iJET EXPLORE International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 5 No. 3,March, 2015

Municipal Solid Waste as Alternative Source of Energy Generation: A Case Study of Jalingo Metropolis – Taraba State

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ABSTRACT

An investigation of the case study on Alternative Energy Recovery from Municipal Solid Waste (MSW) in Jalingo Metropolis of possible technologies and processes that are or can be utilized to convert post-consumers and post-recycled solid waste into useful end-products was conducted. This arises as MSW became a global problem; hence finding a clean method to convert this waste into an alternative renewable energy source became a major play in the resolution to fossil fuel dependency and reduction in quantity land filled. The paper captures a trend in the MSW conversion into alternative energy for Jalingo Metropolis – Taraba State, the energy recovery of the biodegradable and non-biodegradable waste was considered for both the Thermo-chemical and Bio-chemical conversion processes. Approximately 18,144 tons/year of waste was generated and disposed, out of which 15,930.43 tons/year was available for conversion into energy with bio-chemical and thermo-chemical conversion processes producing 62,596.80 kW and 151,016.14 kW Net Power Generation Potential respectively. Full conversion to electricity is unlikely and the resulting energy potential from the Metropolis MSW being substantial. The technologies for the recovery already exist and are being extensively utilized across the globe for various benefits, it is necessary for the success of these technologies in Taraba State to evolve an Integrated Waste Management System, coupled with necessary Legislative and Control measures. Detailed feasibility study, pollution control measures, Environmental Impact Assessment and cost analysis needs to be conducted in each case and relative assessment of the different waste disposal options.

Keywords: *Municipal Solid Waste, Jalingo, Bio-Chemical, Energy, Thermo-Chemical, Technology, Biodegradable, Power Generation.*

INTRODUCTION

Environmental concerns are becoming a priority issue and concern in Jalingo (Taraba State at large) mainly due to economic growth as a result of the increased energy demand, industrialization and urbanization of Jalingo Metropolis.

Municipal Solid Waste (MSW) is characterized to contain organic as well as inorganic materials.
The latent energy present in its organic content can be recovered for gainful utilization through adoption of suitable Waste Processing and Treatment technologies. The recovery of energy from wastes is of benefits such as:

- Demand for land, which is already scarce in the Metropolis, for landfilling is reduced;
- The total quantity of waste gets reduced by nearly 67% to over 90%, depending upon the waste composition and the adopted technology;
- The cost of transportation of waste to far-away landfill sites also gets reduced accordingly; and
- Net reduction in environmental pollution is another important parameter.

It is, therefore, only logical that, while every effort should be made in the first place to minimize generation of waste materials and to recycle and reuse them to the extent feasible, the option of Energy Recovery from Wastes be also duly examined. Wherever feasible, this option should be incorporated in the over-all scheme of Waste Management (ERMSW, 2012).

Municipal Solid Waste is a global problem; so finding a clean method to convert this waste into a renewable energy source may be a major resolution to fossil fuel dependency. What is the conversion process? Is it cost effective? Where is this process being used? Municipal Solid Waste to energy is a fantastic way to turn the garbage we discard into a renewable energy source that can help heat and power our homes. MSW can be a big renewable energy source that has other environmental benefits as well. Municipal Solid Waste to energy programs also lessen the demand for oil and other fossil fuels, because the energy converted from the MSW is used as an alternative for oil or other fossil fuels. (Sparks and Micheal, 2012 ;Demirbas A. 2001)

Energy can be recovered from the organic content of waste (biodegradable as well as non-biodegradable) basically through two methods as follows:

- **Thermo-chemical conversion** : This process entails thermal de-composition of organic matter to produce either heat energy, fuel oil or gas; and
- **Bio-chemical conversion:** This process is based on enzymatic decomposition of organic matter by microbial action to produce methane gas or alcohol.

The Thermo-chemical conversion processes are useful for wastes containing high percentage of organic non-biodegradable matter and low moisture content.

The main technological options under this category include **Incineration and Pyrolysis/ Gasification.** The bio-chemical conversion processes, on the other hand, are preferred for wastes having high percentage of organic bio-degradable matter and high level of moisture/ water content, which aids microbial activity. The main technological options under this category are **Anaerobic Digestion,** also referred to as **Biomethanation** (ERMSW,2012; Sparks and Micheal, 2012).

