Evaluation of Different Biofuels for Power Generation in Villages Through Genset: Evidences from India

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Abstract

Access to electricity is an essential requirement for achieving rural development, and lack of it is closely related to increasing rural poverty. In the farming community, the need for electricity for essential activities like thrashing, lighting for extended working and learning hours, powering small-scale rural enterprises or income generating activities, pumping water for human, animal and crop needs are considerably important from the view point of socio-economic benefits. The Fiji Electricity Authority has a total installed capacity of about 170 MW of which 57% comes from diesel and 43% from hydro. Fiji's dependence on diesel fuel and other imported petroleum products has placed a lot of pressure on the national economy as a result of rising fuel prices. Fuel imports increased by more than 4% in 2004. This paper attempts to identify various biomass resources and their potential as biofuels for DDG for electrifying/energizing remote areas in Fiji.

Introduction

About 46 percent of Fiji's estimated population of 827,000 is rural, spread sparsely in about 1,500 villages and settlements. Approximately 25 percent of the total rural population is poor; in 1986, 69% of rural villages and settlements lacked electricity; by 2007, this figure fell to around 20% as grid extension increased. The provision of energy supplies not only affects the economy at large but the very foundation of our existence. The fact is that energy has become one of the most defining issues

Fijian Studies Vol. 9 No. 1 © Fiji Institute of Applied Studies

of this century. For small island states or economies, the situation is no longer confined or classified as an energy security issue; rather it has become an imminent threat to the security of our economy, our livelihoods and our sovereignty as an independent nation. Among a number of strategies adopted by our small island states, one of the most important one is the development of locally available renewable energy resources.

The Department of Energy (DoE) of Fiji has been given the responsibility of making provisions for electricity in rural areas; this includes provision through local renewable energy resources.

There are a number of renewable options available in Fiji, each with its own merits and demerits. Those which have received considerable attention are: (a) Small Hydro Power (SHP), (b) Solar Power, (c) Wind Energy and (d) Bio-Energy. Micro hydro power is environmentally benign and free from ecological problems unlike large hydro projects. Small hydropower stations mostly in hilly areas are given priority for local benefits and gainful utilization of energy potential of flowing water. Incentive schemes could include renovation and modernization to rehabilitate old units. Micro hydro stations often have limitations for their topographic location and availability of water head. Solar cells installed for home and streetlights in a few villages are still expensive. The main advantage of solar PV system is its maintenance-free operation. However, this system is only economical for village electrification if entire capital cost has been provided as a capital subsidy. The Fiji Government has installed wind farms on an experimental basis in some areas, however, the cost effectiveness of these installations need to be examined. For wind mill, a potential site is considered viable if the average wind speeds at a height of 50m is above 200 W/m^2. Also, the viability of wind is critically dependent on the capacity factor that is site specific.

Energy needs in villages and in industries can also be met through bio-energy using technologies already known for some time and which have been improved and developed further in recent years. Alternative routes for energy production could be selected from among biomass gasifiers, biogas plants or biofuel units, depending upon availability of various resources and end-use applications. Table 1 shows optional bio-energy for Rural Electrification Programmes.

Decentralized generation using diesel genset is used in some areas. Farmers and rural dwellers can use diesel gensets to fulfil their needs like pumping of sub-surface water, pumping river water for crops, artificial irrigation, etc. Diesel fuel based gensets are widely used in Fiji, however, these drain scarce oil resources and generate huge outflow of foreign exchange. In fact, the handling and transporting of diesel in remote areas is a challenging task. The objective of zero net emission of CO_2 makes this also an improbable option for power generation in the long term. Also, a country's dependence on imported petroleum fuels is constantly increasing due to high demand of electricity. Thus, there is an urgent need to explore the alternative substitutes for conventional diesel fuel.

Table 1: Modern Biomass Technologies for Decentralized Applications

Technology	Type of Biomass	Conversion Process	End use Application	Technology status
Biomass Gasification	Wood, Woody biomass, agro and agro industrial residue	Thermo-chemical process which converts biomass into producer gas	Power generation: 10kW -1000 kW. Thermal applications in small industries up to 3MW	Dual fuel and 100% gas engine based Gasifiers available commercially
Biogas	Animal dung, green vegetable matter, leafy biomass	Bio-methanation process which converts biomass into biogas	Cooking in households, Motor Power and Electricity generation	Dung-based plants commonly being built. Pilot plants on leafy biomass.
Bio-oil	Edible and Non-edible vegetable oil seeds	Extraction of bio-oil from oilseeds. Bio-diesel Production through trans-esterification	Motor power and Electricity generation	Bio-diesel and Straight Vegetable Oil (SVO) demonstrated as fuels for transportation and power generation.

