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Energy production from biomass

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■ **ABSTRACT :** The most common form of biomass used as renewable energy and it is widely used. Recently more attention has been focused on identifying suitable biomass species, which can provide high-energy outputs, to replace conventional fossil fuel energy sources. The type of biomass required is largely determined by the energy conversion process and the form in which the energy is required. To provide energy the use of biomass has been mainly to the development of civilization. Recently pressures on the global environment have led to calls for an increased use of renewable energy sources. Biomass is one major potential source of renewable energy and the conversion of plant material into a suitable form of energy, usually electricity or as a fuel for an internal combustion engine, can be achieved using a number of different routes, each with specific pros and cons. A brief review of the main conversion processes is presented, with specific regard to the production of the fuel.

■ **KEY WORDS :** Biomass, Energy conversion, Process, Technology

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Energy demand is increasing continuously worldwide due to speedy development in industrialization and rise in population whereas development of energy sources is not keeping pace with consumption. Developed countries are also finding it difficult to compensate even after increasing the energy production multi-fold due to growth pressure. India is recognized as one of fastest growing economies of the world but basic energy needs of thousands of millions of its citizens are yet to be fulfilled. It is reported that by 2031-2032, power generation capacity must increase to nearly 800 GW from the current capacity of around 183 GW (Hiloidhari *et al.*, 2014). As energy demand is increasing continuously due to speedy development in population and industrialization, the development of energy sources is not keeping pace with consumption (Saxena *et al.*, 2009). With rapid increase in fossil fuel use, share of biomass in total energy has declined steadily over past few years. Biomass still contributes 14% of the world energy and 38% energy in developing countries (Woods and Hall, 1994). Globally, the energy content of biomass residues in agriculture industries annually is estimated at 56×10^{18}J, nearly a quarter of global primary energy use of 230×10^{18}J (World Energy Council, 1994). Wood fuels, including charcoal, are the most prominent biomass energy sources. Substantial use of biomass energy in the developing countries continues to be in the rural and traditional sectors of the economy. Most biomass is not traded, but is home grown or collected by the households. It is used very inefficiently and causes substantial health damage due to indoor air pollution (Shukla, 2000).

A society which utilized the quantum of energy is regarded as benchmark for social and economic development of the society. Punjab being an agricultural state of India there is an ever-growing requirement of energy and obtaining energy from fossil fuels is becoming difficult and expensive. Also, creating new nonrenewable energy generation facilities involves relatively longer gestation periods (Bhargava *et al*., 2009). Since renewable energy resources vary according to geographical conditions, bio–energy generation from paddy straw has very wide scope in Punjab state (Vijay *et al*., 2016 and Trivedi *et al*., 2017).

Biomass :

Biomass which is produced by green plants converting sunlight into plant material through photosynthesis and includes all land and water based vegetation, as well as all organic wastes. The biomass resource can be considered as organic matter, in which the energy of sunlight is stored in chemical bonds. When the bonds are broken by digestion, combustion, or decomposition, these substances release their stored energy. Biomass has always been a major source of energy for mankind and is presently estimated to contribute 10-14% of the world's energy supply. Also, biomass can be defined by the plant material derived from the reaction between CO_2 in the air, water and sunlight, via photosynthesis, to produce carbohydrates that form the building blocks of biomass. In general, the characteristics of the ideal energy crop are high yield, low energy input to produce, low cost, composition with the least contaminants and requires less nutrients. Desired characteristics will also depend on local climate and soil conditions. Biomass can be converted into different types of product like electrical or heat energy, transport fuel and chemical feedstock (Saxena *et al*., 2009).

In fact, biomass is a source of 5 'F', which are, food, fodder, fuel, fibre and fertilizer. In addition to that biomass has advantage that it is widely available technology for production and conversion which is suitable for small or large applications. The production and utilization of biomass energy require low light and low temperature (5^0-35^0C) that incorporates advantage of storage and transportation along with low and negligible pollution (Rathore *et al*., 2007).

Biomass comprises all the living matter present on earth. It is derived from growing plants including algae, trees and crops or from animal manure (Bridgewater, 1991). The biomass resources are the organic matters in which the solar energy is stored in chemical bonds. It generally consists of carbon (C), hydrogen (H), oxygen (O) and nitrogen (N). Sulphur is also present in minor proportions. Some biomass also consists significant amounts of inorganic species. Plants produce carbohydrates which form the building blocks of biomass through photosynthesis process (Saxena *et al*., 2009).

