

**An-Najah National University**

**Faculty of Graduate Studies**

**Experimental and Simulation of Biomass Conversion  
by Gasification and Biodigestion: Potential of  
Bioenergy in Palestine**

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**This Thesis is Submitted in Partial Fulfillment of the Requirements for  
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**Experimental and Simulation of Biomass Conversion  
by Gasification and Biodigestion: Potential of  
Bioenergy in WB&GS**

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### III

## Dedication

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿قُلْ إِنْ صَلَاتِي وَنُسُكِي وَمَحْيَايَ وَمَمَاتِي لِلَّهِ رَبِّ الْعَالَمِينَ ﴿١٦٣﴾ لَا شَرِيكَ لَهُ ۚ  
وَبِذَلِكَ أُمِرْتُ وَأَنَا أَوَّلُ الْمُسْلِمِينَ﴾

(سُورَةُ الْأَنْعَامِ)

11/حزيران

16/رمضان

2017م

1438هـ

#### IV

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16/Ramadan      11/June

1438AH      2017AD

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11/حزيران      16/رمضان

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أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان

**Experimental and Simulation of Biomass Conversion by  
Gasification and Biodigestion: Potential of Bioenergy in  
Palestine**

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**Nomenclature list**

Simple	Description
°C/s	Celsius degree per second
AD	Anaerobic Digestion
AER	Air Equivalent ratio
Ar	Argon
B	Biogas yield
BFB	bubbling Fluidized bed
BTL	Biomass to liquid
C	Carbon Atom
C-	cellulose/hemicelluloses
C <sub>5</sub> H <sub>10</sub>	Light Hydrocarbons

## VII

Simple	Description
CAD	Centralized anaerobic digestion
CFB	Circulating Fluidized bed
CH <sub>4</sub>	Methane Gas
CHP	combined heat and power
Cl	Chlorine
Cl <sub>2</sub>	Molecular Chlorine
CO	Carbon Mono Oxide
CO <sub>2</sub>	Carbon dioxide
COD	chemical oxygen demand
cont.	continue
COS	Carbonyl sulfide
CS <sub>2</sub>	carbon disulfide
E <sub>AD</sub>	the potential for electric recovery
EJ	Exa joule: is equal to one quintillion (10 <sup>18</sup> ) joules

# VIII

Simple	Description
ER	Equivalent Ratio
F-	fast pyrolysis
FT	Fischer-Tropsch
GHG	greenhouse gasses
Gt	Gigatonne
GWh	Giga watt hours
GWhe	Giga watt hours electrical
H	Hydrogen Atom
H <sub>2</sub>	Hydrogen Gas
H <sub>2</sub> O	Water
H <sub>2</sub> S	hydrogen sulfide
HCl	Hydrogen chloride
HHV	Higher heating value
Je.	Jefit
Je.Po.	Jefit & Poultry manure

Simple	Description
Je.Po.Se.	Jefit, Poultry manure & Sewage Sludge
Je.Se.	Jefit & Sewage Sludge
K	kelvin
kWh	kilo watt hour
kWh/m <sup>3</sup>	kilo watt hour per cubic metric
L-	lignin
LHV	Lower heating value
m/s	meter per second
MHSW	Municipal Household solid waste
MJ/Nm <sup>3</sup>	Mega joule per Normal cubic Metric
MPa	Mega pascal
Mt	Megaton
MW	Mega watt
N <sub>2</sub>	Nitrogen Gas
N <sub>2</sub> O	Nitrous oxide

<b>Simple</b>	<b>Description</b>
NH <sub>3</sub>	ammonia
Nm <sup>3</sup>	Normal cubic metric
NO	nitrogen monoxide
NO <sub>2</sub>	nitrogen dioxide
NOx	Nitrogen Oxides
O	Oxygen Atom
O <sub>2</sub>	Oxygen Gas
°C	Celsius degree
ODM	Organic Dry Matter
OER	Oxygen Equivalent ratio
OMWW	olive mill wastewater
OTS	Organic Total Solid
P	Number of Slaughtered Poultry
P-	slow pyrolysis
PCBS	Palestinian Central Bureau of Statistics
PG	Producer gas production
pH	A numeric scale used to specify the acidity or basicity of an aqueous solution.
PM2.5	particulate matter with a diameter of 2.5 micrometers

<b>Simple</b>	<b>Description</b>
Po.	Poultry manure
Po.Se.	Poultry manure & Sewage Sludge
PVSOL	Software for Design and Simulation of Photovoltaic Systems
PWh	Peta watt hour
$Q_{CH_4}$	the heating value
RPR	residue to product ratio
S	Sulfur
S-	steam
Se.	Sewage Sludge
SNG	synthetic natural gas
SO <sub>2</sub>	Sulfur dioxide
SO <sub>x</sub>	Sulfur oxides
Syngas	synthesis gas

Simple	Description
t/cap	tons per capita
TJ	Tera joule
TS	Total Solid
$T_s$	Steam Temperature
UASB	Upflow Anaerobic Sludge Blanket
WB&GS	West Bank and Gaza Strip
WGS	water gas shift
yr	Year
$\eta_e$	Electrical Efficiency

## Table of Contents

Acknowledgment .....	IV
Nomenclature list .....	VI
Table of Contents .....	XIII
List of Tables.....	XVII
List of Figures .....	XX
Abstract .....	XXVII
Chapter One.....	2
1. Introduction.....	2
1.1. Introduction .....	2
1.2. Energy Situation in WB&GS .....	5
1.3. The main sources of renewable energy in WB&GS .....	6
1.4. Objectives: .....	7
Chapter Two.....	10
2. Biomass.....	10
2.1 Introduction: .....	10
2.2 Biomass resources and availability: .....	11
2.3 Global biomass production.....	12
2.3.1 Energy System: .....	14
2.3.2 Materials system:.....	14
2.4 Biomass to energy conversion methods .....	15
2.4.1 Mechanical Extraction.....	17
2.4.2 Biochemical Conversion Processes .....	17
2.4.3 Thermochemical conversion processes.....	27

## XIV

2.4.4 Biogas and Producer Gas production:.....	49
2.5 Environmental concentration of biogas and gasification .....	54
2.5.1 Environmental concentration of producing biogas from manure .....	55
2.5.2 Environmental concentration of gasification .....	58
Chapter Three .....	65
3. Methodology .....	65
3.1. Calculation of Biomass residues .....	66
3.1.1. Agricultural residues .....	66
3.1.2. Olive Press Waste.....	70
3.1.3. The residues of livestock:.....	72
3.2. Calculations of biofuel potential from biomass: .....	73
3.2.1. Biogas production by anaerobic digestion: .....	73
3.2.2. Biogas production by Landfill Method:.....	74
3.2.3. Producer and Synthetic Gas by Gasification: .....	75
3.2.4. Bio Oil Production: .....	76
3.2.5. Electricity Production: .....	76
3.3. Experimental Work on gasification.....	77
3.3.1. Experimental Procedure .....	78
3.4. Simulation Process .....	79
3.4.1. Cold Gas Efficiency calculation (CGE):.....	86
3.4.2 Residence Time .....	87
Chapter Four.....	89
4. The Potential of Biomass in WB&GS .....	89

4.1	Introduction: .....	89
4.2	The agriculture:.....	89
4.3	Livestock: .....	97
4.4	Biomass Residues in WB&GS .....	100
4.4.1	Introduction .....	100
4.4.2	The residues of agricultural plants .....	103
4.4.3	Calculation of Biomass residues .....	104
4.4.4	The residues of livestock:.....	109
4.4.5	Municipal household solid waste .....	112
4.4.6	Calculations of biofuel potential from biomass: .....	115
	Chapter Five .....	117
5.	Results and Discussions .....	117
5.1	Biomass Residue.....	117
5.1.1	Animal Residues: .....	117
5.1.2	Agricultural Residues:.....	121
5.1.3	Industrial Residues: .....	123
5.1.4	Municipal Household Solid Waste: .....	124
5.2	Energy potential:.....	126
5.3	Experimental Work.....	133
5.4	Sensitivity analysis of simulation models .....	138
5.4.1	Effect of Biomass Moisture Content.....	139
5.4.2	Effect of Inlet Air Temperature: .....	140
5.4.3	Effect of Temperature .....	142
5.4.4	Effect of Air and Oxygen Equivalent ratio .....	146

## XVI

5.4.5	Effect of Steam to Biomass Ratio (STBR) .....	148
5.4.6	Effect of steam temperature. ....	152
5.4.7	Effect of Steam with Oxygen or Air equivalent ratio .....	156
5.4.8	Effect of Hydrogen Injection .....	159
5.4.9	Effect of Recycling Ratio.....	161
5.4.10	Effect of CO <sub>2</sub> injection.....	163
5.4.11	Traces Gas generation in gasification process .....	165
5.4.12	Effect of feedstock .....	166
5.4.13	Effect of Residence Time .....	169
Chapter Six.....		172
6. Conclusions and recommendations .....		172
References .....		179
Appendices .....		195
A.	Appendix A.....	196
A.1.	The Energy Balance of WB&GS in Physical Units, 2013 .....	196
B.	Appendix B.....	197
B.1.	Comparison of various plant designs .....	197
C.	Appendix C:.....	203
D.	Appendix D.....	208
D.1.	Percentage of dry matter and biogas production from wastes .....	208
E.	Appendixes E.....	212
المخلص .....		ب

## List of Tables

Table 2.1: Advantages of thermochemical conversion of biomass over biological/biochemical process.....	29
Table 2.2: Product gas qualities achievable via gasification. ....	33
Table 2.3: List of main gasification reactions.....	36
Table 2.4: Comparison of gasification agents.....	40
Table 2.5: DM & ODM contents for manures from livestock and agricultural wastes.....	51
Table 2.6: The total biogas generated from some waste.....	52
Table 2.7: The total biogas generated from Poultry and some animals.....	52
Table 2.8: some properties for the producer or Synthetic gas. ....	53
Table 2.9: Potential of methane emission from Livestock in WB&GS. ....	56
Table 2.10: Amount of Nitrogen emission from Livestock in WB&GS. ....	56
Table 2.11: Environmental aspects of gasification and associated hazards ...	59
Table 2.12: Syngas Contaminants.....	62
Table 3.1: Residue Factor for Date and Olive. ....	66
Table 3.2: The main factor For Olive Mill Wastewater and Jeft measurement.....	71
Table 3.3: main values that used in corrupt egg calculation.....	73
Table 3.4 : Amount of Lo in the percentage of fresh weight.....	75
Table 3.5: Moisture and dry contents for banana, olive cake and date residues.....	75

## XVIII

Table 3.6: the main factors that are used to calculate electricity production.	76
Table 3.7: main streams using in simulation model	81
Table 3.8: Main properties of Jeft.	84
Table 3.9. Proximate analysis of Jeft, Sewage Sludge, and poultry manure (dry basis).	84
Table 3.10: Ultimate analysis of Jeft, Sewage Sludge, and poultry manure (dry basis).	84
Table 3.11: Operation parameters and input data for the simulation of gasification of Jeft and sewage sludge.	85
Table 3.12: The composition of Dry Air (mole basis).	85
Table 3.13: Heating Value for CH <sub>4</sub> , H <sub>2</sub> and CO gases.	86
Table 4.1: Agricultural residues availability during the year.	101
Table 4.2: Comparison between two approaches to calculate potatoes residue in Chile Country.	106
Table 4.3: Number of olive mill in WB&GS according to their waste disposal methods, 2014.	108
Table 4.4: The main factor For Olive Mill Wastewater and Jeft measurement.	109
Table 4.5: The life cycle of poultry.	110
Table 4.6: Waste type and average percentages from poultry.	110
Table 4.7: Daily generation of household solid in WB&GS, 2015.	113
Table 4.8: the Percentage composition of Households solid waste in WB&GS, 2015.	113

## XIX

Table 5.1: the main Wastes that suited anaerobic digester in WB&GS ...	126
Table 5.2: The main Wastes that suited gasification process in WB&GS .....	129
Table 5.3: The physical and combustible properties of producer gas .....	133
Table 5.4: the physical and combustible properties of producer gas .....	135
Table A.1: Energy Balance of WB&GS in Physical Units, 2013 .....	196
Table B.1: Comparison of various plant designs .....	197
Table C.1: The main advantages and disadvantages of different gasification technologies .....	203
Table C.2: Comparison of different types of gasifiers .....	205
Table C.3: Feedstock requirements for different types of gasifiers .....	207
Table D.1: percentage of dry matter and biogas production from wastes .....	208
Table E.1: Wastes from the food and fodder industry .....	212

## List of Figures

Figure 1.1: Comparison of the energy consumption and population growth in the world.....	2
Figure 1.2: Total Primary Energy Supply by resource 2011 and 2020. ....	3
Figure 1.3: Fossil fuels balance in WB&GS in 2013.....	4
Figure 1.4: Energy balance of WB&GS in 2013 .....	5
Figure2.1: Biomass categorization (in terms of use and application). ....	11
Figure 2.2: Global extraction of biomass between 1950 and 2010 in (t/cap) and by main biomass categories.....	13
Figure 2.3: Main global wood flows.....	14
Figure 2.4: From biomass to energy products and fuels.....	15
Figure 2.5: Anaerobic digestion (AD) Process.....	19
Figure 2.6: Steps in anaerobic digestion process with energy flow represented as % chemical oxygen demand (COD). ....	20
Figure 2.7: The Chinese Digester of the dome type. ....	23
Figure 2.8: The Indian Gobar Gas Plant schematic showing cross-sectional design. ....	24
Figure 2.9: The Taiwan rectangular digester design with a separate gas holder.....	25
Figure 2.10: Some examples of second generation biogas digesters.....	27
Figure 2.11: Thermochemical Process.....	28
Figure 2.12: Characteristics of different types of pyrolysis.....	30
Figure 2.13: C-H-O ternary diagram of biomass showing the gasification process.....	37

Figure 2.14: Pyrolysis, gasification and combustion in a burning match stick. ....	41
Figure 2.15: Five Processes in Gasification.....	44
Figure 2.16: Scheme and operating principle of conventional fixed-bed gasifiers Explanations. ....	46
Figure 2.17: Schematic illustration and operating principle of fluidized bed gasifiers. Explanations: Left: bubbling fluidised bed, right: circulating fluidised bed. ....	48
Figure 2.18: type of environmental impacts of producing biogas from manure. ....	55
Figure 2.19: Emissions caused by energy used for transports of manure, and running the digestion facility.....	57
Figure 2.20: The main emission when replacing manure with digested. ...	58
Figure 2.21: Life Cycle Flows of CO <sub>2</sub> within a Biomass Power System gr. CO <sub>2</sub> per kWh of Electricity (% of net).....	63
Figure 3.1: Residue factor (RF) for vegetables crops.....	67
Figure 3.2: Extraction coefficients per harvested area: Horticulture Trees. ....	69
Figure 3.3: daily waste production by the five major livestock.....	72
Figure 3.4: General Sketch of gasifier experimental setup.....	79
Figure 3.5: Flow-Sheet of ASPEN PLUS Simulation for Gasification Process.....	80
Figure 3.6 effect of temperature on Tar formation. ....	82
Figure 3.7: Char formation at a different temperature.....	83

Figure 4.1: Distribution of trees in WB&GS by area & number.....	90
Figure 4.2: Area of Vegetables in WB&GS by Type of Crop.....	91
Figure 4.3: Total cultivated area in WB&GS (Area in Dunam).....	92
Figure 4.4: Agricultural area (dunams) in WB&GS. ....	93
Figure 4.5: Agricultural area (dunam) in WB&GS. ....	93
Figure 4.6: Total Number of trees in WB&GS.....	94
Figure 4.7: Agricultural area of trees (Dunam). ....	95
Figure 4.8: Total number of Olives trees in WB&GS. ....	95
Figure 4.9: Area of vegetables in WB&GS (Area in dunam).....	96
Figure 4.10: Total agricultural area in WB&GS (Area in dunam). ....	96
Figure 4.11: Number of Animals in WB&GS, As in 2013.....	97
Figure 4.12: Number of Animals in WB&GS, As in 01/10/2013. ....	98
Figure 4.13: Number of Camels in WB&GS, As in 01/10/2013.....	99
Figure 4.14: Number of Poultry per Year in WB&GS by Type and Region, 2012/2013.....	99
Figure 4.15: extraction coefficients per harvested area: Horticulture Trees, [ton/(acre.yr)]. ....	105
Figure 4.16: Quantity of Olive Pressed Activity in WB&GS by, 2014 ...	107
Figure4.17: The Main quantities of olives pressed in WB&GS by Governorate, 2014.....	107
Figure 4.18: daily waste production by the five major livestock.....	111
Figure 4.19: Percentage Distribution of Manure in WB&GS, 2012/2013. .....	111

Figure 4.20: Percentage Distribution of Guano Product in WB&GS, 2012/2013.....	112
Figure 5.1: The average collectible wet residues (Dung) of animals (ton/year) .....	117
Figure 5.2: The Average Collecting Factor for goat and sheep wastes for all governorates in WB&GS .....	118
Figure 5.3: The average collecting factor for cattle and camels in WB&GS. ....	119
Figure 5.4: The percentage of the Poultry waste in WB&GS .....	120
Figure 5.5: The actual collecting wet residues (dung) for poultry (ton/year). ....	120
Figure 5.6: Collecting Factor for trees and vegetable crops in WB&GS. ....	122
Figure 5.7: The main residues for trees and vegetable crops in WB&GS (ton/year) .....	122
Figure 5.8: The average theoretical and actual collecting residues for food industries (ton/year) .....	123
Figure 5.9: the percentage of Zabar and Jift in WB&GS.....	124
Figure 5.10: Average potential of Municipal Household solid waste in WB&GS- (ton/year) .....	125
Figure 5.11: The percentage of Daily MHSW Generated in WB&GS ....	125
Figure 5.12: The potential of energy production using CHP Generator in WB&GS .....	127
Figure 5.13: Thermal energy consumption for animal holdings heating in WB&GS. ....	128

Figure 5.14: The percentage of biogas needed to heat animal holdings...	128
Figure 5.15: The potential of electrical energy production using gasification process in WB&GS .....	130
Figure 5.16: The potential of electrical energy production using Pyrolysis process in WB&GS .....	131
Figure 5.17: The potential of electrical energy the can be produced using anaerobic digester and gasification process in WB&GS .....	132
Figure 5.18: The relationship between total consumption of electricity and energy which produced using bioenergy in WB&GS.....	132
Figure 5.19: Preview of pressure inside gasifier.....	134
Figure 5.20: Homemade downdraft gasifier .....	135
Figure 5.21: Operation and testing of homemade gasifier.....	136
Figure 5.22: Char produced using gasification process.....	137
Figure 5.23: The effect of biomass moisture content on mole fraction, LHV & CGE of the producer gas.....	140
Figure 5.24: The effect of the air temperature on the producer gas composition .....	141
Figure 5.25: The effect of inlet air temperature on the CGE & LHV of the producer gas. ....	142
Figure 5.26: The effect of gasifier temperature on produced Gas Composition at AER=0.2 .....	143
Figure 5.27: The effect of gasifier temperature on CGE and LHV under normal conditions.....	145

Figure 5.28: Effect of Air & Oxygen equivalent ratio on producer gas composition. ....	147
Figure 5.29: Effect of Air & Oxygen equivalent ratio on heating value & cold gas efficiency.....	148
Figure 5.30: Effect of steam injection on the composition of producer gas at $T_g = 900^\circ\text{C}$ & $T_s = 150$ & $900^\circ\text{C}$ .....	150
Figure 5.31: The effect of Steam to Biomass Ratio on CGE and LHV,....	151
Figure 5.32: Effect of steam temperature on the composition of producer gas at different STBR values.....	153
Figure 5.33: The effect of steam temperature on LHV of producer gas at different value of STBR & $T_s$ and at $T_g = 900^\circ\text{C}$ . ....	154
Figure 5.34: The effect of steam temperature on CGE at different value of STBR & $T_s$ , and at $T_g = 900^\circ\text{C}$ . ....	155
Figure 5.35: The effect of steam on producer gas- after drying- at different $T_s$ , OER= 0.2 and $T_g = 900^\circ\text{C}$ .....	157
Figure 5.36: The effect of steam to biomass ratio on producer gas at AER of 0.2 and $T_g = 900^\circ\text{C}$ .....	157
Figure 5.37: Effect of steam on producer gas LHV at $\text{O}_2/\text{Air ER} = 0.2$ and $T_g = 900^\circ\text{C}$ . ....	158
Figure 5.38: The effect of STBR on CGE of producer gas with $\text{O}_2/\text{Air ER} = 0.2$ and $T_g = 900^\circ\text{C}$ . ....	159
Figure 5.39: Effect of Hydrogen injection on producer gas .....	159
Figure 5.40: Effect of Hydrogen injection into gasifier on total energy and lower heating value of the producer gas .....	160

Figure 5.41: Effect of recycle stream on the producer gas composition. .	161
Figure 5.42: The effect of recycle stream on LHV of the producer gas ...	162
Figure 5.43: Effect of CO <sub>2</sub> on the composition of the producer gas at STBR is 0.6 and AER is 0.2.....	164
Figure 5.44: The relation between main of Traces Gas generated and temperature during gasification process. ....	165
Figure 5.45: The relation between main Traces Gas generated and equivalent ratio of oxygen or air during gasification process.....	166
Figure 5.46: Effect of type of feedstock on producer gas composition. ..	167
Figure 5.47: Effect of three types of feedstock on the heating value of the producer gas. ....	168
Figure 5.48: The correlation between the residence time and particle size of the gasification process. ....	170
Figure 5.49: The correlation between the residence time and particle temperature of the gasification process.....	170
Figure C.1: Feedstock, processes and final products of biomass energy alternatives. ....	204
Figure C.2: The Five Processes of Gasification.....	206
Figure C.3: The Reduction Reactions- The Heart of Gasification. ....	207
Figure D.1: Higher Efficiency results in significant Economic Advantages for the CHP Plant Operator .....	211

**Experimental and Simulation of Biomass Conversion by Gasification  
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**By**  
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**Dr. Abdelrahim Abu Safa**

**Abstract**

West Bank & Gaza Strip (WB&GS) are known to be very poor territories in terms of fossil fuel resources. At the same time, energy alternatives are not defined well specially the non-conventional types such as biomass. Biomass can be defined as a material which is recently derived from the sources of animals and plants that use sunlight to grow.

This study aims at analyzing all main types and amount of biomass in WB&GS that can be used as an alternative fuel for conventional fossil fuel.

In this research, Types and amount of biomass that exist in WB&GS were defined by a comprehensive field survey. A detailed study of biomass processing and conversion of biomass to biofuel were done referring to the earlier studies and literature. The potential energy from these wastes were calculated based on the proper conversion method that should be used according to the type of biomass. For instance, assuming that the proper conversion method is anaerobic digestion, the mount of potential electrical energy from some agricultural, industrial, animal and poultry residues was estimated to be 192.573GWhe, the potential of electrical energy from agricultural residues and Municipal Household solid waste (MHSW) is 816.716GWhe if a gasification process is used.

## XXVIII

The gasification process was studied in details as an important conversion method. For this purpose a homemade gasifier was designed and constructed. The gasifier was operated using Jeft as feedstock, the effect of inlet air flowrate and feedstock on the effluent producer gas were studied.

the main parameter that affect the gasification process such as: gasification temperature, air or oxygen Equivalent Ratio, steam ratio,  $\text{CO}_2$  to Biomass ratio, hydrogen inject and effect of recycling of the producer gas on the gasification of jeft were investigated using a a proper simulation software.

The optimum temperature of a gasifier was found to be  $900^\circ\text{C}$ . A 20 percent air or oxygen equivalent ratio (air or oxygen injection) gives maximum cold gas efficiency. The optimum steam to biomass ratio was found to be 2.5, whereas the optimum steam temperature was found to be  $150^\circ\text{C}$ .

Steam and air or oxygen equivalent ratios were found to have an effect on the concentration of hydrogen. A higher concentration of hydrogen can be obtained at steam to biomass ratio of 1.4.

When Hydrogen was injected in the gasifier device, the concentration of Hydrogen in producer gas was found to be more than 96%. The generation of traces gas ( $\text{NO}_x$  &  $\text{SO}_x$ ) during the gasification process is low. It was concluded that the percentage of volatile matter and fixed carbon of feedstock are the most important factors that affect the quality of producer gas.

# **Chapter One**

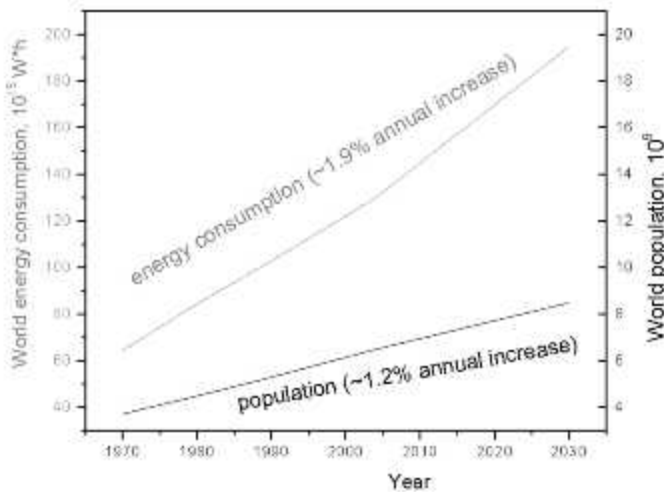
## **Introduction**

## Chapter One

### Introduction

#### 1.1. Introduction

The world energy consumption increases more rapidly than the population growth during the last decades and this tendency is expected to be further increasing next years. For instance and as shown in Figure 1.1, the world population was 3.7 billion in 1970 and expected to be 8.5 billion in 2030 with annual increasing rate of 1.2%. The world energy consumption in 1970 was nearly 27 PWh (Petawatt hour) and 195 PWh in 2030 with annual increasing rate of 1.9%. [1]

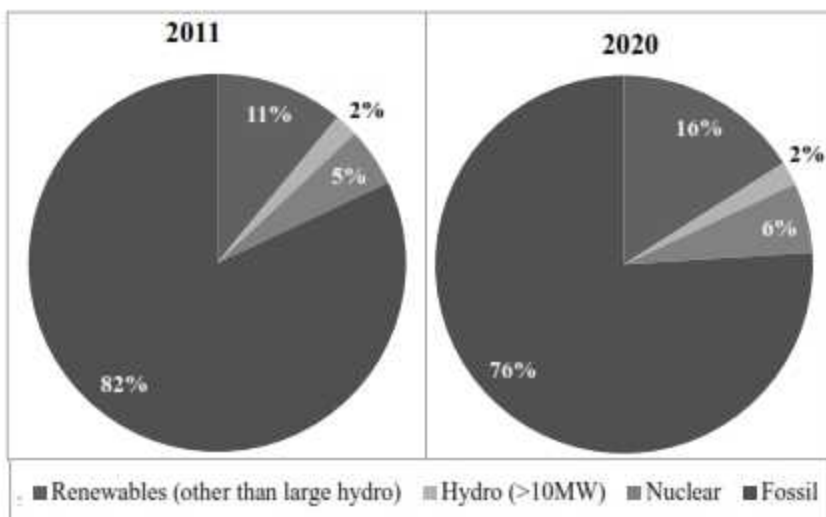


**Figure 1.1:** Comparison of the energy consumption and population growth in the world. [1]

Today, the world depends on the conventional energy system such as fossil fuels. Unfortunately, these sources of energy cause many problems

especially health and environmental problems. These problems caused by non-sustainable use of biomass and fossil fuel combustion.

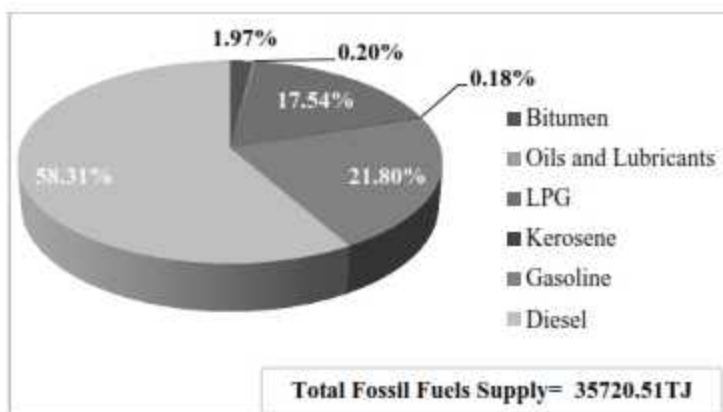
As can be seen in Figure 1.2 fossil fuels are the main source for energy production with 82% of the total energy consumption. Unfortunately, the portion of the renewables from the total world consumption is not more than 11%. The anticipated percentage of renewables is only 16% which is not enough to prevent global warming and facing the increasing energy demand.



**Figure 1.2:** Total Primary Energy Supply by resource 2011 and 2020. [2]

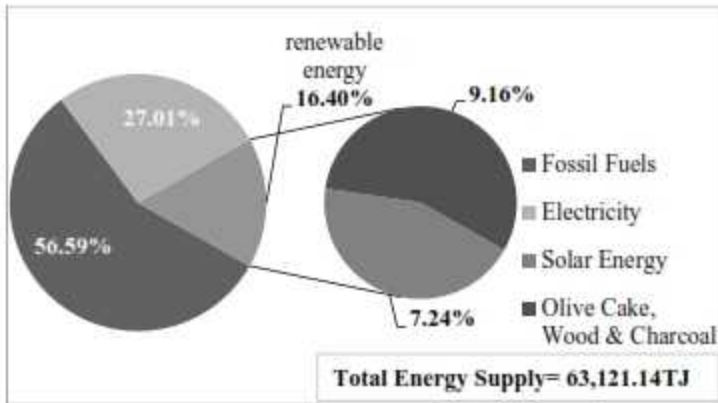
In West Bank and Gaza strip (WB&GS), the energy consumption was about 63,121.14 TJ (Tera Joule) in 2013 and the main source of this energy was the fossil fuel. WB&GS is known to be very poor country in terms of fossil fuel resources. All fossil fuels imported from near countries. [3]

As shown in Figure 1.3 the main types of fossil fuels that are used in WB&GS are Diesel (58.31%), Gasoline (21.80%), and LPG (17.54%). The consumption rate of fossil fuels in 2013 was about 56.59%, while the renewable energy source was not more than 16.4% (Solar thermal and biomass) as indicated in Figure 1.4.



**Figure 1.3:** Fossil fuels balance in WB&GS in 2013

On the other hands, other source of energy in WB&GS is the renewable energy and traditional sources. The main type of this energy in WB&GS is the solar energy specially the thermal energy, geothermal, municipal solid waste and Biomass. Biomass consists of olive cake, wood, coal and other materials produced from biomass. The approximate consumption rate of olive cake, wood and coal is 5791.46 TJ, this value is equivalent to 9.16% of total energy consumption, these values for all type of energy sources in WB&GS show in Figure 1.4 and the energy balance show in Table A.1.



**Figure 1.4:** Energy balance of WB&GS in 2013

## 1.2. Energy Situation in WB&GS

The energy situation in WB&GS is somewhat unique (in terms of availability) when compared to other countries. The major problem for the Palestinian energy sector is the shortage in supply of conventional energy – particularly electricity and petroleum products. There are virtually no available natural resources, and due to the ongoing political situation, the Palestinians rely almost totally on Israel for their energy needs and the monopoly of supply of conventional energy resources by Israel leads to a situation of high energy insecurity. WB&GS faces continuing growth in energy demands, across all sectors. Energy prices in WB&GS are high compared to international prices and other countries in the region. These factors create strong economic and environmental incentives both to invest in renewable energy sources. [4]

### **1.3. The main sources of renewable energy in WB&GS**

In general, WB&GS is considered as one of the poorest countries in the world in terms of energy sources. Traditional domestic energy sources (fossil fuel) are not existent. These domestic energy resources are limited to solar energy for photovoltaic and thermal applications (mainly for water heating), and biomass (wood and agricultural waste) for cooking and heating in rural areas.

The main renewable energy sources considered to have potential in WB&GS are solar energy and biomass. The potential of wind energy is relatively small but not yet utilized in WB&GS.

Biomass is the main source of the renewable energy in WB&GS. It is an agricultural country. It has different types of agriculture and animal residues that can be used as energy sources. Usually, these residues are used in households for heating in the winter.

The more important locally produced energy material is animal dung, which is used for biogas production.

Municipal solid waste can be classified as a source of biomass. Waste output in the WB&GS approximately 2,551 ton/day. This is mostly being disposed in landfills. [5]

In addition to that, WB&GS has high solar energy potential. It has about 3,000 sunshine hours per year and high annual average of solar radiation amounting to  $5.4 \text{ kWh/ (m}^2\text{.day)}$  on horizontal surface. WB&GS is one of the leading countries in using solar water heaters for domestic applications.

The solar energy is used in different applications such as water heating, drying of crops vegetables and fruits, water desalination, water pumping and electrification of remote locations isolated from the electrical networks.

Another type of energy in WB&GS is wind energy. It can be considered as a country of moderate wind speeds. Gaza strip is characterized by a very low wind speed throughout the year (2-3m/s annually). The hilly regions have annual average wind speeds varying in the range of 4–8 m/s. The Jordan Valley, represented in Jericho, also has very low wind speeds (2–3 m/s annually). In fact, the wind energy potential in WB&GS has, until now, not been professionally assessed. [4]

#### **1.4. Objectives:**

The main objectives of this work are to:

- Study and identify the major types of biomass waste and their existence and potentials of biomass for a sustainable energy production and utilization in WB&GS.
- To investigate the biomass, biogas and gasification process to find out a durable and a reliable alternative energy source for Palestinians.
- Highlight some of conversion techniques and routes for the biomass resources.
- Design homemade downdraft gasifier.

- Experimental study of the effect of biomass and operating parameters on the efficiency of gasification process and producer gas quality.
- Study the effect of main parameters on gasification process using a suitable simulation model.

## **Chapter Two**

### **Biomass:**

## Chapter Two

### Biomass

#### 2.1 Introduction:

The word biomass consists of “bio” + “mass”, and originally used in the field of ecology simply referring to amount of animal and plant.

Biomass is the matter that can be derived directly or indirectly from plant which is utilized as energy or materials in a substantial amount.

Biomass is renewable resource and the energy derived from biomass is called renewable energy. The use of biomass as a source of energy is very attractive, since it can be a zero net CO<sub>2</sub> (carbon Dioxide) energy source (carbon neutral fuel), and therefore does not add any additional greenhouse gasses (GHG) to atmosphere as is the case with fossil fuels. The zero net CO<sub>2</sub> means the assumption that new trees, or other plants, will be replanted to the extent that they will fix any CO<sub>2</sub> released during the consumption of biomass energy. [6]

Biomass can be used to meet a variety of energy needs, including generating electricity, heating homes, fuelling vehicles and providing process heat for industrial facilities. Biomass is also an indigenous energy source available in most countries and its application may diversify the fuel-supply in many situations.

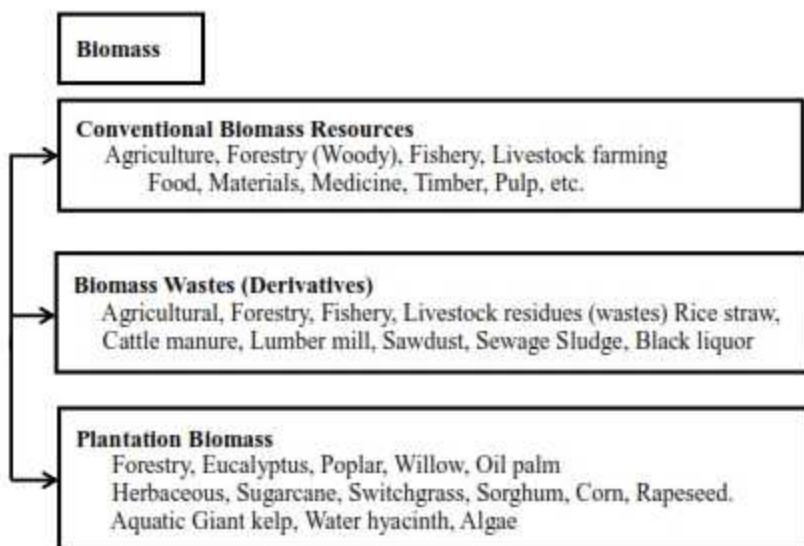
In addition, biomass can also be the starting raw materials for a lot of valuable chemicals, pharmaceuticals and food additives. [7]

## 2.2 Biomass resources and availability:

The resources of biomass includes several species, terrestrial and aquatic, various agricultural, forestry and industrial residues and process waste, sewage, animal wastes and municipal solid waste. [6]

Agricultural biomass was divided into crops, residues and livestock. Forestry biomass was divided into industrial roundwood (for construction, furniture and paper) and fuelwood. [8]

Biomass category and resources can be grouped into the following categories as presented in the Figure 2.1. In this categorization, biomass includes not only the conventional product and waste from agriculture, but also plantation biomass.



**Figure2.1:** Biomass categorization (in terms of use and application). [6]

The main resources of biomass include several species, animal wastes, Agricultural biomass, Forest biomass, and municipal solid waste.

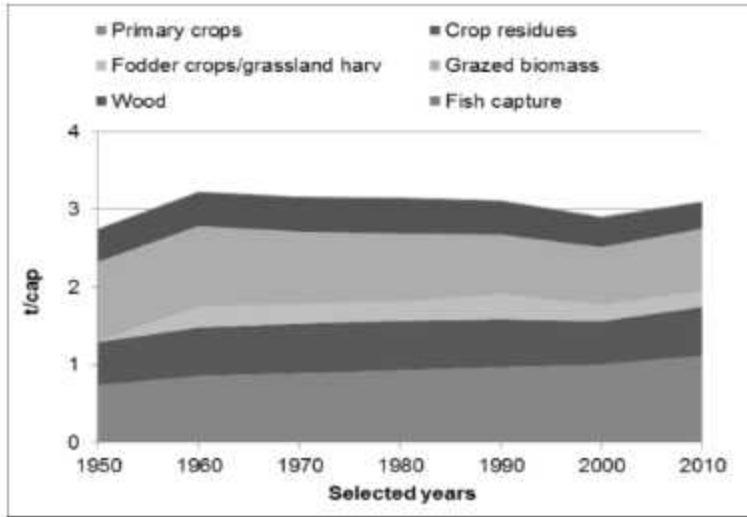
The potential biomass from animal waste includes primarily waste from intensive livestock operations, from poultry farms, cattle farms and slaughterhouses. Another type is an agricultural biomass, which could be used for energy production is defined as biomass residues from field agricultural crops (stalks, branches, leaves, straw, waste from pruning, etc.) and biomass from the by-products of the processing of agricultural products (residue from olive pits, fruit pits, etc.). Forest biomass is another type, which is used or can be used for energy purposes consist of firewood, forestry residues, and byproducts from wood industries. And finally, the Municipal solid waste is the most prominent types of biomass. It is a combination of all of a city's solid and semisolid waste. It includes mainly household or domestic waste, and it can also contain commercial and industrial waste with the exception of industrial hazardous wastes. Biodegradable fractions of municipal solid wastes include food and kitchen waste or vegetable peelings, green waste and paper. [7]

### **2.3 Global biomass production**

Between 1960 and 2010, global biomass consumption increased more than doubled in absolute terms causing per capita availability of biomass to remain almost constant at around 3 (ton) per person per year.

