DEMOCRATIC AND POPULAR REPUBLIC OF ALGERIA

Ministry of Higher Education and Scientific Research

University of Tlemcen

PAN AFRICAN UNIVERSITY

Institute for Water and Energy Sciences (Incl. Climate Change)

EVALUATING THE CRITICAL ROLE OF MODERN BIOENERGY IN THE TRANSITION TO LOW CARBON DEVELOPMENT IN AFRICA

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AUGUST, 2016

Master of Science in ***Energy Engineering track***

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DECLARATION

I, Jumare Ismail Abubakar, a student of the Pan African University Institute of Water and Energy Sciences, including Climate Change (PAUWES) hereby declare that this research project is written by me, and has not been presented elsewhere. The information secured from literatures has been duly acknowledged in the texts and a list of references was provided.

Signature

Date

CERTIFICATION (APPROVAL PAGE)

This is to certify that this project work was conducted by Jumare Ismail Abubakar, under the supervision of Dr. Linus Mofor, and it meets the requirements for the award of Master of Science in Energy Engineering of the Pan African University, Institute of Water and Energy Sciences including Climate Change (PAUWES), Tlemcen, Algeria.

Project Supervisor　　　　　　　　　　　　　　　　Date

DEDICATION

This project work is first dedicated to God Almighty, the sustainer of all, secondly to my beloved parents Hajiya Halima Ahmad and Alhaji Abubakar Balarabe Jumare, and lastly to all my respected mentors at PAUWES and beyond.

ACKNOWLEDGEMENT

My sincere gratitude goes first to God Almighty (Subhanahu Wata’alah) for his guidance, protection and assistance in all my academic pursuit. This is because it is necessary in everything to first give thanks to God Almighty as all things work for good to those that cherish the ways of God. Again, more thanks to God whose grace and mercy has brought me this far and shall lead me on while I live in the body of his glory.

Quite a number of people have contributed in one way or the other to the success of this work. However, I must start by acknowledging the effort of my supervisor in person of Dr. Linus Mofor for his valuable times and guidance in making this work to reality. The co-supervisors and the internship focal points must not be left also for giving their valuable times and assistance all in favour of the research work and beyond.

Moreover, I can’t afford to skip my beloved parents: Hajiya Halima Ahmad and Alhaji Abubakar Balarabe Jumare for their moral upbringing and financial supports. May Jannat Al-Firdaus be their final abode, Ameen. Mention must be made of my elder brother: Dr. Jibreel Jumare and my other elder ones for the generous role they played in my life. May God Almighty reward them all abundantly. I would like to acknowledge the effort of our abled Islamic mentor in person of Mal. Aminu Adam Ahmad who sacrifices his valuable times for the sake of Islamic Ummah. May God Almighty be with him for the rest of his life and hereafter. My appreciation is extended to blood uncles, aunts, cousins, nephews, and nieces too many to be enlisted for standing by my side. Indeed, may God Almighty reward them.

In addition, I would want to acknowledge the effort of my abled director, in person of Prof. Abdellatif Zerga, for excellent management of the institution and also for being a devotion father. I wish to acknowledge the tremendous contributions of our distinguished high class professors of the institute most especially Prof. Venkata Ramaya Ancha, Prof. Khellaf Abdallah, Prof. Yao Azoumah, and Dr. Cherif Ould Lahoucine who have offered their outstanding intellects in refining me for use tomorrow. Thanks so much.

Finally, mention must be made of my academic colleagues at PAUWES and beyond that are also too many to be enlisted for being generous and knowledge sharing. I really learnt a lot from them and it’s indeed nice to stay with them all.

ABSTRACT

Clean and improved energy access is of paramount importance to the African continent and the globe at large due to persistent increase in energy demand and the challenge of climate change. This paper is aimed at evaluating the critical role of modern bioenergy in the transition to low carbon development in Africa. This was done by focusing on the three fundamental energy end uses -i.e. power, transport fuel and heat- to see the status quo on the continent and then explore chances of scaling up the energy supply through full and efficient utilization of the biomass potentials for modern bioenergy, while at the same time lowering fossil fuel consumption for environmental and climate benefits. The results obtained with regards to 2014 power assessment showed that for a 50% reduction of fossil fuel uptake and replacement with 90% of the explored total biomass resources for bio-power will ensure electricity increase by 79.9% with a huge emission savings of 171MT; while with regards to 2030 power projection scenario showed an electricity increase by 43.46% with an emission savings of 194MT based on 25% reduction of fossil fuels and replacement with 90% of total biomass resource. With regards to transport fuel, 2013 base case analysis revealed that reduction of fossil based oils by 50% and a replacement with 90% of the total biomass resource for biofuels will ensure a transport fuel energy increase by 64.16% with a huge emission savings of 155MT; whereas on a 2030 projection scenario ensures transport fuel energy increase by 73.65% with a huge emission savings of 139MT. Lastly was the heating assessment which clearly showed that for industrial process heat assessment of 2011, lowering fossil fuel uptake by 50% and a replacement with 80% of the total biomass resource for bio-heat ensures a process heat increase by 224.16% with a huge emission savings of 55MT; whereas 2030 projection scenario ensures a process heat increase by 234.34% with a huge emission savings of 65MT. Hence, this is a clear indication that Africa as a continent is blessed with huge un-utilized Biomass resource of which when policies are set in place for their full utilization in a sustainable way as proposed, will assist tremendously in addressing the energy deficit of the continent.

Key Words:
[Africa, Globe, Biomass, Bio-heat, Bio-power, Biofuels, Modern Bioenergy, Clean Energy, Low Carbon Development, Transport Fuel, Power, Heat, Energy Deficit, Fossil Fuel]

ABSTRAIT

Accès à l'énergie propre et l'amélioration est d'une importance capitale pour le continent africain et le monde en général due à l'augmentation persistante de la demande énergétique et le défi du changement climatique. Ce document vise à évaluer le rôle critique de la bioénergie moderne en transition à faible développement de carbone en Afrique. Cela a été fait en se concentrant sur les trois finales de l'énergie fondamentale utilise i.e. la puissance, le carburant de transport et de la chaleur pour voir le statu quo du continent et les chances explorées par l'augmentation de l'approvisionnement en énergie grâce à l'utilisation complète et efficace des potentiels de la biomasse pour la bioénergie moderne, tandis que dans le même temps en réduisant la consommation de combustibles fossiles pour les avantages environnementaux et climatiques. Les résultats obtenus en ce qui concerne à 2014 l'évaluation de la puissance ont montré que sur 50% de réduction de l'absorption des combustibles fossiles et le remplacement avec 90% des ressources de la biomasse totale explorées pour la bioénergie permettra d'assurer l'augmentation de l'électricité de 79,9% avec d'énormes économies d'émissions de 171MT; tout en ce qui concerne 2030 le scénario de projection de puissance ont montré une augmentation de l'électricité par 43,46% avec une réduction des émissions de 194MT basée sur la réduction de 25% des combustibles fossiles et le remplacement avec 90% des ressources de la biomasse totale. En ce qui concerne le transport du carburant 2013 analyse du cas de base a révélé que la réduction des huiles à base de fossiles de 50% et un remplacement avec 90% des ressources totales de la biomasse pour les biocarburants garantira une augmentation de l'énergie des combustibles de transport par 64,16% avec d'énormes économies d'émissions de 155MT; alors que sur un scénario 2030 de projection assure l'augmentation de l'énergie des combustibles de transport par 73,65% avec d'énormes économies d'émissions de 139MT. Enfin était l'évaluation de chauffage qui a clairement montré que pour l'évaluation de la chaleur industrielle de 2011, réduisant l'absorption des combustibles fossiles par 50 % et un remplacement avec 80% du total des ressources de la biomasse pour la bio-chaleur assure une augmentation de la chaleur de processus par 224.16% avec d'énormes économies d'émission de 55MT; tandis que 2030 le scénario de projection assure une augmentation de la chaleur de processus par 234,34% avec d'énormes économies d'émissions de 65MT. Par conséquent, cela est une indication claire que l'Afrique en tant que continent est doté d'énormes ressources de la biomasse non utilisée qui lorsque les politiques sont mis en place pour leur pleine utilisation de manière durable tel que proposé, aidera énormément dans la lutte contre le déficit énergétique du continent.

Mots clés:
[Afrique, Globe , biomasse , Bio- chaleur , Bio- énergie , biocarburants , moderne bioénergie , l'énergie propre , développement sobre en carbone , Fuel Transport , Énergie , Chaleur, énergie Déficit , Matière combustible]

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List of Acronyms and Abbreviations

ACPC	African Climate Policy Centre
ADP	Adenosine Di-Phosphate
APR	Agro Processed Residue
ASTM	American Society Testing Method
ATP	Adenosine Tri-Phosphate
BAU	Business as Usual
BC	Before Christ
BCP	Biofuels Commercialization Program
BHT	Beta HydroxyToluene
CCS	Carbon Capture and Storage
CFI	Cold Flow Improver
CSP	Concentrating Solar Power
CHP	Combined Heat and Power
DOE	Department of Energy
EJ	Exa Joule
FAEE	Fatty Acid Ethyl Ester
FAME	Fatty Acid Methyl Ester
FAOSTAT	Food and Agricultural Organization Statistics
FTS	Fischer Tropsch Synthesis
GCV	Gross Calorific Value
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GJ	Giga Joule
GP	Glycerate -3- Phosphate
HTL	Hydrothermal Liquefaction

ICS	Improved Cook Stove
IEA	International Energy Agency
IGCCPP	Integrated Gasification Combined Cycle Power Plant
IRENA	International Renewable Energy Agency
JIE	Japan Institute of Energy
kg	Kilo Gram
kWh	Kilo Watt Hour
LCD	Low Carbon Development
LFG	Land Fill Gas
MT	Mega Tons
Mtoe	Mega tons of oil equivalent
MW	Mega Watt
MWh	Mega Watt Hour
NADPH	Nicotinamide Adenine Di-Phosphate
NCB	National Commission Biofuels
NCV	Net Calorific Value
NPBD	National Program for Biofuels Development
NREL	National Renewable Energy Laboratory
PIDA	Program for Infrastructural Development Association
PJ	Peta Joule
PV	Photovoltaic
R&D	Research and Development
RuBP	Ribulose Bi- Phosphate
TAG	Tri-Acyl Glyceride
TBHQ	Tertiary Butyl Hydro Quinone
TFEC	Total Final Energy Consumption
TP	Triose Phosphate
TWh	Tera Watt Hour
UNECA	United Nations Economic Commission for Africa
USCC	United State Composting Council
USDA	United State Department of Agriculture

CHAPTER ONE

1.0: INTRODUCTION

Africa is the second largest continent following Asia in terms of land area, containing roughly 20% of world total land area with 54 countries (Thornley, et al., 2015). Energy is generally a key pre-condition to sustainable development and also a fundamental human right hence, a critical concern. Africa as a continent is endowed with huge energy resources both conventional and renewables. However, the access level is chronically poor. It is quite unfortunate that more than half of the population do not have access to modern energy service (Thornley, et al., 2015). Despite of the high demand huge resource endowment, Africa's share of the global energy consumption is only 3.5% (Ejigu, 2012) which is of mostly traditional biomass, hence, very low. In addition, end use energy efficiency is also considered a challenge from technical perspective due to low technical knowhow as virtually 10-40% of Africa's total primary energy input is lost on transformations (Ejigu, 2012).

Renewable energy resource is of greatest interest of exploitation to the continent of which a more specific focus is on Biomass as the heart of all the renewables. Biomass is quite distinguishable from modern bioenergy, as the latter is energy derived from the former through various technical and highly sophisticated processes such as thermal, mechanical, chemical, and bio-chemical depending on the product targeted. This energy could basically be in form of heat, power or biofuels (liquid and gaseous fuels). Bioenergy is a matured technology and also a renewable energy with the highest potential expansion among all the renewable energy technologies, hence, considered the heart of energy transformation (African Climate Policy Centre (ACPC), 2011).

Production and utilization of modern bioenergy has been considered a fundamental requirement for rural development bearing in mind the clean energy service access from bioenergy industries (Edjekunbene, et al., 2010). It is evident that modern bioenergy development offers a golden opportunity in investment and infrastructural improvement in the agricultural sector. This is with a view of boosting the agricultural production with their further transformation to energy service, and geared towards socio-economic development continentally and globally (Rainer, et al., n.d).

In line with that, it is important to note that unfortunately, most current bioenergy utilization level in Africa especially in sub-Saharan Africa is quite crude, unsustainable and inefficient hence, non-modern. About 65% of the population relies on traditional biomass (wood fuel) for cooking, heating, and lighting purpose mostly in rural areas of the continent (African Climate Policy Centre (ACPC), 2011). Hence, leading to indoor pollution and resulting to increased health challenge and mortality. Forest devastation is also certain due to continuous deforestation with no proper plans or technical knowhow for replanting. This calls for proper action technically, jointly, judiciously, adequately and in a timely manner.

Finally, Biomass resource utilization in transitioning to low carbon development in view of modern bioenergy approach broadly speaks about sustainable development for the continent as virtually all the pillars of sustainable development are embedded i.e. social / societal, economic and environmental sustainability. This is due to the fact that according to Ewah, et al. (2013), Low Carbon Development (LCD) is understood as using low carbon substitute to fossil fuels in view of reducing emissions (pollutants and GHG), and at the same time improving economic growth and development significantly.

1.1: Problem Statement

Most of the African energy resource utilization comes from conventional sources specifically fossil fuels (i.e. oil, natural gas and coal), being the sources available millions of years ago (Alternative Energy Secret, 2013). This is obviously attributed to their huge abundance and efficient nature (Conserve Energy Future, 2016). It must be noted that the continent also relies strongly on traditional biomass for heating, lighting and cooking at domestic level especially in Sub-Saharan Africa. A study conducted by IRENA (2015) shows over 90% of the total renewable energy use during 2013 goes to traditional biomass of which only around 6% goes to modern bioenergy. This is obviously due to the less energy intensiveness and low costs associated with the traditional use of the biomass.

Unfortunately, the traditional biomass utilization is considered crude, inefficient and contributing to huge indoors pollution and respiratory diseases. On the other hand, the fossil fuels are prone to serious negative impacts to the environment owing to their high greenhouse gases (GHG) emission potential and pollution. Furthermore, the instability in price as well as the finite nature associated with the fossil fuels is critical. With continuous increase in African energy demand, and the challenge of climate change, alternative energy sources are therefore of a necessity, of which in this scenario, ***biomass for modern bioenergy*** is considered the best option and the heart of the continent’s energy transformation.

1.2: Aim and Objectives

The aim of this project is to investigate the crucial role of modern bioenergy in the shift to low carbon development in Africa.

The specific objectives are as follows:

1. To investigate the potential of modern bioenergy in tackling energy access challenge in Africa.
2. To broadly evaluate the environmental and climate co-benefits as well as the socio-economic co-benefits of exploiting modern bioenergy in Africa
3. To address the possible challenges associated with exploiting modern bioenergy in Africa

1.3: Justification

This research work is of paramount importance to the continent; owing to the fact that it will greatly reduce over-dependence on traditional biomass and on conventional energy sources specifically fossil fuels; and will assist in boosting energy supply at low costs and in an environmentally friendly manner.

Moreover, looking at the challenge of global warming and it enormous consequences, ascertaining the viability of the scenario targets for global warming temperature (i.e. 2˚C and 1.5˚C) will tremendously requires the input of this research work.

Finally, Africa is a continent with huge population of roughly more than one-eight of the total world's population (Encyclopedia Britannica, 2012), of which poverty is rampant. With this study adopted calls for employment opportunities thereby reducing the level of poverty to a greater extent.

1.4: Scope

This research work was limited to assessing biomass potential in scaling up energy supply of the continent. This was followed by environmental impact assessments by quantifying the GHG (CO_2) emissions savings of exploiting biomass resources fully for the low carbon development target. Moreover, challenges of implementing the research in the continent as a whole with views of addressing them amicably was also covered. Other aspects were possible opportunity areas in favor of the implementation. These were based on reviews in to some business models and material value chain extensions.

CHAPTER TWO

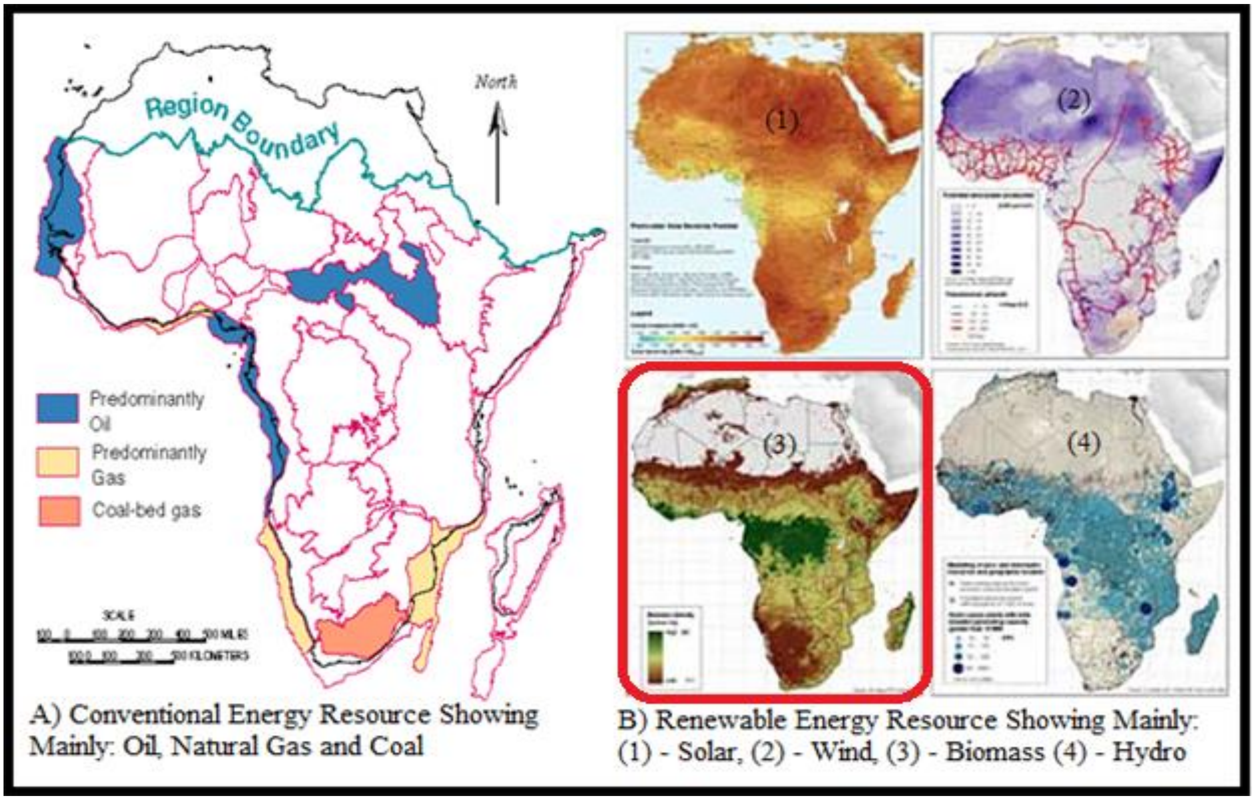
2.0: LITERATURE REVIEW

2.1: African Energy Profile

African energy profile is a critical area of discussion which clearly shows the status quo and predictions for the continent in terms of energy services. The aspects to be covered in this context are principally the energy resources available and the consumption level, the available power systems with the installed capacities and finally the electrification rate of the continent.

2.1.1: African Energy Resources and the Consumption Overview

Africa is endowed with huge energy resource both conventional and renewables (see Fig. 1 & 2) however, low exploitation level arises. Report shows that two-third of the continent is lacking access to modern energy (International Renewable Energy Agency (IEA), 2014). More worrisome are the copious challenges prevailing especially in sub-Saharan Africa. Challenges such as food insecurity, health hazards, environmental degradation, flood, drought etc. are very rampant in the continent. This makes the continent to be underpinning a complex nonlinear development or paradoxical.



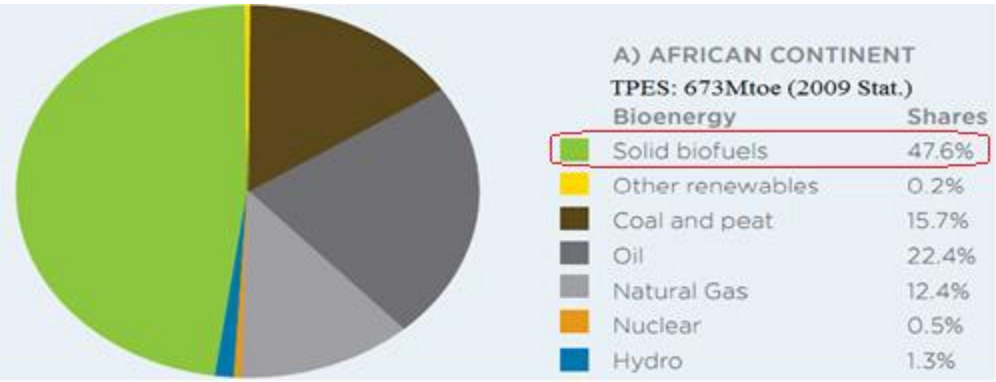
A) Conventional Energy Resource Showing Mainly: Oil, Natural Gas and Coal

B) Renewable Energy Resource Showing Mainly: (1) - Solar, (2) - Wind, (3) - Biomass (4) - Hydro

Source: Azoumah, 2014

Figure 1: Huge Energy Resource (Conventional and Renewable) Potentials in Africa

Moreover, the total primary energy supply for the continent is reported to be 673Mtoe (28177PJ) as at 2009 (International Renewable Energy Agency (IRENA), 2013). Looking at the energy mix, 47.6% of this total primary energy goes to Biomass as being the highest, which is followed by Oil having a share of 22.4%, and the least being other renewables with a share of 0.2% as follows:



Source: International Renewable Energy Agency (IRENA), 2013

Figure 2: Primary Energy Mix for Africa in 2009

In line with the above information, energy consumption of the continent as an indicator of development and living standard has been estimated at 3.8% of world's total during 1980, with a slight increase to 5% in 2000, 5.2% in 2007 and is finally reported to have increased to 5.3% in 2015 (Ejigu, 2012). This represents the lowest energy share and the lowest per capita use of modern energy in comparison with other regions of the world per capita energy consumption. With all these drawbacks, the continent is still considered a major exporter of fossil fuel specifically crude oil and natural gas participated by some countries like Nigeria, Angola and so on. Below shows the final energy consumption level for different energy sources from 1990 to the most recent, of which Biomass resource relatively outweighs to a larger extent:

Table 1: Total Final Energy Resource Consumption in Africa (Mtoe)

Energy Resource	1990	2007	2015	Share (%)
				2007
Biomass and Waste	169	261	287	56
Electricity	21	43	57	9
Other renewables	0	0	0	0
Oil	70	112	122	24
Gas	9	29	34	6
Coal	19	17	16	4
Heat	0	0	0	0
Total	289	463	616	100

Source: IEA, 2009

Added to the above information is the energy consumption specifically to transportation sector also from 1990 to the most recent which is 2015 (see table 2). It clearly shows a high oil consumption of all the applied energy resources relatively, leaving biofuels far behind.

Table 2: African Energy Consumption in Transportation (Mtoe)

Transport Fuel Resource	1990	2007	2015	Share (%)
				2007
Oil	36	66	72	97
Biofuel	0	0	1	0
Other fuels	1	2	2	3
Total	37	68	75	100

Source: IEA, 2009

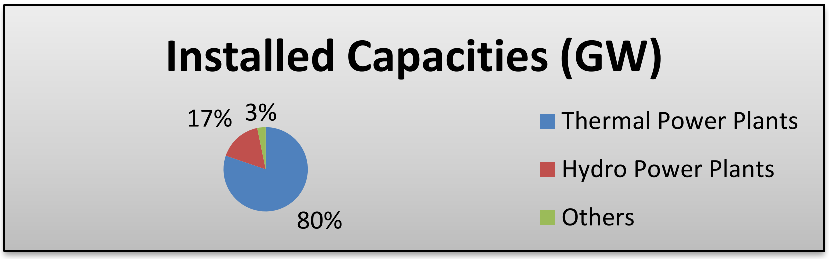
2.1.2: African Power System

Moving on to the power system of the continent, the power generation can be focused either on national or regional basis. The associated power plants could be categorized as small, medium and large scale depending on their specified installed capacities. Majorly, small scale power plants capacity range is 50-99MW, medium scale power plants capacity range is 100-499MW, and finally large scale power plants range is 500MW and above (PIDA, 2011). In general, the power plants are classified in 3 groups viz: thermal which incorporates steam generation (e.g. Biomass, Nuclear, Solar Thermal, Geothermal, Coal, Oil and Gas plants), hydro and others. The last category comprises of the remaining power plants such as solar PV, wind, HPS, Solar Tide Wave etc. Thermal power plants are recorded to have the highest installed capacity of all the 3 power plants in the continent (see Table 3 and Fig. 3). This is due to the overdependence of the continent on fossil fuel for power generation.

Table 3: Existing Installed Generation Capacities in Africa during 2014

Plant Type	Installed Capacities (GW)
Thermal Power Plant	116.9
Hydro Power Plant	24.1
Others	4.7

Source: www.tsp-data-portal.org



Source: www.tsp-data-portal.org

Figure 3: Installed Capacity Mix for the Continent

Finally, In comparison with other continents, Africa has the lowest installed capacity per capital as well as installed capacity per unit of GDP (see Table 4). This is a clear picture of the low investment level in the continent in terms of power generation facilities and low R&D.