Advantages of biomass as energy source :

Biomass has always been a major source of energy for mankind from ancient times. Biomass can be converted into three main types of products: electrical/ heat energy, fuel for transport sector and feedstock for chemicals. Sriram and Mohammad (2005) reported some of the advantages of using biomass as a source of energy as follows. Biomass energy is an abundant, secure, environmental friendly and renewable source of energy. Biomass does not add carbon dioxide to the atmosphere as it absorbs the same amount of carbon in growing as it releases when consumed as a fuel. One of the major advantages of biomass is that it can be used to generate electricity with the same equipment or in the same power plants that are now burning fossil fuels.Biomass energy is not associated with environmental impacts such as acid rain, mine spoils, open pits, oil spills, radioactive waste disposal or the damming of rivers.Biomass fuels are sustainable. The green plants from which biomass fuels are derived fix carbon dioxide as they grow, so their use does not add to the levels of atmospheric carbon. In addition, using refuse as a fuel avoids polluting landfill disposal.Alcohols and other fuels produced by biomass are efficient, viable and relatively clean burning.Biomass is easily available and can be grown with relative ease in all parts of the world.

Biomass resources that can be used for energy production cover a wide range of materials which can be categorized in two ways, namely, modern biomass and traditional biomass. Modern biomass usually involves large-scale uses and aims to substitute for conventional energy sources. Traditional biomass is generally confined to developing countries and small-scale uses (Demirbas, 2001).

Biomass types :

The various types of biomass are available but, it can be defined in four main types, namely woody plants, herbaceous plants/grasses, aquatic plants, and manures.However, there are other factors which must be taken into consideration in determining the selection of the conversion process, apart from simply moisture content, especially in relation to those forms of biomass which lie midway between the two extremes of 'wet' and 'dry'. Examples of such factors are the ash, alkali and trace component contents, which impact adversely on thermal conversion processes and the cellulose content, which influences biochemical fermentation processes (Volesky, 1994).

Biomass properties :

Properties of the biomass source that determines both the choice of conversion process and any subsequent processing difficulties that may arise. Equally, the choice of biomass source is influenced by the form in which the energy is required and it is the inter play between these two aspects that enables flexibility to be introduced into the use of biomass as an energy source. The main properties of interest, during subsequent processing as an energy source, relate to moisture content (intrinsic and extrinsic), calorific value, proportions of fixed carbon and volatiles, ash/residue content, alkali metal content and cellulose/lignin ratio. For dry biomass conversion processes, the first five properties are of interest, while for wet biomass conversion processes, the first and last properties are of prime concern (Peter, 2002a).

Biomass energy conversion technologies :

Biomass can be converted into useful forms of energy using a number of different processes. Factors that influence the choice of conversion process are the type and quantity of biomass feedstock; the desired form of the energy *i.e.* end-use requirements; environmental standards; economic conditions; and project specific factors. In many situations, it is the form in which the energy is required that determines the process route, followed by the available types and quantities of biomass. Biomass can be converted into three main products: two related to energy power/heat generation and transportation fuels and one as a chemical feedstock (Peter, 2002b and Warren *et al.*, 1995).

Thermo-chemical conversion :

Combustion :

The cycle used is the conventional Rankine cycle with biomass being oxidized in a high-pressure boiler to generate steam. The net power cycle efficiencies that can be achieved are about 23% to 25%. The exhaust of the steam turbine can either be fully condensed to produce power or used partly or fully for another useful heating activity. In addition to the exclusive use of biomass combustion to power a steam turbine, biomass can be co-fired with coal in a coal-fired power plant.

Thomas (2003) developed measures for emission reduction viz-a-viz specific fuel properties. It was observed that pollutant formation occurs due to two reasons: (1) Incomplete combustion can lead to high emissions of unburnt pollutants. Although improvements to reduce these emissions have been achieved by optimized furnace design including modelling, there is still a relevant potential of further optimization. (2) Pollutants such as NO_x and particles are formed as a result of fuel constituents such as N, K, Cl, Ca, Na, Mg, P, and S. Hence biomass furnaces exhibit relatively high emissions of NO_x and submicron particles. Air staging and fuel staging have been developed as primary measures for NO_x reduction that offer a potential of 50% to 80% reduction.

