Biomass Energy

Resource Assessment Handbook

Prepared for

APCTT

**Asian and Pacific Centre for Transfer of Technology
Of the United Nations – Economic and Social
Commission for Asia and the Pacific (ESCAP)**

By

Sameer Maithel

September 2009

Disclaimer

The views expressed in this report are those of the author and do not necessarily reflect the views of the Secretariat of the United Nations Economic and Social Commission for Asia and the Pacific. The report is currently being updated and revised. The information presented in this report has not been formally edited.

The description and classification of countries and territories used, and the arrangements of the material, do not imply the expression of any opinion whatsoever on the part of the Secretariat concerning the legal status of any country, territory, city or area, of its authorities, concerning the delineation of its frontiers or boundaries, or regarding its economic system or degree of development. Designations such as 'developed', 'industrialised' and 'developing' are intended for convenience and do not necessarily express a judgement about the stage reached by a particular country or area in the development process. Mention of firm names, commercial products and/or technologies does not imply the endorsement of the United Nations Economic and Social Commission for Asia and the Pacific.

Table of Contents

Chapter 1:
Introduction

1.1 Introduction to Biomass Energy

Biomass is a collective term used for all materials that are biogenic in origin, that is, derived from the product of photosynthesis (Kishore, 2008). Biomass can be of various types, it can have plant-origin or animal-origin. Classification of biomass resources on the basis of their origin is presented in Figure 1.1

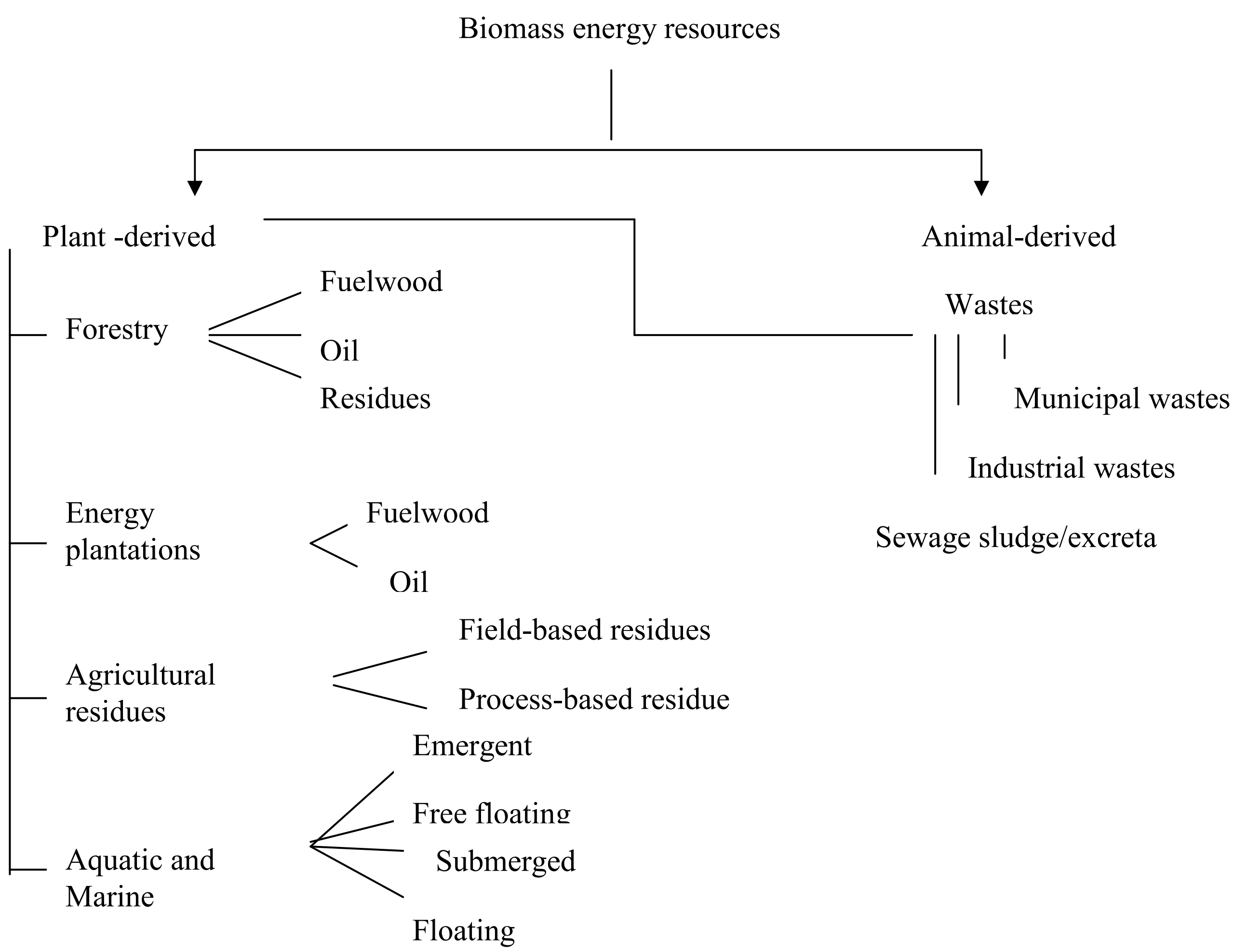

Fig 1.1 Classification of biomass resources on the basis of their origin (Kishore, 2008)

Biomass in the form of fuelwood was perhaps the first energy source used by human beings and was the main fuel till the industrial revolution, after which fossil fuels like coal and oil replaced biomass as the main fuels. Biomass is still an important fuel in developing countries. As per International Energy Agency, biomass energy accounted for 11% of the world's final energy consumption in the year 2001 (Karekezi, Lata and Coelho 2004). This percentage was 18% for Latin America, 25% for Asia and 49% for Africa. Biomass energy offers several advantages in the form of energy security, socio-economic development and environment (box 1.1).

Box 1.1: Benefits of biomass energy

Energy security: Decentralized biomass energy could help nation to substantially reduce dependence on fossil fuels.

Rural economic growth: Biomass energy could stimulate growth in farming, forestry and rural industry leading to overall rural development. Biomass energy could also provide a productive avenue for using agricultural and forestry wastes, besides plantations.

Environmental protection: By offsetting fossil fuel use and related emissions of nitrogen oxides, sulfur dioxides, and other pollutants, biomass energy will contribute to cleaner air and water. Furthermore, increased cultivation of carbon-fixing plants will help mitigate greenhouse gas emissions that contribute to global

Source: Gokhale, Gupta, Kishwan et al. (2007)

It is estimated that around 2.4 billion people in the world depend primarily on biomass fuels to provide energy for cooking. Apart from cooking, biomass fuels are also used for process heating, steam generation, mechanical and shaft power, transport fuel and electricity production. The examples of biomass that are commonly used as fuel includes:

- fuelwood,
- agricultural residues such as husks and stalks,
- vegetable oils and
- animal wastes.

In recent year's , world has seen tremendous interest in biofuels, and a large research effort is focused on finding new biomass resources and processes for production of biofuels.

A variety of physical, thermo-chemical, chemical and biochemical processes are used for converting biomass into energy. In this chapter we will look into three modern biomass energy technologies [1] (refer table 1.1) which can be applied in a decentralized manner and have proved to be useful in developing country context.

Table 1.1. Decentralized modern biomass energy technologies

Technology	Type of biomass	Conversion process	End use applications	Technology Status
Biomass gasification	Wood, woody biomass, agro and agro industrial residues	Thermo-chemical process which converts biomass into producer gas	Power generation: 10kW -1000 kWe. Thermal applications in small industries up to 3 MW_{th}.	Dual fuel and 100% gas engine based gasifiers available commercially
Biogas	Animal dung	Bio-methanation process which converts biomass into biogas	Cooking in households, Motive Power and Electricity generation	Dung-based plants commonly being built.
Biofuels	Non-edible vegetable oil seeds	Extraction of bio-oil from the oilseeds. Bio-diesel production through trans-esterification	Motive power and Electricity generation	Bio-diesel and Straight Vegetable Oil (SVO) demonstrated as fuels for transportation and power generation.

Source: Gokhale, Gupta, Kishwan et al. (2007)

[1] Modern biomass energy technologies results in making available larger quantities of high-quality energy. Generally, the conversion efficiencies are much higher compared to the traditional biomass energy technologies (e.g. traditional wood burning cookstove) and usually these processes also generate large amount of nutrients for sustainable agriculture e.g. slurry from a biogas plant, oil seed cake of vegetable oil seeds (Karekezi, Lata and Coelho 2004) .