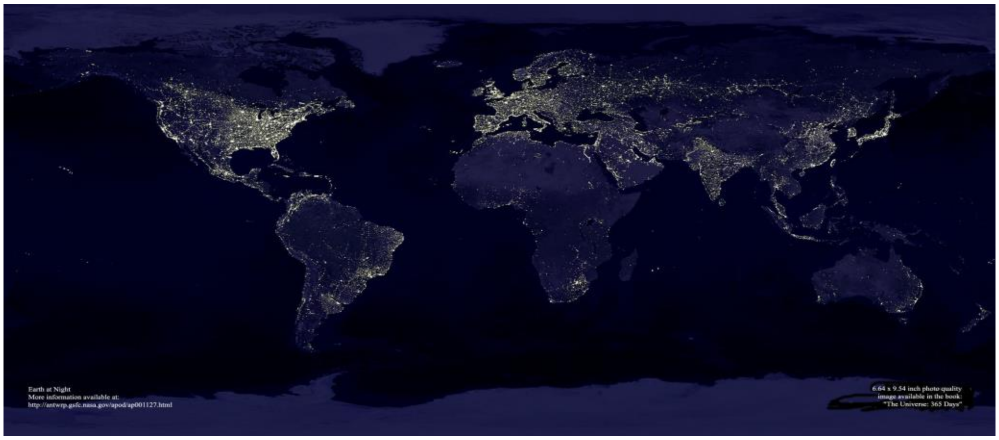
Table 4: Installed Generation Capacity per Capita and per Unit of GDP for Africa and Rest of the World during 2011

Continent	Capacity per Capita (MW/Million Population)	Capacity per Unit of GDP (MW / Billions of GDP)
Africa	123	106
Asia	3600	121
Latin America	515	60
Eastern Europe / Cent. Asia	1078	144

Source: Program for Infrastructural Development Association (PIDA), 2011.

2.1.3: Electrification Rate (Access to Electricity in Africa): - The Status Quo

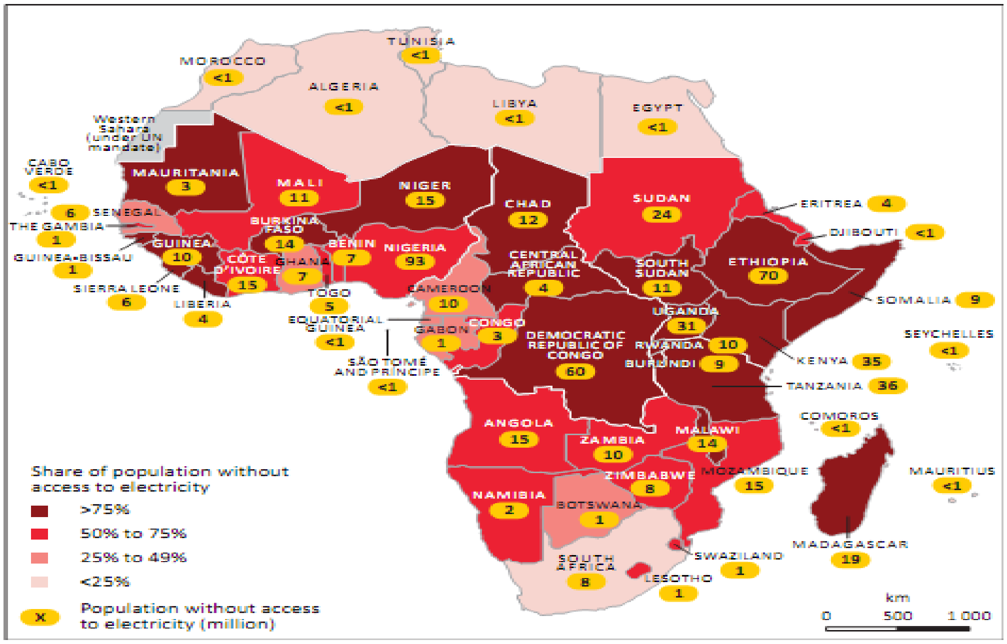
Electricity access is a major challenge in the continent especially in sub-Saharan Africa i.e. the major part of Africa comprising eastern, western, central and southern. Currently, 587 million of Africans are lacking access to electricity of which majority comes from rural areas (Ejigu, 2012). In about 37 countries in sub-Sahara, the number of people lacking access to electricity has increased drastically since 2000 (International Energy Agency (IEA), 2014). However, on a slight positive note, about 145 million people gained access to electricity since 2000, obviously led by Nigeria, South Africa, Ethiopia, Mozambique, Ghana, and Cameroun (International Energy Agency (IEA), 2014). In overall, the electricity access in sub-Saharan Africa rose only slightly from 23% in 2000 to 32% in 2012, which is still poor (International Energy Agency (IEA), 2014). Below shows a pictorial view of Africa at night showing how dark it is especially the sub-Saharan part and in comparison with other regions of the world.



Source: Ejigu, 2012

Figure 4: Electricity Access Map: Africa and the Rest Part of the World

On extension, the below figure shows by countries, percentage of people without access to electricity looking at the whole continent (Northern Africa and sub-Saharan Africa):



Source: International Energy Agency (IEA), 2014

Figure 5: African Electricity Access Challenge by Countries in 2012

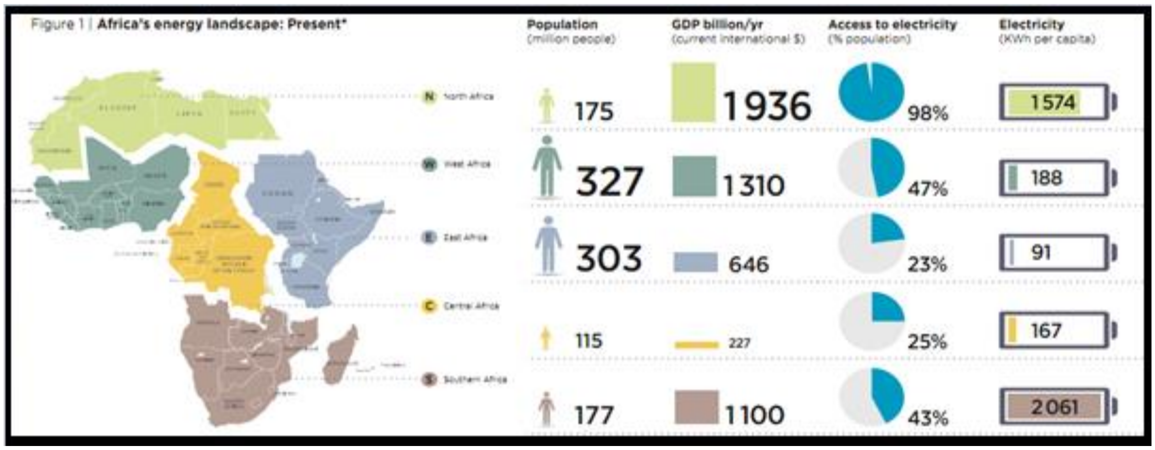
Moreover, on regional basis, it is obvious that the electrification rate for Northern Africa is perfect, almost 100%. The only region of concern is the sub-Sahara, which is where proper attention needs to be paid upon. Below clearly shows the electrification statistics for the two regions as at 2009:

Table 5: African Electricity Access by Region at 2009

Region	Population Without Electricity (Million)	Electrification Rate (%)	Urban Electrification Rate (%)	Rural Electrification Rate (%)
Northern Africa	2	99	99.6	98.4
Sub-Saharan Africa	585	39.5	58.3	14.3
Total (Africa)	587	41.9	68.9	25

Source: Ejigu, 2012

In an expanded view to the above table, the break down for the sub-Saharan region in to Eastern, Western, Central and Southern regions to include also the Northern Africa follows on a 2013 statistics for all components except for electricity access which refers to statistics of 2012 all from International Renewable Energy Agency (IRENA) (2015) as shown below:



Source: International Renewable Energy Agency (IRENA), 2015

Figure 6: Detailed Electrification Rate for the five African Regions

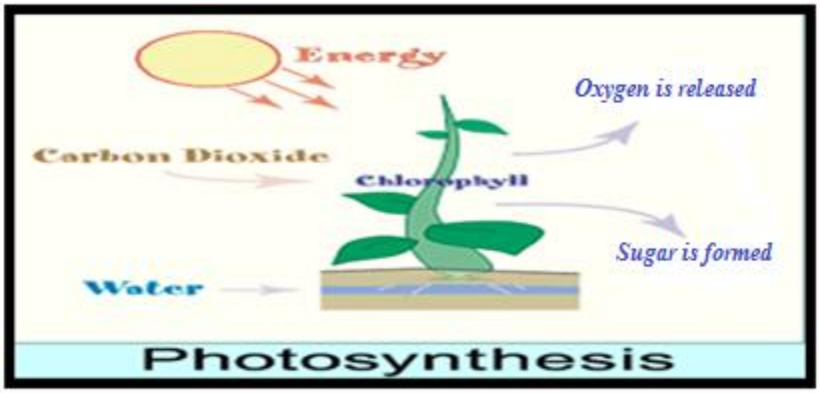
2.2: Biomass Resource from Genesis: - Overview in to Photosynthesis

In order to avoid putting the cart before the horse, it is appropriate to begin detailed Biomass discussion from genesis, which is the very growth phase of it, i.e. ***photosynthesis***. The word photosynthesis is the process by which green plants harness sunlight, air, water, and carbon dioxide for the synthesis of chemical energy in the form of sugar. This is as shown from the basic general reaction below:

$$CO_2 + H_2O + Light + Chlorophyll \rightarrow CH_2O + O_2 \;----------- (1)$$

The building block (CH_2O) is the chemical energy, which is the primary organic product formed from the in-organic molecules (i.e. CO_2 and H_2O) obvious from the reaction. The light is the energy obtained from sun in the visible electromagnetic spectrum which is transmitted in photons. This is the reason why solar energy is considered the origin of biomass energy. A study shows that the upper limit of the capture efficiency of incident solar irradiation in biomass growth is within 8-15% (Klass, 1990). The chlorophyll is found in the leaves of the plant and is the organelle responsible for green coloration of the plant, of which here (see equation 1) is considered the catalyst of the reaction. The oxygen liberated from the reaction as a waste product comes exclusively from the water in accordance with radioactive tracer experiment (Klass, 1990).

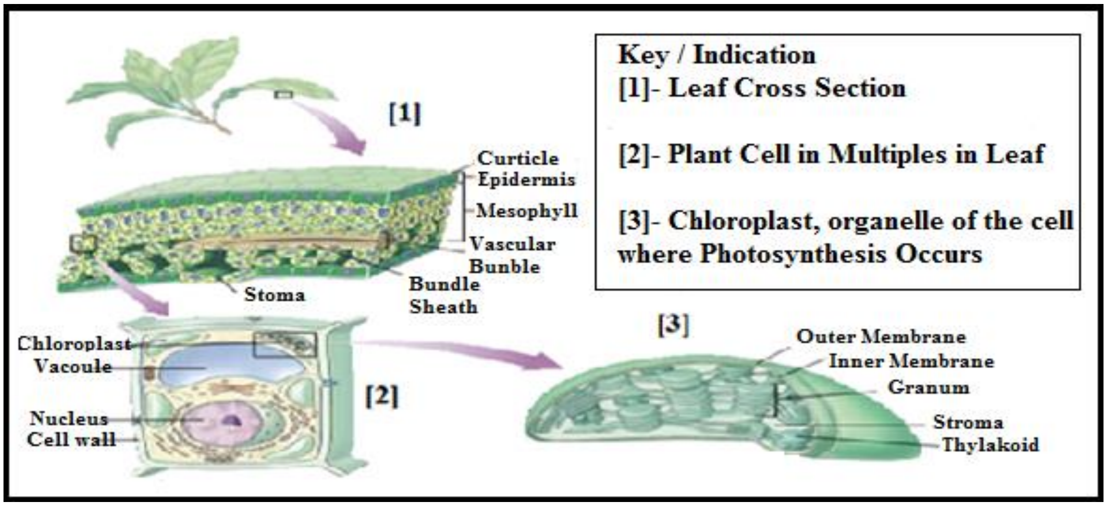
The above general reaction (equation 1) for photosynthesis can be depicted from the below figure, showing all the necessary components explained above for the chemical energy manufacturing in the form of sugar.



Source: http://www.factmonster.com/ipka/A0775714.html

Figure 7: Basic Description of Photosynthesis

It is important to note that photosynthesis occurs in the leaves of the plant because of their large surface area to absorb the sun light. More specifically, the chloroplast, as one of the organelles of the plant cell, is the exact target organ for the successful prevalence of the photosynthesis process. Below shows clearly the microscopic view of the plant leaf itself, the cell of the leaf and the chloroplast as the major organelle of concern.



Source: http://www.mhhe.com/raven6e

Figure 8: Microscopic View of Leaf, Cell and the Chloroplast

2.2.1: Factors Affecting the Rate of Photosynthesis

The success or failure of photosynthesis rate is strongly dependent on some critical environmental factors or parameters as outlined below:

1. Light Intensity: Photosynthesis cannot prevail in the absence of light however; there is a certain limit for the light intensity. Hence, the rate of photosynthesis increases with increase in light intensity and then levels up on attaining maximum

2. Temperature: Photosynthesis usually occurs at a temperature range of 10-40deg.C for most plants however, the optimal range is 25-30deg.C (Finishing Edge Association, n.d).
3. CO_2 Concentration: Rate of photosynthesis increase with increase in CO_2 concentration until a certain point is reached where the rate leveling occurs. It is noted that a stage in CO_2 concentration where no net absorption of CO_2 by illuminated plant organ exists is called CO_2 compensation point or threshold point; and it is usually less than 10ppm for C_4 plants and 50-100ppm for C_3 plants (Finishing Edge Association, n.d).
4. Oxygen Concentration: Increase in oxygen concentration decreases the rate of photosynthesis by Warburg effect. This is due to the fact that high oxygen compensates for oxidation of RuBP to phosphoglycolic acid hence, lowering CO_2 fixation (Finishing Edge Association, n.d).

2.2.2: Phases / Stages of Photosynthesis

Photosynthesis occurs in two fundamental stages or phases of which one is closely dependent on light and is called Photochemical Reaction Stage, widely known as Light Reaction Stage or sometimes referred to as Hill Reaction Stage. The other is light independent and is called Biochemical Reaction Stage, widely known as Dark Reaction Stage or Calvin Cycle or sometimes referred to as Blackmann's Reaction Stage. Below is their detailed breakthrough:

1. Light Reaction Stage: This reaction stage occurs during the day, usually in the presence of sunlight. It basically involves two steps i.e. firstly, is photolysis of water and secondly, the formation of Adenosine Tri-Phosphate (ATP) and Nicotinamide Adenine Di-Phosphate (NADP). The ATP and NADPH are collectively known as Assimilatory Power (Finishing Edge Association, n.d). In the photolysis step, sunlight absorbed helps in splitting the water molecule in to hydrogen and oxygen in the presence of ions such as Cl^-, Mn^{2+}, and Ca^{2+}. The reaction is as shown below:

$$2H_2O \xrightarrow{Cl^-, Mn^{2+}, Ca^{2+}} O_2 + 4H^+ + 4e^- ------(2)$$

The electrons liberated and the protons together results in the formation of the chemical energy or the Assimilatory Power namely ATP and NADPH as follows:

$$NADP^+ + 4e^- + 2H^+ \longrightarrow 2NADPH ----(3)\ Reduction$$

$$ADP + 2H^+ \longrightarrow 2ATP ------- (4)\ Reduction$$

The assimilatory power produced above is the fuels necessary for the dark reactions stage coming up next.

2. Dark Reaction Stage: This reaction stage occurs at night and hence doesn't require sunlight energy. In this stage, the assimilatory power from light reaction stage is used in fixation and

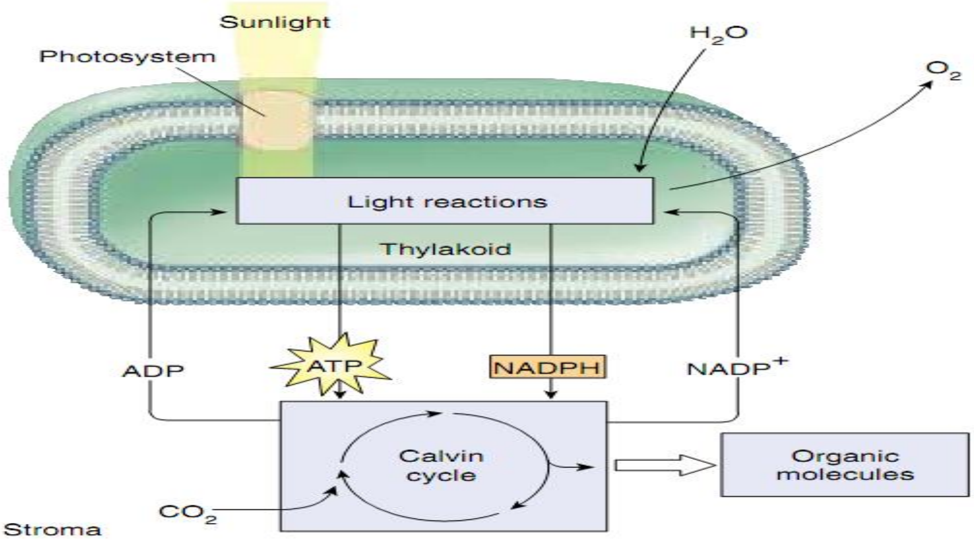
reduction of CO_2 to glucose. In a clearer view, the CO_2 first react with Ribulose Bi-Phosphate (RuBP) to form Glycerate-3- Phosphate (GP) of which the ATP and NADPH then comes in for reduction of GP to Triose Phosphate (TP) and finally the formation of Glucose (IHW, 2006). The reaction mechanism is as shown below:

$$CO_2 + RuBP \xrightarrow{\qquad\qquad} GP - - - - - - - - - - - - - - - (5)$$

$$GP + NADPH + ATP + H_2O \xrightarrow{\qquad\qquad} TP - - - - - - - - - (6)$$

$$TP \xrightarrow{\qquad\qquad} Glucose + ADP + NADP^{+} - - - - - - - - - (7)$$

It is however noted that the by-product of the above reaction (see equation 7) i.e. Adenosine Di-Phosphate (ADP) and $NADP^+$ are the ingredients back in cycle for the formation of the Assimilatory Power in first stage continuously. Below is a scheme showing the overall reaction stages in the continuous cyclic pattern:



Source: http://www.mhhe.com/raven6e

Figure 9: Overall Photosynthesis Reaction Scheme

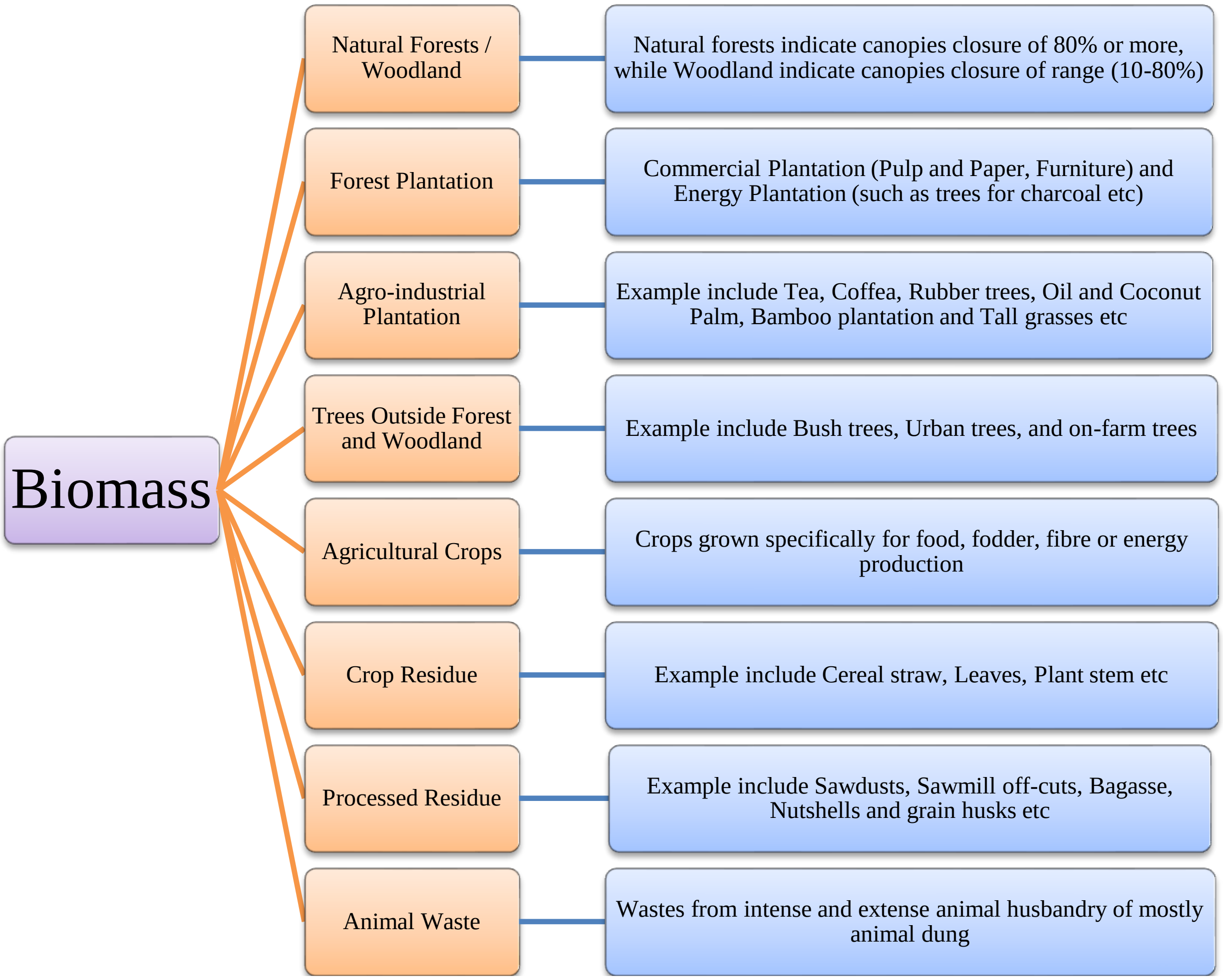
2.3: Biomass General Concept

Biomass in a general sense does not only refer to plant resource, therefore, it should not be misconceived. According to Japan Institute of Energy (2008), the word Biomass is a compound word comprising of 'Bio + Mass', which simply refers to resource procured from plant or animal or the wastes arising from them that has accumulated in certain amount. Based on this, Biomass is considered a renewable energy resource because of its quick replenishing nature however; for it to be hundred percent qualified as a renewable resource, the rate of energy extraction from it has to be considerably lower than the rate of its replenishment.

In addition to what has been said, it is important to clarify further that both biomass and fossil fuels (i.e. oil, gas and coal) are derived from organic matter. The key difference is the age being that fossil fuels are essentially fossilized biomass originating from organic matter created millions of years ago which had been stored underground as sediments (US Department of Energy (DOE); US Department of Agriculture (USDA), 2005). With this insight, we can term fossil fuels as non-recoverable or non-replaceable fuels and hence, totally non-renewable in nature.

2.3.1: Classification of Biomass Resource

Biomass resource could be classified in many ways depending on context. Thus there is no any established standard way for its classification. However, from general perspective, it could be classified in to either woody or non-woody. According to Biomass Users' Network, et al. (2007), biomass resource was broadly classified in to eight fundamental groups, which is summarized as follows:



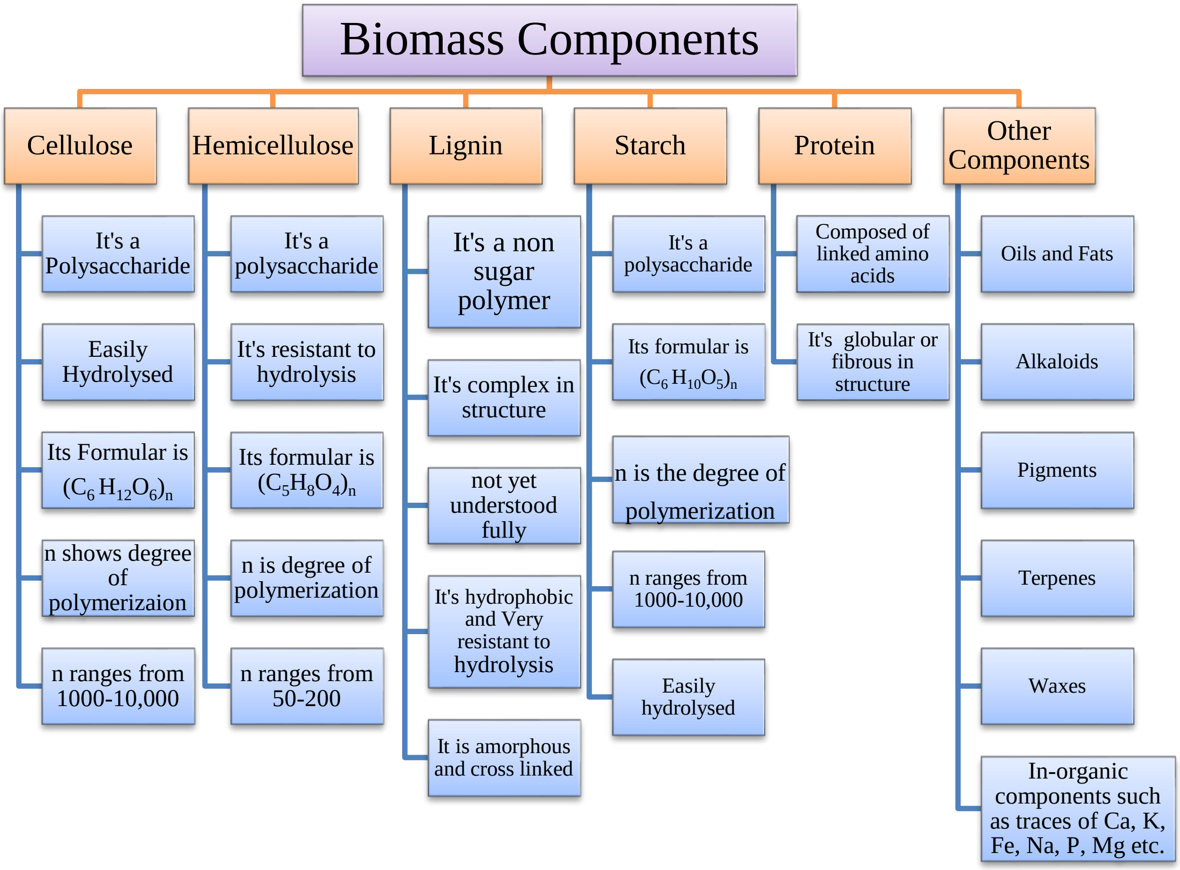
Natural Forests / Woodland	Natural forests indicate canopies closure of 80% or more, while Woodland indicate canopies closure of range (10-80%)
Forest Plantation	Commercial Plantation (Pulp and Paper, Furniture) and Energy Plantation (such as trees for charcoal etc)
Agro-industrial Plantation	Example include Tea, Coffea, Rubber trees, Oil and Coconut Palm, Bamboo plantation and Tall grasses etc
Trees Outside Forest and Woodland	Example include Bush trees, Urban trees, and on-farm trees
Agricultural Crops	Crops grown specifically for food, fodder, fibre or energy production
Crop Residue	Example include Cereal straw, Leaves, Plant stem etc
Processed Residue	Example include Sawdusts, Sawmill off-cuts, Bagasse, Nutshells and grain husks etc
Animal Waste	Wastes from intense and extense animal husbandry of mostly animal dung

Source: Biomass Users' Network, et al., 2007

Figure 10: Biomass Resource Broad Classification with Specifications

2.3.2: Biomass Typical Components

Biomass composition is diverse, depending on the feedstock sample concerned. Primarily, the organic components of biomass are cellulose, hemicellulose, lignin, starch, protein, and fats and oils, while the in-organic components are traces of elements such as Ca, Na, Mg, P, Fe, Si, Al, K etc. Cellulose, lignin and hemicellulose are obtained from lignocellulose's feedstock such as woody materials and herbaceous plants, while grains materials composed principally of starch and finally, livestock waste material composed mainly of protein (Japan Institute of Energy, 2008). Below shows summarized biomass feedstock basic or typical components.