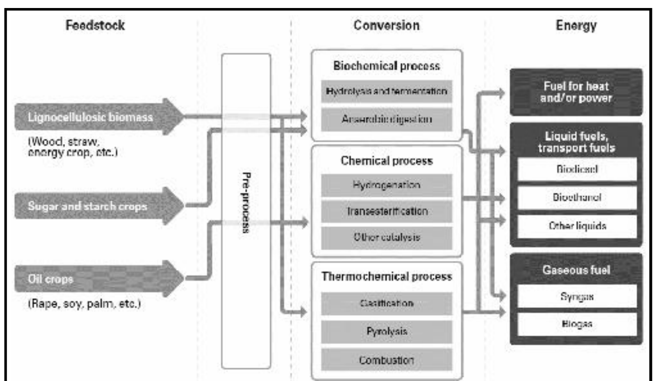

Fig. 1 : Different ways of biomass processing (source: *www.seco.cpa.state.tx.us*)

As per (Khan *et al.*, 2009), among the technologies that can be used for biomass combustion, fluidized beds are emerging as the best due to their flexibility and high efficiency. Although agglomeration problems associated with fluidized bed combustors for certain herbaceous biofuels is still a major issue, however, successful and applicable/implementable solutions have been reported.

Johansson *et al.* (2003) carried out the study on particle emissions which are compared with emissions from combustion of wood pellets and wood briquettes in commercial small-scale combustion devices like, a pellet stove, two pellet burners and two smaller district heating boilers. The influence of operating parameters and fuel quality was investigated. Mass concentration, number concentration and number size distribution of particles were determined. The mass size distribution was analyzed as well as the inorganic components. Gaseous compounds were recorded to give information about the combustion conditions. The number concentration was in the range of 10^7–10^8 particles per N/cm^3. The particle emission was dominated by submicron particles (size <1µm), both from number and mass perspective. The main inorganic components of the submicron particles were potassium, sulphur, chlorine and oxygen. Small amounts of sodium, magnesium and zinc were also found. The contents of potassium, chlorine, and sulphur in the fuel are important for the composition of the emitted inorganic submicron particles.

Gasification :

Gasification is achieved by the partial combustion of the biomass in a low oxygen environment, leading to the release of a gaseous product (producer gas or syngas) (Fig. 2). So, called "allothermal" or indirect gasification is also possible. The gasifier can either be of a "fixed bed", "fluidized bed" or "entrained flow" configuration. The resulting gas is a mixture of carbon monoxide (CO), water (H_2O), CO_2, char, tar and hydrogen (H) and it can be used in combustion engines, micro-turbines, fuel cells or gas turbines. When used in turbines and fuel cells, higher electrical efficiencies can be achieved than those achieved in a steam turbine. It is possible to co-fire a power plant either directly (*i.e.* biomass and coal are gasified together) or indirectly (*i.e.* gasifying coal and biomass separately for use in gas turbines).

Gasification is a process that exposes a solid fuel to high temperatures and limited oxygen, to produce a gaseous fuel. The gas produced by the process (Fig. 2) is a mix of gases such as carbon monoxide, carbon dioxide, nitrogen, hydrogen, and methane. The gas is then used to drive a high efficiency, combined-cycle gas turbine. Gasification has several advantages over burning solid fuel. One is convenience – one of the resultant gases, methane, can be treated in a similar way as natural gas, and used for the same purposes.

Another advantage of gasification is that it produces a fuel that has many impurities removed and could, therefore, cause fewer pollution problems when burnt. Under suitable circumstances, it can also produce synthesis gas, a mixture of carbon monoxide and hydrogen which can be used to make hydrocarbon (e.g., methane and methanol) for replacing fossil fuels. Hydrogen itself is a potential fuel without much pollution which can conceivably substitute petroleum in the future.