1.2 Biomass gasification for electricity generation and thermal applications

1.2.1 Principle of operation

Biomass gasification is a thermo-chemical conversion process in which a solid biomass fuel e.g. wood is converted into a combustible gas. In a biomass gasifier, biomass is burned in a limited amount of air. The amount of air supplied is less than the amount of air required for complete burning. This converts the biomass (which consists of carbon, hydrogen, oxygen, etc) into an inflammable mixture of gases known as producer gas/ wood gas (box 1.2). The producer gas consists of carbon monoxide (CO), hydrogen (H_2), and methane (CH_4) , along with carbon dioxide (CO_2) and nitrogen (N_2).

Box 1.2 : Gasification Reactions

In a gasifier biomass is progressively heated from the ambient temperature to a temperature of around 1100 ^{o}C. The main reactions which take place in a gasifier are:

Drying: Biomass fuels usually contain upto 35% moisture. When the biomass is heated to around 100^{o}C, the moisture gets converted into steam.

Pyrolysis: After drying as the biomass is heated it undergoes pyrolysis. Pyrolysis is the thermal decomposition of biomass fuels in the absence of oxygen. Biomass decomposes into solid charcoal, liquid tars and gases.

Oxidation: Air is introduced in a gasifier in the oxidation zone. The oxidation takes place at about 700-1400 ^{o}C, in which the solid carbonized fuel reacts with oxygen in the air producing carbon dioxide and releasing heat.

$$C + O_2 = CO_2 + 406 \text{ kJ/g.mol}$$

Reduction: At higher temperatures and under reducing conditions several reactions take place which results in formation of CO, H_2 and CH_4.

$$CO_2 + C = 2CO - 172.6 \text{ kJ/g.mol}$$

$$C + H_2O = CO + H_2 - 131.4 \text{ kJ/g.mol}$$

$$CO_2 + H_2 = CO + H_2O - 41.2 \text{ kJ/g.mol}$$

$$C + 2H_2 = CH_4 + 75 \text{ kJ/g.mol}$$

Source: Kishore (2008)

Typical composition of producer gas is presented in Table 1.2. The producer gas so obtained is a low calorific value gas with typical higher heating value (HHV)[2] in the range of 5.4-5.7 MJ/m^3 (Kishore, 2008). The producer gas can be directly burned in a burner to provide thermal energy or it can be used as a fuel in an engine to provide mechanical power or electricity.

Table 1.3 Composition of producer gas (TERI, 2006)

Component	Composition (%)
Carbon monoxide	18 – 22
Hydrogen	13 – 19
Methane	1 – 5
Heavier hydrocarbons	0.2 - 0.4
Carbon dioxide	9 – 12
Nitrogen	45 – 55
Water vapour	4

Box 1.3 : How does calorific value of producer gas compares with other gaseous fuels ?

Producer gas produced from common fixed-bed, air-blown gasifiers is a low calorific value gaseous fuel having HHV ranging from 5.4-5.7 MJ/m^3. In comparison, biogas has a HHV of ranging from 16-25 MJ/m^3 which is 3-4 times higher compared to producer gas and natural gas has HHV of around 38 MJ/m^3, which is around 7.5 times higher compared to that of producer gas.

[2] Calorific value is the amount of heat generated by unit mass of the solid or liquid fuels or unit volume of gaseous fuels on its complete combustion. Higher Heating Value (HHV) considers moisture in liquid state after combustion.

Fixed-bed gasifiers are the most common type of gasifiers and have a long history going back to 1850s when the first gasifier units were built in France. During World War II scarcity of petroleum products resulted in greater interest in gasification technology and gasifiers mounted on vehicles were used to power vehicles. By the end of the war in 1945 more than a million vehicles were in operation using gasifiers throughout the world (Kaupp and Goss 1987). Operation of biomass gasifiers was a cumbersome process and easy availability and cheaper prices of petroleum products resulted in decommission of gasifiers and loss of interest in gasifier technology. The renewed interest in gasifier technology can be traced back to the oil crisis in 1970s. In 1980s developing countries like India started research and demonstration programmes in gasifiers to use local biomass resources and find applications in rural areas e.g. to power water pumps, produce electricity and produce thermal energy in kilns and furnaces. Today, biomass gasifiers are commercially available and are considered an important biomass energy technology for utilizing woody and loose biomass.

Classification of biomass gasifiers based on the density factor (ratio of dense biomass phase to total reactor volume) is a simple and effective method of classification. The gasifiers can be classified into a) dense-phase gasifiers b) lean phase gasifiers. In lean phase gasifiers e.g. fluidized bed, the biomass occupies very little reactor volume i.e. 0.05 -0.2. Most of the gasifiers employed for decentralized applications in developing countries are dense phase reactors, mostly fixed bed reactors, they have typical density factor of 0.3 -.08 (Kishore 2008). There are two main types of fixed bed gasifiers:

- Updraft or counter-current gasifier: In this type of gasifier air enters the gasifier from below the grate and flows in an upward direction within the gasifier. The resulting producer gas is reach in hydrocarbons (tars) and has higher heating value. It is more suitable for burning in furnaces for thermal applications. Due to higher concentration of impurities (tar) it requires a more elaborate gas cleaning system if the gas has to be used in an IC engine.

- Downdraft or co-current gasifier: In the downdraft gasifier, air enters at the middle level of the gasifier above the grate, and the resultant mixture of air and gas flows down into the gasifier reactor through the high temperature oxidation zone resulting in thermal cracking of volatiles resulting in a gas which has relatively lower tar content and is better suited for use in engines.

1.2.2 Common biomass feedstock for gasification

A large type of biomass feedstock have been tried and tested in fixed bed gasifiers. The chemical composition, size, bulk density, moisture content, ash properties are some of the important parameters that determines suitability of a biomass resource for use in fixed bed gasifiers.

The common biomass feedstock used in fixed-bed gasifiers are:

- *Fuelwood:* Dried fuelwood having moisture content less than 20 % and cut into suitable size is the most common biomass feedstock used for gasification. Fuel wood obtained from *Prosopis Juliflora,* eucalyptus, casurina, acacia, neem , mango have been found to be good gasification material.

- *Biomass briquettes:* Due to low bulk densities (50-200 kg/m3), many non-woody biomass residues poses problem in direct utilization in fixed-bed gasifiers. Such biomass materials can be densified and converted into briquettes (density : 800-1200 kg/m^3) and can then be easily used in gasifiers. Briquettes made from sawdust, coffee husk, groundnut shells, pulverized mustard stalk, and cotton sticks are found to be good feedstock for fixed bed gasifiers.

- *Agriculture residue:* Several agriculture residues have been successfully used directly (without densification) in fixed bed gasifiers. However, it should be noted that utilization of some of these materials necessitates modification in the design of gasifiers which are designed primarily for utilization of fuelwood or biomass briquettes. Some of the prominent agriculture residues which have been used in fixed-bed gasifiers are: coconut shells, stalks such as mustard, arhar and cotton, rice husk, cashew nut shell, corn cob, etc.

Some of the important properties (proximate analysis, HHV and bulk density) of common biomass materials used for gasification are tabulated in Table 1.3

Table 1.3 Proximate analysis and HHV of some common biomass materials used for gasification

Biomass	Proximate analysis (%)			Higher Heating Value (MJ/kg)
	Fixed carbon	Volatile matter	Ash	
Bamboo stick waste	47.7	12.7	39.60	17.657
Corncob	16.8	82.10	1.10	18.795
Cotton stalk	17.3	65.4	17.3	15.83
Eucalyptus	21.3	75.35	3.35	18.64
Eucalyptus saw dust	16.20	83.60	0.20	18.502
Hybrid poplar	12.49	84.81	2.70	19.02
Lantana briquette	11.90	20.80	67.30	7.687
Mulberry stick	22.80	75.10	2.10	18.356
Rice husk	13.2	65.3	19.2	13.1
Subabul (*Leucaena leucocephala*)	13.8	85.2	1.0	16.66

(Source: Kishore, 2008)

1.2.3 Typical applications

As mentioned earlier, during Second World War the gasifiers were mainly employed for transportation purposes. However, in recent years the gasifiers have been employed mainly for stationary applications.

a) <u>Electricity generation</u>

For generating electricity, the producer gas from the biomass gasifier is first cleaned and cooled and then used as a fuel in an IC engine. A generator coupled to the engine produces electricity. Biomass gasifier engine sets are typically available in capacities ranging from 10 kWe to 500 kWe. Two types of engines are used. Diesel engines are modified and can be run on a mixture of diesel and producer gas. These are called dual-fuel engines. Typically 60 -85% diesel is replaced with producer gas. Now 100% producer gas engines are also available -- as the name suggests these can operate on 100% producer gas.