Source: Japan Institute of Energy, 2008

Figure 11: Biomass Typical Components with Specifications

2.3.3: Overview in to Analytical Properties of Some Biomass Feed stocks

The Analytical Properties considered here are the Moisture content, Calorific Value (Heating Value), Proximate Analysis, and Ultimate Analysis.

2.3.3.1: Moisture Content and Calorific Value

Moisture Content and Calorific Value have closed correlation in the sense that feed stocks with low moisture content have a much higher calorific value and hence, more efficient on combustion and vice versa.

Dwelling more on the heating value, for fuels containing hydrogen, two calorific values could be distinguished, i.e. Gross Calorific Value (High Heating Value) and Net Calorific Value (Low Heating Value). Gross Calorific Value and Net Calorific Value are all thought of as heat evolved by combusting a unit of fuel, of which in the former, the water produced is condensed to liquid by subsequent cooling of combustion products to the initial temperature of the fuel whereas; in the latter, the water vapor is left to escape without being condensed and cooled (Masshead, 2014).

Table 6: Calorific Value and Moisture Content for Some Selected Biomass Feed stocks

Category	Biomass	Moisture (Wt. %)	High Heating Value (MJ/kg)
Waste	Cattle Dung	20-70	13.4
	Activated Bio solids	90-97	18.3
	Refuse Derived Fuel	15-30	12.7
	Saw dust	15-60	20.5
Herbaceous Plant	Sweet Sorghum	20-70	17.6
	Switch Grass	30-70	18.0
Aquatic Plant	Giant Brown Kelp	85-97	10.3
	Water Hyacinth	85-97	16.0
Woody Plant	Eucalyptus	30-60	18.7
	Hybrid Poplar	30-60	19.5
	Sycamore	30-60	21.0
Derivative	Paper	3-13	17.6
	Pine Bark	5-30	20.1
	Rice Straw	5-15	15.2

Source: Japan Institute of Energy (JIE), 2008.

2.3.3.2: Ultimate Analysis

Ultimate analysis is a quantitative analysis aimed at determining the elemental composition of a given feedstock. It is usually expressed in percentages of the total solid feedstock under study. Below is a table showing the elemental components analysis for some selected feed stocks, majorly carbon, hydrogen, oxygen, nitrogen, sulphur, chlorine, and finally ash content.

Table 7: Ultimate Analysis for Some Selected Biomass Feed stocks

S/N	Biomass	C, %	H, %	O, %	N, %	S, %	Cl, %	Ash, %
1.	Barely straw	39.32	5.27	43.81	1.25	-	-	9.75
2.	Coconut husk	46.80	6.90	43.30	-	-	-	3.00
3.	Cotton stalk	51.01	4.30	40.51	0.98	-	-	3.20
4.	Cotton stalks	47.05	5.35	40.77	0.65	0.21	0.08	5.89
5.	Grape pruning	47.35	5.77	43.32	0.77	0.01	0.07	2.71
6.	Groundnut shell	41.05	4.80	48.15	1.57	-	-	4.43
7.	Maize cob	46.18	4.97	46.30	0.60	-	-	1.83
8.	Maize stalk	41.08	4.22	50.72	0.62	-	-	3.36
9.	Paddy straw	36.83	4.99	38.39	0.59	-	-	19.20
10.	Rice hulls	40.96	4.30	35.86	0.40	0.02	0.12	18.34
11.	Rise husk	37.85	5.00	40.37	0.30	-	-	16.48
12.	Sorghum (stalk)	42.00	4.80	46.50	2.10	-	-	4.60
13.	Sugarcane	48.25	6.00	39.16	0.19	-	-	6.40
14.	Sunflower	31.30	0.50	62.00	1.20	-	-	5.00
15.	Wheat straw	43.20	5.00	39.40	0.61	0.11	0.28	11.40
16.	Wood	35.00	4.30	59.30	0.40	-	-	1.00

Source: Anonym. (2015)

2.3.3.3: Proximate Analysis

Proximate Analysis is sometimes called Weende Analysis, and it is a quantitative analysis for micro nutrients of feed stocks. This analysis consists of parametric determinations such as analysis for crude ash, crude protein, crude fiber, ether extracts etc. In this respect, the analysis shown below was solely on volatile matters, fixed carbon content and ash content.

Table 8: Proximate Analysis of Some Selected Biomass Feed stocks

S/N	Biomass	Fuel Composition on Dry Basis		
		Volatile Matter (dry wt. %)	Fixed Carbon (dry wt.%)	Ash (dry wt.%)
1.	Sugar Cane Bagasse	75.1	16.9	8.0
2.	Bamboo Dust	75.3	15.6	9.1
3.	Cotton Stalks	70.9	22.4	6.7
4.	Coconut Dust	70.3	26.8	2.9
5.	Corn Cobs	80.2	16.2	3.6
6.	Groundnut Shell	68.1	25.0	6.9
7.	Jute Sticks	75.3	19.0	5.7
8.	Mustard Shell	70.1	14.5	15.4
9.	Pigeon Pea	83.5	14.8	1.8
10.	Pine Needles	72.4	26.1	1.5

11.	Prickly Acacia	77.0	22.3	0.6
12.	Prickly Sesban Stalk	80.3	17.0	2.7
13.	Rice Husk	60.6	19.9	19.5
14.	Sal Seed Leaves	60.0	20.2	19.7
15.	Sal Seed Husk	62.5	28.1	9.4
16.	Eucalyptus	82.44	16.14	1.42

Source: Klass, 1990.

2.4: Historical Role of Biomass Resource in Africa

Biomass in Africa has a prolonged historical role being that it is the most dominant energy resource the continent is richly endowed with, and the resource with the highest consumption level but unfortunately on traditional or rudimentary basis. Since around 500BC, Egypt being the country with one of the oldest civilizations in Africa do make use of biomass specifically fire wood and wood charcoal for cooking and heat generation all in a crude manner (Keyhani, 2016). Recently, in sub-Saharan Africa, especially in rural areas, majority of the population strongly depends on the traditional biomass of mostly fire wood for cooking, heating and lighting purposes (Rainer, et al., n.d).

Below shows broadly a quantitative analysis of the biomass role in the continent most recently during the year 2000. The analysis shows clearly the biomass energy portion as percentages of the total energy.

Table 9: Historical Role Played by Biomass in Africa during the year 2000

Resources with Role Played	Indicated Value
Primary Energy	20.7 EJ/Yr.
Biomass % of it	49.5%
Final Energy	15.4 EJ/Yr.
Biomass % of it	59.6%
Estimated Modern Bioenergy	1.0 EJ/Yr.
Its % of Primary Energy	4.7%
Modern Bioenergy input to Electricity, Heat and CHP	0 EJ/Yr.
Its % of the Total Sector Input	0%
Biomass to Industry	0.98 EJ/Yr.
Its % of Total Sector Input	30.3%
Biomass input to Transportation	0 EJ/Yr.
Its % of Total Sector Input	0%

Source: Kartha, et al., 2005

On a final note, biomass production with crude or non-modernized utilization has a strong potential of causing a variety of negative impacts including overuse of natural resources leading to deforestation and desertification, and health challenges due to Indoor Air Pollution (IAP) which could disproportionately affect women and children in the poor areas of such practice (Rainer, et al., n.d).

2.5: Land Availability and Biomass Production Potential in Africa

Land availability has been emphasized by majority of stakeholders in Agricultural sector not to be the limiting factor for bioenergy development in Africa (Rainer, et al., n.d). This is due to the fact that the continent is blessed with abundant and un-utilized lands especially in sub-Saharan regions.

Below is a table showing the available and suitable lands for deployment of bioenergy crops in sub-Saharan Africa for some selected countries of the region, which clearly shows South Africa being the leading in terms of land availability and Senegal being the least.

Table 10: Suitable and Available Areas for Bio-energy Crops in Sub-Sahara's Arid and Semi-Arid Regions

Country	Total Area km^2	Arid and Semi-Arid km^2	Arid and Semi-Arid km^2 (Available and Suitable)	Arid and Semi-Arid % (Available and Suitable)
Senegal	196013	111147	15783	14
Burkina Faso	272339	149973	22756	15
Mali	1252281	637960	192438	30
Kenya	581871	457960	379698	82
Tanzania	941375	316738	147252	46
Zambia	75192	160281	67383	42
Botswana	587337	581605	291860	51
South Africa	1221361	901345	722874	79

Source: Rainer, et al., n.d

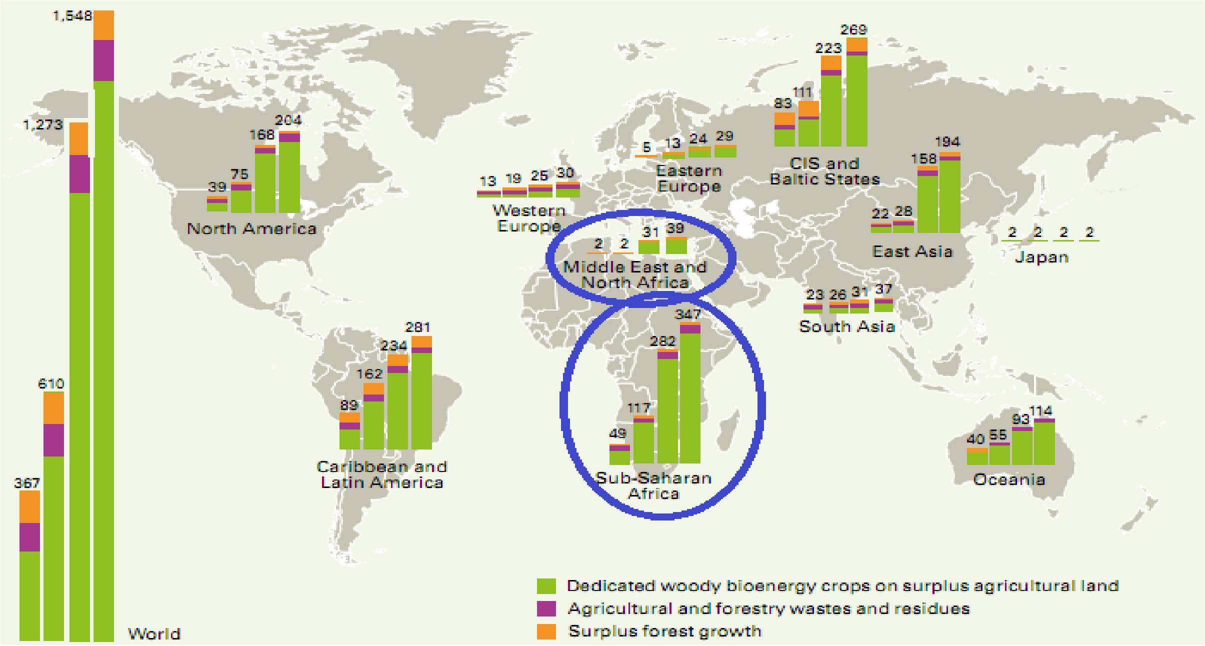
Based on this, it will be of more benefits to dwell more in to the world statistics in general which also includes the African continent. In line with 2050 scenario, below (see table 11) clearly shows the land size estimates with the potential level for biomass production based on four (4) categorization Viz: low, mid (low), mid (high), and high with the appropriate specification for each.

Table 11: Estimated Land Size of the World that could be used for Biomass in Future (2050 Scenario) with their Estimated Production Potential (inclusive of Africa as our major concern)

Band	Estimated Land Use (Million Hectares)	Band Estimate (EJ/Yr.)
Low	390 – abandoned crop land	0 – 100
Mid (Low)	140 – 450 – from new plantations	100 – 300
Mid (High)	1,300 – abandoned agricultural land	300 – 600
High	4,000 – converted from pasture	> 600

Source: Davis, et al., 2014

Lastly, four (4) different scenarios for year 2050 are modelled below (see figure 12), and they represent the following assumptions (from left to right for each region described): Rainfed mixed agricultural systems (including pastoral practice) with modern technological production, irrigated mixed agricultural systems with modern technological production, irrigated cropland with only confined livestock and modern technological production, and irrigated cropland with only confined livestock and newly innovated technology for crop production. All scenarios assume high feed conversion efficiency. Owing to the fact that our major concern is Africa, the two (2) regions (i.e. Sub-Saharan and Northern) where circled in heavy blue, of which clearly shows that the fourth modelled scenario gives the highest estimate of the biomass production potential of all, mainly 39EJ and 347EJ for Northern (including Middle East) and Sub-Saharan part respectively.



Source: Davis, et al., 2014

Figure 12: Biomass Production Potential for North Africa, Sub-Saharan Africa and the Rest of the World in EJ/Yr. (2050 Scenario) Based on 4 Modelled Cases

2.6: Biomass Conversion Techniques to Modern Bioenergy

Fundamentally, bioenergy being the energy derived from biomass could be classified in to bio heat, bio power, and lastly biofuels (i.e. liquid and gaseous fuels). The liquid biofuels are majorly biodiesel and bioethanol while the gaseous biofuel is principally biogas. The conversion techniques for the generation of the above forms of energy generally follow three broad conventions viz: thermochemical, chemical and biochemical as the case may be. The detailed breakdown of all these techniques and the energy derivatives shall be followed.

2.6.1: Thermochemical Conversion Techniques

Thermochemical conversion is a technique that involves the use of heat, pressure chemicals and catalysts of mostly acids, metal or both to exothermically breakdown biomass feedstock in to bio products or in to intermediate materials that can be used to obtain bio products by other means (National Renewable Energy Laboratory (NREL), 2012). Thermochemical conversion options for biomass feed stocks are majorly combustion, pyrolysis and hydrothermal liquefaction, and lastly gasification and Fischer Tropsch synthesis coupled with heat, power and biofuels generation as the case may be.

2.6.1.1: Combustion Technique for Biomass

Combustion of biomass is an exothermic chemical reaction, which is a complete and rapid oxidation of biomass that is accompanied by large heat and luminescence generation (Stephen, 2000). Combustion usually requires high temperature for ignition, high turbulence for proper mixing of the fuel and an oxidant which could be air or oxygen, and finally time to complete the oxidation reaction (Siirala, 2013).

The combustion methods for biomass are conventionally grate (fixed and moving), fluidized bed, rotary hearth furnace and burner as shown below with their sub types and features:

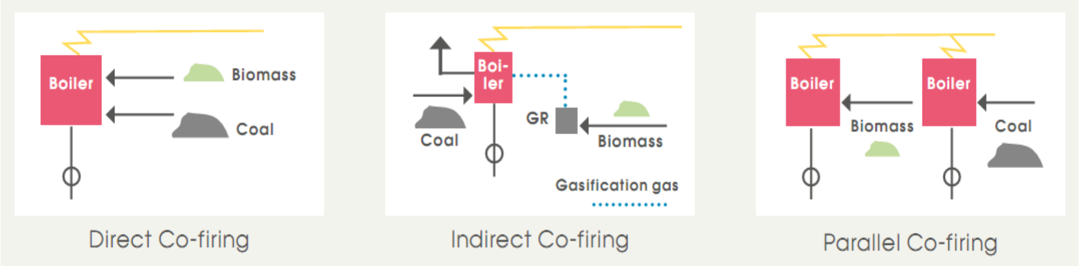
Table 12: Combustion Methods for Biomass with their General Features

Combustion Methods	Sub Types	General Features
Fixed Bed	Horizontal / Inclined Grate Water Cooling Grate Dumping Grate	Grate is level or sloping, used in small scale biomass furnace for biomass with low ash content
Moving Bed	Forward Moving Reverse Moving Step Grate and Louver Grate	Grate has combustion zone and after combustion zone, grate load is large, can be applied to wide range of fuels
Fluidized Bed	Bubbling Fluidized Bed Circulation Fluidized Bed	Uses sand for bed material, high pressure combustion air is required, and suitable for high moisture fuel.
Rotary Hearth Furnace	Kiln Furnace	Used for combustion of high moisture fuel, restricted to fuel size on fluidity
Burner	Nil	Applicable to both solid and liquid fuels

Source: Japan Institute of Energy (JIE), 2008

Moreover, biomass combustion can prevail in a co-fired system i.e. letting the fuel to be a mixture of biomass with fossil fuels mostly coal. The advantage of biomass co-firing over pure biomass combustion is the increase in the thermal and electric efficiency (International Renewable Energy Agency (IRENA), 2012) however, with adverse effects from environmental perspective due to emissions increase.

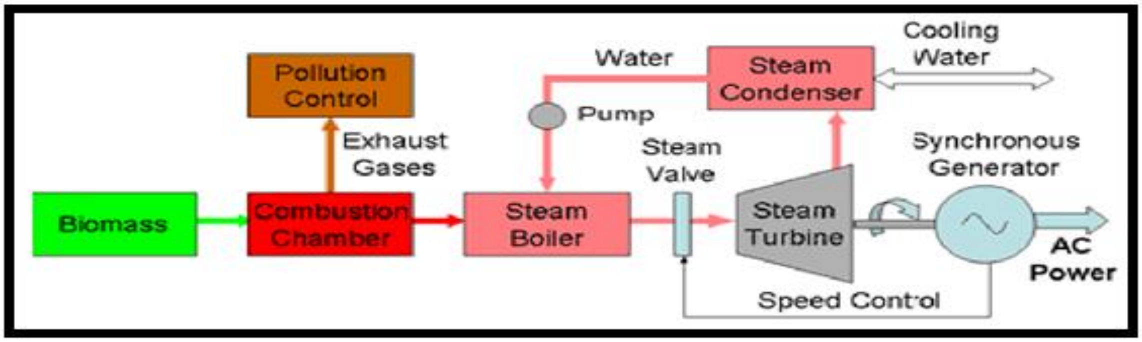
With regards to the co-firing system, three (3) possible techniques are possible viz: direct co-firing where biomass and coal are fed in to the chamber with shared or separate burner, indirect co-firing where solid biomass is first converted to fuel gas before mixing with coal in the chamber, and lastly parallel co-firing where the chambers are separate (International Renewable Energy Agency (IRENA), 2012). These are as shown below:



Source: International Renewable Energy Agency (IRENA), 2012

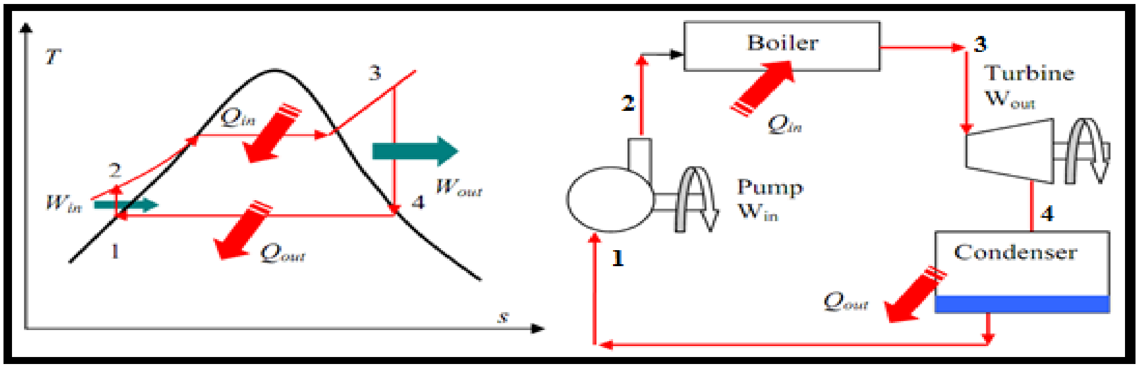
Figure 13: Different Biomass Co-Firing Configurations

Lastly, looking at the whole system i.e. the biomass combustion system, a thermodynamic cycle mainly Rankine cycle is the convention for heat and power generation in which biomass burning in a high pressure boiler generate steam at high pressure necessary to drive a turbine for electricity generation. The net power efficiency of the whole cycle is usually around 23-25% (IRENA, 2012). Below depicts clearly the combustion system with the accompanied cycle:



Source: Azoumah, 2014

Figure 14: Biomass Combustion System for power generation



Source: Bahrami, n.d

Figure 15: Accompanied Thermodynamic (Rankine) Cycle for the System

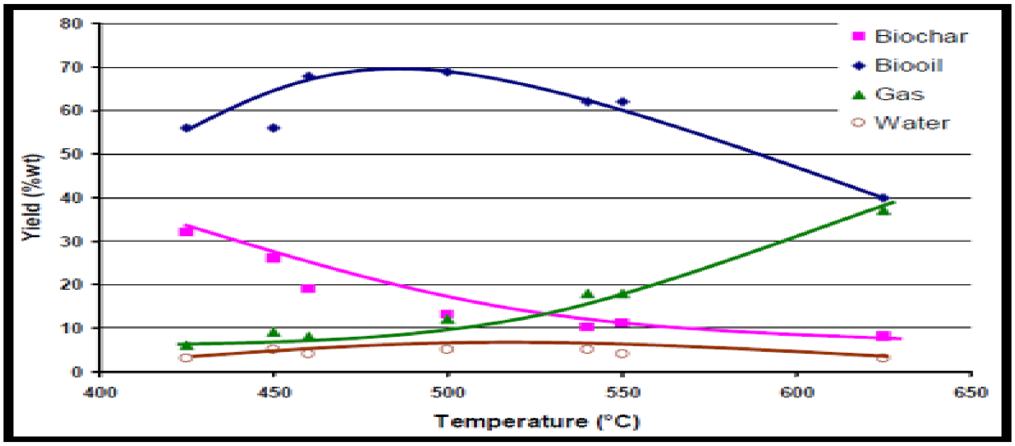
2.6.1.2: Pyrolysis and Hydrothermal Liquefaction (HTL) Techniques for Biomass

Pyrolysis of biomass refers to biomass thermal decomposition in complete absence of oxygen or air to produce liquid bio-oil, mixture of gases and a solid residue called bio-char or charcoal while releasing energy in form of heat (ACPC, 2011). The pyrolysis bio-oil is what is further used as fuel for heat and power generation in a Rankine cycle although, even the bio-char could be used but not as efficient as the bio-oil and not yet on commercialization. Pyrolysis temperature is usually low compared to that of combustion and gasification and it is usually around 450-600deg.C (IRENA, 2012). Below gives the reaction for a given biomass feedstock specifically cellulosic material with an empirical formula $(C_6H_{12}O_6)_n$ according to Japan Institute of Energy (2008).

$$\underset{Biomass}{(C_6H_{12}O_6)_n} \rightarrow \underset{Gaseous\ Mixtures}{(H_2 + CO + CH_4)} + \underset{Liquid\ Mixture}{(H_2O + CH_3OH + CH_3COOH)} + \underset{Char}{C} ------ (8)$$

During the pyrolysis process, composition of the biomass feedstock changes gradually in which the firstly evaporation of moisture occurs at a temperature of 110deg.C, which is followed by decomposition of the hemicellulose content of it at 220-260deg.C, cellulose content of it at 240-340deg.C and finally the decomposition of the lignin content at 280-500deg.C (Japan Institute of Energy, 2008). In line with the above information, high heating rate results in more rapid generation of vapor products hence shortening the residence time for the vapor product in the reactor, increase in pressure and a higher liquid yield by a process termed fast pyrolysis or flash pyrolysis (Japan Institute of Energy, 2008).