Fixed bed updraft gasifiers (Fig. 3A), are characterized by high conversion and high efficiency. The exit gas temperature is generally 100-300°C due to the counter current flow of solid fuel and hot gas. The product gas contains large amounts of hydrocarbons. Tar (large hydrocarbons) make up approximately 15% of the energy content of the gas. The biomass fuel specifications are mild, but there is a risk of too high-pressure drops over the bed if very small particles are fed. Fuels with slagging tendency can cause problems in the hot bottom zone, but updraft gasifiers can also be made "slagging" (Veringa, 2009). This means that inert material leaves

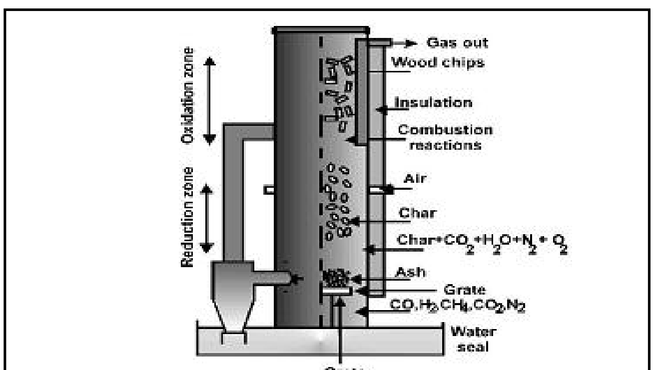

Fig. 2 : Gasification process (Sriram and Mohammad, 2005)

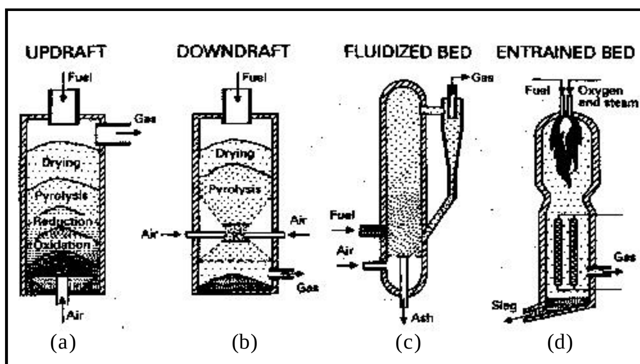

Fig. 3 : Schematics of different direct gasification reactors (source: *www.ecn.nl*)

the gasifier as a liquid slag. This generally requires oxygen in order to reach the desired high temperatures.

Fixed bed downdraft gasification, (Fig. 3B) concerns small scale by definition, the maximum capacity is several tens of MW_{th}. Furthermore, the conversion generally is low. Downdraft gasifiers can also be made "slagging", which means that inert material leaves the gasifier as a liquid slag and the conversion rises to almost 100%. This generally requires oxygen in order to reach the desired high temperatures.

Fluidized bed gasifiers (Fig. 3C) are characterized by the presence of an inert heat carrier like silica sand. Fluidized bed gasifiers can be separated in three types: BFB, CFB, and coupled fluidized beds (indirect). BFB (bubbling fluidized bed) is the simplest concept. It also seems suitable for applications where oxygen must be used instead of air. CFB (circulating fluidized bed) reactors are often seen as the most suitable for large scale applications. BFB as well as CFB gasifiers show a limited conversion of 90-95%. This can be increased to approximately 98% by using smaller fuel particles. Indirect gasifiers contain two reactors where gasification and combustion are separated. Two gases are produced which are N_2 free product gas and a "conventional" flue gas. Because the conversion is complete, indirect gasifiers seem to be the attractive alternative of oxygen/steam-blown fluidized beds when N_2 free gas is required (Veringa, 2009).

Entrained flow reactors (Fig. 3D), are practically empty vessels, where small fuel particles are converted at high temperature. It can either be slagging or non-slagging. Slagging gasifiers are preferable if biomass is used. The conversion is almost complete, but oxygen is needed to achieve the high temperatures needed. Biomass should be pulverized to a size of 1 mm. Entrained flow gasifiers are used to produce syngas to be used either as syngas or for electricity generation. This means that these gasifiers in practice operate at elevated pressure. The entrained flow technology (Fig. 3D) is primarily developed in the petrochemical industry as a means to gasify heavy residues (Veringa, 2009). Hasler (1997) investigated the possibility of using activated carbon granular bed filter to remove tar. The activated carbon filter was installed in the front of a fabric filter. In the experiments, the removal efficiencies for high boiling hydrocarbons and phenols were relative high. Meanwhile, the 'tar' laden activated carbon can be recycled as an extra feedstock.