Global extraction of biomass increased from roughly 7 Gt (Gigatonne) to 19 Gt between 1950 and 2010. However, the per capita

availability of biomass only increased slightly from 2.7 (ton)s per capita in 1950 to 3.1 t/cap (tons per capita) in 2010 (Figure 2.2).



**Figure 2.2:** Global extraction of biomass between 1950 and 2010 in (t/cap) and by main biomass categories [9]

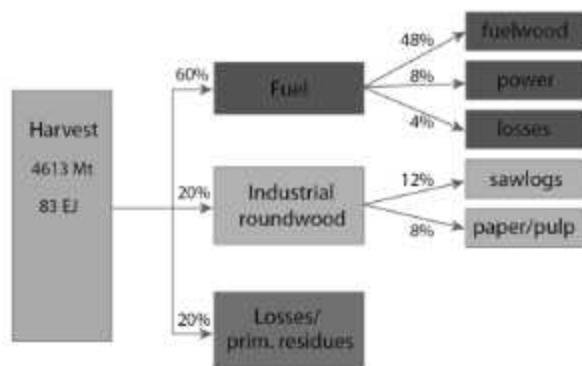
The energy content of all crops (agricultural crops) including residues produced worldwide is estimated at ~200 EJ (Exajoule), and grassland and rangeland produce ~115 EJ, mainly for the human food system. The net input is about 100 EJ/yr (EJ/year), of which about 18 EJ originates from the livestock system. Only 5% of the energy content of crops and residues is used for bioenergy and materials (420 Mt (Megaton) ~11 EJ). [8]

### 2.3.1 Energy System:

About 2700 Mt/yr (~49 EJ/yr) which is about 60% of total annual harvest is currently harvested for fuelwood and power generation. The most is used as fuelwood for heating and cooking (about 2200 Mt, 40 EJ or 48% of global total timber harvest), and about 300 Mt (or ~6 EJ or 8%) is used as solid biomass for power generation and the remaining 4% (~3 EJ) is lost in the process. [8]

### 2.3.2 Materials system:

About 965 Mt or 17 EJ of biomass is harvested annually for industrial roundwood for construction and paper and cardboard (Figure 2.3). Some 570 Mt/yr (10 EJ/yr) of the total industrial roundwood production is annually converted to saw logs for wood products (about 350 Mt/yr) and construction (110 Mt/yr). [8]

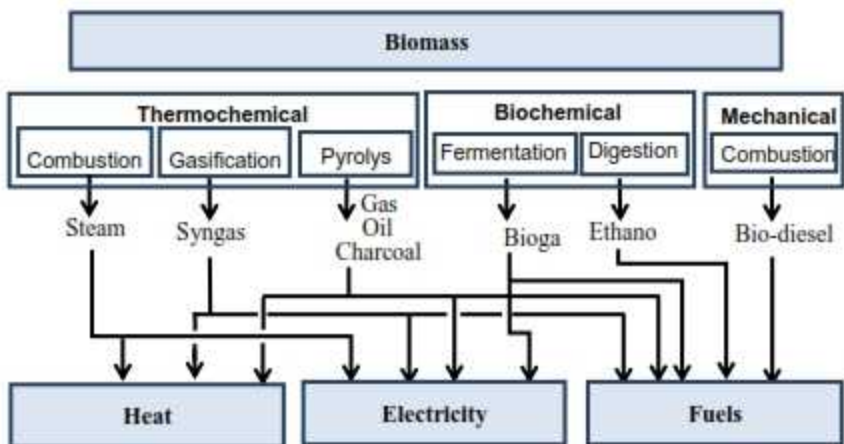


**Figure 2.3:** Main global wood flows [8]

## 2.4 Biomass to energy conversion methods

Biomass energy is an important source of energy in most countries. Huge amounts of biomass energy such as agricultural residues, dung and leaves are used by households and industries. The main household applications are cooking and heating also industrial applications are heating applications, biomass fuels are also used for power generation (steam and electricity). A lot of biomass fuels are available as by-product from other activities, such as saw milling and agricultural crop production. [10]

Biomass can be converted to electricity, heat and fuels via biochemical (Fermentation and anaerobic digestion), mechanical (extraction) and thermochemical (pyrolysis, combustion and gasification) processes (see Figure 2.4). The behavior of different types of biomass during conversion depends on organic and inorganic chemical structures.[6]



**Figure 2.4:** From biomass to energy products and fuels [7]

One way of minimizing the negative effects of wastes and maximizing the value of biomass is to convert biomass into a variety of chemicals, biomaterials and energy. [7]

There are many conversion technologies available for changing the quality of biomass to match its utilization purposes.

In general, conversion technologies for biomass utilization may either be based on physical, biological (bio-chemical) or chemical (thermo-chemical) conversion processes. Chemical and biological techniques are the best methods used for biomass conversion to fuel.

Physical conversion includes milling, grinding and steam explosion to decompose the biomass structure for increasing its surface areas to accelerate chemical, thermal or biological processes. Physical conversion technologies are also often used for the pretreatment to accelerate the main processes.

Chemical conversion includes hydrolysis, partial oxidation, combustion, pyrolysis, hydrothermal reactions for decomposing biomass, and also synthesis, polymerization, hydrogenation for constructing new molecules or reforming biomass.

Biological conversion is mainly composed of fermentation processes such as ethanol fermentation, methane fermentation. [6]

Different available technologies, Feedstock, processes and final products of biomass energy alternatives shown in Figure C.1 that gives clear understanding of these technologies, the processes involved, the types of applicable feedstock and the final products of each technology. [11]

The following are some of the best conversion routes frequently adopted.

#### **2.4.1 Mechanical Extraction**

Extraction is a mechanical conversion process used to produce oil from the seeds of various biomass crops. The process produces oil and a residual solid or 'cake', which is suitable for animal fodder.

Seeds oil can be processed further by reacting it with alcohol using a process termed esterification to obtain bio-diesel. [12]

#### **2.4.2 Biochemical Conversion Processes**

Biochemical conversion involves breaking down the hemicellulose fraction and making the remaining cellulose material more accessible for reaction. The lignin components of the original biomass remain unreacted throughout the biochemical process. The lignin can be recovered and used as fuel by thermochemical conversion process. [13]

Biochemical conversion is used to produce some commercial bulk chemicals, such as ethanol, lactic acid and citric acid, have been produced via yeast and bacterial fermentation processes. [7]

Two main biochemical processes are used, anaerobic digestion (AD) and fermentation processes.

#### **2.4.2.1 Anaerobic digestion (AD):**

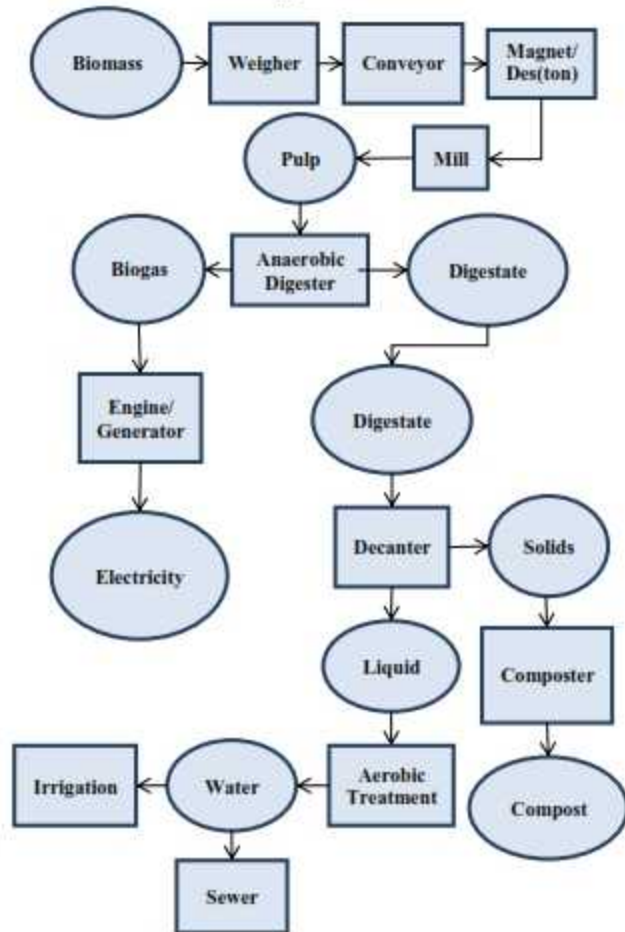
AD is the treatment and conversion of organic material with naturally occurring microorganisms in the absence of oxygen to produce a combustible gaseous fuel.

The biomass is decomposed and converted by micro-organisms (bacteria) in an anaerobic environment (absence of oxygen) to produce a biogas.

Main constituents of biogas are usually methane ( $\text{CH}_4$ ) 60-65 % and 35-40 % of carbon dioxide ( $\text{CO}_2$ ) with small quantities of traces of hydrogen ( $\text{H}_2$ ), nitrogen ( $\text{N}_2$ ), water vapor ( $\text{H}_2\text{O}$ ) and Hydrogen Sulfide ( $\text{H}_2\text{S}$ ) depending upon biomass resource.

AD is used for treating high moisture content organic wastes (80 – 90%) moisture. Biogas can be used directly in gas turbines and can be upgraded to higher such as natural gas quality, by the removal of  $\text{CO}_2$ . A typical flow sheet for processing biomass using AD is shown in Figure 2.5

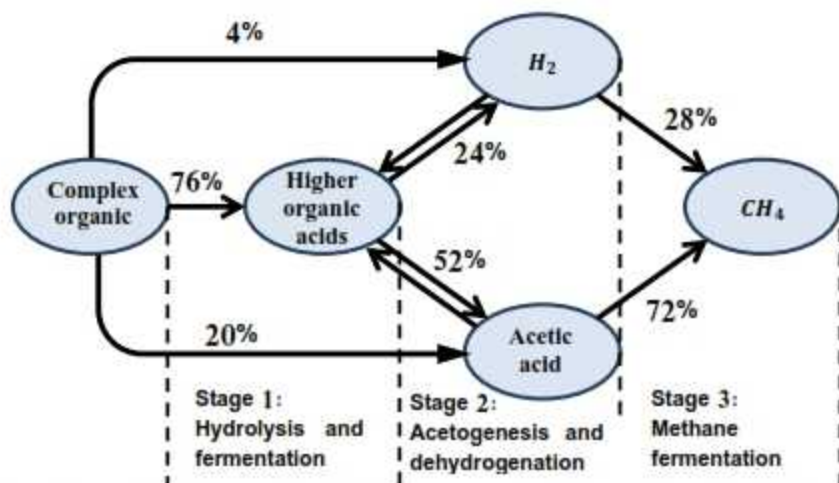
Biogas plant convert organic materials into a biogas and enriched organic fertilizer. Two typical construction designs of the biogas plants are the floating drum-type and the fixed dome-type. The produced biogas can be burned to generate electricity and heat or to be used as transport fuel. [11, 12]



**Figure 2.5:** Anaerobic digestion (AD) Process. [11, 12]

The entire process takes place in three basic steps as shown in Figure 2.6. The first step is the conversion of complex organic solids into soluble compounds by enzymatic hydrolysis. The soluble organic material formed is then converted into mainly short-chain acids and alcohols during the acidogenesis step. In the methanogenesis step, the products of the second step are converted into gases by different species of strictly anaerobic

bacteria. The percentage of methane in the final mixture has been reported to vary between 50 to 80%.



**Figure 2.6:** Steps in anaerobic digestion process with energy flow represented as % chemical oxygen demand (COD).

A typical mixture consists of 65% methane and 35%  $CO_2$  with traces of other gases. The methane producing bacteria generally require a pH range for growth of 6.4 to 7.2. The acid producing bacteria can withstand low pH. In doing their work, the acid producing bacteria lower the pH and accumulate acids and salts of organic acids. If the methane forming organisms do not rapidly convert these products, the conditions become adverse to methane formers. Municipal wastes and livestock manures are the most suitable materials for anaerobic digestion.

A major advantage of anaerobic digestion is that it utilizes biomass with high water contents of as high as 99%. Another advantage is the availability of conversion systems in smaller units. Also the residue has a

fertilizer value and can be used in crop production. The primary disadvantage of anaerobic digestion of diluted wastes is the large quantity of sludge that must be disposed of after the digestion process including the wastewater and the cost of biogas storage. [14]

The lignin fraction of biomass cannot be converted by anaerobic biochemical means and only very slowly through aerobic decomposition. [15]

#### **2.4.2.2 Fermentation:**

Fermentation is used to produce ethanol from sugar crops and starch crops. These crops are crushed to extract juice and the starch converted by enzymes to sugars, with yeast then converting the sugars to ethanol.

The solid residue from the fermentation process can be used as cattle-feed; the dregs can be used as a fuel for boilers or for subsequent gasification. [12]

### **Advantages and Disadvantages of Anaerobic Digestion**

#### **Advantages:**

- 1- AD contributes in reducing the greenhouse gases and reducing overall emission.
- 2- AD provides a source of clean energy with net zero CO<sub>2</sub>.
- 3- The feedstock for AD is a renewable source, and therefore does not deplete finite fossil fuels.
- 4- Energy generated through this process can help reducing the demand for fossil fuels.

- 5- The use of the digestate also can help reducing fuels that can be used in fertilizer manufacturing.
- 6- AD reduces the likelihood of soil and water pollution to happen, compared to disposal of untreated animal manure/slurries.
- 7- The treatment can also lead to reduction up to 80% of the odor and it destroys virtually all weed seeds, thus reducing the need for herbicide and other weed control measures.
- 8- AD converts residues into potentially saleable products: biogas, soil conditioner, liquid fertilizer.

**Disadvantages:**

AD projects will create some risks and have some potential negative environmental impact. AD has significant capital and operational costs. All waste management systems create traffic movement. This can become a problem in CAD (centralized anaerobic digestion) plants and alternative methods of transport should be investigated as transport greatly influences costs and emissions. Nuisance for the neighborhood has also to be taken into account.

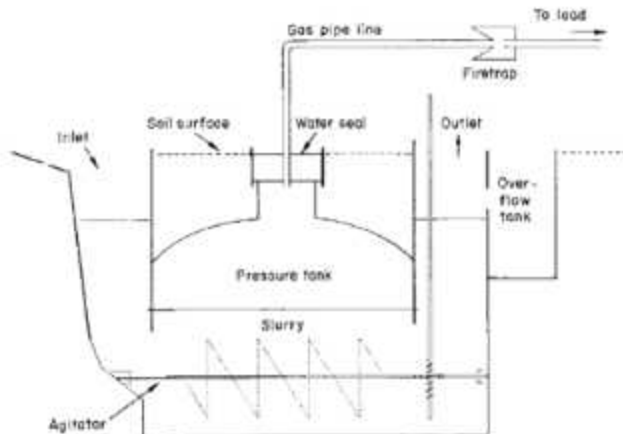
About health and safety, there may be some risks to human health with the pathogenic content of the feedstock but it can be avoid with an appropriate plant design and feedstock handling procedures. There may also be some risks of fire and explosion. [16]

### 2.4.2.3 Anaerobic Digesters Types:

There are many types of anaerobic digesters that can be used for agricultural, industrial, and wastewater treatment facility wastes. They differ by degree of complexity and the type of waste being digested. These types are described below.

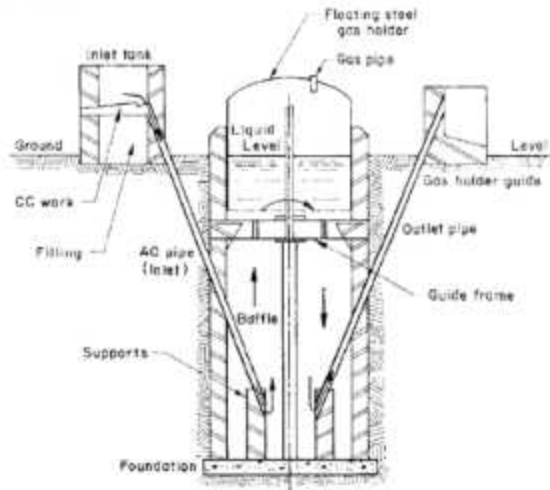
#### ii. The first generation biogas reactors:

Three main types of biogas facilities have been successfully developed for widespread biogas production in households and industrial use. These are the “Chinese Digester” of fixed dome type, the “Indian Gobar Gas Plant” of floating gas holder type and the rectangular commercial size biogas digesters developed in Taiwan. Shown in Figure 2.7 is the common Chinese digester design.



**Figure 2.7:** The Chinese Digester of the dome type.

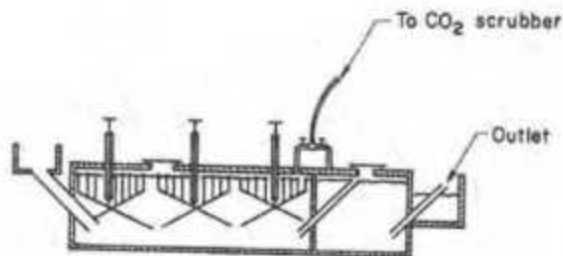
Biogas is pressurized in the dome and can be easily used for cooking and other application. Figure 2.8 shows the “Indian Gobar Gas Plant” with floating gas holder.



**Figure 2.8:** The Indian Gobar Gas Plant schematic showing cross-sectional design.

The Indian design uses concrete inlet and outlet tanks and reactor. The steel cover acts as the floating gasholder. These digesters have no pumps, motors, mixing devices or other moving parts and digestion takes place at ambient temperature. As fresh material is added each day, digested slurry is displaced through an outlet pipe. The digesters contain a baffle in the center which ensures proper utilization of the entire digester volume and prevents short circuiting of fresh biomass material to the outlet pipe.

Figure 2.9 is an example of a rectangular biogas digester used in commercial animals in Taiwan. The gas holder is designed and constructed separately.



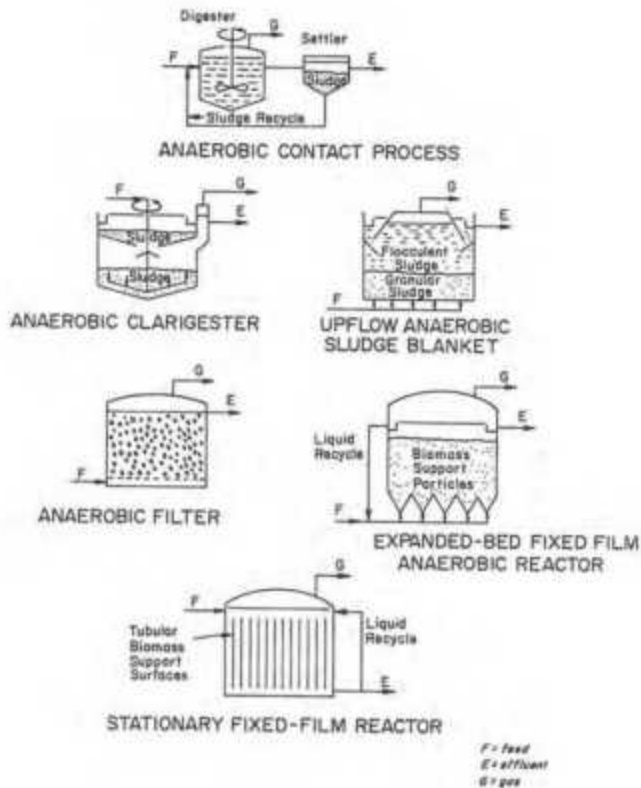
**Figure 2.9:** The Taiwan rectangular digester design with a separate gas holder.

While the above designs have been operated successfully, but the main disadvantage is the long retention times of between 30 to 60 days. Thus, for large scale units, they require larger reactor volumes which make the initial cost and area requirements quite high. Their main advantage is the fact that these units have less maintenance and operational costs and they are less prone to breakdowns due to variations in the quantity and quality of feed, they are resistant to shock loadings. The only operating procedure made is the daily mixing of the slurry. Table B.1 shows the comparison of various plant designs of digester. [17]

### **iii. The second generation biogas digesters:**

There are now new and high rate digester technologies which we may call the second generation biogas digesters. These high rate bio-reactors were originally designed for low strength liquid wastes but the progress has been remarkable and most units can now be used for even the high strength wastes with high quantities of suspended solids like those of livestock manure. The improvements of such digesters can be largely

attributed to better understanding of the microbiology of the methane production process. The most popular high rate anaerobic digesters originated from many conventional wastewater treatment plants that utilizes the anaerobic contact process (Figure 2.10) followed by the anaerobic digester. Perhaps the design that has caused widespread attention is the development of the upflow anaerobic sludge blanket (UASB) developed in Netherlands. Many commercial high rate digesters are now based on this design. Other reactors include the anaerobic filters, the expanded bed fixed film reactor, and the stationary fixed film reactor. As researchers began to understand the microbiology of the processes, they began to realize the varied nature and characteristics of the microorganisms used in the conversion. Thus recent designs call for the separation of two types of microorganisms in the reactors. Some new reactors are designed whereby acid forming bacteria are separated from the methane producing bacteria. With this design, the acid formers are now independent from the methane formers and therefore each group of microorganisms can do its job without harming the population of the other types of microorganisms. The retention times have been reduced for most of the high rate biogas digesters and thus reducing the size of the digesters. However, there are corresponding needs for a modest laboratory for microbial analysis, system pH control and monitoring of other parameters such as buffering capacity, solids retention times, alkalinity and the like.



**Figure 2.10:** Some examples of second generation biogas digesters. [17]

### 2.4.3 Thermochemical conversion processes

Biomass wastes can be easily converted into other forms of energy at high temperatures; they break down to form smaller and less complex molecules both liquid and gaseous including some solid products. Combustion represents a complete oxidation to carbon dioxide ( $\text{CO}_2$ ) and water ( $\text{H}_2\text{O}$ ). By controlling the process using a combination of temperature, pressures and various catalysts, and through limiting the

oxygen supply, partial breakdown can be achieved to yield a variety of useful fuels.

The thermo-chemical conversion involves any of the following process options; combustion, pyrolysis (charcoal production) and gasification.

Among all these processes, gasification of biomass is one of the most promising processes due to its high energy efficiency.

The advantages of thermo-chemical conversion processes include the following:

- a. Rapid completion of reactions.
- b. Large volume reduction of biomass.
- c. Range of liquid, solid and gaseous products is produced.
- d. Some processes do not require additional heat to complete the process. [20, 12]

The main processes and the final energy products resulting from thermo-chemical conversion are illustrated in the flowchart shown in Figure 2.11.

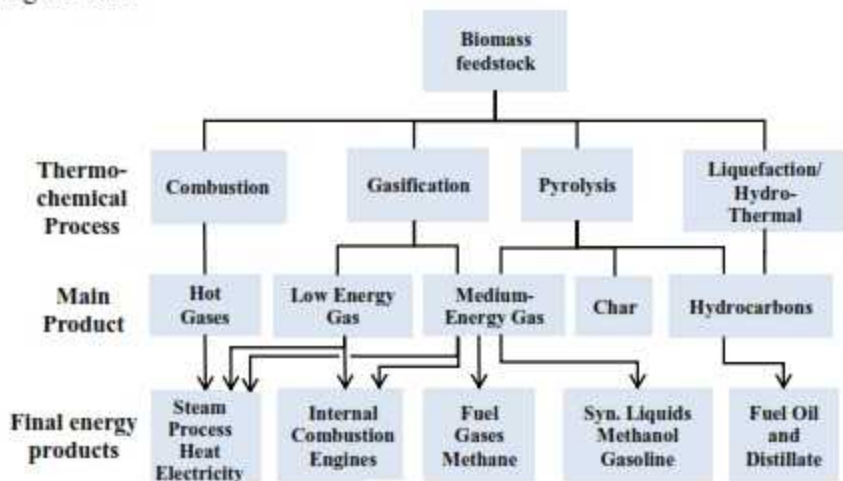


Figure 2.11: Thermochemical Process. [12]

The following Table (Table 2.1) shows the advantages of thermochemical conversion of biomass over biological/biochemical process.

**Table 2.1: Advantages of thermochemical conversion of biomass over biological/biochemical process. [21]**

Thermochemical	Biological/ biochemical
(1) Effectively applied to almost any biomass feedstock.	Involves the use of microbes, enzymes, and/or chemicals to utilize the limited range of biomass
(2) Relatively higher productivity (production per unit time) due to completely chemical nature of reaction.	Productivity is limited due to biological conversion. Increase would require higher capital investment such as bigger reactor
(3) Multiple high-value products possible using fractional separation of products.	Normally, limited to one or few products and would require additional microbial culture, enzymes for more products
(4) Independent of climate conditions, operates at much higher temperature range, therefore, effect of ambient temperature will be minimal	Mostly susceptible to ambient temperature, and so forth such as anaerobic digester, sunlight for algal ponds
(5) Mostly complete utilization of the waste/biomass.	Production of secondary wastes such as biomass sludge

The conversion of lignin into added-value products was mostly performed using thermochemical processes. These conversion processes include three sub-categories: gasification ( $> 900$  K), pyrolysis (650-800 K, 0.1-0.5 MPa) and liquefaction (500-600 K, 5-20 MPa). [22]

### 2.4.3.1 Combustion:

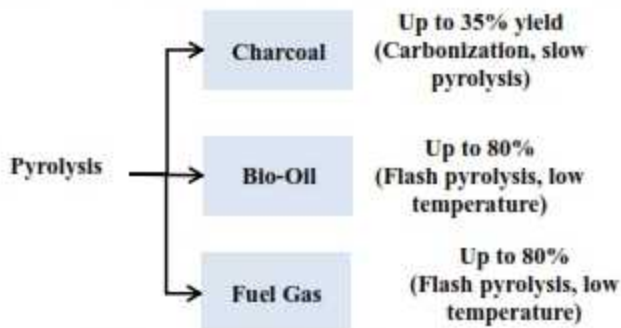
Combustion is the burning of biomass in air and rapid oxidation generating heat, or both light and heat. It is used to convert the chemical energy stored in biomass into heat, mechanical power, or electricity using stoves, furnaces, boilers, steam turbines, turbo-generators, etc. Combustion of biomass produces hot gases at temperatures around 800–1000°C. [23, 12]

Combustion used mostly for biomass with moisture content less than 50%. The combustion technologies can either by fixed bed or fluidized bed systems. [13]

The heat released from combustion can be used directly in thermal applications. It is used to raise steam which, when driving turbines or steam engines, can be converted into shaft power or electricity. [24]

### 2.4.3.2 Pyrolysis:

Pyrolysis is the conversion of biomass to produce three phases: Solid (Charcoal), liquid (Bio oil), and gaseous fractions (mainly CO<sub>2</sub>, CO, H<sub>2</sub> and CH<sub>4</sub>), by heating the biomass in the absence of air, Figure 2.12 shows the range and possible yields of pyrolysis energy products. [12, 25]



**Figure 2.12:** Characteristics of different types of pyrolysis [12]

The distribution among these three phases depends mainly on the temperature, the speed of heating and the residence time. [25]

There are different types of pyrolysis which show in the following section.

**i. Slow or Conventional pyrolysis:**

Slow or conventional pyrolysis is characterized by relatively low temperatures, a temperature of about 350 °C, low heating rates, and high residence times; A heating rates of this pyrolysis about <50°C/min and residence time of several hours. The methodology is based on using large solid pieces of feedstock and heating in situ to a set temperature for a period of time. The best known application of slow pyrolysis is the manufacture of charcoal. This technology called carbonization. [25, 26]

**ii. Fast pyrolysis:**

This type of pyrolysis used to produce mostly liquid (bio oil) product. The yield of oil or liquid is normally around 65-75% of the feedstock biomass and the amounts of char and gas are typically 10–25 and 10–20%, respectively.

The residence time of solid in fast pyrolysis is of the order of a few seconds or less with a heating rate of hundreds of °C/s (>100°C/s )and the temperature range used is normally about 500°C. The effluents are rapidly cooled to the ambient temperature. The bio-oil can be used in engines, turbines and feedstock refineries. [25, 26]

### iii. Flash pyrolysis

Flash pyrolysis is an extension to fast pyrolysis where heating rates reach around  $1000^{\circ}\text{C/s}$ . The residence time of the solid is less than a second and depending on the type of reactor. The major advantage of flash pyrolysis is the improved energy efficiency of the process. [26]

#### 2.4.3.3 Gasification:

Gasification is the conversion of biomass (carbonaceous materials) into a combustible gas mixture by breaking down of biomass to form a flammable gas by the partial oxidation of biomass at high temperatures, typically in the range  $(800\text{--}900)^{\circ}\text{C}$  and under a controlled amount of oxidizers. It is a partial oxidation process in a sense that the oxygen added is less than the stoichiometric amount required for complete combustion. This gas is known as a producer gas or a synthesis gas (syngas) which contains mainly mixture of hydrogen ( $\text{H}_2$ ), carbon monoxide ( $\text{CO}$ ), a little of carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), small quantities of other light hydrocarbons ( $\text{C}_5\text{H}_{10}$ ) and steam ( $\text{H}_2\text{O}$ ) including nitrogen ( $\text{N}_2$ ) present in the air that was supplied for the reaction. This gas used as fuel to generate electricity in large system through the use of a gas turbine in smaller systems, and also it used into transportation fuels; the syngas can be directly burned in internal combustion engines, reciprocating engines, micro turbines, Stirling engines, fuel cells, or further processed to produce chemicals, liquid fuels, SNG (synthetic natural gas) or hydrogen.

The range of calorific value of gas produced is between (4-40)

MJ/Nm<sup>3</sup> as show in Table 2.2, these differences depend on the type of material that using in oxidizing gas.

The low calorific value (CV) gas produced can be burnt directly or used as a fuel for gas engines and gas turbines. The product gas can be used as a feedstock (syngas) in the production of chemicals (e.g. methanol). [27, 28, 12, 13, 29]

Table 2.2: Product gas qualities achievable via gasification. [12]

Type	CV range (MJ/Nm <sup>3</sup> )
Low CV	4-6
Medium CV	12-18
High CV	40

Gasification has gained more interest than other thermochemical methods as it offers higher efficiencies compared to combustion and pyrolysis. [29]

Gasification has many advantages over combustion. The main advantages of producing heat and electricity using gasification over direct combustion are:

- Fuel-gas based technologies such as gas engines or gas turbines can achieve higher efficiencies than combustion efficiency.
- The overall efficiency of gasification is higher because gaseous fuels, having improved combustion characteristics, burn more efficiently than solid fuel.
- Production of gas provides an opportunity to remove contaminants that ultimately produce NO<sub>x</sub> and SO<sub>x</sub> emissions. [30]

However, one of the main disadvantages of gasification is the formation of tars. In general, tars are defined as being a complex mixture of condensable hydrocarbons. Tars can be removed from the product syngas by either chemical or physical methods. In chemical methods tar are decomposed to smaller molecules. Physical methods completely remove the tars from the syngas. Typical physical devices are cyclones, filters, electrostatics precipitators and scrubbers. [29]

#### **i. Advantages of biomass gasification:**

There are several advantages of biomass gasification compared to direct combustion:

- Numerous options for power production including gas engines, gas turbines and fuel cells. Direct combustion on the other hand is limited to mainly steam processes in addition to Stirling engines and indirectly red gas turbines.
- Easier combustion control due to combustion of gaseous fuel, compared to the inherently more complex control necessary for combustion of solid fuels.
- Relatively lower emission due to the fact that some components can be removed in the gasifier itself, in addition to in the gas cleaning system.
- Integration or co-firing in existing natural gas or coal fired power plants thus reducing the net CO<sub>2</sub> emissions.
- Hydrogen production or production of a high-yield hydrogen gas mixture.

- Basis for further chemical synthesis potentially able to produce a wide range of chemicals. [31]

## **ii. Gasification Reactions**

The complexity of the gasification process is illustrated by the number of reactions taking place, and the considerably number of components in the biomass.

In Table 2.3 the main reactions in the gasification process are listed. As observed, the most relevant equations for carbon conversion are (2.1-2.5), which also yield most of the CO and H<sub>2</sub> (main producer gas compounds). Gas-solid reactions of char oxidation are the slowest and, hence, they limit the overall rate of the gasification process. On the other hand, more H<sub>2</sub> can be produced in the WGS (water gas shift) reaction at expenses of CO and H<sub>2</sub>O (Equation 2.9). In order to achieve a high thermodynamic efficiency, exothermic reactions should be coupled with the endothermic reactions (2.1) and (2.2). [29]

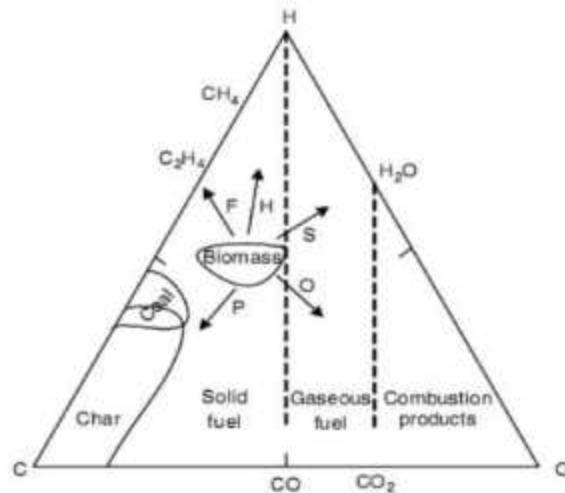
Table 2.3: List of main gasification reactions. [32, 33]

Reaction Type	Equation	$\Delta H_{298}$ (kJ/mol)	Equation No
Carbon Reactions			
(Boudouard)	$C + CO_2 \leftrightarrow 2CO$	+172	2.1
(water-gas or steam)	$C + H_2O \leftrightarrow CO + H_2$	+131	2.2
(hydrogasification)	$C + 2H_2 \leftrightarrow CH_4$	-74.8	2.3
Partial combustion	$C + 0.5O_2 \rightarrow CO$	-111	2.4
Oxidation Reactions			
The combustion reaction	$C + O_2 \rightarrow CO_2$	-394	2.5
	$CO + 0.5O_2 \rightarrow CO_2$	-284	2.6
Methanation reaction	$CH_4 + 2O_2 \leftrightarrow CO_2 + 2H_2O$	-803	2.7
The combustion reaction	$H_2 + 0.5O_2 \rightarrow H_2O$	-242	2.8
Shift Reaction			
Water-gas-shift (WGS) reaction	$CO + H_2O \leftrightarrow CO_2 + H_2$	-41.2	2.9
Methanation Reactions			
	$2CO + 2H_2 \rightarrow CH_4 + CO_2$	-247	2.10
	$CO + 3H_2 \leftrightarrow CH_4 + H_2O$	-206	2.11
	$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$	-165	2.12
Steam-Reforming Reactions			
	$CH_4 + H_2O \leftrightarrow CO + 3H_2$	+206	2.13
	$CH_4 + 0.5O_2 \leftrightarrow CO + 2H_2$	-36	2.14
Sulfur combustion	$S + O_2 \rightarrow SO_2$	-297	2.15
H <sub>2</sub> S formation	$SO_2 + 3H_2 \leftrightarrow H_2S + H_2O$	-207	2.16
CS <sub>2</sub> formation	$C + 2S \leftrightarrow CS_2$	+115	2.17
COS formation	$CO + S \leftrightarrow COS$	+63	2.18
NH <sub>3</sub> formation	$N_2 + 3H_2 \leftrightarrow 2NH_3$	-46	2.19
NO <sub>2</sub> formation	$N_2 + 2O_2 \leftrightarrow 2NO_2$	+66	2.20
COS hydrolysis	$COS + H_2O \rightarrow H_2S + CO_2$	-34	2.21

### iii. The ternary diagram

The ternary diagram (Figure 2.13) is a tool for representing the biomass conversion processes. The three corners of the triangle represent pure carbon, oxygen, and hydrogen- that is, 100% concentration. Points within the triangle represent ternary mixtures of these three substances. The side opposite to a corner with a pure component (C, O, or H) represents zero concentration of that component. For example, the horizontal base in

the diagram opposite to the hydrogen corner represents zero hydrogen that is, binary mixtures of C and O. A biomass fuel is closer to the hydrogen and oxygen corners compared to coal. This means that biomass contains more hydrogen and more oxygen than coal contains. Lignin would generally have lower oxygen and higher carbon compared to cellulose or hemicellulose. The diagram can also show the geological evolution of fossil fuels. With age the fuel moves further away from the hydrogen and oxygen corners and closer to the carbon corner. [34]



**Figure 2.13:** C-H-O ternary diagram of biomass showing the gasification process.

Where: H-hydrogen, S-steam, O-oxygen, P-slow pyrolysis, F-fast pyrolysis, L-lignin, C-cellulose/hemicelluloses. [34]

As mentioned above, the ternary diagram can depict the conversion process. For example, carbonization or slow pyrolysis moves the product toward carbon through the formation of solid char; fast pyrolysis moves it

toward hydrogen and away from oxygen, which implies higher liquid product. Oxygen gasification moves the gas product toward the oxygen corner, while steam gasification takes the process away from the carbon corner. The hydrogenation process increases the hydrogen and thus moves the product toward hydrogen. [34]

#### **iv. Types of Gasifiers:**

The main reactors types can be classified into three main groups depending upon the flow conditions:

- a. Entrained flow gasifiers.
- b. Fluidized bed gasifiers: subdivided into bubbling (BFB) and circulating (CFB) beds.
- c. Fixed bed gasifiers: subdivided into counter-current (updraft), co-current (downdraft) and cross-current moving beds.

The reactors can be operated at atmospheric pressure or at higher pressures, but the latter is only available to BFB or CFB reactors.

