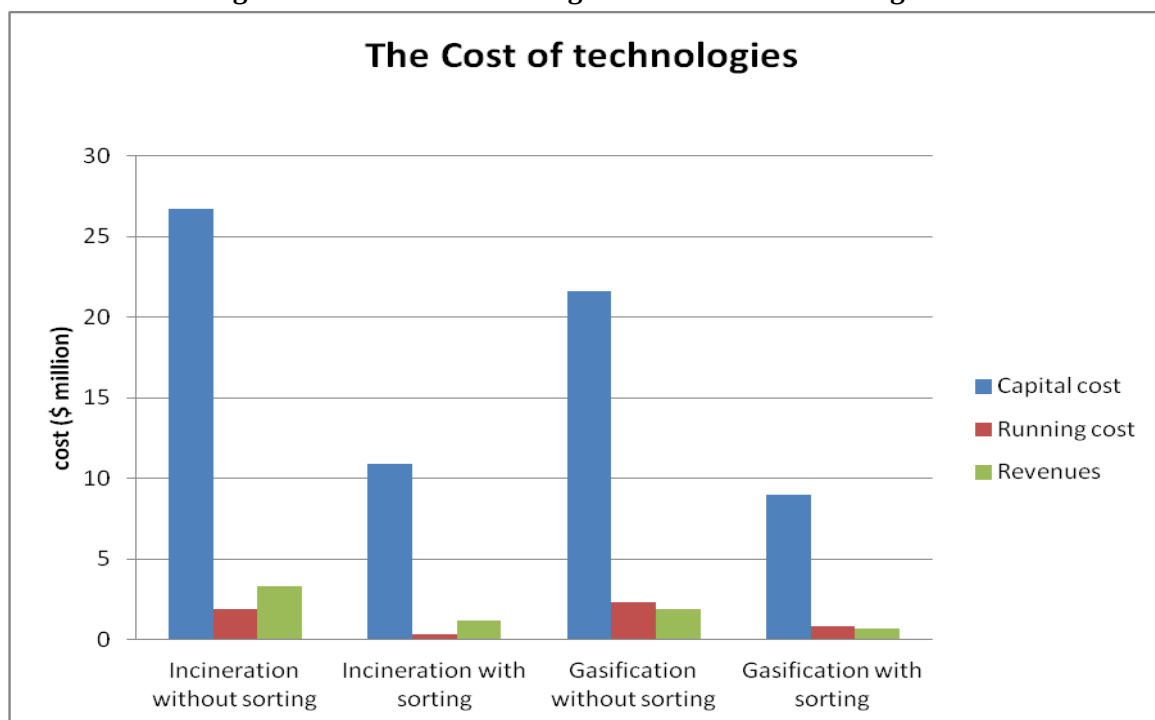
The total annual costs are the annual capital cost and the revenues of the project. The lifetime of the plant which is 50 years and the lifetime of each component in the plant were considered in the annual capital cost of the biogas plant in this study. As the calculations for the annual cost, the capital cost at the first year was 2,80 million \$/year and the cost for each year was calculated until 50 years [Appendix A].

A cash-flow diagram is a tool used to represent the income and outcome which will take place over the course of given project. This diagram can include the capital cost, running costs and revenues to the end of the project. This method used in economic estimation through calculation such as annual cost, cumulative cost, and simple payback period.

The cash-flow diagram for the biogas plant in N & NW of Jerusalem through calculates the cumulative cost (\$/yr) during the lifetime of the project [Appendix A].