If all municipal solid waste was converted into energy, instead of simply discarded, we could end up reducing our dependence on oil and coal by at least three or four percent, which translates into hundreds of thousands of barrels of oil and thousands of tons of coal.

Municipal Solid Waste is a renewable energy source that shows great promise, and all waste to energy facilities follow almost the same procedures when the waste is first received. The waste is sorted, with recyclable materials being set aside. Even tires and many plastics can be turned into energy, but metal cans and other items that can be reused are removed and set aside. At this point, a waste to energy facility that burns the waste will put the materials into the incinerator to burn, so the released energy can be captured in the form of steam. This steam is then used to create electricity (Jaeger and Mayer, 2000 ; Weitz *et al*, 2000).

The most efficient and effective way to convert municipal solid waste to energy is to use landfills created for this purpose. These landfills are designed to maximize the production and recovery of the methane gas that is created by decomposing waste in the landfill. Methane gas can be dangerous when it builds up, and some landfills will simply burn off the gas safely, to remove it and keep it from building to dangerous levels. In a waste to energy landfill however, this gas is collected, purified, and then either used or sold to utilities and other businesses. These landfills are designed to make it easier to recover the gas, and encourage the municipal waste to decompose more quickly, producing more methane gas as well.

Municipal Solid Waste is an alternative energy source that is renewable, sustainable, and ecologically-friendly, and this renewable energy source may be the answer to an energy crisis. Your garbage leaves your home as trash and comes back in the form of electricity, while protecting the environment and eliminating the need for oil and other fossil fuels. Metals are removed before municipal waste is converted to energy, and this means mining for metals will be reduced because of recycling and lower demand (Sparks and Micheal, 2012 ; Williams *et al*, 2003).

- **Disposal System**

In Nigeria like most developing countries, wastes are commonly dumped in open dumps, uncontrolled landfills where a waste collection service is organized. Dumps are located along or beside major roads. In Jalingo, Taraba state, there are two (2) dumpsites which are 3km away from the city along Wukari/Jalingo road (WK/JLB/pit) and Jalingo/Yola road (JL/YLAB/pit) with disposal starting in 1991 and at present, they are used up or filled (ERMSW, 2012; Ogwueleka *et al*, 2009 ; ME&UD, 2014).

Open dumping of waste cannot be considered as a long-term environmental method of disposal. The dangers of open dumping are many; health hazard to scavengers at the dump sites, pollution of ground water, spread of infectious diseases, highly toxic smoke from continuously smoldering fires and foul odors from decomposing refuse. In addition, refuse spreads into the road, blocking traffics, culvert within the metropolis and the wastes are burnt open on the side of the road.

Waste can be disposed in several ways but sanitary landfill is the only land disposal option that enables control and effective mitigation of extreme emission and of surface and groundwater contamination. Sanitary landfills require much greater initial investment and hence higher operating costs than controlled dumps.

Sanitary landfill is not practiced in Taraba State but open dumping is the most commonly practiced. There is no landfill regulation or standard that provides a basis for compliance and monitoring. Wastes in open dumps are set on fires in order to reduce the volume of the wastes (Ogwueleka *et al*, 2009 ; Tsunatu and Abdullahi, 2013).

METHODOLOGY

The solid waste from the different segments (Household, Commercial Setup, Markets, Institutions, Industries, Hospitals and Clinics) of the society was collected, mixed and one kilogram (1kg) sample was prepared by using quartering method. The waste was then characterized and the percentage of each component was calculated. Secondary source of data include municipality information, direct observation, and personal interview were embarked upon. Questionnaire was administered to determine how each of the ministries and agencies in SWM participate or cooperate in solid waste collection services, disposal methods and how the waste was generated and quantified (Tsunatu and Abdullahi, 2013 ; Themelis *et al*, 2002).

RESULTS AND DISCUSSION

The amounts of solid waste generated per capital, per day in Jalingo metropolis was determined so as to estimate the total amounts of domestic solid waste generated per day.

