Use of Biomass Gas in Running Internal Combustion Engine to Generate Electricity-A Review

D. M. Dzombo, R. Kiplimo and J.K. Kiplagat

Abstract**—** The world is faced with inadequate fuel supply for household and industrial application. Fossil fuels are mostly used to run machineries with the emission of carbon monoxide, carbon dioxide, oxides of nitrogen, sulphur oxides and particulates from their combustion affecting human health and the environment. Biomass also forms a larger percentage of energy utilized in the household and other areas. Apart from its emission after combustion, biomass waste contributes greatly to pollution. One of the alternatives to effective use of biomass such as rice husk waste is to generate electricity.

In this paper a review of energy production from biomass gasification to run internal combustion engines is presented. The gasification process is discussed under drying, pyrolysis, reduction, and oxidation. Different types of designs of gasifiers are reviewed. The current status of gasification technology in developed and developing countries is discussed. The gas generated is introduced to a modified engine with small amounts of diesel used to ignite the mixture. This is because the producer gas cannot ignite by itself under the prevailing pressure. Thus for a compression ignition engine to run on producer gas they have to be either; a dual fuel engine or, converted into a spark ignition engines. Since diesel engines have compression ratios between 16 – 20 and are run at lower revolutions per minute than gasoline engines they are ideally suited to run on producer gases without spark ignition. The paper also looks at current work that has been done and identifies areas that need further research.

Keywords**—** Biomass, Energy, Fossil fuels, Gasification, Internal combustion engine, Syngas.

I INTRODUCTION

Gasification is the conversion of biomass to a gaseous fuel by heating in a gasification medium such as air, oxygen or steam. Unlike combustion where oxidation is substantially complete in one process, gasification converts the intrinsic chemical energy of the carbon in the biomass into a combustible gas in two stages. The gas produced can be standardized in its quality and is easier and more versatile to use than the original biomass e.g. it be used to power gas engines and gas turbines or used as chemical feedstock to produce liquid fuels.

A Fundamentals of gasification

Gasification takes place at high temperatures (between 500 and 1400°C) at a range of pressures that run from atmospheric pressure to 33 bar [1]. According to Prabir Basu [2] the different stages of gasification overlap and there is no clear limit between them. These stages are as shown in Fig.1

B Heating and drying of solids

The typical moisture content of freshly cut wood ranges from 30% to 60%, and may exceed 90% in some types of biomass. Every kilo of moisture in biomass requires a further 2260kJ to vaporize the water, and that the energy cannot be recovered. When little can be done to dry the water present inside the cell walls of biomass the utmost effort must be made to eliminate surface moisture. Depending on the moisture level of biomass, drying processes are usually needed, preferably prior to entry in the gasifier. For gasification, moisture content should be between 10% and 15% [2].

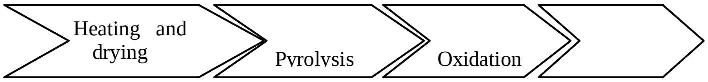

Fig.1. Gasification process steps

C Pyrolysis

This process occurs at between 150 and 400°C and results in the formation of a solid carbonaceous waste known as “char” along with gases (condensable and non-condensable). The main components of this gaseous phase are H_2O, CO_2, H_2, hydrocarbons and smaller quantities of other compounds (Organic acids). The hydrocarbon fraction comprises methane and organic compounds known as tars (which are a problem above a certain concentration). The breakdown of this hydrocarbon fraction maybe influenced by various parameters such as particle size , temperature, pressure, heating time and residence time. Pyrolysis is a stage where char is eliminated but no hydrogen is added [2]. Pyrolysis can be divided into three sub classes: slow pyrolysis, fast pyrolysis, and flash pyrolysis [3]. The main operational parameters are outlined in Table I.

D. M. Dzombo, Department of Mechanical Engineering, JKUAT +2540722737003; fax: +2546752711; e-mail: ddzombo@ jkuat.ac.ke

R.Kiplimo, Department of Mechanical Engineering, JKUAT (e-mail:kiprob @eng. jkuat.ac.ke).