Hermann (2002) studied a pre-coated fabric filter used to remove particles and tar at a gasifier plant in Austria. The filter had been tested for more than 2500 h without any problems. The disadvantages of the filters were the following: the tar deposited in filter could not be easily cleaned; tar accumulation on the filter surface would lead to eventual plugging. Generally, barrier filters were not suitable for tar removal even though the filters were successfully demonstrated in some cases.

Pyrolysis :

Pyrolysis is a subset of gasification systems. In pyrolysis, the partial combustion is stopped at a lower temperature (450°C to 600°C), resulting in the creation of a liquid bio-oil, as well as gaseous and solid products. The pyrolysis oil can then be used as a fuel to generate electricity (Fig. 4).

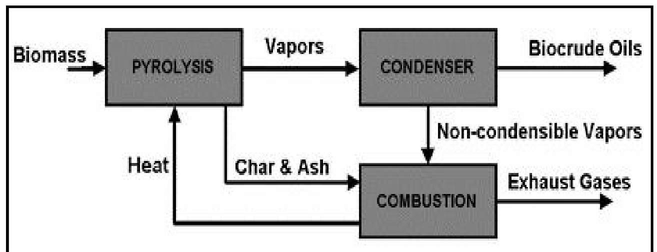

Fig. 4 : Biomass pyrolysis process diagram (source: *www.physics.oregonstate.edu*)

Wright *et al.* (2010) explored the cost of converting corn stover into naphtha-range and diesel-range stock fuel via fast pyrolysis and bio-oil upgrading. Based on the current analysis, naphtha and diesel can potentially be produced from biomass. For a pioneer plant, projected fuel PV increases cost of hydrogen-production technology as compared to hydrogen-purchase technology. To obtain biomass pyrolysis models, the TG–FTIR technique provides useful input in the form of kinetic information under low heating rate conditions. The analysis was applied to wheat straw, three types of tobacco and three biomass model compounds (xylan, chlorogenic acid and Dglucose) (Bassilakis *et al.*, 2001).

Application of the fluidized bed system in the study of the formation of gases from municipal solid waste (MSW) pyrolysis at high nominal temperatures (700–850^{0}C) was researched. Biomass decomposition followed by tar cracking reactions took place inside the reactor. The yields of the gases formed were determined as CH_4, C_2H_6, C_2H_4, C_3H_8, C_3H_6, C_2H_2, C_4H_8, H_2, CO and CO_2 as a function of operation conditions (Garcia *et al*., 1995).

Bio-chemical conversion :

Two main processes are used, fermentation and anaerobic digestion, together with a lesser-used process based on chemical conversion.

Fermentation :

Fermentation is used commercially on a large scale in various countries to produce ethanol from sugar crops (e.g. sugar cane, sugar beet) and starch crops (e.g. maize, wheat). The biomass is ground down and the starch converted by enzymes to sugars, with yeast then converting the sugars to ethanol. Purification of ethanol by distillation is an energy-intensive step, with about 450 lit. of ethanol being produced per ton of dry corn. The solid residue from the fermentation process can be used as cattle-feed and in the case of sugar cane, the bagasse can be used as a fuel for boilers or for subsequent gasification (Peter, 2002b). As with many micro-organisms, *S. cerevisiae* metabolizes glucose by the Embden–Meyerhof (EM) pathway. Beside this, the Entner–Doudoroff (ED) pathway is an additional means of glucose consumption in many bacteria, such as *Zymomonas*. The high ethanol yield and productivity observed for *Zymomonas* are a consequence of its unique physiology. *Zymomonas* is the only micro-organism that metabolizes glucose anaerobically using the ED pathway as opposed to the EM or glycolytic pathway (Matthew *et al*., 2005). All the enzymes involved in fermentation are expressed constitutively and fermentation enzymes comprise as much as 50% of the cells' total protein (Sprenger, 1996).

