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Sustainable rural micro-enterprises through co- and tri-generation: Review of concepts

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Biomass production, conversion and utilization can be done locally with value addition to small farmers. However, new technical inputs are needed for profitable exploitation of biomass within the constraints related to land, water and skill availability and to provide higher quality of energy needed for rural industries. Trigeneration, which is generating energy simultaneously in three forms (electric power, heat for processing and refrigeration), helps in fully utilizing the stored energy in biomass and would be most appropriate for micro enterprises. This paper presents concepts in terms of trigeneration systems feasible for rural areas.

Keywords: Energy from biomass, Sustainable rural industrialization, Trigeneration

Introduction

In India, where 70% population depends on agriculture, majority of farmers live with small land holdings and face the problems of degraded soil, poor quality of water and inadequate sources for irrigation and marketing of their perishable produce. Such a large chunk of population cannot be sustained on agricultural land and the solution lies in not only enhancing agricultural production but also in providing employment opportunities in secondary and tertiary sectors. Biomass, which is traditionally used in villages essentially for heating and lighting, has to be made useful for providing higher forms of energy in down sized units[1]. This way benefits would reach directly to small farmers, who will be involved in the production and utilization of biomass locally. Electricity production by biomass-based systems utilizes < 30% of heat energy from biomass and balance heat is wasted. If systems are designed to use simultaneously the waste heat for heating and chilling, this can sustain micro enterprises. Once technologies are available, they can be integrated into systems matching the load needed for micro-industrial complex, leading also to low waste and low carbon emissions, besides leading to economic gains.

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This paper presents a conceptual framework for generating sustainable livelihood using locally accessible biomass for trigeneration, which is generating energy simultaneously in three forms (electric power, heat for processing and premises heating and for refrigeration).

Electricity Generation from Biomass

Biomass is available in rural areas in following forms: i) Agro-residues (straws, rice husk, groundnut shell etc.); ii) Non-edible oils [Karanj (*Pongamia pinnata*), Jatropha (*Jatropha curcas*) etc.]; iii) Weeds (*Lantana camara*, *Ipomea fistulosa* etc.); and iv) Specially raised energy plantations [Subabul (*Leucena leucocephala*) etc.]. Most of the plant biomass (leaf, stem, wood etc.) is lignocellulosic (cal val, 4,000-5,000 kcal/kg). Energy content in vegetable oils is typically 8,000 kcal/kg. Energy stored in biomass can be released by burning and heat generated can be used to produce electricity (10-500 kW suitable for small enterprises) through different routes.

Proposed Trigeneration Systems

Boiler Route

This involves combustion in a boiler for raising steam for running a back-pressure steam turbine for electric power generation. Energy from exhaust steam at 2-3 bar gauge can be used for food processing or absorption