J.K.Kiplagat,EnergyDepartment,KenyattaUniversity,email: jeremykiplagat@gmail.com

TABLE I
OPERATING PARAMETERS OF PYROLYSIS PROCESS [3]

Pyolysis	Heating Rate (k/s)	Residence Time (s)	Temperature (^oC)	Particle Size(mm)	Product
Slow	< 1	300- 1800	400 600	5 - 50	Char,Gas Oil,char
Fast	$500 - 10^5$	0.5- 5	500-650	< 1	70% oil 15% char, 15%gas
Flash	$>10^5$	<1 <1 <0.5	< 650 >650 1000	<0.2	Oil Gas Gas

Oxidation or Partial Combustion of some gases, steam and char by a gasification agent, usually air. Part of the compound is converted to CO, CO_2 and d H_2O. The energy needed for the reduction and pyrolysis reactions is generated at this stage.

Reduction or Gasification of the char produced during pyrolysis. The char is converted mainly to CO, CH_4 and H_2. Biomass char is usually more porous and reactive than coke. Its porosity level is between 40% and 50%, while that of char is between 2% and 18%,moreover,the pores in biomass char are larger than those in char from fossil char. The differences are large enough for the gasification reactions to be different from those of coal, lignite or peat. For instance the reactivity of peat char decreases with conversion and over time while that of biomass char tends to increase. This opposite tendency may be due to the increase in catalytic activity of the alkaline metals in biomass char.

The gasification of biomass char entails several reactions between the char and the gasifying agents which produce CO and H_2. The main reactions that take place in the gasification process are shown in Table II.

TABLE II
MAIN GASIFICATION REACTIONS AT 25°C

Char or gasification reactions	
R1(Boudouard)	$C+CO_2 \leftrightarrow 2CO+172kJ/mol$
R2(Steam)	$C+H_2O \leftrightarrow CO+H_2+131kJ/mol$
R3(Hydrogasification)	$C+2H_2 \leftrightarrow CH_4 - 74.8kJ/mol$
R4	$C+0.5O_2 \rightarrow CO - 111kJ/mol$
Oxidation Reactions	
R5	$C+O_2 \rightarrow CO_2 - 394kJ/mol$
R6	$CO+0.5O_2 \rightarrow CO_2 - 284kJ/mol$
R7	$CH_4+2O_2 \leftrightarrow CO_2+2H_2O - 803kJ/mol$
R8	$H_2+0.5O_2 \rightarrow H_2O - 242kJ/mol$
Shift reaction	
R9	$CO+H_2O \rightarrow CO_2+H_2 - 41.2kJ/mol$
Methanization reactions	
R10	$2CO+2H_2 \rightarrow CH_4+CO_2 - 247kJ/mol$
R11	$CO+3H_2 \leftrightarrow CH_4+H_2O - 206kJ/mol$
R14	$CO_2+4H_2 \rightarrow CH_4+2H_2O - 165kJ/mol$
steam reactions	
R12	$CH_4+H_2O \leftrightarrow CO+3H_2+206kJ/mol$
R13	$CH_4+0.5O_2 \rightarrow CO+2H_2 - 36kJ/mol$

The first two reactions (R1 and R2) are endothermic and the heat required to produce them is supplied mainly by the oxidation reaction (R5), which is highly exothermic.

The result of this process is a gas made up of mainly of CO, H_2, N_2, CO_2, H_2O and hydrocarbons. Very small quantities of NH_3, H_2S and tars are also obtained. After treatment this gas can be burned cleanly to produce mechanical or electrical energy with no waste products, well within environmental regulations on pollutant gas emissions.

II BIOMASS

A Biomass composition

It is often affirmed that scant attention is paid to the biomass to be used in a gasification process, and that the focus is on the plant's technological design, ignoring the fuel, which leads to numerous operational problems.

Concerning the fuel, biomass is a heterogeneous mixture of organic matter, including several solid and liquid phases with different contents.