CFB are the most reliable system for large scale plants whereas fixed bed gasifiers are more convenient for small applications due to their inability to keep uniform radial temperatures profiles and avoid local slagging problems. CFB gasifiers are an extension of BFB concept, with the difference that with cyclones or other separators are employed to capture and recycle solids in order to extend the solids residence time. CFB have been successfully demonstrated up to 100 MW, and they are also expected to be stable and reliable at higher power ratings. Atmospheric BFB

gasifiers are proven reliable up to 25 MW, but larger reactor size makes up-scaling difficult. [29]

The main benefits and drawbacks of these different techniques (fixed bed and fluidized bed) are presented in Table C.1. [35]

The feedstock requirements, mode of operation, and output products obtained in each gasifier type are compared in Table C.2 and C.3.

#### **v. Gasifying Medium**

There are mainly 3 gasifying media or blasts; air, steam and pure oxygen. Hence, the blast always contains oxygen, either as free oxygen or bound as for steam or  $\text{CO}_2$ . [29]

The simplest form of gasification is air gasification in which biomass is subjected to partial combustion with a limited supply of air. Air gasifiers are simple, cheap and reliable. Their chief drawback is that the gas produced is diluted with nitrogen and hence has low calorific value. The gas produced is uneconomical to distribute; it must be used on-site for process heat.

In oxygen gasification, pure oxygen is used so that the gas produced is of high energy content. The chief disadvantage of oxygen gasification is that it requires an oxygen plant and thus increases the total cost of gasification. [14]

Biomass oxygen-blown gasification leads to the production of a syngas with medium heating value (10-13 MJ/Nm<sup>3</sup>).

Steam blown gasification produces a syngas with an acceptable HHV value (10-16 MJ/Nm<sup>3</sup>). Steam is the preferred gasifying media when the desired end-product is the production of SNG. Conversely, air (or oxygen) is preferred for the production of BTL (Biomass to liquid) fuels, such as methanol. [29]

The advantages and disadvantages of using the deferent gasification media can be summarized as shown in Table 2.4.

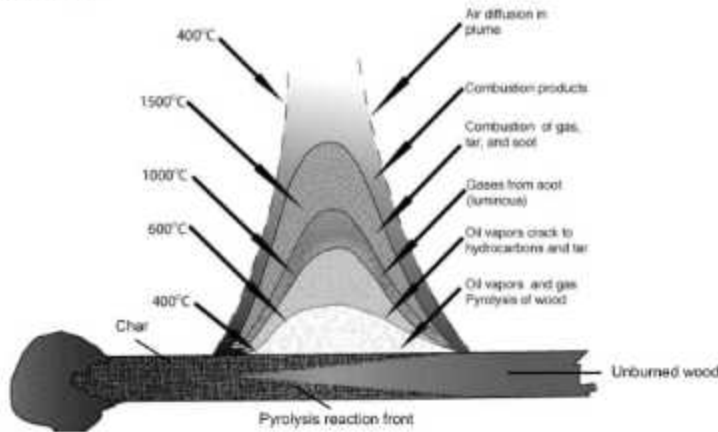
**Table 2.4: Comparison of gasification agents. [29, 36]**

Gasification agent	Advantages	Disadvantages	Heating value of product gas	
			MJ/Nm <sup>3</sup>	kWh/Nm <sup>3</sup>
<b>Air</b>	Inexpensive	Low heating value	4-7	1.111-1.944
<b>Oxygen</b>	N <sub>2</sub> - free product gas Medium heating value	Expensive	10-18	2.777-5.000
<b>Steam</b>	N <sub>2</sub> - free product gas Medium heating value Enhanced H <sub>2</sub> content	Very endothermic process	13-19	3.611-5.278

#### **vi. How Gasification Works**

Gasification is most simply thought of incomplete combustion. It is burning solid fuels like wood or coal without enough air to complete combustion. The output gas is combustible gas. The unburned gas is then piped away to burn elsewhere as needed.

The conversion of biomass to a low- or medium-heating-value gaseous fuel in a gasifier generally involves several processes that show in Figure 2.14.



**Figure 2.14:** Pyrolysis, gasification and combustion in a burning match stick. [37]

The first process is the drying step where water evaporates using the heat released from later stages.

The dried biomass then undergoes pyrolysis reactions, which releases the volatile components of the feedstock.

These volatile vapors contain hydrocarbon gases, hydrogen, carbon monoxide, carbon dioxide, tars, and water vapor. The non-volatile fraction is commonly referred as char, and it mainly consist of fixed carbon and ash. Another gasification process is char conversion, where the remaining carbon reacts with steam or oxygen. The exothermic combustion reactions are the heat source to drive the endothermic process of pyrolysis and char gasification reactions. Generally, pyrolysis occurs at much higher rates than the gasification reactions.

In direct gasifiers, all processes of pyrolysis, char gasification and combustion occurs in one vessel. In the case of using steam, the gasification reactions are endothermic overall. The heat required to drive those reactions can be supplied externally or by introducing some air into the gasifier to burn part of the available fuel. This second alternative has the inherent disadvantage of diluting the syngas with nitrogen and, hence, lowering its calorific value.

Direct gasifiers use both air and steam, indirect gasifier only use steam as gasifying medium. Produced syngas has a heating value ~ 13-19 MJ/Nm<sup>3</sup>. [29, 36]

#### **vii. The Five Processes of Gasification**

Gasification is made up through five thermal processes: Drying, Pyrolysis, Oxidation (Combustion), Cracking, and Reduction, these process shows in Figure 2.15 & C.2.

The gasification process can be classified into the following stages, which occur consecutively:

##### **1- Drying:**

In this stage, the moisture content of the biomass is reduced before it enters pyrolysis. Typically, the moisture content of biomass varies from 5% to 40%. Drying occurs at about 100–200°C with a reduction in the moisture content of the biomass to less than 2%. This step can be subdivided into two; the primary step is inert heating, whereby the feedstock particles reach the allotted moisture temperature to evaporate and release. [36]

**2- Devolatilization (Pyrolysis):**

This is essentially the thermal decomposition of the biomass in the absence of oxygen or air. [38]

In this process, the volatile matter in the biomass is reduced. This results in the release of hydrocarbon gases from the biomass, which reduces the biomass to solid charcoal. [36]

Biomass begins to rapidly decompose with heat once its temperature rises above around 240°C. The biomass breaks down into a combination of solids (charcoal), liquids (tar) and gasses. [38]

The hydrocarbon gases can condense at a sufficiently low temperature to generate liquid tars.

**3- Oxidation (Combustion):**

This is a reaction between solid carbonized biomass and oxygen in the air, resulting in formation of  $\text{CO}_2$ . Hydrogen present in the biomass is oxidized to generate water. A large amount of heat is released with the oxidation of carbon and hydrogen. If oxygen is present in sub-stoichiometric quantities, partial oxidation of carbon may occur, resulting in the generation of carbon monoxide. [36]

**4- Cracking:**

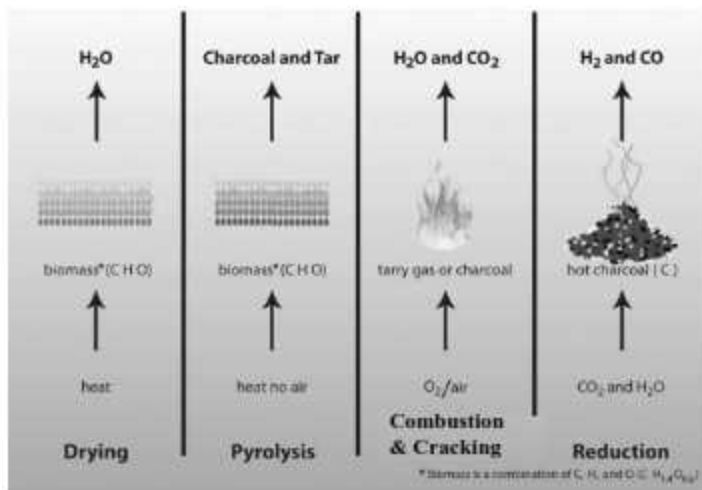
Cracking is the process of breaking down large complex molecules such as tar into lighter gases by exposure to heat. This process is crucial for the production of clean gas that is compatible with an internal combustion engine because tar gases condense into sticky tar that will rapidly foul the

valves of an engine. Cracking is also necessary to ensure proper combustion because complete combustion only occurs when combustible gases thoroughly mix with oxygen. In the course of combustion, the high temperatures produced decompose the large tar molecules that pass through the combustion zone. [38]

### 5- Reduction:

In the absence (or sub-stoichiometric presence) of oxygen, several reduction reactions occur in the (800-1000)°C temperature range. These reactions are mostly endothermic. The main reactions in this category are the water-gas, Boudouard ( $C + CO_2 \leftrightarrow 2CO$ ), shift, and methane.

These process shows in Figure 2.15 and Figure C.3. [36]



**Figure 2.15:** Five Processes in Gasification. [38]

**viii. Gasification Classifications and Technologies:**

Gasification can be classified in several parameters:

**- By the agent, such as:**

- a. Air-blown.
- b. Oxygen blown.
- c. Steam gasifiers.

**- By heat source, either:**

- a. Auto-thermal or direct:

Heat is provided by partial combustion of biomass.

- b. Allothermal or indirect gasifiers:

Heat is supplied by an external source via a heat exchanger or an indirect process.

**- By the gasifier pressure:**

- a. Atmospheric.
- b. Pressurized.

**- The fourth and most common are by the reactor design and that follows three main subcategories:**

- a. High temperature entrained flow.
- b. Fixed bed (sometimes referred to as moving bed).
- c. Fluidized bed gasifiers.

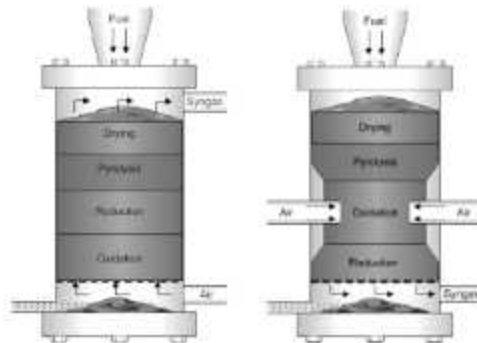
### ix. The common gasifier types

More details on each of these designs are given below.

#### 1- Fixed Bed Gasifiers:

Moving bed gasifiers are countercurrent flow reactors in which the particle enters at the top of the reactor and air or oxygen enters at the bottom. As the particle slowly moves down through the reactor, it is gasified and the remaining ash drops out of the bottom of the reactor. Because of the countercurrent flow arrangement, the heat of reaction from the gasification reactions serves to pre-heat the particle before it enters the gasification reaction zone. Consequently, the temperature of the syngas exiting the gasifier is significantly lower than the temperature needed for complete conversion of the particle.

Fixed bed gasifiers are simple to construct and generally operate with high carbon conversion, long feedstock residence time, low gas velocity, and low ash carry-over. , this type of gasifier shows in Figure 2.16. [36]



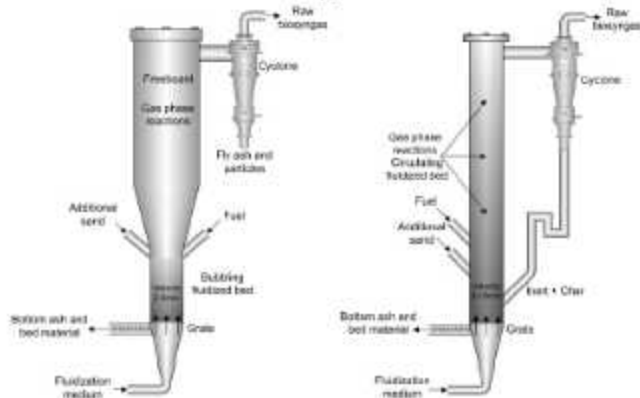
**Figure 2.16:** Scheme and operating principle of conventional fixed-bed gasifiers

Explanations: Left: updraft gasifier; Right: downdraft gasifier. [39]

## **2- Fluidized Bed Gasifiers:**

A fluidized bed gasifier is a back-mixed or well-stirred reactor in which there is a consistent mixture of new particle, particles mixed in with older, partially gasified and fully gasified particles. The mixing also fosters uniform temperatures throughout the bed. The flow of gas into the reactor (oxidant, steam, recycled syngas) must be sufficient to float the particles within the bed but not so high as to entrain them out of the bed. However, as the particles are gasified, they will become smaller and lighter and will be entrained out of the reactor. It is important that the temperatures within the bed are less than the initial ash fusion temperature of the particle to avoid particle agglomeration. These gasifiers are characterized by short residence time, high temperatures, high pressures, and large capacities.

**Entrained Flow Gasifiers** A finely ground particle is injected in concurrent flow with the oxidant. The particle rapidly heats up and reacts with the oxidant. The residence time of an entrained flow gasifier is seconds to several seconds. Because of the short residence time, entrained flow gasifiers must operate at high temperatures to achieve high carbon conversion. Consequently, most entrained flow gasifiers use oxygen rather than air and operate above the slagging temperature of the particle. The Feedstock requirements for different types of gasifiers and the effect of the different gasifier technologies on the gas composition are presented in Figure 2.17 and Tables C.2. [36]



**Figure 2.17:** Schematic illustration and operating principle of fluidized bed gasifiers.

Explanations: Left: bubbling fluidised bed, right: circulating fluidised bed. [39]

#### **x. Thermochemical conversion**

The main advantages are that the feedstock for thermochemical conversion can be any type of biomass including agricultural residues, forestry residues, non-fermentable byproducts from biorefineries, byproducts of food industry, byproducts of any bioprocessing facility and even organic municipal wastes; and the product gases can be converted to a variety of fuels ( $H_2$ , Fischer-Tropsch (FT) diesels, synthetic gasoline) and chemicals (methanol, urea) as substitutes for petroleum-based chemicals;

The major disadvantages are the high cost associated with cleaning the product gas from tar and undesirable contaminants like alkali compounds, inefficiency due to the high temperatures required, and the unproven use of products (syngas and bio-oil) as transportation fuels. [30]

## **2.4.4 Biogas and Producer Gas production:**

### **2.4.4.1 Biogas Production:**

Biogas is produced from wet residues of animals, plants waste, and organic household and industrial wastes.

Generally, all types of biomass can be used in AD process as long as they contain carbohydrates, proteins, fats, cellulose, and hemicellulose as main components.

The substrates for AD can be classified according to various criteria: origin of biomass, dry matter (DM) content, methane yield and other. Table D.1 gives percentage of dry matter and biogas production for some wastes.

Substrates with DM content lower than 20% are used for what is called wet digestion (wet fermentation). This category includes animal slurries and manure as well as various wet organic wastes from food industries. When the DM content is as high as 35%, it is called dry digestion (dry fermentation), and it is typical method for energy crops and silages.

In dry fermentation anaerobic digestion the material mainly has moisture content less than 75%. No mixing, no pre-treatment of organic waste also there is no need for liquid addition. On contrast, wet fermentation requires that biomass and organic waste input undergo multiple treatment steps prior to entering digester system. Anaerobic digestion using input material that has moisture content greater than 75%

and a system that requires the addition of liquid for the movement of organic material.

The choice of types and amounts of feedstock for the AD substrate mixture depends on their DM content as well as the content of sugars, lipids and proteins. [10]

The caloric value of biogas mainly depends on conversion method and the used biomass. The average calorific value of biogas is approximately  $6.4\text{kWh/Nm}^3$  ( $23\text{ MJ/Nm}^3$ ). [41]

For example the energy value of biogas obtained by the anaerobic treatment of  $1\text{m}^3$  of OMWW reaches 60–80kWh of energy. [40]

The dry matter (DM) and organic dry matter (ODM) contents for manures from livestock and agricultural wastes are given in Table 2.5.

**Table 2.5: DM & ODM contents for manures from livestock and agricultural wastes. [42-44]**

Animal		Dung- Fresh			
		DM		ODM in DM	
		Range	Average	Range	Average
Poultry	Broilers	0.10-0.29	0.195	0.67-0.77	0.72
	Mothers of Broiler				
	Layer				
	Turkey				
	Corrupt eggs & Eggshell	0.25		0.92	
	Slaughterhouse waste	0.33		-----	
Cattle	Calf	0.180		0.783	
	Hurry				
	Cow-milk				
Sheep		0.18-0.25	0.215	0.80-0.85	0.825
Goat		0.18-0.25	0.215	0.80-0.85	0.825
Camel		0.080		---	---
Household solid waste		0.47		-----	-----
Agriculture Waste		0.43		-----	-----

**DM:** dry matter

**ODM:** organic dry matter

The potential of biogas production from cattle waste, Poultry waste, Sheep waste, Goat waste and Camel waste are 0.575, 0.550, 0.350, 0.350 and 0.040 m<sup>3</sup>/(kg. OTS), respectively. [10]

The amount of produced biogas depends on the origin and amount of manure discharged into the unit, as well as the ratio manure/water.

The total biogas generated can be calculated by using some factors as given Tables 2.6 and 2.7. These tables present the gas yield per unit of kg of total solid and organic total solid, respectively.

**Table 2.6: The total biogas generated from some waste. [42, 45]**

Substrate for biogas production		Biogas yield-(m <sup>3</sup> /kg.TS)
Poultry waste	Corrupt eggs & Eggshell	0.98
	Slaughterhouse waste	0.50
Agriculture Waste		0.60
Household solid waste		0.21

**Table 2.7: The total biogas generated from Poultry and some animals. [42-45]**

Animal		Biogas yield-(m <sup>3</sup> /kg.OTS)	
		Range	Average
Poultry	Broilers	0.3-0.8	0.550
	Mothers of Broiler		
	Layer		
	Turkey		
Cattle	Calf	-----	0.575
	Hurry		
	Cow-milk		
Sheep		0.3-0.4	0.350
Goat		0.3-0.4	0.350
Camel			0.040

#### 2.4.4.2 Producer Gas:

Producer gas is the mixture of gases produced by the gasification of organic material at relatively low temperatures (700°C to 1000°C). Producer gas is composed of carbon monoxide (CO), hydrogen (H<sub>2</sub>),

carbon dioxide ( $\text{CO}_2$ ) and typically a range of hydrocarbons such as methane ( $\text{CH}_4$ ) with nitrogen from the air. Producer gas can be burned as a fuel gas such as in a boiler for heat or in an internal combustion gas engine for electricity generation or combined heat and power (CHP). The composition of the gas can be modified by manipulation of gasification parameters. Syngas (synthesis gas) is a mixture of carbon monoxide ( $\text{CO}$ ) and hydrogen ( $\text{H}_2$ ), which is the product of high temperature steam or oxygen gasification of organic material such as biomass. Following clean-up to remove any impurities such as tars, syngas can be used to produce organic molecules such as synthetic natural gas (SNG-methane ( $\text{CH}_4$ )) or liquid biofuels such as synthetic diesel (via Fischer-Tropsch synthesis). [46]

Producer gas or synthetic gas, which is one of the renewable energy resources, is produced by dry organic materials or organic residues. In general, all types of biomass can be used in gasification process if it is used as dry materials.

The following Table 2.8 demonstrates some properties of producer or synthetic gas.

**Table 2.8: Some properties for the producer or Synthetic gas. [47]**

Producer Gas	
Process	chemical/thermal conversion
Main gas product	$\text{H}_2$ , CO
Residence time	several minutes up to hours
Maximum Producer gas production (Air agent used) ( $\text{Nm}^3/\text{kg Wood}$ ).	2.1

## **2.5 Environmental concentration of biogas and gasification**

Environmental pollution is a major problem facing all nations of the world. The pollutants emitted into the atmosphere can be transported over long distances. Various opportunities exist for the substantial reduction in industrial emissions through the use of alternative energy.

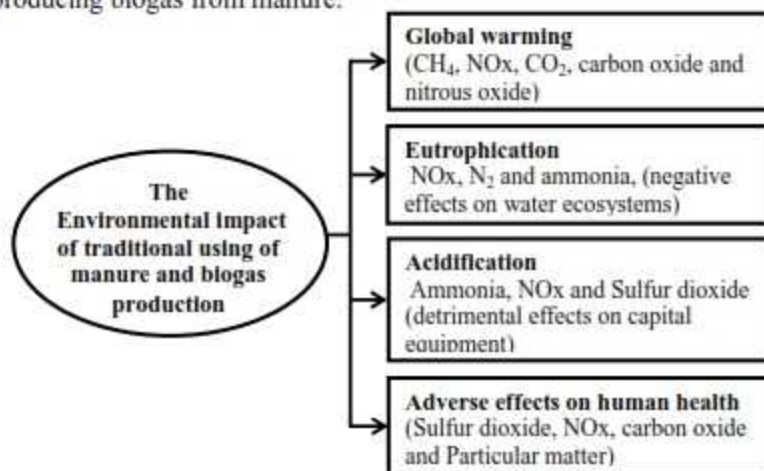
In this context, biomass resources are an alternative to help reduce the fossil fuel use. Besides being renewable, the continued utilization of biomass for energy production can bring about other environmental benefits including the recovery of degraded land, reduction of soil erosion, and protection of watersheds. [7]

Here are some examples of impacts to the community from using biomass.

- 1- There are some negative impacts of forest management and farming of biomass crops on ecosystems and habitats (biodiversity loss, Changes in forest biomass density, the impacts on birds).
- 2- Transporting biomass has noise and emissions implications.
- 3- There is air quality implications depending on the type of biomass used.
- 4- There are high levels of water use for biomass cropping which can be problematic in areas where access to water is limited. [48]

### 2.5.1 Environmental concentration of producing biogas from manure

The environmental concentration can be studied through comparing emissions from traditional using of manure to emissions from a biogas system. Although this is one of the scopes of this study, but also more concentration will be given to the impact of the process which can be divided into four effects; Figure 2.18 shows type of environmental impacts of producing biogas from manure.



**Figure 2.18:** type of environmental impacts of producing biogas from manure. [18]

#### 2.5.1.1 The emissions from traditional using of manure

The amount of methane emissions from traditional use of manure (storage and use as fertilizer) depends on the climatic conditions (especially the temperature and humidity). This means WB&GS can be divided to two climate zones, based on temperature data from PVSOL premium 7.0 software. According to that, the first climatic zone is divided to; Gaza strip, Jericho & Al- Aghwar area with the hottest climate, and the Second zone

includes Hebron, Bethlehem, Jerusalem, Nablus, Tubas, Salfit, Jenin, Tulkarm, Qalqiliya, Ramallah and Al-Bireh area as coldest climate. [18]

Table 2.9 shows amount of methane emission from Livestock in WB&GS

**Table 2.9: Potential of methane emission from Livestock in WB&GS. [19]**

Type of Livestock		Annual percentage of nitrogen emission for one animal
		kg N <sub>2</sub> / (one cattle. Year)
Cattle	Cows	70.26
	Others	49.88
Sheep		11.96
Goats		15
Camels		36.43
Poultry		0

Next, distributing manure on agricultural lands causes emissions of ammonia (NH<sub>3</sub>) and nitrous oxide (N<sub>2</sub>O). However, it contributes to eutrophication and acidification. Table 2.10 shows the amount of Nitrogen emission from Livestock in WB&GS. [18]

**Table2.10: Amount of Nitrogen emission from Livestock in WB&GS.[19]**

Type of Livestock		kg CH <sub>4</sub> /(one cattle. Year)	
		emission factor for manure	Emission factor for stomach fermentation
Cattle	Cows	2	40
	Others	1	31
Sheep		0.15	5
Goats		0.17	5
Camels		1.92	46
Poultry		0.02	0

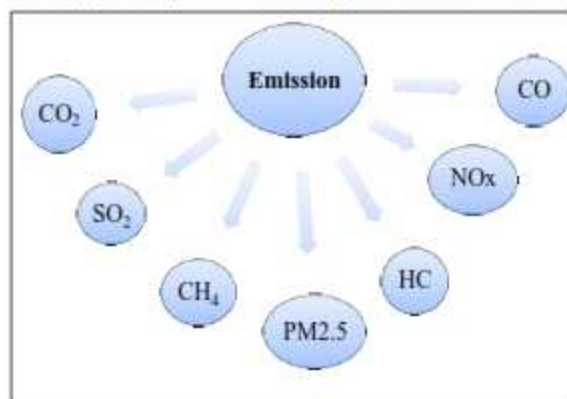
### 2.5.1.2 Emissions from biogas production

Emissions from biogas production arise from the use of energy for transports the manure from several individual farms and running the digestion facility.

Hence, emissions are caused by the use of energy when:

1. Transporting manure to the digestion facility.
2. Transporting the digestate back to the farm and distributing it on the lands.
3. Running the digestion facility.

These emissions are summarized in Figure 2.19 which shows the emissions caused by energy used for transports of manure

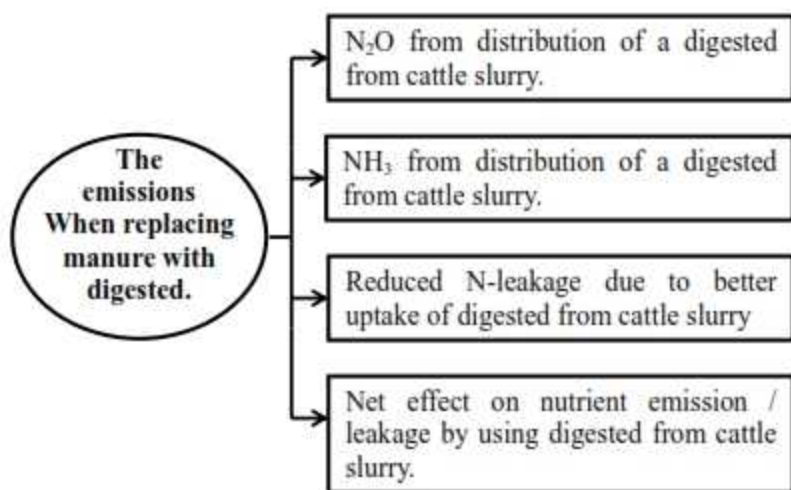


**Figure 2.19:** Emissions caused by energy used for transports of manure, and running the digestion facility

PM<sub>2.5</sub>: particulate matter with a diameter of 2.5 micrometers or less.

The generating emissions per Nm<sup>3</sup> methane produced differ between types of residues that used in digester and the nature of digester

(decentralized or centralized digester). When using the centralized digester, the wastes are transported from farms to digester by lorry. On the other sides, the slurry production from digester is transported back to agricultural lands by lorry. This process leads to generate emissions to atmosphere from the combustion of diesel, Figure 2.20 shows the main emission when replacing manure with digested.



**Figure 2.20:** The main emission when replacing manure with digested. [18]

### 2.5.2 Environmental concentration of gasification

Gasification processes cause many environmental problems including water and air pollution, disposal of ash and other by-products. Gasification process includes health, safety, and odor problems. Environmental aspects of gasification and associated hazards are given in Table 2.11.

**Table 2.11: Environmental aspects of gasification and associated hazards**

Process activity	Fuel preparation	Fuel feeding System	Gasifier	Gas cleaning system	Gas utilization
<b>Environmental concern</b>					
Dust	×	×		×	
Noise	×	×	×	×	×
Odor	×		×	×	
Wastewater				×	×
Tar				×	×
Fly ash				×	
Exhaust gases					×
Hazards					
Fire	×	×	×	×	×
Dust explosion	×	×	×		
Mechanical Hazard	×	×	×		×
Gas poisoning		×	×	×	×
Skin burns			×	×	×
Gas explosion			×	×	×
Gas leak			×	×	×

During gasification, tars, alkaline compounds, halogens and heavy metals are released and can cause environmental and operational troubles.

#### **2.5.2.1 Air pollution**

During the gasification process, different byproducts are released in the environment such as dust, biomass ash, fly ash and gaseous emission.

#### **2.5.2.2 Dust:**

Dust is generated during feedstock preparation, storage and handling, feeding, and fly ash removal. The gasifier should not generate more than 2–6 g/m<sup>3</sup> of dust. The dust can cause many problems for persons; these problems are lung damage, irritation of skin and eyes

#### **2.5.2.3 Biomass ash**

The percent of ash which remains after gasification around 8-15% of the original volume is toxic and presents special problems because of the acidic.

#### **2.5.2.4 Fly ash and char**

There are two types of particles existed in fly ash from gasification. The first type is unburned carbon particles and mineral substances, and the second is formed by volatilization and condensation. This emission may cause risk of fire and shows the similar issues as dust and biomass ash

#### **2.5.2.5 Gaseous emissions**

Gaseous emissions produced from gasification process by the conversion of biomass to produced gas and burning it.

Using the non-woody biomass as a raw material in gasification cause relatively a high amount of sulfur, chlorine and ash was produced, compared with woody biomass. [49]

(Woody biomass is wood from trees without the leaves, bark and roots. Non-woody biomass is waste from the industry, agriculture and animals (straw, grass, manure, and sludge). [50]

Many emissions as CO, Nitrogen and sulfur oxides are produced during combustion of the fuel gas; these emissions can have a negative environmental impact. [49]

#### **2.5.2.6 Water pollution**

Wastewater is produced during the process of cooling and cleaning of producer gas. Phenolic and terry components are presents in wastewater released from gasification power plant. Disposal of this waste generates environmental problems (such as drinking water) and needs to a pretreatment before its discharge.

However, during the cooling process, some hydrocarbons are condensed with the water vapor out of the gas resulting in a condensate contaminated with organic compounds. These compounds are carcinogenic and highly toxic leading to a risk of water pollution.

#### **2.5.2.7 Hazards of gasifier operation**

When a flammable mixture of gas and air is formed, an explosion may occur when the mixture is ignited.

The main fire risks in gasifier systems are associated with Fuel storage and drying, combustible dusts formed in fuel preparation, Ignition procedure and the product gas

Biomass gasification process has the disadvantage of generating a high amount of tar as a byproduct. According to biomass tar is referred to as condensable organics in the producer gas produced in the gasification process of biomass. Gasifier should put out less than  $1 \text{ g/m}^3$  of tar. [51]

#### 2.5.2.8 Tar yield problem

Biomass gasification process has the disadvantage of generating a high amount of tar as a byproduct. According to biomass tar is referred to as condensable organics in the producer gas produced in the gasification process of biomass. Gasifier should put out less than  $1 \text{ g/m}^3$  of tar. [51]

#### 2.5.2.9 Trace impurities:

These trace gases like  $\text{N}_2$ , S, Cl and some elements volatilized from the biomass during gasification. Nitrogen compounds are present in the form of ammonia, with hydrogen cyanide. [51]

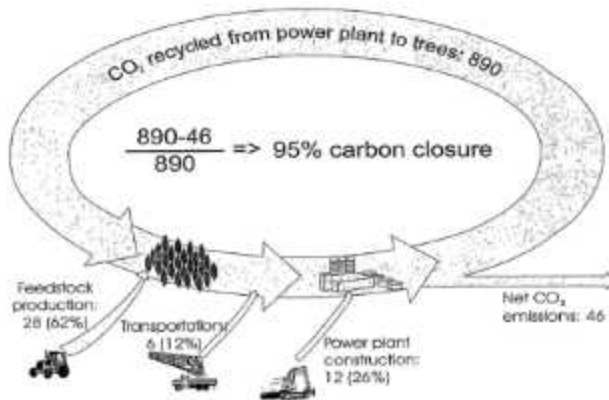
Table 2.12 illustrates main contaminants released during the gasification process and problems.

**Table 2.12: Syngas Contaminants. [52]**

Contaminant	Example	Potential Problem
Particles	Ash, Char, Fluid bed material	Erosion
Alkali Metals	Sodium and Potassium Compounds	Hot corrosion, Catalyst Poisoning
Nitrogen Compounds	$\text{NH}_3$ and HCN	Emissions
Tars	Refractive aromatics	Clogging of filters
Sulfur, Chlorine	$\text{H}_2\text{S}$ and HCl	Corrosion, emissions, Catalyst poisoning

### 2.5.2.10 Carbon Dioxide Emissions

The carbon released during gasification is removed from the atmosphere during the growing cycle. Biomass power is not a zero-net CO<sub>2</sub> process. Carbon dioxide is emitted from biomass production and farming operations that used fossil fuels, transportation of the biomass to the power plant, and from the power plant itself. Figure 2.21 shows the Life Cycle Flows of CO<sub>2</sub> within a Biomass Power.



**Figure 2.21:** Life Cycle Flows of CO<sub>2</sub> within a Biomass Power System gr.

CO<sub>2</sub> per kWh of Electricity (% of net). [53]

## **Chapter Three**

### **Methodology**

## **Chapter Three**

### **Methodology**

In this study, production of clean alternative energy based on biomass using the gasification and bio digestion technology are discussed.

Biomass waste in this study is investigated as an important source of energy in the form of clean and environmentally friendly gas. This biofuel can be used easily in electricity production.

This study can be summarized in three parts: the first part is a comprehensive survey of the amount and type of biomass waste in WB&GS. It is based on several available data such as Palestinian Central Bureau of Statistics, Palestinian National Center for Agricultural Research, meeting with farmers and others.

The second part is to select and design a suitable gasifier for this study. In this study a downdraft gasifier was designed and constructed successfully and tested.

Finally, the third part is a simulation of the main parameters of the gasification process

The details of these parts can be broken down as:

- Calculation of Biomass residues.

- Calculations of biofuel potential from biomass.

- Experimental Work on gasification.

- Simulation Process.

### 3.1. Calculation of Biomass residues

#### 3.1.1. Agricultural residues

The biomass residues can be calculated based on the following methods:

**The first method is:**

##### a. Residue factor.

Biomass residues are calculated using the following equation

$$BR = P \times RF \dots\dots\dots(3.1)$$

BR:

Pr:

RF : RF is given in Table 3.1 and Figure 3.1

**Table 3.1: Residue Factor for Date and Olive. [54, 55]**

Type		Waste residue
Date	Date leaves- (Palm fronds per tree)	0.15
	seeds/dunam	0.15
Olive	twigs & leaves (per tree)	0.025

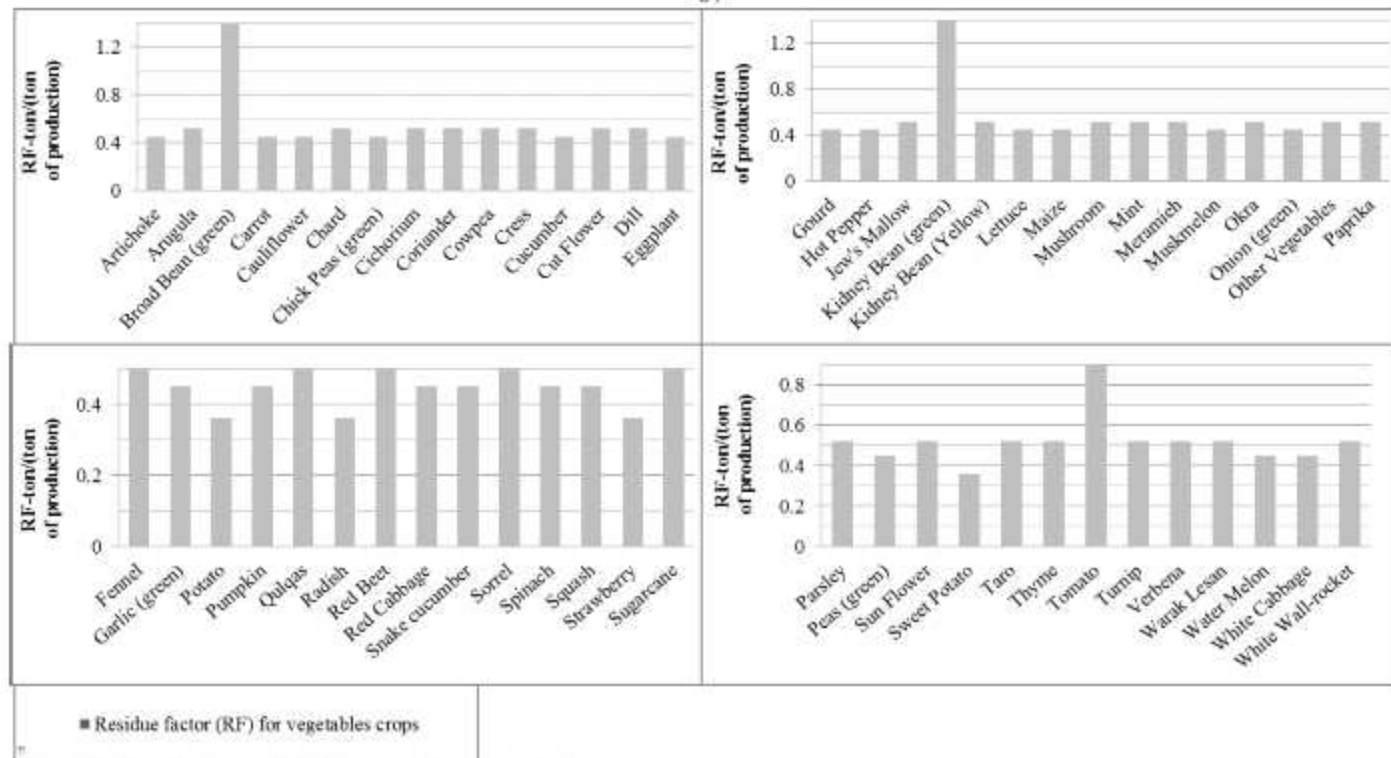


Figure 3.1: Residue factor (RF) for vegetables crops. [56]

**The second method is:**

**b. Extraction coefficients per harvested area.**

In this method, the Biomass Residues [ton/yr] are calculated using the following equation:

$$BR = AH \times C.....( 3.2)$$

**AH:**

EC: This coefficient is given in Figure 3.2

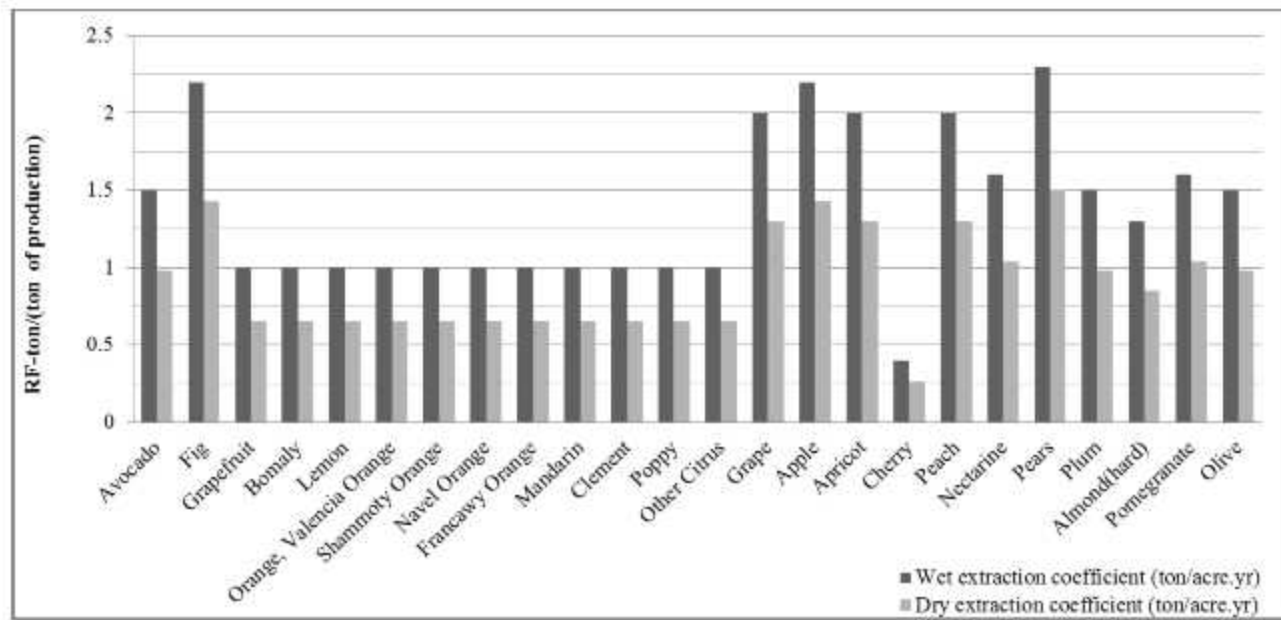


Figure 3.2: Extraction coefficients per harvested area: Horticulture Trees. [54]

### 3.1.2. Olive Press Waste

The main wastes of olive press that is generated can be divided into two types: The first type is olive cake (jeft). The second type of olive press waste is a liquid waste (zebar).