**Figure5.10: the cash flow diagram of the centralized digester**



**Figure5.111: the Cost of technologies**

2. Biodigester for unit: the percentage according to Palestinian Central Bureau of Statics.

**Table5. 12: cost for decentralized bio-digestion**

|                          | Percentage distribution of households in Jerusalem Governorate(%) | Number of housing units in the N&NW of Jerusalem(units) | Number of home digester in N&NW of Jerusalem(units) | Total cost (\$) |
|--------------------------|-------------------------------------------------------------------|---------------------------------------------------------|-----------------------------------------------------|-----------------|
| Availability of a garden | 8.6                                                               | 225                                                     | 225                                                 | 159,144.12      |
| Agriculture activity     | 98.2                                                              | 221                                                     | 221                                                 | 156,314.99      |
| Rearing of Livestock     | 3.5                                                               | 92                                                      | 92                                                  | 65,072.43       |
| Number of housing unit   | 27.34                                                             | 2616                                                    | 2616                                                | 1,850,314.77    |

### **Pyrolysis:**

The list of equipment is determined by considering the amount of the plastic and the capacity necessary equipment. Investment cost is \$ 5.7 million and operating costs is \$ 334075 [65]. The cost of kWh in N & NW of Jerusalem is 0.3 NIS/kWh , so the cost of electrical energy produced from the Pyrolysis of ton/day of MSW with 16110 kWh/day was 4833 NIS/day and 1.8 million NIS/yr (0.47 million \$/yr).

## **5.4 General environmental recommendations for the selected technologies**

### **5.4.1Environmental aspects for Incineration of MSW technology**

In the incineration, the reduced volume of waste by this technology helps to save scarce and valuable space for landfill and protect the environment. MSW facilities also generate large amounts of flue gases which must be treated, even when incineration has taken place under optimum combustion conditions. To avoid irreversible health risks to local populations and the environment, compliance with international emissions standards is essential and continuous monitoring and reporting of emissions must be guaranteed. Pollutants in flue gases take the form of dust and gases such as hydrogen chloride (HCl), hydrogen fluoride (HF) and sulphur dioxide (SO<sub>2</sub>). A number of compounds containing mercury, dioxins or nitrogen dioxide (NO<sub>2</sub>) may only be removed using highly advanced chemical processes, which substantially increase project costs [66].

The main environmental aspects to deal with are [66].

- Control and monitoring of process emissions to air and water (including odor);
- Quality and use potential of slag production (e.g. heavy metal contamination levels);
- Secure disposal or recycling of hazardous fly ash residues;

- Process noise and vibration;
- Water and other raw material (reagent);
- Fugitive emissions – mainly from waste storage;
- Storage/handling/processing risks of hazardous wastes.

### **Legal aspects for Incineration of MSW technology**

It must be assumed that environmental legislation in most developing and emerging countries do not explicitly deal with the application of MSW incineration technology. This makes the entire process of impact assessment and operation licensing more complicated and time-consuming. If comprehensive and legally binding standards are not available, these should first be developed and should follow the application of internationally recognized standards [66].

#### **5.4.2 Environmental aspects for Anaerobic Digestion for Biogas Production.**

The conversion of organic waste to biogas can be associated with a number of environmental benefits. Biogas usually replaces another form of energy, in many cases either a fossil fuel or wood. If a fossil fuel is replaced, biogas from organic waste reduces the emission of additional greenhouse gases to the atmosphere, because carbon contained in biomass originates from atmospheric CO<sub>2</sub> [66].

A possible environmental hazard is the leakage of biogas from improperly operated digesters. Since the global warming potential of methane is approximately 21 times higher than that of CO<sub>2</sub>, such leaks must be avoided and correct operation assured. The leakage of digestate to water bodies must also be avoided, as this can disrupt local ecosystems [66].

### **Legal aspects for Anaerobic Digestion for Biogas Production.**

AD is already widely applied in many developing countries at small scale and can generally be embedded in national legal and policy frameworks. However, for large-scale AD implementation in urban contexts, additional legal regulations have to apply including safety regulations and concerns about odor nuisance. Unfortunately, those regulations are rarely in place and/or enforced in developing countries, which might negatively affect the immediate implementation of this WtE technology. A legal framework to set minimum quality standards of digestate is also important to avoid potential risks in agricultural use[66].

#### **5.4.3 Environmental aspects for Gasification and pyrolysis technologies**

Gasification & pyrolysis had potential global warming impacts and has high potential environmental impacts in terrestrial eco-toxicity and photochemical oxidation categories. Gasification & pyrolysis has the least global warming potential and a lower contribution in human toxicity impact compared to incineration. Arsenic, cadmium, mercury, nickel, nitrogen oxide, and hydrogen fluoride are the primary pollutants for the human toxicity which are emitted to atmosphere and water by the gasification & pyrolysis process. Heavy metals

such as mercury, cadmium emission to the atmosphere are the main reason for terrestrial ecotoxicity[66].