The diversity of biomass fuels (agricultural wastes, energy crops, forestry wastes, industrial wastes, etc.) renders it essential to characterize them thoroughly, as this will have a direct impact on the design of the power plant that will convert them into electricity. This should be done prior to choice of the technology to be used with a view to avoiding subsequent problems.

There is currently deemed to be need for a more detailed investigation into the study and characterization of the biomass that can be used for energy purposes, as less is known about these fuels than about fossil fuels such as coal [4]. For example, some biofuels, such as oat hulls, have recorded unsatisfactory results, in gasification processes, producing a syngas with a very low calorific value [5], so they are not recommended in processes of this nature.

Vaezi,M et al[6] have developed a numerical algorithm that simulates the gasification of 80 types of biomass. This makes it possible to choose the most suitable type of biomass fuel for obtaining syngas with particular characteristics in a moving/fixed bed atmospheric reactor.

Another case analyzed in the laboratory is that of Qin at el [7], in which the syngas generated in an atmospheric entrained flow, reactor at high temperatures (up to 1350°C) was very similar for cereal straw and wood.

B Types of Gasifiers

Gasifiers are of two main types, fixed bed and fluidized bed, with variations within each type [8]. A third type, the entrained suspension has been developed for coal gasification but the need for a finely divided feed material (0.1 – 0.4mm) presents problems for fibrous material such as wood, which make the process largely unsuitable for most biomass materials.

1 Fixed bed gasifier

The fixed bed gasifier has been the traditional process used for gasification, operated at temperatures around 1000^{o}C. Depending on the direction of airflow, the gasifiers are classified as updraft, downdraft, or cross – flow.

2 Updraft gasifier

In the updraft gasifier the feed is introduced at the top and the air at the bottom of the unit via a grate as shown in Fig.2

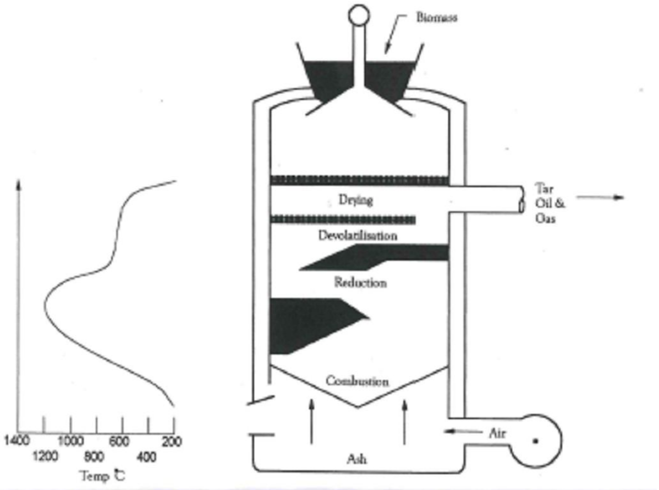

Fig. 2. Schematic of updraft gasifier

Immediately above the grate the solid char (the residual solid remaining after the release of volatiles) formed higher up the gasifier is combusted and the temperature reaches about 1000^{o}C. Ash falls through the grate at the bottom and the hot gases pass upwards and are reduced.

Higher up the gasifier again, the biomass is pyrolised and the top zone, the feed is dried, cooling the gases to around 200- 300^{o}C. In the pyrolysis zone, where the volatile compounds are released, considerable quantities of tar are formed which condenses partly on the biomass higher up and partly leaves the gasifier with the product gas. The temperature in the gasification zone is controlled by humidifying the air. Due to the low temperature of the gas leaving the gasifier, the overall energy efficiency of the process is high but so is the tar content of the gas. The filtering effect of the feed helps to produce a gas with a low particulate content.

3 Downdraft gasifier

In the downdraft gasifier, the feed and air move in the same direction. The product gasses leave the gasifier after passing through the hot zone, enabling the partial cracking of the tars formed during gasification and giving a gas with low tar content. Because the gases leave the gasifier unit at temperatures about 900 – 1000^{o}C, the overall efficiency of a downdraft gasifier is low due to the high heat content carried over by the hot gas. The tar content of the product gas is lower than for an updraft gasifier but the particulates content of the gas is high.