The amount of olive cake can be calculated by using this equation:

$$\text{Amount of olive cake (Jeft)} = \text{OP} \times \text{JP} \dots\dots\dots (3.3)$$

**OP:**

**JP:** JP that can be obtained in Table 3.2

The quantities of olive mill wastewater (Zebar) generated from different types of olive mills (Full Automatic, Traditional & Half Automatic olive mill) can be calculate by the following.

**Zebar generated from traditional and Half Automatic olive mill:**

$$\text{Zebar} = \left( 1 - \left[ \frac{\text{OE}}{\text{OP}} + \text{JP} \right] \right) \times \text{OP} \dots\dots\dots (3.4)$$

**OE:**

**OP:**

**JP:** JP that can be obtained in Table 3.2

**Zebar generated from Full Automatic olive mill:**

$$Zebar = [BW \times OP] + \left[ \left( 1 - \frac{OE}{OP} + JP \right) \times OP \right] \dots\dots\dots (3.5)$$

**BW:**

**OP:**

**OE:**

**JP:** JP that can be obtained in Table 3.2

(These equations number 3.5 were derived by me)

**Table 3.2: The main factor For Olive Mill Wastewater and Jeft measurement. [55, 57, 58]**

Type			Value Range		Average
The quantity for 100kg olives	Quantity of water needed- depending on category- Liter	Traditional & Half Automatic Presses	40	55	47.5
		Full Automatic Olive Presses	85	120	102.5
Quantity of Olive cake- jeft in 2011			48000		
Quantity of Olive Pressed- ton- in 2011			104763		
Percentage of Olive cake- Jeft			%		

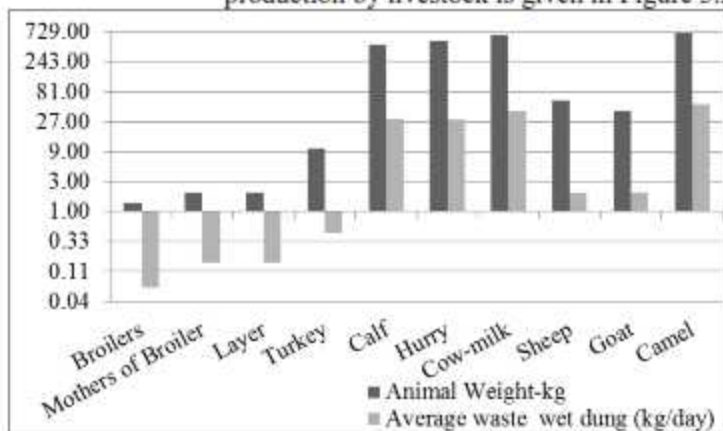
### 3.1.3. The residues of livestock:

The annual waste that generate from livestock, can be calculate by using equation

$$\text{Annual Waste} = \text{An} \times \text{WF} \times 365 \dots\dots\dots (3.6)$$

**An:**

**WF:** WF that produced by animal. The daily waste production by livestock is given in Figure 3.3.



**Figure 3.3:** daily waste production by the five major livestock. [43,59]

**Slaughterhouse waste:**

$$\text{SI} = \text{PN} \times \text{IO} \times \text{W} \dots\dots\dots (3.7)$$

**SI:**

**PN:**

**IO:**

**SW:**

$$CE \& ES = (WE \times CE) + (HE \times CH \times WE) \dots\dots\dots(3.8)$$

**CE & ES:**

**WE:**

**CE:**

**CH:**

**HE:** The value of these factor shows in Table 3.3

**Table 3.3: main values that used in corrupt egg calculation. [60, 61]**

Type	Value
Average weight of eggs	65
The percent of waste in egg after the hatching	32%

### **3.2. Calculations of biofuel potential from biomass:**

As can be seen from the aforementioned resources of biomass, methods of conversion of agricultural, livestock, and municipal household solid wastes into gaseous fuels can be summarized into two main categories: gasification and anaerobic digestion.

#### **3.2.1. Biogas production by anaerobic digestion:**

The dry matter (DM) and organic dry matter (ODM) contents for manures from livestock and agricultural wastes were presented in Table 2.7, D.1 and E.1.

The total biogas that can be generated can be calculated by using the following equation:

$$\text{Biogas Yield}(m^3) = Wa \times DM \times BY \dots\dots\dots (3.9)$$

**Wa:**

**DM:** This factor is given in Table 2.7, D.1 and E.1.

**BY:** BY which is given in Tables 2.6, 2.7, D.1 and E.1.

### 3.2.2. Biogas production by Landfill Method:

The potential of power generation from household solid waste using Landfill method can be calculated based on Equation number 3.10

$$LFGt = L_o \times R(e^{-kc} - e^{kt}) \dots\dots(3.10). [62]$$

Where: **LFGt:**

**LFG:**

**L<sub>o</sub>:**

**R:**

**t:**

**c:** c = zero, if the landfill is still accepting waste.

**k:**

**e:** The value of e is based on the Napierian or natural logarithm (approximately 2.718).

**L<sub>o</sub>:** is estimated from Table 3.4.

Total LFG yield per kilogram MSW is 0.17m<sup>3</sup>/kg.

Table 3.4 : Amount of  $L_o$  in the percentage of fresh weight. [62]

	moisture	Average of moisture	Dry
direct-cut banana crop residue	80-90%	85%	15%
Olive Cake	44.78%		55.22%
Date Residues	20%		80%

### 3.2.3. Producer and Synthetic Gas by Gasification:

$$\text{Producer Gas (Nm}^3\text{)} = Ws \times DM \times GO \dots\dots\dots (3.11)$$

**Ws:**

**DM:** It can be obtained from Tables.

**GO:** It can be obtained from Table

Table 3.5: Moisture and dry contents for banana, olive cake and date residues. [63-65]

Material	The Value of $L_g$
Paper and paperboard	0.40
Textiles	0.40
Wood and straw	0.30
Garden and park waste (green waste)	0.17
Food waste	0.15

### 3.2.4. Bio Oil Production:

$$\text{Bio Oil Production (kg)} = BR \times DM \times BF \dots\dots(3.12)$$

BR:

DM:

BF: equal 64%, (wt.%).

### 3.2.5. Electricity Production:

$$EPB = Bi \times CV \times GF \dots\dots\dots(3.13)$$

EPB:

Bi:

CV:

GF:

All of these values are given in Table 3.6.

Table 3.6: the main factors that are used to calculate electricity production. [41, 66]

Biogas caloric value -MJ/Nm <sup>3</sup>		23
Biogas caloric value -kWh/Nm <sup>3</sup>		6.4
Average lower heating value for Bio Oil		15.5MJ/kg, (4.3kWh/kg)
Generator efficiency (Figure D.1).	Electrical	38.2%
	Thermal	46.8%

$$EPP = PG \times CV \times GF \dots\dots\dots (3.14)$$

**EPP:**

**PG:**

**CV:** from Table.

**GF:** From Table 3.6.

$$EPO = BO \times CV \times GF \dots\dots\dots (3.15)$$

**EPO:**

**BO:**

**CV:** CV from Table 3.6.

**GF:** GF from Table 3.6.

### 3.3. Experimental Work on gasification

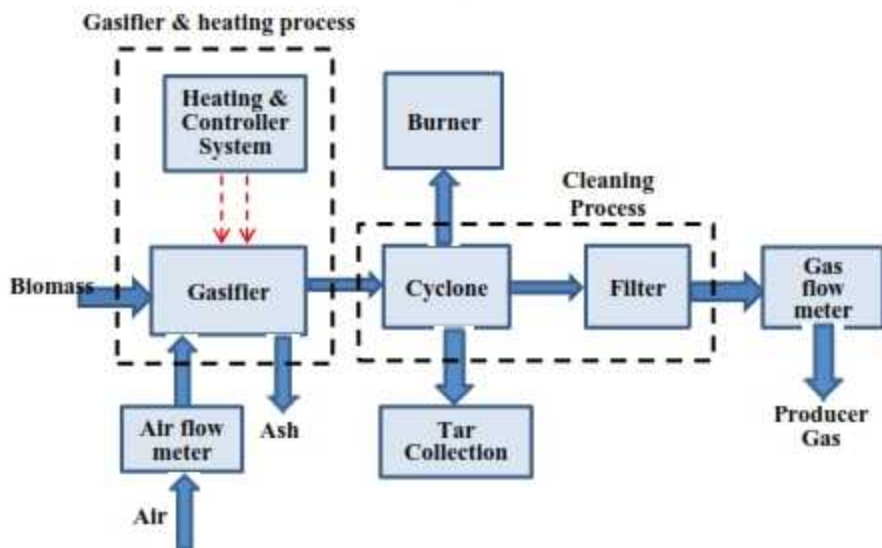
Olive cake (Jeft) and wood pellets are used as a feedstock for gasification. It is a renewable source of energy and easily available at large scale. Olive cake (Jeft) can be produced by extracting olive oil from the olive seeds. Generally, it is used as a source of fire and heating, because of its higher energy content. In the present study, olive cake (Jeft) is used for feed to the gasifier.

Gasifier unit consists of a downdraft gasifier, heating process, and cleaning process.

### **3.3.1. Experimental Procedure**

The aim of the experiments was to evaluate the effects of air equivalent ratio and biomass size on the efficiency of the producer gas.

1. Initially all parts of the gasifier system necessary for the experiments were designed and fabricated.
  2. The moisture content of Jeft was determined.
  3. The gasifier was loaded with Jeft and a measurement of the load was recorded.
  4. The valve of air was open and air was allowed to flow.
  5. The air injection was set to the desired level.
  6. The electrical heating unit was set to the desired temperature.
  7. The Jeft was ignited through the electrical heating unit.
  8. When the producer gas started, the gas was ignited.
  9. After the gasifier started gas production, the producer gas is directed toward a special designed filter in which the solid and liquid particles are captured and removed.
  10. Finally, readings such as volumetric flow rate of producer gas and air, temperatures and pressure drop measurements were recorded.
- A schematic sketch of the experimental procedure is shown in Figure 3.4.



**Figure 3.4:** General Sketch of gasifier experimental setup.

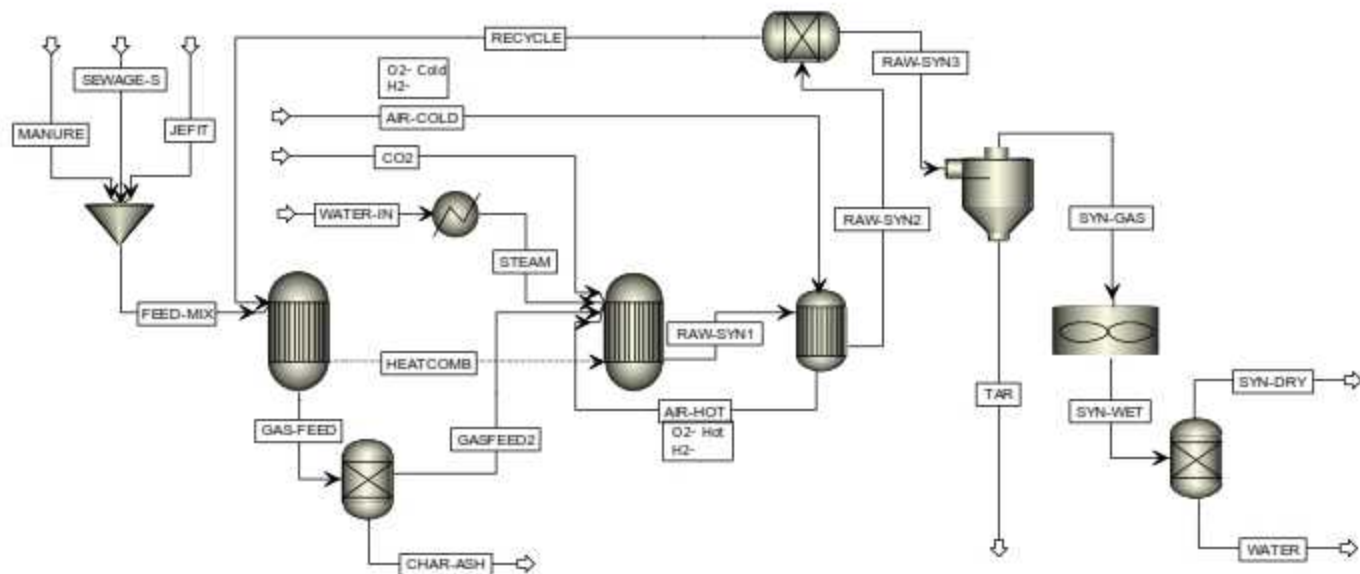
### 3.4. Simulation Process

The simulation process section helps in optimizing the process by estimating the effect of various parameters on gasification process using simulation software (ASPEN PLUS) and chemical reaction equations in Table 2.3. Figure 3.5 and Table 3.7 illustrate flow-Sheet of ASPEN PLUS Simulation and main streams using in simulation model.

The following assumptions are made in this study to during the simulation:

- 1- Gasifier is a steady-state and isothermal system.
- 2- No pressure and no heat losses occur in the gasifier.
- 3- No unconverted carbon is present in the produced gas.

### Simulation Flow Sheet:



**Figure 3.5:** Flow-Sheet of ASPEN PLUS Simulation for Gasification Process.

The following Table 3.7 illustrates main streams using in simulation model.

**Table 3.7: main streams using in simulation model**

No.	Stream	Notes
1	MANURE	feedstock
2	SEWAGE-S	feedstock
3	JEFIT	feedstock
4	FEED-MIX	-----
5	HEATCOMB	Heat Combustion
6	GAS-FEED	-----
7	CHAR-ASH	Char and ash is produced from gasifier
8	GASFEED2	-----
9	WATER-IN	Used to steam generation
10	STEAM	-----
11	CO2	Carbon Dioxide
12	AIR-HOT	Air is heated by exploiting the heat from producer gas (heat recovery unit)
13	O2-Hot	Oxygen is heated by exploiting the heat from producer gas (heat recovery unit)
14	H2-	Hydrogen is heated by exploiting the heat from producer gas (heat recovery unit)
15	RAW-SYN1	Producer gas at high temperature
16	AIR-COLD	Inlet Air
17	O2-Cold	Inlet Oxygen
18	H2-	Inlet Hydrogen
19	RAW-SYN2	Producer gas after losing his heat
20	RECYCLE	-----
21	RAW-SYN3	-----
22	TAR	-----
23	SYN-GAS	Producer gas
24	SYN-WET	Producer gas with water
25	SYN-DRY	Producer gas without water
26	WATER	-----

- 4- Char and tar yield when using Jeft, Sewage sludge and Poultry manure are assumed the same.
- 5- Estimation of tar formation can be found using Figure 3.6 and for Temperature more than 900 °C using equation 3.16.

$$w_{tar} = (6.411 - 0.203 * \sqrt{T_g})^2 + 0.248 \times AF - 0.024 \times w \dots (3.16).$$

$w_{tar}$ :

$T_g$ :

AF:

w:

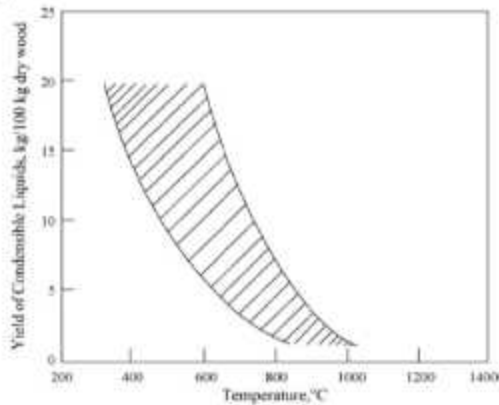
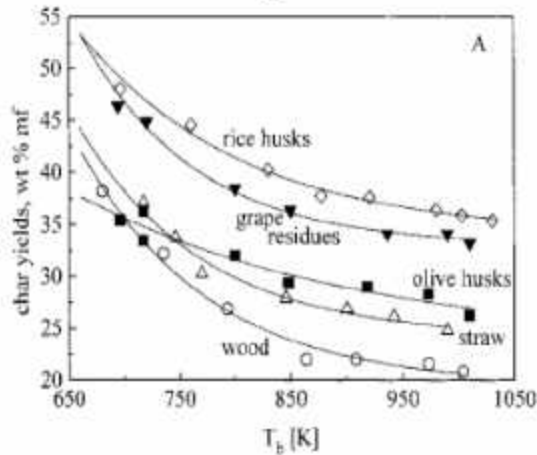


Figure 3.6 effect of temperature on Tar formation. [68]

- 6- Char formation at a different temperature is considered using Figure 3.7 and Char contains only carbon and ash.



**Figure 3.7:** Char formation at a different temperature. [69]

- 7- The gases involved obey Peng-Robinson equation of state with Boston-Mathias (PR-BM) modification property method.
- 8- The temperature differences between hot and cold stream in a heat exchanger which is used to recover waste heat from gasifier equal to zero.
- 9- Jeft, Sewage sludge and Poultry manure were chosen as feedstock. The main properties of feedstock: Jeft, Sewage Sludge and poultry manure are listed in Tables 3.8 -3.10. The original data of Jeft were modified to suit the mass conservation law.

**Table 3.8: Main properties of Jeft. [70]**

Ultimate Analysis (% dry basis)			Proximate Analysis (% dry basis)		
Symbol	Original Values	Modified Values	Symbol	Original Values	Modified Values
Carbon	52.270	51.9789	Volatile	80.94	80.9431
Hydrogen	7.485	7.4433	Ash	0.56	0.5569
Nitrogen	0.060	0.0597	Fixed Carbon	18.50	18.50
Oxygen	40.097	39.7772	Moisture	9-10	9.6
Sulfur	<0.1	0.0965	heating value (MJ/kg, dry basis)	Higher	20.61
Chlorine	0.088	0.0875		Lower	18.96

**Table 3.9. Proximate analysis of Jeft, Sewage Sludge, and poultry manure (dry basis). [70-72]**

Components (wt %)	Jeft	Sewage Sludge*	Poultry manure
Moisture	9.6	5.2	27.4
Fixed Carbon(dry)	18.50	4.6	13.66
Volatile Matter (dry)	80.9431	42.6	64.97
Ash (dry)	0.5569	52.8	21.37
Lower heating valued (MJ/kg)	18.96	9.9	14.79

\* This value of moisture of sewage sludge after drying.

**Table 3.10: Ultimate analysis of Jeft, Sewage Sludge, and poultry manure (dry basis). [70-72]**

Ultimate	Jeft	Sewage Sludge	Poultry manure
Ash	0.5569	52.8	21.37
Carbon	51.9789	21.1	37.05
Hydrogen	7.4433	3.4	5.06
Nitrogen	0.0597	3.2	3.66
Oxygen	39.7772	18.4	31.44
Sulfur	0.0965	1.1	0.45
Chlorine	0.0875	---	0.97

Details of operation parameters and input data for the simulation are illustrated in Tables 3.11 and 3.12

**Table 3.11: Operation parameters and input data for the simulation of gasification of Jett and sewage sludge.**

parameters			Value	Parameter for Inlet streams	Notes
Feed in Flow rate (kg/hr)			4.21	Gasifying agent	Air, Oxygen, CO <sub>2</sub>
Gasifier Temperature (°C)			850		Steam, Air/steam
Gasifier Pressure (atm.)			1	Type of material	Jett, Sewage Sludge, Poultry manure
Inlet temperature (°C)	feed in	25		Air Equivalent Ratio	6.67% - 100%
	Air	25		Temperature (°C)	350- 1200
	Steam	150		Steam to biomass ratio	0.05 - 4
	CO <sub>2</sub>	25		Oxygen Equivalent Ratio	6%- 100%
Inlet Pressure (atm.)	feed in	1		Produced gas recycle	0% - 68%
	Air	1		CO <sub>2</sub> to biomass ratio	0.05-1
	Steam	1		Trace gases	HCl, NH <sub>3</sub> , H <sub>2</sub> S, SO <sub>2</sub> , Cl <sub>2</sub> , NO <sub>2</sub> , N <sub>2</sub> O, NO, Ar
	CO <sub>2</sub>	1			

**Table 3.12: The composition of Dry Air (mole basis). [73]**

Component	Original Value	Modified Values
CO <sub>2</sub>	0.0385 %	0.0385 %
N <sub>2</sub>	78.0818 %	78.0848 %
O <sub>2</sub>	20.9435 %	20.9435 %
AR	0.9332 %	0.9332 %

The performance of gasification can be evaluated by some parameters such as Lower Heating Value of the producer gas, producer gas yield, Cold Gas Efficiency (CGE).

### 3.4.1. Cold Gas Efficiency calculation (CGE):

Cold Gas Efficiency (CGE) can be calculated using the following equation # 3.17

$$CGE = \frac{\text{Mass flow rate of producer gas} \times LHV_{\text{producer gas}}}{\text{Mass flow rate of Biomass} \times LHV_{\text{Biomass}}} \dots\dots (3.17). [74]$$

### - Lower Heating Value) calculation (LHV):

$$\begin{aligned} LHV \left( \frac{\text{MJ}}{\text{Nm}^3} \right) = & (\%CO \times \text{heating value of CO}) \\ & + (\%CH_4 \times \text{heating value of } CH_4) \\ & + (\%H_2 \times \text{heating value of } H_2) \dots\dots (3.18). \end{aligned}$$

Gross heating Value (Higher heating value (HHV)) and net heating values (Lower heating value (LHV)) for  $CH_4$ ,  $H_2$  and  $CO$  gases can be found in Table 3.13

**Table 3.13: Heating Value for  $CH_4$ ,  $H_2$  and  $CO$  gases. [75]**

Fuel Gas	Heating Values (kcal/kg)		Heating Values (kcal/Nm <sup>3</sup> )	
	Gross	Net	Gross	Net
Carbon Monoxide	2,411	2,411	3,014	3,014
Hydrogen	33,889	28,555	3,050	2,570
Methane	13,284	11,946	9,530	8,570
	Heating Values (MJ/kg)		Heating Values (MJ/Nm <sup>3</sup> )	
	Gross	Net	Gross	Net
Carbon Monoxide	10.1	10.1	12.6	12.6
Hydrogen	141.9	119.6	12.8	10.8
Methane	55.6	50.0	39.9	35.9

### 3.4.2 Residence Time

$$\tau = 2.673 \times d^n \dots\dots (3.19). [76]$$

$$n = 1.02 \times e^{(233/T)}$$

$\tau$ :

$d$ :

$T$ :

**Chapter Four**  
**The Potential of Biomass in WB&GS**

## **Chapter Four**

### **The Potential of Biomass in WB&GS**

#### **4.1 Introduction:**

WB&GS is blessed with fertile soil and suitable climate for food production. This chapter concentrates on the evaluation of the potential of biomass in WB&GS. The potential of the biomass was recorded depending on PCBS (Palestinian Central Bureau of Statistics) and some interviews with agricultural specialists. Also this chapter provides an overview of estimates on the production of residues, and beside those rough estimates of other uses (actual and potential) for these residues.

Agricultural residues can provide a substantial amount of biomass in WB&GS. One significant issue with agricultural residues is the seasonal variation of the supply. Pruning of horticulture trees make up a substantial portion of the agricultural residue. Agricultural residues could be a supplemental feedstock for energy needs in WB&GS, but not primary fuel.[77]

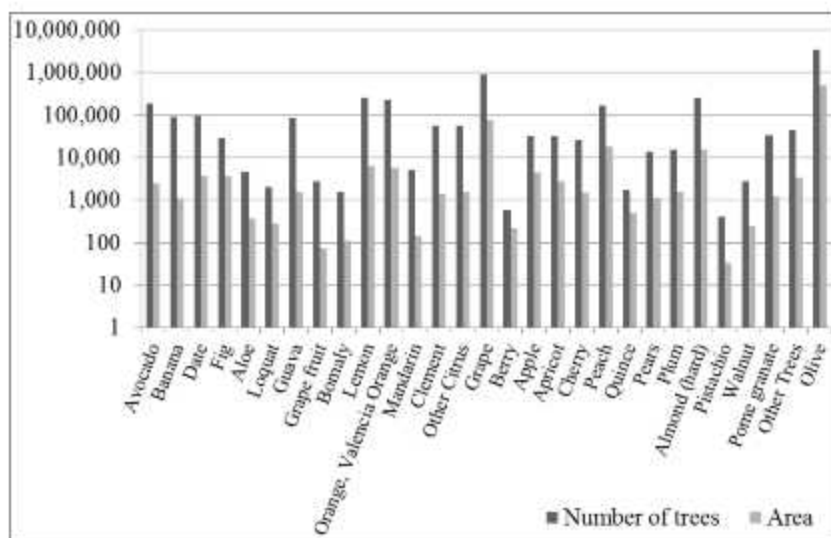
#### **4.2 The agriculture:**

The total area of agricultural holdings in WB&GS for the 2009/2010 agricultural year was 1,207,061 (dunam). The Cultivated land area in WB&GS during the 2009/2010 agricultural year was 1,029,280 (dunam). Uncultivated land made up 177,781 (dunam). This agriculture lands distributed throughout 16 governorates. Most of this land is cultivated with

Horticulture Trees which include olives, genus *Prunus*, citrus, grape and others trees. [78, 79]

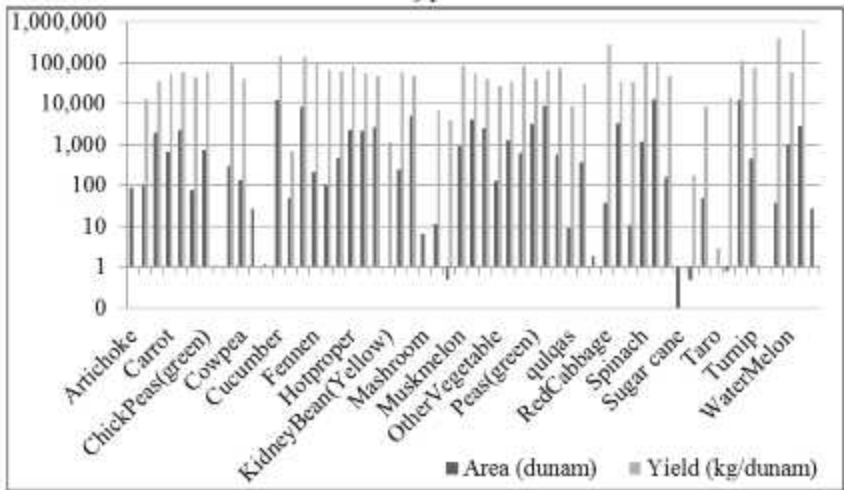
Lemons trees constitute a major part of the total crops trees (after Olives and Grapes trees), this percentage about 4.3% respectively. There are around 261806 Lemon trees.

Almond (hard) trees constitute the second major part of the total crops trees (after Olives and Grapes trees). This type of crop constitutes about 4.2%. There are around 260444 Almond (hard) trees. All of these values and others show in Figure 4.1.



**Figure 4.1:** Distribution of trees in WB&GS by area & number. [79-96]

The remaining portion is dedicated to vegetable production such as potatoes, tomatoes; these types are shown in Figure 4.2.



**Figure 4.2:** Area of Vegetables in WB&GS by Type of Crop. [79-96]

In WB&GS (West bank and Gaza), around 688142 dunams are cultivated with vegetables, field crops and horticulture tree.

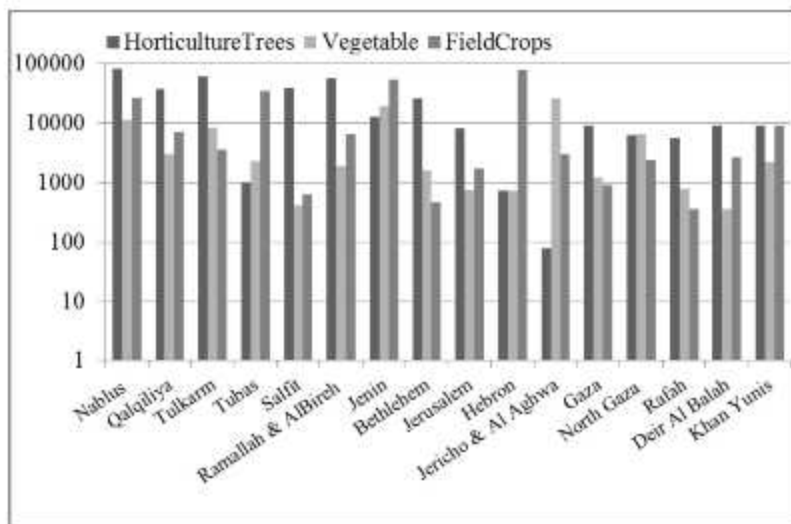
Tulkarm and Qalqiliya governorates have the highest percent of cultivated Area, this amount around 30% & 29% respectively of the total land in WB&GS. Also Jericho & Al Aghwar governorates have the highest percentage of vegetables-cultivated area, this amount around 30%. This means that Jericho & Al Aghwar is the food basket of WB&GS. Figure 4.3 shows the cultivated area distribution in WB&GS.

The total land cultivated with field crops in WB&GS in 2011 illustrate in Figure 4.3 and it was 235007 dunam: 219676 dunams in the West Bank and 15331 dunams in the Gaza Strip. Hebron governorate had the highest amount of cultivated land with 33.7% of the total area cultivated with field crops in WB&GS.

The total land cultivated with vegetables in WB&GS in 2011 was 87235 dunams: 76010 dunams in the West Bank and 11225 dunams in the Gaza Strip.

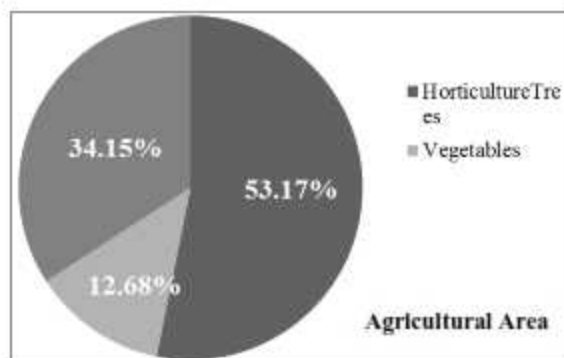
Jericho and Al-Aghwar governorate had the highest percent with 30% of the total land cultivated with vegetables in WB&GS. Figure 4.3 illustrates all of these values in WB&GS.

The total land cultivated with horticulture trees, vegetables and field crops in WB&GS in 2011 illustrate in Figure 4.3 and it was 365900 dunam: 326,345 dunams in the West Bank and 39,555 dunams in the Gaza Strip. About 22% of the land cultivated with horticulture trees was in Nablus governorate: this means that Nablus had the highest percent in WB&GS.



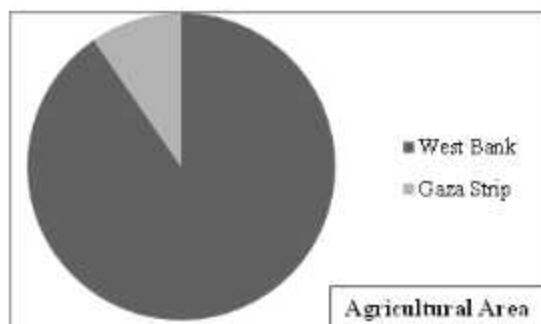
**Figure 4.3:** Total cultivated area in WB&GS (Area in Dunam). [79-96]

During the agricultural year 2011, the percentage area cultivated with horticulture trees are 53.17%, vegetables about 12.68%, and field crops in WB&GS was 34.15%, these percentage shows in Figure 4.4.



**Figure 4.4:** Agricultural area (dunams) in WB&GS. [79-96]

In West Bank, about 688142 dunams are cultivated with vegetables, field crops and horticulture tree. This amount means about 90% in the West Bank, while this percentage was 10% of the total number of all agricultural types in Gaza Strip. The following Figure 4.5 illustrates these values.

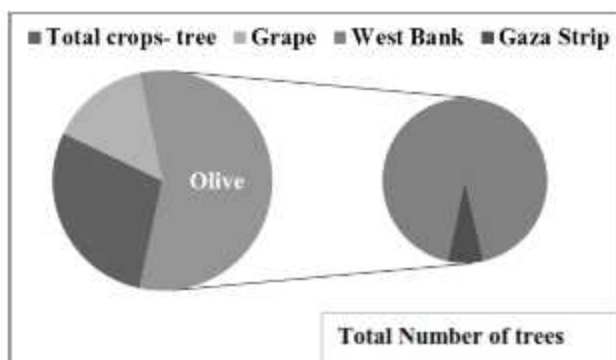


**Figure 4.5:** Agricultural area (dunam) in WB&GS. [79-96]

Olive trees is the highest percentage between Horticultural trees, it represent approximately 57% of the total number of horticultural trees.

The total number of Olive trees in WB&GS was approximately 3,477,222 trees, while this percentage was 93% of the total number of horticultural trees in West Bank and 7% in the Gaza Strip.

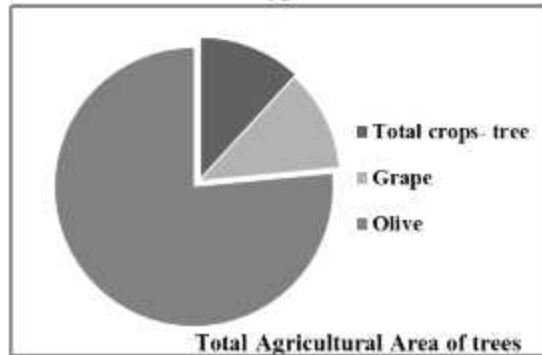
These values show in Figure 4.6.



**Figure 4.6:** Total Number of trees in WB&GS. [79-96]

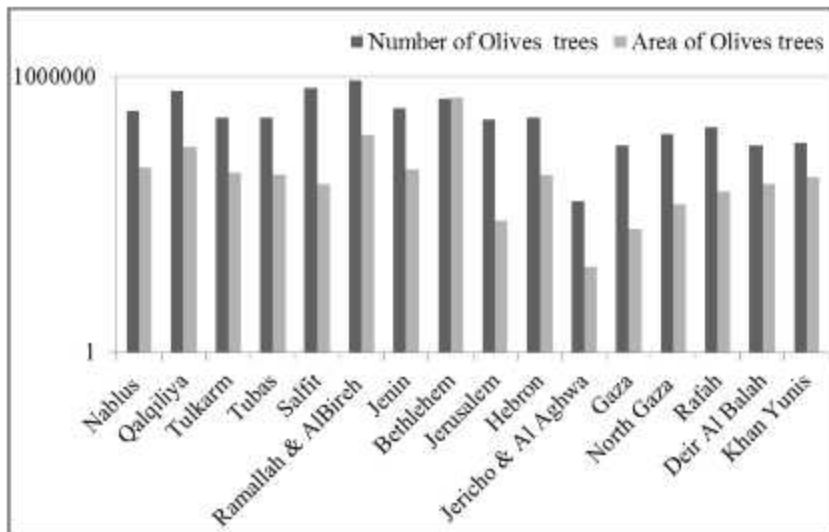
Agricultural areas of Olive trees constitute a major part of the total crops trees, this percentage about 75.6% (the lands planted with Olives of total arable land). There are around 3477222 olive trees.

Grape trees constitute the second major part of the total crops trees, Figure 4.7 shows this type of crop that constitutes about 11.7%.



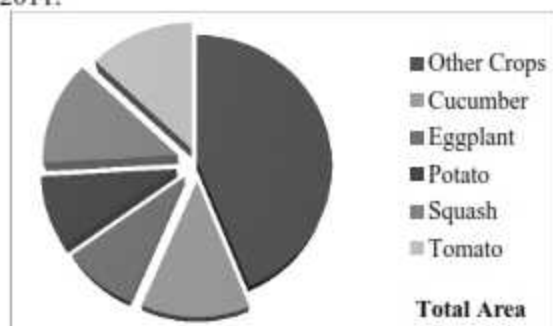
**Figure 4.7:** Agricultural area of trees (Dunam). [79-96]

Olive plantations are concentrated in Ramallah & AlBireh, Salfit, Qalqiliya, Bethlehem, Jenin and Nablus governorates. Figure 4.8 contains names of the Palestinian cities that produce a significant amount of the total production.



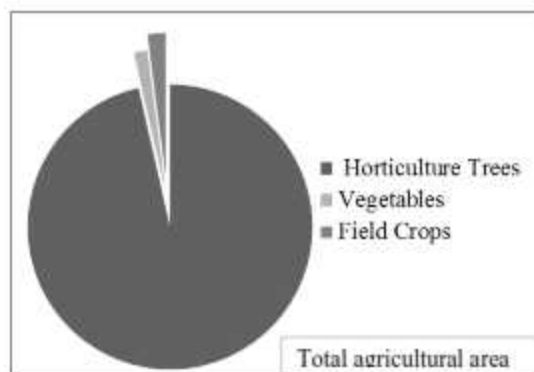
**Figure 4.8:** Total number of Olives trees in WB&GS. [79-96]

The Figure 4.9 below shows and summarizes the total cultivated area of vegetables, the main crop areas and the amount of production in WB&GS in 2011.



