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ENERGY THROUGH AGRICULTURAL RESIDUES IN RURAL INDIA: POTENTIAL, STATUS AND PROBLEMS

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ABSTRACT

Energy from non-conventional resources like biomass would be crucial in meeting the growth targets in the power sector. Biomass is the most commonly used domestic fuel and for independent power plants. Based on up-to-date combustion technologies, biomass and waste supply approximately 4.5 EJ (105 Mtoe) of direct heat to the industrial and residential sectors, and 2 to 3 EJ (47 to 70 Mtoe) of heat from combined heat and power (CHP) plants. Small and medium-size CHP plants may be sourced with locally available biomass. 'Bihar Husk Power systems' in various districts of Bihar are a burning example of commercially successful electricity production system for rural India. It is a social enterprise providing off-grid rural electricity solutions through gasification process. However efficiency can be increased by generating various value-added products. The interfering elements in the biomass need to be cleaned up to improve the efficiency of the bio-gasifier. A brief review of the biomass thermo-chemical conversion pathways and particularly the utilization of agricultural residues, properties of biomass interfering with the process to increase the efficiency will be discussed along with the success story of Bihar Husk systems. These generation processes will be able to meet economical and environmental challenges in rural sector area.

Keywords: Bioenergy, Gasification, Biomass, Agricultural residues, Rice husk.

1. INTRODUCTION

Energy sector is the key to India's future growth. Energy from non-conventional resources like biomass would be crucial in meeting the growth targets in the power sector and overall economy. Biomass is the most commonly used domestic fuel apart from being the energy source for several smallscale industries and fuel for independent power plants. Based on up-to-date combustion technologies, biomass and waste supply approximately 4.5 EJ (105 Mtoe) of direct heat to the industrial and residential sectors, and 2 to 3 EJ (47 to 70 Mtoe) of heat from combined heat and power (CHP) plants. Ministry of New and Renewable Energy (MNRE) has estimated biomass availability at about 120 – 150 million metric tons per annum covering agricultural and forestry residues corresponding to a potential of about 18,000 MW and the reported total installed capacity of biomass based power in India was 2,559 MW [1]. Biomass energy holds considerable promise in India. MNRE has estimated biomass availability at about 120 – 150 million metric tons per annum covering agricultural and forestry residues corresponding to a potential of about 18,000 MW and the reported total installed capacity of biomass based power in India was 2,559 MW [1]. Biomass-fired power plants and CHP plants have capacities ranging from a few MWe up to 35 MWe. The country has a potential to generate an additional 20 GW of electricity from biomass residues. Small and medium-size CHP plants may be sourced with locally available biomass like 'Bihar Husk Power systems' in various districts is a burning example of commercially successful electricity production system for rural India. It is a social enterprise providing off-grid rural electricity solutions through gasification process. The plant is utilizing various agricultural residues to ensure the availability of feedstock throughout the year. However efficiency can be increased by generating various value-added products. The interfering elements in the biomass need to be cleaned up to improve the efficiency of the bio-gasifier. A brief review of the biomass thermo-chemical conversion pathways and particularly the utilization of agricultural residues, properties of biomass interfering with the process and value added product from the process to increase the efficiency will be discussed along with the success story of Bihar Husk systems. These generation processes will be able to meet economical and environmental challenges in rural sector area and India is poised to become world leader in power generation for biomass in the near future.

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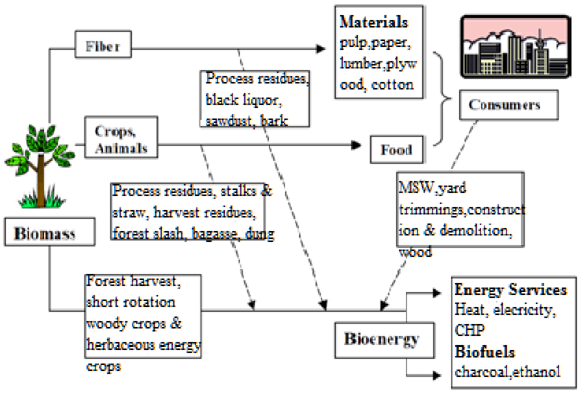

Fig 1: Biomass harvesting processes [34].