Biomass gasifier based electricity generation has typically been used for three types of applications:

i) Village electrification in an off-grid mode

In recent years biomass gasifiers have been used for electrification of remote villages. The size of such systems can vary from 10kWe to 500 kWe. In India, several of the smaller size (10-20 kWe) biomass gasifier systems have been established under two Government of India schemes called Remote Village Electrification (RVE) and Village Energy Security Programme (VESP). Apart from the Government programmes, several NGOs and corporate have also established such systems. There have been a few instances like 500 kWe biomass gasifier based power plant at Gosaba island in Sundarbans (India) where large capacity gasifiers have been used.

Box 1.4. Gosaba rural electrification project

One of the first successful applications of biomass gasifier for rural electrification in an off-grid mode is 500 kWe gasifier plant set-up at Gosaba island of Sundarban in India. The plant was set-up in 1997 and consists of 5 x 100 kWe units. The gasifiers are closed-top downdraft systems based on woody biomass. The plant has dual-fuel engines. The transmission and distribution line is spread over a length of 6.25 km of high-tension line and 13.67 km of low-tension line. The plant serves around 900 consumers. The plant is managed by a local co-operative and the state government.

Source: Ghosh, Sagar and Kishore (2003)

ii) Grid-connected biomass gasifier based power plants

There are some examples of grid-connected biomass gasifier power plants. These are relatively large sized gasifier with capacities ranging in hundreds of kW. A typical example is presented in box 1.5

Box 1.5: Arashi Hi-Tech Bio Power Pvt Ltd, Sulthanpet, Coimbatore, Tamilnadu

Arashi Hitech Bio power an independent power producer (IPP) has set up a gasifier based power plant linked to the State grid. It is located in Sultanpet village in Coimbatore district of Tamilnadu, where there is abundance availability of coconut shells. The power plant comprises a biomass processing system, gasification system, PLC based automation and control system, full fledged water treatment plant, power package and a power evacuation system. In the first phase, an 800 kg/hr gasifier system was integrated with a low speed marine diesel engine in July, 2002. The power plant has operated in the dual-fuel mode at an average load of 600 kWe for nearly 6000 hours. The average liquid fossil replacement recorded is about 68%, with specific biomass consumption being 0.6-0.7 kg/kWh. Recently the dual-fuel engine has been replaced with 5 x 250 kWe producer gas engines. Another identical stream consisting of 800

Source: Gokhale, Gupta, Kishwan et al. (2007)

iii) Biomass gasifier for captive power generation:

Biomass gasifier plants in an industry or an institute are usually used as captive power generation unit. In India, a large number of systems have been put-up in rice mills, with rice-husk as the feed material for gasifiers.

b) Thermal applications

A very large number of micro, small and medium enterprises (MSME) use biomass as well as fissile fuels for generating heat. With continued rising prices of fossil fuels coupled with their scarcity (quota) in open market many of these small and are facing serious problems in controlling fuel cost and as a result keeping competitive pricing for existence in the market. Gasification technology offers them an option to have all benefits of gaseous fuels using comparatively cheaper locally available solid biomass fuel. There are a variety of fuel-fired furnaces that are ideal candidates for switching over to producer gas from biomass. Theses are listed in table 1.4

Table 1.4 Furnaces which are suited for biomass gasifier applications

Type	Application/ Temperature (^oC)
Forging furnace	1200 -1250
Re-rolling mills	900-1200
Direct fired process heaters	food, textile, paper, printing, chemical, rubber, plywood and plastic industries

Dryers	paper, cardboard, wood and lumber, textile, ceramic, tobacco, plastic, paint, food, and pharmaceutical industries
Kilns	Gypsum, vitreous china-plumbing fixture, brick and structural clay, and concrete industries.
Ovens	Low-temperature (ranging between 20 to 370 degree Celsius) cooking, baking, curing, or to vulcanize (a treatment that stabilizes and adds elasticity) rubber or plastic. The food industry uses ovens to bake bread, cookies, crackers, pretzels, while the rubber and plastic industries use the lower temperature heat produced in ovens in the production of tires, footwear, hosiery, and rubber belts (e.g., fan belts).
Small boilers	Various industries

Source: CII, 2005

A large experience exists now in use of thermal gasifiers for industrial applications. A good documentation of different applications can be found in CII (2005) ; Mande and Kishore (2007).

1.2.4 Economics

The typical capital cost of gasifier based power generation systems consisting of a gasifier, producer gas cleaning and cooling system, engine and generator is provided in table 1.5. A large variation is observed in the capital cost of gasifiers, some of the reasons are:

a) The capital cost depends on the size of the power plant. The unit cost (Rs/ kW) decreases with increase in size of the power gasifier plant. The unit cost is significantly higher for smaller sized systems (<25 kWe).
b) 100% producer gas engines are costlier compared to dual fuel engines.
c) The cost of the biomass gasifier reactor, cleaning and cooling train, depends significantly upon the choice of material (e.g. stainless steel or mild steel, its thickness) and the quality of fabrication

Table 1.5 Typical capital cost of power gasifiers

	Capital cost (Rs/kW)	**Source**
10 - 25 kWe systems with 100% producer gas engines	70 -80000	VESP Guidelines, MNRE, 2008
50 -500 kWe with 100% producer gas engines	44000	CII, 2005
50-500 kWe in dual fuel mode	30000	CII, 2005

1 US $ = Rs 47

A large variation is also observed in the cost of electricity generation using a biomass gasifier. Various studies (CII, 2005; Ghosh, Sagar and Kishore, 2003) estimate the cost of generation to range between Rs 2 -7/ kWh. Plant Load Factor and cost of fuel are two important parameters which have an influence on the cost of power generation.

When used in a thermal mode to replace fossil fuels, biomass gasifiers have very attractive pay-backs. Typically, by application of a gasifier, 1 kg of fossil fuel is replaced with 3.5 to 4 kg of wood resulting in significant reduction in the energy cost (table 1.6).

Table 1.6. Fuel cost reduction with fuel switching for various fossil fuels

Fuel	Price (Rs/kg)	Wood/ kg fuel	Wood price (Rs/kg)	Wood cost (Rs/kg fuel)	Fuel cost reduction (%)
Kerosene	20	3.5	1.5	5.25	74
Diesel	38	4	1.5	6.00	83
LPG	25	4	1.5	6.00	76
Note: neglecting small electrical power (0.25-1hp) required for blower					

Source: Mande and Kishore (2007)

1.2.5 Operation of gasifiers

The operating conditions play an important role in obtaining clean producer gas from a gasifier. In case of gasifiers using woody biomass, fuel size is an important operating parameter. Fuel size affects the fuel movement within the gasifier as well as it has an impact on rate of reaction. Large wood pieces provide a smaller surface area per unit volume of the reactor; hence the pyrolysis reaction is less intense. Larger particles can also give rise to bridging which hampers fuel movement inside the gasifier. It is recommended to use fuel of one-fourth or one-fifth of the smallest dimension of reactor cross-section (Kishore 2008). Fuel moisture is another important parameter. High moisture content fuel reduces the calorific value of the producer gas and a value lower than 20 % is desirable. Adequate provision of biomass storage to store air-dried biomass is essential for a biomass gasifier system. The storage should be sufficient to take care of biomass requirements during the rainy season. A high fuel-bed temperature (above 800 ^{o}C) is preferred to achieve a low tar gas.

