www.rericjournal.ait.ac.th

Production of Thermoelectric Power from the Solid Wastes: the case of Lahore School of Economics

Mohammad Rafiq Khan[*1] and Sana Sheikh[*]

Abstract – *This paper describes the feasibility of production of thermoelectric power from biomass of solid waste of Lahore School of Economics (LSE). The primary data concerning quantity and nature of solid waste were collected from LSE. Data concerning the production of thermoelectric power from solid waste such as bagasse were collected by visiting Pattoki Sugar Mills. The data were processed; the project was cost-designed and appraised by applying standard techniques of project appraisal to determine its B/C ratio (BCR), NPV and payback period (PBP). The appraisal showed that LSE produces approximately 200 metric tons solid waste per annum from which 280,000 KW of electricity could be produced which covered about one- fourth of its current consumption. The BCR at this scale of production was 0.15 which was less than 1, NPV was -$ 1,016,403 which was below zero and PBP was infinite as the net cash flow per annum was negative. These results clearly indicated that the projection was not feasible. The evaluation was revised to pull the project towards feasibility if solid waste was increased to 600 and 1000 metric ton per annum including and excluding price of land from expenditure stream (six alternatives). Some of the projects at these scales of processing turned out to be feasible as the BCR increased to 1.04 and 1.73 respectively, if price of land was excluded. The impact of inflation on all alternatives was studied at constant inflation rate of 8%. The inflation impact resolved in favor entrepreneur as above alternatives turned out to be more profitable (BCR=1.24 and 2.09 and NPV=$ 171,718 and $ 757,152) respectively.*

Keywords – Biomass, Lahore, power, solid waste, thermo.

1. INTRODUCTION

The world population explosion has placed the problem of coping with the demand for energy at the highest priority and thus experts all over the world are working very hard to cope with this problem. One of the attempts being made in this connection involves the techno-economic disposal of the solid waste by incineration of its biomass and subsequent conversion of recovered heat energy into thermoelectricity. This has a dual advantage of cleaning environment and producing electricity. It strongly supports the concept of sustainable development, which means that every kind of development should be carried out in a sustainable manner, which implies the economic use of resources and wastes because there is nothing in this world that cannot be assigned an economic value [1].

Keeping this two-prong approach in mind, many ways and means are being investigated to evaluate solid waste for the production of electric power and for making different products. One of the potential sources under investigation is the biomass content of different types of wastes. Different methods to dispose of hazardous materials such as land-filling, incineration, composting, recycling, resource recovery, etc., are in use to clean the environment with side by side production of products such as electricity, agricultural manure and others.

The picture presented above is equally true for Pakistan. It is also facing the energy problem along with the environmental problems. The search of solutions to these national problems forms the basis of the choice of the research undertaken here to trigger the task of techno economic disposal of solid waste for the production of electric power.

The choice of enquiry was Lahore School of Economics (LSE) as it is the institution where the authors are based. Another consideration was an easy access to local data sources. Moreover, LSE seemed to be a good choice at lower end of the plan that was framed to extend the spectrum of enquiry step by step to techno-economic disposal of solid waste to village, town and city level.

2. LITERATURE REVIEW

As today's world has a growing concern for the environment these days the responsibilities are transcending down to the lowest levels of management [2]. That is why the pressure for solving environmental problems is being placed more on local authorities to deal effectively with them in a sustainable manner. The question facing many local authorities is to what extent and how to respond to this green challenge [3], [4]. Moreover, the issue of solid waste disposal has negatively affected many countries including many states of USA and European Union [5]-[8]. The best example may be that of New York Council that bears a history of more than half a century in this activity.

The history of production of thermoelectric power by incineration of solid waste in Pakistan is not very old. For a long time after creation of Pakistan no

*Lahore School of Economics, 19 km Burki Road, Lahore 53200, Pakistan.