2. BIOMASS ENERGY SECTOR

About 24,500 villages in various states of India have been identified as remote villages where extension of grid electricity is not at all feasible. Therefore, all of these villages are proposed to be electrified with renewable energy options such as photovoltaic, micro-hydro, wind and biomass gasification. Among all these options, biomass-based electrification stands higher in the Indian context as the biomass is uniformly spread in the country. Biomass based energy has a vital role in the rural life where agriculture holds the principal activity of the common masses. Biomass includes agricultural crops and trees, wood and wood residues, grasses, municipal residues, and other plant and plant-derived matter with its variety of applications, including bioenergy, liquid biofuel production, residential heating, industrial heat, and processing energy [2].. More than 320 million tonnes of agricultural residues, quantity is equivalent to 250 million tonnes of coal, are produced every year which can generate 17,000 MW of power.

In a rural area, each household using an average amount of electricity (10 kWh/month), requiring biomass production in 0.0108 ha of sustainably managed feedstock-plantation land, divided equally across a three-year harvesting rotation [3]. The results indicate that in India around 74 million tonne agricultural residues as a biomass feedstock can be used for energy applications on an annual basis. In terms of the plant capacity the potential of biomass gasification projects could reach 31 GW that can generate more than 67 TWh of electricity annually. The annual CER potential of biomass gasification projects in India could theoretically reach 58 million tonnes. Under more realistic assumptions about diffusion of biomass gasification projects based on past experiences with the government-run programmes, annual CER volumes by 2012 could reach 0.4–1.0 million and 1.0–3.0 million by 2020 [4].

3. RURAL ELECTRICITY SCARCITY

Rural loads are generally characterized by the following features:

• Dispersed loads which require long medium voltage lines.

• Unreliable supply of about 6–8 hours per day and frequent phase imbalance.

• The Average load in the villages ranges from 5 KW to 25 KW per village.

• Poor load factor of around 0.2 (average demand/maximum demand).

• Low load factor due to dominant domestic consumption in particular, lighting, agricultural demand with seasonal periodicity and absence of industrial demand.

• Rural grids are often weak and high peak loads and relatively large inductive load scan occur. As the number of irregular, decentralized, power generators increases, so will their impact on the dynamic behaviour of the power system.

• Farmers go for higher capacity pumps, use capacitors and phase converters and thus sometimes leading to higher energy consumption [5].

Table 1: Status of rural electrification in India as on 31-3-2011[1]

Total number of villages	593,732
Villages electrified	493,163
Villages to be electrified	100,569
Total number of households	138,271,559
Electrified households	60,180,685 (43.5%)
Un-electrified households	78,090,874 (56.5%)

There is considerable interest in India in exploring the possibility of decentralized power generation systems for meeting the power needs of village settlements, isolated smal1 industries in the rural sector and irrigation pumping for accompanying the economic and environmental benefits for the masses [6].

4. GASIFICATION AND GASIFIERS: EFFICIENT WAY OF CONVERSION

Biomass can be utilized through three different processes for energy conversion: gasification, pyrolysis and direct combustion [7]. Gasification is the thermo-chemical process of obtaining energy from solid matter in a gaseous form [8]. Among all biomass conversion processes, gasification is one of the promising ones as the energy efficiency in case of gasification is higher than that of combustion [9]. 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. In principle, the process is a thermal decomposition of organic matter to produce combustible gases thus converting calorific value of organic material into a gaseous energy carrier [10-11]. In contrast, to complete combustion of solid carbonaceous material, the process of pyrolysis refers to combustion in a deficient supply of air/oxygen [12]. The process gives out carbon monoxide and methane, which are condensed to form tar and aqueous liquor. The latter is then distilled to give methanol and other organic substances.

The gasifier can either be of a “fixed bed”, “fluidised bed” or “entrained flow” in configuration. The resulting gas is a mixture of carbon monoxide, water, CO2, char, tar and hydrogen, 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). Portable gasifiers have been applied in running motor vehicles while stationary gasifiers integrated with engines are being used to generate electricity (10- 100 kWe), sericulture, textile dyeing, drying cardamom and rubber, tobacco curing, brick making and in large scale cooking. These technologies are widely in use in rural areas of developing countries [13-14]. Biomass-fired power plants and CHP plants have capacities ranging from a few MWe up to 35 MWe.

4.1 Use of Agricultural Feedstock

Agricultural residues are divided into two groups: Crop residues, and Agro-industrial residues. Crop residues are plant materials that remain in the farm after the removal of the main crop produce. The remaining materials could be of different sizes, shapes, forms and densities, i.e. straw, stalks, sticks, leaves, haulms, brous materials, roots, branches, twigs, etc. Agricultural industrial residues are by-products of the post-harvest processes of crops, i.e. cleaning, threshing, delinting, sieving, crushing etc., and could be in the form of husk, dust, straws, etc. [15]. The major crop residues produced in India are straws of paddy, wheat, millet, sorghum, pulses, oil seed crops, maize stalks and cobs, cotton stalks, jute sticks, sugar cane trash, mustard stalks, etc. The agricultural processing residues are groundnut shells, rice husk, bagasse, cotton waste, coconut shell and coir pith [16].