Anaerobic digestion :

Anaerobic digestion is the conversion of organic material directly to a biogas which is a mixture of mainly methane and carbon dioxide with small quantities of other gases such as hydrogen sulphide. The biomass is converted by bacteria in an anaerobic environment, producing a gas with an energy content of about 20–40% of the lower heating value of the feedstock. Anaerobic digestion is a commercially proven technology and is widely used for treating high moisture content organic wastes, *i.e*. 80-90% moisture. Biogas can be used directly in gas turbines and can be upgraded to higher quality *i.e*. natural gas quality, by the removal of CO_2 (Peter, 2002b). Researchers from Austria try to optimizing anaerobic digestion of maize and dairy cattle manures. Manure received from dairy cows with medium milk yield that were fed a well-balanced diet produced the highest specific methane yield of 166.3 Nl CH_4 kg VS^{-1}. Late ripening varieties produced more biomass than medium or early ripening varieties. Silaging increased the methane yield by about 25% compared to green, non-conserved maize. Maize (*Zea mays* L.) is optimally harvested, when the product from specific methane yield and VS yield per hectare reaches a maximum. Maximum methane yield per hectare from late ripening maize varieties ranged between 7100 and 9000 Nm^3 CH_4 ha^{-1}. From the digestion experiments a multiple linear regression equation, the Methane Energy Value Model, was derived that estimates methane production from the composition of maize. It is a helpful tool to optimize biogas production from energy crops. The Methane Energy Value Model requires further validation and refinement (Amon *et al*., 2007).

The anaerobic digestion process results in a mineralization of organically bounded nutrients, in particular nitrogen and in a lowering of the C/N ratio. Both effects increase the short-term N fertilization effect. The digester allows an accurate dosage and integration in a fertilization plan with a reduced application of additional mineral nitrogen fertilizers. The ammonia nitrogen content increases in some cases by a factor of three if energy crops are used as the only substrate. The most common reactor configuration employed for wet fermentation is the vertical continuously stirred tank fermenter which is applied in nearly 90% of modern biogas plants in Germany (Gemmeke *et al*., 2009).

Another approach is to apply continuous dry fermentation processes for substrates that contain more than 25% dry matter (Weiland *et al*., 2009). For continuous dry fermentation, horizontal mechanically mixed fermenter or vertical plug flow fermenter are applied, which are known from anaerobic treatment of municipal organic solids (Schon, 1994 and De Baere and Mattheeuws, 2008).

Bio methanation was carried out in, two anaerobic digesters of 3400 m^3 water volume capacity. The prepared paddy straw substrate was fed to two digesters through the feeding unit using pumps. No external heating source was provided in the digester as annual mean temperature in the area lies within mesophilic range. Loading rate was kept constant at 6.75 tonne VS/day to maintain 8–10% TS in the digester, while the digester was maintained at a hydraulic retention time (HRT) of 30 days based on previous work done by our group. The digested slurry was passed through two horizontals solid–liquid separating machines with a slurry handling capacity of 8.0 m^3/h. The system was able to separate solid material at the rate of 600 kg/h with 65% moisture content. The separated liquid was recycled to prepare paddy straw substrate in blending tank (Trivedi *et al.*, 2017).

Mechanical extraction :

Extraction is a mechanical conversion process used to produce oil from the seeds of various biomass crops, such as oilseed rape, cotton and groundnut. The process produces not only oil but also a residual solid or 'cake', which is suitable for animal fodder. Three tons of rapeseed are required per ton of rapeseed oil produced. Rapeseed oil can be processed further by reacting it with alcohol using a process termed esterification to obtain RME or bio-diesel. RME is used in some European countries as a supplementary transport fuel (Peter, 2002a). Some researchers studied the effect of mechanical extraction method to the physio-chemical properties of the extracted oil from the seed of Jatropha. The oil extraction was performed using a specially designed laboratory scale mechanical extractor, and the yield was calibrated. They took four types of sample (seeds, kernel, crushed seeds, and crushed kernel), four extraction temperature (ambient, 50^0C, 60^0C and 80^0C), and three preheating time (600 s, 1200 s, and 2400 s), and analysed. The results show that crushing the kernel of Jatropha before extracting the oil mechanically will give higher oil yield and higher extraction efficiency. However, the maximum applicable temperature for mechanical extraction is 60^0C (Tambunan *et al.*, 2012).