Vegetable oils (bio-oil) is the most promising candidate as substitute for fossil-derived fuels for diesel engine. Vegetable oils have potential to reduce the country's dependence on imported fossil fuel and help to make farming communities self-sufficient in terms of fuel needed to continue their businesses. The idea is not new. As early as 1900, a diesel-cycle engine was demonstrated running wholly on groundnut oil at the Paris exposition. Interest has been rekindled in bio-oils as diesel fuel researchers in many parts of the world are applying new technologies to the concept. Generally, vegetable oil is found to have fuel properties similar to that of conventional diesel fuel except viscosity, CFPP (cold filter plugging

point), carbon residue and ash content. An unmodified engine can perform satisfactorily on neat vegetable oils or their blends with diesel (Chaturvedi and Mande, 2006).

In this paper, an attempt is made to identify various biofuel resources and their potential as fuel for DDG for electrifying/energizing remote areas in Fiji.

Potential of Bio Oil in Fiji

It has been estimated (Cloin, 2007) that current plantations in the South Pacific have the potential to produce over 126 million litres of coconut oil per year, as shown in Table 2. In the larger countries, like Fiji and Papua New Guinea, this would make only a very minor contribution to national energy production, however in smaller island countries such as Vanuatu, coconut oil could theoretically replace a substantial proportion of the fossil fuel-derived oil currently in use.

Table 2: Potential of Coconut Oil in South Pacific Region

Country	Potential coconut oil production (million L)	Crude oil consumption (m L)	% of energy demand that could be met from coconut oil
Fiji	17.47	1,056	1.5%
Kiribati	3.06	16	17.2%
Marshall Is.	3.44	n/a	n/a
PNG	53.91	1,654	3.0%
Samoa	10.92	70	14.3%
Solomon Is.	7.1	87	7.4%
Tonga	0	73	0.0%
Tuvalu	0.29	n/a	n/a
Vanuatu	30.51	41	68.5%

Source : Cloin J, 2007

Technological Option for Energizing Genset using Bio-Oil

There are three common ways to run a diesel engine on bio-oil using vegetable oils. All three can be used with fresh and used oils. These are:

- Converting it to biodiesel;
- Mixing/blending with petroleum diesel fuel, or with biodiesel;

- Using the oil just as it is - usually called SVO fuel (Straight Vegetable Oil).

Converting to Biodiesel

The most common method used to lower the viscosity of vegetable oil is called trans-esterification. This is the process by which long chain of fatty acid ester is converted into shorter chain of esters, resulting in reduction of viscosity. From transportation point of view, biodiesel is a better fuel compared to petro-diesel fuel since it is more reliable, requiring minimal additional maintenance and has low emission profile. However, for decentralized power generation in remote rural areas, this might not always be feasible or even advisable. Centralized large scale-production of biodiesel is more preferable since it requires extensive chemical inputs, technological expertise and skilled labour. Also, substantial transportation costs involved in centralized collection of bio-oils from widespread geographical areas and redistribution of processed biodiesel to remote rural areas may adversely affect the economic viability of using it as a genset fuel for DDG.

Mixing or blending with diesel

A large volume of research have been conducted on the use of bio-oil and diesel fuel blend. The blends containing 10 to 30 percent bio-oil oil have their kinematic viscosity and relative density compatible for use in diesel engine (Chaturvedi, Mande and Bhattacharya, 2004). The performance of low power (hp) engines and regulated emission from stationary internal combustion (IC) engines are comparable with diesel. Many studies suggest that beyond 30 per cent bio-oil in the blend may not be advisable, as it reduces engine performance and increases engine maintenance costs substantially. Complete replacement of diesel fuel from the IC engine is not possible, making it a weak case for DDG.

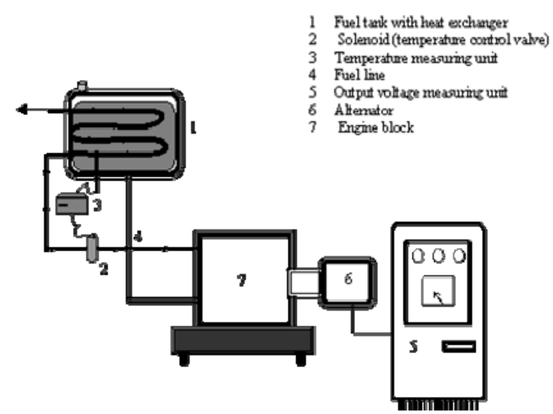
Use as SVO (Straight Vegetable Oil)

Straight vegetable oil (SVO) fuel systems can be a clean, effective and economical DDG option. SVOs, referred to as neat vegetable oils are derived from oil seeds, both edible and non-edible. SVOs can be directly used in diesel engines. There are several advantages of SVO over biodiesel, especially for its decentralized ability as SVO can work in remote areas where the availability of power is almost uncertain. The oil, produced from edible and non-edible seed oil, can be used for decentralized

power generation or pumping irrigation water as well as for various farm operations using tractors and machinery. Though biodiesel may be a better option for transportation fuel as such, use of SVO in diesel engines in remote areas can be an appropriate option for effectively exploiting potential of biofuels in Fiji.