Measurement of waste generation in the metropolis was carried out every week on Friday for a period of ten months and mean value determined. The result suggests that, the waste generation rate in Jalingo metropolis is currently about 0.34kg/ca/day.

Table 1: Solid Waste Generation in Jalingo Metropolis

Waste Source	Total Waste Generated (tons/day)	Percentage of Total
Household	18.72	34.70
Commercial Setup	12.00	22.22
Markets	10.08	18.67
Institutions	6.00	11.11
Others including Industries	2.88	5.33
Hospitals and Clinics	4.32	8.00
Total	54.00	100.00

Source: Field Experiment by Author's, June 2013

Table 2: Composition of Municipal Solid Waste in Jalingo Metropolis Using Quartering Method of 1kg.

S/N	Components	Fraction in 1kg	Approximate Value (%)
1.	Organic Components (Leaves, Crop Straws, Vegetable waste e.t.c.)	0.30	30
2.	Metals (Cans, Scraps, Zinc e.t.c)	0.10	10
3.	Rubber/Leather	0.35	35
4.	Plastics	0.15	15
5.	Clothes/Rags	0.028	2.8
6.	Glass	0.003	0.3
7.	Stones/Sands/Silts/Pebbles	0.019	1.9
8.	Wooden Materials	0.05	5.0

Source: Field Experiment by Author's, June 2013

ENERGY CONVERSION PROCESSES

Gasification is an old technology used for the production of energy from solid materials. Generally, gasification has been used for the conversion of carbonaceous materials into a gaseous product for the production of energy products and byproducts in an oxygen starved environment. The carbonaceous material, whether from Municipal Solid Waste (MSW) or other sources, is processed in an oxygen deficient environment with heat to produce a Syngas comprised mostly of Carbon monoxide (CO) and Hydrogen (H_2). Chemical bonds of the carbonaceous materials (complex chemical compounds) break down with heat to produce the more simple and thermodynamically stable gaseous molecules of Carbon monoxide (CO) and Hydrogen (H_2). The inorganic or "mineral" materials are converted to a solid rock like material, called slag or vitrified slag or ash.

A typical process for the gasification of Municipal Solid Waste (MSW) to Syngas, energy, products and byproducts is illustrated in Figure 1. The organic components of MSW are converted into Syngas, primary product, and the mineral components are converted into slag or vitrified slag or Ash, a byproduct. For some gasification processes, some (limited) amount of oxygen is supplied to the gasification reactor to provide heat in the form of combustion heat necessary for the oxygen deficient reactions to produce Syngas, which are endothermic reactions. Sufficient steam/water is supplied to the gasification reactor to promote some Syngas reactions.