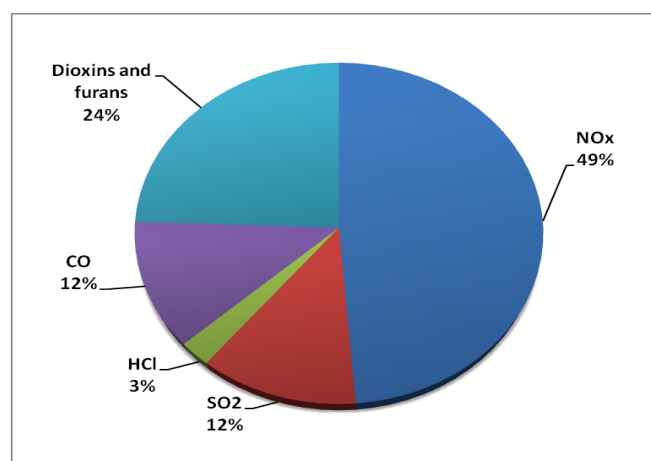
### Legal aspects for Gasification and pyrolysis technologies

It must be assumed that environmental legislation in most developing countries does not deal with the application of gasification and pyrolysis as combustion (or WtE) technology. This makes the entire process of impact assessment and operation licensing quite complicated and time consuming, if not impossible [66].

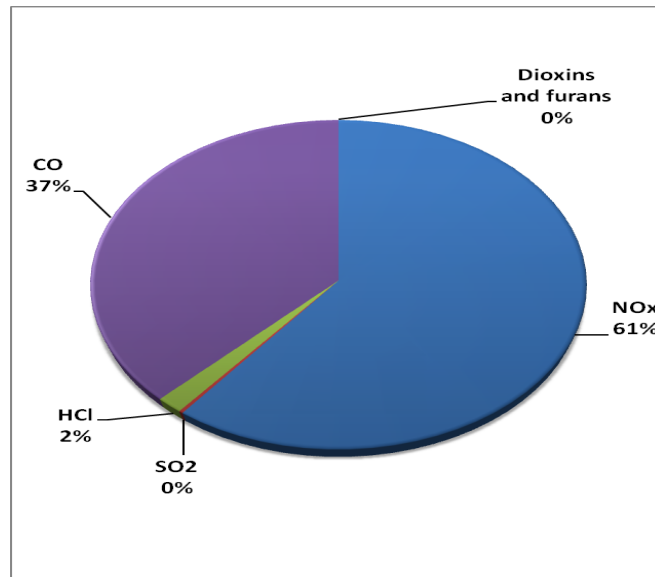
The environmental performance of thermal waste to energy plants and limits its capacity as well as effluent gases composition emitted to the atmosphere. Below at table 5.13 [67] the expected gaseous emissions for MSW incineration, pyrolysis and gasification are thermal systems:

**Table5.13: Gaseous emissions for each technology**

| WTE process              | Gaseous effluent   | Mass percentage              |
|--------------------------|--------------------|------------------------------|
| Incineration             | CO <sub>2</sub>    | 7.31 wt%                     |
|                          | NO <sub>x</sub>    | 0.134 wt%                    |
|                          | SO <sub>2</sub>    | 0.0335 wt%                   |
|                          | HCl                | 0.00672 wt%                  |
|                          | CO                 | 0.0336 wt%                   |
|                          | Dioxins and furans | 0.0672 wt%                   |
| Pyrolysis & Gasification | CO <sub>2</sub>    | 58 wt%                       |
|                          | NO <sub>x</sub>    | 0.0147 wt%                   |
|                          | SO <sub>2</sub>    | 0.000062 wt%                 |
|                          | HCl                | 0.000407 wt%                 |
|                          | CO                 | 0.0091 wt%                   |
|                          | Dioxins and furans | 3.12 x 10 <sup>-12</sup> wt% |



**Figure5.122: the emissions of incineration**



**Figure5.133: the emissions of gasification and pyrolysis**

### **Legal Framework and Environmental aspects:**

Emission standards and other environmental prescriptions for WtE require legal anchorage and regular control by qualified and well-equipped public authorities [66].