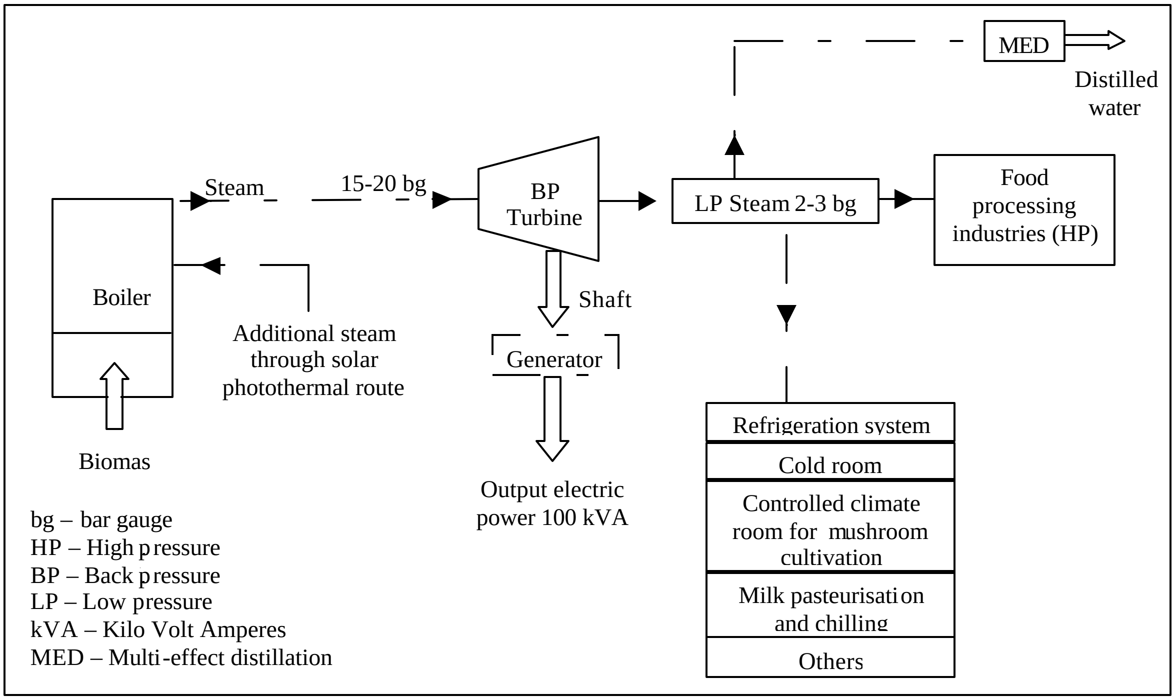

Fig. 1— System based on boiler route

cooling. In proposed system (Fig. 1), high pressure steam [10-20 bar gauge (bg)] generated in a boiler is fed to a back-pressure turbine. Output of electric power from steam turbine is ~ 100 kW. Low (back) pressure steam (1-3 bg) exhaust can be used in a variety of micro-enterprises (Table 1). Additionally, as per need, some steam at high pressure can be bled into a thermal vapour compressor system, combining it with low pressure steam from turbine to produce steam (3-5 bg). Low pressure exhaust steam can be used to produce distilled water through a multi effect distillation unit, and also for food processing industries[2]. Steam can be used for heating purposes in drying, pasteurization, sterilization, cooking etc. typically useful in food processing It can also be used for cooling. Cooling through absorption refrigeration can be done by phase change or sorption/desorption processes (Lithium Bromide based, or carbon ammonia based systems). Cooling system may be used for cold storage kept at 10-15°C, or lower, depending on the level of cooling needed.

For example, biomass (1 kg) containing 16000 kJ of thermal energy can raise 3-4 kg of steam. Thus 750 kg of biomass (say rice husk) may be burnt for 1 h to produce 3 tonnes (t) of steam. In this system, for circulation of steam at 3 t/h, make up water requirement may be only 20% or 0.6 t/h. Steam (18-20 bg) may be expanded down to 2-3 bg back pressure, or, steam at 10-12 bg expanded to 1 bg back pressure, in a back pressure turbine, to generate 100 kW energy. Energy content of expended steam at 1-3 bg, can be used for thermal refrigeration, food processing, distillation, etc. For example, in a micro industrial complex for 50 t refrigeration by lithium bromide systems, 400 kg steam may be used. For 200 t refrigeration, only 1.6 t of steam would be sufficient. If 1 t of steam is used for food processing, balance (0.4 t) can be used for producing drinking water in a small scale multi-effect distillation unit[2]. Other combinations of loads can be worked out appropriately to the needs of micro enterprise.