Indian biomass energy conversion policy :

In recent years, India's energy consumption has been increasing at a relatively fast rate due to population and economic growth. With rapid urbanization and improving standards of living for millions of Indian households, the demand is likely to raise a lot. Therefore, Govt. of India is now making various planning and policies in energy sector. Since sustainable development is now the key target of the world, therefore renewable energy resources are considering for power generation. Ministry of new and renewable energy of India has developed many project and policies in this field and promoting to adopt these methodologies by providing various subsidies and incentives (Bhat *et al.*, 2001 and Ravindranath and Balachandra, 2009).

Conclusion :

The use of biomass, as a traditional energy source for the third world, can play a major role in helping the developed world reduce the environmental impact of burning fossil fuels to produce energy. Biomass is an accepted form of renewable energy and is seen as a means of helping to reduce global warming. The four main types of biomass, woody plants and herbaceous plants and grasses are the main types of interest for producing energy. The stored chemical energy in plants is contained in the cellulose, hemicellulose and lignin components of the plant, the proportions varying with the type of plant. All biomass can be burned in thermo-chemical conversion plant *i.e.* combustion, to produce steam in a turbo-generator to produce electricity: some biomass species are better suited for biochemical conversion processes to produce gaseous or liquid fuels. The energy content of biomass (on a dry, ash-free basis) is similar for all plant species, lying in the range 17–21 MJ/kg. The principal selection criteria for biomass species are growth rate, ease of management, harvesting and intrinsic material properties, such as moisture/ash/alkali content, the latter properties influencing the operational characteristics of thermal conversion plant. Selection of a conversion technology for biomass depends upon the form in which the energy is required pyrolysis, fermentation and mechanical extraction all produce liquid fuels suitable for use as transportation fuels other conversion processes produce energy in a form that is best used at the point of production *i.e.* hot air or a gas pyrolysis oils and liquid fuels are suitable only for diesel cycle engines.

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■ REFERENCES

Amon, T., Amon, B., Kryvoruchko, V., Zollitsch, W., Mayer, K. and Gruber, L. (2007). Biogas production from maize and dairy cattle manure- influence of biomass composition on the methane yield. *Agric., Ecosys. & Environ.,* **118**(1): 173-182.

Bassilakis, R., Carangelo, R.M. and Wojtowicz, M.A. (2001). TG–FTIR analysis of biomass pyrolysis. *Fuel*, **80**(17):65–86.

Bhargava, N., Singh, B. and Gupta, S. (2009). Consumption of electricity in Punjab: Structure and growth. *Energy Policy*, **37**(6):2385–2394.

Bhat, P.R., Chanakya H.N. and Ravindranath, N.H. (2001). Biogas plant dissemination:success story of Sirsi, India. *Energy Sustainable Dev.,* **5**(1): 39-41.

Bridgewater, A.V.(1991). Principles and practice of biomass fast pyrolysis processes for liquids. *J. Anal. Appl. Pyrolysis*, **51** : 3–22.

De Baere, L. and Mattheeuws, B. (2008). State-of-the-art 2008—anaerobic digestion of solid waste. *Waste Mgmt. World*, **9** : 1–8.

Demirbas, A. (2001). Biomass resource facilities and biomass conversion processing for fuels and chemicals. *Energy Convers Manage*, **42** : 1357–1378.

Garcia, A.N., Font, R. and Marcilla, A. (1995). Gas production by pyrolysis of municipal solid-waste at high temperature in a fluidised bed reactor. *Energy Fuels*, **9** : 648–658.

Gemmeke, B., Rieger, C. and Weiland, P. (2009). Biogas-Messprogramm II, 61 BiogasanlagenimVergleich. FNR, Gülzow.

Hasler (1997). Report on evaluation of gas cleaning technologies for small scale biomass gasifiers. Zurich: Swiss Federal Office of Energy and Swiss Federal Office for Education and Science.

Hermann, H. (2002). Biomass CHP plant gussing- A success story. In: Proceedings of an expert meeting, Strasbourg: pp. 21–30.

Hiloidhari, M., Dhiman, D. and Baruah, D.C. (2014). Bioenergy potential from crop residue biomass in India. *Renew. & Sustain. Energy Rev.,* **32**: 504-512.

Johansson, L.S., Tullin, C., Leckner, B. and Sjövall, P. (2003). Particle emissions from biomass combustion in small combustors. *Biomass & Bioenergy*, **25**(4): 435-446.

