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Design of a Factories' Supply System with Biomass in Order to Be Used as an Alternative Fuel—A Case Study

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Nowadays, the need for the use of alternative energy sources (except fossil fuels) as a fuel has shown a marked increase, especially in the sector of industrial production. This fact has been necessitated by the continuous rise of crude oil prices and by increased pressures to protect the environment, such as the Kyoto convention. Biomass of agricultural residues such as cotton stalks is considered as one of the alternative types of fuels. Cotton stalks were used as a fuel for household needs from the very early ages. The subject of this study is the determination of a company's factory supply system with cotton stalk biomass in order to use it as a fuel. This study has taken place within the framework of the feasibility of such a supply system. It was proved that the substitution of conventional fuel in the industry sector by cotton stalk biomass is feasible technically and economically.

1. Introduction

Biomass is in general the matter that is produced from live organisms such as animals and plants on a renewable basis.[1–3] Biomass as a result of cotton cultivation takes the form of "cotton stalks" or "cotton sticks". Normally, after cotton harvest, cotton stalks remain in the field. This is a problem for cotton farmers because they become carriers of the "pink worm", an undesirable disease. Due to this, the cotton stalks are cut after the cotton harvest in chops and these spread out around the field where the physical process of their fermentation begins (for their decomposition into CO_2). The main component of the cotton stalks is cellulose. The main physicochemical properties of the cotton stalks are given in Table 1.

The cotton stalk collection is mainly related to the ability for baling or not of the collected matter. The following are the two main cotton stalk collection methods:

• collection of bulk biomass

• biomass collection which is followed by packing in small rectangle or large round bales

These two collection methods are materialized with different equipment (tractors, mowers, balers, trucks, etc.). The choice of one of these two collection methods is based on the evaluation of the following parameters:[4,5]

• technical requirements for the needed equipment (such as minimum power for the tractors, working width for the mowers and balers, mowing rate, baling rate, loading rate, dimension of bales, bulk density of biomass, bale density, etc.)

• performance data (such as labor needed, equipment workload, etc.)

• advantages and disadvantages of each item of the needed equipment

For the project materialization, the cotton stalk cutting technique was selected (while the uprooting technique is theoretically more efficient) due to the lack of uprooting machines in the Greek or European market. Combi balers were selected. This type of baler can transfer an already made bale in a carrier while it works to pack another one. When it approaches the edge of the field, it unloads the existing bale and continues. This technique was proven to be more efficient because the loading from the edge of the field is easier than the loading in the middle of it. Also, large cylindrical bales ($L = 1.2$ m/$D = 1.2$ m) were selected, as they were proven to be more practical than the others.

Generally, the transportation of the biomass is materialized in two phases. The first phase is transportation of the biomass from the field (where it is collected) to an intermediate depot. The first phase is followed by the transportation from this intermediate depot to the factory. The existence of the intermediate depot is necessary because of the low density of biomass which demands a very large storage space. Factories are generally restricted for storage space.

For the valuation of the biomass transportation system, data such as truck type (dimensions, capacity), performance data

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Table 1. Main Physicochemical Properties of Cotton Stalk Biomass (for Both Areas A and B)

property	value
bulk density (kg/m^3)	100–130
thermal value (kJ/kg)	16 750
bale density (kg/m^3)	170–230
water content after 2 days from cutting (% w/w)	about 20

(transportation speed, loading and uploading rates, etc.), and cost data (fuel consumption, trucks' labor cost, insurance, etc.), were taken into account.

Finally, another important parameter of this supply system is the quality control scheme through which the values of the declared biomass characteristics (such as content moisture, thermal value, etc.) are checked. The major aspects of this scheme are the following:

• sampling frequency

• testing frequency

• specifications for the values of the biomass characteristics

This paper deals with the methodology of estimating delivered cost of cotton stalks from the field to the factory. The remainder of this paper is organized as follows. First, the arrangement of the system is presented. Then, the feasibility study is outlined. Finally, the results of the case study are presented and analyzed and the major findings are discussed.