1.2.6 Gasifier sizing

a) Thermal gasifier to replace petroleum fuel

Kishore and Mande (2007) have provided a nomogram to estimate appropriate gasifier size (capacity in terms of kg of biomass/hr) based on prevailing fossil fuels of different heating values like Furnace oil, diesel, LPG etc. based on following assumptions:

- No change in system efficiency between petroleum fuel and producer gas operation
- Producer gas calorific value (1100 kcal/Nm^3)
- Specific gas production rate (2.5Nm^3/kg biomass)

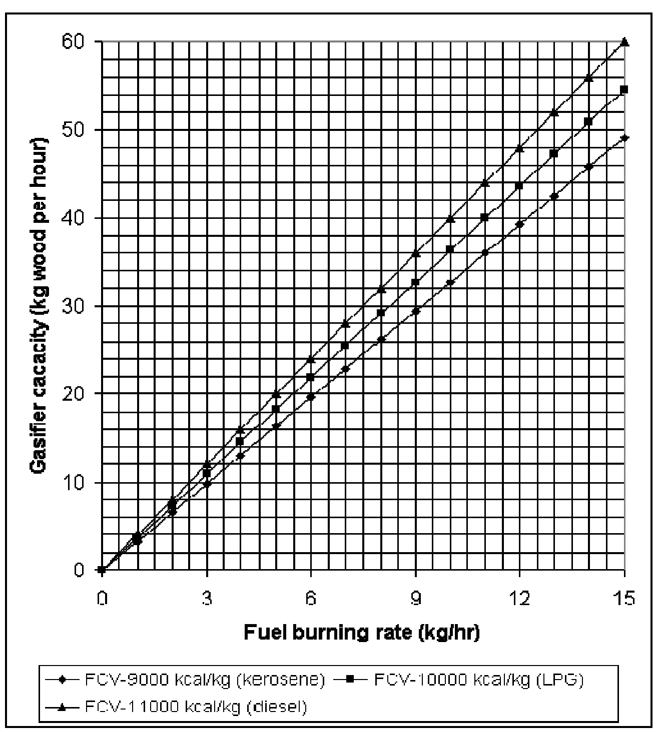

Figure 1.2 Gasifier sizing for replacing fossil fuels for thermal applications (Kishore and Mande 2007)

An example illustrating the sizing of a gasifier for thermal application using the nomogram is given below.

Example

Fuel consumption and firing schedule for a LPG fired downdraught kiln for firing decorative pottery is given in the table below. The owner would like to replace LPG firing with producer gas firing using a biomass gasifier. Calculate the size of biomass gasifier required using the nomogram.

Hours	Average kiln temperature (^oC)	Consumption of LPG (kg)
0-1	83	0.5
1-2	125	0.5
3-4	182	0.5
4-5	260	0.5
5-6	325	0.5
6-7	455	1.0
7-8	535	1.0
8-9	665	2.0
9-10	770	2.5
10-11	895	3.5
11-12	970	4.0
12-12.30	970	1.5

Solution:

We notice that the consumption of LPG is not constant during the firing process. In the initial stages the consumption is 0.5 kg/hr, which rises and peaks at 4 kg/hr. The gasifier should be sized so as to meet the peak power requirements, thus we have to find gasifier capacity corresponding to the peak LPG consumption of 4 kg/hr.Using the nomogram the corresponding capacity of gasifier is read as 15 kg of wood/hr.

b) Power gasifier

Typical specific fuelwood consumption values for power gasifiers having dual-fuel engines and 100% producer gas engines are given in table 1.7. Using these values it is possible to calculate the quantity of fuelwood required for a power gasifier.

Table 1.7 Typical specific fuelwood consumption for power gasifiers

Power gasifier	Specific fuelwood consumption	Reference
3.7 kWe dual-fuel engine	1.2 -1.4 kg/kWh	Mukunda, Dasappa, Paul et al.
100 kWe dual fuel engine	0.9-1.0 kg/kWh	Mukunda, Dasappa, Paul et al.
120 kWe 100% producer gas engine	1.0 -1.2 kg/kWh	Sridhar, Sridhar, Dasappa et al.

Example :

A brick kiln has a 100 kWe dual fuel engine for producing power. The power is supplied to run brick forming machinery. The machinery operates on an average 8 hours per day for 200 days in a year and the average load is 70 kW. Calculate the annual requirement of fuelwood to operate the dual fuel engine.

Solution:

i) Annual electricity generation = 70 kW x 8 h x 200 days = 112000 kWh

ii) Taking an specific fuelwood consumption of 0.95 kg of wood/kWh (table 1.7), the annual fuelwood consumption would be = 112000 x 0.95 = 106400 kg = 106.4 tons

1.3 Biogas

1.3.1 Principle of operation

Biogas is a fuel gas consisting of a mixture of methane (CH_4) and carbon dioxide (CO_2), produced through microbial processes under anaerobic conditions from a variety of organic material like animal, agricultural, industrial and domestic wastes. Production of biogas from cattle dung, piggery waste, human excreta, etc using simple anaerobic digesters has been is in use in several developing countries now for over half century. In recent years biogas digesters have been developed to operate on canteen waste, kitchen waste, vegetable market waste, sugar cane press mud, leafy biomass.

1.3.2 Common biomass feedstock for biogas production

The common biomass feedstock for biogas production include animal residues such as cattle dung; poultry litter; piggery waste; human waste; MSW (municipal solid waste), including food and vegetable market waste; and industrial organic waste such as that from food-processing industries, sugar industry, plantation industries, such as coffee-processing industry, leather, distilleries, pulp and paper, etc .

The potential biogas production from various types of substrates is tabulated in table 1.8

Table 1.8 Potential biogas production from various substrate

Substarte	**HRT* (days)**	**Solid concentration (%)**	**Temperature (^oC)**	**Biogas yield added (m^3/kg VS #)**	**Methane (%)**
Sewage sludge	25	6.0	35	0.52	68
Domestic garbage	30	5.0	35	0.47	-
Piggery waste	20	6.5	35	0.43	69
Poultry waste	15	6.0	35	0.50	69
Cattle waste	30	10.0	35	0.30	58
Canteen waste	20	10.0	30	0.60	50
Food-market waste	20	4.0	35	0.75	62
Mango-processing waste	20	10.0	35	0.45	52
Tomato-processing waste	24	4.5	35	0.63	65
Lemon waste	30	4.0	37	0.72	53
Citrus waste	32	4.0	37	0.63	62
Banana peel	25	10.0	37	0.20	55
Pineapple waste	30	4.0	37	0.37	60
Mixed feed of	20	4.0	37	0.62	50

fruit waste					

* HRT: Hydraulic retention time
\# VS: Volatile Solids[3]
Source: Somayaji (2005)

1.3.3 Typical applications

a) Household biogas plants

Millions of household biogas plants based on cattle dung, piggery waste, night soil are operational around the world. India alone has over 3.8 million biogas plants in the capacity of 1–6 m^3. These plants usually provide gas for cooking and lighting, the latter through specially designed mantles.

A typical household biogas plant consists of a digester in which the slurry (dung mixed with water) is fermented; an inlet tank used to mix the feed and let it into the digester; a gas holder/dome in which the generated gas is collected; an outlet tank to remove the spent slurry; distribution pipeline(s) to take the gas into the kitchen; and a manure pit, where the spent slurry is stored.

Based on the gas storage system there are two main digester designs, viz., the floating dome and the fixed dome. In the floating dome biogas plant the biogas is stored in a drum that can be made of steel, ferro-cement, or fibreglass. Based on the quantity of the gas stored in it, the drum moves up and down on a guide frame, which is fixed in digester walls. In the fixed dome type, the digester and gas storage dome are integrated with the space for storing usable gas between dome and digester.

Almost all the dung based biogas plants are based in rural households, recently a compact biogas plant that uses starchy or sugary feedstock, such as, waste grain flour, spoilt grain, overripe or misshapen fruit, non-edible seeds, fruits and rhizomes, green leaves, kitchen waste, leftover food, etc). In the plant, 2 kg of feedstock produces about 500 g of methane, and the reaction is completed with 24 hours. As per ARTI[4], the institute that has developed the technology several thousand such plants has been installed in urban areas.

---

[3] All feed materials consist of solid material and water. Fresh cattle dung, for example, consists of about 80% water and 20% total solids (TS). The TS in turn consist of Volatile Solids (VS) – which is the organic matter which can be digested and Fixed Solids (FS) which are essentially mineral matter which can not be digested. In case of fresh cattle dung , TS consist of 70% Vs and 30%FS. (Kishore, Raman and Ranga Rao, 1987)

[4] http://www.arti-india.org/content/view/45/40/#Benefits accessed on 15 August 15, 2009

Attempts are being made to develop digesters based on leafy biomass for household applications. A plugflow digester design developed by Indian Institute of Science is based on fermentation and floating properties of biomass feedstock, mainly leaves twigs branches etc.

b) Institutional and Industrial biogas plant

Biogas plants have been established at canteens, hostels, dairy, agriculture farms, poultry farms, food-processing industries etc, these are categorized as institutional/industrial biogas plants. The biogas generated is either used for thermal application (e.g. cooking in canteen kitchen) or is used for electricity generation by using the gas in an IC engine. A case study on one of the largest such plant working in India is provided in box 1.6.