Khan, A.A., Jong, W.D., Jansens, P.J. and Spliethoff, H. (2009). Biomass combustion in fluidized bed boilers: potential problems and remedies. *Fuel Processing Technol.,* **90**(1): 21-50.

Matthew, H., Ashley, O., Brian, K., Alisa, E., and Benjamin, J. S. (2005). Wine making 101. Available at http://www.arches.uga.edu/<“matthaas/strains.htm

Peter, McKendry (2002a). Energy production from biomass (part 1): overview of biomass. *Bio Resour. Technol.,* **83**(1): 37-46.

Peter, McKendry (2002b). Energy production from biomass (part 2): conversion technologies. *Bio Resou. Technol.,* **83**(1): 47-54.

Rathore, N.S., Mathur, A.N. and Kothari, S. (2007). *Alternate source of energy*. Indian council of agricultural research. New Delhi. pp. 1-264.

Ravindranath, N.H. and Balachandra, R. (2009). Sustainable bioenergy for India: technical, economic and policy analysis. *Energy*, **34** (8):1003–1013.

Saxena, R.C., Adhikari, D.K. and Goyal, H.B. (2009). Biomass-based energy fuel through biochemical routes: a review. *Renew. & Sustain. Energy Rev.,***13**(1): 1-12.

Schön, M. (1994). Verfahrenzur Vergärungorganischer Rückstände in der Abfallwirtschaft. Erich Schmidt Verlag, Berlin.

Shukla, P.R. (2000). Biomass energy in India: policies and prospects. In workshop on biomass energy: Key issues and priority needs. International Energy Agency, Paris: 20.

Sprenger, G.A. (1996). Carbohydrate metabolism in Zymomonasmobilis: a catabolic highway with some scenic routes. *FEMS Microbiol Lett.*, **145** : 301–307.

Sriram, N. and Mohammad, S. (2005). Renewable biomass energy. In Power Engineering Society General Meeting, IEEE. pp. 612-617.

Tambunan, A.H., Situmorang, J.P., Silip, J.J., Joelianingsih, A. and Araki, T. (2012). Yield and physicochemical properties of mechanically extracted crude *Jatropha curcas* L oil. *Biomass & Bioenergy*, **43** : 12-17.

Thomas, N. (2003). Combustion and co-combustion of biomass: fundamentals, technologies, and primary measures for emission reduction. *Energy & Fuels*, **17**(6): 1510-1521.

Trivedi, A., Verma, A.R., Kaur, S., Jha, B., Vijay, V., Chandra, R., Vijay, V. K., Subbarao, P.M.V., Tiwari, R., Hariprasad, P. and Prasad, R. (2017). Sustainable bio-energy production models for eradicating open field burning of paddy straw in Punjab, India. *Energy*, **127** : 310-317.

Veringa, H.J. (2009). Advanced techniques for generation of energy from biomass and waste.*ECN Biomass*,1-24.

Vijay, V. K., Chandra, R., Vijay, V., Jha, B. and Trivedi, A. (2016). Biogas: A clean energy alternative. *Kurukshetra*,

64(7):42–44.

Volesky, B. (1994). Advances in biosorption of metals: selection of biomass types. *FEMS Microbiol. Rev.,* **14**(4) : 291-302.

Warren, T. J., Poulter, R. and Parfitt, R.(1995). Converting biomass to electricity on a farm-sized scale using downdraft gasification and a spark-ignition engine. *Bio resou. Technol.,* **52** : 95–98.

Weiland, P., Verstraete, W. and van Haandel, A. (2009). Biomass digestion to methane in agriculture: A successful pathway for the energy production and waste treatment worldwide. *J. Biofuels*, 171–195.

Woods, J. and Hall, D.O. (1994). Bioenergy for development: technical and environmental dimensions, FAO Environment and Energy Paper, 13.

World Energy Council (WEC) (1994). Report on New Renewable Energy Resources Kogan Page Limited.

Wright, M.M., Daren, E., DaugaardJustinus, A.S. and Robert, C.B. (2010). Techno-economic analysis of biomass fast pyrolysis to transportation fuels. *Fuels*, **89** : 2-10.

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