2. Arrangement of the System

The designation of the current supply system was based on the framework of the agricultural residue (like straw, alfalfa, etc., that are used in Greece as feedstuff) supply system. The feedstuff supply system consists of the following:

• Collection of the residues on the field

• Baling of the residues in the form of small, rectangular bales (40 cm × 50 cm × 130 cm). Large, cylindrical or rectangular bales are rarely used.

• Bale loading on the trucks. The small bales are loaded by workers. For the large bales, fork lifts are used.

• Transportation of the feedstuff directly to the consumption endpoint (farm). Rarely, the feedstuff is stocked in depots.

The low density of the feedstuff bales contributes to a big transportation cost which the farmers can afford. It should be noted that the use of a supply system of agricultural residues for industrial use (as a fuel) is an innovation in Greece.

The company in question is the owner of two factories in geographical areas A and B (Figure 1). In these two areas, cotton is cultivated. The cotton stalk quantities that are produced from

Figure 1. Biomass collecting areas.

Table 2. Cotton Stalk Biomass in the Areas of Interest

area	cotton stalk biomass (tons)	biomass yield (tons/ha yr)	thermal content (TJ)
area A	150 000	2–3.5	2510
area B	450 000	1.8–3.5	7530

each of the above areas are presented in Table 2. The energy content of the potentially available cotton stalk is 3 times the biomass utilization target of the company. In fact, these quantities cover 3 times the target degree of substitution. This is very important because there are enough quantities for the competitors. The opposite would bring about unfavourable consequences with regard to the final price of the product (cotton stalk biomass) and the safety of its supply to the company's production units.

In area A, there is only one geographical place for cotton stalk collection, as opposed to area B where we can distinguish three discrete collection places (B_1, B_2, and B_3). Due to this, the price of the product delivered to the factory in area B is expected to depend on the three different distances from the collection places (B_1, B_2, and B_3). It can be noticed that the distance between the two factories (in areas A and B) is too large for biomass transportation to be economically viable. Figure 2 presents the work flow of the supply system that has been designed during this project.

As already mentioned above, the low density of the cotton stalk biomass in combination with the quantities needed by the company postulate the use of a very big volume of biomass. In this particular case study, the quantities needed are approximately 100 000 tons (or 400 000 m^3). The fact that