The main problem faced while using SVO as engine fuel is its high viscosity and high flash point. High viscosity interferes with the fuel-injection process in the engine, leading to poor atomization of fuel and inefficient combustion. Heavy smoke emissions and carbon deposition in the combustion chamber have been reported. Unlike biodiesel, one has to slightly modify the diesel engine to use SVO. The simpler way to reduce viscosity is to fit a waste heat recovery heat exchanger to heat up fuel going from fuel tank to engine by using hot engine exhaust gases. Figure 1 provides an illustration. Two fuel tanks can be used in SVO systems. The engine can be started on ordinary petroleum diesel in one tank and then switched to SVO in the other tank, which is preheated to desired temperature to reduce viscosity using heat of hot exhaust gases, and switched back to diesel before stopping the engine. It is proven that the viscosity of jatropha decreases with increases in the oil temperature. Drop in the viscosity of jatropha oil is very fast upto 70°C and thereafter the viscosity decreases comparatively at slower rate. At 110°C, viscosity of jatropha oil attains the viscosity in the range of diesel fuel (2.5 to 7.0 cSt) as specified by BIS (Chaturvedi and Mande, 2005).

Figure 1: Engine Operation with Jatropha Oil Preheated Using Engine Exhaust



Economics of Power Generation in Remote Areas via Biofuel Route

Here, an attempt has been made to analyze the cost of electricity generation using various biofuel DDG options viz biomass-gasifier based system (100% producer gas engine), biodiesel genset, SVO genset vis a vis diesel genset.

In order to estimate the unit cost of electricity generation (Ce), levelized annual cost (LAC) approach is adopted here. The unit cost of electricity produced can be calculated as the ratio of the total annualized cost (TAC) to the annual quantity of electricity produced (AEP) through system operation on an annual basis.

$$C_e = \frac{TAC}{AEP}$$

The annual electricity production (AEP) depends upon the rated capacity of the system (P, kW) and its utilization. Capacity utilization is taken into account by defining a capacity utilization factor (CUF), which is the ratio of actual amount of electricity generated to the maximum amount of electricity generation possible. CUF depends on load of operation and the annual/daily hours of system operation.

$$AEP = CUF \times P \times 8760$$

The total annualized cost (TAC) of a DDG option will comprise various components:

$$TAC = ACC + AFC + AOC + AMC$$

where, ACC = Annualized capital cost of the DDG system,
AFC = Annual fuel cost for system operation
AOC = Annual operation cost of system
AMC = Annual repair and maintenance cost of system

Annualized capital cost of the system is calculated by multiplying capital cost of system with CRF (capital recovery factor) based on useful life of system and discount rate. Annual fuel cost is calculated, based on specific fuel consumption (SFC-kg/kWh) and amount of units generated (AEP) as

$$AFC = AEP \times SFC$$

Annual operation cost can be calculated by taking into account the number of personnel (N_l) required for operating the system and their monthly salary (S_l) as

$$AOC = N_1 \times 12 \times S_1$$

Annual repair and maintenance costs are normally taken as some fraction of the capital cost of the system. The fraction R for diesel genset, gasifier power system, biodiesel genset and SVO genset is taken as 0.05, 0.075, 0.05, 0.075 respectively.

$$AMC = R \times C$$

Thus, the unit cost of electricity production for given biofuel DDG option can be calculated from the following equation:

$$C_e = \frac{ACC + AFC + AOC + AMC}{AEP}$$

The base values of various input parameters for reference case of the analysis are summarized in Table 3. Figure 3 gives the summarized results of the economic analysis of various biofuel DDG options. It can be observed from the figure that gasifier is cheapest option if one considers only fuel and/or O&M costs but it has higher capital cost. However SVO is cheapest option considering even capital cost for energizing the rural areas, especially suitable for remote areas; this can also be used for other robust applications like irrigation pumping, mills etc

Sensitivity Analysis

It can be seen from the analysis that the cost of electricity produced depends on various parameters, such as useful life, prevailing discount rate, fuel prices, and system capacity utilization (load and hours of operation). In view of the possible variations in these parameters, sensitivity analysis was carried out to study the effects of such variations on unit cost of electricity generation (Rs per kWh – hasn't been converted to $/kWh including in figure/graph). The results of the sensitivity analysis are presented graphically in Figure 4. It can be observed that the unit cost of electricity is quite sensitive to the capacity utilization of the system and fuel price. Other factors, such as discount rate, have a rather moderate effect on the unit cost.