In addition to what has been said already, below gives the pyrolysis products yields mainly the bio-char, bio-oil, gaseous mixture and water as functions of temperature for a fast pyrolysis. It is obvious that bio-oil gives the best yield of all the products hence, considered the major product of the pyrolysis whereas, water being the least in yield.



Source: International Energy Agency (IEA), 2007

Figure 16: Relative Proportion of End Products after a Fast Pyrolysis

The other thermochemical process that is somewhat similar to pyrolysis is the hydrothermal liquefaction (HTL). Hydrothermal liquefaction is a thermal decomposition or de-polymerization of aqueous biomass or biomass slurry in to bio-crude oil and other aqueous products (Elliott, et al., 2015). The bio-crude oil is what could be further used as a fuel in a boiler for steam generation necessary to generate power. On a final note, the major difference between the two (2) techniques is that HTL uses wet biomass feedstock as opposed to pyrolysis which utilizes dry biomass, and the temperature for HTL is relatively lower usually in a range of 200-400deg.C (Christensen, 2014).

2.6.1.3: Gasification Technique and Fischer Tropsch Synthesis (FTS)

Gasification technique for biomass is an incomplete or partial oxidation or combustion of biomass feedstock to produce volatiles, ash and fuel gases either in the form of producer gas or syngas. In this regard, two basic steps are involved, the first being biomass heating in complete absence of oxygen or air to obtain bio-char and other components by pyrolysis at relatively lower temperature and the second step where the gasification at increased temperature occurs by reactions with limited oxygen or air (Siirala, 2013). Further reactions with carbon dioxide and steam are possible in the process and for that reason, four major gasification reactions have been distinguished according to Prabir (2006) as follows:

1. Water Gas Reaction: this is the partial oxidation of the produced bio-char in the process line with steam. The steam could come either from water vapor associated with air or from the vapor produced from evaporation of water and pyrolysis of the solid fuel. The heterogeneous reaction is as follows:

$$C + H_2O \rightarrow H_2 + CO \quad \frac{131.38kJ}{kgmol\ C} ---\ ------- (9)$$

2. Boudouard Reaction: In this case, the carbon dioxide present in the gasifier reacts with the produced bio-char in the process series to generate carbon monoxide as shown below:

$$C + CO_2 \rightarrow 2CO \quad \frac{172.58kJ}{mol\ C} -------------(10)$$

3. Water Gas Shift Reaction: This reaction occurs between carbon monoxide and steam to produce hydrogen. This results in an increase in hydrogen to carbon monoxide ratio, and is employed in the manufacture of syngas. The basic reaction is as follows:

$$CO + H_2O \rightarrow CO_2 + H_2 \quad \frac{-41.98kJ}{mol} ---------- (11)$$

4. Methanation: Tendency of methane formation in a gasifier is sure, and it is suitable if gasification products are to be used as feed stocks for other chemical processes due to its high calorific value. The basic reaction is as follows:

$$C + 2H_2 \rightarrow CH_4 \; \frac{-74.9kJ}{mol} - - - - - - - - - - - - - - (12)$$

Based on these reaction mechanisms, it is of great interest to clearly differentiate between the fuel gases viz: producer gas i.e. a mixture of CO, CO_2, CH_4, H_2, and N_2 and synthesis gas or syngas i.e. a mixture of CO and H_2. Gasification at relatively low temperatures (700-1000deg.C) leads to producer gas generation while gasification using steam or oxygen at a temperature higher than the above mentioned leads to syngas generation (Samy, n.d).

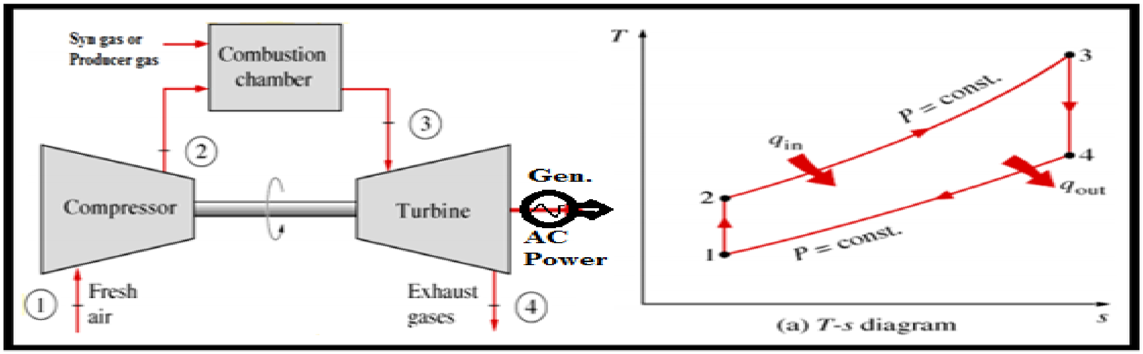
In addition, Gasification could be carried out in three (3) conventional methods such as fixed bed, fluidized bed and entrained flow with their sub types and general features as follow:

Table 13: Gasification Methods for Biomass with their General Features

Gasification Methods	Sub-types	General Features
Fixed Bed	Updraft Fixed Bed Gasifier	They have grate to support the fuel and maintain a stationary reaction bed, they are easy to design and operate, and they experienced minimum erosion effect.
	Downdraft Fixed Bed Gasifier	
	Cross draft Fixed Bed Gasifier	
Fluidized Bed	Bubbling Fluidized Bed (Atmospheric or Pressurized)	Gasification occurs in a bed of hot inert materials (sand or alumina), the use of inert materials increases the rate of the biomass reaction, wide range of fuels is allowed.
	Circulating Fluidized Bed (Atmospheric or Pressurized)	
Transport or Entrained Flow	Pressurized	Operates at high temperature (1200-2000˚C), requires biomass of fine particles
	Non pressurized	

Source: International Renewable Energy Agency (IRENA), 2012.

Furthermore, the fuel gases i.e. producer gas or syngas as the case may be are used for power generation in a thermodynamic (Brayton) cycle using a simple gas turbine as follows:



Source: Saha, n.d

Figure 17: Simple Gas Turbine with the Brayton Cycle for biomass fuel gas to power

Finally, in line with gasification comes the Fischer Tropsch Synthesis (FTS) for gasification product transformation to liquid fuels for transportation as an alternative rather than for heat and power generation in the simple gas turbine described above. Fischer Tropsch Synthesis is basically a thermo-catalytic process of transforming syngas to liquid hydro carbons developed by Han Fischer and Franz Tropsch in 1923 (Yongwu, et al., 2012). The operation mode for the synthesis could be classified in to two (2) according to Chevron (2005) as follows:

1. Low Temperature FTS: This operation mode occurs at a temperature range of (200-250deg.C) in the presence of cobalt or precipitated iron catalyst. The reactors employed in this case could be either slurry bed or fixed bed reactors.
2. High Temperature FTS: This operation mode occurs at a relatively higher temperature of range (300-350deg.C) in the presence of fused iron catalyst. The reactors employed in this case are mostly fluidized bed reactors.

The basic reactions in Fischer Tropsch synthesis leading to alkanes (paraffin), alkenes (olefins) and alcohols production according to Yongwu, et al. (2012) are as given below:

$$Paraffins - (2n+1)H_2 + nCO \rightarrow C_nH_{2n+2} + nH_2O - - - - - - - - - - - (13)$$

$$Olefins - 2nH_2 + nCO \rightarrow C_nH_{2n} + nH_2O - - - - - - - - - - - - - - (14)$$

$$Alcohols - 2nH_2 + nCO \rightarrow C_nH_{2n} + 2O + (n-1)H_2O - - - - - - - - - - (15)$$

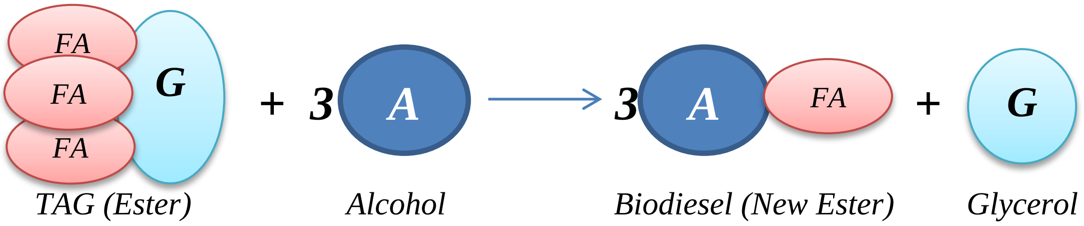
2.6.2: Chemical Conversion Techniques

Chemical conversion of biomass involves the use of chemicals to transform biomass feed stocks or bio-products in to liquid fuels also referred to as biofuels. In this regards, the techniques to be covered will be solely Trans-esterification technique for biodiesel production.

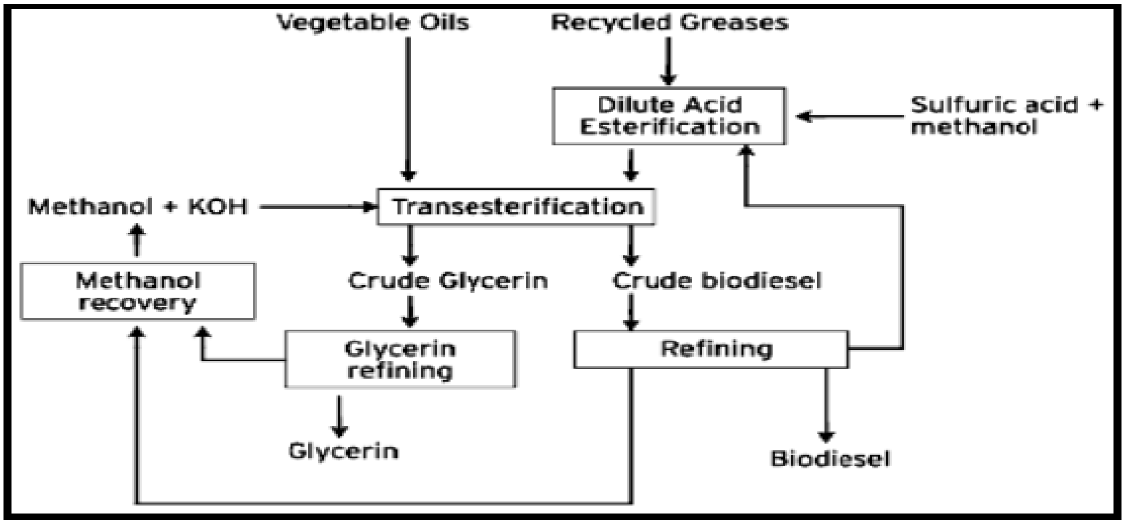
2.6.2.1: Trans-esterification Technique for Biodiesel Production

The word trans-esterification reaction also known as alcoholysis is referred to as the displacement of an alcohol from an ester by another alcohol. On the other hand, it is the reaction between ester and an alcohol to form a new ester and a new alcohol. The esters used are natural vegetable oils.

Based on this general definition, biodiesel also referred to as fatty acid methyl ester (FAME) or fatty acid ethyl ester (FAEE) is a biofuel obtained from the trans-esterification reaction described above. The basic reaction is between a vegetable oil (i.e. oil obtained from mechanical processing of some agricultural crops or residues) or sometimes animal fats with an alcohol mostly methanol or ethanol in the presence of a base catalyst (Hamza, et al., 2012). The oil is referred to as tri-acyl glyceride (TAG), which is a complex mixture of fatty acid (FA) and glycerol (G). The general chemistry of the reaction is as shown below:



Based on this, the technology for the Biodiesel synthesis is explicitly shown in the below block diagram:



Source: Hamza, et al., 2012

Figure 18: Technology for Biodiesel Production from Vegetable Oils

Finally, biodiesel (biofuel) could be classified in to three (3) generations viz: first generation biodiesel i.e. biodiesel from edible plant materials, second generation biodiesel i.e. biodiesel from non-edible plant material, and lastly the third generation biodiesel i.e. biodiesel from algae and microbes (Hamza, et al., 2012).

2.6.3: Biochemical Conversion Techniques

Biochemical conversion of biomass involves the use of microbes and enzymes to decompose biomass in to liquid, gaseous fuels and sometimes heat. The areas covered here are fermentation techniques for bioethanol production, anaerobic digestion technique or bio methanation for biogas production, land filling for land fill gas (LFG) production also known as biogas or bio methane, and lastly aerobic digestion technique for compost and bio-heat production.

2.6.3.1: Fermentation Technique for Bioethanol Production

Fermentation technique for bioethanol production is simply the breaking down of biomass feedstock in the presence of enzyme zymase obtained from yeast and at a temperature of 32-35deg.C in complete absence of oxygen. The chemistry of the reaction is as follows:

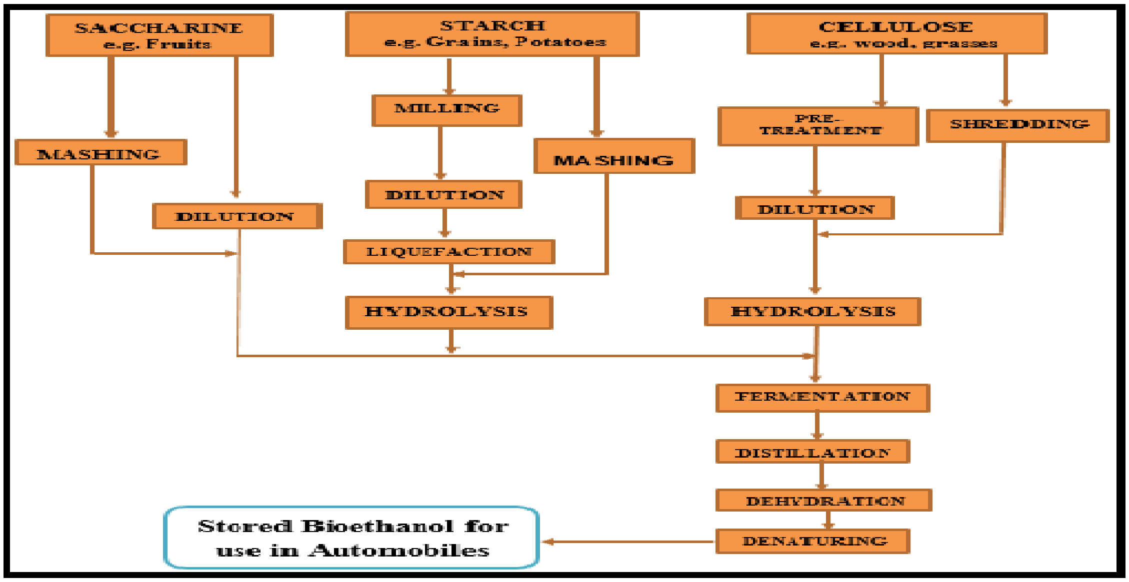
$$\underset{Simple\ Sugar}{C_6H_{12}O_6} \quad \rightarrow \quad \underset{Bioethanol}{2C_2H_5OH} \quad + \quad \underset{Carbon\ dioxide}{2CO_2} - - - - - - - - - - - - - - (16)$$

However, fermentation technique strongly depends on the nature of the biomass feedstock concerned. This is because some feed stocks are not easily fermentable hence; pre-fermentation operations are required as opposed to others. Biomass feed stocks that are lignocellusosic in nature such as woody material and herbaceous plants require pre-treatment operations such as delignification to get rid of their lignin and cellulose content followed by hydrolysis to break the complex structure in to simple ones necessary for fermentation (Balat, et al., 2008). In addition, starchy feed stock such as maize, wheat, potatoes etc. cannot be fermented directly as well instead; hydrolysis operation also called saccharification is first required to break their complex structure in to simple ones in order to be fermentable (Balat, et al., 2008).

The reaction chemistry of the hydrolysis operation for the bond breaking of complex sugar into simple sugar is shown below:

$$(C_6H_{12}O_6)_n + nH_2O \rightarrow nC_6H_{12}O_6 - - - - - - - - - - - - - - (17)$$

The block diagram below describes the fermentation techniques for bioethanol production from the range of biomass feed stocks differentiated above:



Source: Sims, et al., 2008

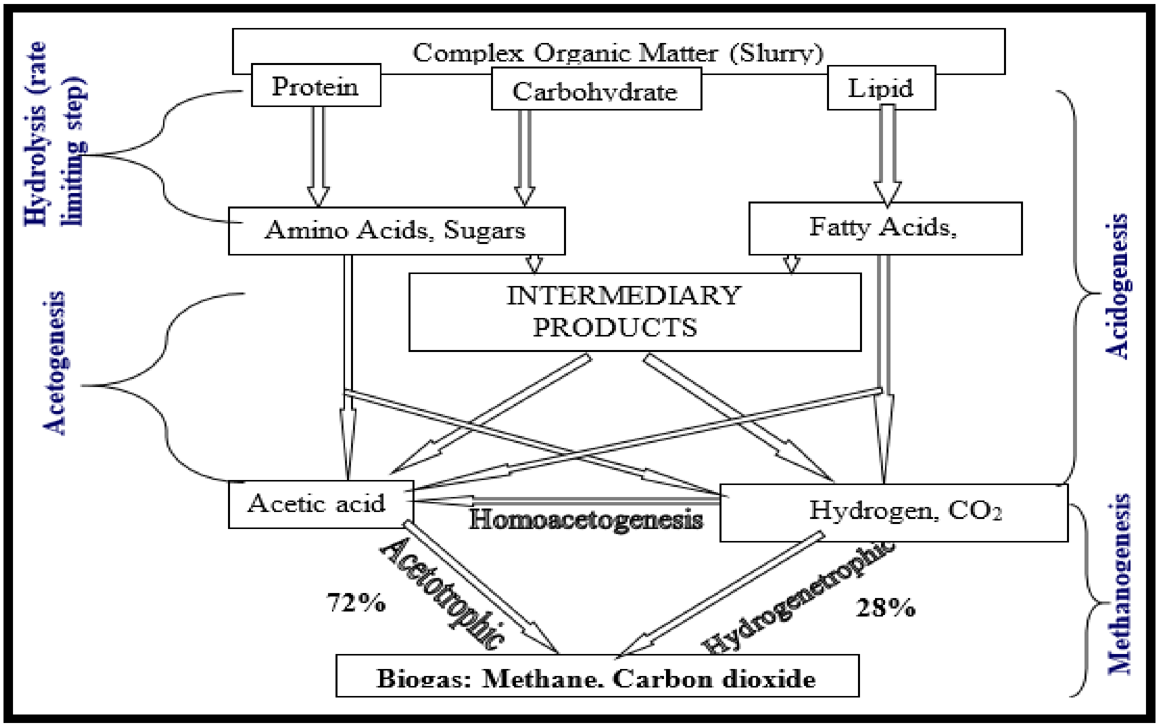
Figure 19: Bioethanol Production Technique from Different Feed stocks

Finally, in line with the above figure, it could be understood that bioethanol (biofuel) production is in two (2) generations i.e. first generation and second generation unlike biodiesel which comprises of three (3) generations. First generation bioethanol comes from edible feed stocks viz: complex sugars such as maize, cassava, potatoes etc., and simple sugars such as sugar cane, beet sugar, whey etc.; whereas the Second generation bioethanol comes from non-edible feed stocks that are lignocellulose.

2.6.3.2: Anaerobic Digestion Technique for Biogas Production

Anaerobic digestion technique involves breaking down of organic wastes either from plant or animal by micro-organisms in complete absence of air or oxygen to yield biogas and a solid byproduct called sludge. The biogas is a mixture of gases such as methane, carbon dioxide, hydrogen sulphide, water etc... Prakash (2011) asserts that methane content of biogas is around 50-65% by volume, carbon dioxide is around 35-40% by volume, hydrogen sulphide is around 4-6g/m^3, and lastly water content is around 30-160g/m^3. The biogas is a suitable and very efficient fuel for use in automobiles after severe purification or in a power plant for electricity generation of which purification is not required. The sludge byproduct is a bio-fertilizer (manure) that could be used in arable land to enhance soil fertility.

According to Swedish Biogas Trade Association (2007), Anaerobic digestion process consists principally of three (3) to four steps as depicted from the below figure:



Source: Swedish Biogas Trade Association, 2007

Figure 20: Detailed Anaerobic Digestion Scheme for Biogas Production

Furthermore, there are different anaerobic digestion techniques based on the digesters used of which include covered lagoons, complete mix digesters, plug flow digesters, and fixed film digesters. Their characteristics are as below:

Table 14: Anaerobic Digestion Technologies with their Features

Features	Covered Lagoons	Complete Mix Digester	Plug Flow Digester	Fixed Film Digester
Digestion Vessel	Deep Lagoons	Round/Square In/Above Ground Tank	Rectangular in Ground Tank	Above Ground Tank
Level of Technology	Low	Medium	Low	Medium
Supplemental Heat	No	Yes	Yes	No
Total Solids	0.5-3%	3-10%	11-13%	3%
Solids Characteristics	Fine	Coarse	Coarse	Very Fine
Hydraulic Retention Time (HRT) (days)	40-60	15+	15+	2-3
Optimum Location	Temperate and Warm Climate	All Climate	All Climate	Temperate and Warm Climate

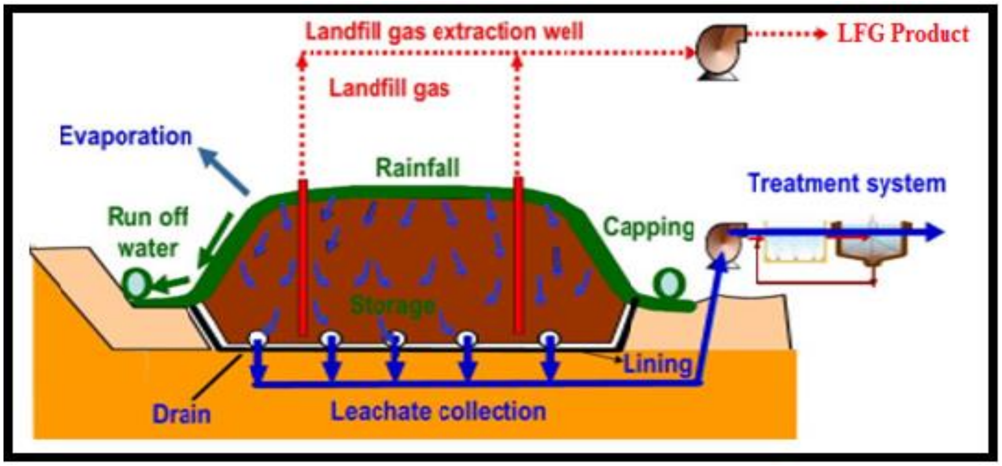
Source: AgSTAR, n.d

Finally, it is of great interest to specify that for optimum performance of anaerobic digestion, some optimum parameters must be complied with i.e. temperature within mesophilic range (30-35deg.C), carbon to nitrogen ratio (C: N) of less than 43:1, carbon to phosphorus ratio (C: P) of less than 187:1, and lastly pH of near 7.0 (James, et al., 1988).

2.6.3.3: Land Filling Technique for Land Fill Gas (LFG) Production

Production of biogas known as land fill gas (LFG) in this regards can be achieved using the land filling technique as an alternative to anaerobic digestion discussed earlier. The word land filling is defined as the burying of solid and semi-solid organic wastes onto the ground with compaction thereby isolating it from the environment. Land filling results in series of biochemical reactions for the decomposition of the buried organic waste material leading to generation of land fill gas (LFG) and a liquid called leachate i.e. a water and waste mixture (Ghosh & Syed, n.d).

The detailed biochemical operation starts with aerobic reactions (i.e. in the presence of oxygen as a terminal electron acceptor) resulting in carbon dioxide production as a principal gas. With continuous depletion of oxygen, reaction changes to anaerobic in the presence of microbes there by resulting in the production of carbon monoxide together with methane and some trace amount of ammonia and hydrogen sulphide. Below shows the land filling system for the LFG production:



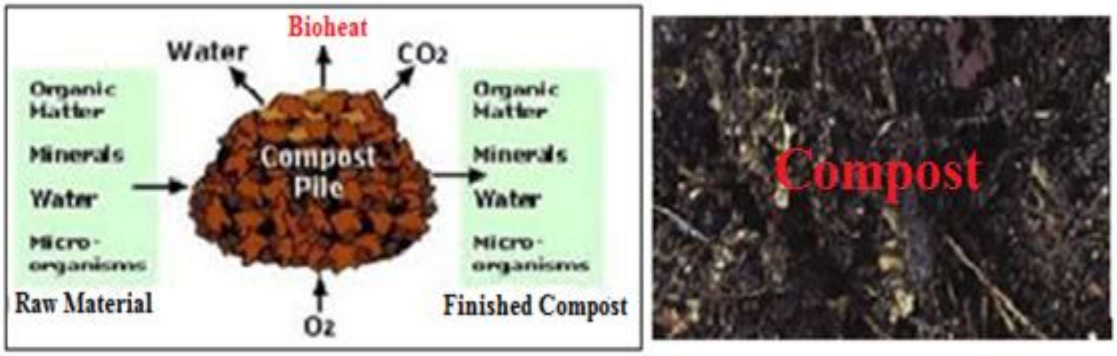
Source: Kromann, 2014

Figure 21: Land Fill Gas (LFG) Production Well (Land Filling System)

Lastly, the LFG produced in this technique could be further used in a power plant as a fuel for electricity generation or as a transportation fuel in automobiles after severe purification.

2.6.3.4: Aerobic Digestion Technique for compost and heat production

The word composting is a term used to describe the controlled biological decomposition of organic waste in an aerobic condition leading to compost and heat generation (US Composting Council (USCC), 2001). The produced compost is a black like humus and a bio-fertilizer that could be used in arable land to improve soil fertility. Below shows clearly the compost pile and the accompanied compost and bio-heat:



Source: Peter, et al., 2008

Figure 22: Compost Pile with the Raw Materials Involved and the Nature of the Compost

The optimum condition for yield of high quality compost in a compost pile is ensuring that the pile is sufficiently aerated at least once a weak, high surface area exposure for the waste in the pile, at least 50% moisture availability in the waste and lastly keeping the volume of the system around $3ft^3$ (Peter, et al., 2008).