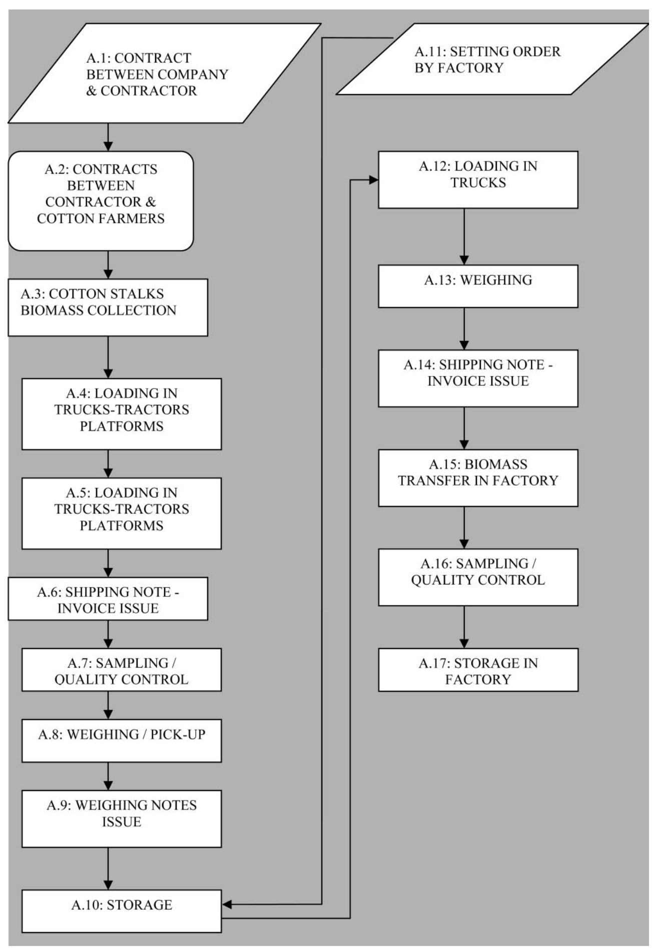

Figure 2. Work flow of the designed supply system.

there is not enough space in the company's production units entails the use of an intermediate depot. In this depot, the cotton stalks collected from the field are stored for a certain period of time before being transported to the factories. Due to the relatively short period of collection of biomass (50–60 days), there is a need for the use of trucks for its direct transportation to the factories. This is another important reason for an intermediate depot.

Table 1 presents the values for the basic properties and characteristics of the biomass under examination such as the thermal value (calorific value), the bulk density, the bale density, etc. These values were used in the present study for the investigation of alternative supply systems and the designing of the best among them, for this case.

3. Feasibility Study

For the determination of the cost for the different supply systems, the fixed and variable expenses were taken into account for each system separately.

The *fixed expenses* include the equipment acquisition expenses needed for the biomass collection, the equipment acquisition expenses needed for the operation of the depot, the expenses for the configuration of the depot, etc. These expenses were taken into account, for each of the supply systems under evaluation, because they contribute to the final cost through their depreciations. More specifically, for the determination of the equipment acquisition expenses needed for the biomass collection, the below equation was used.

$$D = [\text{integer}(\Pi/(50u))]T$$

where D represents the total expenses for the equipment acquisition needed for the biomass collection (euros), Π represents the quantity of biomass that could be collected in the area of each depot during a period of 50 working days (tons), u represents the collection rate of each of the machines (tons/day), and T represents the price of each of the machines (euros).

The determination of the cost for the configuration of the depot and the cost for the networks (power supply, water supply, etc.) was based on the following assumptions:

• The expenses for the installation of the networks are approximately 2,000 euros.

• The expenses for the configuration of the depot's terrain are approximately 3,000 euros.

• The price of fence setting in the depot is, following market research, approximately 5 euros/m. Assuming that each depot has a square form, then the cost for fence setting at each depot would be:

$$20(E)^{1/2} \text{ (euros)}$$

where E is the area of each depot.

For the determination of each depot's geometrical area, the following equation is used:

$$E = (\Pi/\beta)(A/n)$$

where β is the weight of each bale's form (tons), A is the cross-sectional area of each bale's form (m^2), Π is the quantity of biomass that could be collected in the area of each depot during a period of 50 working days (tons), and n is the number of bale layers in stowage.

The *operating cost* includes labor expenses, expenses for services (collection cost, transportation cost), depot rental cost, and other operational expenses such as power and water supply cost, etc. According to research during the project, the above expenses are broken down into the following.

Biomass collection expenses include

• the labor cost for the cotton stalk biomass collection (workers who deal with the machines that collect, load, or transfer the collected biomass to the depot)

• the cost of the machine fuels

• the machine maintenance cost

For the determination of biomass collection expenses, the following assumptions were made:

• The labor cost has been calculated on the basis of collection rates in each collection method (stalk cutting/biomass in bulk, stalk cutting/small, rectangular bales, stalk cutting/large, round bales, stalk uprooting/large, round bales, etc.).

• The average specific consumption of the fuel for each of the needed machines is 180 mL/hp·h approximately. This value was the result of research in the field of agricultural machine manufacturers.

• The maintenance cost for these machines is focused especially on the maintenance cost of the tractors. This cost as shown by the research is about 8% of the corresponding fuel cost and includes expenses for repairs, tires, grease, etc.