[1] Corresponding author; Tel: 042-6560954
E-mail: rafiq_aquarius@yahoo.com.

thermoelectric power plants based on solid waste were encountered. The pioneers in this field were some sugar mills who started this activity by burning of sugarcane bagasse. In the past it was normally used as fuel for supplying of heat in multiple effect evaporators used for the concentration of clarified sugar cane juice to produce crystalline sugar. Many mills these days are applying it to produce electricity for their needs.

Unfortunately, no published study with special reference to thermoelectric power from solid waste in Pakistan is encountered. Some studies, of course, have been undertaken in foreign countries.

Kanagawa [9] undertook a study which presented the development of thermoelectric power generation system utilizing heat of municipal solid waste. Kajikawa [10], [11] reviewed the status and future prospects of development of thermo-electric power generation systems using heat from the municipal solid waste in Japan. He also presented the conceptual designs of a small scale system for the next phase of the research and development program. Carbo [12] reviewed the market for Municipal Solid Waste Management Equipment in Colombia. It was recommended that thermoelectric devices are reliable energy converters with no noise or vibration [13]. Dubois *et al.* [14] carried out a study on municipal solid waste treatment in the European Union with an objective to set a policy line for sustainable waste management. This study focused on different ways of treating municipal solid waste: recycling, composting, incineration and land filling. The study indicated that the major stress in European Union was on recycling and minor on its disposal by incineration to produce electricity. Hogg *et al.* [15] compiled the Leicestershire Municipal Waste Management Strategy Environmental Report.

With the background chalked out above and literature survey, this piece of work was undertaken. The objectives of research were as follows:

1. Safe and techno-economic disposal of LSE solid waste.
2. The feasibility of production of thermo-electric power from solid waste biomass.
3. Later extension of the study to higher levels such as village, town and city level.

3. METHODOLOGY OF RESEARCH

Collection of Data

The secondary data about disposal of solid waste and production of thermoelectric power from biomass was collected from literature in different libraries, the material published by different concerned establishments and Internet. The primary data pertaining to the production of solid waste and related to the technological, environmental and financial aspects of the project under investigation were collected by paying successive visits to different spots in LSE. Before visiting different solid waste spots in LSE, a comprehensive questionnaire was designed and developed for taking responses of the concerned officials and workers in the study institution. The responses were gathered and subsequently computed. The solid waste produced at different sites is computed in Table 1. The table tells the mode of collection, nature of waste, etc., yet it does not give the total solid waste because the researchers were unable to collect data from some spots. That is why it was calculated from the overall waste collected by cleaners and gardeners as computed in Appendix 1. The overall waste turned out to be 195,400 metric ton / annum which was considered as 200,000 kg or 200 metric ton / annum. The balance might account for the waste on some sites not accessed. That is 85.28 kg per head and 1.85 kg per square meter per year.

The electricity and diesel bills for the last three years were supplied by the Accounts Office (Table 2). From the bills, the kW consumption of LSE was calculated at an average cost of $ 0.108/kW (Appendix 1). The total consumption turned out to be 1,322,696 kW; 730,784 from Lahore Electric Supply Company (LESCO) and 591,912 from generators.

Data Analysis

The data were computed and project was cost designed. Discounted cash flow techniques used by the Asian Development Bank for appraisal in the developing countries (ADB 2001, 2003) were applied for project evaluation. The cost was appropriately dispersed over the duration of the life of the project. Both expenditure and returns were projected over ten years that was the project life and discounted to the base year (2000 – 2001) at 10% discount rate. The net present value (NPV), benefit to cost ratio (BCR) and payback period (PBP), were computed.

Interpretation of Results

The results were interpreted as explained in Results Section.

Cost Analysis

The project analysis is based on the project specifications narrated in Appendix 1. The cost summary is given below.

Different cost components responsible for adding value to both expenditure and return streams are given below.

Initial Fixed Investment

It included the cost of land, building, machinery and equipment and pre-production expenditure as computed in Appendix 1. Total initial fixed investment with land was $ 930,833 while that without land is $ 272,500.