Finally, the potential benefits of the generated compost according to the US Composting Council (2001) are as outlined below:

1. It improves the soil structure, porosity, density and pH
2. It increases the infiltration and permeability of heavy soil hence, reducing erosion
3. It improves water holding capacity thereby reducing water loss and leaching in sandy soil
4. It supplies a variety of micro and macro nutrients to the soil
5. It controls and suppress soil-borne plant pathogens
6. It improves cation exchange capacity of the soil

2.7: Bioenergy Policy Initiatives in Africa

In general, energy policies initiative is very fundamental and a pre-condition to development on national, continental and global bases. Bioenergy policy in this regard is considered the most critical aspect of concern and the area that needs proper attention for energy solutions offer in Africa. Currently, several African countries are in the progression of developing bioenergy policies as well as their execution strategies for sustainable development (Rainer, et al., n.d). Below (see table 15) shows the list of some African countries having adopted bioenergy policies with the date specified and the primary feed stocks.

Table 15: African Countries with Bioenergy Policies and Dates of Issue

Countries	Policy	Date of Issue	Primary Feedstock
Angola	Biofuels Policy	24th March, 2010	
Botswana	Energy Policy	2009	
Ghana	Bioenergy Policy (Draft)	2010	
Kenya	National Biofuel Policy (Draft)		
Mali	Agricultural Legislations	2006	Jatropha
Mauritius	Energy Policy	2005-2009	Sugar Cane
Mozambique	National Biofuel Policy and Strategy	21st May, 2009	Jatropha for Biodiesel / Sugar Cane for Bioethanol
Nigeria	Biofuel Policy and Incentives (No 74 Vol. 94)		
Rwanda	National Energy Policy and Strategy		
Senegal	National Bioenergy Strategy	2006	Jatropha for Biodiesel / Sugar Cane for Bioethanol
South Africa	Biofuels Industrial Strategy	2007	
Zambia	National Energy Policy	May, 2008	

Source: Ejigu, 2012

It was revealed from same study by Ejigu (2012) that the above mentioned countries had energy security, diversification and capacity building for biofuels development, job creation and poverty alleviation. Further assessments in the study disclosed that environmental concerns and cogeneration practice are the top priorities of these countries bioenergy policy practice where as food security aspect was unfortunately laid far behind.

Furthermore, going in to details of the policies highlighted above, selection of at least one country to further elaborate on the provided information will be of great interest. In this regard, Mozambique has been selected as a case of study, and its bioenergy policy details is as follows:

2.7.1: Details of Bioenergy Policy in Mozambique as a Case Study

The biofuel policy adopted by this country as seen from table 15 above is with the objective intension of saving foreign currency, reducing environmental problems of increased transport sector, reducing the overdependence on unpredictable and volatile world market oil prices, and lastly contributing to rural development by generating jobs and increasing income opportunities (Rainer et al, n.d).

To expatiate on the biofuel benefits, the government of Mozambique has initiated the biofuel based rural electrification projects and an improved biofuel based cooking and lighting facilities with the sole idea of increasing modern energy access to the rural population thereby improving their living standard significantly.

The development of bioenergy sector in Mozambique was made possible due to their suitable climate for sugar cane and other energy crops. Mozambique is endowed with 7 million hectares of available arable land, enough labor and water resources for the production without any threat to food production and security (Rainer et al, n.d).

The national biofuel policy and strategy elaboration for the country states clearly the vision *to establish the country's biofuels sector to contribute to energy security and socio*-economically *sustainable development*. The frame work will include the creation of *National Program for Biofuels Development (NPBD)* to give financial supports to activities and projects, a *National Commission for Biofuels (NCB)* to supervise the implementation of the biofuels strategy, and *Biofuels Commercialization Program (BCP)* for purchasing bioethanol and biodiesel for blending with fossil fuels.

Moreover, proposition was made regarding the country's biofuels proceedings that bioethanol will be produced solely from sugar cane and sorghum feed stocks, and biodiesel solely from jatropha curcas and coconut feed stocks (Rainer et al, n.d). Conclusively, Mozambique is among the leading countries in Africa on bioenergy development specifically on biofuels.

To wrap it up, a lot of gaps still exist in bioenergy policies formulation in the continent which need to be addressed technically, innovatively, strongly, adequately, and in a timely manner in order to realize the huge potentials of our blessed continent (Africa).

CHAPTER THREE

3.0 METHODOLOGY (EVALUATION APPROACH)

3.1 Introduction

In view of the Energy Sustainable Development Goals as well as the CoP21 Paris Agreement on the Nationally Determined Contribution (NDC) on climate change all of 2015 base year, the methodology for this research work in view of the low carbon development targets focused on the Bioenergy contributions in the African energy transformation agenda. Biomass for modern bioenergy is considered the heart of this transformation and therefore, its absence makes the journey worthless. The detailed assessments were addressed on the pillars of sustainable development i.e. social, economic and environmental aspects broadly on a step by step proceeding.

3.2 Energy Access Scale Up Through Modern Bioenergy

Detailed assessments of biomass resource potential for modern bioenergy in addressing energy access challenge (i.e. Power, Heat, and Fuel) in the continent's transition target from Business as Usual (BAU) scenarios based on a given baseline year and on projection was addressed. This was done majorly by looking at the biomass resource potentials for each of the year cases (i.e. base year and projection) with the explored chances of effectively exploiting it for scaling up the energy mix at the same time lowering the fossil fuels for power, transport and heating end uses. However, each end use was analyzed as a priority area independent on the other for the policy makers to decide on the end use domain they will want to prioritize on adopting the modern bioenergy.

3.3 Environmental and Climate Co-Benefits Assessment of the Energy Scale Up

Detailed Environmental and Climate co-benefits assessment was looked at as a follow up to the energy scale up assessment for each of the three end uses i.e. power, transport and heating independently. This was addressed solely by quantifying the CO_2 emissions for each end use priority area based on base or conventional case and the proposed energy scale up case on full biomass resource exploitation and fossil fuels reduction. Concluding assessment was on quantification of the CO_2 emissions savings from Business as Usual on replacing the base or conventional case energy mix with the proposed case energy mix for each end use priority area.

3.4 Socio-Economic Co-Benefits Assessment of the Energy Scale Up

As a follow up to the energy scale up assessment as well as the associated environmental and climate co-benefits assessment, Socio-economic co-benefits associated with the continent modern bioenergy transformation was also included for each of the end uses analyzed. These benefits are collectively linked to economic growth and development at all levels starting from the domestic / residential level to the various sectors of development of the continent that were discussed appropriately in this section.

3.5 Addressing the Challenges of Implementation

Obviously, modern bioenergy processes in view of the low carbon development target of the continent cannot prevail without obstacles or challenges. The possible challenges in adopting biomass for modern bioenergy (i.e. Bio-power, Biofuel and Bio-heat) were discussed with viable views of addressing them amicable for each of the end uses i.e. power, transport and heating**.**

3.6 Opportunity Areas in Favor of Implementation

Finally, possible opportunity areas in favor of the rapid transitioning to low carbon development through the modern bioenergy (i.e. bio-power, biofuels and bio-heat) was covered. These opportunity areas of interest were generally business models, improved techniques and value chain extensions which were strongly recommended in favor of the rapid continental energy transformation and improved sustainable development. The opportunity areas were addressed appropriately by considering each end use priority area.

CHAPTER FOUR

4.0 DETAILED ASSESSMENTS, RESULTS AND DISCUSSION

4.1 Power End Use Assessment for Africa

4.1.1 Assessment of Electricity Scale up Through Bio-power

This aspect of analysis is aimed at scaling up or improving power access as a priority area by full exploitation of biomass resource. This was done based on the business as usual energy information for the 2014 base year and 2030 projection in order to clearly see the enormous potentials of biomass for bio-power in the continent's power sector transformation as follows:

- General Information for the Analyses

Energy Conversion Efficiencies for Fuels: the overall energy conversion efficiencies (i.e. from chemical to thermal and to electrical energy) for Oil, Natural Gas, Coal, and Biomass power plants are as shown in the below table:

Table 16: Energy Conversion Efficiencies for Thermal Power Plants

Power Plants	Technique of Transformation	Overall Efficiencies ($\eta_{overall} = \eta_{th} \times \eta_{el}$)
Biomass	Combustion and Steam Turbine Generator Shaft-work for Power Generation	25%
Coal	Same as above	35%
Oil	Same as above	38%
Natural Gas	Same as above	45%

Sources: Zeiss, 2010; IRENA, 2012

According to the above table, it can be deduced that Biomass is less energy dense than fossil fuels, hence, more of it energy is required than the fossils to produce the same final energy needs.

1) 2014 Baseline Power Analyses

- Base Case Assessment

The 2014 baseline installed and generation capacity mix as obtained from total shift project database is as follows:

Table 17: Installed Capacities and Electricity Generation Mix for Africa during 2014

Fuel Mix	Installed Capacities (GW)	Fuel Mix	Electricity Generation (TWh)
Fossils	113.6	Oil	91
		Gas	234
		Coal	241
Hydro	24.1	Hydro	120
Wind	2.1	Geothermal	32
Nuclear	1.9	Biomass	2
Others	4	Others	19
Total	145.7	Total	739

Source: www.tsp-data-portal.org

From the above table, the Fossil Fuel Consumption could be established based on the overall efficiencies information for their respective power plants as follows:

$$\text{Total Oil Consumption} = \frac{Electricity\ Produced}{Overall\ Efficiency\ for\ Oil\ Power\ Plant} = \frac{91TWh}{0.38} = 239.47TWh$$

$$\text{Total Gas Consumption} = \frac{Electricity\ Produced}{Overall\ Efficiency\ for\ Gas\ Power\ Plant} = \frac{234TWh}{0.45} = 520TWh$$

$$\text{Total Coal Consumption} = \frac{Electricity\ Produced}{Overall\ Efficiency\ for\ Coal\ Power\ Plant} = \frac{241TWh}{0.35} = 688.57TWh$$

$$\text{Total Biomass Consumption} = \frac{Electricity\ Produced}{Overall\ Efficiency\ for\ Biomass\ Power\ Plant} = \frac{2TWh}{0.35} = 8TWh$$

Table 18: Calculated Fossil Fuel and Biomass Consumption Leading to the Established Power Generations of 2014

Fuel Use	Energy Consumption (TWh)	Power Generation (TWh)
Oil	239.47	91
Gas	520	234
Coal	688.57	241
Biomass	8	2
Total	1456.04	568

- Proposed Case Assessment

According to the Food and Agricultural Organization of the United Nations Statistics website, the following information regarding Agro Processing and Forestry for Africa were obtained:

Table 19: Biomass Resource Data for Africa in 2014

Domain	Item	Quantity	Cal. E.C (MJ)	Cal. E.C (TWh)
Agro Processing	Crop Residue	2490367870kg	3.2549×10^{10}	8.79
Forestry Production	Wood Fuel	656920317m^3	1.4347×10^{13}	3873.69
Total		N/A	1.4380×10^{13}	3882.48

Source: FAOSTAT, 2015

Note that the calculation of the energy content was done based on the breakdown of the crop residue different varieties for the whole continent during the specified year, their total quantity obtained and the energy content factor (i.e. Specific Energy) for each of the produced residues. This procedure is also similar for the wood fuel, of which is based on the obtained total volume produced and the energy content factor (i.e. Energy Density).

Based on the energy information from FAO Statistics database, as well as the electricity mix information obtained from Total Shift Project Database, it is quite obvious that the continent electricity generation could be scaled up by lowering the fossil fuel uptake and replacing with the huge biomass resource available during the baseline year. This will play a multiple role of lowering costs of energy generation, improving energy access, and with enormous socio-economic, environmental and climate co-benefits that will be addressed latter on.

Reducing the fossil fuel consumption for energy by 50% for each of oil, natural gas and coal, and replacing with 90% portion of the total biomass resource available as shown in table 19 is a proposal that is feasible as shown from the below table:

Table 20: Proposed New Electricity Generation Mix for the 2014 base year

Fuel Mix		Fuel Consumption (TWh)	Electricity Generation (TWh)
Fossil Fuel	Oil	50% of 239.47 = 119.735	50% of 91 = 45.5
	Gas	50% of 520 = 260	50% of 234 = 117
	Coal	50% of 688.57 = 344.285	50% of 241 = 120.5
Total for Fossils		724.02	283
Biomass in Mix		8	2
Proposed Biomass		90% of 3882.6 = 3494.34	3494.34 × 0.25 = 873.59
Total for Biomass		3502.34	875.59
Hydro		N/A	120
Geothermal		N/A	32
Others		N/A	19
Grand Total			1329.59

Concluding Assessment:

Proposed Electricity Generation Mix = 1329.59TWh

Conventional Electricity Generation Mix from Total Shift Project Database = 739TWh

$$\% \text{ Electricity Generation Increase} = \frac{1329.59-739}{739} \times 100\% = \mathbf{79.9\%}$$

- Total Biomass required (90% Proposed Use + Biomass for Existing 2TWh$_{el.}$) = 3502.34TWh
- Total Biomass Resource (Wood Fuel + Agro Residues) for the 2014 base year = 3882.48TWh

Therefore, Biomass Resource Left over = 3882.48 – 3502.35 = 380.13TWh

This huge Biomass resource left over of **380.13TWh** could then be utilized for other applications

2) 2030 Projection Power Analysis

➢ Base Case Assessment

Below shows the installed and generation capacities mix for 2030 scenario as obtained from IRENA (2012)

Table 21: BAU Installed Capacities and Electricity Generation Mix Scenario (2030)

Fuel Mix	Installed Capacities (GW)	Fuel Mix	Electricity Generation (TWh)
Fossil Fuels and Nuclear (Use of Uranium)	440	Oil	216
		Gas	490
		Coal	570
Hydro	50	Biomass	40
Wind	22	Nuclear	35
Geothermal	12	Hydro	250
Others	2	Other Renewables	120
Total	526	Total	1721

Source: IRENA, 2012

From the above table, the Fossil Fuel and Biomass Energy Consumption could be established based on the overall efficiencies information for their respective power plants as follows:

$$\text{Total Oil Consumption} = \frac{Electricity\ Produced}{Overall\ Efficiency\ for\ Oil\ Power\ Plant} = \frac{216TWh}{0.38} = 568.42TWh$$

$$\text{Total Gas Consumption} = \frac{Electricity\ Produced}{Overall\ Efficiency\ for\ Gas\ Power\ Plant} = \frac{490TWh}{0.45} = 1088.89TWh$$

$$\text{Total Coal Consumption} = \frac{Electricity\ Produced}{Overall\ Efficiency\ for\ Coal\ Power\ Plant} = \frac{570TWh}{0.35} = 1628.58TWh$$

$$\text{Total Biomass Consumption} = \frac{Electricity\ Produced}{Overall\ Efficiency\ for\ Biomass\ Power\ Plant} = \frac{40TWh}{0.25} = 160TWh$$

Table 22: Calculated Fossils and Biomass Consumption Leading to the Established Power Generation of the 2030 Scenario

Fuel Use	Energy Consumption (TWh)	Power Generation (TWh)
Oil	568.42	216
Gas	1088.89	490
Coal	1628.58	570
Biomass	160	40
Total	3445.89	1316

- Proposed Case Assessment

The proposed case energy analysis for the continent base on proper adjustment to the base case is as follows:

Table 23: 2014 Data for Agro Residues and Forestry Production with the 2030 Forecasted Data

Year	Crop Residue (kg)	Wood Fuel (m^3)	Crop Residue Cal. E.C (MJ)	Wood Fuel Cal. E.C. (MJ)	Total E.C (MJ)	Total E.C (TWh)
2014	2490367870	656920317	3.2549×10^{10}	1.4347×10^{13}	1.4380×10^{13}	3882.6
2030	3752248609	801919796.1	4.8497×10^{10}	1.7514×10^{13}	1.7562×10^{13}	4741.74

Source: FAOSTAT, 2015

Note that the 2030 forecasting was done using M.S Excel database based on the obtained historical data trend from the FAOSTAT.

Therefore, from the table, the following could be extracted:
Total Biomass Energy Content (Agro Residues + Wood Fuel) for the Excel Forecasted / projected data of 2030 = 4741.74TWh

Based on the energy information from the FAO Statistics database, as well as the electricity mix information obtained from Total Shift Project Database, it is obvious that the continent electricity generation can be feasibly scaled up by lowering the fossil fuel uptake and replacing with the huge biomass resource available as shown in table 23. This will play a multiple role of lowering costs of energy generation, improving energy access, and with enormous environmental and climate co-benefits that will be analyzed latter on.

Reducing the fossil fuel consumption for energy by 25% for each of oil, natural gas and coal, and replacing with 90% portion of the total biomass resource available from table 23 is a proposal that is feasible as shown from the below table:

Table 24: Newly Proposed Electricity Generation Mix for the 2030 Projection

Fuel Mix		Fuel Consumption (TWh)	Electricity Generation (TWh)
Fossil Fuel	Oil	75% of 568.42 = 426.315	75% of 216 = 162
	Gas	75% of 1088.89 = 816.67	75% of 490 = 367.5
	Coal	75% of 1628.56 = 1221.42	75% of 570 = 427.5
Total for Fossils		2464.405	957
Biomass in Mix		160	40
Proposed Biomass		90% of 4741.74 = 4267.57	4267.57 × 0.25 = 1066.91
Total for Biomass		4427.57	1106.91
Hydro		N/A	250
Nuclear		N/A	35
Other Res		N/A	120
Grand Total			2468.91

Concluding Assessment:

Proposed Electricity Generation Mix Total = 2468.91TWh

Conventional Electricity Generation Mix from IRENA database (BAU) = 1721TWh

$$\% \text{ Electricity Generation Increase} = \frac{2468.91-1721}{1721} \times 100\% = \mathbf{43.46}\%$$

- Total Biomass required (90% Proposed Use + Biomass for Existing $40TWh_{el.}$) = 4427.57TWh
- Total Biomass Resource (Wood Fuel + Agro Residues) for the 2030 Scenario = 4741.74TWh

Therefore, Biomass Resource Left over = 4741.74 – 4427.57 = 314.17TWh

Note that this huge Biomass resource left over of **314.17TWh** could then be utilized judiciously for other possible applications.

4.1.2 Environmental and Climate Co-Benefits Assessment

As a follow up to the power scale up analyses based on 2014 baseline year and 2030 projection, this analysis is further aimed at quantifying the CO_2 emissions savings from Business as Usual (BAU) scenarios based on the power scale up through the full and efficient utilization of biomass resource (Agro Residues and Forestry Production) and fossil fuel lowering.

- ➢ General Information for the Analysis

GHG Emission Factors: According to RETSCREEN decision tool for energy systems feasibility analyses, the following GHG Emission Factors were established.

Table 25: GHG Emission Factors for Fuels

Fuel	GHG Emission Factors		
	CO_2 Emission Factor	CH_4 Emission Factor	N_2O Emission Factor
Oil	0.269ton/MWh	0.0029kg/GJ	0.0019kg/GJ
Natural Gas	0.179ton/MWh	0.0036kg/GJ	0.0009kg/GJ
Coal	0.338ton/MWh	0.0145kg/GJ	0.0029kg/GJ
Biomass	0.007ton/MWh	0.0299kg/GJ	0.0037kg/GJ

Source: www.retscreen.net

1) 2014 Baseline Emission Analyses

- Base / Conventional Case Emission Analysis

According to Table 18 of calculated fossil fuel and biomass energy consumption with the power generation mix showcased in power scale up analyses which is brought down as follows:

Table 18: Calculated Fossil Fuel and Biomass Consumption Leading to the Established Power Generation of the 2014 Base Year

Fuel Use	Energy Consumption (TWh)	Power Generation (TWh)
Oil	239.47	91
Gas	520	234
Coal	688.57	241
Biomass	8	2
Total	1456.04	568

The CO_2 Emission for the Base / Conventional Case in the above table is as follows:

$$\text{Base Case Coal } CO_2 \text{ Emission} = \text{Total Energy Consumption} \times \text{Coal } CO_2 \text{ Emission Factor}$$
$$= (688.57\times 10^6)\text{MWh} \times 0.338\text{tons/MWh} = 232.7\text{MT}$$

$$\text{Base Oil } CO_2 \text{ Emission} = \text{Total Oil Energy Consumption} \times \text{ Oil } CO_2 \text{ Emission Factor}$$
$$= (239.47 \times 10^6)\text{MWh} \times 0.269\text{tons/MWh} = 64.42\text{MT}$$

$$\text{Base Gas } CO_2 \text{ Emission} = \text{Total Gas Energy Consumption} \times \text{Gas } CO_2 \text{ Emission Factor}$$
$$= (520 \times 10^6)\text{MWh} \times 0.179\text{tons/MWh} = 93.1\text{MT}$$

$$\text{Base Biomass } CO_2 \text{ Emission} = \text{Total Biomass Energy Use} \times \text{Biomass } CO_2 \text{ Emission Factor}$$
$$= (8 \times 10^6)\text{MWh} \times 0.007\text{tons/MWh} = 0.056\text{MT}$$

Base Case Total CO_2 Emission from the Fossil Fuels and Biomass Use = 390.26MT

- Proposed Case Emission Analysis

In line with what has been done for the energy analysis previously, which was reducing the total fossil fuel consumption by 50% for each of oil, gas and coal and then replacing with 90% of the total biomass resource (Wood fuel + Agro Residues) available for the 2014 base year, the following table gives the Fossil Fuel and Biomass extracts of the previous table 20:

Table 26: Proposed Fossil Fuel and Biomass Consumption with the Power Generations for 2014

Fuel		Fuel Consumption (TWh)	Electricity Generation (TWh)
Fossils	Oil	50% of 239.47 = 119.735	50% of 91 = 45.5
	Gas	50% of 520 = 260	50% of 234 = 117
	Coal	50% of 688.57 = 344.285	50% of 241 = 120.5
	Total Fossil Fuel	724.02	283
Biomass in Mix		8	2
Proposed Biomass		90% of 3882.6 = 3494.34	3494.34 × 0.25 = 873.59
Total Biomass		3502.34	875.59
Grand Total		4218.36	1158.59

The CO_2 Emission for the proposed Case is as follows:

New Oil CO_2 Emission = New Oil Consumption × Oil CO_2 Emission Factor
$= 119.735 \times 10^6 \text{MWh} \times 0.269 \text{tons/MWh} = 32.2 \text{MT}$

New Gas CO_2 Emission = New Gas Consumption × Gas CO_2 Emission Factor
$= 260 \times 10^6 \text{MWh} \times 0.179 \text{tons/MWh} = 46.54 \text{MT}$

New Coal CO_2 Emission = New Coal Consumption × Coal CO_2 Emission Factor
$= 344.285 \times 10^6 \text{MWh} \times 0.338 \text{tons/MWh} = 116.37 \text{MT}$

Proposed Case Total CO_2 Emission from Fossil fuels = 195.11MT

New CO_2 Emission from the total Biomass Scale Up
= total Biomass Fuel Consumption × Biomass CO_2 Emission Factor
$= 3502.34 \times 10^6 \text{MWh} \times 0.007 \text{tons/MWh} = 24.516 \text{MT}$

Overall CO_2 Emission for the Newly Proposed Case (Fossils + Biomass) = 219.63MT

Therefore, the Overall CO_2 Emission Savings
= Base / Conventional Case Emission – Newly Proposed Case Emission
= 390.26MT – 219.63MT = 170.63MT

According to RETSCREEN Baseline, the **170.63MT** emission savings of 2014 baseline is equivalent to **31325162** automobiles not used during the year.

2) 2030 Projection Emission Analysis

- Base / Conventional Case Emission Analysis

  According to the Table 22 showcased in the power scale up assessment, it is further brought down for Emission analysis as follows:

Table 22: Calculated Fossil Fuel and Biomass Consumption Leading to the Established Power Generation for the 2030 Projection

Fuel Use	Energy Consumption (TWh)	Power Generation (TWh)
Oil	568.42	216
Gas	1088.89	490
Coal	1628.58	570
Biomass	160	40
Total	3445.89	1316

The Base / Conventional Case CO_2 Emission Quantification for Fossil Fuels and Biomass are:

Base Coal CO_2 Emission = Total Coal Energy Consumption × Coal CO_2 Emission Factor
$= (1628.58\times 10^6)\text{MWh} \times 0.338\text{tons/MWh} = 550.46\text{MT}$

Base Oil CO_2 Emission = Total Oil Energy Consumption × Oil CO_2 Emission Factor
$= (568.42 \times 10^6)\text{MWh} \times 0.269\text{tons/MWh} = 152.9\text{MT}$

Base Gas CO_2 Emission = Total Gas Energy Consumption × Gas CO_2 Emission Factor
$= (1088.89 \times 10^6)\text{MWh} \times 0.179\text{tons/MWh} = 194.19\text{MT}$

Base Biomass CO_2 Emission = Total Biomass Energy Use × Biomass CO_2 Emission Factor
$= (160 \times 10^6)\text{MWh} \times 0.007\text{tons/MWh} = 1.12\text{MT}$

Therefore, total CO_2 Emission for the Base / Conventional Case = 898.67MT

- Proposed Case Emission Analysis

In line with what has been done for the energy analysis previously, i.e. reducing the total fossil fuel consumption by 25% for each of oil, gas and coal and then replacing with 90% of the total biomass resource available for the projected year 2030, below table gives the extracts of Fossil Fuel and Biomass part of the proposed case of Table 24 showcased previously:

Table 27: 2030 Newly Proposed Fossil Fuel and Biomass Use with the Power Generation

Fuel		Fuel Consumption (TWh)	Electricity Generation (TWh)
Fossils	Oil	75% of 568.42 = 426.315	75% of 216 = 162
	Gas	75% of 1088.89 = 816.67	75% of 490 = 367.5
	Coal	75% of 1628.56 = 1221.42	75% of 570 = 427.5
Total for Fossils		2464.405	957
Biomass in Mix		160	40
Proposed Biomass		90% of 4741.74 = 4267.57	4267.57 × 0.25 = 1066.91
Total for Biomass		4427.59	1106.91
Grand Total		6891.995	2063.91

CO_2 Emissions of the Fossil Fuel Consumption Reduction from the Conventional Case follows:

Oil CO_2 Emission = New Oil Consumption × Oil CO_2 Emission Factor
$= 426.315 \times 10^6\text{MWh} \times 0.269\text{tons/MWh} = 114.68\text{MT}$

Gas CO_2 Emissions = New Gas Consumption × Gas CO_2 Emission Factor

$= 816.67 \times 10^6\text{MWh} \times 0.179\text{tons/MWh} = 146.18\text{MT}$

Coal CO_2 Emissions = New Coal Consumption × Coal CO_2 Emission Factor

$= 1221.42 \times 10^6\text{MWh} \times 0.338\text{tons/MWh} = 412.84\text{MT}$

Therefore, total CO_2 Emissions from Proposed Fossil fuels = 673.7MT

CO_2 Emission from the Total Proposed Biomass Scale Up

= Total Biomass Fuel Consumption × Biomass CO_2 Emission Factor

$= 4427.59 \times 10^6\text{MWh} \times 0.007\text{tons/MWh} = 30.993\text{MT}$

Hence, Total CO_2 Emission for the Proposed Case (Fossils + Biomass) = 704.69MT

Therefore, the Overall CO_2 Emission Savings

= Base / Conventional Case Emission – New Proposed Case Emission

= 898.67MT – 704.69MT = 193.98MT

According to RETSCREEN Baseline, the **193.98MT** emission savings for the 2030 projection is equivalent to **35611305** Automobiles not used for the projected year.