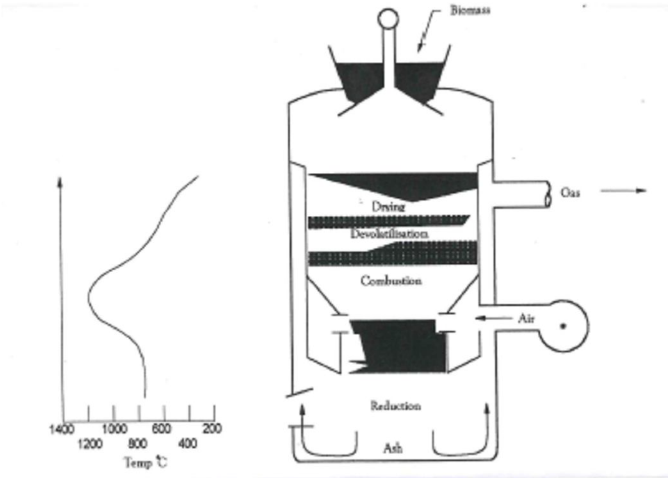

Fig.3 Schematic of downdraft gasifier

4 Cross flow

In a cross- flow gasifier the feed moves downwards while the air is introduced from the side, the gases being withdrawn from the opposite side of the unit at the same level. A hot combustion/gasification zone forms around the entrance of the air, with the pyrolysis and drying zone being formed higher up in the vessel. Ash is removed at the bottom and the temperature of the gas leaving the unit is about800 – 900^{o}C: as a consequence this gives a low overall efficiency for the process and a gas with high tar content.

C Operations and performance

Fixed- bed gasifiers have the advantage of a simple design but the disadvantage of producing a low CV gas with high tar content. The product gas composition is typically 40 – 50% N2, 15 -20% H2, 10 – 15% CO, 10 -15%CO2 and 3 – 5% CH4, with a net CV of 4 – 6MJ/Nm^{3}. When using air as the medium, the resulting high N2 content doubles the volume of the producer gas and increases the size of the downstream gas cleaning equipment. To obtain a high CV gas the moisture content of the feed should be < 15 – 20%, so that pre-drying of the feedstock is required.

Waste heat from the gasifier/engine system can be used to assist with pre – drying the feedstock. The energy content of the producer gas is up to 75% of the biomass energy content, the losses being accounted for by the sensible heat in the product gas, the heat content of the of the ashes and radiation losses. In addition to the initial release of volatiles, a solid char residue is produced (termed charcoal if produced from wood or coal). The char can be reacted further to produce additional gas, making a high char content indicative of considerable gas producing potential. The char derived from straw and wood biomass is typically in the range 22 – 29% w/o but the reactivity of the char varies greatly. Good correlations exist between the yield of char and the C and N contents and also between the CaO content of the char and its reactivity. Char reaction rates at 240 and 260^{o}C generally increase with an increasing char yield but decrease as the content in the char increases.

Improvements to gas quality have been proposed by operating a two- stage, two- reactor process. Pyrolysis of the biomass takes place in the first stage using external heating at 600^{o}C. The gases formed in the first stage are then reacted with steam to crack the tars. In the second stage the gases react with the char from the first stage to produce the final gas. After clean – up the gas quality is sufficient for use in a spark ignition gas engine [9]

D Fluidized bed gasification

Fluidized bed gasification bed (FB) gasification has been used extensively for coal gasification for many years, its advantage over fixed bed gasifiers being the uniform temperature distribution achieved in the gasification zone. The uniformity of temperature is achieved using a bed of fine –grained material and ensuring intimate mixing of the hot bed material, the hot combustion gas and the biomass feed.

Two main types of FB gasifier are in use:

- Circulating fluidized bed,
- Bubbling bed.