The following data was also taken into account:

• The market price for the transportation fuel is (diesel) 0.9 euros per liter according to the Prices Observatory of the Greek Ministry of Development.[6]

• The labor cost (insurance included) concerning the examination areas is 8 euros/8 h shift according to the Ministry of Labor & Welfare.[7]

• The average yield of the fields in cotton stalk biomass is 0.3 tons per 1000 m^2 (for cut stalks) or 1 ton per 1000 m^2 (for uprooted stalks).

Expenses for Biomass Transportation from the Field to Depot. This expense correlates with the transporters' wages for biomass transfer from the fields where it was collected to the depot. A logical average distance was corresponded to each depot of interest in order to make calculations feasible. On the basis of the transporters' wages, it has been calculated that the average expenses for cotton stalk biomass transportation in bulk is 1.8 euros per ton and for cotton stalk bales 1.2 euros per ton, respectively.

Expenses for Biomass Transportation from Depot to the Factories. The charge for such a service depends on the transportation distance, the type of product to be transferred, the legal constrictions for the transportation (such as the obligation for truck covering, the restriction for vehicular circulation on Sundays, etc.). Market research has shown that for the particular product and for the particular distances between the depots and the factories the transportation expenses are 0.15 euros/ton km approximately. This is generally 2 times greater than the expenses for common materials transportation due to the small density of cotton stalk biomass.

Depot operation cost. This includes:

• the salaries for the people which operate the depot

• the expenses for the power and water supply, etc.

• the expenses for the rent of each depot. According to the research, the price for this kind of renting is 120 euros/1000 m^2 approximately. Therefore, the yearly expenses for the rent of a depot are

$$120E \text{ (euros)}$$

where E is the area of the depot.

Finally, in the calculated cost for each supply system, a profit was added in order to set the final commercial price for biomass

(6) Greek Ministry of Development. Observatory for transportation fuel prices (2005).

(7) Greek Ministry of Labor & Welfare. National Wage Agreement (2005).

Table 3. DDP Cotton Stalk Biomass Price (% of the Conventional Fuel CIF Price)

	collection method		
collection area - factory	uprooting and baling	cutting and baling	cutting and transfer in bulk
area A - factory A	70.5	69.7	99.5
area B_1 - factory B	87.2	85.3	124.5
area B_2 - factory B	58.5	57.4	80.2
area B_3 - factory B	49.6	48.1	71.3

Table 4. Breakdown of the DDP Cotton Stalk Biomass Price

	cost factor	% of DDP price
fixed cost	collection equipment	0.2
	depot operation equipment	0.6
	depot configuration	0.1
	fence setting	0.0
	networks setting	0.1
	subtotal	**1.0**
operational cost	labor	7.5
	fuel	8.8
	maintenance	0.7
	biomass transfer from field to depot	9.7
	biomass transfer from depot to factory	60.7
	other operational cost	2.5
	subtotal	**90.0**
	contractor's profit:	**9.0**
	total:	**100**

delivered at the factories (duty delivery paid (DPP) price). For the determination of this price, a reasonable value for the profit (10% of the final commercial price) was considered.

4. Results

Table 3 shows the biomass DDP prices for each of the supply systems under examination. The DDP prices are presented as percentages of the thermal equivalent CIF (at the factory) conventional fuel price that is used today in factories. This equivalent thermal price, which represents the break-even point for the project of the particular conventional fuel substitution, results from the equation below.

$$\text{thermal equivalent price}_{\text{cotton stalk biomass}} = \text{CIF price}_{\text{of the conventional fuel}}\ (\text{euros/ton}) \times \text{thermal value}_{\text{cotton stalk biomass}} / \text{thermal value}_{\text{of the conventional fuel}}$$

According to laboratory testing, the thermal value of the cotton biomass is 16 750 kJ/kg in contrast to the thermal value of the conventional fuel which is 32 870 kJ/kg. Consequently, the thermal equivalent price (DDP at the factory) for the biomass is equal to 51% of the corresponding price of the conventional fuel (CIF at the factory). This means that in order for the substitution of conventional fuel with biomass to be "economically neutral" it must be less than 51% of the corresponding equivalent thermal price.