ISSN: 2049-3444

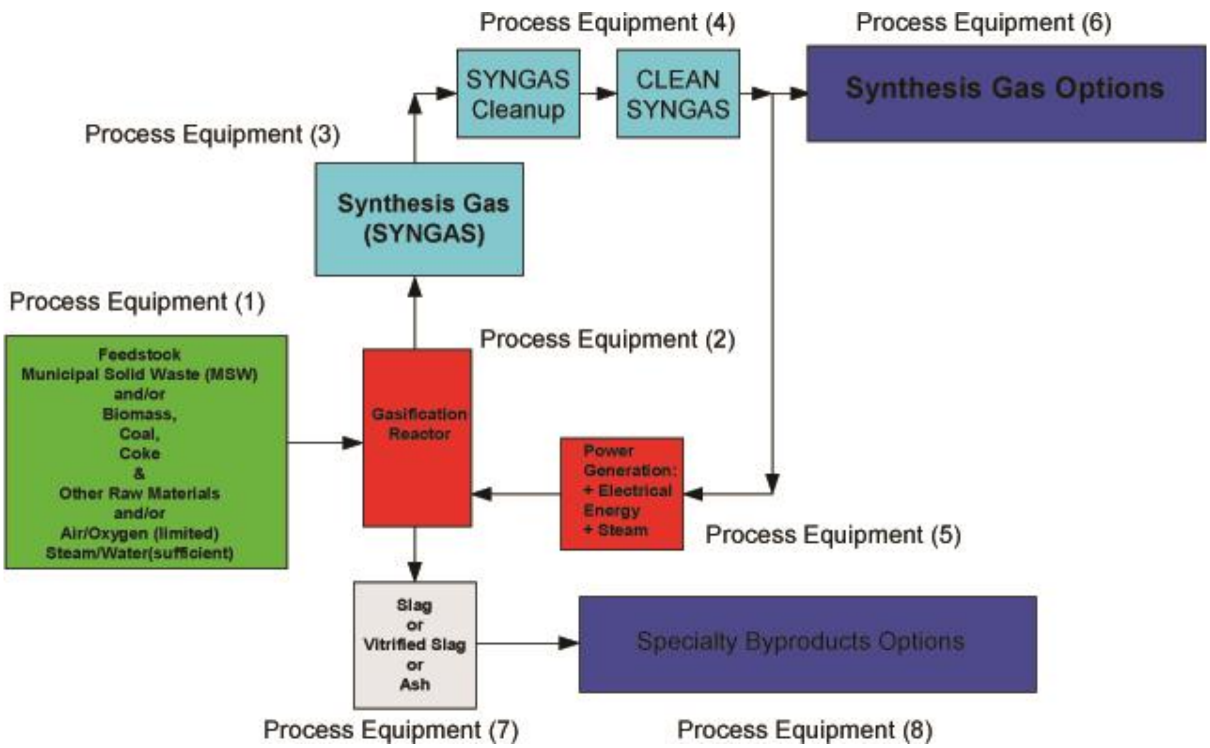

Fig. 1: Process Equipment for the Gasification of MSW to SYNGAS, Energy, Products & Byproducts adapted from (Gary C.Y, 2010).

For energy conversion processes, several basic process approaches (options) exist for the Syngas produced from the management of Municipal Solid Waste (MSW). These Basic process approaches are as follows:

- Power Options,
- Chemistry Options
- Bio-chemistry Options.

Options denote the various uses of the Syngas such as the production of electricity and/or steam in the “Power Option.” Process Options for Syngas are shown in Figure 2.