Box 1.6 1-MW Biogas Power Project

1-MW power project based on cattle manure at Haebowal Dairy Complex, Ludhiana The Haebowal Dairy Complex in Ludhiana, spread over an area of over 20 hectares, has 1490 dairies with an animal population of 150 000. The complex generates about 2250 tonnes of animal droppings each day. The project, which has been implemented at a cost of about Rs 13.60 crores, will use about 235 tonnes of animal waste each day to produce about 10 000 m^3 of biogas, which, in turn, will be burnt to generate 0.965 MW of electrical energy. The surplus energy after meeting the in-house power requirement will be fed to the state electricity grid. Besides electrical energy, the project will also produce about 50 tonnes of stabilized organic manure per day. The plant has been commissioned in December 2004. The plant is based on biogas-induced mixing arrangement (BIMA) technology, developed and commercialized by ENTEC Environment Technology, Austria. The Punjab Energy Development Agency (PEDA) owns the plant.

Source: MNRE Annual Reports

1.3.4 Economics

The capital cost of family sized biogas plants is Rs 5000/m^3. The pay-back period of the floating dome dung based household biogas plants vary between 1 to 3 years (MNRE, 2004). The capital cost of a 10 kWe (2 x 5 kW) biogas power plant having 2 x 45 m3 biogas reactors is around Rs 850000 (MNRE, 2008)

1.3.5 Operation of biogas

The anaerobic microbial conversion of organic substrates to methane is a complex biogenic process involving a number of microbial populations, controlled by various environmental factors like pH, temperature, ionic strength or salinity, nutrients and toxic or inhibitory substrates. In case of household biogas plants there can be substantial difference between the performance of the plant measured under standard operating conditions in the lab and performance under real field conditions (please refer to Box.

Box 1.7 Performance monitoring of a biogas plant in rural household

Performance of biogas plants in rural households, is a function of several parameters, such as, technical design, cooking pattern, operation practices, etc. Most of the performance data available in literature on biogas plants is for plants working in field research stations under standard operating conditions. As a part of a rural energy demonstration project in Sultanpur district of Uttar Pradesh, performance of two family size (2 m^3/day), fixed dome (TERI mark 4-D model) biogas plants, operating in rural households, was monitored for a calendar year. A low cost monitoring system, involving, biogas users, a trained field assistant and TERI technical staff was established for data collection. The average (over one year) biogas consumption was found to be about 1.2 m^3/day/biogas plant. About 50% drop in biogas availability was observed during winter, compared to peak biogas availability during summer. The biogas generation (using slurry level rise test method) was found to be 36 l/day/kg of dung in the month of April. Comparing the performance of the two plants, it was observed that consistent and adequate dung feeding resulted in higher gas production. A survey of energy use was carried out in about 200 households. It was found that the biogas supply from a family size biogas plant was able to meet about 90% of the energy requirement for cooking (on annual basis) for a typical household in the study area.

Source: Pal, Singh, Sharma and Maithel [2000]

1.3.6 Sizing calculations

For a given size of plant (rated gas production capacity per day) the amount of feed required can be estimated using the biogas yield data provided in table 1.8. The specific biogas consumption in biogas engines is 0.6-0.8 m^3/kWh. This specific fuel consumption value can be used to calculate the requirement for biogas for power generation purposes. Biogas consumption in other devices is as follows:

Household burner	: 200-450 lit/hr
Gas lamp (light output equivalent to a 60W lamp)	: 120 -150 lit/hr

Example :

A dairy has 100 cattle. The fresh dung production per cattle is 10 kg/day. If all the cattledung is used for biogas production a) calculate the capacity of biogas plant needed (in m^3/day) and b) the electricity generation potential in kWh/day.

Solution:

i) Total daily fresh dung production = 100 x 10 = 1000 kg/day

ii) As per table 1.8, the biogas yield is 0.3 m^3/kg VS. To calculate the total biogas yield, we would first have to calculate the Volatile Solid (VS) content in fresh dung.

iii) Generally fresh dung has 20% Total Solid (TS) content, out of which 70% is VS.
Thus VS content in the fresh dung = 1000 kg/day x 0.2 x 0.7 = 140 kg VS/day

iv) Gas production per day and capacity of biogas plant = 140 kg VS/day x 0.3 m^3/kg VS = 42 m^3/day.

v) Assuming a biogas consumption of 0.7 m^3/kWh, the daily electricity generation potential = 42 (m^3/day) /0.7 (m^3/kWh) = 60 kWh/day

1.4 Biofuels

1.4.1 Principle of operation

Biofuels can be defined as the renewable liquid fuels, derived from biological raw materials, which can be used as a substitute to petroleum fuels. Biofuels being considered in this document comprise vegetable oils in their natural form called straight vegetable oil (SVO) and esterified vegetable oils referred to as bio-diesel.

SVO and bio-diesel are used as fuel in IC engines to produce motive power and electricity. Though the experience of using biofuels for decentralized power generation is relatively less compared to that in biogas and biomass gasifier, none the less, biofuels are considered important renewable energy option for decentralized power generation.

1.4.2 Common biomass feedstock for biofuel production

The vegetable oils can be edible or non-edible. Several edible oils like sunflower, coconut, palm, rapeseed can be used as SVO or converted into biodiesel. Given the issues related with food security by diversion of food crops for fuel production, non-edible vegetable oils seems better choice for production of SVO and bio-diesel in developing countries. *Jatropha curcas, Pongamia pinnata, Calophyleem inophyllum, Calotropis gigantia, Euphorbia tirucalli* and *Boswelia ovalifololata* are some of the non-edible species which are hardy and can grow under adverse climatic conditions and are considered good feedstock for SVO/bio-diesel production (Kumar, Dhavala, Goswami and Maithel, 2006).

Oil content of different types of vegetable oils is presented in table 1.9

Table 1.9 Oil content in vegetable oil feedstock

Type of seed	% Oil content
Coconut	50 %-70%
Soybean	16.6% - 21.6%
Neem	33% -45%
Oil palm	50% (palm kernel)
Pongamia (India)	30.4% - 39.5%
Jatropha (India)	28% - 38.4%
Rapeseed	33.2 % -47.6%
Camelina	30% -40%
Castor beans	50%
Safflower	26% -32%

Source: Kishore (2008); Wani, Osman, D' Silva and Sreedevi (2006)

1.4.3 Technology and typical applications

a) Production of SVO

For small-scale production mechanical extraction in used. Depending upon the seed being processed, various types of grinding, cracking, flaking and rolling equipment is used to rupture oil cells. Oil seeds are heated, generally using indirect steam, to increase recovery of oil. For large-scale production, solvent extraction method is used, in which oil is extracted using an organic solvent, like hexane. The extracted oil is then refined, through processes like degumming, neutralization, bleaching, deodorization, etc.

b) Production of Biodiesel

Bio-diesel is produced by transesterification of triglycerides and fatty acids present in oil. Both batch and continuous processes are used for biodiesel production. While batch processes are used for small-scale production, continuous processes are used for large-scale production. Several groups in India have been working on developing batch processes which can be used in rural areas for producing bio-diesel in small quantities for local application.

c) Use of SVO in engines

Comparison of some of the main properties of different types of SVOs with diesel are presented in table 1.10

Table 1.10 Comparison of properties of SVOs and diesel

Vegetable oil	Kinematic viscosity (cS)	Cetane number	Heating value (MJ/kg)	Flash Point (^{o}C)	Density (kg/litre)
Jatropha	50.7	51	39.65	240	0.9186
Pongamia	27.8	-	34.60	205	0.912
Rapeseed	37.0	37.6	39.7	246	0.9115
Palm	39.6	42.0	-	274	0.9180
Diesel	3.06	50.00	43.8	76	0.855

Source: Kishore (2008)

SVOs have been used as fuel in diesel engines. However, as can be observed in table 1.10, SVOs have high viscosity, which can lead to a number of problems in engine operation, such as, choking of injectors, poor fuel atomization, etc. This can result in incomplete combustion, giving rise to smoke emissions. Recent studies have shown that with preheating and preconditioning of SVOs, changing of maintenance schedule and use of appropriate lubricants it is possible to get improved engine performance with SVOs (Agarwal, 2008).

d) Use of biodiesel in engines

The properties of bio-diesel produced from various feed stocks are much closer to properties of diesel and hence bio-diesel gives better engine performance in comparison with SVOs (table 1.11)

Table 1.11 Comparison of properties of bio-diesel and diesel

Vegetable oil	Kinematic viscosity (cS)	Cetane number	Heating value (MJ/kg)	Flash Point (^oC)	Density (kg/litre)
Jatropha	4.84	52	41	163	0.88
Pongamia	4.80	55.8	36.1	141	0.876
Soybean	4.5	45	33.5	178	0.885
Palm	5.70	62	33.5	164	0.860
Diesel	3.06	50.00	43.8	76	0.855

Source: Kishore (2008)

Studies show that most of the existing diesel engines can be operated with biodiesel blends (with up to 20% biodiesel) with out any major operational problems. Bio-diesel blends may require additives to improve storage stability and allow use in a wide range of temperatures. Neat bio-diesel and bio-diesel blends reduce particulate, HC and CO emissions, and increase NOx emissions compared with petroleum based diesel fuel uned in an un-modified diesel engine (Das and Mathew, 2006).