Agricultural residues are not available throughout the year, and the amounts available depend upon harvesting time, their storage related characteristics, the storage facility, etc. It has been observed that, except for rice husk, all other residues considered in the present work are avail- able for a maximum period of 6 months. The rice husk may be available for about 9 months in a year.

Agricultural residues may be used in several competing applications, such as fuels for cooking, water and process heating, fodder for animals, feedstocks for fertilizer, materials for roof construction, direct burning in boilers, etc. All the non-fodder, non-fertilizer agricultural residues with low moisture content can, in principle are considered as feedstocks for biomass gasification and briquetting. It is with this background that a preliminary attempt to estimate the net residue availability has been made in this work. Since the crop production depends upon the agro-climatic conditions, all residues are not available in all parts of the country [16].

4.2 Interfering problems of the process

Biomass presents wide variation in physical and chemical properties, and many publications relate the biomass properties relevant to thermochemical conversion processes

- Some biomass is not considered suitable as energy source because they have poor energy characteristics (low density, low heating value, and high moisture content), causing high costs during transportation, handling, and storage.
- The high moisture content typically found in biomass fuels can cause ignition and combustion problems, influence the biomass pyrolysis behaviour (the first step of the gasification and combustion processes) and affect the physical properties and the quality of the products [17].
- In biomass Nitrogen (N), sulphur (S), and chlorine (Cl) can also be found, usually in quantities lower than1 wt.% (db), but occasionally well above this. These constituents are directly related to the gaseous emissions of nitrogen oxides (NOx), sulphur derived compounds (SOx, H2S, COS), hydrochloric acid (HCl) and the occurrence of fouling and slagging in thermal conversion systems [18-19].
- Processing biomass containing different mineral matter compositions may create various problems which can affect the reactor operation or make the thermo chemical conversion of biomass in conventional systems unprofitable. The production of tar as a result of pyrolysis greatly hampers the dual fuel and producer gas enginewhich can be reduced via mechanical, catalytic and thermal methods [20].

Table 2: Contaminant presence in the gas and its related problems [21]

Contaminant	Presence	Problems
Particulates	Derive from ash, char, condensing compounds and bed material for the fluidized bed reactor	Cause erosion of metallic components and environmental pollution
Alkali metals	Alkali metals compounds, specially sodium and potassium, exist in vapour phase	Alkali metals cause high-temperatur e corrosion of metal, because of the stripping off of their protective oxide layer
Fuel-bound nitrogen	Cause potential emissions problems by forming NOx during combustion	NOx pollution
Sulfur and chlorine	Usually sulfur and chlorine contents of biomass and waste are not considered to be a problem	Could cause dangerous pollutants and acid corrosion of metals

Tar	It is bituminous oil constituted by a complex mixture of oxygenated hydrocarbons existing in vapour phase in the producer gas, it is difficult to remove by simple condensation	Clog filters and valves and produce metallic corrosion

5. Success story of Bihar husk power systems

Husk Power Systems (HPS) came into existence in 2007 with the main goal to provide affordable, reliable and environmentally sustainable energy to rural India by using husk as the feedstock. HPS supplies electricity to the villagers using environment friendly biomass gasification technology. HPS builds, owns and operates 35- 100 kW 'mini power-plants' that use waste rice husks to deliver electricity to off-grid villages in the Indian 'Rice Belt'. Husk Power Systems started its operations with one plant in 2007 and on date, it has 80 plants in operation across 300 villages of Bihar and Uttar Pradesh impacting 2,00,000 rural lives. The HPS initiative saves 42,000 litres of kerosene and 18,000 litres of diesel per year. HPS trains local villagers for the plant processes. The duration of the training is two months and covers the operation and maintenance of the power plant. Thus, a job platform has been created for unemployed literate/neo-literate villagers. 'Pay-for-Use' service approach is followed by HPS for raising revenue and supplying electricity. The HPS business model is attractive and successful in the rural areas because of its low cost.