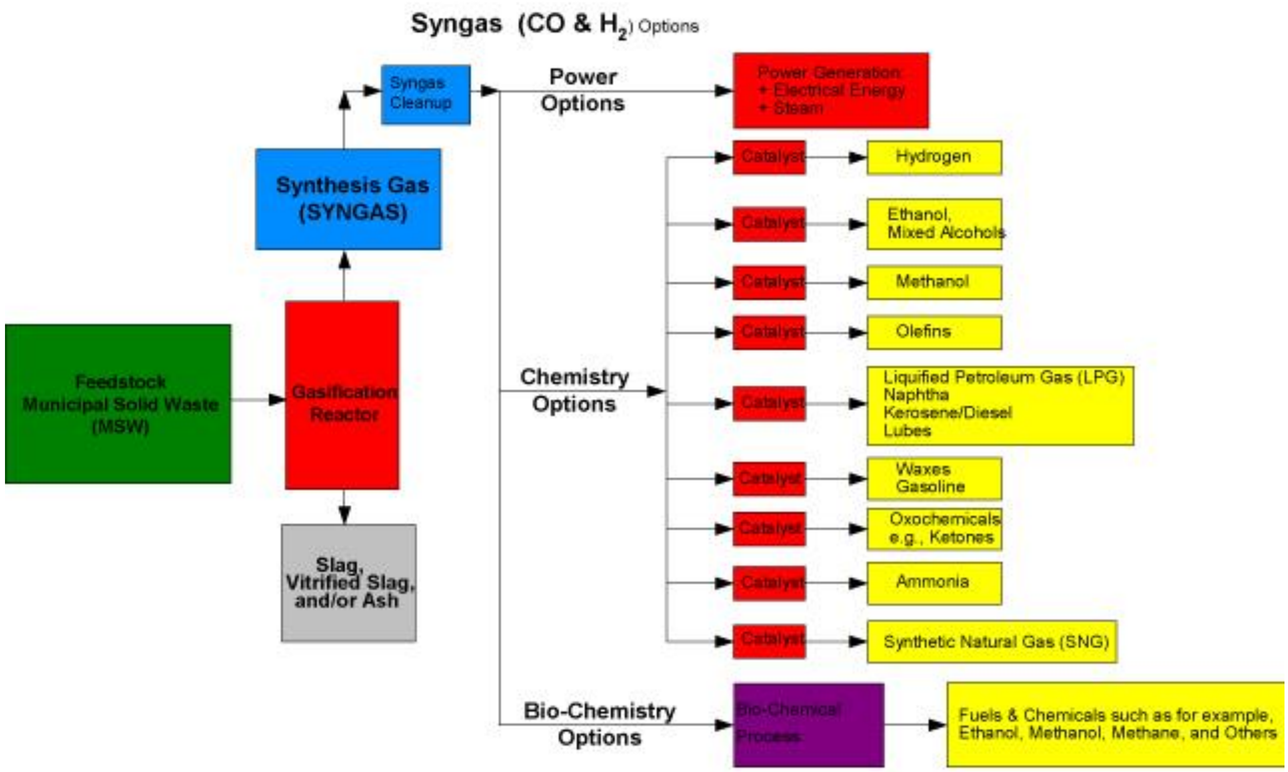

Fig. 2: Syngas (CO & H_2) Process Options adapted from (Gary C.Y, 2010).

➢ The Power Option

One approach for the use of Syngas produced from the conversion of MSW by a Thermal Process is for generation of electricity in a powerhouse. This approach is called the "Power Option." Thermal processes using the Power Option could be: Pyrolysis, Pyrolysis/Gasification, Conventional Gasification and Plasma Arc Gasification. A comparison of these "thermal processes technologies" and the "net energy" produced and exported to "the Grid" is shown in Table 3.

Table 3: Thermal Process Technology and Net Energy (Electricity) to the Grid (ERMSW, 2012;Gary C.Y, 2010)

Type of Thermal Process Technology	Net Energy Production to Grid
Mass Burn (Incineration)	544 kWh / ton MSW
Pyrolysis	571 kWh / ton MSW
Pyrolysis/Gasification	685 kWh / ton MSW
Conventional Gasification	685 kWh / ton MSW
Plasma Arc Gasification	816 kWh / ton MSW

Mass Burn is a thermal process with excess of oxygen environment. The other thermal processes have an environment with a deficiency of oxygen.

From the Net Energy Production to Grid of the various types of thermal process technologies, Plasma Arc Gasification produces about 816 kWh / ton MSW compared to only about 685 kWh / ton MSW for a Conventional Gasification technology. Thus, Plasma Arc Gasification could be considered one of the most efficient thermal gasification processes.
Note, Mass Burn (Incineration) technology produces only 544 kWh/ton MSW (net energy to the Grid) (Gary C.Y, 2010 ; Williams *et al*, 2003 ; Energy.ca.gov, 2012).

➢ Bio-Chemistry Option

Another approach for using the Syngas produced from the management of MSW is the "Bio-Chemistry Option" (Bio-chemical or Biological technologies) that by necessity operates at conditions appropriate for living organisms/microbes. Consequently, the reaction rates are lower and these technologies require feedstock that is biodegradable. One therefore could conclude that these bio-chemical technologies have limitations for applicability for treating Municipal Solid Waste (MSW) compared to the Chemical Option.

However, the real niche for Bio-chemical processes is to take the Syngas, [predominantly, Carbon monoxide (CO) and Hydrogen (H_2)], produced by a Thermal Process] and have the Bio-chemical process (bacteria/microbes) and convert the Syngas to products such as fuels & chemicals, for example, Ethanol, Methanol, etc. (Gary, C.Y, 2010 ; Weitz *et al*, 2002)

➢ Chemistry Option

Another approach could be labeled the "Chemistry Option" which converts Syngas to fuels and chemicals by catalytic chemistry. A catalyst that is used typically is called, Fischer-Tropsch catalyst. Thus, a thermal process can be used to produce Syngas from MSW and then convert the Syngas to chemicals by Fischer-Tropsch chemistry. With this approach termed the "Chemistry Option", a variety of chemicals and products can be produced via the Chemistry Option as shown in Figure 2.