Environmental framework legislation and a national waste act should determine the objectives, and fundamental rules of WtE activities for MSW including emission control principles. In particular, it should contain [66]:

- **Planning:** In general, the national standards are considered when planning new infrastructure. However, when looking at WtE options, it is recommended to apply internationally recognized emission and safety standards.
- **Obligations of operators:** The legislation should require that WtE installations are subject to an environmental impact assessment and permitting under the national emission control and/or waste law.
- **Safety and environmental standards:** The emission thresholds and safety requirements have to be controlled on the basis of legally binding standards. Emission limit values imposed on WtE should comply with internationally recognized and applied standards. The application of low and inadequate environmental standards will lead to additional hazards for public health and environmental costs.
- **Monitoring of the compliance with safety and environmental standards:** Monitoring is the core responsibility of a competent and independent regulating authority. National laws should lay down air quality standards and ensure compliance near WtE installations.

## **Conclusion**

From the results presented in this study, we have seen that there is a potential to generate energy from MSW in the N & NW of Jerusalem. This study has revealed the importance of developing appropriate means of harnessing MSW instead of throwing on roadsides or in random dumps and highlights the potential of WtE technologies as effective methods for disposal of waste and as an energy source and reducing dependence on imported fuels. In addition to the energy advantage, trash to energy will also establish a clean environment for N & NW of Jerusalem and reduce health hazards associated with environmental pollution.

In this study, the generation of municipal solid waste was assessed to estimate the energy generation potential in the N & NW of Jerusalem. Calculations clearly illustrated that by the thermochemical process, the electrical energy from the incineration of MSW technology without sorting was estimated 112 MWh/day and with sorting was 42.4 MWh/day. And the electrical energy from the gasification of MSW technology without sorting was estimated 64.9 MWh/day and with sorting was 24.4 MWh/day, but from Pyrolysis of plastic was 16.11 MWh/day. By using biochemical processes, the electrical energy from the centralized bio-digestion was estimated 22.4 MWh/day.

The use of WTE technologies can impudence the economics of states in a positive manner and at the same time provide a means of assisting with the environmental problems posed by the disposal of wastes and for the developing countries the use of a simple and robust technology represented by incineration, gasification, Anaerobic digestion, and pyrolysis can assist the development of countries' economies by providing electricity produced from wastes.

We recommend that the incineration had the largest output of energy but at the same time it had a very bad effect on environment. As to gasification and pyrolysis they are environmentally friendly with low harmful gases if suitable treatment systems followed. However, they had a lower energy output and needed more maintenance.

According to economic aspects and without considering the capital cost of each technology, the incineration is recommended with the largest revenues and less running cost. Also the centralized bio-digestion and pyrolysis is good economically, but with fewer revenues. And the gasification is the largest running cost, but reasonable revenues. So, the decision is related to stakeholders in determining their priorities and possibilities by referring to the detailed study that be introduced.