Operating Cost

The operating cost has been computed in Appendix 1.

Expenditure in the Base Year

Initial fixed Investment = $ 930,833
Operating Cost = Nil
Total Expenditure = $ 930,833

Expenditure in Future Years

Assumptions and computation are given in Appendix 1. The computation is displayed in Table 5. Total operating cost discounted to the base year = $ 275,766.

Benefits

The benefits are computed in Appendix 1

B/C Ratios, NPV and PBP

The values are computed in Appendix 1. The BCR for the project came out to be 0.15 while NPV was -$ 1,016,403. The PBP for this reference alternative turned out to be infinite implying no chances of recovery of investment.

Alternative Projects

Six alternative projects were framed with reference to the project evaluated above both including and excluding the cost of land from expenditure stream. These were appraised exactly the same way as was done in Alternative 1. The alternative projects were framed as reported in Appendix 1 and Table 7 (Appendix 2). Their BCRs, NPVs and PBPs are reported in Table 12 and 13.

Study of Impact of Inflation on Project Status

Impact of inflation is difficult to study due to the reason that its rate is subject to abnormal changes that occur even on the global economic scene. Moreover, the governments, particularly in the developing countries are hesitant to declare the exact figure as it presents them in the court of voters for accountability. Different doors were knocked to get the exact figure but reports were quite diverse. Some sources presented a figure of 7.7%. Thus here the evaluation was revised at constant inflation rate of 8%. The methodology followed was that of Asian Development Bank [16], [17].

There are different approaches to settle project appraisal matters. These are stated below:

1. The increase or decrease of inflation means a proportionate rise or fall of prices of goods and services. Thus, the assumption is that whenever the prices of goods and services involved in expenditure undergo a rise, there is a proportionate rise in the prices of the products sold for earning revenue and vice verse. Thus the impact on expenditure is nullified by the impact on returns. There is even no need to enhance the salaries of the workforce as this is the major factor that presses for increase in the salaries.
2. The second approach is to see the trend in the salaries of employees and prices of other inputs at the place for which the project is to be planned. As the salaries are usually revised to adjust the impact of inflation, it is automatically adjusted. The appraisal of the project computed above has been done under this approach.
3. The inflation impact is appraised at constant rate as done by ADB [16], [17]. The prices of the basic inputs such as raw material, salaries, etc, are compounded at the rate of inflation taking care that every future year is also impacted by the previous year. Thus, while compounding by multiplying a figure with an inflation adjusted factor, an additional multiplication is done with a factor that adds the impact of last year at half the rate of inflation. Mathematically it may be expressed as $S = P(1+r)^n(1+0.5r)$ where P is the figure to be adjusted, r is the compounding factor (Rate of Inflation/100), n is the number of future years and S is inflation adjusted figure.

This is illustrated with the example of compounding of operating costs the only cost to be affected by inflation in Table 8 (Appendix 2). Similarly, the increase in the revenue is illustrated in Table 9 (Appendix 2). The discounted inflation adjusted expenditures and revenues (Table 10 and 11 in Appendix 2) were used to calculate BSR and NPV (Table 14 in Appendix 2)

4. RESULTS

The results are reported at two levels. At the first level, the general information gathered in the form of primary data such as nature of waste and technology are recorded and described as results of the descriptive research. At the second level, the results of the cost analysis are reported and discussed. An account of these aspects is given below.

Nature and Composition of Solid Waste

The bases of assessment of the weight of solid waste produced are already given in Table 1. The general nature of waste is narrated below.

As told by the manager of the cafeteria and the working staff that the solid waste produced in the cafeteria was basically composed of leftover food, polythene bags, disposable plates, glasses, spoons, tea bags, milk sachets, biscuit packets, water bottles and also some disposable drink bottles. The use of regular beverage glass bottles was no more in LSE. The waste is thrown outside LSE after adequate packing in the plastic bags and it is taken away by the corporation rubbish vans/trucks. There is no health hazardous stuff in the solid waste of the cafeteria. Thus no environmental problems are encountered.