**Figure 4.9:** Area of vegetables in WB&GS (Area in dunam). [79-96]

The agricultural area of Horticulture trees is estimated to be about 96.44% (6,134,129 dunam) of the total cultivated area, and about 2.03% (128,906.66 dunam), 1.53% (97,554 dunam) is covered by Field crops and Vegetables respectively. More information is shown in Figure 4.10.



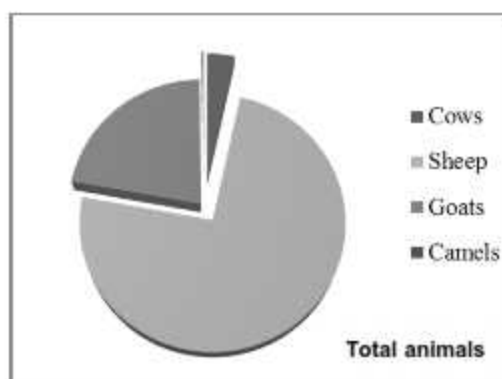
**Figure 4.10:** Total agricultural area in WB&GS (Area in dunam). [79-96]

### 4.3 Livestock:

The following section shows some information of livestock such as amount of livestock distribution in 2013.

Jenin and Hebron had the highest number of cattle, Jerusalem the least:

The number of cattle in WB&GS totaled 33,980, of which 75.4% were in the West Bank and 24.6% in Gaza Strip. Jenin and Hebron governorates had the highest number of cattle with (15.51% and 15.46% respectively) of the total cattle in WB&GS, while Jerusalem had the lowest with 0.78% on 01 October 2013. Figure 4.11 and 4.12 show all of these values.



**Figure 4.11:** Number of Animals in WB&GS, As in 2013. [97]

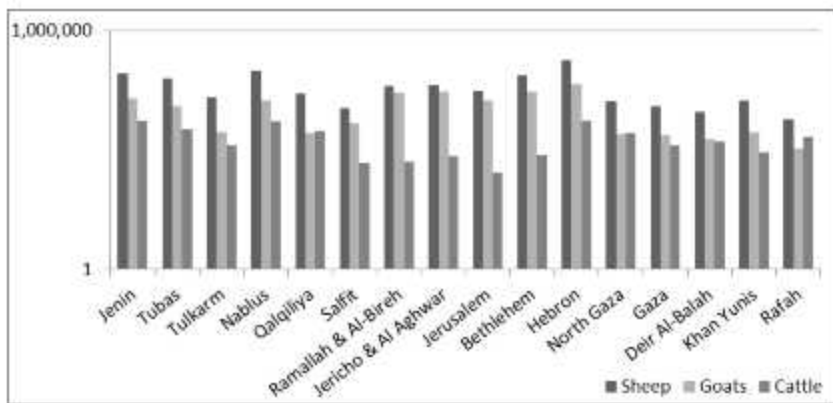
About 25.2% of sheep in WB&GS were raised in Hebron governorate:

The number of sheep in WB&GS totaled 730,894 of which 91.7% were in the West Bank and 8.3% in the Gaza Strip. The highest number of sheep

was in Hebron with 25.2% of all sheep in WB&GS on 01 October 2013. Figure 4.12 illustrates more information of Sheep numbers in WB&GS.

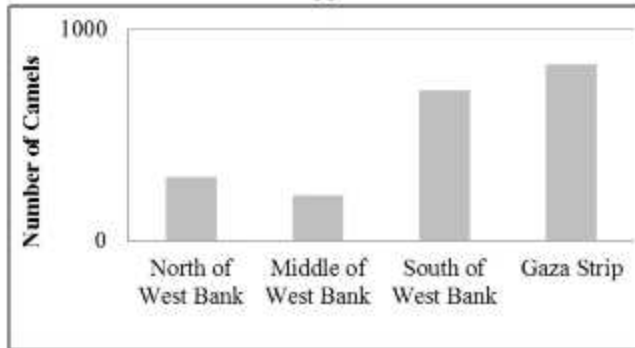
The highest percentage of goats in Hebron governorate:

The number of goats in WB&GS was 215,335 of which 95.2% were in the West Bank and 4.8% in the Gaza Strip. The highest number of goats was in Hebron with 21% of all goats in WB&GS in October 2013. Figure 4.12 illustrates more information of Goat numbers in WB&GS.



**Figure 4.12:** Number of Animals in WB&GS, As in 01/10/2013. [97]

About 34.5% of camels in WB&GS were raised in South of West Bank governorates: There were 2,058 camels in WB&GS, of which 59.6% were in the West Bank and 40.4% in the Gaza Strip. South of West Bank governorates had the highest percentage of camels with 34.5% of all camels in WB&GS and on 01 October 2013. Figure 4.13 illustrates more information of Camels numbers in WB&GS.

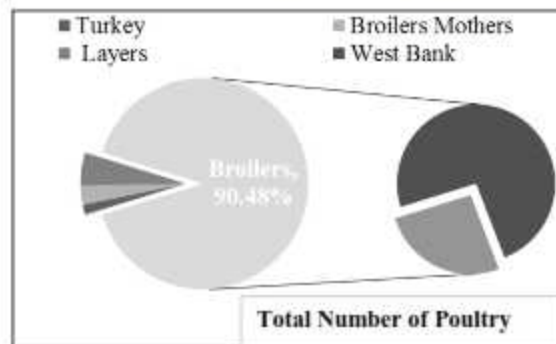


**Figure 4.13:** Number of Camels in WB&GS, As in 01/10/2013. [97]

### The Poultries:

The poultries number in WB&GS (during the 2013 agricultural year) totaled 34,833,194 of which 75.4% were in the West Bank and 24.6% in the Gaza Strip.

During this agricultural year there were 538,320 turkeys in WB&GS, 994,620 Broiler mothers, 1,425,579 Layers and 23,297,203 Broilers which (Broilers) 66.88% in the West Bank and 23.59% in Gaza Strip. Figure 4.14 illustrates more information of Poultry numbers in WB&GS.



**Figure 4.14:** Number of Poultry per Year in WB&GS by Type and Region, 2012/2013. [97].

## **4.4 Biomass Residues in WB&GS**

### **4.4.1 Introduction**

This section discusses the main source of organic waste in WB&GS that produced from plant, animals and household.

The main wastes generate in WB&GS can be dividing into three parts: The first type is the residue of plants (Agriculture). This type can be divided into three types; Field crops, Vegetables, and Horticulture Trees.

Horticulture trees generate considerable amounts of wood residues from pruning and replanting activities. Two different methods can be used to calculate the amount of residues generated. The first one, often used for woody residues from horticulture trees, is based on the cultivated area. This method assumes that tree crops grow with standard planting density. The other method, often used for annual crops, is to use a residue to product ratio (RPR). With this method the amount of residues is calculated from the crop production using an average RPR value. [10]

The main waste generated in WB&GS can be collecting during the seasons; Table 4.1 gives the agricultural residues availability during the year.



The second type of organic waste source is produced by poultry and animals (Livestock). The poultry include: Turkey, Broilers Mothers, Layers, and Broilers.

The final type of residue is generated by household (municipal household solid waste).

This study summarizes the research on unused biomass extraction in agriculture. Our research was based on literature reviews, interviews with farmers and internet searches. The presented calculations procedures only consider a rough estimation of amounts of unused biomass extractions.

In most publications and studies, unused domestic extraction of biomass was neglected. Only very few studies reporting absolute amounts of these unused extractions are available.

In this study we present procedures for the calculation of unused biomass extractions, based on information of residues of agriculture.

Fruit crop residues include prunings and brushes. Vegetable crop residues consist of vines and leaves remaining on the ground after harvesting.

In the following sections we determined coefficients to calculate the amount of unused biomass extractions by using the annual used production of biomass.

#### 4.4.2 The residues of agricultural plants

The potential of crop residues are mostly overestimated since some of these residues must remain in the field to ensure soil fertility, and other portions are lost during collection. The ratio of the residual waste to the product of most of seed crops are found to be between 0.36 and 1.4. These ratios are show in Figure 3.1.

Large quantities of residues are generated in agricultural production systems. Crops cultivation, fruits and vegetables generate considerable amounts of residues. These residues constitute a major part of total annual production of biomass residues and are an important source of energy. [56]

Unused biomass from agriculture can be divided into two categories:

1. Parts of the plants which are retained to the field.
2. Losses of parts of the plant due to harvest methods.

These days, these biomass extractions can be reused for several purposes, including forage, biogas and biofuels production. [99]

We identified two main ways to calculate residues from agriculture. Equation 3.1 and 3.2 are used to calculate the unused domestic extraction

The amounts of residues used for various purposes are not well defined. This lack of knowledge is due to the scattered locations of the residue generation, its seasonality and the variety of production circumstances.

Residues also play an important role in soil fertility and a total removal of all above ground residues can accelerate soil degradation.

The ratios of residue to product which are presented in this study are derived from several sources.

In this evaluation, crop straw and stalk outputs are calculated based on crop outputs and the ratio of grain production to stalk mass.

Data of this study are given as “waste factor” which is the proportion of residue to product.

The residue factors of agricultural crops like Broad Bean (green) are about 1.4, of other food crops like sweet potatoes, beans and groundnut between 0.36 and 1.4. The residue factor of fruits and vegetables is between 0.36-1.4.

#### **4.4.3 Calculation of Biomass residues**

The biomass residues can be calculated based on the following methods:

- 1- Residue factor.
- 2- Extraction coefficients per harvested area.

##### **4.4.3.1 Calculation of biomass residue using residue factor method:**

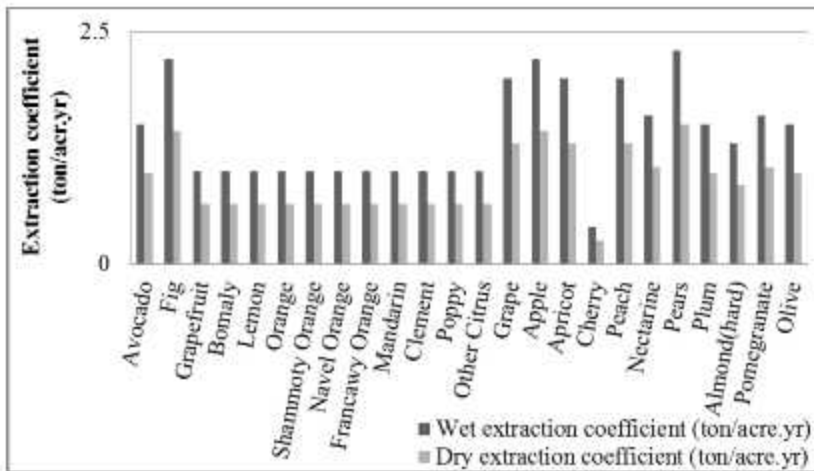
In this method, the Biomass Residues [ton/yr] are calculated using equation (3.1).

##### **4.4.3.2 Calculation based on extraction coefficients per harvested area**

Extraction coefficients per harvested area, is a factor that used to calculate a product of agricultural residues per dunam or acre (1 acre = 4047m<sup>2</sup>), per year.

By using this factor, the amount of the agricultural residues can be calculated using the coefficient of unused agricultural residues with the cultivated area. Some data of this factor are listed in Figure 4.15

In this method, the Biomass Residues [ton/yr] are calculated using equation (3.2):



**Figure 4.15:** extraction coefficients per harvested area: Horticulture Trees, [ton/(acre.yr)]. [56]

In order to compare between the two approaches the following examples are given as in Table 4.2

**Table 4.2: Comparison between two approaches to calculate potatoes residue in Chile Country. [56]**

<b>Residue factor Method</b>	<b>Extraction coefficients per harvested area</b>
<b>Production:</b> 791,998 ton (metric ton) <b>Residue Factor:</b> 0.36 <b>Residues:</b> 285,119.3 ton (metric ton)	<b>Area Harvested:</b> 56,376Ha = 139,248.7 acres (1ha= 2.47 acres) <b>Extraction coefficients:</b> 1.48 <b>Residues:</b> 83,436.5 ton/year

This example shows the quantities of biomass residues remaining and that the two methods deliver different results. The first method (Residue factor) is more accurate than the second method. The residue factor method depends on the production rate while the extraction coefficients method depends on acreage area. [96]

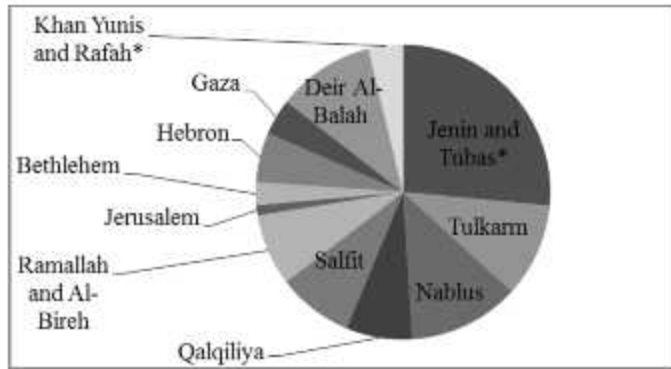
#### **Olive Press Waste:**

This section discusses the main type of residues in WB&GS that produced from olive press.

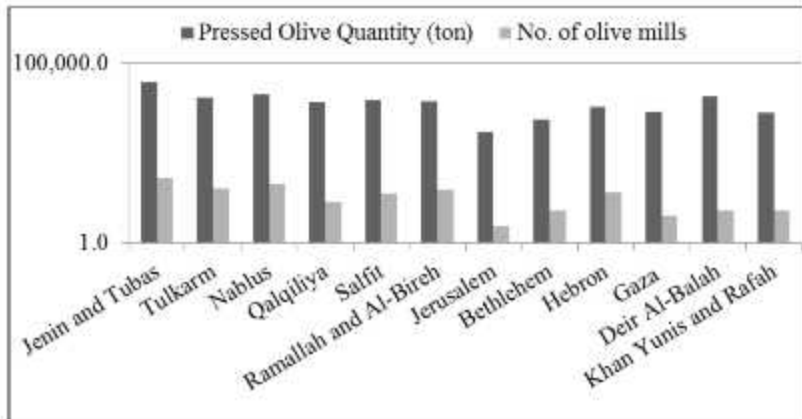
The main wastes of olive press that generated in WB&GS can be divided into two types: The first type is olive cake (jeft). Olive cake is the solid material that remaining after the olive pressing as a byproduct. The second type of olive press waste is a liquid waste (zebar) or olive mill wastewater (OMWW). Zebar is the olive liquid that remaining after olive pressing.

The amount of olive pressed in WB&GS in 2014 was 108,379.1 tons, of which 81.53% were in West Bank and 18.47% in the Gaza Strip. The highest amount of olive pressed was concentrated in Jenin, Tubas and

Nablus 26.49% of which in Jenin and Tubas governorates, and 12.23% in Nablus governorate. More details about the Main quantities of olives pressed in WB&GS by Governorate are given in Figure 4.16 and 4.17. [57]



**Figure 4.16:** Quantity of Olive Pressed Activity in WB&GS by, 2014



**Figure4.17:** The Main quantities of olives pressed in WB&GS by Governorate, 2014. [57]

Most of olive mills use tight cesspit (43.02%) and Porous Cesspit (30.19%) to dispose of the zebat. About 84.15% of olive cakes (jeft) are given back to owners. Table 4.3 illustrates number of olive mill in WB&GS according to their waste disposal methods.

Table 4.3: Number of olive mill in WB&amp;GS according to their waste disposal methods, 2014. [57]

Governorate		Methods of Waste Disposal							No. of Operating Presses
		Olive Cake			liquid Waste (Zebar)				
		Others	Sell	Farmers	Others	Tight Cesspit	Sewage Network	Porous Cesspit	
	Palestine	34	8	223	34	114	37	80	265
Percentage Value (%)	West Bank	50.00	37.50	100	100	100	56.76	92.50	91.70
	Jenin and Tubas	17.65	0	26.01	50.00	30.70	2.70	13.75	24.15
	Tulkarm	5.88	25.00	12.56	2.94	17.54	13.51	7.50	12.08
	Nablus	0	12.50	18.83	17.65	21.05	10.81	11.25	16.23
	Qalqiliya	0	0	6.28	11.76	2.63	0	8.75	5.28
	Salfit	0	0	10.76	0	8.77	0	17.50	9.06
	Ramallah and Al- Bireh	8.82	0	12.11	14.71	7.02	8.11	17.50	11.32
	Jerusalem	0	0	1.35	0	0	2.70	2.50	1.13
	Bethlehem	17.65	0	0.90	0	3.51	8.11	1.25	3.02
	Hebron	0	0	11.21	2.94	8.77	10.81	12.50	9.43
	Gaza Strip	50.00	62.50	0	0	0	43.24	7.50	8.30
	Gaza	17.65	0	0	0	0	13.51	1.25	2.26
	Deir Al-Balah	8.82	62.50	0	0	0	21.62	0	3.02
	Khan Yunis and Rafah	23.53	0	0	0	0	8.11	6.25	3.02

The quantities of olive mill wastewater (Zebar) generated from different types of olive mills (Full Automatic, Traditional & Half Automatic olive mill) during the harvest season (about 90 days) are calculated for 265 mills located in the WB&GS area. The main factor For Olive Mill Wastewater and Jeft measurement are listed in the Table 4.4.

**Table 4.4: The main factor For Olive Mill Wastewater and Jeft measurement. [57,58,100]**

Type			Value Range		Average
Olive density- (gm/cm <sup>3</sup> )			0.915	0.916	<b>0.9155</b>
Zebar density- (gm/cm <sup>3</sup> )			1.015	1.086	<b>1.0505</b>
The quantity for 100kg olives	Quantity of water needed- depending on category	Traditional & Half Automatic Presses- (Liter)	40	55	<b>47.5</b>
		Full Automatic Olive Presses- (Liter)	85	120	<b>102.5</b>
Quantity of Olive cake- jeft- in 2011- (ton)				<b>48000</b>	
Quantity of Olive Pressed- in 2011- (ton)				<b>104763</b>	
Percentage of Olive cake- Jeft				<b>45.8%</b>	

#### 4.4.4 The residues of livestock:

Livestock manure is a readily available source of biomass waste in WB&GS. In general, manures are used directly as soil fertilizers. However, there are many problems associated with direct application of manure to soils including bacterial contamination of surface and groundwater supplies, over-enrichment of soils with nitrogen or phosphorus and nuisance odors. In addition, manure produces methane gas and nitrous

oxide; these products are part of greenhouse gases. Treatment of manure by anaerobic digestion systems could mitigate these problems, while producing biogas and a nutrient-rich fertilizer.

There are many sources of livestock that produces manure in WB&GS. These livestock includes poultry, cattles, goats, sheep, and camels. In order to calculate the potential of these wastes some additional data are required, for instance, to calculate the annual waste from poultry, the life cycle of poultry is analyzed and is given in Table 4.5.

**Table 4.5: The life cycle of poultry.**

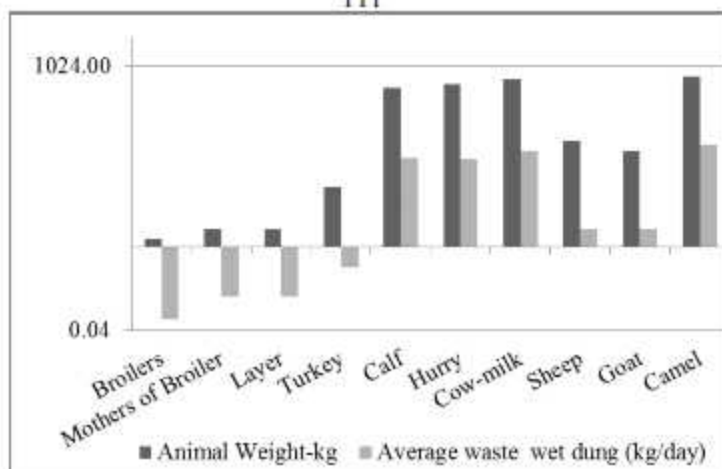
		<b>Turkey</b>	<b>Broiler</b>
<b>Weight- kg</b>		10	1.35
<b>Net weight</b>		0.75	0.72
<b>Slaughterhouse waste</b>	Blood & Feathers	8.5%	9.5%
	head, legs & offal	14.5%	15.5%

Table 4.6 gives more details about the waste type and percentages from poultry. [101]

**Table 4.6: Waste type and average percentages from poultry. [43, 60]**

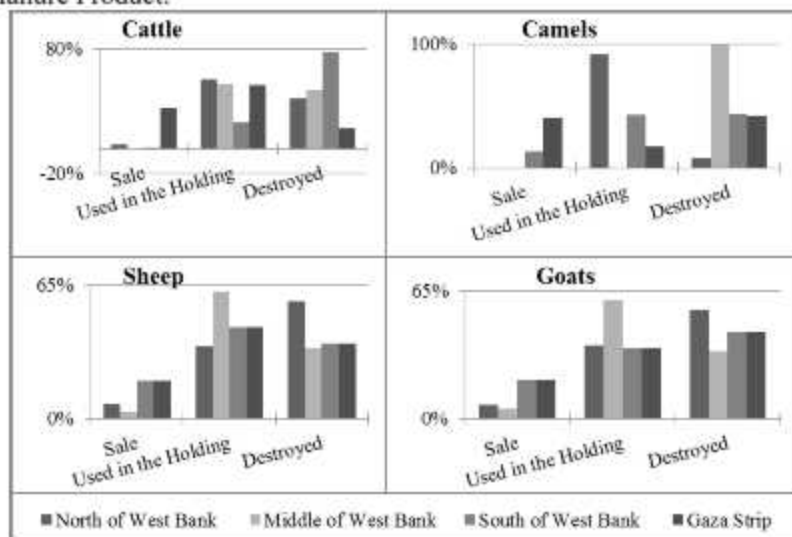
<b>Poultry type</b>	<b>Life cycle (days)</b>
<b>Broilers</b>	50
<b>Mothers of Broiler</b>	365
<b>Layer</b>	365
<b>Turkey</b>	150

The wastes which are produced by Cattles, Goats, Sheep, and camels are important resources biofuel. The daily waste production by the five major livestock is given in Figure 4.18.

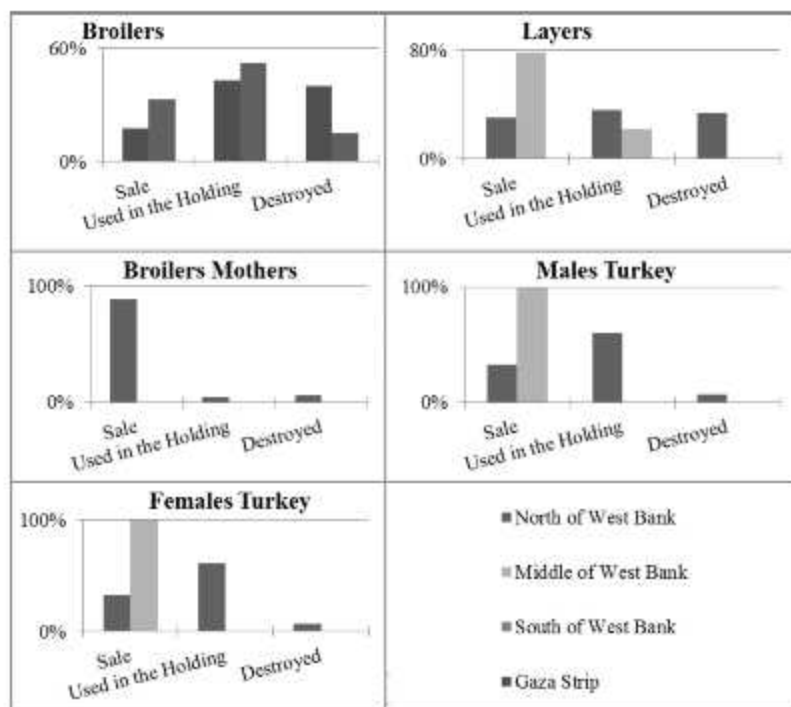


**Figure 4.18:** daily waste production by the five major livestock. [43, 59]

For livestock and poultry dung, there are several ways to get rid of this dung in WB&GS, such as sale as fertilizers, onsite use (holding) or destroying. Figure 4.19 and 4.20 shows the Percentage Distribution of Manure Product.



**Figure 4.19:** Percentage Distribution of Manure in WB&GS, 2012/2013. [97]



**Figure 4.20:** Percentage Distribution of Guano Product in WB&GS, 2012/2013. [97]

#### 4.4.5 Municipal household solid waste

The final part of waste is municipal household solid waste which is generated by household. The daily overall quantity of household solid waste which is produced in WB&GS is approximately 2551 tons. The average daily household waste generation in 2015 was estimated to be around 3.2 kg in the West Bank and 2.4 kg in Gaza Strip. All of these details are show in Table 4.7.

**Table 4.7: Daily generation of household solid in WB&GS, 2015. [ ]**

<b>Region</b>	<b>Total Daily Generated Quantity (ton)</b>	<b>Daily Average Household Generation (kg)</b>
<b>WB&amp;GS</b>	<b>2,551</b>	<b>2.9</b>
<b>West Bank</b>	<b>1,835</b>	<b>3.2</b>
North of West Bank	711.5	3.2
Middle of West Bank	563.5	3.4
South of West Bank	560	3
<b>Gaza Strip</b>	<b>716</b>	<b>2.4</b>

Municipal household solid waste contains mainly organic waste and other material such as glass, plastic, paper and some metals. Tables 4.8 show the Percentage composition of Households solid waste in WB&GS.

There are two major sources of bioenergy from Municipal household solid wastes:

- a. Municipal solid waste (MSW)
- b. Bio-solids (sewage, sludge).

**Table 4.8: the Percentage composition of Households solid waste in WB&GS, 2015. [ ]**

Region		Solid Waste Components						Total
		Baby's Nabs	Food Wastes	Paper & Cartoon	Agriculture Waste	Plastic	Others	
WB&GS		27.004	59.773	12.295	0.212	0.649	0.067	100
West Bank		23.767	63.264	11.906	0.285	0.738	0.041	100
West Bank	North	21.783	66.904	9.973	0.502	0.837	0.000	100
	Middle	16.398	71.924	11.503	0.000	0.087	0.087	100
	South	32.717	51.156	14.608	0.275	1.195	0.049	100
Gaza Strip		33.218	53.072	13.042	0.071	0.478	0.119	100

The recommended technologies that used to generate energy from municipal household solid waste can be divided into four types; these types can be summarized as following:

- Combustion/Incineration
- Pyrolysis/Gasification
- Landfill Gas Recovery
- Anaerobic Digestion/ Biomethanation

Incineration process is considered unsuitable due to high moisture content of waste; Incineration is 10 times more expensive than landfill disposal. [102]

The potential of power generation from household solid waste (Landfill method) can be calculated based on Equation number 3.10 and 3.13

**4.4.6 Calculations of biofuel potential from biomass:**

As can be seen from the aforementioned resources of biomass, methods of conversion of agricultural, livestock, and household solid wastes into gaseous fuels can be summarized into three main categories: gasification, anaerobic digestion and landfill. The produced quantity and properties of gas depends on the conversion method used. For instance, the generated gas from gasification of agricultural waste is called syngas or producer gas, while the gas produced using anaerobic digestion or land fill is called biogas. All mentioned processes are considered as environmentally friendly processes as the main sources are renewable. [103]

## **Chapter Five**

### **Results and Discussions**

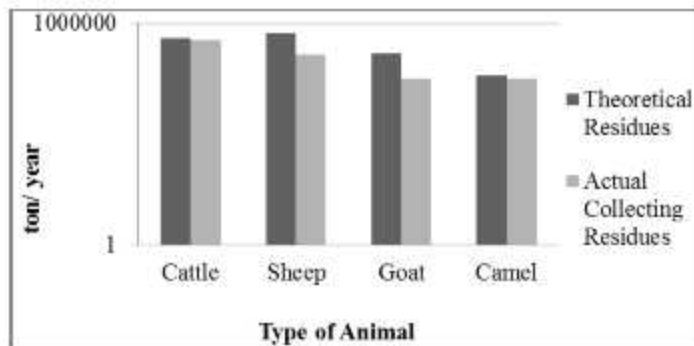
## Chapter Five

### Results and Discussions

#### 5.1 Biomass Residue

##### 5.1.1 Animal Residues:

When the potential of animal residues was calculated, the waste percent that can be collected for the actual residues were calculated based on the population density of animals in each holding, knowing that the animals and holdings of animals were taken into consideration. This method was used to calculate the collecting factor. The potential of actual collecting residues for animal residues are 566541ton/year. These residues were calculated based on equation (3.6). Figure 5.1 shows the average collectible wet residues (Dung) of animals.

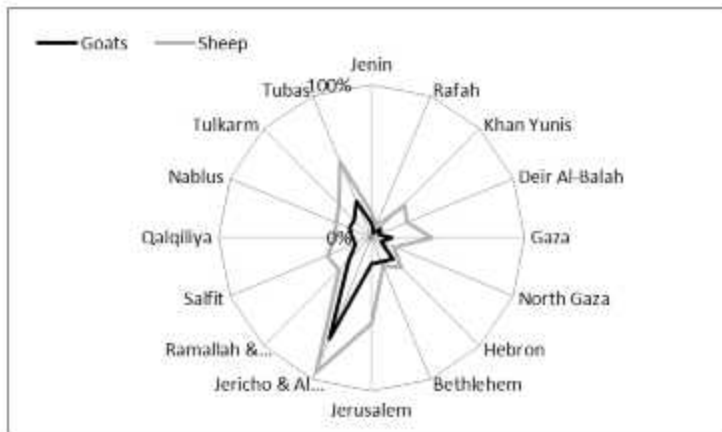


**Figure 5.1:** The average collectible wet residues (Dung) of animals (ton/year)

A complete collection of all residues is hard since animals holdings are distributed on a wide area. Knowing that each holding of sheep or goat contains five heads, and each holding of cattle or camels contains one head.

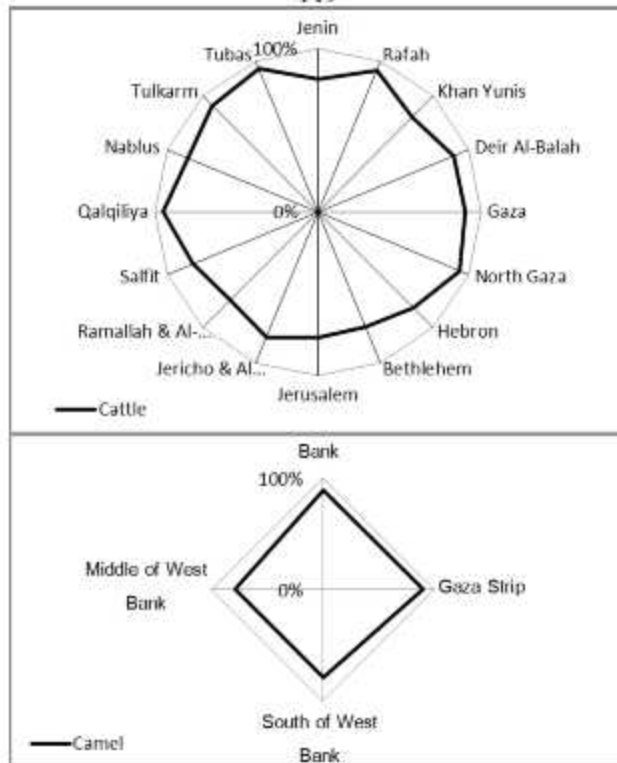
Waste collecting factor for animal waste was calculated depending on animal population density and the amount of residues that produced from animals in one holding.

Figure 5.2 shows the Average Collecting Factor of goat and sheep for all cities in WB&GS based. The maximum collecting factor was found to be about % 95 Jericho governorates.



**Figure 5.2:** The Average Collecting Factor for goat and sheep wastes for all governorates in WB&GS

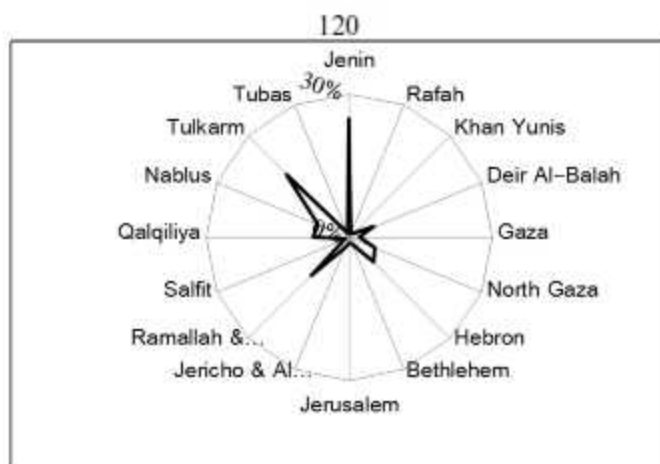
The collecting factors for cattle waste were also calculated based on animal population density. The collecting factors value for cattle varies between (76%-95%). Figure 5.3 illustrates the average collecting factor for cattle and camels in WB&GS.



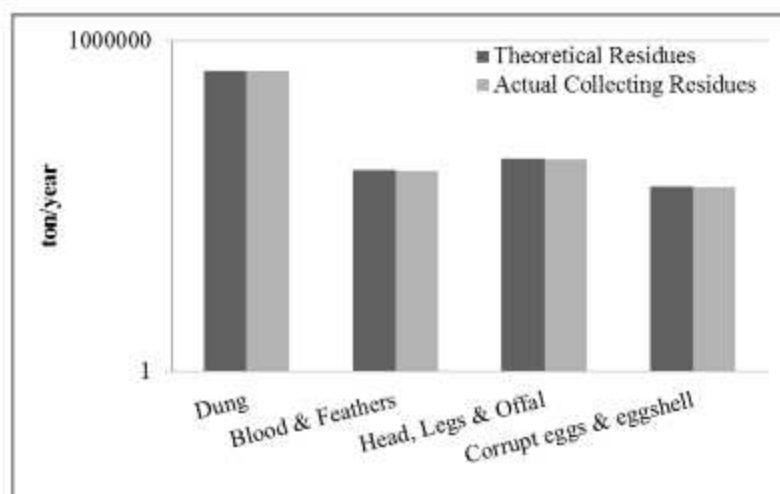
**Figure 5.3:** The average collecting factor for cattle and camels in WB&GS.

### Poultry Residues:

Poultry residues are differing from other animal residues because the poultry is concentrated in a limited number of holding with high population density. The potential of actual collecting residues for poultry is 290952ton/year. These residues were calculated based on equations (3.6-3.8). Figure 5.4 & 5.5 show the percentage of the Poultry waste in WB&GS and the actual collecting residues for poultry.



**Figure 5.4:** The percentage of the Poultry waste in WB&GS



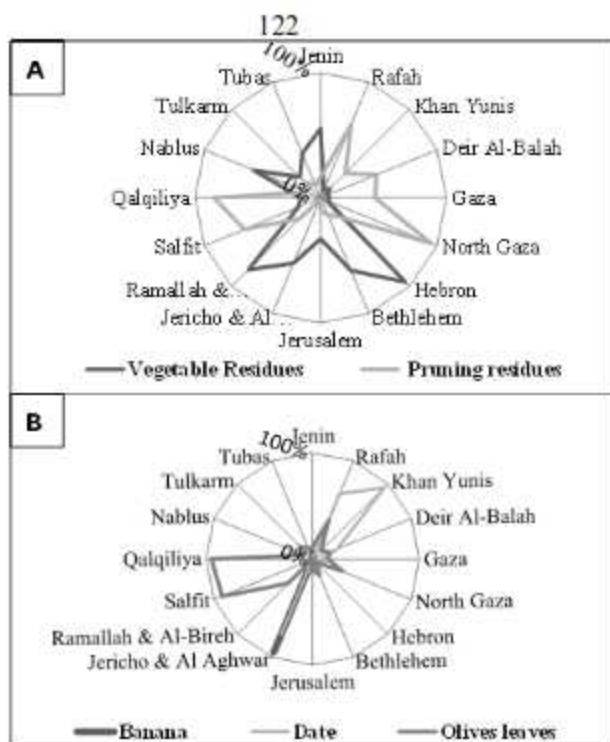
**Figure 5.5:** The actual collecting wet residues (dung) for poultry (ton/year).

### **5.1.2 Agricultural Residues:**

#### **Natural Residues:**

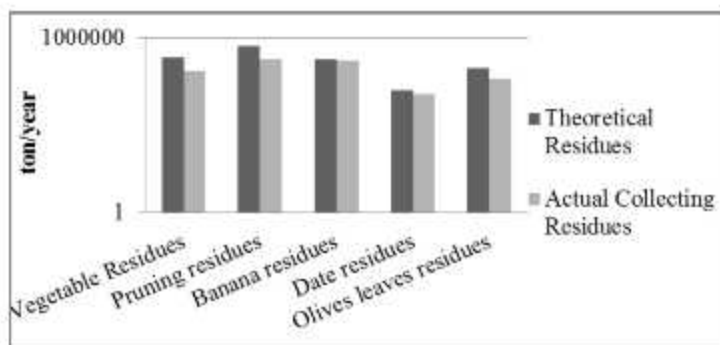
This section summarizes the final results of biomass residues from agriculture waste. The calculations of the vegetable residues depending on some local reviews and statistics and were based on European study (for European countries) due to the scarcity of information for the local area, knowing that the percentage of generated waste in our country is higher than in Europe due to the use of modern harvesting machines.

For this reason, a new factor was calculated depending on a real data. The actual amount of tomato residues is known for each dunam which is approximately (3-5) ton per dunam. A new factor was calculated that shows the differences between the tomato residue produced by using European factor and actual tomato residues which produced in WB&GS; the new factor is the result of dividing the actual residue to residues that produced depending on European. This factor was used to calculate the actual residue for all vegetable residues (assume the new factor was calculated for all vegetable crops is the same. The new factor is 1.45. Figure 5.6 shows the Collecting Factor for trees and vegetable crops in WB&GS. The potential of agricultural residues that can be collected is 472043ton/year. These residues were calculated based on equations (3.1-3.5).



**Figure 5.6:** Collecting Factor for trees and vegetable crops in WB&GS.

Figure 5.7 illustrates the potential of main residues for trees and vegetable crops in WB&GS, the highest potential for pruning residues.