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# Appendix A

| year | Total cost(\$/yr) | revenues(\$/yr) | Total(\$/yr) | Cum(\$/yr)    |
|------|-------------------|-----------------|--------------|---------------|
| 0    | 2,810,885         | 658,835.60      | -            | -2,221,906.40 |
| 1    | 140513            | 632482.176      | 491,969.18   | -1,729,937.22 |
| 2    | 140513            | 607182.889      | 466,669.89   | -1,263,267.34 |
| 3    | 140513            | 582895.5734     | 442,382.57   | -820,884.76   |
| 4    | 140513            | 559579.7505     | 419,066.75   | -401,818.01   |
| 5    | 140513            | 537196.5604     | 396,683.56   | -5,134.45     |
| 6    | 140513            | 515708.698      | 375,195.70   | 370,061.25    |
| 7    | 140513            | 495080.3501     | 354,567.35   | 724,628.60    |
| 8    | 140513            | 475277.1361     | 334,764.14   | 1,059,392.73  |
| 9    | 140513            | 456266.0507     | 315,753.05   | 1,375,145.78  |
| 10   | 2,261,111         | 658,835.60      | -            | -227,129.62   |
| 11   | 140513            | 632482.176      | 491,969.18   | 264,839.56    |
| 12   | 140513            | 607182.889      | 466,669.89   | 731,509.45    |
| 13   | 140513            | 582895.5734     | 442,382.57   | 1,173,892.02  |
| 14   | 140513            | 559579.7505     | 419,066.75   | 1,592,958.77  |
| 15   | 174886            | 537196.5604     | 362,310.56   | 1,955,269.33  |
| 16   | 140513            | 515708.698      | 375,195.70   | 2,330,465.03  |
| 17   | 140513            | 495080.3501     | 354,567.35   | 2,685,032.38  |
| 18   | 140513            | 475277.1361     | 334,764.14   | 3,019,796.52  |
| 19   | 140513            | 456266.0507     | 315,753.05   | 3,335,549.57  |
| 20   | 2392947           | 658,835.60      | -            | 1,601,438.17  |
| 21   | 140513            | 632482.176      | 491,969.18   | 2,093,407.34  |
| 22   | 140513            | 607182.889      | 466,669.89   | 2,560,077.23  |
| 23   | 140513            | 582895.5734     | 442,382.57   | 3,002,459.81  |
| 24   | 140513            | 559579.7505     | 419,066.75   | 3,421,526.56  |
| 25   | 140513            | 537196.5604     | 396,683.56   | 3,818,210.12  |
| 26   | 140513            | 515708.698      | 375,195.70   | 4,193,405.82  |
| 27   | 140513            | 495080.3501     | 354,567.35   | 4,547,973.17  |
| 28   | 140513            | 475277.1361     | 334,764.14   | 4,882,737.30  |
| 29   | 140513            | 456266.0507     | 315,753.05   | 5,198,490.35  |
| 30   | 2295484           | 658,835.60      | -            | 3,561,841.95  |
| 31   | 140513            | 632482.176      | 491,969.18   | 4,053,811.13  |
| 32   | 140513            | 607182.889      | 466,669.89   | 4,520,481.02  |
| 33   | 140513            | 582895.5734     | 442,382.57   | 4,962,863.59  |
| 34   | 140513            | 559579.7505     | 419,066.75   | 5,381,930.34  |
| 35   | 140513            | 537196.5604     | 396,683.56   | 5,778,613.90  |
| 36   | 140513            | 515708.698      | 375,195.70   | 6,153,809.60  |
| 37   | 140513            | 495080.3501     | 354,567.35   | 6,508,376.95  |
| 38   | 140513            | 475277.1361     | 334,764.14   | 6,843,141.09  |

|    |         |             |                   |              |
|----|---------|-------------|-------------------|--------------|
| 39 | 140513  | 456266.0507 | 315,753.05        | 7,158,894.14 |
| 40 | 2392947 | 658,835.60  | -<br>1,734,111.40 | 5,424,782.74 |
| 41 | 140513  | 632482.176  | 491,969.18        | 5,916,751.91 |
| 42 | 140513  | 607182.889  | 466,669.89        | 6,383,421.80 |
| 43 | 140513  | 582895.5734 | 442,382.57        | 6,825,804.38 |
| 44 | 140513  | 559579.7505 | 419,066.75        | 7,244,871.13 |
| 45 | 178788  | 537196.5604 | 358,408.56        | 7,603,279.69 |
| 46 | 140513  | 515708.698  | 375,195.70        | 7,978,475.38 |
| 47 | 140513  | 495080.3501 | 354,567.35        | 8,333,042.73 |
| 48 | 140513  | 475277.1361 | 334,764.14        | 8,667,806.87 |
| 49 | 140513  | 456266.0507 | 315,753.05        | 8,983,559.92 |