Fischer-Tropsch synthesis is a process for producing mainly straight-chain hydrocarbons (CxHy) from a synthesis gas rich in CO and H_2. Catalysts are usually employed. Typical operating conditions for Fischer-Tropsch synthesis are temperatures of 390-660°F and pressures of 15-40 atmospheres depending on the desired products. The product range includes the light hydrocarbons methane (CH_4) and ethane (C_2), LPG (C_3-C_4), gasoline (C_5-C_{12}), diesel (C_{13}-C_{22}), and waxes (>C_{23}). The distribution of the products depends on the catalyst and the process conditions (temperature, pressure, and residence time).

The synthesis gas must have very low tar and particulate matter content. Biomass derived synthesis gas for Fischer-Tropsch liquid production is still developmental due to gas cleaning issues (ERMSW, 2012 ; Gary C.Y. 2010 ; Boerrigter and Den, 2002).

➢ Parameters affecting Energy Recovery:

The main parameters which determine the potential of Recovery of Energy from Wastes (including MSW), are:

- Quantity of waste, and
- Physical and chemical characteristics (quality) of the waste

The actual production of energy will depend upon specific treatment process employed, the selection of which is also critically dependent upon (apart from certain other factors described below) the above two parameters. Accurate information on the same, including % variations thereof with time (daily/ seasonal) is, therefore, of utmost importance.
The important **physical parameters** requiring consideration include:

- Size of constituents
- Density
- Moisture content

Smaller size of the constituents aids in faster decomposition of the waste. Wastes of the high density reflect a high proportion of biodegradable organic matter and moisture. Low density wastes, on the other hand, indicate a high proportion of paper, plastics and other combustibles. High moisture content causes biodegradable waste fractions to decompose more rapidly than in dry conditions. It also makes the waste rather unsuitable for thermo-chemical conversion (incineration, pyrolysis/ gasification) for energy recovery as heat must first be supplied to remove moisture.

The important **chemical parameters** to be considered for determining the energy recovery potential and the suitability of waste treatment through bio-chemical or thermo-chemical conversion technologies include: -

- Volatile Solids
- Fixed Carbon content
- Inerts,
- Calorific Value
- C/N ratio (Carbon/Nitrogen ratio)
- Toxicity

The desirable range of important waste parameters for technical viability of energy recovery through different treatment routes is given in the Table 4. The parameter values indicated therein only denote the desirable requirements for adoption of particular waste treatment method and do not necessarily pertain to wastes generated / collected and delivered at the waste treatment facility. In most cases the waste may need to be suitably *segregated/ processed/ mixed with suitable additives* at site before actual treatment to make it more compatible with the specific treatment method. This has to be assessed and ensured beforehand. For example, in case of Anaerobic digestion, if the C/N ratio is less, high carbon content wastes (straw, paper etc.) may be added; if it is high, high nitrogen content wastes (sewage sludge, slaughter house waste etc.) may be added, to bring the C/N ratio within the desirable range (Williams *et al*, 2003 ; Energy.ca.gov, 2012).

Table 4: Desirable range of important waste parameters for technical viability of energy Recovery [ERMSW, 2012 ; Williams *et al*, 2003]

Waste Treatment Method	Basic principle	Important Waste Parameters	Desirable Range*
Thermo-chemical conversion -Incineration -Pyrolysis -Gasification	Decomposition of organic matter by action of heat.	Moisture content Organic/ Volatile matter Fixed Carbon Total Inerts Calorific Value (Net Calorific Value)	< 45 % > 40 % < 15 % < 35 % >1200 k-cal/kg
Bio-chemical conversion -Anaerobic Digestion/ Bio-methanation	Decomposition of organic matter by microbial action.	Moisture content Organic / Volatile matter C/N ratio 25-30	>50 % > 40 % 265

*Indicated values pertain to suitably segregated/ processed / mixed wastes and do not necessarily correspond to wastes as received at the treatment facility.

