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A mathematical model for transporting the biomass to biomass based power plant

Jagtar Singh [a,*], *B.S. Panesar* [b], *S.K. Sharma* [c]

[a] *Mechanical Engineering Department, SLIET Longowal, District Sangrur, Punjab, India*
[b] *Project Professional, SCS Engineers, 11260 Roger Bacon Drive, #300, Virginia 20190, USA*
[c] *Mechanical Engineering Department, NIT Kurukshetra, Haryana, India*

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ABSTRACT

In Punjab, million of tons of agricultural biomass are being generated every year, but it is spatially scattered. The spatial distribution of this resource and the associated costs on collection and transportation are the major bottleneck in the success of biomass energy-conversion facilities. This paper deals with the mathematical model for collection and transporting the biomass from fields to biomass based power plant. The unit transport cost was calculated by using this model. Four systems of transport were conceptualized for two transport modes (tractor with wagon and truck). Three types of agricultural biomass (loose, baled and briquetted) were considered for transport analysis. For all modes of transport, it was observed that unit cost of transport decreases with increase in distance. The transport cost was least for briquetted biomass as compared to loose and baled biomass.

1. Introduction

Availability of energy is critical for all round economic, social, cultural and political developments in developing countries like India. In India, the energy shortages are increasing day by day thereby threatening the sustainability of all round development of the country. The energy self-reliance has depleted as our domestic production of petroleum products is below 30% resulting into increased import bill. A need is now being felt by scientists, planners and policy makers to find alternate and dependable energy resource not only to sustain the present level of development but also to accelerate its growth. Biomass is one such energy resource that meets all these requirements. Agricultural biomass residues have the potential for sustainable production of biofuels and to offset greenhouse gas emissions [1–3]. The straw and agricultural residues existing in the waste streams from commercial crop processing plant have little inherent value and have traditionally constituted a disposal problem. In fact, these residues represent an abundant, inexpensive and readily available source of renewable energy resource [4–6]. Due to technological developments and cost reductions, renewable especially solar, hydro, wind and biomass energy are gaining momentum. Further, the renewable sources, particularly biomass, are less environmentally destructive than the current fossil fuel sources [7]. Of all the renewable energy sources, agricultural biomass is the largest,

List of abbreviations: hr, Hour; Km, Kilometer; L, Liter; MJ, Mega Joule (1 MJ = 10^6 J); m, Meter; US$, US Dollar {1US$ = 47.49 Rs.(Indian Rupees)}; ρ, Spatial density (ton km^{-2}).

* *Corresponding author*. Tel.: +91 98726 68101; fax: +91 1672 280057.
E-mail address: j_s_ranu@rediffmail.com (J. Singh).
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most diverse and most readily exploitable resource. Bioenergy technologies provide opportunities for conversion of biomass into liquid and gaseous fuels as well as electricity [8].

Department of Energy, US is going to replace 30% of current petroleum consumption by biomass and its products by the year 2030, various systems capable of harvesting, storing and transporting biomass efficiently, at a low cost, need to be designed. A biomass transportation system of cotton gin has been simulated using discrete event simulation procedure [9].There are a number of system- related issue associated with the harvest, storage and transport from on farm storage locations to centrally located plant. A linear programming (LP) models for designing an herbaceous biomass delivery system and for solving the day to day tactical planning problem were also developed [10]. These efforts were directed towards the design of a biomass delivery system that considers storage, scheduling and transportation issues.