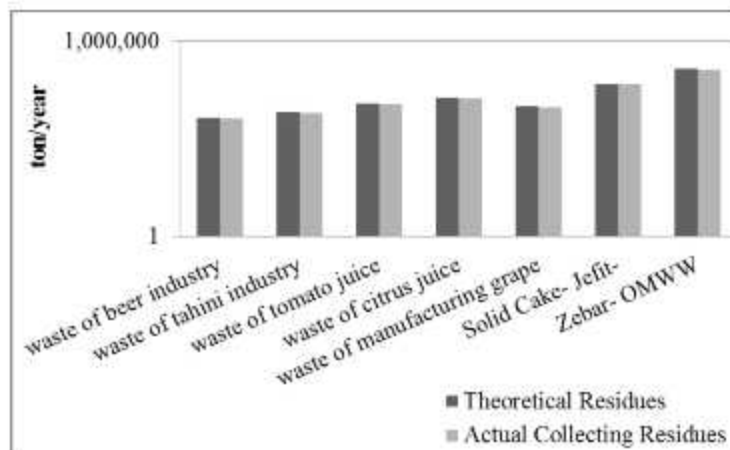


**Figure 5.7:** The main residues for trees and vegetable crops in WB&GS (ton/year)

### 5.1.3 Industrial Residues:

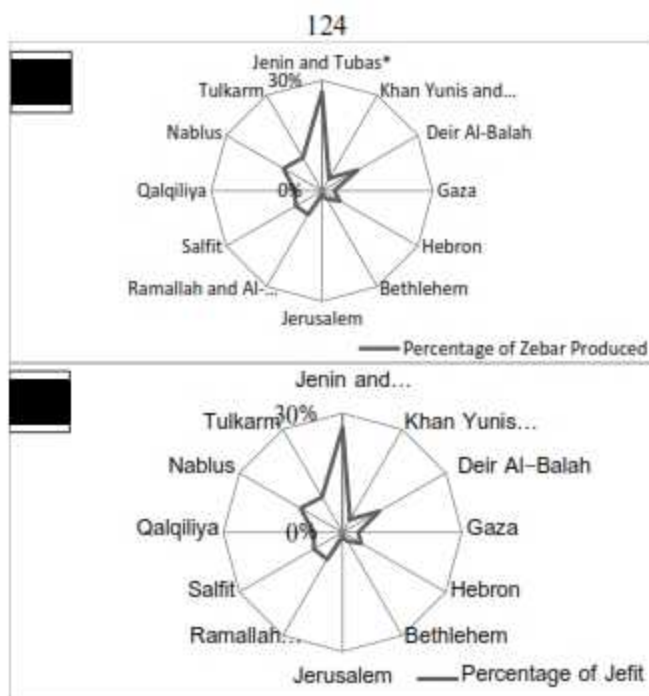
Industrial residues are differing from natural residues, and the collectible industrial residues are easier because it is concentrated in a limited area such as food factories.

In industrial residues, most of the waste can be collected, collecting factor can be up to 95%, and Figure 5.8 shows the average theoretical and actual collectible residues for food industries, knowing that the amount of waste is 48,925 ton/year. These residues were calculated based on equations (3.1-3.5).



**Figure 5.8:** The average theoretical and actual collecting residues for food industries (ton/year)

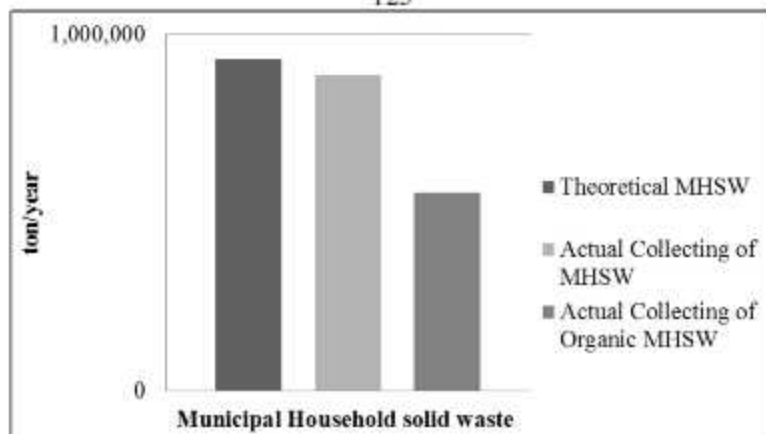
Other types of industrial residues are Zebar and Jelfit, these residues deployed across the whole of WB&GS as shown in Figure 5.9.



**Figure 5.9:** the percentage of Zabar and Jelit in WB&GS.

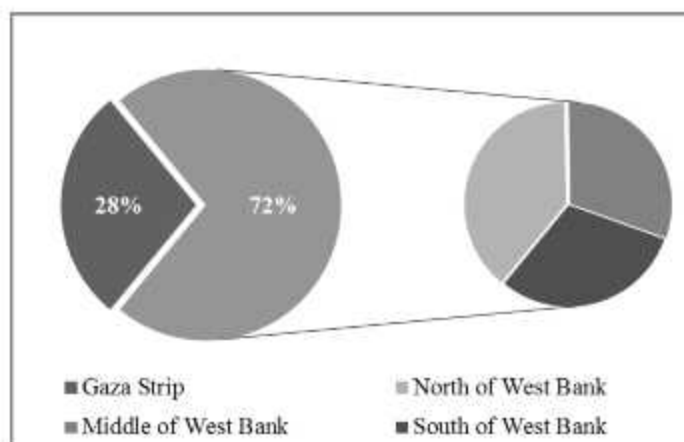
#### 5.1.4 Municipal Household Solid Waste:

The daily average of solid waste of the household generation is approximately 3.2kg in West Bank and 2.4kg in Gaza Strip. The actual potential of MHSW is 884549ton/year and the actual potential of organic MHSW is 556549 ton/year in WB&GS. Approximately 95% of MHSW can be collected. Figure 5.10 shows the average potential of Municipal Household solid waste in WB&GS.



**Figure 5.10:** Average potential of Municipal Household solid waste in WB&GS- (ton/year)

MHSW residues deployed across the whole of WB&GS. Figure 5.11 shows the percentage of Daily MHSW Generated in WB&GS



**Figure 5.11:** The percentage of Daily MHSW Generated in WB&GS

## 5.2 Energy potential:

Biomass residues have been divided into two parts, the first part is more suitable for an anaerobic digester, and the second one is more suitable for the gasification process. This section describes the nature of these residues and the potential of energy production.

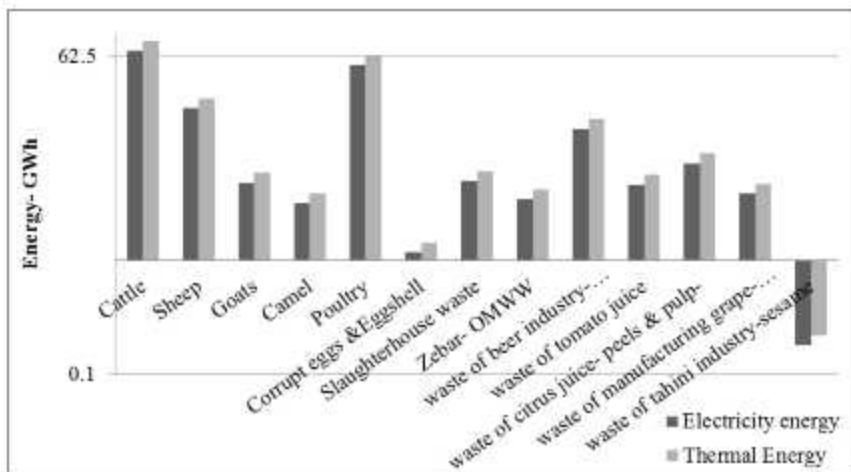
### Biogas potential:

There are many types of waste that can be used for biogas production using anaerobic digester process. In general, non-woody wastes are very suitable to use in anaerobic digester because they are easily degraded by anaerobic bacteria. Table 5.1 summarizes the main Wastes that suited anaerobic digester in WB&GS.

**Table 5.1: the main Wastes that suited anaerobic digester in WB&GS**

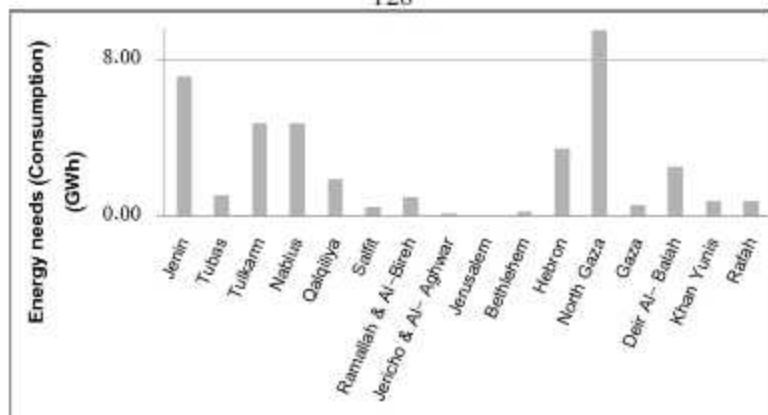
Type of Residues	
<b>Animal</b>	Cattle, Camel, Sheep, Goats
<b>Poultry</b>	Poultry
	Corrupt eggs & Eggshell, Slaughterhouse waste
<b>Agriculture</b>	Zebar
	waste of beer industry- fermentation barley
	waste of tomato juice
	waste of citrus juice- peels & pulp-
	waste of manufacturing grape-juice, alcohol, Qamar Uddin
	waste of tahini industry-sesame

CHP Generator is the best choice to produce the electrical energy from these wastes using anaerobic digester. The potential of electrical energy that can be produced by CHP generator is approximately 192.573 GWh<sub>e</sub> yearly and a by-product generate 236.146 GWh<sub>th</sub> of thermal energy. Figure 5.12 illustrates the potential of electrical and thermal energy which can be produced from anaerobic digesters using CHP generator in WB&GS. These values were calculated based on equations 3.13 and 3.14.



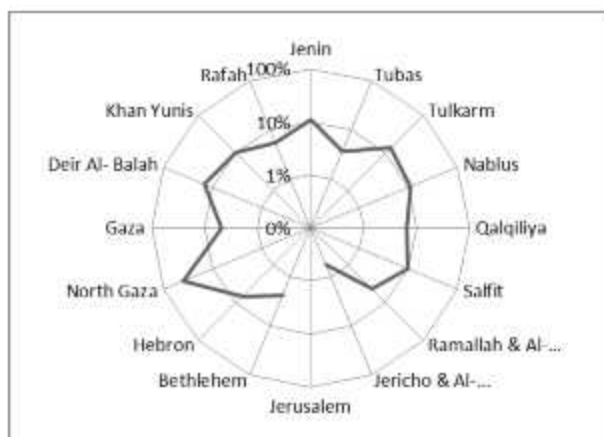
**Figure 5.12:** The potential of energy production using CHP Generator in WB&GS

The farmers consume approximately 2963 Ton LPG gas annually heating animal holding facilities. Figure 5.13 shows consumption of energy for heating holdings in WB&GS.



**Figure 5.13:** Thermal energy consumption for animal holdings heating in WB&GS.

In general, 15% (on average) of animal dung can be enough to produce the necessary biogas needed to heat the animal holdings. Figure 5.14 illustrates the percentage of biogas needed to heat animal holdings.



**Figure 5.14:** The percentage of biogas needed to heat animal holdings.

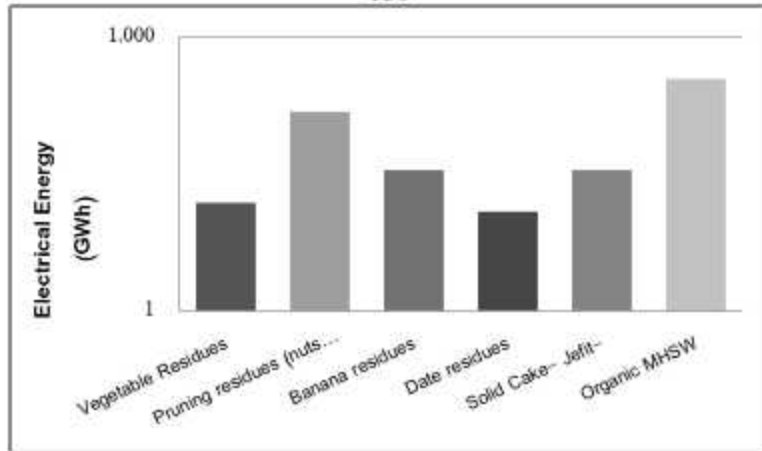
**Producer Gas:**

There are many types of waste that can be used for producer gas production using gasification process. Generally, woody wastes are very suitable to use in gasification processes. Table 5.2 summarized the main Wastes that suited gasification process in WB&GS.

**Table 5.2: The main Wastes that suited gasification process in WB&GS**

Type of Residues	
Natural Residues	Vegetable Residues
	Pruning residues (nuts and apples, grapes, etc.)
	Banana residues
	Date residues
Food Industries	Solid Cake- Jeft-
Municipal Household solid waste (MHSW)	

The potential of electrical energy that can be produced using gasification process is approximately 816.7161GWh<sub>e</sub> based on equations (3.11 and 3.14). Figure 5.15 illustrates the potential of electrical energy production using gasification process in WB&GS.



**Figure 5.15:** The potential of electrical energy production using gasification process in WB&GS

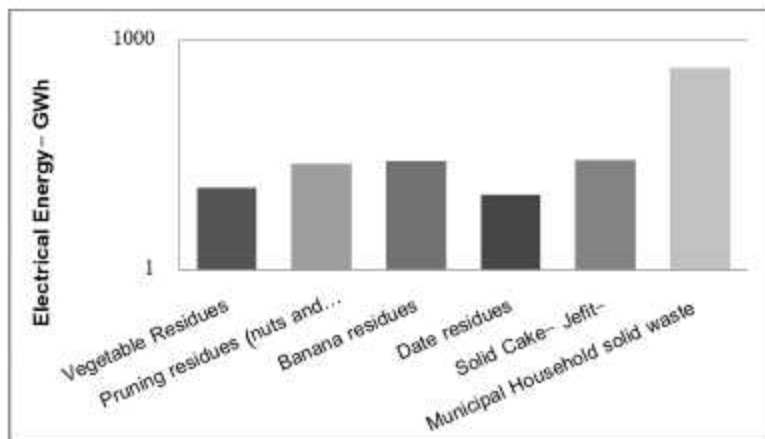
In this study organic MHSW can be used for energy production using gasification process. MHSW needs many sorting processes to get rid of metals, glass, and plastic before using in the gasifier, and also special treatment may be required if other undesirable and hazardous materials exist.

There are several advantages of gasification of MHSW compared to conventional methods (burning methods) for the disposal of MHSW, The use of oxygen in limited quantities reduces the quantity of dioxins, sulfur and nitrogen oxides that formed. Furthermore, the volume of produced gas is low; this leads to reducing the cost of treatment and cleaning equipment. Finally, gasification method generates combustible gas that can be used to generate electricity. In addition to these advantages, there are some negatives such as tars and heavy metals that cause environmental problems.

For these reasons, the use of MHSW in gasification needs more investigations.

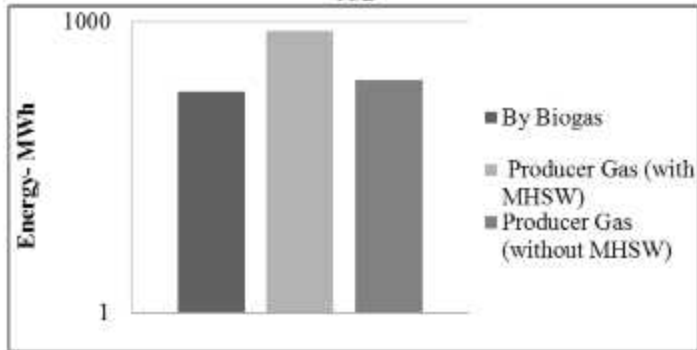
The potential of energy production from gasification is higher than pyrolysis, but dealing with pyrolysis products more easily and less complex than gasification products. There are many caveats and limitations on the use of pyrolysis especially with regard to gaseous emissions, these emissions are toxic especially when plastic and polymers are used.

Figure 5.16 shows the potential of electrical energy production using Pyrolysis process in WB&GS based on equations (3.12 and 3.15)



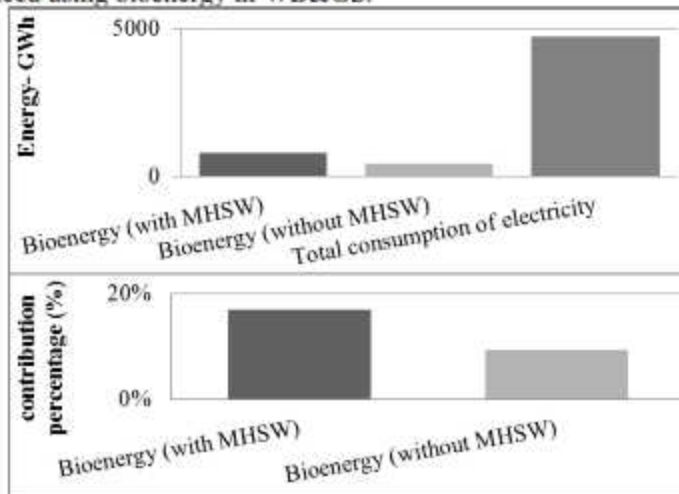
**Figure 5.16:** The potential of electrical energy production using Pyrolysis process in WB&GS

Finally, the potential of energy that may be produced using anaerobic digester and gasification process is illustrated in Figure 5.17.



**Figure 5.17:** The potential of electrical energy the can be produced using anaerobic digester and gasification process in WB&GS

Biomass residues can be contributed up to 9% of the total electricity consumption in WB&GS if the residues are used properly, while it can be contributed up to 17% when using the Solid Waste. Figure 5.18 shows the relationship between total consumption of electricity and energy which produced using bioenergy in WB&GS.



**Figure 5.18:** The relationship between total consumption of electricity and energy which produced using bioenergy in WB&GS

### 5.3 Experimental Work

In this study, a homemade downdraft gasifier was designed and constructed successfully and tested.

In the first operating, Olive cake (Jeft) residue was used. Gas evolution was noticed to start at 500°C. The produced gas was burned successfully in the presence of air at 720°C and.

The flow rate of producer gas in this run was calculated to be 3.3 m<sup>3</sup>/hr. Table 5.3 illustrates the operating parameters and amount of products from the gasifier for the first run

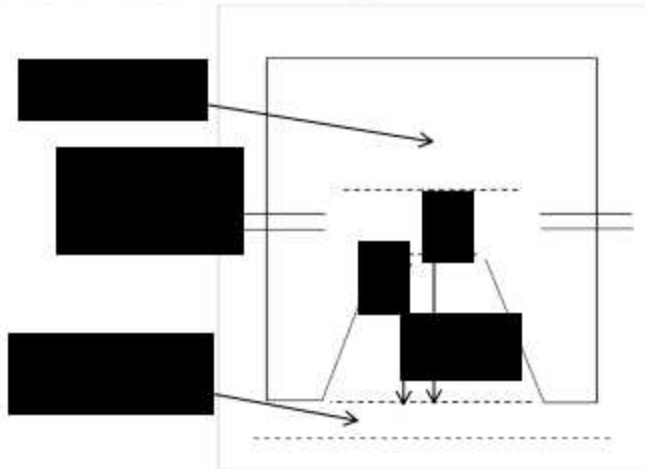
**Table 5.3: The physical and combustible properties of producer gas**

Parameter	value
Gasifier Temperature	720°C
Gasifier Pressure drop	4cm H <sub>2</sub> O
Air Blast Volumetric @ 25°C	1.184m <sup>3</sup> /h, (1.401kg/hr)
Biomass Consumption	5kg/h
Gas Output @ 35°C	3.3m <sup>3</sup> /h

As shown in Table 5.3, the volumetric flow rate of producer gas volume is 2.79 times of the air input volume. When comparing the volumetric flow rate of air- which injected into gasifier- with a simulation model, it is shown that this value (The flowrate of injected air in the experiment is 1.1836m<sup>3</sup>/h) which is less than the appropriate value (the appropriate value of injected air in simulation is 6.0928m<sup>3</sup>/h).

Using Jeft as feed stock for gasification process has negative effect on the pressure drop inside the gasifier due to small particle size. When gasifier filling up to level (a) (as shown in Figure 5.19) and water filter was used, pressure drop across full reactor is 4cm H<sub>2</sub>O, and when it was filled

up to level (b), pressure drop rises to 47cm H<sub>2</sub>O, knowing that the average pressure drop across full reactor based on the design parameters should be between (1.54-30.5) cmH<sub>2</sub>O according to the literature.



**Figure 5.19:** Preview of pressure inside gasifier

When gasifier was filled up to level (b), the pressure rises from 1atm. to more than 1.086atm. (1.1bar), knowing that the operating pressure inside gasifier is 1atm. This problem led to burn the producer gas inside gasifier.

In the second run, Gas evolution was noticed to start at 215°C after two minutes of gasifier start. After 2.14 minutes, the temperature reached 700°C. The flow rate of producer gas in this operating was calculated to be 3.6m<sup>3</sup>/hr. Table 5.4, Figure 5.20 and 5.21 illustrate the operation of gasifier and operating parameter and amount of products from the gasifier for the second run.

**Table 5.4: the physical and combustible properties of producer gas**

Parameter	Values
Gasifier Temperature	500-850°C
Gasifier Pressure	2cm H <sub>2</sub> O
Biomass Consumption( dry Olive cake- Jeft)	4.6 kg/h
Tar	126.36gr/h
Gas Out put	3.6m <sup>3</sup> /h

**Figure 5.20: Homemade downdraft gasifier**



**Figure 5.21:** Operation and testing of homemade gasifier.

The actual mass of tar is slightly more than 126.36kg because some of the tar remains in burner and filter. The producer gas temperature after cooling is 35°C. Figure 5.22 shows Char and tar produced using gasification process.

We were not able to analyze the producer gas due to the lack of possibilities currently.



**Figure 5.22:** Char produced using gasification process

#### **5.4 Sensitivity analysis of simulation models**

The gasification performance can be evaluated by many parameters such as Thermal efficiency, Gasification system efficiency (it can be used to better evaluate non-conventional gasification processes), Hot Gas efficiency, Cold gas efficiency (CGE), carbon conversion efficiency and gas yield.

Normally, to evaluate a performance of conventional gasification system, cold gas efficiency can be used. The CGE refers to the fraction of energy stored in the biomass feed that is converted into energy of the produced producer gas. The higher the value of CGE the better the biomass conversion into gas.

In this section, a sensitivity analysis process -using simulation software- was carried out in order to determine the most pronounced parameters that affect the gasification process. The properties of Jelf feedstock has been used for this purpose.

The effect of the following parameter on the composition, lower heating value, cold gas efficiency of the producer gas were investigated

1. Biomass moisture content.
2. Air temperature.
3. Gasification Temperature.
4. Air and Oxygen Equivalent ratio
5. Steam to Biomass Ratio (STBR)
6. Steam temperature.
7. Steam with Oxygen or Air equivalent ratio

8. Hydrogen injection.
9. Recycling Ratio.
10. CO<sub>2</sub> injection.
11. Traces Gas generation.
12. Feedstock type.
13. Residence Time on producer gas.

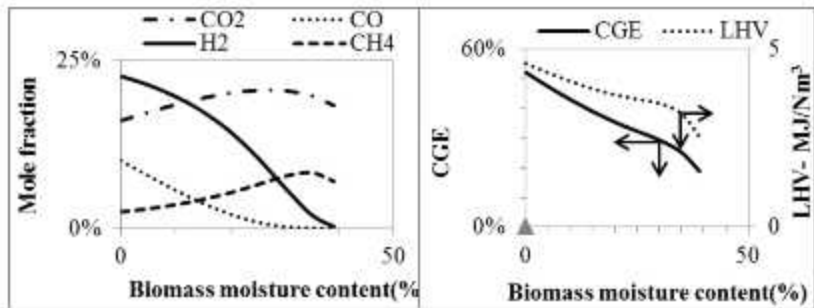
Moreover, the effect of temperature on tracer gases formation and the effect of temperature and feedstock particle size on residence time were also determined.

#### **5.4.1 Effect of Biomass Moisture Content.**

Biomass has a high percentage of moisture. The moisture in the biomass has an undesirable effect on gasification process. Knowing that the high moisture in biomass absorbs the heat and results in decreasing the temperature of gasification process. Therefore, it is necessary to decrease the moisture content as possible, especially at low gasification temperature.

Biomass moisture content (dry basis mole fraction %) was found to have high impact on producer gas composition, for example the H<sub>2</sub> content decreased from 22.7-10.6% over the moisture range 0-25%. Moisture content higher than 25% was found to have a very strong influence on hydrogen concentration. The hydrogen content decreased from 10.6 to 6.1% when moisture content rises from 25 to 30%). Reminding that the hydrogen content has a high effect on LHV of producer gas. The effect of increasing moisture content on mole fraction, LHV & CGE of the producer

gas is illustrated in Figure 5.23. However, moisture content was found to have a very strong influence on CGE (CGE decreases from 52.2% at 0% moisture to 18.9% at 39% moisture). CGE depends on both the LHV of producer gas and mass flow rate. The high moisture content drops the producer gas mass flow rate that causes the dramatic reduction in CGE for high moisture content. Based on these results the biomass moisture content proved to be the most significant parameter regarding gasifier CGE and therefore should be as low as possible. These results especially LHV (to some extent) correspond to the finding of Kumar et al., (2016) [104].

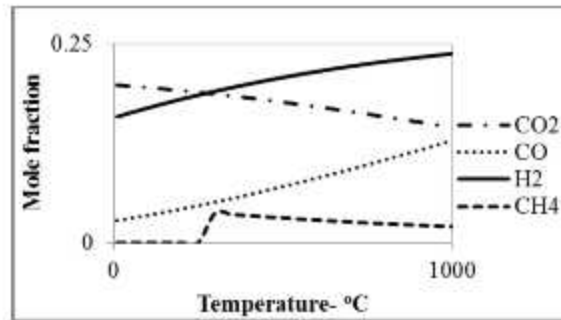


**Figure 5.23:** The effect of biomass moisture content on mole fraction, LHV & CGE of the producer gas.

#### 5.4.2 Effect of Inlet Air Temperature:

In this case, air temperature was varied from 10-1000°C while other parameters kept constant. The producer gas composition, LHV and cold gas efficiency of producer gas were studied. Figure 5.24 shows the effect of the air temperature on the producer gas composition (dry basis mole fraction %). As the air temperature increases from 10-1000°C, both  $\text{H}_2$  and

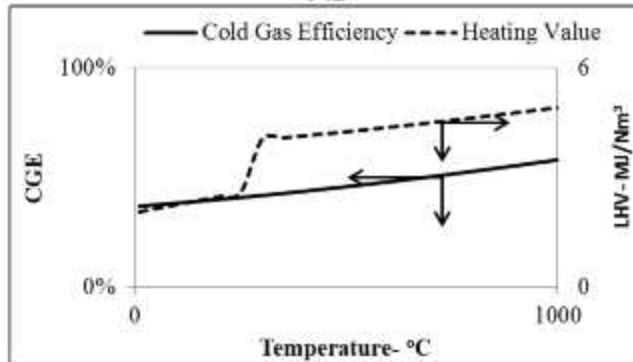
CO rise percent from 15.87 & 2.80 to 23.82 & 12.84 %, respectively.  $\text{CO}_2$  dropped from 19.87% to 14.54%.  $\text{CH}_4$  content is very low.



**Figure 5.24:** The effect of the air temperature on the producer gas composition

When the air temperature increases from (10-1000) °C, both the LHV and CGE of the producer gas increase from 2.06 MJ/Nm<sup>3</sup> & 37% to 4.91 MJ/Nm<sup>3</sup> & 58%, respectively. The effect of the air temperature on the CGE and LHV of the producer gas is illustrated on Figure 5.25.

Use of highly air temperature provides additional energy to the gasification process, which enhances the decomposition of the feedstock. Increase of air temperature reduces the production of tars and char residues as well as increases the heating value of the dry producer gas. Overall, it has been shown that the LHV and the CGE of the dry producer gas increase with increasing temperature.

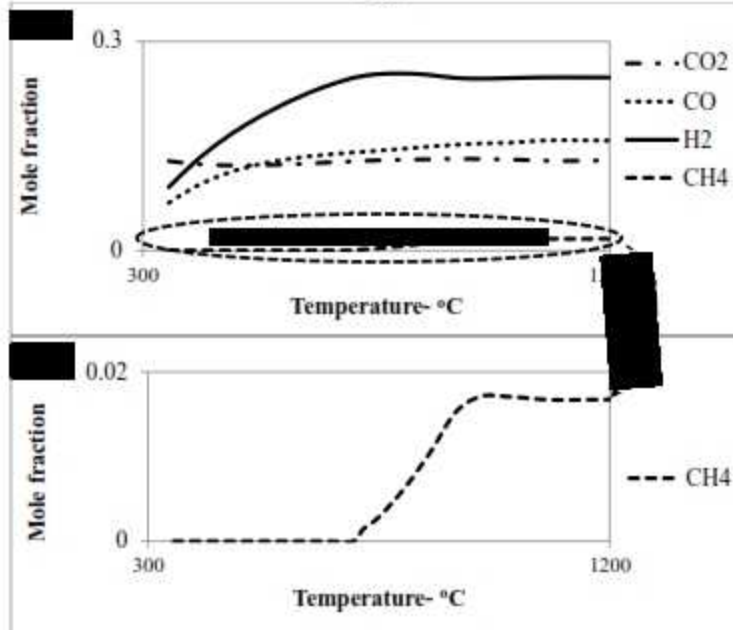


**Figure 5.25:** The effect of inlet air temperature on the CGE & LHV of the producer gas.

All of these results correspond to the finding of Doherty et al., (2009) [105]. Except for a slight difference in a results due to different feedstock characteristics.

### 5.4.3 Effect of Temperature

The gasifier temperature has a pronounced effect on producer gas composition. At low temperature, the concentrations of main gases in producer gas are low. When the temperature rises, the concentration of main gases increased especially CO & H<sub>2</sub>. The effect of temperature on the composition of producer gas is illustrated in Figure 5.26 at AER=0.2



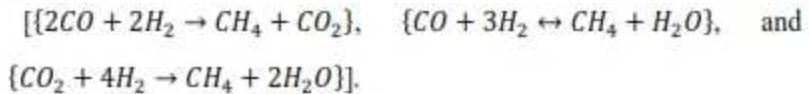
**Figure 5.26:** The effect of gasifier temperature on produced Gas Composition at AER=0.2

The gasification temperature has a very strong influence on producer gas composition, because the main reactions in gasification process are endothermic reaction (equation 1 and 2 in Table 2.3: [ $C + CO_2 \leftrightarrow 2CO$ ], [ $C + H_2O \leftrightarrow CO + H_2$ ]). That means the reaction rate to generate of hydrogen and carbon monoxide from biomass increases by increasing the gasifier temperature.

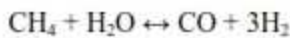
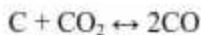
Over the gasification temperature range of (350-900) °C, H<sub>2</sub> increases 16 points (from 9 to 25%) and CO rises 8 points (from 7 to 15%).

CH<sub>4</sub> formation starts at °C. Temperature has low impact on CH<sub>4</sub> formation for temperature above 900°C. Referring to reaction equation for

methane formation, as in equations 2.10-2.12, methane generation depends on hydrogen and carbon monoxide concentrations in producer gas, hydrogen and carbon monoxide concentrations rises dramatically at 720°C where the methane formation starts.



The variation in producer gas composition with gasification temperature can be understood by considering that rising temperature favors the endothermic gasification reactions as in Eq. 2.1, 2.2 and 2.13

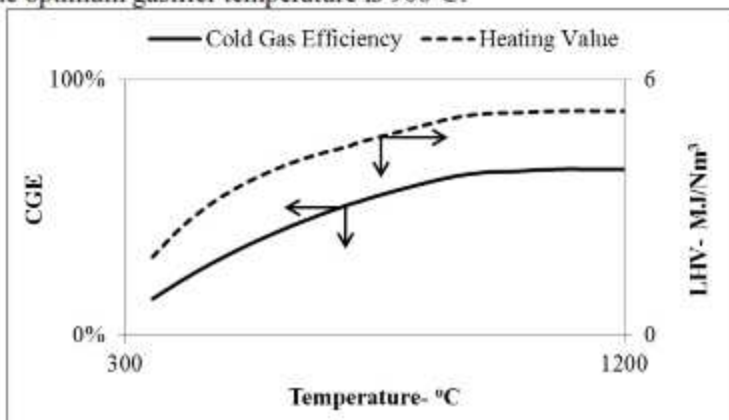


And simultaneously the reactants of exothermic reactions as in Eq. 2.3 ( $C + 2H_2 \leftrightarrow CH_4$ ) and 2.9 ( $CO + H_2O \leftrightarrow CO_2 + H_2$ ). From these results, it can be concluded that gasification temperature is the most important parameter with respect to producer gas composition and it is recommended to operate the gasifier in the temperature range (800-950) °C in order to maximize  $H_2$  and  $CO$  concentrations and to minimize  $CO_2$  concentration

The LHV is calculated from the dry gas composition and the CGE is determined using LHV values for both producer gas and biomass input (equation 3.17). LHV increases from 1.84 to 5.27 MJ/kg over the gasifier temperature range (350-1100) °C. Gasifier CGE rises over the gasifier temperature range; with a maximum at 1100°C and a minimum at 350°C (65.1% and 14.3%). the gasifier should be operated in the Temperature

range around 900°C in order to maximize CGE and produce a high heating value syngas with high H<sub>2</sub> and CO content.

Cold Gas Efficiency is calculated to determine the suitable temperature of a gasifier that gives the highest heating values under normal conditions. Figure 5.27 shows the effect of temperature on cold gas efficiency and heating value under normal conditions. When the temperature increases, the heating value increases significantly up to 900°C. After that the change in heating value is negligible, according to that the optimum gasifier temperature is 900°C.



**Figure 5.27:** The effect of gasifier temperature on CGE and LHV under normal conditions

Taking into account the difference in feed stock, these results correspond to the finding of Chen et al., (2010) [106].

### 5.4.4 Effect of Air and Oxygen Equivalent ratio

#### 5.4.4.1 Air Equivalent Ratio:

Air Equivalent ratio (AER) is the ratio of actual amount of air supplied to the gasifier and the stoichiometric amount of air required for the complete combustion of feed. The amount of air needed to produce the producer gas must be less than stoichiometric value at a gasifier temperature of 900°C. When a limited air is used in the gasification process, the CO and H<sub>2</sub> is formed. Figure (5.28-a) shows the effect of Air equivalent ratio on producer gas composition

The AER is the most important parameter which controls the composition of producer gas. The AER has been varied in the range of 0.1-1. At very low AER (limited oxygen) the conversion of feed is not complete and it converts to carbon monoxide and hydrogen as show in the following equations:

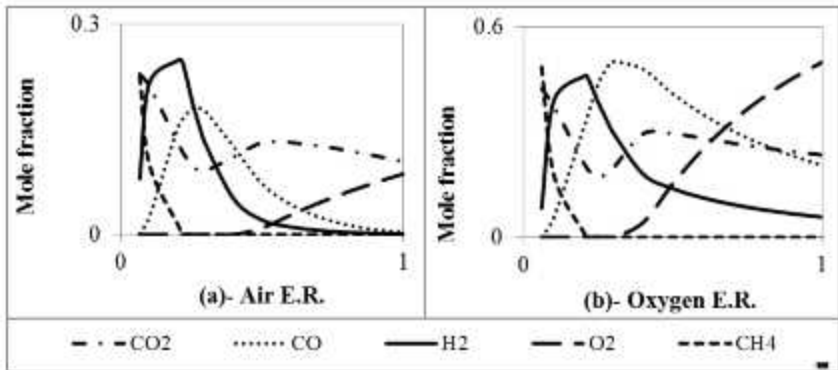
( $C + 0.5O_2 \rightarrow CO$ ,  $CO + H_2O \leftrightarrow CO_2 + H_2$ ). At very high AER close to unity the carbon and hydrogen present in the feed are converted into carbon dioxide and water respectively and no combustible gas is produced based on equation ( $C + O_2 \rightarrow CO_2$ ,  $CO + 0.5O_2 \rightarrow CO_2$ ,  $H_2 + 0.5O_2 \rightarrow H_2O$ ).

When the Cold Gas Efficiency is calculated, the best value of air equivalence ratio is determined. The suitable value of Air Equivalent Ratio is 0.2 and the heating value at this point was equal to 5.126MJ/Nm<sup>3</sup>. Cold gas efficiency 42.6% was recorded at AER of 0.1. When AER raised to 0.2 the CGE raised to 69.1%. Based on these findings, the AER is kept at 0.20

during other analysis. Figure (5.29-a&b) illustrates the Effect of AER on heating value & cold gas efficiency. All of these results correspond to the finding of Ramzan et al., (2013) [107], Except for a slight difference in a results due to different in feedstock characteristics and changes of some operating parameter.

#### 5.4.4.2 Oxygen Equivalent Ratio:

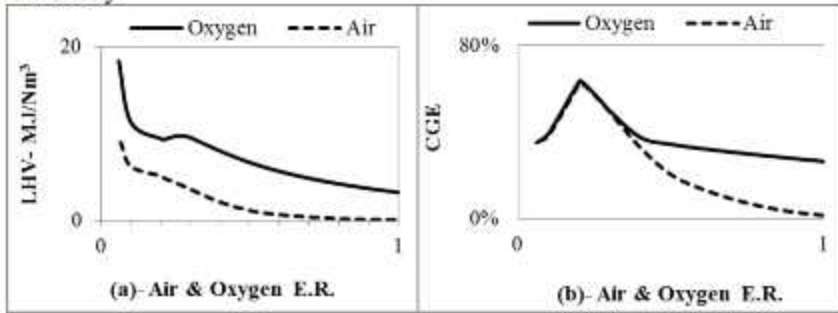
Oxygen needed to produce the producer gas must be less than stoichiometric value where the temperature of the gasifier is kept at 900°C. This parameter (oxygen equivalent ratio) effect is very similar to Air equivalent Ratio effect. (Figure 5.28-b) shows the Effect of Oxygen equivalent ratio on producer gas composition.



**Figure 5.28:** Effect of Air & Oxygen equivalent ratio on producer gas composition.

For the same ratios, oxygen always gives higher cold gas efficiency than air. The highest heating value was obtained at Oxygen Equivalent ratio equal to 0.2 (heating value = 9.419 MJ/Nm<sup>3</sup>). Figure (5.29a&b)

illustrates the Effect of oxygen equivalent ratio on heating value & cold gas efficiency.