➢ Assessment of Energy Recovery Potential

A rough assessment of the potential of recovery of energy from MSW through different treatment methods can be made from knowledge of its calorific value and organic content, as under:

- ➢ In thermo-chemical conversion all of the organic matter, biodegradable as well as non-biodegradable, contributes to the energy output :

Total waste quantity : W tones
Net Calorific Value: NCV k-cal/kg.
Energy recovery potential (kWh) = NCV x W x 1000/860 = 1.16 x NCV x W
Power generation potential (kW) = 1.16 x NCV x W/ 24 = 0.048 x NCV x W
Conversion Efficiency = 25%
Net power generation potential (kW) = 0.012 x NCV x W
If NCV = 1200 k-cal/kg., then
Net power generation potential (kW) = 14.4 x W

- ➢ In bio-chemical conversion, only the biodegradable fraction of the organic matter can contribute to the energy output :

Total waste quantity: W (tones)
Total Organic / Volatile Solids: VS = 50 %, say
Organic bio-degradable fraction : approx. 66% of VS = 0.33 x W
Typical digestion efficiency = 60 %
Typical bio-gas yield: B (m^3) = 0.80 m3 / kg. of VS destroyed
= 0.80 x 0.60 x 0.33 x W x1000 = 158.4 x W
Calorific Value of bio-gas = 5000 kcal/m3 (typical)
Energy recovery potential (kWh) = B x 5000 / 860 = 921 x W
Power generation potential (kW) = 921 x W/ 24 = 38.4 x W
Typical Conversion Efficiency = 30%
Net power generation potential (kW) = 11.5 x W

TYPICAL ASSESSMENT OF ENERGY RECOVERY POTENTIAL OF JALINGO METROPOLIS

From Table 1 and 2 above;

- ➢ 54 tons/day of waste was generated resulting to approximately 18,144 tons/year.

- ➢ Carrying out an analysis for Energy Recovery Potential using the following Net Power Generation Potential (kW)parameters:-
  a. 14.4 x W(tons) [for Thermo-Chemical Conversion]
  b. 11.5 x W(tons) [for Bio-Chemical Conversion]

- ➢ The following results were obtained for characterized waste components and Net Power Generation Potential of the study area is presented in Table 5 and Figure 3.

- ➢ In Table 5, the electrical generation estimates were simply calculated from the potential primary energy by applying the appropriate thermo-chemical or bio-chemical conversion efficiency.

The resulting electrical energy potential from Jalingo Metropolis MSW is substantial. Figure 3 displays some of Table 5 information graphically; the waste stream component disposal amounts and their associated potential electric energy (annual basis). Full conversion to electricity is unlikely, but solid waste nonetheless represents a significant potential source of energy for Jalingo Metropolis aside that supplied by National Grid.

Table 5: Jalingo Metropolis Disposed Waste Stream Characterized and Potential for Generation of Electrical Power (kW)

S/N	Disposed Waste Components	% of Total	Land filled (W) (tons/year)	Conversion Process	Net Power Generation Potential (kW)
1.	Organic Components	30	5,443.20	Bio-chemical Process (11.5 x W)	62,596.80
2.	Rubber/Leather	35	6,350.40	Thermo-chemical Process (14.4 x W)	91,445.76
3.	Plastics	15	2,721.60	Thermo-chemical	39,191.04
4.	Textile(Cloths/Rags)	2.8	508.03	Thermo-chemical	7,315.66
5.	Wooden Materials	5	907.20	Thermo-chemical	13,063.68
6.	Metals	10	1,814.40	-	-
7.	Glass	0.3	54.43	-	-
8.	Stones/Sand/Silts etc	1.9	344.74	-	-
	TOTAL	100	18,144		213,612.94