1.4.4 Economics

The capital cost of a 10 kWe biofuel engine with alternator including all accessories (based on 100% Biofuel / SVO) is around Rs 200000. The oil Expeller with filter press and heater having a capacity of 100 kg/hour is Rs 175000 (MNRE, 2008).

1.4.5 Sizing calculations

The sizing of a biofuel based industrial power plant is explained with an example below.

Example:

An industry collects 50 tonnes of Jatropha seeds per year. It would like to set-up a small plant to process Jatropha seeds into bio-diesel and use the bio-diesel for generating electricity (8 hrs/day). Calculate the potential annual electricity generation (kWh) and size of the power plant (kW).

Solution:

i) First we have to calculate the amount of biodiesel that can be produced from 50 tonnes of Jatropha seeds. For this we would have to make some assumptions:

- Oil content in Jatropha seeds is 30%
- The recovery efficiency of raw oil using an expeller in the village is 80%
- The recovery efficiency of biodiesel from raw oil is 90%.

Total amount of biodiesel that can be produced annually = 50000 kg x 0.3 x 0.8 x 0.9 = 10800 kg

ii) The specific Jatropha biodiesel consumption in a small diesel engine with 100% Jatropha biodisel operation = 0.355-0.424 kg/kWh (Hanumantha Rao, Voleti1, Raju and Reddy, 2009)

Taking an average specific Jatropha biodiesel consumption as 0.4 kg/kWh, the annual electricity generation would be = 10800 kg/ 0.4 (kg/kWh) = 27000 kWh /year

Daily electricity generation = 27000/365 = 74 kWh/day

As the plant has to operate 8 hrs, the capacity of the power plant = 74/8 = 9.25 kW or 10 kW

Chapter 2:
Biomass Assessment

2.1 Biomass assessment for a country or region

Estimation of quantity of biomass available for energy production for a country or a province is a complex subject, which requires collection and processing of a large amount of data from diverse sources and involves several approximations which results in large uncertainties in the estimations. For estimation of biomass resource for a country or a region it becomes necessary to take assistance of departments and experts dealing with forestry and remote-sensing (for estimation of woody biomass as well as tree based oil seeds), agriculture (for estimation of agriculture residues), animal husbandry (for estimation of animal wastes), local city/ town governments (for estimation of municipal wastes) and industries (for estimation of industrial wastes). A general approach for estimating woody, non-woody and cattle-waste is presented in the following paragraphs

2.1.1 Estimation of woody biomass

Estimation of woody biomass follows a two step process:

Step I is map preparation -- the objective is to produce maps to determine the spatial extent of the various ground cover types and to enable the biomass types to be stratified. Techniques which are used for map preparation include:

- Low spatial resolution imagery : These satellite imageries provide overview data with low level of accuracy for cover typing and type borders, that is, maps with (1:5 000 000) broad vegetation types.
- Imagery: For more accurate information, satellite imagery with higher spatial resolution (30-80 m) or aerial photography is used.

Step II is ground inventories, in which sample areas are selected representing various ground cover types and primary measurements are taken to calculate sustainable woody biomass yield in tones/year. For estimating annual sustainable yield following formula is used (Kishore, 2008):

$$ASY = 2 \times G\,S / R \qquad \text{(2.1)}$$

Where,
ASY is Annual Sustainable Yield in tonne/year;

GS is Growing Stock in tonne and is calculated using the formula

GS = Area of the forest (ha) x Productivity (m3 of biomass/ha) x Density of biomass (tonne/m3) ………………………………………….(2.2)

R is rotation age for various trees, which varies from 2-3 years for fast growing agro-forestry trees to 60-100 years for high forest trees. Productivity of some forest plantations in tropical countries is given in table 2.1

Table 2.1 Productivity of some forest plantations

Plant species	Productivity (m3/ha)
Eucalyptus grandis	15-50
Acacia mearnsii	14-25
Pinus radiate	12-35
Pinus caribaea	20-50

Source: Yokoyama and Matsumura (2008)

Due to various factors such as accessibility, machinery efficiency, etc., it may not be possible to extract the entire annual sustainable yield from the forests. Thus we have to define an collection efficiency factor (ranging from 0 to 1) to calculate extractable sustainable yield (ESY)

ESY = collection efficiency factor x ASY …………………………………(2.3)

If we want to calculate the surplus woody biomass availability for energy production, we will also have to estimate the present alternate uses of biomass (X) in tonne/year. Biomass has several other usages, primarily as timber and construction material.

Surplus woody biomass availability (tonne/year) = ESY – X …………...(2.4)

Example:

A forest has an area of 2000 ha, annual productivity of 75 m^3/ha, rotation age of 50 years and density of 0.8 tonne/m^3 (wet basis). Calculate Extractable Sustainable Yield for the forest if the efficiency factor for extraction in 0.6.

Solution :

First we will calculate growing stock

GS = 2000 (ha) x 75 (m3/ha) x 0.8 (tonne/m3) = 120000 tonne

ASY = 2 x 120000/50 = 4800 tonne/year

ESY = 0.6 x 4800 = 2880 tonne/year

2.1.2 Estimation of non-woody biomass

Estimation of agriculture residue production is done using the formula

Residue production (tonne/year) = Grain production (tonne/year) x RPR (residue-product ratio) …………….(2.5)

Residue-product ratio can be estimated by direct measurements in the fields during harvesting. Air dried residue-product ratio for some of the common crops is tabulated in table 2.2. However, it should be noted that it is always beneficial to cross-check these values by conducting direct field measurements, as a large number of parameters, such as, variety of seeds, soil, irrigation, weather impacts the crop yield as well as agriculture residue production.

The surplus agriculture residue available for energy production is generally much lower compared to the value of residue production, this is because:

- Collection efficiency factor: It is generally not possible to collect the entire agriculture residue, some of it is lost during the collection. Thus we have to define an collection efficiency factor (ranging from 0 to 1)
- Alternate uses (X) : agriculture residue has several other usage, such as, animal feeding, mulching, roof thatch, burning in the field, use as fuel in local industries e.g. pottery, brick, food-processing, etc. Thus it becomes necessary that a survey be done

Surplus agriculture residue available for energy production = Residue production x collection efficiency factor – X …………..(2.6)

Table 2.2 Air dry weight of residue produced per tonne of crop produced

Crop	Residue	RPR
Groundnut	Shell	0.3-0.5
	Straw	2.3-2.9
Maize	Straw	1.0
	Cob	0.18-0.27
	Husk	0.2
	Stover and leaves	1.0-2.5
Millet	Straw	1.4
	Stalk	2.0-3.7
Rice paddy	Husk	0.22-0.5
	Straw	0.45 -2.9
	Bran	0.1
Sugarcane	Baggase	0.1 -0.3
	Top and trash	0.125
Wheat	Straw	0.7-1.8

Source: Kishore (2008)

2.1.3 Estimation of animal dung

Potential supply of animal dung for a country or a province can be calculated by knowing the population of the particular animal and relevant dung productivity factor.