**Figure 5.29:** Effect of Air & Oxygen equivalent ratio on heating value & cold gas efficiency.

Up to the researcher knowledge, no simulation similar results and detailed of oxygen equivalent ratio effect on the composition of producer gas are found in the open literature, therefor, the obtained results cannot be compared with others.

#### 5.4.5 Effect of Steam to Biomass Ratio (STBR)

In this part, the effect of using only steam media in gasification process at gasifier temperature of 900°C and different steam temperature was investigated. Unlike the previous simulations, the methanation and hydrogasification reactions are the main reactions. At low steam temperature, ( $T_s=150^\circ\text{C}$ ). These reactions are:  $\{2\text{CO} + 2\text{H}_2 \rightarrow \text{CH}_4 + \text{CO}_2\}$ ,  $\{\text{CO} + 3\text{H}_2 \leftrightarrow \text{CH}_4 + \text{H}_2\text{O}\}$ ,  $\{\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}\}$ ,  $\{\text{C} + 2\text{H}_2 \leftrightarrow \text{CH}_4\}$ . As seen from these equations, the main gases are methane, carbon dioxide, and water. The Methane gas is the main effluent when a

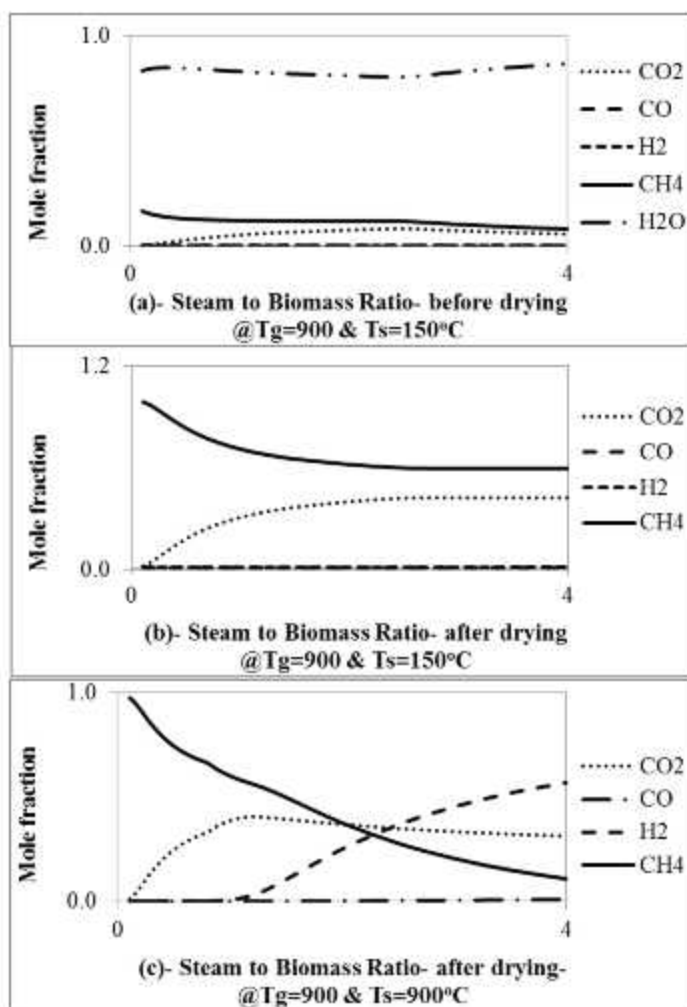
pure steam is injected instead of air or oxygen and at low temperature ( $T_s=150^\circ\text{C}$ ). Hydrogen and carbon monoxide are consumed during these reactions for the production of methane. This causes the low concentration of hydrogen and carbon monoxide significantly. Over the STBR range 0.107-2.5  $\text{CH}_4$  decreases by 39 percentage points (97.7%- 58.7% as dry basis). However, on a wet basis, only 4.9 percentage points (16.5%-11.6%) were observed. Other gases especially  $\text{H}_2$  and  $\text{CO}$  are limited due to conversion to methane.  $\text{CO}_2$  increases by 39.913 percentage points (1.045%-40.958%).

Figure (5.30-a&b) shows the effect of steam ratio on the composition of producer gas at  $T_s=150^\circ\text{C}$ .

On the other hand, the steam reaction ( $\text{C} + \text{H}_2\text{O} \leftrightarrow \text{CO} + \text{H}_2$ ) and Steam-Reforming reaction ( $\text{CH}_4 + \text{H}_2\text{O} \leftrightarrow \text{CO} + 3\text{H}_2$ ) are endothermic reactions. When using steam at high temperature ( $T_s=900^\circ\text{C}$ ), these reactions are starting to form hydrogen as a main gas. Methanation reaction ( $\text{CH}_4 + 2\text{O}_2 \leftrightarrow \text{CO}_2 + 2\text{H}_2\text{O}$ ), Water-gas-shift (WGS) reaction ( $\text{CO} + \text{H}_2\text{O} \leftrightarrow \text{CO}_2 + \text{H}_2$ ) and Steam-Reforming Reactions ( $\text{CH}_4 + 0.5\text{O}_2 \leftrightarrow \text{CO} + 2\text{H}_2$ ) Are the dominant reactions for hydrogen production at the specified conditions. Methane and carbon monoxide are consumed during these reactions for the production of hydrogen. This causes the low concentration of methane and carbon monoxide.

Over the STBR range of 0.107-4, hydrogen increases by 56.947 percentage points (0.052%-56.999% as dry basis). The concentration of Methane drops by 86.952 percentage points (97.700%-10.748%).

Figure (5.30-c) illustrate the effect of steam ratio on the composition of producer gas at  $T_g = 900^\circ\text{C}$ .



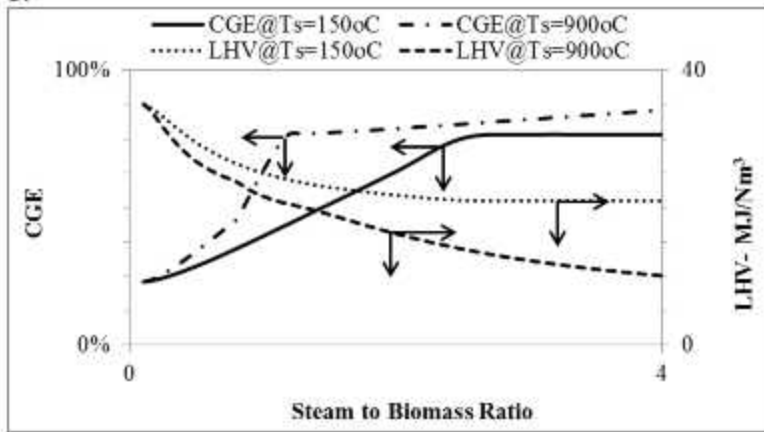
**Figure 5.30:** Effect of steam injection on the composition of producer gas at  $T_g = 900^\circ\text{C}$  &  $T_s = 150$  &  $900^\circ\text{C}$ .

It is obvious from Figure 5.31 that STBR above 1.2 at  $T_s=900^\circ\text{C}$  & 2.5  $T_s=150^\circ\text{C}$ , has little impact on CGE.

The increasing of STBR helps in increasing the effluent flow rate and decreasing in heating value. These opposing trends result in little change in the CGE.

Steam injection is used to generate hydrogen at high steam temperature and high STBR (Figure (5.30)). But If the objective to obtain a high CGE, the optimum STBR was found to be 2.5 at  $T_s=150^\circ\text{C}$  &  $T_g=900^\circ\text{C}$ .

Figure 5.31 that illustrate the effect of Steam to Biomass Ratio on lower heating value and CGE under optimum gasifier temperature of  $900^\circ\text{C}$ .



**Figure 5.31:** The effect of Steam to Biomass Ratio on CGE and LHV.

From these results, it is clear that STBR is the most important parameter with respect to producer gas composition. The operation at higher STBR is not advisable considering the detrimental effect on

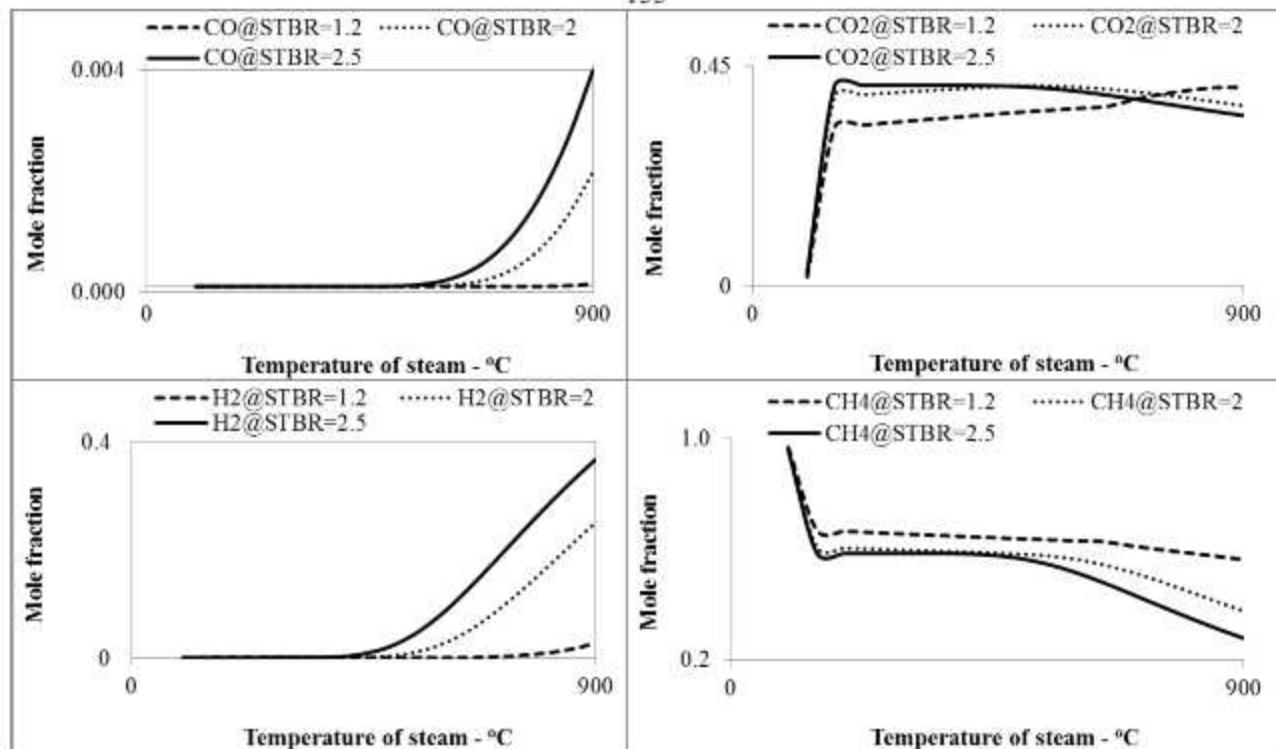
producer gas LHV and the energy that would be required to generate the steam.

Up to the researcher knowledge, no similar simulation results of Steam to Biomass Ratio effect on the composition of producer gas at different temperature are found in the open literature, therefore, our results cannot be compared with others.

#### 5.4.6 Effect of steam temperature.

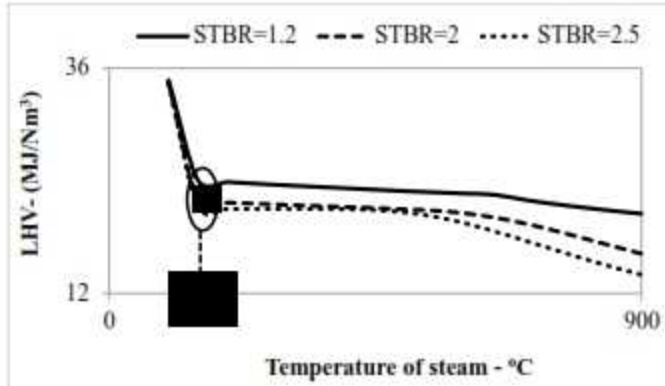
The reaction rate of steam ( $C + H_2O \leftrightarrow CO + H_2$ ) and Steam-Reforming ( $CH_4 + H_2O \leftrightarrow CO + 3H_2$ ) increases when the steam temperature rises, due to nature of these reactions (endothermic). These reactions are starting to form hydrogen as a main gas with reduction in methane concentration during increasing steam temperature and STBR. Figure 5.32 shows the changing in hydrogen and main concentrations of producer gas over steam temperature 100-900°C.

The optimum steam temperature to generate producer gas at high cold gas efficiency was found to be at 150°C and at high STBR. On contrary, the high concentration of hydrogen is generating at a high steam temperature and high STBR. At low steam temperature, the main component of effluent gas was methane. The methane formation was predominant until 550°C. For temperature higher than 550°C, it was found that the formation of hydrogen starts to increase rapidly while abrupt decrease in methane formation occurs. Figure 5.32 shows the effect of steam temperature on producer gas composition.



**Figure 5.32:** Effect of steam temperature on the composition of producer gas at different STBR values.

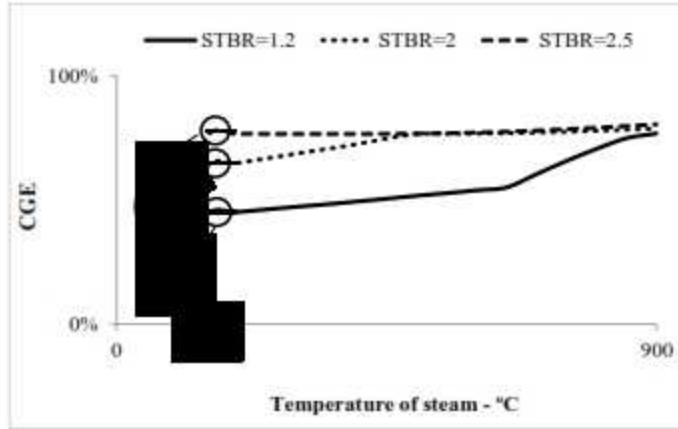
Any increasing in steam temperature caused to reduction in lower heating value of producer gas as a result of reduction in methane concentration and increasing in hydrogen concentration. Figure 5.33 shows the effect of steam temperature on the lower heating value for producer gas.



**Figure 5.33:** The effect of steam temperature on LHV of producer gas at different value of STBR &  $T_s$  and at  $T_g=900^\circ\text{C}$ .

The elevated steam temperature and STBR rise the CGE which have a positive effect on gasifier performance. When the temperature of the steam increases from  $100^\circ\text{C}$  to  $150^\circ\text{C}$ , the Cold Gas Efficiency increased significantly. It increased from 23.5%-75.2% (up 51.7 percentage points) at STBR is 2.5, while The CGE increases from 75.2%-80.4% (up 5.2 percentage points) at steam temperature range  $150$ - $900^\circ\text{C}$  and STBR is 2.5. The improvement in performance is only slight; therefore, preheating the steam to high temperature (e.g.  $500$ - $900^\circ\text{C}$ ) is not recommended if the economy energy that would be required is considered.

The Cold Gas Efficiency is affected by changes in STBR significantly. It increased from 44.2%-75.2% (up 31 percentage points) at steam temperature is 150°C. Figure 5.34 shows the effect of steam temperature on CGE at different value of STBR and steam temperature.



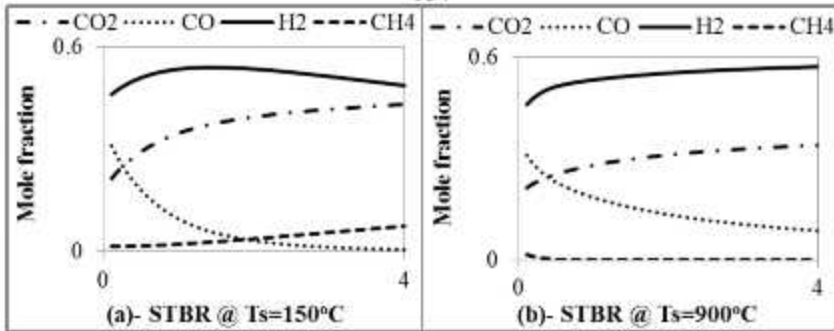
**Figure 5.34:** The effect of steam temperature on CGE at different value of STBR &  $T_{ss}$ , and at  $T_g = 900^\circ\text{C}$ .

Up to the researcher knowledge, no simulation similar results and detailed of the effect of steam temperature on produced gas Composition are found in the open literature, there for our results cannot be compared with others.

#### 5.4.7 Effect of Steam with Oxygen or Air equivalent ratio

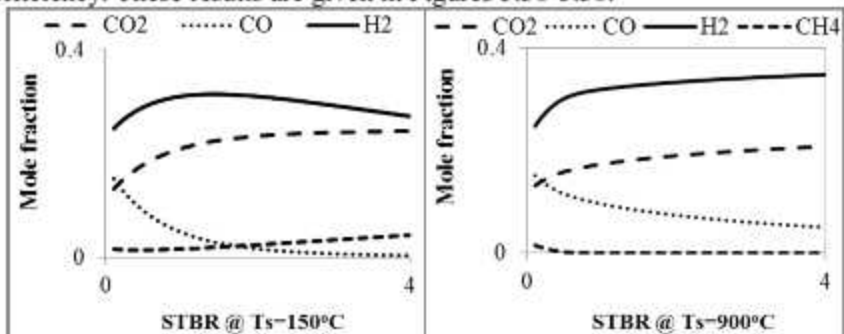
Any increases in STBR up to 1.4 with limited amount of oxygen and at low steam temperature, the concentration of Hydrogen and carbon dioxide increase significantly, on contrast, the carbon monoxide fraction decreased dramatically by increasing the steam to biomass ratio as a result of increasing of water-gas or steam reaction rate ( $C + H_2O \rightarrow CO + H_2$ ) and water-gas-shift reaction rate ( $CO + H_2O \rightarrow CO_2 + H_2$ ). After point (STBR>1.4), the rate of Methanation Reactions ( $2CO + 2H_2 \rightarrow CH_4 + CO_2$ , and  $CO + 3H_2 \rightarrow CH_4 + H_2O$ ) increases, which means a reduction in hydrogen and carbon monoxide concentrations. Figure (5.35-a) shows the changing in hydrogen and main concentrations of producer gas over STBR at low steam temperature.

Any increase in STBR and steam temperature can cause the increasing of the concentration of hydrogen and carbon monoxide with reduction of methane and carbon dioxide concentrations, as a result of the increase in reaction rate of the water-gas or steam reaction (endothermic reaction) ( $C + H_2O \rightarrow CO + H_2$ ) and Methanation Reactions ( $CH_4 + H_2O \rightarrow CO + 3H_2$ ). This method can be used for hydrogen production. Figure (5.35.b) shows the changing in hydrogen and main concentrations of producer gas over STBR range at high steam temperature.



**Figure 5.35:** The effect of steam on producer gas- after drying- at different  $T_s$ , OER= 0.2 and  $T_g = 900^\circ\text{C}$

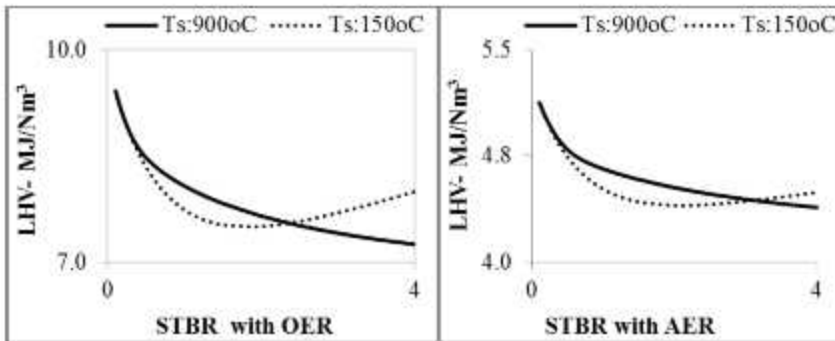
The effect of using steam with air instead of oxygen is discussed in the following part. Similar results to the previous section were obtained; decreasing in hydrogen and other gases fractions were noticed due to increasing of the nitrogen dilution effect which carries out the heat from gasifier. Also, in this case the heating value was lower with similar cold gas efficiency. These results are given in Figures 5.36-5.38.



**Figure 5.36:** The effect of steam to biomass ratio on producer gas at AER of 0.2 and  $T_g = 900^\circ\text{C}$

The high concentration of hydrogen is generated at a high steam temperature and high STBR. All of these results correspond to the finding of Mohandas et al., (2015) [108], Except for a slight difference in a results due to different feedstock characteristics and changes of some operating parameter.

In general, any increasing in STBR caused to reduction in lower heating value of producer gas especially at high steam temperature as a result of reduction in methane concentration and increasing in hydrogen concentration. Figure 5.37 shows the effect of STBR at different value of steam temperature on the lower heating value for producer gas.



**Figure 5.37:** Effect of steam on producer gas LHV at  $O_2/Air$  ER = 0.2 and  $T_g = 900^\circ C$ .

The Cold Gas Efficiency is slightly affected by changes in STBR. At high steam temperature ( $T_s=900^\circ C$ ) with oxygen or air as the gasifying reagent the CGE decreased from (63.62/62.98)% to (61.76/ 61.71)% respectively (up 1.86/1.27 percentage points). The maximum CGE at STBR is (0.3/0.6) when using ( $O_2/Air$ ) with steam at high steam temperature, after that any increasing in STBR causes reduction in CGE. The increasing of

STBR helps in increasing the effluent flow rate and decreasing in heating value. These opposing trends result in little change in the CGE.

Figure 5.38 shows the effect of STBR with  $O_2$ /Air on CGE.

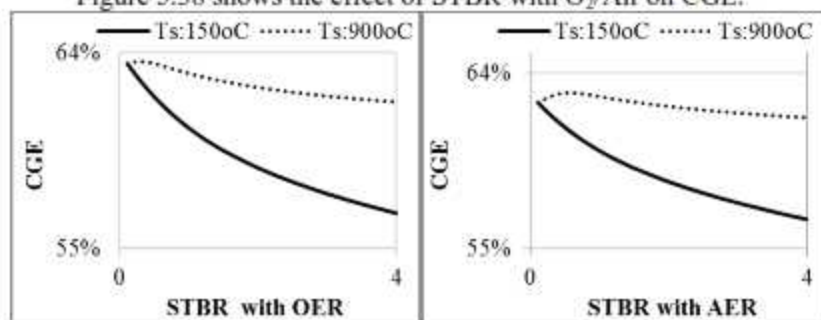


Figure 5.38: The effect of STBR on CGE of producer gas with  $O_2$ /Air ER= 0.2 and  $T_g=900^{\circ}\text{C}$ .

#### 5.4.8 Effect of Hydrogen Injection

Hydrogen injection into the gasifier enhances the properties of producer gas. In case of hydrogen injection, The concentration of Hydrogen in producer gas is more than 96%. Figure 5.39 shows the Effect of Hydrogen injection on producer gas.

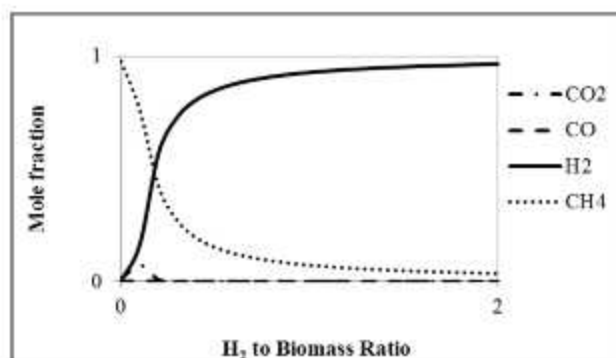
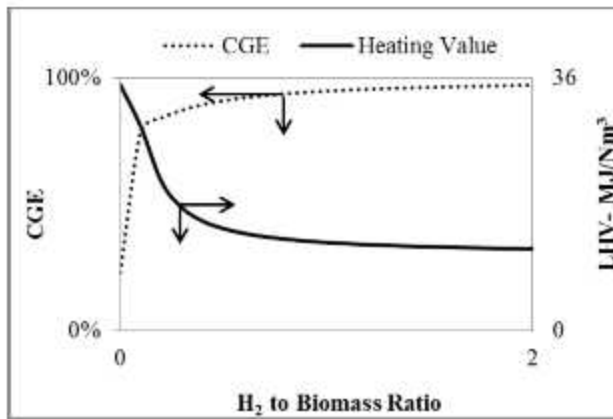


Figure 5.39: Effect of Hydrogen injection on producer gas

The final Heating value of the producer gas is decreased when Hydrogen is injected. This method uses to generate a hydrogen from biomass and to prepare special chemical components. It needs special attention due to the hydrogen properties. Figure 5.40 illustrates the effect of Hydrogen injection on the heating value and cold gas efficiency of the producer gas.



**Figure 5.40:** Effect of Hydrogen injection into gasifier on total energy and lower heating value of the producer gas

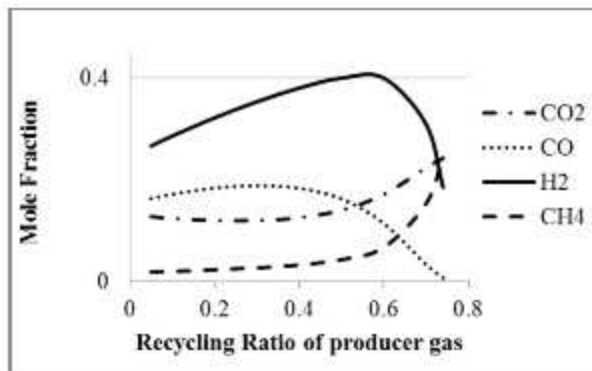
However, the lower heating value of producer gas decreases with the increase of Hydrogen to biomass ratio, because the increment in  $H_2$  is outweighed by the drop in both  $CO$  and  $CH_4$ . The variation in total energy may be explained by the fact that at low Hydrogen to biomass ratio the Lower heating value is high; however, the producer gas flow rate is low.

Up to the researcher knowledge, no similar simulation results of the effect of hydrogen injection on Producer Gas Composition are found in the open literature, therefor our results cannot be compared with others.

### 5.4.9 Effect of Recycling Ratio

Recycling of producer gas affects the composition of final producer gas composition.. Figure 5.41 illustrates the Effect of recycle stream on the composition of producer gas.

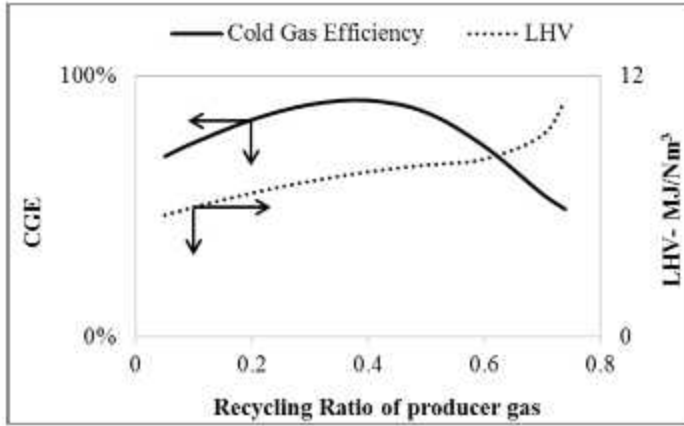
The maximum hydrogen fraction was obtained when a recycling ratio is 56% is used. Recycling ratio above 0.56 causes a rapid decrease in hydrogen concentration, at the same point the methane concentration starts increasing. The increment of hydrogen and methane fractions could be a result of recycling a gas contains steam and hydrogen, which increase the rate of Water-gas-shift reaction ( $CO + H_2O \rightarrow CO_2 + H_2$ ) and hydrogasification reaction ( $C + 2H_2 \rightarrow CH_4$ ). Besides that, the decomposition of tar in the recycled gas may occur. Figure 5.41 shows the Effect of recycle stream on the producer gas.



**Figure 5.41:** Effect of recycle stream on the producer gas composition.

Recycling ratio up to 0.38, increase the lower heating value and cold gas efficiency of the producer gas from 5.126MJ/Nm<sup>3</sup> and 62.5% to 7.487

$\text{MJ}/\text{Nm}^3$  and 90.08%, respectively. Figure 5.42 illustrates the effect of recycling stream on the lower heating value of the producer gas. The optimum value of the recycling ratio, which can be obtained to get a highest energy is 0.38.



**Figure 5.42:** The effect of recycle stream on LHV of the producer gas

Up to the researcher knowledge, no similar simulation results and detailed of the effect of recycling ratio on producer gas Composition are found in the open literature, there for our results cannot be compared with others.

#### 5.4.10 Effect of CO<sub>2</sub> injection.

The injection of CO<sub>2</sub> to gasifier affects the composition of the producer gas. CO<sub>2</sub> addition at relatively low temperature (150°C) has a negative effect on the LHV and the composition of producer gas especially carbon monoxide and hydrogen. On the other side, The high temperature of CO<sub>2</sub> injection enhances the CGE and concentration of carbon monoxide as a result of increased rate of Boudouard endothermic reaction ( $C + CO_2 \rightarrow 2CO$ ). Figure 5.43 shows the effect of CO<sub>2</sub> on the composition of the producer gas at Steam to Biomass Ratio equal to 0.6 and Air Equivalent Ratio equal to 0.2.

Up to the researcher knowledge, no simulation similar results and detailed of effect of CO<sub>2</sub> injection on producer gas composition are found in the open literature, there for our results cannot be compared with others.

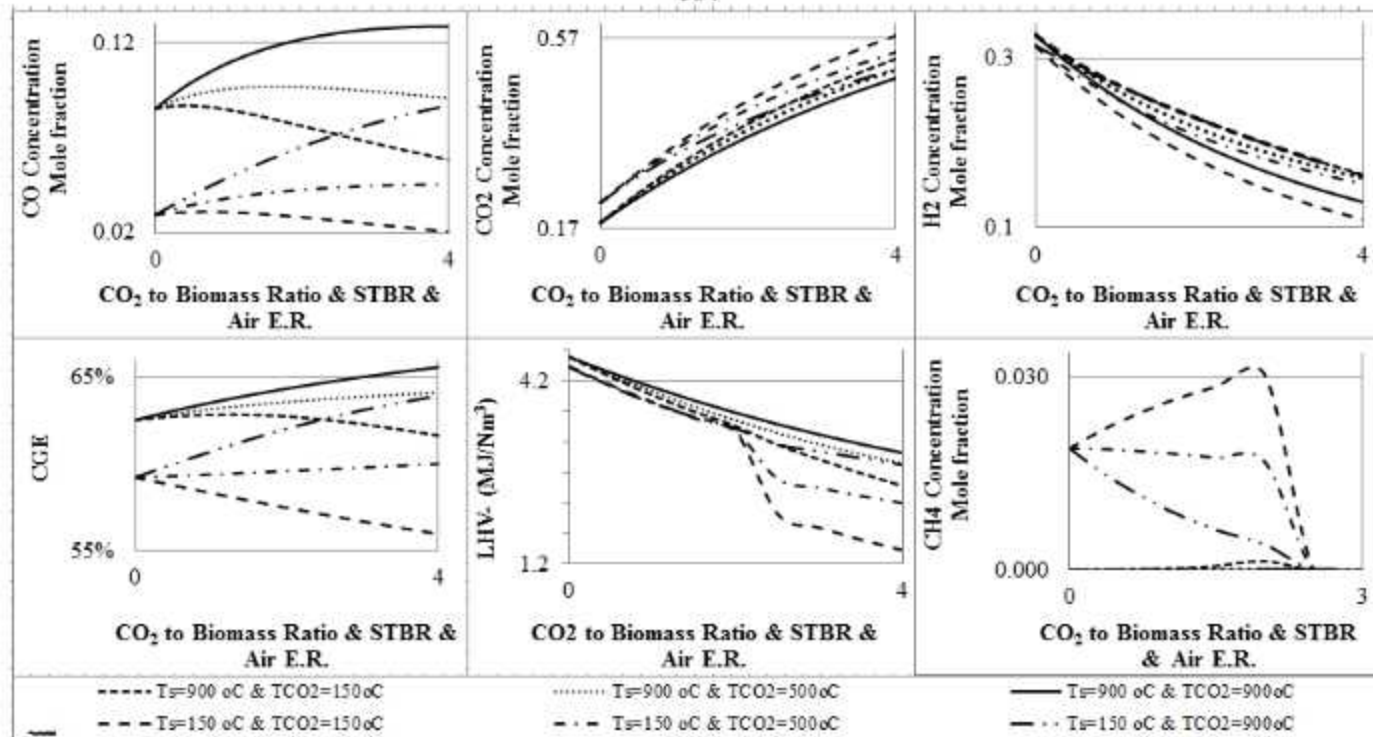


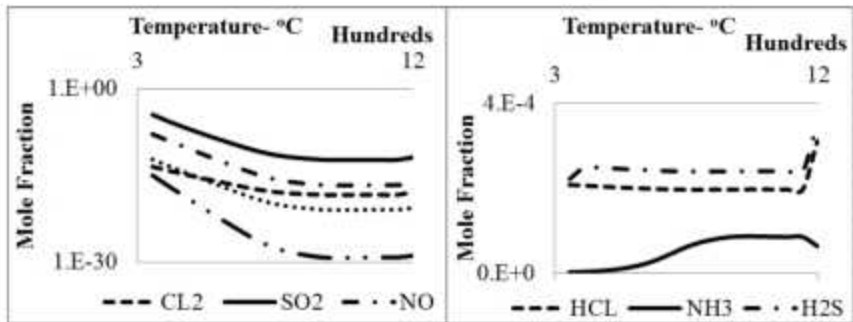
Figure 5.43: Effect of  $\text{CO}_2$  on the composition of the producer gas at STBR is 0.6 and AER is 0.2.

#### 5.4.11 Traces Gas generation in gasification process

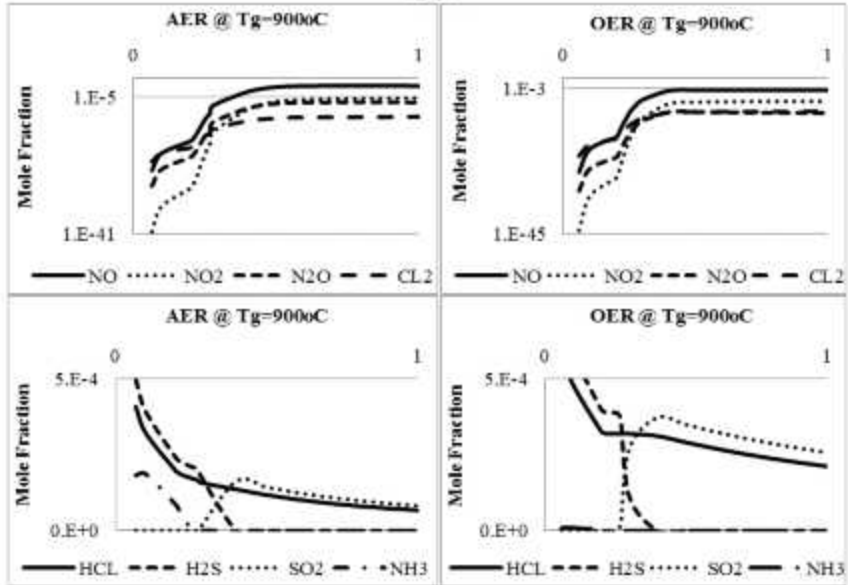
In this part, the effect of temperature and air or oxygen injection on traces gas (especially NO<sub>x</sub> and SO<sub>x</sub>) formation is studied for Jefit. Oxygen and nitrogen or sulfur reacts at high temperatures and stoichiometric ratio. They undergo endothermic reaction produces various oxides of nitrogen and sulfur.

In the presence of limited oxygen, nitrogen reacts with oxygen to form Nitric oxide ( $N_2 + O_2 \rightarrow 2NO$ ). In the presence of excess oxygen, nitrogen and sulfur react with the oxygen to form nitrogen and sulfur dioxide ( $N_2 + 2O_2 \leftrightarrow 2NO_2$ ), ( $S + O_2 \rightarrow SO_2$ ) respectively.

In general, the generation of traces gas (especially NO<sub>x</sub> & SO<sub>x</sub>) during the biomass gasification process is low since the degradation takes place in limited oxygen supply. Figure 5.44 and 5.45 show the fractions of trace gases generated during gasification process.



**Figure 5.44:** The relation between main of Traces Gas generated and temperature during gasification process.



**Figure 5.45:** The relation between main Traces Gas generated and equivalent ratio of oxygen or air during gasification process.

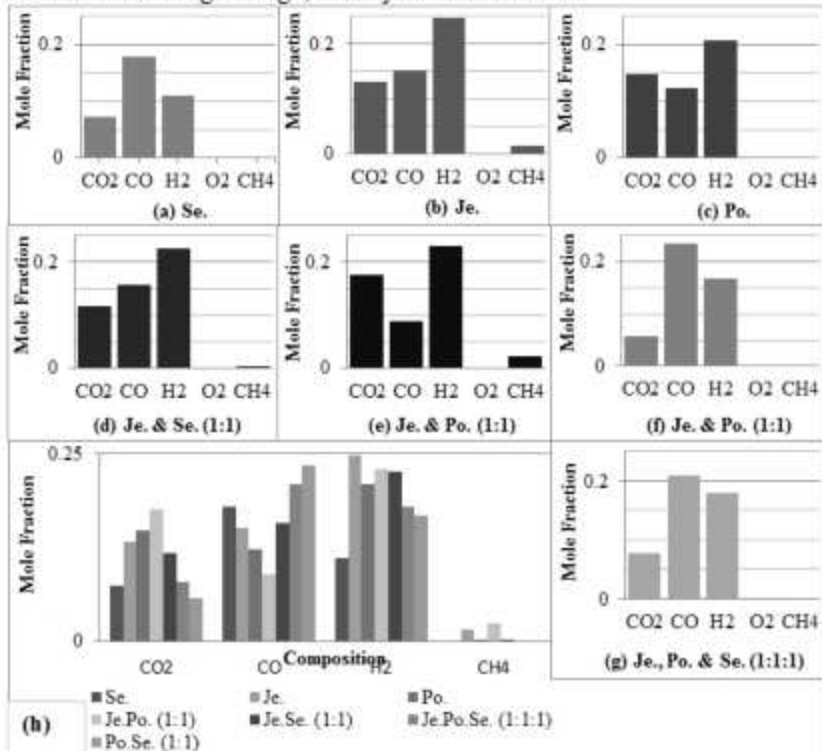
Up to the researcher knowledge, no similar simulations results and of traces gas generation in gasification process are found in the open literature, there for our results cannot be compared with others.

#### 5.4.12 Effect of feedstock

The properties of the producer gas depend on the type of feedstock. The percentage of volatile material and fixed carbon for each feedstock are the main factors that affect the quality of producer gas.