Bio-Oil Route

This route involves using seed oils[3], neat (as such) or after transesterification, in internal combustion (IC) engines for producing electricity. All vegetable oils are basically triglycerides of long chain fatty acids, whereas fossil fuels (diesel and petrol) mostly consist of hydrocarbons. Bio-oil can be produced and used locally[4]. For a stationary engine, raw bio oil, including kitchen waste oil after frying etc., can be used directly in a diesel engine[5], provided such oils are initially heated to 70-170°C (depending on type of oil) to reduce viscosity. Initial heating of bio-oil can be done by diverting a fraction of exhaust heat to oil pre-heater. On a practical scale, bio-oil run diesel engine (20 kW) rejects 20kW of waste

Table 1—Use of trigeneration in micro enterprises

Activity	Heating/Steaming	Cooling	Electricity
Water purification	Multi effect distillation	Ice making	Running feed water pump
Vegetable & fruits processing	Steaming cooking for jelly, jam, pickle etc.	Storage	Running machinery
Fishing using boats with genset	Distillation of brackish water	Cooling for fish storage	Running boat
Milk based	Pasteurization	Refrigeration for storage	Testing packaging and other machinery
Poultry farming	Composting, use in hatchery	Storage of produce	Running machinery
Herbs	Room temperature drying steam extraction	Cooling storage	Juicers, grinder, running machinery
Mushroom cultivation	Composting, pasteurization	Maintaining suitable temperature in mushroom hut	Running machinery

heat (exhaust temp., 350°C), which can be used for preheating the oil and also for biomass drying, water distillation etc. (Table 1).

Gasifier Route

This route involves gasifying biomass to obtain producer gas (PG), which is used to substitute fuel in IC engines for generating electricity. Efficient gasifiers have been developed in India, though not at very small scales. In one system reported, first stage is a reactor, where gasification takes place through a pyrolytic process. In the next stage, PG is taken to a cyclonic separator, where most of the solid particles ((tar) are precipitated. PG is scrubbed by a cool water spray. Extensive scrubbing reduces almost all residual particles in PG. After this stage, PG is ready for use straight in a spark ignition (SI) engine without mixing/blending with any additional fossil fuel. Dirty wash water, after scrubbing of PG in spray shower, may be passed through a nano filtration unit, for recycling (some water is used for backwash of nano filtration unit). Recycled water, along with some make up water added, is fed to second ancillary unit, namely, a refrigeration unit for chilling. This refrigeration unit may be based on an absorption and desorption system working on energy derived from exhaust heat. Such gasifier units are already in markets, but once again cost effectiveness in down sizing is to be seen. Small scale and less elaborate gasification systems are prone to corrosion, due to insufficient tar removal.

Pyrolysis Route

Normally only dry biomass has been used for pyrolysis for generation of gaseous and liquid fuels, including char. Slow pyrolysis for charcoal and fast pyrolysis for liquid fuel production are well known[3]. Intermediate pyrolysis is now being tried for using even moisture loaded biomass such as algae. Pyrolyser can sustain 20-30kW stand alone power[6] generation. One such unit using biomass feedstock has been developed by Aston University, UK, and is undergoing field trials.

Biomethanation Route

Biogas can be produced by anaerobic digestion of soft biomass (cow dung, kitchen waste etc.), and is used for power generation. Daily feed (fresh cow dung 25-50 kg) is needed per biogas digester (vol, 2 m^3) and many such small units are in operation at household levels in India.. Large biogas plants using poultry wastes have been set up by KVIC and other organizations. In poultry farms, up to 5 t of poultry wastes, collected daily by 50,000 birds, are used for a 1,000 m^3 biogas unit for generating electricity. Biogas contains methane (CH_4, 60%), carbon dioxide (40%) and some hydrogen sulphide and water vapour. Scrubbing in lime-water removes CO_2, and renders biogas easier for direct use in SI IC engines. In case of biogas (cal val, 20 MJ/m^3) burning in IC engine only 10-20% of heat gets converted into electricity and a large quantity rejected as waste heat can be suitably harnessed in the microenterprise.