About 300 kg of rice husk is required as raw material to produce 40 kilowatt of energy, which is sufficient to supply energy to 500 households for 6-12 hours per day. Raw material (waste rice husk) is purchased for Rs. 1 per kg from rice mills. Generally, electricity is supplied to domestic and commercial consumers for fixed 6 – 8 hours in a day. Charge rates are Rs 80/month/2*15 Watt CFL`s and mobile charging. Low cost pre-paid meters have been installed that can efficiently regulate the flow of low-watt electricity and reduce electricity theft to less than 5 per cent.

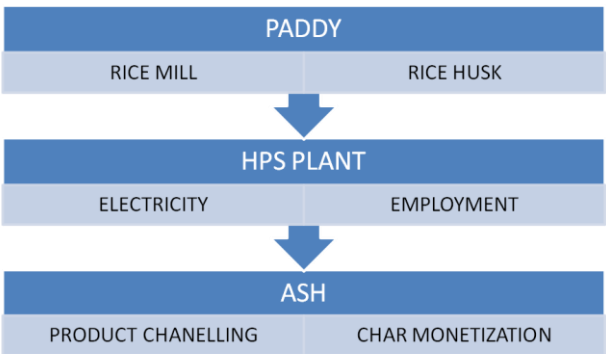

Fig 2: System story of a HPS power plant [22].

The success story of HPS lies in the pioneering areas such as efficient recycling of by-products used in making incense sticks, rubber and manure, employment of 1200 women and many others. For each Megawatt of power generated about 5800 tonnes of carbon dioxide emission reductions can be achieved every year, sustainable development leading to its worldwide recognition [22].

6. CURRENT STATUS OF GASIFICATION IN INDIA

The Ministry of New and Renewable Energy (MNRE) of the Government of India has been promoting productive and efficient utilization of biomass for energy generation realizing the enormous potential for power generation available from biomass. It covers (a) off-grid power projects for meeting unmet demand of electricity in semi-electrified villages; and (b) grid-interactive MW level power project with 100% producer gas engine with the objective to meet the unmet demand of electricity in villages, demonstration projects (for 100% producer gas engine) coupled with gasifier for off-grid and grid power operation, and to support and thus enlarge activities, through awareness creation, publicity measures, seminars/workshops/ business meets/training programme,etc. The MNRE has been providing support for promoting development and deployment of biomass resources through combustion, gasification and co-generation technologies for power generation (captive, off-grid and grid connected) and also for thermal applications**.** Most of the biomass gasification systems for electricity generation installed up to 2002–2003 were based on dual-fuel engine technology. In recent years installation of biomass gasifier systems equipped with engines operating on 100% producer gas has also been taken up. The cumulative installed capacity of biomass gasifier systems (including both dual fuel as well as 100% producer gas mode systems) with aggregate capacity of 76MWe have been deployed so far in the country under the programme implemented by the MNRE [23]. Under its programme on biomass gasifiers, the MNRE is providing capital subsidy to the users for installation of biomass gasifiers. The amount of capital subsidy on pro-rata basis during 2006–2007 is to the extent of Rs. 1.5 million for a basic package of a 100 kW biomass gasification projects covering housing for system and local electricity distribution network for electricity generation [23].

6.1 TERI: A front runner in biomass gasifier technology

Small capacity (10-20 kWe) biomass gasifier systems are ideally suited to provide remote rural electrification at an affordable cost. TERI has developed a 100% producer gas engine with good field performance reliability. In an effort to spread their use, it has so far commissioned four systems in the states of Chattisgarh, Orissa and Rajsthan.

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A few more systems are currently in the different stages of installation under the ambit of Village Energy Security Programme (VESP) of the Ministry of New and Renewable Energy (MNRE) and the recently envisaged renewable energy charter of NTPC.

6.2 Some other case studies related to biomasss gasification in India

A. Gasifier system at Jamera (District Korba), Chhattisgarh

Biomass gasifier technology was deemed as a best possible alternative for this village having a forest cover of nearly 5247.7 ha, grazing land around 124.7 ha. Jamera has an annual surplus availability of woody biomass in the range of 3567.46 tonnes enough to keep a biomass gasifier system of 10 kWe going on for a daily operation of 4-6 hours. However, to run the system on a long-term basis, unanimity was reached with the villagers to use 5 acres of village forest. The local forest department along with TERI developed this forest for supply of fuel wood by a massive plantation drive. Around 100 households availing the benefit of biomass based lighting with two light bulbs of 40 W each for indoor lighting, remains operational for about 4 hours (6-10 p.m.) on a daily basis. Five nos. of street lights also lit up a few vital entry and exit points within the village at night for about 4 hours daily. The plant capacity is around 8.20 kWe as per the following breakup. The system capacity was scaled up to 10 kWe. However assured supply of biomass is needed [24].