The only scenario which does not involve any economical interest is that of the biomass collection from area B and its transportation in bulk to factory B_1. For this scenario, the DDP price of biomass is about 24% above its corresponding thermal equivalent price. The scenario for biomass collection from area A and its transportation in bulk to factory A is a borderline case. The other scenarios are obviously economically interesting. The most economically interesting scenarios are those for cutting or uprooting biomass from area B and its transportation in bales to factory B_3. For these scenarios, the DDP biomass price is about 48–50% of their corresponding thermal equivalent prices.

In Table 4, the breakdown of DDP cotton biomass price into its cost factors is presented for the scenario of cutting biomass from area B and its transportation in bales to factory B_3. As it appears in Figure 2, 90% of the DDP price is operational cost. This cost mostly arises from

• the transportation of biomass from the depot to the factory (at about 60% of the price)

• the operational cost for the collection (at about 16% of the price)

• the transportation of the biomass from the fields to the depot (at about 10% of the price)

Table 5. Breakdown of the Variable Cost of the Briquetting System Studied by Ehab El Saeidy[6]

process	% of DDP briquette price
collection of the stalks	30
storage of the stalks on the field	8
chopping of the stalks	20
briquetting	14
briquette transport	14
briquette storage	13
total	100

Ehab El Saeidy[8] studied the feasibility of cotton stalk briquetting in Egypt. Ehab El Saeidy used for its calculations, among others, the following values: % water content (room temperature), 10–20; bulk density (kg/m^3), 450; field yield in cotton stalks (kg/1000 m^2), 450; heating value - max (kJ/kg), 18.26; heating value - min (kJ/kg), 17.15.

The values of the bulk density and field yield are obviously larger compared to those in Table 1. This is due to the different (and probably more efficient) cotton varieties cultivated in Egypt. In Table 5 is presented a breakdown of the variable cost of the briquetting system studied by Ehab El Saeidy. As comes out from this table, the supply cost (collection, storage, and transportation) is equal to 86% of the variable cost of the briquetting system. This is not far away from the corresponding value (operational cost 90%) of Table 4.

5. Conclusions

The aim of this study was the determination of the best supply system from a technical and economical point of view.[9,10] The social and economical extensions of a project of substitution of conventional fuel with biomass are of major importance.[11] The main extensions are the following:

• The reduction of CO_2 emission in the atmosphere. This reduction corresponds to the amount of CO_2 emissions by the

(8) El Saeidy, E. Renewable energy in Egypt. Technological fundamentals of briquetting cotton stalks as a biofuel. Dissertation, Humbolt Universitaaet, 2004.

(9) Kartha, S. *Biomass sinks and biomass energy: key issues in using biomass to protect the global climate* **2001**, *5* (1), 10–14 (Energy for Sustainable Development).

(10) Larson, E. D.; Kartha, S. *Expanding roles for modernised biomass energy* **2000**, *3*, 15–25 (Energy for Sustainable Development).

(11) Hoogwijk, M.; den Broek, R.; Berndes, G.; Faaij, A. *A Review of Assessments on the Future of Global Contribution of Biomass Energy*,1st World Conference on Biomass Energy and Industry, Sevilla, James & James: London, 2000.

use of biomass. The reason is that the biomass is considered as CO_2 neutral.

• The social and economical boost of the local areas of interest.

• The improvement of the country's commercial balance regarding the value of the imported amount of conventional fuels that are no longer needed.

By substituting the conventional fuel used in its factories with biomass, the owner company aims

• to achieve partial independence of the one and only fuel that is used

• to reap the potential profit that may come out of the trading of CO_2 rights via the global emissions trading system.

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