Solar Photothermal / Biomass Energy Based Hybrid System

Solar thermal energy may be concentrated by solar collectors to produce steam and used for co- or tri-generation with biomass based back up systems. By the photothermal route, 40-60% of solar insolation (approx. 1 kW/m^2) energy may be harnessed. It is also possible to conceptualize hybrid systems using gensets (bio-oil, biogas or diesel) for electricity generation, where

Table 2—Crop residue and yield of selected crop produce in India

Crop	Grain & seed production t/ha	Agro residues	Utilization of crop residue
Wheat[7]	2.7	Straw, 25%	Animal feed, hard board and paper industry, energy
Rice[7]	1.9	Straw, 63%	Animal feed, packaging
		Husk, 15-20% of paddy milled	Fuel, pulverized husk as cattle feed
		Bran, 4-9% of paddy milled	Vegetable oil, bio-fuel, food and fodder
Jatropha[8]	0.7-4.0	Oil, 30-40% Seed cake, 10-15%	Bio-fuel, manure, fuel, insecticidal properties

Table 3—Potential biogas production from different feedstocks

Feedstock	Availability kg/animal/d	Gas yield m^3/day/animal
Cattle waste	10	0.36
Buffalo waste	15	0.54
Piggery waste	2.0	0.18
Chicken waste	0.18	0.011
Human excreta	0.4	0.030

additionally a boiler fed by biomass is used for steam generation. Solar energy can also be hybridized with these for generating steam. Amount of steam generated by different routes must match the rates of heating and cooling needed in different processes.

Feasibility of Trigeneration in Micro Enterprise

Cogeneration and trigeneration systems are already in operation in industries generating electricity (> 1 MW), often using locally generated agro-residues. Use of bagasse in sugar industries is well known. Main issue is down sizing this concept to the level of 20-100 kW of electric power, sufficient for village level micro-industries, and also utilize the exhaust steam energy (≥ 1-2 MW). In fact, electric power is viewed as only one of the products, thermal energy being the other equally or more important product in biomass conversion. Some illustrative examples of micro enterprises where trigeneration can be used are listed in Table 1.

Biomass Availability

For running trigeneration system for energizing micro enterprises, sustained availability of biomass in adequate quality and quantity is a prerequisite. For raising plants, right kind of plant species have to be selected ensuring the right mix of soil, plant nutrition, water and other inputs, for sustainable production. Also, biomass production for energy use has to be integrated with biomass production for food, fodder, timber and other applications. Yield potential of agricultural crops, trees as well as weeds has to be looked into, to evaluate the amount of biomass, which can be obtained from agri-horticultural, silvipastural and wasteland systems for energy generation. An estimate of yields from some plants is listed (Table 2). Biomass yield of energy plantations of some multipurpose tree species are reported as follows: *Eucalyptus*[9], 31.0-58.0; *Populus*[9], 4.0-19.0; *Acacia nilotica*[10], 30.8; *Leucaena leucocephala*[11], 40.6; S24 (5 y)[11], 32.1; Coppiced S24 (Ist y)[12], 26.7; Coppiced S24 (IInd y)[12], 45.4; and Coppiced S24 (IIIrd y)[12], 38.1 t/ha/y. Actual yields would vary with soil, water and other inputs. Fertigation, which is judicious use of wastewater (which has plant nutrients) for irrigation of energy plants, is useful in enhancing biomass production. Growth rate of algal biomass is several times higher than that of terrestrial biomass. Also, algae can be directly converted to bio-oil. Sewage sludge is being looked into as a possible fuel source in pyrolysers and boilers. Use of biogas, for cooking, lighting and running diesel pumps for water lifting etc. is already known. Considerable amounts of wastes, generated as animal wastes in dairies, piggery and poultry farms (Table 3), can be used for biogas production.

Conclusions

Trigeneration can help in fully utilizing the energy stored in biomass. Already such systems are in operation for generating power of the order of several MW in industrial applications. The challenge lies in scaling it down to power a rural industrial complex comprising micro enterprises. This has been conceptualized especially through boiler, gasifier, pyrolysis, and bio-oil routes for electricity generation, as also discussed by the authors in the ICME conference held in December, 2007, at Dhaka[13]. Trigeneration is being researched globally[14,15].

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