Table 3: Base Values of Input Parameters in Economic Analysis

Parameter	Value
Capacity (kW)	10
Capital cost (Rs) Diesel genset, Biodiesel genset Gasifier system SVO genset	 250 000 750 000 280 000
Capacity utilization factor, CUF	0.30
Discount rate, d (%)	10
Useful life of system (yrs): Diesel genset Gasifier system Biodiesel genset SVO genset	 25 10 20 15
Repair & maintenance cost (fraction of capital cost Diesel and biodiesel genset SVO genset and gasifier system	 0.005 0.075
Fuel price (Rs/kg) Fuelwood Diesel SVO Biodiesel	 1.50 30.00 20.00 45.00
Specific fuel consumption SFC (kg/kWh) Diesel genset, biodiesel genset Gasifier system SVO genset	 0.300 1.75 0.350
Salary of labor, S_l (Rs/month)	3,000
Manpower required for system operation (N_l) SVO, biodiesel, Diesel genset Gasifier system	 1 2

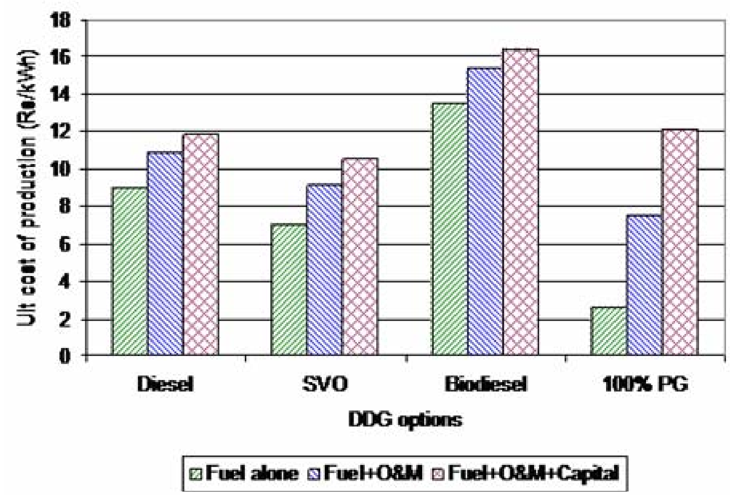


Figure 3. Comparison of economic cost of various biofuel DDG options

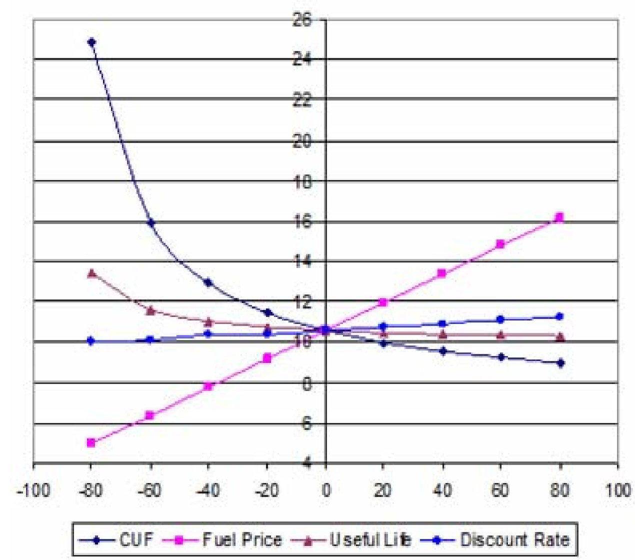


Figure 4. Sensitivity analysis of cost of generation through SVO genset

Conclusion

In spite of rigorous efforts by government, a large number of villagers especially in the rural areas need to be supplied with electricity. Government has selected some such remote villages to be supplied with electricity through renewable energy sources. For India, being an agriculture based country, biofuel based DDG options are more appropriate and viable. Among various biofuel DDG options, SVO based is one of the promising options for remote rural areas. Using simple techniques of preheating the viscous bio oil using simple device for utilizing waste heat of hot exhaust gases to preheat the bio oil can be a good solution to overcome the problems associated with its high viscosity. Comparative economic analysis reveals that among various biomass based DDG options, tough gasifier fuel costs are lower, while SVO emerges as an overall cheapest DDG option even when capital costs are taken into account.

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