A third type of FB is currently being developed, termed a fast, internally circulating gasifier, which combines the design features of the two types. The reactor is still at the pilot – stage of development [10]

1 Circulating FB

Circulating FB gasifiers are able to cope with high capacity through puts and are used in the paper industry for the gasification of bark and other forestry residues. The bed material is circulated between the reaction vessel and a cyclone separator, where the ash is removed and the bed material and the char returned to the reaction vessel. Gasfiers can be operated at elevated pressures, the advantage being for that end – use applications where the gas is required to be compressed afterwards, as in a gas turbine.

2 Bubbling Bed FB

Bubbling bed FB gasifiers consist of a vessel with a grate at the bottom through which air is introduced. Above the grate is the moving bed of fine – grained material into which is the prepared biomass feed is introduced. Regulation of the bed temperature to 700 – 900^{o}C is maintained by controlling the air/biomass ratio. The biomass is pyrolysed in the hot bed to form a char with gaseous compounds, the high molecular weight compounds being cracked by contact with the hot bed material, giving a product gas with low tar content, typically $< 1 – 3$ g/Nm^3

3 Operations and performance

The major operational difficulty experienced with FB gasifiers is the potential for the slagging of the bed material due to the ash content of the biomass. Of particular importance is the alkali metal content of the biomass, which is a problem with biomass derived from herbaceous annual plants. To avoid slagging the bed temperature can be lowered but this results in an increased loss of char with the ash removed. The gas formed in the gasifier contains a number of impurities:

- Particulates,
- Tar,
- Nitrogen compounds,
- Sulphur compounds,
- Alkali compounds.

The end – use of the gas determines the degree of clean – up required and can be achieved by either hot or cold gas cleaning. The benefit of hot- gas cleaning is that more energy is gained from the gas but the process poses significant technical challenges, while cold-gas cleaning is technically simpler but produces a wastewater contaminated with tar, which is likely to pose a disposal problem.

E Other gasification Technologies

1 Plasma gasification – used principally with mainly organic Municipal solid waste (MSW) and other wastes such as paper, plastics, glass, metals, textiles, wood, rubber etc [11] ‘plasma’ is any gas in which at least part of the atoms or molecules are partly or fully ionized. Plasma is formed when an electric arc is generated by running an electric current through gas. This results in high temperatures in the plasma current which make any molecule within that current break its bonds, thus generating a syngas. At the same time the melting of inorganic components (glass, metal, silicates and heavy metals) give rise to a slag that vitrifies on cooling. Plasma gasification process es may reach temperatures from 2000 to 3000^{o}C. There are systems currently under study that have a fluidized bed gasifier and a plasma process arranged in series [12].

2 Supercritical water gasification

These systems make use of the conditions of the critical point of water at 647.3K and a pressure of 22.1MPa as a favourable environment for biomass gasification reactions [13].

Gasification systems with supercritical water are currently the subject of research, with satisfactorily results [13]. This system can be used not just for treating wet biomass but also for treating liquid effluent from gasification plants, according to experiments conducted DibBlasi at.el [14]

3 Properties of syngas

The producer gas is affected by various processes hence one can expect variations in the gas produced from biomass sources. The gas composition is also a function of the gasifier design and thus the same fuel may give different calorific value as when used in two different gasifiers. Table III lists the composition of gas produced from biomass sources.

TABLE III.
COMPOSITION OF PRODUCER GAS FROM VARIOUS FUELS

Fuel	Gasification method	Volume Percentage					C.V .(MJ/m^3)	Ref
		CO	H_2	CH_4	CO_2	N_2		
Charcoal	Downdraft	28-31	5 - 10	1-2	1-2	55-60	4.65 – 5.65	19
Wood with 12-20% moisture content	Downdraft	17-22	16-20	2-3	10-15	55-50	5.00-5.86	19
Wheat straw pellets	Downdraft	14-17	17-19	-	11-14	-	4.50	20
Coconut husks	Downdraft	16-20	17-19.5	-	10-15	-	5.80	20
Coconut shells	Downdraft	19-24	10-15	-	11-15	-	7.20	20
Pressed sugarcane	Downdraft	15-18	15-18	-	12-14	-	5.30	20
charcoal	Updraft	30	19.7	-	3.6	46	5.98	28
Corn cobs	Downdraft	18.6	16.5	6.4	-	-	6.29	29
Rice hulls pelleted	Downdraft	16.1	9.6	0.95	-	-	3.25	29
Cotton stalks cubed	Downdraft	15.7	11.7	3.4	-	-	4.32	29