Potential animal dung (kg/day on dry basis) = number of animal x dung productivity (kg/head/day on dry basis) ………………….(2.7)

The production of dung differs from country to country or even region to region in a country. This is because of differences in animal size and weight as well as feed intake. Average animal dung production in different countries is given in table 2.3

Table 2.3 Animal dung production in different regions

Country	Animal	Dung production (dry basis)	Volatile solid

		kg/head/day	(kg/head/day)
North America	Dairy cattle	5.68	5.23
	Non-dairy cattle	2.55	2.35
Western Europe	Dairy cattle	5.52	5.08
	Non-dairy cattle	2.88	2.65
Eastern Europe	Dairy cattle	4.49	4.13
	Non-dairy cattle	2.91	2.68
Oceania	Dairy cattle	3.77	3.47
	Non-dairy cattle	3.29	3.03
Latin America	Dairy cattle	3.16	2.91
	Non-dairy cattle	2.70	2.48
Africa and Middle East	Dairy cattle	2.01	1.85
	Non-dairy cattle	1.68	1.54
Asia	Dairy cattle	3.07	2.82
	Non-dairy cattle	2.49	2.29
Indian Subcontinent	Dairy cattle	2.87	2.64
	Non-dairy cattle	1.50	1.38
	Buffalo	2.65	2.43
Other livestock	Swine		0.34
Developing countries	Sheep		0.32
	Goat		0.35
	Camel		2.49
	Horse		1.72
	Mule/Ass		0.94
	Poultry		0.02

(Source: Kishore, 2008)

The surplus dung available for biogas production may be significantly lower than the potential calculated above. There are two important factors influencing the availability of surplus dung available for biogas production, these are:

- Collection efficiency factor: All the dung is not collected. One of the main reasons is that cattle in many regions are not stall fed and are left in the fields to feed. In such cases the collection of dung becomes difficult. Also in several areas, the cattle are not kept in covered shed and dung during the rainy season gets washed away and is not collected. Thus we have to define an collection efficiency factor (ranging from 0 to 1)

- Alternate uses of dung (X): Dung has several alternate uses. In India it is dried and used as fuel , it is mixed with clay to plaster walls and floor of the house or it is used as a fertilizer

Surplus dung available for energy production = Potential animal dung x collection efficiency factor – X ……………………………….(2.8)

Thus it becomes important to establish both the collection efficiency as well as carry out a survey to estimate the quantity of dung that is used for alternate applications.

2.2 Biomass assessment for a village for application of decentralized biomass energy technologies

2.2.1 Estimation of woody biomass

A. Fuelwood supply

There are several sources of fuelwood in a village.

a. Extractable annual sustainable yield from forest: If the village has a forest, extractable yield from forest needs to be calculated using the methodology given in 2.1.1. This requires both field visits as well as assistance from the local forest office.

b. Estimated annual sustainable yield from agro-forestry
c. Estimated annual sustainable yield from existing plantations on private land.
d. Estimated annual sustainable yield from existing plantations on public land

B. Fuelwood consumption

a. Estimated annual fuelwood consumption in households for cooking to be established through primary survey and measurement
b. Estimated annual fuelwood consumption in commercial and industrial activities e.g. pottery, brick making, sweet making, etc to be established through primary survey and measurement
c. Estimated annual fuelwood consumption for institutional/community activities e.g. religious festivals, cooking in the village school, cremation, etc to be established through primary survey and measurement

d. Estimated annual wood consumption for uses other than fuel e.g. timber to be established through primary survey and measurement

C. Net outflow of fuelwood across the village boundary: Several villages may be involved in trading of fuelwood, thus net inflow/outflow across the village boundary needs to be estimated.

Surplus fuelwood availability = A + B –C

In several cases, the net surplus fuelwood availability may not be sufficient for establishing a biomass gasifier plant. In such cases, possibility of establishing plantations of fast growing tree species can be considered. In such a case identification of land both public and private for such plantations becomes a part of the resource assessment exercise.

2.2.2 Estimation of non-woody biomass

A. Non-woody biomass supply:

a. Estimation of farm-based agriculture residue production: The methodology given in section 2.1.2 is applied. Information on area and crops is collected from the local government.
b. Estimation of industry-based agriculture residue production: Several of the agriculture residues get generated during their processing e.g. rice husk is generated at the rice mill. For estimating such residues, information on production/processing capacities of all such processing units and residue generation need to be collected.
c. Estimation of forest-based industries: Residue like saw-dust is generated in a saw-mill. Thus information on forest-based industries as well as residue generation is needed.

B. Non-woody biomass consumption: Non-woody biomass is used for several applications in a village, such as, thatching, fodder and fuel. In several parts, burning of agriculture residue in fields is practiced.

C. Net outflow of non-woody biomass across the village boundary

Surplus non-woody biomass availability = A + B –C

The estimation of non-woody biomass should be done source-wise and season-wise. This information is required if the non-woody biomass has to be used for gasification.

2.2.3 Estimation of animal dung

A. Animal dung supply: Data on household-wise animal population, average dung production, dung collection efficiency is collected through a household survey.

B. Animal dung consumption: Data on animal dung usage as fuel, fertilizer and other applications are collected through household survey.

C. Net outflow of animal dung across the village boundary: In some cases animal dung may be traded as fertilizer or fuel (e.g. dung cake in North India) with other villages.

Surplus dung availability = A+B-C

Chapter 3:
Biomass Assessment for Energy

Production – Case Studies

The methodology for carrying out biomass assessment for finding potential of the three biomass energy technologies covered in this document is illustrated through two case studies. The first case study is for a country –Bhutan and is based on information available in Bhutan Energy Data Director 2005 (DoE, 2007). The second case study is for a village.

3.1 Biomass Assessment for a country – A case study of Bhutan

3.1.1 Forest Biomass for biomass gasification

The forest classification for Bhutan is given in table 3.1, while table 3.2 gives values of forest productivity, rotation and density.

Table 3.1 Forest classification for Bhutan

National Forest Class	Definition
Mixed conifer	Single species not exceeding 60% of the total
Fir forests	Fir constituting about 80% of the total
Blue pine	Blue pine forests. Blue pine constituting about 80% of the total
Chir pine	Chir pine forests. Chir pine constituting about 80% of the total
Broadleaf +conifer	Mixture of broadleaf and conifer species of about 80% of the total.
Broadleaf/hardwood	Mixture of broadleaf forests of about 80% of the total

Source: DoE (2007)

Table 3.2 Forest productivity, rotation and density for various forest types in Bhutan

Forest Type	Productivity (m3/ha)	Rotation (year)	Basic density (tonne/m3)
Mixed conifer	82.74	140	0.41
Fir	268.27	140	0.40
Blue pine	43.6	100	0.30
Chir pine	83.91	120	0.39
Broadleaf + conifer	528.45	120	0.45
Broadleaf/hard wood	224.59	100	0.49

Source: DoE (2007)

Using the data available in table 3.1 and table 3.2, along with data available on area of various forest types, the methodology described in section 2.1.1 can be used to estimate the sustainable wood supply for energy production.

a) Growing Stock: Based on the total area under different forest types, the total growing stock of forests in the country is estimated at about 527.529 million m^3.

b) Annual Sustainable Yield is estimated at 849 437 m3 or 3913 850 tonnes.

c) Extractable Sustainable Yield is estimated as 1 565 540 tonnes (taking collection efficiency factor as 0.4)

d) Total consumption of fuelwood (in residential, commercial and industrial sectors) is 724 597 tonnes.

e) Surplus woody biomass availability = 1565540 – 724597 = 840943

f) Assuming specific wood consumption of 1.1 kg / kWh (table 1.7), the total theoretical electricity generation potential using 100% producer gas engine based biomass gasifier plants is 764.49 MU (Million Units)

3.1.2 Agriculture residue for biomass gasification

The estimation of agriculture residue production is given in table 3.3.

Table 3.3. Selected crops and residue production potential in Bhutan (2004/05)

Crop	Production (tonnes/year	Residue type	RPR	Theoretical residue production (tonnes/year)
Paddy	54326	Paddy straw	1.80	97786.8
		Paddy husk	0.27	14668.0
Maize	90568	Maize stalk	2.10	190192.8
		Maize cob	0.48	43472.6
		Maize husk	0.27	24453.4
Wheat	4192	Wheat straw	1.46	6120.3
Millet	2367	Millet straw	1.55	3668.9
Mustard	1768	Mustard stick	2.50	4420.0

Source: DoE, 2007

Crop residues in Bhutan are primarily used for fodder as well as are source of manure. Thus except for non-fodder crop residues such as maize stalk and mustard stick, which are not used as fodder, none of the other residues are expected to be available for energy production.

For calculating the electricity generation potential, it is assumed that 30% of these two residues are available as fuel for biomass gasifier plants. Assuming specific biomass consumption as 1.1 kg/ kWh, the total theoretical electricity generation potential using 100% producer gas engine based biomass gasifier plants is 51.8 MU (Million Units)

3.1.3 Cattle dung for biogas production

The cattle population in low altitude regions of the country are considered for biogas estimation. The higher altitude regions are not considered because of low ambient temperatures in which the production of biogas is very low.