The gasification process is also flexible with respect to feedstock quality and the use of mixed feedstock. The use of mixed feedstock in a gasifier is an attractive option, and it will enhance energy production, due to the production of high-value material from low-value material.

CO<sub>2</sub> concentration in producer gas decreases 1.62 points (7.35-5.73%) and it decreases 9.01 points (14.74-5.73%) comparing with sewage sludge and poultry manure values, respectively. These results are obtained when a mixed feedstock is used (50% Sewage sludge & 50% Poultry manure). Figure 5.46 shows the mole fraction of main gases produced from the gasification of sewage sludge, Poultry manure and left.



**Figure 5.46:** Effect of type of feedstock on producer gas composition.

**Se.:** Sewage Sludge

**Je.:** Jefit

**Po.:** Poultry manure

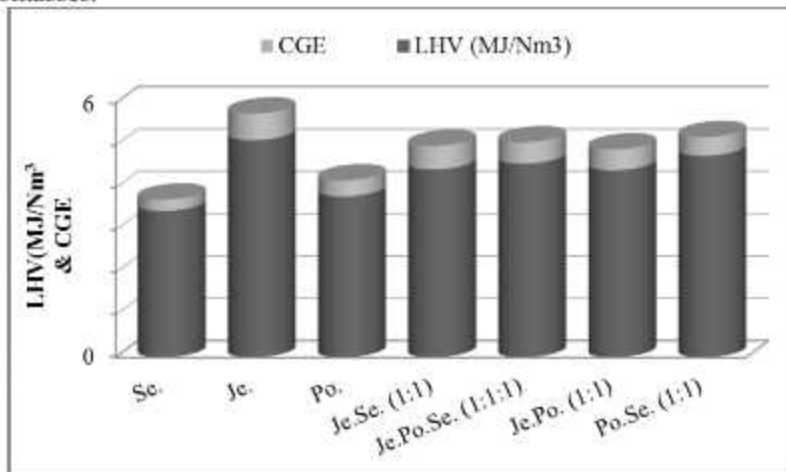
**Je.Se.:** Jefit & Sewage Sludge

**Je.Po.:** Jefit & Poultry manure

**Po.Se.:** Poultry manure & Sewage Sludge

**Je.Po.Se.:** Jefit, Poultry manure & Sewage Sludge

The potential of energy production from Jeft is higher than Poultry manure and sewage sludge is the lowest. The LHV of the producer gas when using a single feedstock in gasification process is 3.455 MJ/Nm<sup>3</sup> for sewage sludge and 3.797 MJ/Nm<sup>3</sup> for poultry manure. It increases 1.303 points (3.455–4.758 MJ/Nm<sup>3</sup>) and 0.961 points (3.797–4.758 MJ/Nm<sup>3</sup>) comparing with sewage sludge and poultry manure values, respectively. These results are obtained when a mixed feedstock is used (50% Sewage sludge & 50% Poultry manure). The comparison of the heating values of the producer gases is given in Figure 5.47 for the aforementioned biomasses.



**Figure 5.47:** Effect of three types of feedstock on the heating value of the producer gas.

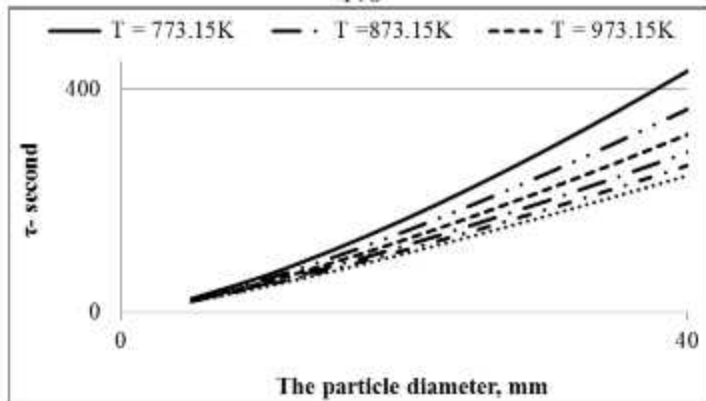
There are many caveats and limitations on the use of poultry manure and sewage sludge as a feedstock into gasifier especially with regard to gaseous emissions, these emissions are toxic. Also there are some negatives such as Ash and heavy metals that cause environmental problems. For

these reasons, the use of Poultry manure and Sewage Sludge in gasification needs more investigations.

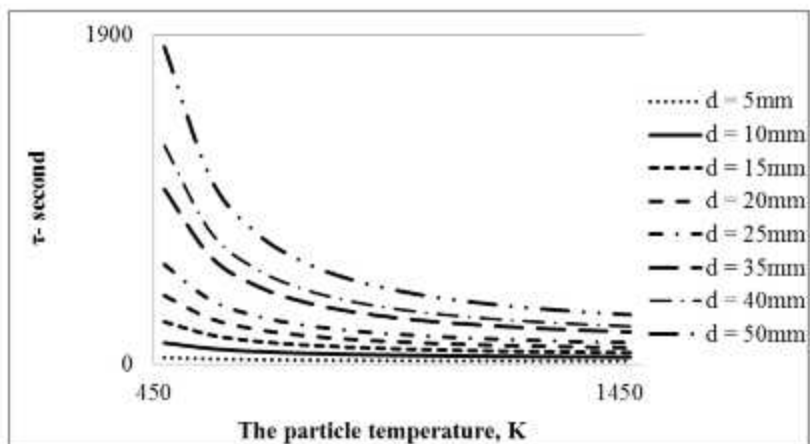
Up to the researcher knowledge, no similar simulation results on the effect of feedstock on producer gas Composition are found in the open literature, there for our results cannot be compared with other.

#### **5.4.13 Effect of Residence Time**

The residence time represents the required time for gasification process to completely convert biomass into combustible gases remaining within the gasifier. It can be affected by many parameters especially gasifier design, the temperature of gasifier and particle size. The residence time can be shorter when gasification temperature increases. Also, reducing particle size reduces residence time which improves the overall gasification process efficiency. Figure 5.48 and 5.49 illustrate a correlation between the residence time and particle size. All of these results correspond to the finding of Shakorfow, (2016) [76].



**Figure 5.48:** The correlation between the residence time and particle size of the gasification process.



**Figure 5.49:** The correlation between the residence time and particle temperature of the gasification process.

## **Chapter Six**

### **Conclusion and recommendation**

## Chapter Six

### Conclusions and recommendations

This study discusses the potential of animal and agricultural residues in WB&GS for biofuel production. A complete collection of all residues is hard since animals holdings are distributed on a wide area. Wherefore the collecting factor of animal and agricultural residues was determined. The actual collectable residues were tabulated based on the population density of animals and agricultural areas. The potential of actual collecting residues for animal residues are 566541ton/year. The maximum collecting factor was found to be about % 95 in Jericho governorates (for sheep), and the collecting factor varies between (76%-95%) for cattle. The poultry is concentrated in a limited number of holding with high population density. The potential of actual collecting residues for poultry is 290952ton/year.

Another type of studied waste is agricultural residues. The potential of agricultural residues that can be collected in WB&GS is 472043ton/year. Other types of residues are industrial residues which are found to be concentrated in a limited area. Most of the industrial residues can be collected, knowing that the amount of waste is 48,925ton/year. The actual potential of municipal household solid waste is found to be 884549ton/year in WB&GS.

In terms of energy production from biomass residues, it was divided into two parts, the first part is more suitable for an anaerobic digester to generate a biogas, and the second one is more suitable for the gasification process to generate a producer gas.

CHP Generator is found to be the best choice to produce the electrical energy from these wastes using anaerobic digester. The potential of electrical energy that can be produced from anaerobic digesters using CHP generator is approximately 192.573GWh<sub>e</sub> yearly in WB&GS and a by-product generate 236.146 GWh<sub>th</sub> of thermal energy.

For heating animal holding facilities the farmers consume LPG. In general, 15% (on average) of animal dung can be enough to produce the necessary biogas needed to heat the animal holding facilities.

Other part for energy production from biomass residues is gasification process. The potential of electrical energy that can be produced using gasification process is approximately 816.7161GWh<sub>e</sub>.

There are several advantages of gasification of MHSW compared to conventional methods for the disposal of MHSW such as the reduction in the quantity of toxic emissions that formed. There are some negatives such as heavy metals that cause environmental problems.

The potential of energy production from gasification is higher than pyrolysis, but dealing with pyrolysis products more easily and less complex than gasification products. Unfortunately, there are many limitations on the use of pyrolysis especially with regard to gaseous emissions.

Biomass residues can be contributed up to 9% of the total electricity consumption in WB&GS if the residues are used properly, while it can be contributed up to 20% when using the MHSW.

In the experimental work section, a homemade downdraft gasifier was designed and constructed successfully and tested. In the operating of

gasifier, Olive cake (Jeft) residue was used. The produced gas was burned successfully in the presence of air at 215°C after two minutes of gasifier start. The flow rate of producer gas at this operating was calculated to be 3.6m<sup>3</sup>/hr at gasifier temperature is 700°C.

Final section helps in analysis and determination the optimal parameters in gasification by estimating the effect of various parameters on the nature of heating value and composition of producer gas using suitable simulation software. These parameters were: Type of feedstock, the temperature of gasifier and agent, an Equivalent ratio of the Air, Oxygen, Steam, CO<sub>2</sub> and Hydrogen injection, residence time. In addition, the effect of recycling portions of the producer gas was also investigated.

For the simulation process, the Jeft, slurry sludge and Poultry Minor feedstocks were taken as the gasified biomass.

From the aforementioned investigations and simulation process, the following conclusions can be drawn:

1. The biomass feedstock needs to be dried before feeding it into the gasifier, because the high moisture in biomass uses the energy, which determines an inefficient gasification process.
2. The effect of Air temperature on producer gas composition was observed. Results of simulation conducted in a high air temperature show the capability of this way of maximizing the gaseous product yield as a result of the high heating rates involved, and the LHV increasing.

3. The gasifier temperature has a pronounced effect on producer gas composition. When the temperature rises, the concentration of main gases increased. According to that the optimum gasifier temperature should be operated around 900°C in order to maximise CGE and produce a high heating value syngas with high H<sub>2</sub> and CO content.
4. The amount of Oxygen or air needs to produce the producer gas must be less than stoichiometric value. The suitable value of Oxygen and Air Equivalent Ratio is 0.2 and the lower heating value at this point was equal to 9.419 MJ/Nm<sup>3</sup> for OER and 5.126MJ/Nm<sup>3</sup> for AER.
5. Using Jelf as feed stock for gasification process has a negative effect on the pressure drop inside the gasifier due to small particle size, thus it is recommended to pelletize (minimum diameter is 5 mm) any biomass before gasification.
6. Air flow rate must be injected into the gasifier and regulated to the necessary steady state value before running the heater; this was helpful in reaching the optimum temperature in shorter time.
7. Air calibration (for air injection into gasifier) is done after gasifier operation to prevent the effect of back pressure on air flow rate.
8. The temperature set point should be around 50°C less than the optimum temperature to avoid heating up the system more than the optimum temperature.
9. Steam injection is used to generate hydrogen at high steam temperature and high STBR or to generate Methane gas at low

temperature ( $T_s=150^\circ\text{C}$ ). The optimum STBR to obtain a high CGE was found to be 2.5 at  $T_s=150^\circ\text{C}$  &  $T_g=900^\circ\text{C}$ .

10. Any increases in STBR up to 1.4 with limited amount of oxygen or air and at low steam temperature, the concentration of Hydrogen and carbon dioxide increase significantly. On contrast, the carbon monoxide fraction decreased dramatically. Any increasing in STBR helps in increasing the effluent flow rate and decreasing in heating value as a result of increasing in hydrogen concentration.
11. Hydrogen injection in gasifier uses to generate a hydrogen from biomass. It enhances the properties of producer gas. The main gas in producer gas is Hydrogen (more than 96%).
12. The recycle stream of producer gas affects on the composition of final producer gas. The highest hydrogen fraction was obtained when a recycling ratio of 56% is used. The optimum value of the recycling ratio, which can be obtained to get a high energy is 0.38. This ratio goes to increasing of hydrogen concentration and LHV (from  $5.126\text{MJ/Nm}^3$  to  $7.487\text{ MJ/Nm}^3$ ).
13. The injection of  $\text{CO}_2$  into gasifier enhances the CGE which increased from 59% (at  $\text{CO}_2$  to Biomass Ratio is 0) to 64% at  $\text{CO}_2$  to Biomass Ratio is 4,  $T_s=150^\circ\text{C}$  &  $T_{\text{CO}_2}=900^\circ\text{C}$ .
14. The generation of traces gas (especially  $\text{NO}_x$  and  $\text{SO}_x$ ) during the biomass gasification process is low since the degradation take place in limited oxygen supply.

15. The properties of the producer gas depend on the type of feedstock. The percentage of volatile material and fixed carbon for each feedstock is the main factors that affect the quality of producer gas. The use of mixed feedstock in a gasifier will enhance energy production. The LHV of the producer gas when using a single feedstock (Sewage sludge) in gasification process is  $3.455\text{MJ/Nm}^3$  and for poultry manure is  $3.797\text{MJ/Nm}^3$ . It is increased to  $4.758\text{MJ/Nm}^3$  when using mixed feedstock (50% Sewage sludge & 50% Poultry manure).

#### **Recommendations:**

The following recommendations may be implemented in future studies:

1. It is recommended to carry out experimental work using the design gasifier in order to support the simulation result in this work. This can include analysis of produced gas.
2. Carry out experimental work to study the effect of producer gas on the gas engine generator.
3. The main parameters of producer gas can be studied using different types of feedstock such as Sewage Sludge, woody agricultural residues ....etc.
4. Study the possibility takes advantage of the gasifier to get rid of some harmful residues (such as Medical Waste) in WB&GS.
5. Study of the effect of catalysts on producer gas generation and composition.

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## **Appendices**

## Appendix A

### A.1. The Energy Balance of WB&GS in Physical Units, 2013

Table A.1: Energy Balance of WB&GS in Physical Units, 2013. [109]

Flows	Energy Products									
	Solar Energy (MWh)	Wood and and Charcoal (Tons)	Olive Cake	Bitumen (Tons)	Oils and Lubricants (Tons)	LPG (Tons)	Kerosene	Gasoline	Diesel	Electricity (MWh)
							(1000 Liters)			
Primary production	1,269,124	329,864	26,000	-	-	-	-	-	-	2,000
Imports	-	10,150	-	17,507	2,110	132,464	1,648	237,545	556,780	4,734,254
Exports	-	-600	-	-	-318	-	-	-	-	-
Stock change	-	-	-	-	-	-	-	-	-	-
Total energy supply	1,269,124	339,414	26,000	17,507	1,792	132,464	1,648	237,545	556,780	4,736,254

(-): Nill. Notes: 1. in all accounts related to charcoal and wood, a unified calorific value was used for each of the charcoal and wood based on the weight of each type in the balance; and the calorific value for both was considered to be 15.75 gigajoules/ton

2. The efficiency of the solar water heater was considered to be 45% and the consumed energy is half of the produces quantity.

3. The technical losses in electricity in the Palestinian Territory are considered to be 10% based on the Palestinian Electricity Distribution Companies.

## Appendix B

### B.1. Comparison of various plant designs

Table B.1: Comparison of various plant designs. [110]

Criteria:	Design:	Floating-drum	Water-jacket	Fixed-dome
Daily gas-output $\text{cm}^3 \text{ gas/m}^3 \text{ Vd}$ (depends on substrate composition; here: cattle dung)		0.3 -0.6	0.3 -0.6	0.2-0.5
Cost elements		metal gasholder, digester	metal gasholder, digester	combined digester/ gasholder, Excavation
Comparison factor		100	120	60-90
Recommended uses		fully developed, reliable familysize system	like floating-drum, plus longer useful life and operational reliability (incl. operation with night soil)	inexpensive equipment, good for agroresidue, extensive building experience required
Suitability for dissemination		+	++	+
++ highly recommended, + recommended with certain reservations o recommended under certain circumstances, - not yet ready for recommendation				

Table B.1: Continue. [110]

	Design:	Floating-drum	Water-jacket	Fixed-dome
<b>Criteria:</b>				
<b>Design principle</b>		continuous-feed, mixed digester	continuous-feed, mixed digester	continuous-feed, mixed digester with slurry store
<b>Main components</b>		masonry digester, floating metal gasholder	masonry digester, floating metal gasholder in sep. water jacket	masonry digester/gasholder with displacement pit
<b>Referred substrates</b>		animal excrements, with or without vegetable waste	animal excrements with or without vegetable waste	animal excrements plus vegetable waste
<b>Anticipated useful life</b>		8-12 years	10-15 years	12-20 years
<b>Digester volume (Vd)</b>		6-100 m <sup>3</sup>	6-100 m <sup>3</sup>	6-20 m <sup>3</sup>

Table B.1: Continue. [110]

	Design:	Floating-drum	Water-jacket	Fixed-dome
<b>Criteria:</b>				
<b>Suitability:</b>	- advantages	easy construction and operation, uniform gas pressure, mature technology	very reliable, easy construction and operation, uniform gas pressure, long useful life, mature technology	low cost of construction, long useful life, well-insulated
	- drawbacks	metal gasholder can rust	expensive	sealing of gasholder, fluctuating gas pressure
	- All biogas plants require careful, regular inspection/monitoring of their gas-containing components -			
<b>Operation and maintenance</b>		simple and easy ; regular painting of metal gas-holder	simple and easy; regular painting of metal gas-holder	easy after careful familiarization

Table B.1: Continue. [110]

<b>Criteria:</b>	<b>Design:</b>	<b>balloon-type</b>	<b>Earth pit</b>	<b>Ferro cement</b>	<b>Horizontal (shallow)</b>
<b>Design principle</b>		continuous-feed, fermentation channel	continuous-feed, mixed digester	continuous-feed, mixed digester	continuous-feed, fermentation channel
<b>Main components</b>		integrated digester/gasholder made of plastic sheeting	earth pit as digester, plastic gasholder	Ferro cement digester, gasholder made of metal or Ferro cement	masonry digester, floating metal gasholder (or separate)
<b>Referred substrates</b>		animal excrements only	animal excrements only	animal excrements, with or without vegetable waste	animal excrements, with or without vegetable waste
<b>Anticipated useful life</b>		2-5 years	2-5 years	6-10 years	8-12 years

Table B.1: Continue. [110]

Criteria:	Design:	balloon-type	Earth pit	Ferro cement	Horizontal (shallow)
Digester volume (Vd)		4-100 m <sup>3</sup>	4-500 m <sup>3</sup>	4-20 m <sup>3</sup>	20- 150 m <sup>3</sup>
Suitability:	- advantages	Prefab. construction, easy operation	extremely inexpensive, easy operation	potentially inexpensive construction, long useful life, easy operation, reliable	shallowness, easy operation
	- drawbacks	in-situ processing and short useful life (2-5 years) of plastic material, low gas pressure	same as with plastic gas-holder, plus soil permeability	Ferro cement construction not yet adequately time-tested	expensive, metal gasholder
		- All biogas plants require careful, regular inspection/monitoring of their gas-containing components -			

Table B.1: Continue. [110]

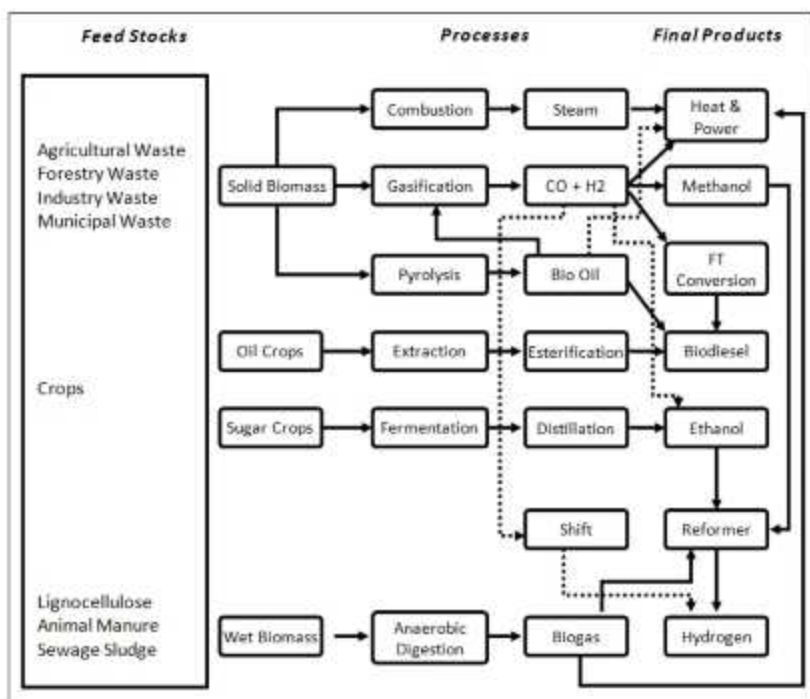
Criteria:	Design	balloon-type	Earth pit	Ferro cement	Horizontal (shallow)
Operation and maintenance		easy ; regular control of gas-pressure weights	easy	simple and easy	simple and easy
Daily gas-output $\text{cm}^3$ gas/ $\text{m}^3$ Vd) (depends on substrate composition; here: cattle dung)		0.3 -0.8	0.1-0.5	0.3 -0.6	0.3 -0.7
Cost elements		plastic sheeting	plastic sheeting	concrete (cement), lathing	digester, metal gasholder
Comparison factor		20- 110	20-40	70-90	90
Recommended uses		mostly for large scale plants and fast solutions	very inexpensive plant	like floating-drum but requires experience in Ferro cement construction	medium-size system where shallowness is required
Suitability for dissemination		0	0	-	0
++ highly recommended, + recommended with certain reservations 0 recommended under certain circumstances, - not yet ready for recommendation					

## Appendix C:

The main advantages and disadvantages of different gasification technologies

**Table C.1: The main advantages and disadvantages of different gasification technologies. [35]**

Type	Advantages	Disadvantages
<b>Downdraft fixed</b>	<ul style="list-style-type: none"> <li>- Simple construction.</li> <li>- High carbon conversion.</li> <li>- Low tar content.</li> <li>- High ash content feedstock possible</li> </ul>	<ul style="list-style-type: none"> <li>- Low moisture fuels required.</li> <li>- Limited scale-up potential.</li> <li>- Poor heat exchange.</li> </ul>
<b>Updraft fixed</b>	<ul style="list-style-type: none"> <li>- Simple and robust construction.</li> <li>- High thermal efficiency.</li> <li>- High carbon conversion.</li> <li>- High ash content feedstock possible</li> </ul>	<ul style="list-style-type: none"> <li>- High tar content.</li> <li>- Limited scale-up potential.</li> <li>- Poor heat exchange</li> </ul>
<b>Bubbling fluidized</b>	<ul style="list-style-type: none"> <li>- Good temperature control.</li> <li>- Good gas-solid contact and mixing.</li> <li>- Moderate tar content.</li> <li>- Easily started and stopped.</li> <li>- High conversion efficiency.</li> <li>- Good scale-up potential.</li> <li>- Broad particle-size distribution</li> </ul>	<ul style="list-style-type: none"> <li>- Operation can be more difficult.</li> <li>- Higher amounts of particulates in the producer gas.</li> <li>- Ash not molten</li> </ul>
<b>Circulating fluidized</b>	<ul style="list-style-type: none"> <li>- High carbon conversion.</li> <li>- Moderate tar content.</li> <li>- High conversion efficiency.</li> <li>- Good scale-up potential.</li> <li>- Broad particle-size distribution</li> </ul>	<ul style="list-style-type: none"> <li>- Operation can be more difficult.</li> <li>- Ash not molten.</li> <li>- More costly</li> </ul>



**Figure C.1:** Feedstock, processes and final products of biomass energy alternatives. [11]

Table C.2: Comparison of different types of gasifiers. [29]


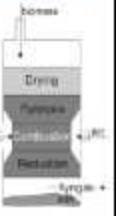
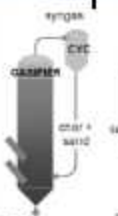
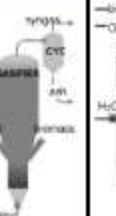

Gasification types	Fixed beds		Fluidized beds		Entrained flow
	Updraft	Downdraft	CFB	BFB	
					
<b>Parameters</b>					
<b>Feedstock characteristics</b>					
Particle size	5-100mm	20-100mm	0-20mm	0-20mm	<100 $\mu$ m
Ash tolerance	Max. 6%	Max. 6%	Max. 25%	Max. 25%	Max. 25%
Moisture content	Max. 60%	Max. 35%	-	-	-
<b>Operational conditions</b>					
Oxygen demand	Low	Low	Moderate	Moderate	High
Steam demand	High	Low	Moderate	Moderate	High
Feed-blast flow	Counter-current	Co-current			
Temperature (°C)	800-1000 (Less uniform)	1000-1200 (Less uniform)	750-950 (more uniform)	900-1000 (more uniform)	1100-1500
Operating pressure	Atmospheric	Atmospheric	Atmospheric or pressurized	Atmospheric or pressurized	Atmospheric or pressurized
Feeding pressure	7-70kPa	35-1050kPa	7-35kPa	7-35kPa	7-350kPa
Gas velocity	Low	Low	Higher than BFB	High	High
$\theta$ time	Long (15-30 min)	Long (15-30 min)	Short (5-50s)	Short (5-50s)	Very short (1-10s)

Table C.2: Continue. [29]

Gasification types	Fixed beds		Fluidized beds		Entrained flow
	Updraft	Downdraft	CFB	BFB	
Product characteristic					
Temperature gas (°C)	425-650	425-650	900-1050	900-1050	1250-1600
HHV ( MJ/Nm <sup>3</sup> )	5-6	4.5-5	~5	~5	-
(air-blown)	Very high	Low	Moderate	Moderate	Almost free
Tar content g/Nm <sup>3</sup>	0.015-0.5	0.015-0.5	<5	<5	
Plant					
Turndown ratio	5-10	3-4	3	3	-
Scale-up gasifier	Limited	Limited	Possible	Possible	Possible
Thermal capacity	<10MW	1kW-10MW	1-100 MW	1-25 MW	-

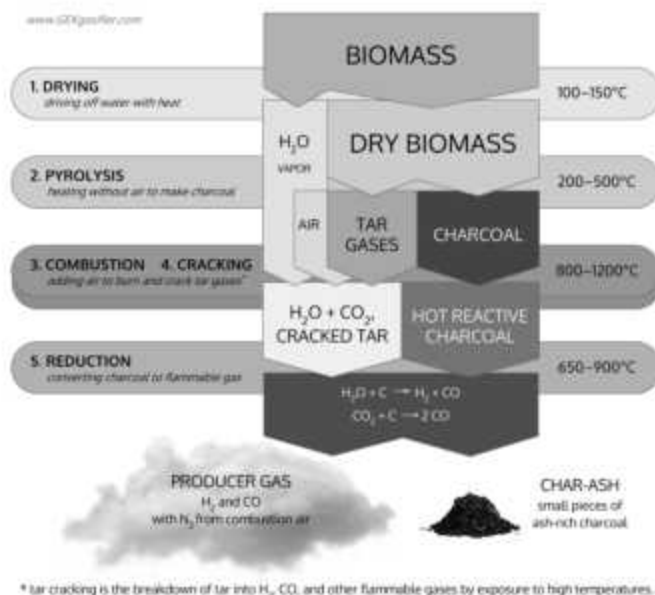
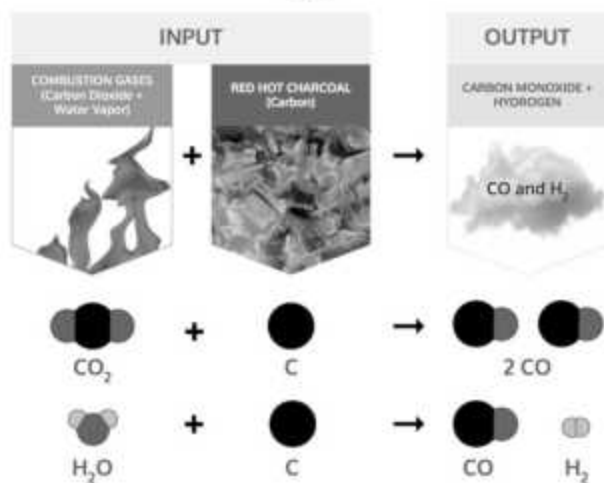






Figure C.2: The Five Processes of Gasification. [38]



**Figure C.3: The Reduction Reactions- The Heart of Gasification. [38]**

**Table C.3: Feedstock requirements for different types of gasifiers. [36]**

Gasifier	Size	Moisture	Composition	Other
EF	 <1mm	15%	Should not change over time. Limited proportion of high-ash agricultural residues	Pre-treatment steps being used
BFB (and Dual with BFB gasifier)	 <50-150mm	10-55%	Can change over time Care needed with some agricultural residues	
CFB (and Dual with CFB gasifier)	 <20mm	5-60%	Can change over time Care needed with some agricultural residues	
Plasma	 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

## Appendix D

### D.1. Percentage of dry matter and biogas production from wastes

**Table D.1: percentage of dry matter and biogas production from wastes. [42]**

Substrate for biogas production	DM [%] ODM in DM [%]	Biogas yield [Nm <sup>3</sup> / kg OTS]
Marc	40–50	0.6–0.7
	80–95	–
Apple mash	2–3	0.5
	95	3–10
<b>Animal waste</b>		
Slaughterhouse waste	–	0.3–0.7
	–	–
Meat and bone meal	8–25	0.8–1.2
	90	–
Blood liquid	18	680
	96	–
Blood meal	90	0.65–0.9
	80	34–62
Rumen content (untreated)	12–16	0.3–0.6
	85–88	62
<b>Greens, gras, cereals, vegetable wastes</b>		
Vegetable wastes	5–20	0.4
	76–90	8–20
Leaves	–	0.6
	82	8–20
Greens (fresh)	12–42	0.4–0.8
	90–97	–
Market wastes	8–20	0.4–0.6
	75–90	30
Leaves of sugar beet/ fodder beet ensilaged	15–18	0.4–0.8
	78–80	–

Table D.1: Continue. [42]

Substrate for biogas production	DM [%] ODM in DM [%]	Biogas yield [Nm <sup>3</sup> / kg OTS]
<b>Greens, gras, cereals, vegetable wastes</b>		
Sugar beet/fodder beet	12–23	0.7
	80–95	–
Fodder beet mash	22–26	0.9
	95	–
Potato haulm	25	0.8–1.0
	79	–
Maize ensilaged	20–40	0.6–0.7
	94–97	–
Sunflower	35	–
	88	–
Sorghum	24–26	–
	93	–
Maize straw	86	0.4–1.0
	72	–
<b>Wastes from the food and fodder industry</b>		
Potato mash, potato pulp, potato peelings	6–18	0.3–0.9
	85–96	3–10
Potato pulp dried, potato shred, potato flakes	88	0.6–0.7
	94–96	–
Mash from fermentations	2–5	0.5–85
	90–95	35–60
Mash from distillations	2–8	0.42
	65–85	14
Mash from fruits	2–3	0.3–0.7
	95	–
Oilseed residuals (pressed)	92	0.9–1.0
	97	–
Pomace	63	–
	53	–
Molasses	77–90	0.3–0.7
	85–95	–
Molasse of lactose	30	0.7
	74	–
Waste from tinned food industry	–	–

Table D.1: Continue. [42]

Substrate for biogas production	DM [%] ODM in DM [%]	Biogas yield [Nm <sup>3</sup> / kg OTS]
<b>Wastes from households and gastronomy</b>		
Leftovers (canteen kitchen)	9–37	0.4–1.0
	75–98	
Sewage sludge (households)	–	0.20–0.75
	–	17
Leftovers, overstored food	14–18	0.2–0.5
	81–97	10–40
Sewage sludge (industry)	–	0.3
	–	20
<b>Wastes from pharmaceutical and other industries</b>		
Vegetable extraction residues	–	0.2–0.75
	–	–
Egg waste	25	0.97–0.98
	92	40–45
Blood plasma	30–40	0.66–1.36
	95–98	43–63
Waste from paper and carton production	–	0.2–0.3
Pulp	13	0.65–0.75
	90	–
<b>Productive livestock husbandry</b>		
Liquid manure from cattle	6–11	0.1–0.8
	68–85	–
Excreta from cattle (fresh)	25–30	0.6–0.8
	80	–
Excreta from chicken	10–29	0.3–0.8
	67–77	–
Excreta from sheep (fresh)	18–25	0.3–0.4
	80–85	–
Excreta from horses (fresh)	28	0.4–0.6
	25	–



Efficiency

## Comparison Example

Source: Official Manufacturers Spec Sheets

 Efficiency  
 Electrical Thermal Total

CAT Gas Engine G3412	375 ekW cont.	30.4 %	38.9 %	69.3 %
CAT Gas Engine G3406	150 ekW cont.	30.1 %	37.2 %	67.3 %
Waukesha Engine VHP360	500 ekW cont.	34.4 %	40.3 %	74.7 %
Jenbacher Engine JMS 312	525 ekW cont.	40.4 %	40.2 %	80.6 %
280E MAN Optimized Gas Engine	280 ekW cont.	37.4 %	46.8 %	84.2 %
380E MAN Optimized Gas Engine	380 ekW cont.	37.2 %	46.0 %	83.2 %
400E MAN Optimized Gas Engine	400 ekW cont.	38.2 %	46.8 %	85.0 %
265E MAN Aгенитор® Nat. Gas	265 ekW cont.	41.2 %	46.4 %	87.6 %
450E MAN Aгенитор® Nat. Gas*	450 ekW cont.*	42.1 %	45.9 %	88.0 %

(\*Available in 2011)



Figure D.1: Higher Efficiency results in significant Economic Advantages for the CHP Plant Operator [66]

## Appendix E

### Potential of biomass in WB&GS

Table E.1: Wastes from the food and fodder industry. [42]

Substrate for biogas production	DM [%] ODM in DM [%]		Biogas yield [Nm <sup>3</sup> / kg OTS]	
	Value	Average	Value	Average
Mash from fermentations	2–5	3.5%	0.5–85	42.75
	90–95	92.5%	35–60	47.5
Mash from distillations	2–8	5.0%	0.42	0.42
	65–85	75.0%	14	14
Mash from fruits	2–3	2.5%	0.3–0.7	0.5
	95	95.0%	–	–
Pomace	63	63.0%	–	0.5
	53	53.0%	–	–
Vegetable wastes	8.3–22.1	0.152	–	–
	38–76	0.57	–	–

جامعة النجاح الوطنية

كلية الدراسات العليا

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اللاهوائي والتغويز: إمكانات الطاقة الحيوية في فلسطين

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وترشيد الاستهلاك بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2017م

ب

دراسة تجريبية ومحاكاة لعمليات تحويل الكتلة الحيوية بالهضم اللاهوائي والتغويز:

إمكانات الطاقة الحيوية في فلسطين

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### الملخص

من المعروف أن الضفة الغربية وقطاع غزة هي منطقة فقيرة جداً من حيث موارد الوقود الأحفوري. وفي الوقت نفسه، لم يتم تعريف بدائل الطاقة بشكل جيد خاصة الأنواع غير التقليدية مثل الكتلة الحيوية. ويمكن تعريف الكتلة الحيوية بأنها المادة المشتقة حديثاً من المصادر الحيوانية، والنباتية التي تستخدم أشعة الشمس لنموها.

تهدف هذه الدراسة إلى تحليل جميع أنواع وكميات الكتلة الحيوية الرئيسية في الضفة الغربية وقطاع غزة والتي يمكن استخدامها كوقود بديل للوقود الأحفوري التقليدي.

في هذا البحث، تم تحديد أنواع وكمية الكتلة الحيوية الموجودة في الضفة الغربية وقطاع غزة من خلال المسح الميداني الشامل. فأجريت دراسة تفصيلية لمعالجة الكتلة الحيوية وتحويلها إلى وقود حيوي بالرجوع لبعض المراجع و الدراسات السابقة. تم حساب كميات الطاقة المحتملة من هذه المخلفات بناءً على طريقة التحويل المناسبة التي ينبغي استخدامها وفقاً لنوع الكتلة الحيوية. على سبيل المثال، على افتراض أن طريقة التحويل المناسبة هي الهضم اللاهوائي، قدرت كمية الطاقة الكهربائية المحتملة من بعض المخلفات الزراعية والصناعية والحيوانية والدواجن بحوالي 192.573 جيجا واط ساعة، وكمية الطاقة الكهربائية من المخلفات الزراعية والنفايات المنزلية البلدية الصلبة بحوالي 816.716 جيجا واط ساعة إذا تم استخدام عملية التغويز.

تم دراسة عملية التغويز بشكل مفصل كطريقة مهمة للتحويل. ولهذا الغرض تم تصميم وبناء جهاز محلي الصنع للتحويل إلى غاز. تم تشغيل جهاز التحويل إلى غاز باستخدام الجفت

كمادة خام ، و تم دراسة تأثير معدل تدفق الهواء المدخل (في جهاز التغويز) وتأثير المواد الخام على تدفق الغاز الناتج.

العوامل الرئيسية التي تؤثر على عملية التغويز مثل درجة حرارة التغويز ، ونسبة الهواء أو الأكسجين المكافئة، ونسبة البخار، ونسبة ثاني أكسيد الكربون للكتلة الحيوية، ونسبة الهيدروجين المحقون، وتأثير نسبة الراجع من (الغاز الناتج) على عملية تغويز الجفت درست باستخدام برنامج خاص للمحاكاة.

درجة الحرارة المثلى لجهاز التغويز وجدت تساوي 900 درجة مئوية و 20% نسبة الهواء أو الأكسجين المكافئة (الهواء أو الاكسجين المحقون) ليعطي أقصى كفاءة للغاز الناتج. ووجد أن النسبة المثلى من البخار للكتلة الحيوية تساوي 2.5 حيث كانت درجة حرارة البخار المثلى 150 درجة مئوية.

وجد أن النسبة المكافئة من البخار والهواء أو الأكسجين تؤثر على تركيز الهيدروجين. يمكن الحصول على تركيز أعلى من الهيدروجين عندما تكون نسبة البخار الى الكتلة الحيوية تساوي 1.4.

عند حقن الهيدروجين في جهاز التغويز وجد أن تركيز الهيدروجين في الغاز الناتج يتجاوز 96%. كمية الغازات الجانبية الناتجة خلال عملية التغويز منخفضة، ويمكن استنتاج أن نسبة المواد المتطايرة والكربون الثابت في المواد الخام هي أهم العوامل التي تؤثر على نوعية الغاز الناتج.