In order to reduce industry's operational costs, as well as to meet the requirement of raw material for biofuel production, biomass must be processed and handled in an efficient manner. Because of its high moisture content, irregular shape and sizes, low bulk density and spatially scattered biomass is very difficult to handle, transport, store and utilize in its original form [11]. Densification of biomass into durable compacts is an effective solution to these problems and it can reduce material waste. Densification can increase the bulk density of biomass from an initial bulk density of 40–200 kg m^{-3} to a final compact density of 600–1200 kg m^{-3} [12–16]. The availability of agricultural biomass in Punjab is spatially scattered. The spatial distribution of this resource and the associate costs of collection and transportation are major bottlenecks for the success of biomass energy-conversion facilities. Biomass, being scattered and loose, has huge collection and transportation costs, which can be reduced by properly planning and developing the proper methodology. A study was conducted in 2007–2008 to evaluate the spatial potential of biomass with geographical information system (GIS) and a mathematical model for collection of biomass in the field has been developed. The total amount of unused agricultural biomass is about 13.73 Mt year^{-1}. The total power generation capacity from unused biomass is approximately 900 MW. The collection cost in the field up to the carrier unit is US$3.90 t^{-1} [17]. This amount of biomass can support to generate electricity 15–20% of its present installed capacity, but the spatial distribution of this resource and the associated costs on collection and transportation are the major bottleneck in the success of biomass based power plant. To simplify such type of problems, in this paper an attempt has been made to develop mathematical model for transporting the biomass from fields to power plant.

2. Mathematical models

Mathematical models of costs of biomass collection and transporting the biomass have been developed. These are discussed below:

2.1. *Model for collection cost*

Collection cost is the cost to collect the biomass from the field in scattered form near the transport unit for its loading. For manually and reaper harvested field, the collection costs are to be assumed zero, because biomass already collected at one location in the field. So collection costs are considered for combine-harvested field only. Collection costs depend on the spatial density, unit costs of recovery and capacity of the transportation units. The collection costs are the sum of total recovery costs for harvesting biomass and transport costs for moving the biomass from a loosely spread form to the transport unit. The recovery costs depend on technology used for biomass recovery. It is assumed that recovery costs are proportional to the area from where the biomass is recovered. A mathematical model has been developed for unit collection cost in the field and presented below:

Let the transport unit be placed at 'O' in Fig. 1 and biomass be recovered from a circular area of radius 'r_o' surrounding the transport unit. If q_c is load capacity of transport unit, ρ is spatial density of biomass availability, C_r is the biomass recovery costs, US$ km^{-2}; and C_t is the unit costs of biomass transport (manual or machine transport) from place where it is lying to the transportation unit, US$ km^{-1} t^{-1}.

$$q_c = \int_0^{r_o} \rho 2\pi r dr = \pi \rho r_o^2 \Rightarrow r_o = \sqrt{\frac{q_c}{\pi\rho}} \tag{2.1}$$

Total Collection costs of biomass in the field

$$\begin{aligned} &= \int_0^{r_o} (C_r 2\pi r\, dr + C_t r \rho 2\pi r\, dr) = \pi\rho r_o^2\left[\frac{C_r}{\rho} + \frac{2}{3}C_t r_o\right] \\ &= q_c\left[\frac{C_r}{\rho} + \frac{2}{3}C_t r_o\right] \end{aligned} \tag{2.2}$$

Unit collection cost (C_c) is defined as the ratio of total collection cost to the carrying capacity of transport unit (q_c).

$$\therefore C_c = C_r\frac{1}{\rho} + \frac{2}{3}C_t r_o \tag{2.3}$$

From Equation (2.3) it is clear that unit cost of biomass collection (C_c) is a function of ρ, C_r and C_t. The value of Cr considered in the present model is 1862.43 US$ km^{-2} [17].

2.2. *Model for transportation*

Transport analysis is to find out the best modes and systems of transport for different distances of transport. Two modes of transport are considered for analysis. These are tractor with

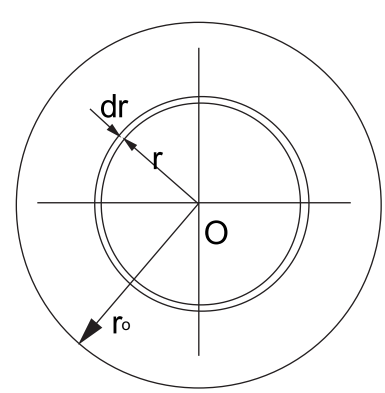

Fig. 1 – Collection cost analysis.