Table 28: Overall Emission Reduction Summary for the Analyses Performed (2014 and 2030)

2014 Baseline Emission Analysis Summary				*2030 Projection Emission Analysis Summary*			
Base Case		*Proposed Case*		*Base Case*		*Proposed Case*	
Fuel Type	*Energy Use (TWh)*	*Fuel Type*	*Energy Use (TWh)*	*Fuel Type*	*Energy Use (TWh)*	*Fuel Type*	*Energy Use (TWh)*
Fossil	*1448.04*	*Fossil*	*724.02*	*Fossil*	*3285.88*	*Fossil*	*2464.405*
Biomass	*8*	*New Biomass*	*3494.34*	*Biomass*	*160*	*New Biomass*	*4267.59*
		Ex. Biomass	*8*			*Ex. Biomass*	*160*
390.2MT CO_2 Emission.		*219.63MT CO_2 Emission*		*898.67MT CO_2 Emission*		*704.69MT CO_2 Emission*	
***170.63MT** CO_2 Emission Savings on Substituting the Base Case with the Proposed Case, which is equivalent to **31325162** automobiles not used during the Base Year*				***193.98MT** CO_2 Emission Savings on Substituting the Base Case with the Proposed Case, which is equivalent to **35611305** automobiles not used for the Projected Year*			

4.1.3 Socio-Economic Co-Benefits Assessment

Scaling up the power access of the continent through the bio-power as clearly analyzed will offer a lot of tremendous socio-economic benefits in terms of both economic growth and development which will be highlighted as a follow up:

The benefits could be viewed critically from household level and to a larger extent the various sectors of development for the continent such as agricultural, educational, health, transport, industrial, and so on.

On the household level, the improved access to electricity will assist greatly in addressing a lot of household issues such as lighting, abundance in water supply, and above all, makes activities more efficiently and in a timely and less stressful manner. Hence, this ensures boosting of livelihood / standard of living at the domestic level significantly.

Moving on further to the sectors of development, starting with the agricultural sector, the improved access to energy / electricity assists greatly in enhancing more diversified and sophisticated agricultural practice thereby improving agricultural system efficiencies, quality and yield of produce to a greater extent. Therefore agricultural transformation of the continent is only sound on greater access to sustainable power supply.

The improved access to electricity is also very critical to the educational sector. This will assists greatly in modern schools empowerment by improving the use of modern learning facilities for students' welfare. Access to all this facilities could be made more feasible only with the sustainable and reliable power supply.

Moreover, the improved access to electricity is equally important to health sector of the economy. This is in view of having greater access and use of modern and sophisticated diagnostic facilities for proper check-up of patients. It is quite a pity to the continent that most hospitals in remote areas especially in the sub-Saharan Africa lack access to electricity, which subjects patients to life at stake.

Furthermore, Industrial sector is another key area of development to the continent which ensures improved access to processed goods. This sector could not function effectively on the base of unsustainable and unreliable power supply. Therefore, the improved power supply is also a critical concern to the industrial transformation of the continent.

On a final note, employment opportunities are made possible at all levels of implementation, starting from feedstock extraction to the power generation and to distribution levels for end use.

4.1.4 Possible Challenges of Implementation with Viable Solutions

A. The Challenges of Implementation

Venturing in to Biomass for bio-power projects offer substantial benefits in meeting up with the African energy demand in power sector while also addressing environmental issues as seen previously however; some challenges prevail along the line of actions as follows:

i. Securities in Water: The continuous use of water for biomass growing specifically for energy as well as in the bio-power generation offers a challenge of water shortage to regions with low level rainfall experience. This is owing to the fact that more pressure will be on the use of water bodies for irrigation practices and power generation thereby resulting in continuous water bodies draining and severe drought. With the drought prevalence, further biomass plantation is impeded as well as the associated modern bio-power generation as water is needed for both. Above all, other activities very critical such as operations for consumption, food crops plantation and soon are also hindered, making the economy at stake. Therefore, biomass plantation practice for energy could be considered unviable in areas with such misfortune.

ii. Land Use Challenge: Land resource is a fixed asset that could be either arable or non-arable. Arable lands are used for plantation (i.e. Biomass Plantation for either food or energy) or for grazing purpose. This land also permits activities such as power plants installation. On the other hand, non-arable land unfavors plantations but could be applied for other activities such as the power plants installations and beyond. Therefore, excessive use of lands for biomass plantation for energy as well as for power plants installation renders land usage for other activities like food production and soon unfavored. Hence, this could pose a challenge to bio-power projects.

iii. Deforestation Impact: Continuous deforestation in securing biomass feedstock for bio-power generation is another critical issue disrupting the ecosystem by contributing to increased CO_2 Emissions, desertification and land degradation hence, affecting the successful implementation of bio-power projects.

B. Possible Solutions to the challenges

This aspect of interest is all about integrating all biomass resources for modern bio-power in the continent by a win-win relationship with the outlined challenges without any interference.

i. Addressing the Water Security Challenge: Addressing water issues to modern bio-power is very crucial in ensuring sustainable agriculture and forestry as well as the power generation. Sustainable water management is the only way out to tackling the water scarcity challenge to the associated locations such as setting up in place rainfall harvesting systems in conserving water for future use, the practice of expanded irrigation schemes coupled with use of sophisticated machines in having access to untapped water, and finally the efficient practice of water recycling and reusing. These are all in favour of sustainable agriculture, forestry and power generation.

ii. Addressing the Land Use Change: to counteract what has been said concerning land use in the previous discussion for the challenges, it must be emphasize from what has been disclosed in the literature review that various stakeholders have emphasized the fact that land availability is not a limiting factor to bioenergy development in the continent (Rainer, et al., n.d). This is in view of the fact that the continent is commended with abundant and unutilized lands both arid and Semi-arid most especially in the Sub-Sahara. Another study by Devis et al. (2014) as revealed also in the literature review showed the estimated land size that could be used in future (2050 scenario) for biomass development. Although the analysis was for the whole world which also includes Africa, and showed clearly 390million hectares suitable for crops on low band (0-100EJ), 1300million hectares for agriculture on mid band (300-600EJ) and lastly 4000million hectares that could be converted from a pasture on high band (>600EJ).

iii. Addressing Deforestation Impact: The aspect of Sustainable Forest Management majorly by Afforestation and Reforestation is strongly advocated for in neutralizing the effect of deforestation for the sustainable supply of biomass resource for modern bio-power projects.

4.1.5 Opportunity Areas in Favor of Implementation

i) **Carbon Capture and Storage (CCS) Model:** Biomass is considered carbon neutral on net basis due to the fact that the amount of CO_2 captured during the growth phase i.e. photosynthesis is what is equally released on transformation to energy. However, opportunities exist in transitioning from the carbon neutrality to a more environmentally friendly approach which is carbon negativity in ensuring a more de-carbonized economy for tackling climate change. The carbon negative strategy in this regard is termed Carbon Capture and Storage (CCS) or Carbon Sequestration Model. In this business model approach, biomass feedstock is not utilized fully for bioenergy however; pyrolysis process is applied instead of the complete combustion. This will then lead to bio-char (charcoal), bio-oil and gaseous products generation. Since most of the CO_2 is embedded in the charcoal, it is then seized from further uptake in the bioenergy operations but buried beneath the ground. The bio-oil is what is usually used further for bio-power generation. This approach ensures that not all the CO_2 captured by the plants during photosynthesis is released back in cycle due to charcoal burial and hence, termed carbon negative strategy.

Below figure shows clearly the carbon negative strategy explained above for more insight.

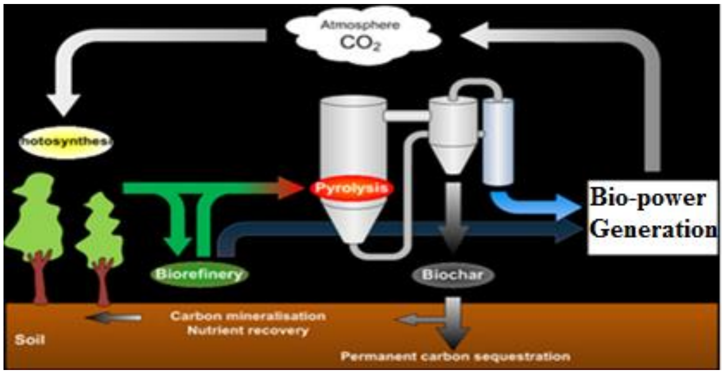


Figure 23: Carbon Negative Strategy with Biomass

ii) **Value Chain Extension:** Value Chain Extension for Bio-Power Projects is another critical opportunity area which basically entails feedstock value addition by various pre-treatment operations coupled with the conversion or transformation chains. According to Centre for Bioenergy Sustainability (2009), value chain analysis stands to address many project related issues constructively such as:

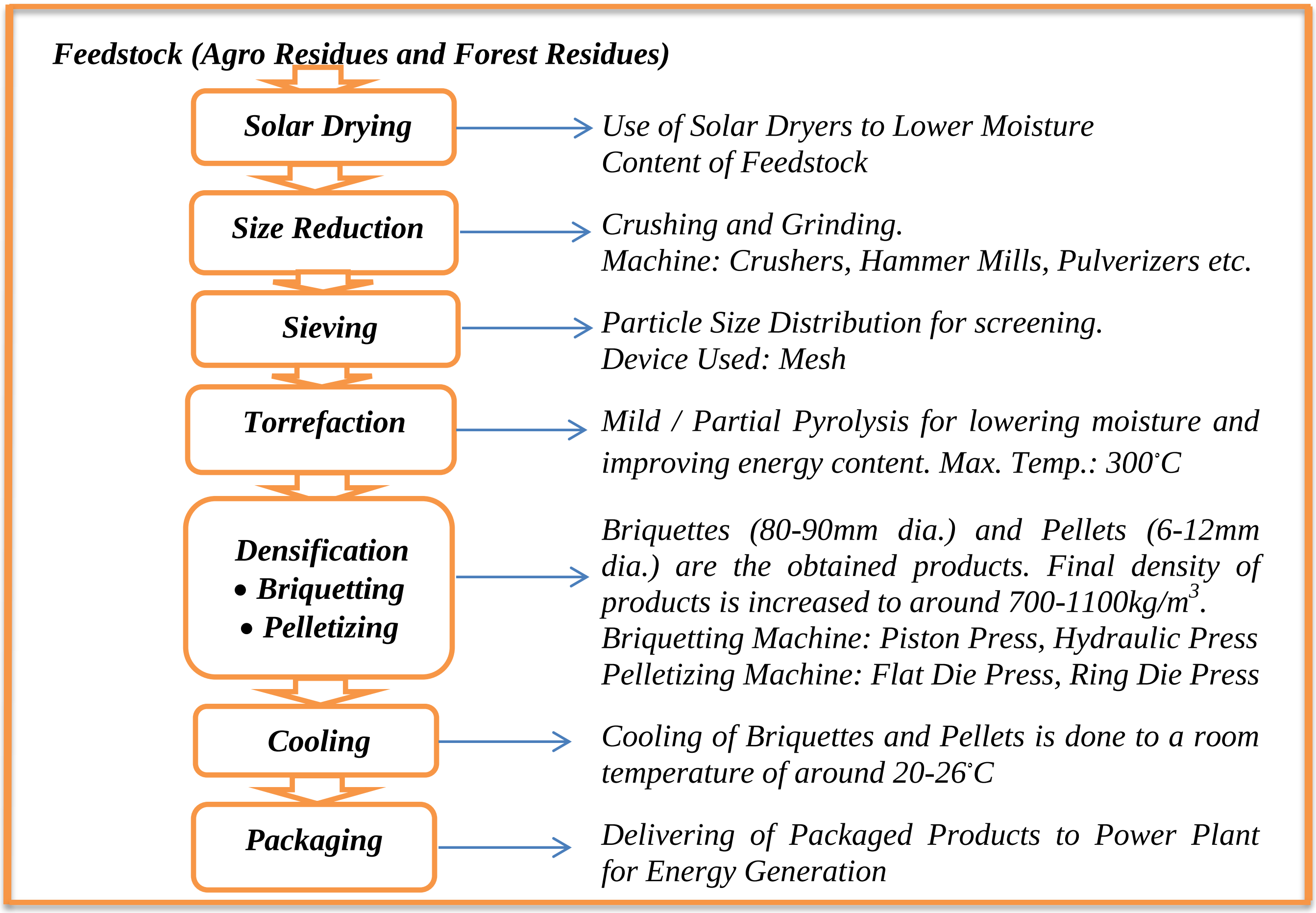
- Cutting net costs
- Improving systems efficiency thereby increasing yield and product quality
- Eliminating waste i.e. ensuring zero waste for sustainability
- Reducing products development time.

The feedstock of interest will majorly be Agro and forest residues for all the technical flow of operations due to the huge economic benefits and waste management opportunities associated. Possible Agro Residues that could be utilized for energy are Cobs, husks, straws, stalks, bagasse, shells, sticks etc.; while possible forest residues are bark, chips, shavings, sawdust etc.

Step 1: Feedstock Value Addition
The technique involved here is called Densification (i.e. compaction by lowering volume and increasing density). Densification of Residues offers the following advantages:

- It ensures sustainable waste management thereby resolving the issue of waste disposal
- Increases the Net Calorific Value (i.e. Low Heating Value) per unit volume of the residues thereby improving the overall efficiency of their conversion to bioenergy.
- Densified Feedstock are easy to transport and less costly

The Operational flows in the densification process of adding value to feedstock is shown below:



Use of Solar Dryers to Lower Moisture Content of Feedstock

Crushing and Grinding.
Machine: Crushers, Hammer Mills, Pulverizers etc.

Particle Size Distribution for screening.
Device Used: Mesh

Mild / Partial Pyrolysis for lowering moisture and improving energy content. Max. Temp.: 300˚C

Briquettes (80-90mm dia.) and Pellets (6-12mm dia.) are the obtained products. Final density of products is increased to around 700-1100kg/m^3.
Briquetting Machine: Piston Press, Hydraulic Press
Pelletizing Machine: Flat Die Press, Ring Die Press

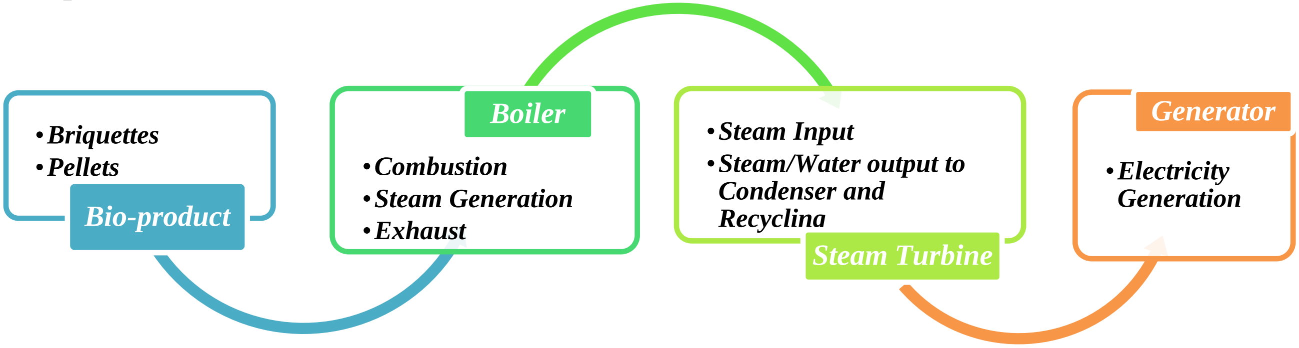
Cooling of Briquettes and Pellets is done to a room temperature of around 20-26˚C

Delivering of Packaged Products to Power Plant for Energy Generation

Figure 24: Block Diagram for Densification Process

Step 2: Bio-products (Briquettes and Pellets) Transformation Chain to Modern Bio-power

i) Bio-power Generation Chain

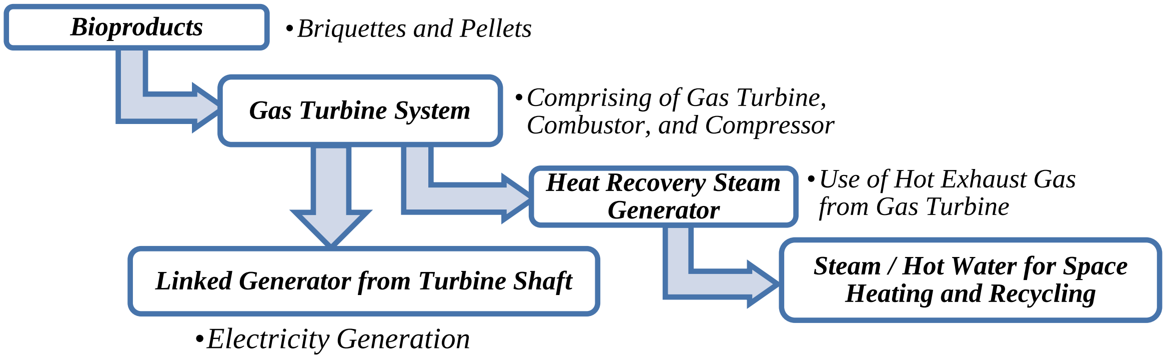


Energy Conversion Route Specification:

Chemical → Thermal → Mechanical → Electrical

Figure 25: Bio-power Generation Chain

ii) Cogeneration (Combine Heat and Power (CHP)) Chain



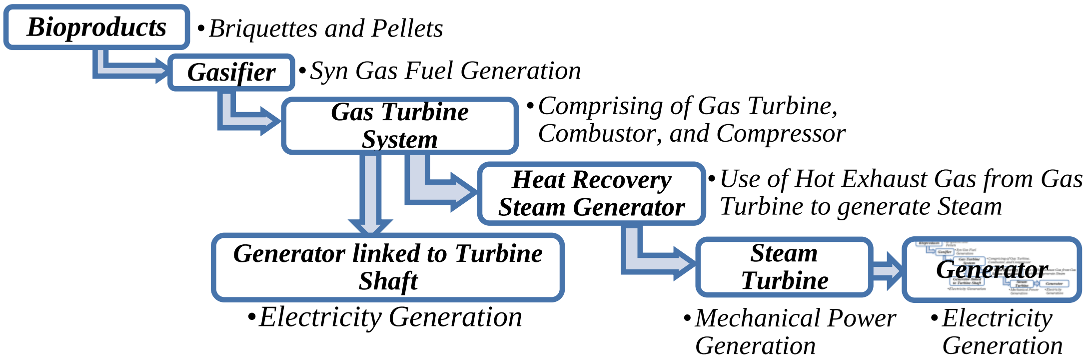
Energy Conversion Route Specification:

*Chemical → Thermal → Mechanical → Electrical **[Power Route)***

*Chemical → Thermal → Thermal **[Heating Route]***

Figure 26: Combined Heat and Power Generation Chain

iii) Integrated Gasification Combined Cycle System (Double Power Generation) Chain



Energy Conversion Route Specification:

*Chemical → Chemical → Thermal → Mechanical → Electrical **[1st Power]***

*Chemical → Chemical → Thermal → Thermal → Mechanical → Electrical **[2nd Power]***

Figure 27: Integrated Gasification Combined Cycle Power Generation Chain

4.2 Transport End Use Assessment for Africa

4.2.1 Assessment of Transport Fuel Scale Up Through Biofuels

This aspect of analysis is aimed at scaling up or improving transport fuel access as a priority area by full exploitation of biomass resource for biofuels. This was done based on the business as usual (BAU) energy information for the 2013 base year and 2030 projection in order to clearly see the enormous potentials of biomass for biofuels in the continent's transport sector energy transformation as follows:

- General Information for the Analysis

Energy Conversion Efficiencies for the Fuels: the energy conversion efficiencies specifically for converting lignocellulosic biomass feedstock to biofuels are as shown below:

Table 29: Energy Conversion Efficiencies from Biomass to Biofuels

Feedstock	Biofuels	Technique of Transformation	Conversion Efficiency
Lignocellulose	Bioethanol	Hydrolysis and Fermentation	35%
Lignocellulose	Biodiesel (FT Diesel)	Gasification and F.T Synthesis	36%

Source: Connor, et al. (2014)

1) 2013 Baseline Transport Fuel Analyses

- Base Case Overview

The 2013 data for the Total Final Energy Consumption (TFEC) by fuel in the Transport Sector according to IRENA (2015) is as shown below:

Table 30: Total Final Energy Consumption by Fuel in Transport Sector during 2013

Fuel Type	Specifications	Energy Consumption (PJ)	Share
Fossil Fuels	Oil (i.e. Diesel, Gasoline, LPG, Kerosene etc.)	3960	99%
Biofuels	Bioethanol	0	0%
	Biodiesel	0	
Others	Such as Electricity used in Electric Vehicles	40	1%
Total		4000	100%

Source: IRENA (2015)

- Proposed Case Assessment

According to the Food and Agricultural Organization of the United Nations Statistics website, the following information regarding Agro Processing and Forestry were obtained for Africa:

Table 31: Biomass Resource Data for Africa during the 2013

Domain	Item	Quantity	Calculated Energy Content (PJ)
Agro Processing	Crop Residue	2373924884kg	31.082
Forestry Production	Wood Fuel	650136757m^3	14199
Total		N/A	14230

Source: FAOSTAT, 2015

Based on the above table showing the huge potentials for Biomass (Agro residues and Forestry Production) for the baseline year, possibilities exist for lowering the fossil fuel portion in the transport fuel energy mix and then replacing with huge amount of the biomass for biofuels in the transport fuel scale up of the base year.

Lowering the fossil fuel consumption by 50% for the oils, and then replacing with 90% portion of the total Biomass resource available for biofuels is a proposal that is feasible. The suggested 90% portion is assumed to be divided equally for the production of the two (2) Biofuels, i.e. 45% for Biodiesel production based on its conversion efficiency and 45% for Bioethanol production also based on its conversion efficiency. The analysis is as shown in the below table:

Table 32: Newly Proposed Total Final Energy Consumption by Fuel in Transport during 2013

Fuel	Specifications	Energy Consumption (PJ)	Share
Fossils	Oil (i.e. Diesel, Gasoline, LPG, Kerosene etc.)	50% of 3960 = 1980	30.2%
Biofuel	Bioethanol (Based on 45% of total biomass use)	(45%×14230)×0.35=2241.23	69.2%
	Biodiesel (Based on 45% of total biomass use)	(45%×14230)×0.36=2305.26	
	Total Biofuels	4546.485	
Others	Such as Electricity used in Electric Vehicles	40	0.6%
Grand Total		6566.485	100%

Concluding Assessment:

Proposed Total Final Energy Consumption in the Transport Sector = 6566.485PJ

Conventional Total Final Energy Consumption in the Transport Sector (IRENA) = 4000PJ

% Fuel Energy Increase = $\frac{6566.485-4000}{4000} \times 100\% = \mathbf{64.16\%}$

- The 90% of the total Biomass Consumption resulting to the 4546.485PJ Biofuel Production is estimated to be 12807PJ, i.e. 6403.5PJ for Biodiesel and 6403.5PJ for Bioethanol.
- The total Biomass resource energy value was estimated at 14230PJ for the 2013 base year.

  Therefore, Biomass Left Over = 14230PJ - 12807PJ = 1423PJ

Note that this huge biomass resource left over of **1423PJ** could then be utilized judiciously and efficiently for other possible applications

2) 2030 Projection Transport Fuel Analyses

➢ Base Case Overview

Below table shows the Business as Usual Total Final Energy Consumption by fuel in the Transport Sector as obtained from IRENA (2015).