The maximum dilution of gas takes place because of presence of nitrogen. Almost 50 – 60% of gas is composed of non combustible nitrogen. Thus it may be beneficial to use oxygen instead of air for gasification. However the cost and availability of oxygen may be limiting factor in this regard. Nevertheless, where the end product is methanol – a high energy quality item, then the cost of oxygen can be justified [20].

On average 1kg of biomass produces about 2.5m^3 of producer gas at S.T.P. in this process it consumes about 1.5m^3 of air for combustion [21]. For complete combustion of wood about 4.5m^3 of air is required. Thus biomass gasification consumes about 33% of theoretical Stoichiometric ratio for wood burning.

The average energy conversion efficiency of wood gasifiers is about 60 – 70 % and is defined as

$$\textbf{Gas eff.} = \frac{\textit{Calorific value}\,\frac{gas}{kg}\,\textit{of fuel}}{\textit{Average Calorific Value of 1 kg of fuel}}$$

4 Temperature of Gas

On average the temperature of gas leaving the gasifier is about 300°C to 400°C [22]. If the temperature is higher than this (approx. 500°C) it is an indication that partial combustion of gas is taking place. This happens when the air flow rate through the gasifier is higher than the design value.

F Current status of gasification technology

Current status of gasification technology has been carried out by Foley and Barnard [17]. However, there is confusion regarding the number of manufacturers of gasification equipment. Quite a number of these manufacturers have just produced few units, which are still on experimental stages. There are therefore, close to 64 manufacturers all over the world [15][16]. In US alone there are 27 manufacturers and about 13 universities and USDA research stations working on various aspects of biomass gasification [15]. The world largest gasification manufacturing facility is Gasifier and Equipment Manufacturing Corporation (GEMCOR) in Philippines. They produce about 3000 units/year ranging in size from 10 – 250Kw. Their main application has been for irrigation pumps and power generating sets. To date about 1000 units have been installed within Philippines running on charcoal, wood chips and briquettes. Brazil is another country where large scale gasification manufacturing program has been undertaken about 650 units of various sizes have been installed.

In both the Brazillian and Philippines programs the gasifiers are mostly charcoal powered. in this strict quality control of the fuel has to be maintained. Thus the companies involved in gasifier manufacturing also supply quality fuel. Inadequate fuel quality is the biggest problem in running these gasifiers.

In Europe there are many manufacturers especially in Sweden, France, West Germany and Netherlands who are engaged in manufacturing gasification systems for stationary applications. Most of market for these European manufacturers has been in developing countries [17].