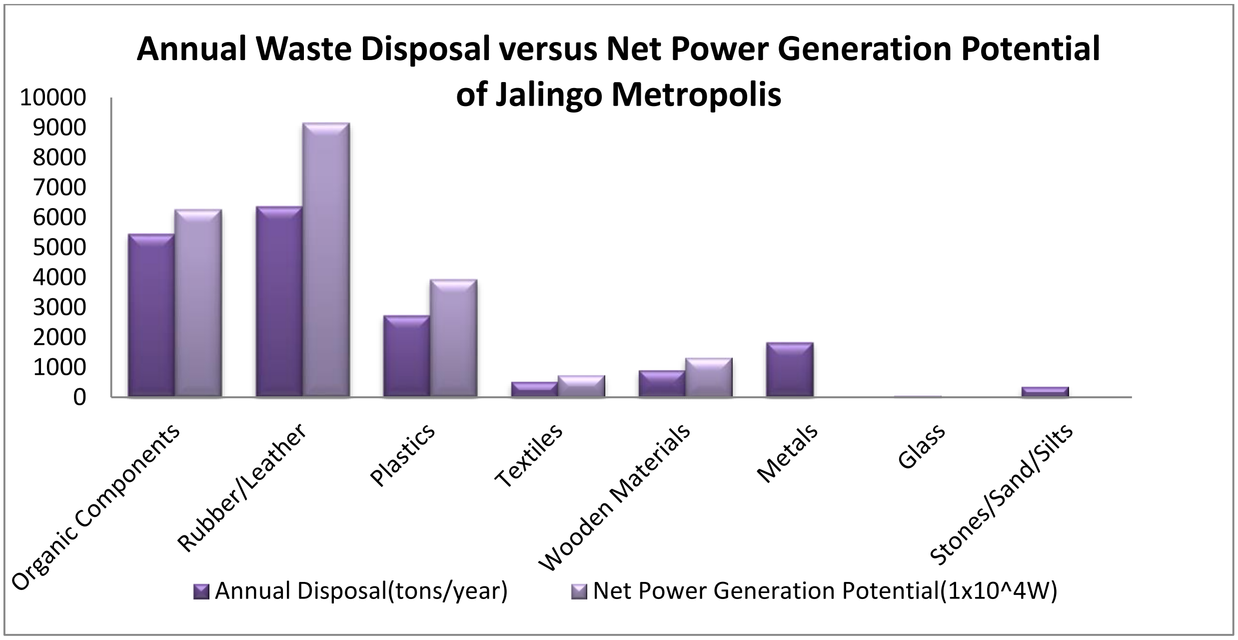

Figure 3: Annual Disposal versus Net Power Generation Potential of Jalingo Metropolis (Authors, 2014)

CONCLUSION

The conclusion is that with the current trends of increasing population and invariant per-capita disposal, waste disposal in the Metropolis can be expected to increase substantially. Without major changes in consumption patterns, economic activity, packaging methods and material, and/or compost and recycle markets, there will be continued long term opportunity and need for utilization of components in the waste stream. Any single strategy for reduction of landfill materials is not likely to be sufficient. Increased recycling and composting, reduction in waste generation and safe and reliable conversion technologies can each contribute to reducing or stabilizing the landfilled waste stream, but a combination of all potential reduction schemes will probably have the best chance for success.

The different technologies for recovering useful energy from Municipal Solid Wastes already exist and are being extensively utilized in different countries for their multiple benefits. It is necessary for the success of these technologies in Taraba State to evolve an Integrated Waste Management system, coupled with necessary legislative and control measures.

RECOMMENDATIONS

Based on the finding of this study, the following recommendations can efficiently improve current issues of Municipal Solid Waste Conversion to Alternative Energy of Jalingo Metropolis:-

- A detailed feasibility study needs to be conducted in each case, duly taking into account the available waste quantities and characteristics and the local conditions as well as relative assessment of the different waste disposal options.
- Suitable safeguards and pollution control measures further need to be incorporated in the design of each facility to fully comply with the environmental regulations and safeguard public health.
- A detailed Environmental Impact Assessment Analysis of the Selected Option either Thermo-chemical or Bio-chemical conversion process should be carried out
- Detailed Capital cost, Operating and Maintenance costs including manpower, Revenue, Cost benefit analysis, etc should be extensively conducted.
- The State Government should provide funds for this alternative source of energy as a means of bridging the problem of electricity supply shortage by the National Grid even if it's a pilot plant to test run before full scale operation.

The Waste-to-Energy facilities, when set up with such consideration, can effectively bridge the gap between waste recycling, composting and land filling, for tackling the increasing problems of waste disposal in the Metropolis, in an environmentally benign manner, besides augmenting power generation in the State - Taraba.

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