Table 33: BAU 2030 Projection Data for Final Energy Consumption by Fuel in Transport Sector

Fuel Type	Specifications	Energy Consumption (PJ)	Share
Fossil Fuels	Oil (i.e. Diesel, Gasoline, LPG, Kerosene etc.)	4438.22	96.4%
Biofuels	Bioethanol	41.87	0.9%
	Biodiesel		
Others	Such as Electricity used in Electric Vehicles	125.61	2.7%
Total		4605.7	100%

Source: IEA (2009)

- Proposed Case Assessment

According to the Food and Agricultural Organization of the United Nations Statistics website, the following information regarding Agro Processing and Forestry were obtained for Africa:

Table 34: 2013 Data for Agro Residues and Forestry Production with the 2030 Forecasted Data

Year	Crop Residue (kg)	Wood Fuel (m^3)	Crop Residue Calculated Energy C. (PJ)	Wood Fuel Calculated Energy C. (PJ)	Total Energy C. (PJ)
2013	2373924884	650136757	31.082	14199	14230
2030	3752248609	801919796.1	48.497	17514	17562

Source: FAOSTAT, 2015

Based on the above table showing the huge potentials for Biomass (Agro residues and Forestry Production) for the 2030 Projection, possibilities exist also for lowering the fossil fuel portion of the transport fuel energy mix and then replacing with huge amount of the biomass for biofuels in the transport fuel scale up of the forecasted year similar to what has been done for the 2013 base year.

Lowering the fossil fuel consumption by 50% for the oils, and then replacing with 90% portion of the total Biomass resource available for biofuels is a proposal that is feasible. The suggested 90% portion is assumed to be divided equally for the production of the two (2) Biofuels, i.e. 45% for Biodiesel production based on its conversion efficiency and 45% for Bioethanol production also based on its conversion efficiency.

Moreover, for the BAU Biofuels consumption already in the mix, which is 41.87PJ, suggesting these production be 50% Bioethanol i.e. 20.935PJ and 50% Biodiesel i.e. 20.935PJ, and all to be produced as advanced biofuels from the forecasted quantified lignocellulose Biomass potential of the 2030 projection from FAOSTAT baseline is worth doing:

Therefore, the newly proposed Total Final Energy Consumption (TFEC) for the 2030 projection based on the above arguments is as follows:

Table 35: Newly Proposed Total Final Energy Consumption by Fuel in Transport for 2030

Fuel	Specifications	Energy Consumption (PJ)	Share
Fossils	Oil (i.e. Diesel, Gasoline, LPG, Kerosene etc.)	50% of 4438.22 = 2219.1	27.7%
Biofuel	Bioethanol (to be 50% of total biofuel already in Mix)	20.935	70.7%
	Biodiesel (to be 50% of total biofuel already in Mix)	20.935	
	Total Biofuels in Mix i.e. existing biofuels	41.87	
	Bioethanol Proposed (for the 45% of total biomass use)	(45%×17562)×0.35=2766.02	
	Biodiesel Proposed (for the 45% of total biomass use)	(45%×17562)×0.36=2845.04	
	Total Proposed Biofuels	5611.059	
	Total Biofuels (Proposed + Existing)	5652.929	
Others	Such as Electricity used in Electric Vehicles	125.61	1.6%
Grand Total		7997.639	100%

Concluding Assessment:

Proposed Total Final Energy Consumption in the Transport Sector = 7997.639PJ

Conventional Total Final Energy Consumption in the Transport Sector (IEA) = 4605.7PJ

% Fuel Energy Increase = $\frac{7997.639-4605.7}{4605.7} \times 100\% = \mathbf{73.65}\%$

- The 90% of the total biomass used in replacement of the reduced 50% Oils = 15806PJ
- Biomass required for the 41.87PJ Biofuels already in mix on equal share for Biodiesel and Bioethanol = $\frac{20.935}{0.35} + \frac{20.935}{0.36}$ = 117.97PJ
- Total Biomass required for both proposed Biofuels and the existing Biofuels = 15923.97PJ

Therefore, Biomass Left Over = 17562PJ - 15923.97PJ = 1638.03PJ

Note that this huge biomass resource left over of **1638.03PJ** could be utilized judiciously and efficiently for other possible applications.

4.2.2 Environmental and Climate Co-Benefits Assessment

As a follow up to the transport fuel scale up analyses based on the 2013 baseline and 2030 projection, this analysis is further aimed at quantifying the CO2 emissions savings from Business as Usual (BAU) scenarios based on the transport fuel scale up through the full and efficient utilization of biomass resource (Agro Residues and Forestry Production) for biofuels and lowering of the fossil fuel utilization. The benefits will not only be from environmental perspective but also from economic point of view due to massive reduction in the cost of incur from fossil fuels utilization for energy.

- ➢ General Information for the Analyses:

GHG Emission Factors: According to RETSCREEN decision tool for energy systems feasibility analyses, the following GHG Emission Factors were established.

Table 36: GHG Emission Factors for Oil and Biofuels

Fuel type	GHG Emission Factors		
	CO_2 Emission Factor	CH_4 Emission Factor	N_2O Emission Factor
Oil	0.269ton/MWh	0.0029kg/GJ	0.0019kg/GJ
Biodiesel (FT Diesel)	0.007ton/MWh	0.0299kg/GJ	0.0037kg/GJ
Bioethanol	0.007ton/MWh	0.0299kg/GJ	0.0037kg/GJ

Source: www.retscreen.net

1) 2013 Baseline Emission Analysis

- ➢ Base Case Emission Analysis

According to the Total Final Energy Consumption from Transport Sector which was obtained from IRENA (2015) and used for the energy scale up analysis, the table is brought as follows:

Table 30: Final Energy Consumption by Fuel in Transport Sector during 2013

Fuel Type	Specifications	Energy Consumption (PJ)	Share
Fossil Fuels	Oil (i.e. Diesel, Gasoline, LPG, Kerosene etc.)	3960	99%
Biofuels	Bioethanol	0	0%
	Biodiesel	0	
Others	Such as Electricity used in Electric Vehicles	40	1%
Total		4000	100%

Source: IRENA (2015)

The Base / Conventional Case CO_2 emission analysis could be carried out as follows:

Base Oil CO_2 Emission = Oil Consumption × Oil CO_2 Emission Factor
= (3960 × 277778)MWh × 0.269tons/MWh
= 295.90MT

- Proposed Case Emission Analysis

From the proposed case total final energy consumption for the transport sector i.e. based on 50% reduction in Oils consumption and 90% use of biomass for biofuels that was previously analyzed in transport fuel energy scale up, the table for the proposed case transport fuel energy scale up which was Table 32 is brought down here for the Emission Analysis:

Table 32: Newly Proposed Total Final Energy Consumption in Transport during 2013

Fuel Type	Specifications	Energy Consumption (PJ)	Share
Fossil Fuels	Oil (i.e. Diesel, Gasoline, LPG, Kerosene etc.)	50% of 3960 = 1980	30.2%
Biofuels	Bioethanol (Based on 45% of the Feedstock Use)	14230 × 0.35 = 2241.225	69.2%
	Biodiesel (Based on 45% of the Feedstock Use)	14230 × 0.36 = 2305.26	
Others	Such as Electricity used in Electric Vehicles	40	0.6%
Total		6566.485	100%

The Proposed Case CO_2 emission analysis could be carried out as follows:

CO_2 Emission for Newly Proposed Oil Consumption
= Oil Consumption × Oil CO_2 Emission Factor
= (1980 × 277778)MWh × 0.269tons/MWh
= 147.95MT

CO_2 Emission for Newly Proposed Biodiesel Use
= Biodiesel Energy Use × Biodiesel CO_2 Emission Factor
= (2305.26 × 277778)MWh × 0.007tons/MWh
= 4.48MT

CO_2 Emission for Newly Proposed Bioethanol Use
= Bioethanol Energy Use × Bioethanol CO_2 Emission Factor
= (2241.225 × 277778)MWh × 0.007tons/MWh
= 4.36MT

Total CO_2 Emission for the Newly Proposed Case (Oils + Biofuels) = 156.79MT

Therefore the CO_2 Emission Savings on replacing the Conventional / Base Case with the Proposed Case for the 2013 base year is as follows:

CO_2 Emissions Savings = Conventional Case Emission – Proposed Case Emission
= 295.90MT – 156.79MT = 139.11MT

According to RETSCREEN Baseline, this Emission savings of **139.11MT** is equivalent to **25117084** automobiles not used during the year

2) 2030 Projection Emission Analysis

- Base Case Emission Analysis

According to the BAU Total Final Energy Consumption from Transport Sector which was obtained from IRENA (2015) and used for the energy scale up analysis, the table is brought down as follows:

Table 33: BAU Total Final Energy Consumption in Transport for 2030 Projection

Fuel Type	Specifications	Energy Consumption (PJ)	Share
Fossil Fuels	Oil (i.e. Diesel, Gasoline, LPG, Kerosene etc.)	4438.22	96.4%
Biofuels	Bioethanol	41.87	0.9%
	Biodiesel		
Others	Such as Electricity used in Electric Vehicles	125.61	2.7%
Total		4605.7	100%

Source: IEA (2009)

The Base / Conventional Case CO_2 emission analysis could be carried out as follows:

Base Case Oil CO_2 Emission = Oil Consumption × Oil CO_2 Emission Factor
= (4438.22 × 277778)MWh × 0.269tons/MWh
= 331.63MT

Note that since both biodiesel and bioethanol have same CO_2 emission and which is same as that of biomass, it will equally be same for biofuels since what is accounted for is the indirect CO_2 emission due to the fact that biomass and biofuel resources are carbon neutral on net basis as already established previously.

Base Case Biofuel CO_2 Emission = Biofuel Consumption × Biofuel CO_2 Emission Factor
= (41.87 × 277778)MWh × 0.007tons/MWh
= 814.14MT

Hence, Total CO_2 Emission for the Base Case (Oils + Biofuels) = 331.71MT

- Proposed Case Emission Analysis

From the proposed Total Final Energy Consumption for the Transport Sector in scaling up the transport fuel as seen previously, the summarized table for the proposed case scale up is brought down as follows for the emission analysis.

Table 35: Newly Proposed Total Final Energy Consumption in Transport for 2030 Projection

Fuel	Specifications	Energy Consumption (PJ)	Share
Fossils	Oil (i.e. Diesel, Gasoline, LPG, Kerosene etc.)	50% of 4438.22 = 2219.1	27.7%
Biofuel	Bioethanol (to be 50% of total biofuel already in Mix)	20.935	70.7%
	Biodiesel (to be 50% of total biofuel already in Mix)	20.935	
	Total Biofuels in Mix i.e. existing biofuels	41.87	
	Bioethanol Proposed (for the 45% of Feedstock Use)	(45%×17562)×0.35=2766.02	
	Biodiesel Proposed (for the 45% of Feedstock Use)	(45%×17562)×0.36=2845.04	
	Total Proposed Biofuels	5611.059	
	Total Biofuels (Proposed + Existing)	5652.929	
Others	Such as Electricity used in Electric Vehicles	125.61	1.6%
Grand Total		7997.639	100%

The Proposed Case CO$_2$ emission analysis could be carried out as follows:

CO$_2$ Emission for Newly Proposed Oil Energy Consumption
= Oil Energy Consumption × Oil CO$_2$ Emission Factor
= (2219.11 × 277778)MWh × 0.269tons/MWh
= 165.82MT

CO$_2$ Emission for Newly Proposed Biodiesel Use + Biodiesel already in Mix
= Biodiesel Energy Use × Biodiesel CO$_2$ Emission Factor
= ((2845.044 + 20.935) × 277778)MWh × 0.007tons/MWh
= 557.27MT

CO$_2$ Emission for Newly Proposed Bioethanol Use + Bioethanol already in Mix
= Bioethanol Energy Use × Bioethanol CO$_2$ Emission Factor
= ((2766.015 + 20.935) × 277778)MWh × 0.007tons/MWh
= 541.91MT

Total CO$_2$ Emission for the Newly Proposed Case (Oils + Biofuels) = 176.81MT

Therefore the CO$_2$ Emission Savings on replacing the Conventional / Base Case with the Proposed Case for the 2030 Projection is as follows:

CO2 Emissions Savings = Conventional Case Emission - Proposed Case Emission
= 331.71MT – 176.81MT = 154.90MT

According to RETSCREEN Baseline, the CO_2 Emission Savings of **154.90MT** is equivalent to **27968056** Automobiles not used for the 2030 projection.

Table 37: Overall Emission Reduction Summary for the Analyses Performed (2013 and 2030)

2013 Baseline Emission Analysis Summary				*BAU 2030 Forecast Emission Analysis Summary*			
Base Case		*Proposed Case*		*Base Case*		*Proposed Case*	
Fuel Type	*Energy Use (PJ)*	*Fuel Type*	*Energy Use (PJ)*	*Fuel Type*	*Energy Use (PJ)*	*Fuel Type*	*Energy Use (PJ)*
Oil	*3960*	*Oil*	*1980*	*Oil*	*4438.22*	*Oil*	*2219.12*
Biofuels	*0*	*New Biofuel*	*4546.485*	*Biofuels*	*41.87*	*New Biofuel*	*5611.059*
		Ex. Biofuels	*0*			*Ex. Biofuels*	*41.87*
295.90MT CO_2 Emission.		*156.79MT CO_2 Emission*		*331.71MT CO_2 Emission*		*176.81MT CO_2 Emission*	
***139.11MT** CO_2 Emission Savings on Substituting the Base Case with the Proposed Case, which is Equivalent to **25113084** Automobiles not used during the Base Year*				***154.90MT** CO_2 Emission Savings on Substituting the Base Case with the Proposed Case, which is Equivalent to **27968056** Automobiles not used for the Projected Year*			

4.2.3 Social and Economic Co-Benefits Assessment

Scaling up the transport fuel through the biofuels i.e. Bioethanol and Biodiesel as a way of boosting the transport sector of the continent as clearly analyzed previously will offer a lot of tremendous socio-economic benefits in terms of economic growth and development which are highlighted below as a follow up:

- Drastic reduction of overdependence on petroleum based fuels thus, lowering their utilization in favour of the green transformation target of the continent.
- Ensuring greater access to biofuels for automobiles to the masses.
- Continuous fall in the costs of transportation as more and more modern biomass is exploited for biofuels at low costs as compared to the conventional fuels.
- Chances exist also in improving job opportunities from biomass feedstock extraction to processing level and finally to distribution level for end use.

4.2.4 Challenges of Implementation with Viable Solutions

A. The Challenges of Implementation

Venturing in to Biomass for biofuels projects offer substantial benefits in meeting up with the African energy demand in transport sector while also addressing environmental issues as seen previously however; some challenges prevail along the line of actions as follows:

i. Food Impact: Since what is advocated for is solely advanced biofuels i.e. biofuels from non-edible feedstock, which has no direct negative impact on food however, it could have indirect impact due to excessive use of lands for growing the biomass feedstock for advanced biofuels production rather than for food crops. This will leads to food production shortage thereby resulting to increase in food prices.

ii. Water Impact: It must be stated that biomass plantation requires huge amount of water to realize the full benefits, which is same to the processing activities to biofuels. This severely affects areas of water scarcity in trying to implement, thereby making the plantations and other processing activities to biofuels unsustainable. Moreover, excessive processing of the biomass to biofuels results in increased ethanol and biodiesel spillage to water bodies thereby contaminating or polluting the water bodies and serving as threat to aquatic animals and to some water requiring activities.

iii. Deforestation Impact: Continuous deforestation as an anti-forestry operation for securing biomass feedstock in abundance for the advanced biofuels production is another critical issue that affects the ecosystem in quite a number of ways such as giving room to increased CO_2 Emission, higher tendencies for soil erosion, land degradation and soon.

B. Possible Solutions to the challenges

This aspect of interest is all about integrating all biomass resources for biofuels in the continent by a win-win relationship with the outlined challenges without any interference.

i. Addressing the Food Impact: to counteract what has been said regarding the indirect impact on food resulting from excessive use of land for biofuels, land availability is not and has never been a problem to execution of activities due to huge unutilized lands available in the continent especially in sub-Saharan Africa as mentioned previously in Bio-power analysis.

ii. Addressing the Water Impact: Water scarcity issue to areas with such experiences could be addressed in a similar way to the proposal given on Bio-power analysis. These are the practice of rainfall harvesting technique, water recycling and reusing, and finally the adoption of improved irrigation systems all in favour of sustainability of biofuels projects at all levels.

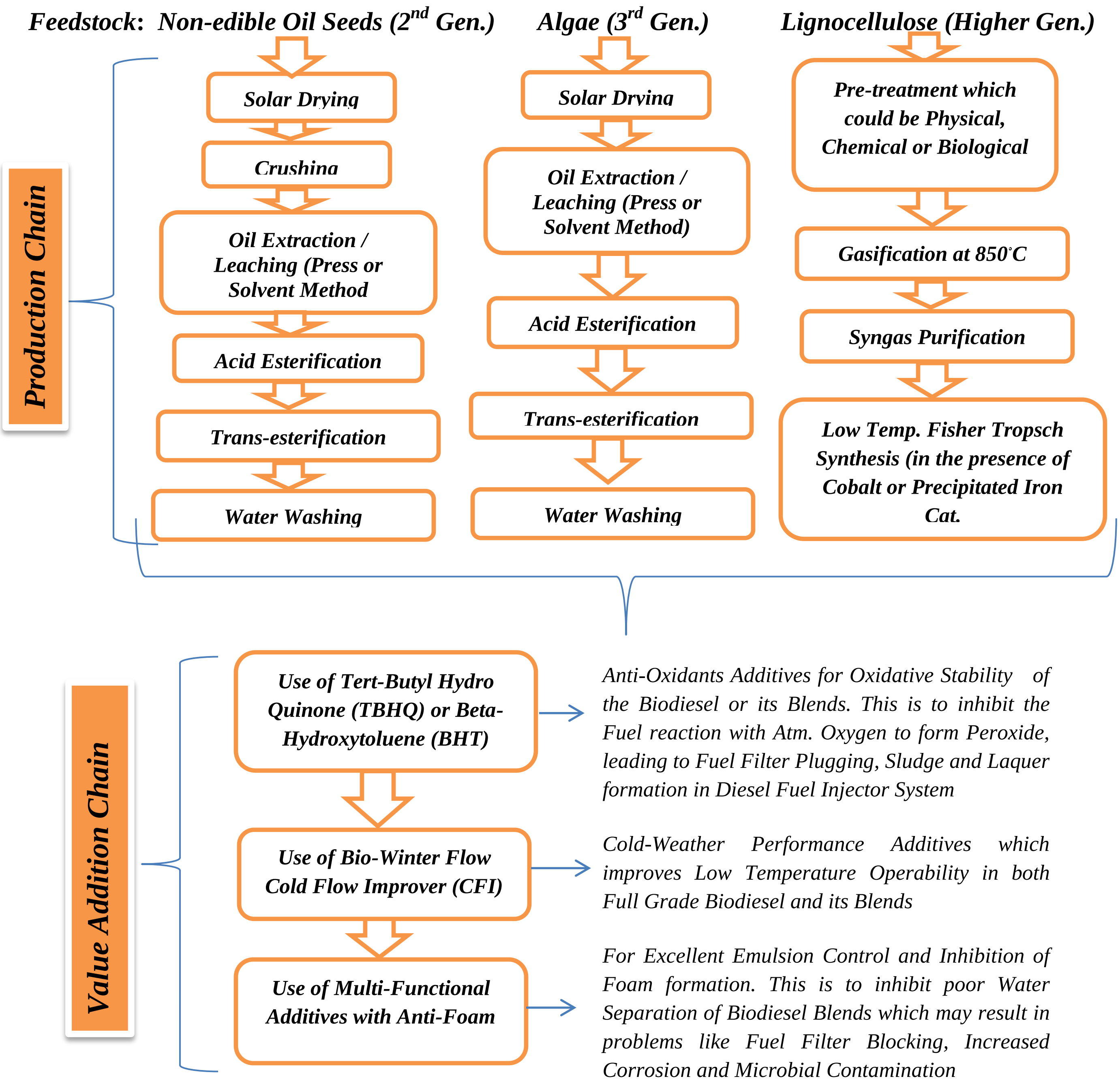
iii. Addressing the Deforestation Impact: Addressing the negative impacts of deforestation could be done also similar to what has been proposed in Bio-power analysis, which is the practice of Sustainable Forest Management in terms of Afforestation and Reforestation. This will to a greater extent ensures sustainability of biomass feedstock supply for biofuels production and energy scale up at large.

4.2.5 Opportunity Areas in Favor of Implementation

A) Biofuel Value Chain Extension: The Opportunity area of interest in this regard is solely the value chain extension which aims at valorization or adding value to biofuels in the processing chain for end use. This offers a lot of benefits as stated previously in bio-power value chain analysis. The major biofuels value chain extension are biodiesel and bioethanol as follows:

i) Advanced Biodiesel Production And Value Addition Chain

Feedstock: Having proposed the use of lignocellulose materials in the transport fuel scale up analysis, opportunities exist in applying other feed stocks like the Non-edible Oil Seed Crops (such as Jatropha Curcas, Castor Seed, Pongame Seed, Neem Seed etc.), and the use of Algae coupled with the value addition. All these applications have no direct impact on food. Below shows the operational chain:



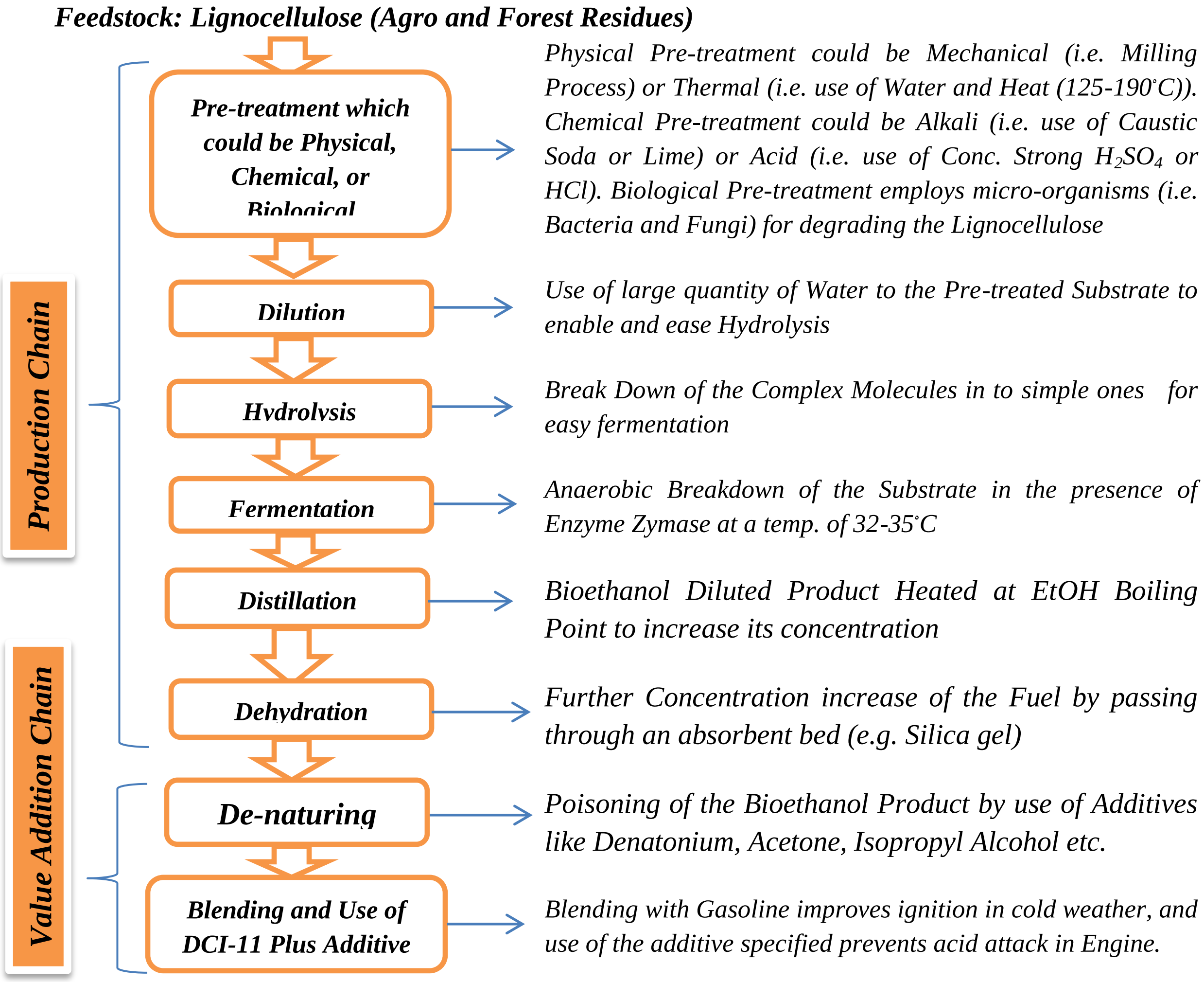
Anti-Oxidants Additives for Oxidative Stability of the Biodiesel or its Blends. This is to inhibit the Fuel reaction with Atm. Oxygen to form Peroxide, leading to Fuel Filter Plugging, Sludge and Laquer formation in Diesel Fuel Injector System

Cold-Weather Performance Additives which improves Low Temperature Operability in both Full Grade Biodiesel and its Blends

For Excellent Emulsion Control and Inhibition of Foam formation. This is to inhibit poor Water Separation of Biodiesel Blends which may result in problems like Fuel Filter Blocking, Increased Corrosion and Microbial Contamination

Figure 28: Advanced Biodiesel Production and Value Addition Chain

ii) Advanced Bioethanol Production and Value Addition Chain



Physical Pre-treatment could be Mechanical (i.e. Milling Process) or Thermal (i.e. use of Water and Heat (125-190˚C)). Chemical Pre-treatment could be Alkali (i.e. use of Caustic Soda or Lime) or Acid (i.e. use of Conc. Strong H_2SO_4 or HCl). Biological Pre-treatment employs micro-organisms (i.e. Bacteria and Fungi) for degrading the Lignocellulose

Use of large quantity of Water to the Pre-treated Substrate to enable and ease Hydrolysis

Break Down of the Complex Molecules in to simple ones for easy fermentation

Anaerobic Breakdown of the Substrate in the presence of Enzyme Zymase at a temp. of 32-35˚C

Bioethanol Diluted Product Heated at EtOH Boiling Point to increase its concentration

Further Concentration increase of the Fuel by passing through an absorbent bed (e.g. Silica gel)

Poisoning of the Bioethanol Product by use of Additives like Denatonium, Acetone, Isopropyl Alcohol etc.