Total cattle population in lower altitude regions = 234 958

Dung production (kg/head/day) = 4.5
Total dung production (tonnes/day) = 4.5 x 234 958 /1000 = 1057
Dung collection efficiency = 50%
Total dung collection = 528 tonnes/day
If we assume 30% of this dung is available for biogas production and take 0.035 m3/ kg of dung as biogas yield, the total biogas production = 5550 Nm3/day

3.2 Biomass assessment for a village

Biomass assessment for a village is taken from a report on estimation of biomass energy potential at village Majpara (TERI, 2008)

3.2.1 Sustainable yield of wood from forest

Forest area : 150 ha (approx)

Average productivity of forest in Bongaigaon district is 129.591 m^3/ha and considering rotation age as 50 years and density to be 0.6-ton/m^3,

Growing stock= Forest area (ha) x productivity (m^3/ha) x density (ton/m3) = 150 x 129.591 x 0.6 =11663.19 ton

Annual sustainable yield = 2 x growing stock/Rotation = 2 x 11663.19 /50 = 466.53 ton/year

Extractable sustainable yield of woody biomass = 0.8 x 466.53 ton/year (taking collection efficiency factor as 0.8) = 377.2 tons/year

Surplus fuelwood availability = Annual sustainable yield – consumption = (377.2 – 288) ton/year = 89.2 ton/year

Fuelwood savings after installation of improved cook stove = 86.4 tons (Assuming an average savings of 30%)

Total surplus biomass available for biomass gasification = 89.2 +86.4 = 175.6 tons/ year

Total electricity generation potential (assuming specific fuelwood consumption as 1.1 kg/kWh) = 175.6 x 1000/1.1 = 159636 kWh

Capacity of the power plant in kW (assuming that the plant would operate for 8 hours per day) = 159636/(365x8) = 54 kW or nearest available biomass gasifier plant is of 50 kW.

3.2.2 Crop residue

Paddy is the main crop grown in the village followed by mustard and jute. The average landholding size is small at 1.08 ha/household, with the holding size ranging from 0.07 ha to 4.48 ha. Lack of irrigation facilities and a poor cropping pattern lead to low yield, low productivity and low income for the farmers. For the assessment of biomass, paddy was taken as the main crop, as other crops are grown over less area. As per discussion with the villagers, the average production of paddy varies between 18 to 27 quintal per hectare and the total paddy production in the village is approximately 66 tonnes from the land area that is cultivated annually.

Crop residue generation from paddy in Majpara

Crop	Total Production (t/y)	Type of residue	RPR	Residue production (t/y)
		Straw	1.76	116.16
Paddy	66	Husk	0.267	18.216

Thus, the residue generation from paddy in the village in the form of straw and husk is about 134.376 tons. Villagers shared that that the residue from paddy is mainly fed to the cattle and used for making roofs. As paddy stalk is not sufficient and whatever is generated is currently used as fodder, it is not being considered for power generation.

3.2.3 Cattle dung

The cattle population here is 203 cattle of local breed, which are open grazed. The cattle dung available has the potential to be used for biogas generation through biochemical conversion. The national figure of average collectable animal dung is 10kg/day but low productivity due to not being stall-fed, only 4 kg/day per cattle is considered. Hence the total collectable dung estimated is 812 kg/day.

Potential of energy generation through available cattle dung

Total collectable dung (kg/day)	Total bio-gas generation potential (m^3/day)
812	32.48

Reference

Agarwal A K. 2008. Scope and Limitations of Utilisation of Non-edible Vegetable Oils as a Substitute Fuel for Diesel Engines – An Experimental Study. Engine Research Laboratory, Indian Institute of Technology, Kanpur.

CII. 2005. Development of small ESCOs to undertake biomass gasification projects for industrial applications. Report prepared for MNES. Confederation of Indian Industries.

Das LM and V Mathews. Research issues in development of bio-diesel engines. In *Biofuels towards a greener and secure energy future* (Editor Bhojvaid P P), 181-206, TERI Press, 2006.

DoE.2007. Bhutan Energy Data Directory 2005. Thimphu: Department of Energy.

Ghosh D, Sagar A and V V N Kishore. 2003. Scaling-up biomass gasifier use: applications, barriers and interventions. World Bank.

Gokhale A M, Gupta A K, Kishwan J, Bahuguna V K, Sanjappa M, **Maithel S**, Dasappa S, Vettival S K, Dhamija P. *National Mission on Decentralized Biomass Energy for Villages and Industries*, 62 pp, January 2006.

Hanumantha Rao Y V, Ram Sudheer Voleti1 , A.V.Sitarama Raju and P.Nageswara Reddy. 2009. Experimental investigations on jatropha biodiesel and additive in diesel engine. Indian Journal of Science and Technology, Vol.2 No 4 (Apr. 2009)

Karekezi S, Lata K, and Coelho S T. 2004. Traditional Biomass Energy . Thematic Background Paper No 11. Secretariat of the International Conference on Renewable Energies, Bonn. 56 pp.

Kaupp A and Goss J R.1987. History of Small Gas Producer Engine Systems. Wiesbaden: GATE Vieweg

Kishore VVN and S Mande. 2007. Development benefits of clean energy in India: Biomass gasification prospects in India. Report prepared for The William and Flora Hewlett Foundation. New Delhi: The Energy and Resources Institute.

Kishore V V N (editor). 2008. Renewable Energy Engineering and Technology a knowledge compendium. New Delhi: The Energy and Resources Institute.

Kishor VVN, P Raman and V V Ranga Rao. 1987. Fixed Dome Biogas Plants – A Design, Construction and Operation Manual. New Delhi: Tata Energy Research Institute.

Kumar N V L, P Dhavla, A Goswami and S Maithel. Liquid Biofuels in South Asia: Resources and Technologies. *Asian Biotechnology and Development Review*, Vol. 8, No. 2, March 2006.

Kumar N V L and S Maithel . Alternate feedstock for ethanol production in India. In *Biofuels towards a greener and secure energy future* (Editor Bhojvaid P P), 89-104, TERI Press, 2006.

Mande S and Kishore V V N (eds). 2007: Towards Cleaner Technologies: a process story on biomass gasifiers for heat applications in small and micro enterprises. New Delhi: The Energy and Resources Institute.280 pp.

MNRE.2004. Outline Plan for Creating Energy Security in Villages through Biomass. New Delhi: Ministry of New and Renewable Energy

MNRE, 2008. Revised Guidelines for VESP projects. New Delhi: Ministry of New and Renewable Energy

Mukunda H S, Dasappa S, Paul P J, Rajan N KS, Sridhar G, Sridhar H V and U. Shrinivasa . Thermo-chemical conversion of biomass – a retrospective and a prospective.
Bangalore: Indian Institute of Science.

Pal R C, Singh P B, Sharma S P and Maithel S. Performance Monitoring of TERI Mark- 4 D model biogas plants in rural households. SESI Journal 10 (2): 95-105 (2000).

Somayaji D. 2005. Methanogenesis from agro-residual residues: potential and prospects. In "Wealth from waste – trends and technologies" editors Banwari lal and MRVP Reddy. New Delhi: The Energy and Resources Institute

Sridhar G, H. V. Sridhar, S. Dasappa, P. J. Paul, D. N. Subbukrishna and N. K. S. Rajan, Sudarshan Kumar And H. S. Mukunda - Green Electricity from Biomass Fuelled Producer Gas Engine, Proceedings Of 14th European Biomass Conference and Exhibition, Biomass for energy, Industry and climate Protection.

T E R I. 2006. RETs II theme - Thermal applications of biomass gasifier in SMiEs
New Delhi: The Energy and Resources Institute. 55 pp. [Project Report No. 2005BE28]

TERI.2008. Detailed Project Report for Village Majpara, Assam prepared for Village Energy Security Programme.

Yokoyama S and Matsumura Y (eds). 2008. The Asian Biomass Handbook –A guide for biomass production and utilization. The Japan Institute of Energy. 326 pp.

List of web resources

S.No	Web-site	Topics covered
1	http://cgpl.iisc.ernet.in	Biomass Atlas of India Biomass gasification technology Research papers on biomass gasification Case studies on biomass gasification
2	http://www.ankurscientific.com	Biomass gasifier product information Case studies on biomass gasification
3	http://www.cosmile.org	Detailed case studies on biomass gasifier applications in industries
4	http://www.borda-net.org	Handbook on biogas technology Case studies on biogas technology
5	http://www.bspnepal.org.np	Case studies on biogas technology
6	http://www.pcra-biofuels.org	Biofuels in India
7	http://www.nrel.gov/biomass/	Basics of biomass energy Advanced biomass energy technologies