The U.S. and North American Manufacturing activities have been summarized by Goss [18]. In the research area the most active program in gasification is at university of California, Davis and university of Florida, Gainesville. [18]. Many systems in the range of 10 – 100KW have been developed at Davis. U.S. also is ahead of the rest of the world in direct heat application gasifiers. Fluidized and fixed bed gasifiers have been developed for this purpose. In countries in Asia and Africa the work is being carried out in research institution and few prototypes have been made and tested [17]. In Africa biomass has not been extensively explored in the Africa region except South Africa. There have been attempts in recent times by different countries in the region to establish demonstration projects. An example of this is the recent effort by the Ministry of Energy and mineral Development, Uganda, for a gasification system package being implemented to meet heat and power requirements of small capacity [21]. Carbo consult and Engineering (Pvt) Ltd has established a gasification Technology-System Johanssson gas producers- in South Africa. The company has small installations in SA [22] the technology package is to operate on dual fuel mode as well in the gas alone mode. In Uganda a 10KW system was supplied by an Indian company, Ankur Scientific, to operate on dual fuel mode. A minigrid was connected to farmhouse, pigsty and security lights. Eucalyptus branches are used as fuel, with a generation of about 18KWh daily with a specific fuel consumption of 0.84kg/kWh of wood and 0.17litres/kWh of diesel. A simple analysis of this data would show about 60% diesel substitution [23] another operation dating back to the 1960s is based on rice husk gasification in Mali in cooperation with a Chinese group. In Burundi, a dual – fuel system for about 36KW under a European program was supplied from Belgium. The criteria for gasifier selection should include feedstock, manpower, spare parts and environmental conditions to meet the local conditions rather than the available global choice. India has shown leadership in biomass gasification technology. The ministry of new and renewable energy sources has played a key role in India, in both Research and Development and implementation [24] there are about five groups involved both in the development and implementation of the technology package directly using or using a licensing mechanism. The technology packages developed between these groups are different using gas engines, electricity can be generated at a specific fuel consumption of 1.0 – 1.2 kg/kWh. This modern bioenergy technology is also an important component of the mitigation options for climate change [25] coal fired electricity is a major factor in Australia's greenhouse gas emissions (GHG). The country has adopted a mandatory renewable energy target (MRET) to ensure that 20% of electricity comes from renewable sources by 2020 [26] in order to support the MRET a market scheme of tradeable renewable energy certificates (RECs) has been implemented since 2001. In Malaysia the potential of electricity from agriculture residue is shown in table 4 [27] it seems the palm oil residue contribute the highest percentage in the electricity generation compared to others.

TABLE IV
POTENTIAL OF AGRICULTURE RESIDUE BASED ELECTRICITY GENERATION.

Year	E_{total} coconut residue(kWh)	E_{total} sugarcane residue(kWh)	E_{total} paddy residue(kWh)	E_{total}(kWh)
2000	646,491.62	941,574.9721	1785.133	3373199
2001	626,581.006	941,574.9721	1746.853	3315009
2002	626,581.006	941,574.9721	1832,199	3400355
2003	1,465,743.02	588,484.3575	1881967	3936194
2004	1,577,664.8	559,110.7263	1910580	4047356
2005	1,444,234.64	559,110.7263	1929779	3933124
2006	1,296,067.04	588,484.3575	1824001	3708553
2007	1,271,223.46	329,471.0615	1980830	3581525
2008	1,151,335.2	408,267.8212	1962009	3521612
2009	1,160,396.65	411,939.0503	2093762	3666098

Lack of experts in optimization of biomass residues makes the country still low in utilization of biomass therefore most of the industries are not aware of this benefit and they are reluctant to take the risk in utilization of biomass for power generation.[27]

Interesting enough no mention of Japan is there in any worldwide gasification literature. However if the gasification does pick up it will be a matter of time before Japan flexes its economic muscle and mass produces the gasifiers at cheaper rates. Most of the gasifiers (up to 100KW range) being sold by different manufacturers show a leveling off price of USdollars 380/KWe for plant prices and about USdollars 150KWe for basic gasifier price [15]. This leveling off comes at about 100KW system. However, for small systems the prices are extremely high. Thus a 10 KWe gasifier plant costs about USdollars 840/KWe while the basic gasifier is Usd 350/KWe. To this must be added the transportation costs (especially for shipment to development countries). These prices therefore can make the gasifiers uneconomic. This explains the big gasifier manufacturing push being given in countries like Phillipines,Brazil etc.

Unfortunately with all activities going around the world the impact of gasification technology to date on the economy has been negligible and far smaller than that of other renewable energy solar. However, gasification is a recently rediscovered technology and most of the development is still on learning curve.

III. CONCLUSIONS

Increasing concerns about atmospheric CO_2 concentration have further aroused our interest in biomass energy. Woody biomass energy is thought to be nearly CO_2 neutral and is likely to emerge as a means to offset CO_2 emissions from the combustion of fossil fuels. Areas that need further research have been identified in this paper. This paper has explored various options for biomass thermal conversion, for power generation..

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