B. Hosahalli and Hanumanthenagara in Karnataka

Fig 3(a) : Biomass Gasification System (20 kWe) at Hosahalli, Karnataka [27].

Indian Institute of Science Bangalore has installed 20 kW gasifier in the two villages of Hosahalli and Hanumanthenagara (in Karnataka) in 1987 and 1994, respectively. The population of these villages is small (220 and 300, respectively) and agriculture was primary business. The gasifier installed in these villages have duel fuel generator with efficiency of about 23%. Woody biomass obtained from social forestry is used as fuel in the gasifier. The typical specific consumption of these gasifiers is 1.25 kg/kWh and the tariff is fixed at Rs. 3.34/kWh. Electricity was mainly used for domestic and street lighting, irrigation, drinking water supply and flour mills. The gasifiers were operated by locally trained people and managed by village committee. Electricity was generated and provided for 90% days in a year [25-27].

C. Kasai Village Gasifier, M.P

The system operates for 5 hours in a day and on an average generates 40 units per day and 1200 units per month. The operation and maintenance of the plant is done by the local youth who have been trained. As a startup process, a diesel engine is used to operate the gasification system before switching the operations to gas alone mode. During this period the amount which can be reduced is about Rs. 0.2 per kWh for diesel and with labour cost around Rs. 2.5 per kWh. This has provided an opportunity to local employment. At current the cost of electricity generation is about Rs 3.79; however there is ample scope for cost reduction with the increase of usage through introduction of water supply for irrigation, power supply for bio-diesel production and other micro enterprises. The system has been in operation for over 10 months and the overall performance is satisfactory. During this period, a few operational issues and the logistics of establishing and using local operational skills were addressed. [26] [28].

Fig. 3(b): Gasifier System at Kasai (2 x 10 kWe) [28]

D. Odanthurai and Nellithurai in Tamil Nadu

Village Panchayat of Odanthurai (Tamil Nadu) has installed 9 kW-capacity Ankur Gasifier for electricity required for water pumps for drinking water supply, thus reducing the load on grid electricity by over 70%. The gasifier operates on waste wood obtained from a local sawmill purchased at Rs. 0.3/kg. The efficiency of gasifier is typically 1.5 kg of wood/kWh. The number of consumers is approximately 4000 and the tariff is fixed

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at Rs. 30 per household per month. The installation at Nellithurai is similar as that in Odanthurai except that the village committee has decided to operate the streetlights on gasifier electricity. The specific fuel consumption and tariff structure is same as that in Odanthurai but the cost of biomass purchase is much higher at Rs. 800/ton dry wood [29-31].

E. Installation at Sundarbans in West Bengal

Two remote islands in Sundarbans, viz. Gosaba and Chottomollakhali have been electrified by West Bengal Renewable Energy Development Authority by installation of biomass gasifiers. The Gosaba Island has five units of 100 kW-capacity. To meet the fuel wood needs, energy plantation has been carried out on 100 ha wasteland yielding 10 tons of biomass per hectare per year. A cluster of five villages with total population of approximately 10,000 has been provided electricity from this installation. The generators are of dual fuel type, which consume 70% producer gas and 30% diesel at full load. The specific biomass consumption is 0.8 kg of dry wood/kWh and units are operated for 16 h each day. The tariff structure is Rs. 5.60/kWh for domestic users, Rs. 6.75/kWh for commercial users and Rs. 8/kWh for industrial users. The total capital cost of installation is Rs. 9.5 million, and this operation has provided direct and indirect employment to about 84 people. Similar installations have been made in the village of Chottomollakhali at Sundarbans with population of 9219 (total 1726 households). In June 2001, four units of 125 kWcapacity each have been set up in this village at a cost of Rs. 14 million. The capacity utilization factor is 80% and operation of the plant lasts for 5 h each day. To meet the fuel needs of the gasifiers, plantation has been carried out in 10 ha land at a cost of Rs. 500,000 and the yield is estimated at 5 tons ha^{-1} $year^{-1}$. The tariff structure is similar to the Gosaba Island and total number of beneficiaries from this venture are 225 (1 industry, 74 commercial and 150 domestic households) [29] [31-33].

Current technical research, development and demonstration (RD&D) efforts to advance biomass gasification are concentrated in three general areas: progress in scale-up; exploration of new and advanced applications; and improving operational reliability for a sustainable development in rural sector.

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