Blending with Gasoline improves ignition in cold weather, and use of the additive specified prevents acid attack in Engine.

Figure 29: Advanced Bioethanol Production and Value Addition Chain

4.3 Heating End Use Assessment for Africa

4.3.1 Industrial Domain

4.3.1.1 Industrial Heat Scale Up Assessment through Bio-heat

This aspect of analysis is aimed at scaling up or improving process heat at industrial level as a priority area by full exploitation of biomass resource for biofuels. This was done based on the business as usual energy information for the 2011 base year and 2030 projection in order to clearly see the enormous potentials of biomass for bio-heat in the industrial sector transformation journey for the continent as follows:

1) 2011 Baseline Heating Analyses

- Base Case Heating Overview

Table 38: Fuel Used for Process Heat at Industrial Level in Africa during 2011

Fuel	Boiler Efficiency	Chemical Energy Input (PJ)	Final Energy Use / Process Heat (PJ)
Coal	85%	591.11	502.44
Oil	80%	785.06	628.05
Gas	75%	781.57	586.18
Biomass	70%	1734.6	1214.2
Total		3892.3	2930.9

Source: IEA (2013); Vatopaolus et al. (2012)

- Proposed Case Heating Assessment

According to the Food and Agricultural Organization of the United Nations Statistics website, the following information regarding Agro Processing and Forestry were obtained for Africa:

Table 39: Biomass Resource Data for Africa during the 2011

Domain	Item	Quantity	Calculated Energy Content (PJ)
Agro Processing	Crop Residue	2226860165kg	29.15
Forestry Production	Wood Fuel	620430540m^3	13550
Total		N/A	13579

Source: FAOSTAT, 2015

Based on the above table showing the huge potentials for Biomass (Agro residues and Forestry Production) for the baseline year, possibilities exist for lowering the fossil fuel portion and then replacing with huge amount of the biomass for the industrial process heat scale up.

Lowering the fossil fuel consumption by 50% (i.e. 50% reduction for each of oil, Gas and Coal) and then replacing with 80% portion of the total Biomass resource quantified for the year is a proposal that is feasible as shown from the below table:

Table 40: Newly Proposed Fuels Use for Process Heat at Industrial Level in Africa during 2011

Fuel	Chemical Energy Input (PJ)	Final Energy Use / Process Heat (PJ)
Coal	50% of 591.11 = 295.555	50% of 502.44 = 251.22
Oil	50% of 785.06 = 392.53	50% of 628.05 = 314.025
Gas	50% of 781.57 = 390.785	50% of 586.18 = 117.236
Total Fossil Fuel	1078.87	682.481
Biomass in Mix	1734.6	1214.2
Biomass Proposed	80% of 13579 = 10863	10863 × 0.7 = 7604.1

Total Biomass	12598	8818.3
Grand Total	13676	9500.8

Concluding Assessment:

Proposed Industrial Process Heat Generation = 9500.8PJ

Conventional Industrial Heat Generation from IEA database = 2930.9PJ

% Process Heat Generation Increase = $\frac{9500.8-2930.9}{2930.9} \times 100\% = \mathbf{224.16}\%$

- Total Biomass Required (80% Proposed Use + Biomass for existing 12142$PJ_{th.}$) = 12598PJ
- Total Biomass Resource (Wood Fuel + Agro Residues) for the 2011 Base Year = 13579PJ

Biomass Resource Left over = 13579PJ – 12598PJ = 981PJ

Note that this huge Biomass resource left over of **981PJ** could then be utilized judiciously for other applications

2) 2030 Projection Analyses

➢ Base Case Overview

Table 41: BAU Fuel Consumption for Process Heat at Industrial Level in Africa for 2030

Fuel	Boiler Efficiency	Chemical Energy Input (PJ)	Final Energy Use / Process Heat (PJ)
Coal	85%	492.59	418.7
Oil	80%	994.41	795.53
Gas	75%	1284	963.01
Biomass	70%	1973.4	1381.7
Total		4744.4	3558.9

Source: IEA (2009); Vatopaolus et al. (2012)

➢ Proposed Case Assessment

According to the Food and Agricultural Organization of the United Nations Statistics website, the following information regarding Agro Processing and Forestry were obtained for Africa:

Table 42: 2011 Data for Agro Residues and Forestry Production with the 2030 Forecasted Data

Year	Crop Residue (kg)	Wood Fuel (m^3)	Crop Residue Calculated Energy C. (PJ)	Wood Fuel Calculated Energy C. (PJ)	Total Energy C. (PJ)
2011	2373924884	650136757	29.15	13550	13579
2030	3752248609	801919796.1	48.497	17514	17562

Source: FAOSTAT, 2015

Based on the above table showing the huge potentials for Biomass (Agro residues and Forestry Production) for the projected year, possibilities exist also for lowering the fossil fuel portion and then replacing with huge amount of the biomass for the industrial process heat scale up of the projected year.

Lowering the fossil fuel consumption by 50% (i.e. 50% reduction for each of oil, Gas and Coal) and then replacing with 80% portion of the total Biomass resource quantified for the year is a proposal that is feasible as shown from the below table:

Table 43: Newly Proposed Fuels Use for Process Heat at Industrial Level in Africa for 2030

Fuel	Chemical Energy Input (PJ)	Final Energy Use / Process Heat (PJ)
Coal	50% of 492.59 = 246.295	50% of 418.70 = 251.22
Oil	50% of 994.41 = 497.205	50% of 795.53 = 314.025
Gas	50% of 128.40 = 64.2	50% of 9063.01 = 117.236
Total Fossil Fuels	807.7	682.481
Biomass in Mix	1973.4	1381.7
Biomass Proposed	80% of 17562 = 14050	14050 × 0.7 = 9834.7
Total Biomass	16023	11216
Grand Total	16831	11899

Concluding Assessment:

Proposed Industrial Process Heat Generation = 1.1899×10^4PJ

Conventional Industrial Power Generation from IEA database = 3.5589×10^3PJ

% Process Heat Generation Increase = $\frac{11899-3558.9}{3558.9} \times 100\% = \mathbf{234.34}\%$

- Total Biomass required (80% Proposed Use + Biomass for existing 1381.7$PJ_{th.}$) = 16023PJ
- Total Biomass resource (Wood Fuel + Agro Residues) for the 2030 Scenario = 17562PJ

Therefore, Biomass Resource Left over = 17562 – 16023 = 1539PJ

Note that this huge Biomass resource left over of **1539PJ** could successfully be utilized effectively for other applications

4.3.1.2 Environmental Assessment for the Industrial Heat Scale Up

As a follow up to the Industrial Process Heat scale up through bio-heat, which was based on 2011 baseline and 2030 projection, this analysis is further aimed at quantifying the CO_2 emissions savings from Business as Usual (BAU) scenarios based on the process heating scale up through the full and efficient utilization of biomass resource (Agro Residues and Forestry Production) and fossil fuel lowering.

1) 2011 Baseline Emission Analyses

➢ Base Case Emission Analysis

According to the table already showcased in the industrial process heat scale up analysis which is brought down as follows:

Table 38: Fuels Used for Process Heat at Industrial Level in Africa during 2011

Fuel	Boiler Efficiency	Chemical Energy Input (PJ)	Final Energy Use / Process Heat (PJ)
Coal	85%	591.11	502.44
Oil	80%	785.06	628.05
Gas	75%	781.57	586.18
Biomass	70%	1734.6	1214.2
Total		3892.3	2930.9

Source: IEA (2013); Vatopaolus et al. (2012)

The CO_2 Emissions quantification for the Base / Conventional case is as follows:

Base Coal CO_2 Emission = Coal Energy Consumption × Coal CO_2 Emission Factor
$= (591.11 \times 277778)\text{MWh} \times 0.338\text{tons/MWh} = 55.49\text{MT}$

Base Oil CO_2 Emission = Oil Energy Consumption × Oil CO_2 Emission Factor
$= (785.06 \times 277778)\text{MWh} \times 0.269\text{tons/MWh} = 58.66\text{MT}$

Base Gas CO_2 Emission = Gas Energy Consumption × Gas CO_2 Emission Factor
$= (781.57 \times 277778)\text{MWh} \times 0.179\text{tons/MWh} = 38.86\text{MT}$

Base Biomass CO_2 Emission = Biomass Energy Use × Biomass CO_2 Emission Factor
$= (1734.6 \times 277778)\text{MWh} \times 0.007\text{tons/MWh} = 3.37\text{MT}$

Total CO_2 Emission for the Base /Conventional Case (Fossils + Biomass) = 156.39MT

- Proposed Case Emission Analysis

In line with the 50% fossil fuel reduction and replacement of the reduced fossils with 80% of the total lignocellulosic Biomass resource available during the base year as showcased in the process heat scale up assessment with the summarized table brought down as follows:

Table 40: Newly Proposed Fuels Use for Process Heat at Industrial Level in Africa during 2011

Fuel	Chemical Energy Input (PJ)	Final Energy Use / Process Heat (PJ)
Coal	50% of 591.11 = 295.555	50% of 502.44 = 251.22
Oil	50% of 785.06 = 392.53	50% of 628.05 = 314.025
Gas	50% of 781.57 = 390.785	50% of 586.18 = 117.236
Total Fossil Fuel	1078.87	682.481
Biomass in Mix	1734.6	1214.2
Biomass Proposed	80% of 13579 = 10863	10863 × 0.7 = 7604.1
Total Biomass	12598	8818.3
Grand Total	13676	9500.8

The CO_2 Emissions quantification for the Proposed Case is as follows:

New Coal CO2 Emission = Coal Energy Consumption × Coal CO_2 Emission Factor
$= (295.555 \times 277778)\text{MWh} \times 0.338\text{tons/MWh} = 27.75\text{MT}$

New Oil CO_2 Emission = Oil Energy Consumption × Oil CO_2 Emission Factor

= (392.53 × 277778)MWh × 0.269tons/MWh = 29.33MT

New Gas CO_2 Emission = Gas Energy Consumption × Gas CO_2 Emission Factor

= (390.785 × 277778)MWh × 0.179tons/MWh = 19.431MT

New Biomass CO_2 Emission = Biomass Energy Use × Biomass CO_2 Emission Factor

= (12598 × 277778)MWh × 0.007tons/MWh = 24.49MT

Total CO2 Emission for the Proposed Case (Fossil Fuel + Biomass) = 101.01MT

Therefore, the CO_2 Emission Savings on Substituting the Base Case with the Proposed Case is as follows:

CO_2 Emission Savings = Base / Conventional Case Emission – Proposed Case Emission

= 156.39MT - 101.01MT = 55.380MT

According to RETSCREEN Baseline, **5.5380 × 10^7tons/yr.** Emission Savings is equivalent to **9999167** Automobiles not used during the base year

2) 2030 Baseline Emission Analyses

- Base Case Emission Analysis

According to the 2030 Business as Usual industrial process heat as showcased in process heat scale up assessment with the summarized table brought down as follows:

Table 41: BAU Fuel Consumption for Process Heat at Industrial Level in Africa for 2030

Fuel	Boiler Efficiency	Chemical Energy Input (PJ)	Final Energy Use / Process Heat (PJ)
Coal	85%	492.59	418.7
Oil	80%	994.41	795.53
Gas	75%	1284	963.01
Biomass	70%	1973.4	1381.7
Total		4744.4	3558.9

Source: IEA (2009); Vatopaolus et al. (2012)

The CO_2 Emissions quantification for the Base / Conventional case is as follows:

Base Coal CO_2 Emission = Coal Energy Consumption × Coal CO_2 Emission Factor

= (492.59 × 277778)MWh × 0.338tons/MWh = 46.25MT

Base Oil CO_2 Emission = Oil Energy Consumption × Oil CO_2 Emission Factor

= (994.41 × 277778)MWh × 0.269tons/MWh = 74.305MT

Base Gas CO_2 Emission = Gas Energy Consumption × Gas CO_2 Emission Factor
= (1284 × 277778)MWh × 0.179tons/MWh = 63.84MT

Base Biomass CO_2 Emission = Biomass Energy Use × Biomass CO_2 Emission Factor
= (1973.4 × 277778)MWh × 0.007tons/MWh = 3.84MT

Total CO_2 Emission for the Conventional Case (Fossil Fuel + Biomass) = 188.23MT

- Proposed Case Emission Analysis

In line with the 50% fossil fuel reduction and replacement with 80% of the total lignocellulosic biomass for the projected year, the summarized table is brought down as follows:

Table 43: Newly Proposed Fuels Use for Process Heat at Industrial Level in Africa for 2030

Fuel	Chemical Energy Input (PJ)	Final Energy Use / Process Heat (PJ)
Coal	50% of 492.59 = 246.295	50% of 418.70 = 251.22
Oil	50% of 994.41 = 497.205	50% of 795.53 = 314.025
Gas	50% of 128.40 = 64.2	50% of 9063.01 = 117.236
Total Fossil Fuels	807.7	682.481
Biomass in Mix	1973.4	1381.7
Biomass Proposed	80% of 17562 = 14050	14050 × 0.7 = 9834.7
Total Biomass	16023	11216
Grand Total	16831	11899

The CO_2 Emissions quantification for the Proposed Case is as follows:

Newly Coal CO_2 Emission = Coal Energy Consumption × Coal CO_2 Emission Factor
= (246.295 × 277778)MWh × 0.338tons/MWh = 23.41MT

Newly Oil CO_2 Emission = Oil Energy Consumption × Oil CO_2 Emission Factor
= (497.205 × 277778)MWh × 0.269tons/MWh = 37.15MT

Newly Gas CO_2 Emission = Gas Energy Consumption × Gas CO_2 Emission Factor
= (64.2 × 277778)MWh × 0.179tons/MWh = 31.92MT

Newly Biomass CO_2 Emission = Biomass Energy Use × Biomass CO_2 Emission Factor
= (16023 × 277778)MWh × 0.007tons/MWh = 31.157MT

Total CO_2 Emission for the Proposed Case (Fossil Fuel + Biomass) = 123.64MT

Therefore, the CO_2 Emission Savings on Substituting the Base Case with the Proposed Case is as follows:

CO_2 Emission Savings = Base / Conventional Case Emissions – Proposed Case Emission
= 188.23MT - 123.64MT = 64.59MT

According to RETSCREEN Baseline, **64.59MT** Emission Savings is equivalent to **11662084** automobiles not used for the projected year

Table 44: Overall Emission Reduction Summary for the Analyses Performed (2011 and 2030)

2013 Baseline Emission Analysis Summary				*2030 Forecast Emission Analysis Summary*			
Base Case		*Proposed Case*		*BAU Base Case*		*Proposed Case*	
Fuel Type	*Energy Use (PJ)*	*Fuel Type*	*Energy Use (PJ)*	*Fuel Type*	*Energy Use (PJ)*	*Fuel Type*	*Energy Use (PJ)*
Fossils	2.1577×10^3	*Fossils*	1.0789×10^3	*Fossils*	2.771×10^3	*Fossils*	*807.7*
Biomass	1.7346×10^3	*New Biomass*	1.0863×10^4	*Biomass*	1.973×10^3	*New Biomass*	1.405×10^4
		Ex. Biomass	1.7346×10^3			*Ex. Biomass*	1.973×10^3
156.39MT CO_2 *Emission.*		*101.01MT* CO_2 *Emission*		*188.23MT* CO_2 *Emission*		*120.36MT* CO_2 *Emission*	
55.38MT CO_2 *Emission Savings on Substituting the Base Case with the Proposed Case, which is Equivalent to **9999167** Automobiles not used during the Base Year*				***64.59MT*** CO_2 *Emission Savings on Substituting the Base Case with the Proposed Case, which is Equivalent to **11662084** Automobiles not used for the Projected Year*			

4.3.1.3 Socio Economic Benefits of the Industrial Heat Scale Up

It is important to note that industrial processes cannot prevail without heat energy access. Scaling up heat energy through bio-heating at industrial level assists tremendously in improving the operations of industries in a sustainable manner. This also ensures speeding up industrial processes and ensuring an improved end products qualities and greater availability to the market for the masses. With greater availability of products also calls for drastic fall in purchase prices and the continental economy blooms up.

4.3.1.4 Opportunity Areas in Favor of Implementation

i) **Carbon Capture and Storage (CCS Model):** In ensuring a more decarbonized economy similar to power projects, chances exist in adopting a carbon negative strategy for heat generation at industrial level through the Carbon Capture and Storage Model. In this business model, Pyrolysis of Biomass feed stock is first incorporated to produce solid (Bio-char), liquid (Bio-oil) and gaseous products. The Bio-char is then buried as a means of lowering the carbon dioxide release on combustion to energy. Bio-oil is what is proposed to be used as a fuel in the industrial boilers for process heat generation.

ii) **Value Chain Extension:** Similar to the power generation projects, value addition of biomass feedstock is equally important in boosting process heat supply at industrial level. The technique involved is Densification in obtaining densified biomass feedstock for industrial boilers so as to improve the efficiency of combustion thereby increasing process heat yield for industrial processes.

The densification process path is similar to what has been showcased in the opportunity areas for power project assessment and is as described below:

Feedstock: Lignocellulose Material (from Agro and Forestry)

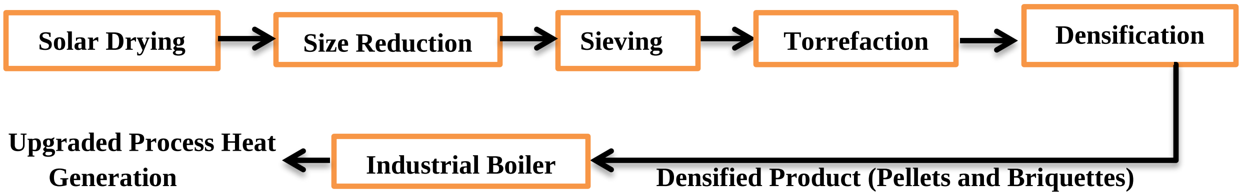


Figure 30: Densification Process Chain with Heat Generation

4.3.2 Building Domain (Residential, Commercial and Institutional)

4.3.2.1 Building Heating Overview with Views of Upgrading

The heating requirement for building is basically for operations such as water heating, space heating, and cooking. Below table shows the total final energy consumption in form of heat for the above mentioned operations as obtained from International Energy Agency (IEA) (2013).

Table 45: Building Final Energy Consumption for 2011 and 2030 Projection

2011 Base year Statistics		2030 Projection Statistics (Current Policy Scenario)	
Fuel Type	Final Energy Use (Heat) (PJ)	Fuel Type	Final Energy Use (Heat) (PJ)
Coal	167.48	Coal	167.48
Oil	837.4	Oil	1172.4
Gas	251.22	Gas	418.70
Biomass	11179	Biomass	13608
Total	12435	Total	15367

Source: IEA (2013)

Based on the data from the above table, it is obvious that most of the building heat utilization comes from Biomass but usually in a traditional way especially in Sub-Saharan regions as seen from numerous literatures. This traditional mode of utilization is considered rudimentary and inefficient, resulting in excessive use of fuel resource with less output at end. This problem can be addressed by adopting improved system of heat generation rather than the conventional or the traditional system of the generation that has been persistent. The improved system recommended is the use of **Improved Cook Stoves (ICS)** for the domestic activities outlined such as water heating, space heating, and cooking. **The Improved Cook Stoves (ICS)** are matured technologies for efficient conversion of the fuel resource especially Biomass to Heat end use. Typical efficiency of **ICS** according to ClimateTechWiki (n.d) is in a range of **(11-40%)** depending on type and design. This improved system of heat generation technique if strongly adopted will ensure the following:

- Less fuel requirement and improved heat generation due to the improved efficiency
- Less pressure on forest resource and fossil fuels for domestic needs.

4.3.2.2 Environmental Benefits of the Building Heat Upgrade

Domestic Heating is considered a low efficiency operation hence, what is majorly accounted for in this regard is air pollutants (such as CO, NO_x, SO_x, PM, etc.) release not Greenhouse Gaseous Emissions. The traditional system of the heat generation at domestic level is considered to be highly polluting i.e. releasing of high Indoor Air Pollutants (IAP) affecting air quality. With the proposed improved system of heat generation at the domestic level calls for significant reduction in air pollutants as well as the reduction in the trace GHG emissions.

4.3.2.3 Socio-Economic Benefits of the Building Heat Upgrade

Adopting the Improved Heating Technique offers a lot of Socio-Economic benefits which are highlighted below:

- With the fuel efficient system, less fuel is required hence, money and time are saved in acquiring fuel for heat generation
- Health Conditions of the population is drastically improved due to the drastic reduction in the indoor pollutants that have severe health impacts mainly respiratory diseases.
- The system gives room for employment opportunities as people will like to invest in the ICS business.
- Continuous investments in the ICS business increases market competition, giving room for improving the technical knowhow of the population.

4.3.2.4 Business Opportunity Areas for the Improved Heating System

In venturing in to the Improved Heating systems, a lot of opportunities exist in form of Business Models all aiming at rapid expansion of the market ranging from rural to peri-urban and to urban areas of the continent significantly. They are as follows:

- ICS Stocking and Distribution
- ICS Assembling
- ICS Installation
- Production of Ceramics Liners and Steel Cladding (ICS Synthesis Materials)

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In Conclusion, Africa is endowed with enormous unutilized Biomass resource which if proper policies are set up for their full utilization to modern bioenergy as proposed will considerably be the heart of the continent energy transformation. The major focuses were in power, transport and heating sectors all in favor of the socio-economic, environmental and climate development.

Buttressing the above argument will be based on the low carbon development assessments performed on the 3 major energy end uses i.e. electricity, transport fuel and heat for the continent based on existing scenarios and forecasting with the summarized results as follows:

- *Power End Use as a Priority Area*

Basing on 2014 scenario, reducing Fossil Fuel consumption by 50% and replacing with 90% of the total available Biomass resource (i.e. Agro Residues and Wood Fuel) for power generation during the year will ensure a percentage power increase by 79.9%, with a huge Emission Savings of 171MT, which is equivalent to 31325162 automobiles not used during the year.

Basing on 2030 forecasting, reducing Fossil Fuel consumption by 25% and replacing with 90% of the total available Biomass resource (i.e. Agro Residues and Wood Fuel) for the forecasted year will ensure a percentage power increase by 43.46%, with a huge Emission Savings of 194MT, which is equivalent to 35611305 automobiles not used for the forecasted year.

- *Transport Fuel End Use as a Priority Area*

Basing on 2013 scenario, reducing Oil consumption by 50% and replacing with 90% of the total available Biomass resource (i.e. Agro Residues and Wood Fuel) for Biofuels (i.e. Biodiesel and Bioethanol) generation during the year will ensure a percentage transport fuel energy increase by 64.16%, with a huge Emission Savings of 155MT, which is equivalent to 27968056 automobiles not used during the year.

Basing on 2030 forecasting, reducing Oil consumption by 50% and replacing with 90% of the total available Biomass resource (i.e. Agro Residues and Wood Fuel) for Biofuels (i.e. Biodiesel and Bioethanol) generation for the forecasted year will ensure a percentage transport fuel energy increase by 73.65%, with a huge Emission Savings of 139MT, which is equivalent to 25117084 automobiles not used for the forecasted year.

- *Heating End Use as a Priority Area*

Basing on 2011 scenario, reducing Fossil Fuel consumption by 50% and replacing with 80% of the total available Biomass resource (i.e. Agro Residues and Wood Fuel) for Industrial Process Heat during the year will ensure a percentage process heat energy increase by 224.16%, with a huge Emission Savings of 55MT, which is equivalent to 9999167 automobiles not used during the year.

Basing on 2030 forecasting, reducing Fossil Fuel consumption by 50% and replacing with 80% of the total available Biomass resource (i.e. Agro Residues and Wood Fuel) for Industrial Process Heat for the forecasted year will ensure a percentage process heat energy increase by 234.34%, with a huge Emission Savings of 65MT, which is equivalent to 11662084 automobiles not used for the forecasted year.

On Switching to Domestic Heat, which is of mostly traditional form of generation, adopting improved heating system majorly the use of Improved Cook Stove (ICS) as recommended will lower the fuel utilization by improving the system efficiency to a range 11-40% with improved Heat energy output depending on system design. This will also ensure a significant air pollutants and GHG emission reduction.

5.2 Recommendations

As a follow up to the conclusion drawn, the following points are strongly recommended in adopting bioenergy systems and ensuring its sustainability in Africa:

- Proper policies and regulatory framework in favor of bioenergy projects implementation need to be set up at all levels and in all the 54 member states of the continent, stating clearly its relevance and the copious opportunities associated.
- Committees need to be set up for sensitizing the 54 member states of the continent about the needs for sustainable energy supply to the continent and for monitoring the successful implementation of the bioenergy policies in the member states.
- Bioenergy researchers need to be supported adequately in terms of finance and the enabling environments for conducting bioenergy research thereby improving their technical knowhow in coming up with multiple innovations in the field of bioenergy all in favor of the continent energy transformation.
- Energy Efficiency practice is of paramount importance in the implementation of bioenergy projects in order to avoid resource over extraction and utilization for realizing the sustainable development target of the continent.
- Need also arises for the continent’s collaboration with external bodies for supports in terms of finances, technology transfer and capacity building in the field of renewable energy with more emphasis on bioenergy.

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