There are three canteens in LSE that are arbitrarily numbered as 1, 2, and 3: canteen 1 is situated near the Center for Research. Canteen 2 is located soon after the entrance to LSE main campus from the car park and Canteen 3 in the gymnasium.

The supervisor of canteen 1 told that the solid waste produced in the canteen contained potato chips bags and boxes, plastic bottles, cartons, milk sachets, sugar sachets, tea bags, disposable spoons, disposable glasses and also some food wrappers. The waste is collected in a rubbish bin and disposed off. No environmental problems are encountered. Similar was the report from canteen 2.

The workforce employed in canteen 3 told us that their wastes included plastic bottles, juice packs, chips packets, disposal plates, disposable glasses, spoons, tea bags, vegetable peel offs, egg shells, etc. As mentioned in the above cases the waste was thrown out of the LSE campus, which was collected by the corporation rubbish van at the end of each day. No environmental problems were encountered by the residents so far and there were no chances in near future.

As far as library waste was concerned, there was hardly any except left over plastic bottles, chips packets or some used paper.

There were three girl's hostels in LSE each containing 15 to 16 rooms. The total number of girl residents was around 50. The major contributors to the solid waste were resident's rooms. The waste from the rooms was collected in rubbish baskets, which was integrated in rubbish bin that collected 1 kg per day. Hostels resulted into about 60 kg of waste every day which included left over food, disposable bottles, glasses, some used paper, tissues, etc. No waste resulted in any environmental problems.

Technology of Thermo-electric Power Plant

The operations and sub-processes involved in the production of thermo-electricity from bagasse in Pattoki Sugar Mills are shown in the flow sheet (Figure1). Further illustrations are made in Figures 2, 3 and 4.

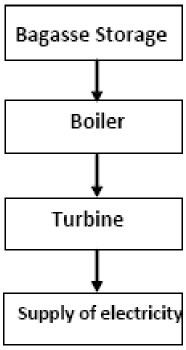

Fig. 1. Flow sheet showing sub-processes involved in production of electricity from bagasse.

1. *Bagasse Storage*: Bagasse was used as a fuel in boilers for the generation of steam. From the cane crushers bagasse was transferred to boiler on bagasse feeding shoots through electric driven rack type carriers. The extra bagasse is returned to the storage and stored in open air.
2. *Transport to Boilers*: The bagasse was transported to boilers by a specially designed conveying system (Figure 2).
3. *Boilers*: The boilers were fire-tube type. These were operated manually. There were three boilers in the mill which differed on the basis of their steam production capacity i.e., 60, 70 and 80 metric ton. Only two were in operation during the season whereas one was kept as stand by.

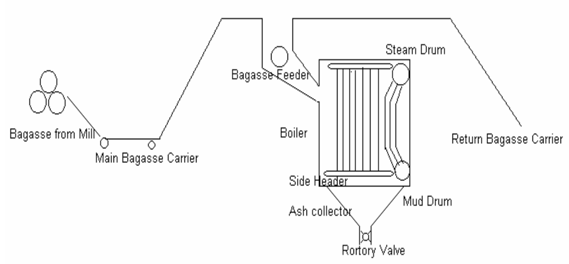

Fig. 2. Flow sheet of bagasse transport to boiler.

4. *Turbine*: There were three multistage turbines in the powerhouse. Superheated steam from boilers was injected through the nozzles into the turbines. The rotor of the turbines rotated the generator, which produced electrical energy. The exhaust steam coming out of the turbine was being used for evaporation and juice heating.
5. *Supply of Electricity*: The generated electricity from the power house was distributed to the whole plant through an electric supply system.

The above technology in action formed the basis of four project design with the only change that bagasse was substituted by LSE solid waste. The same flow sheet was valid for the project with the same sub-processes and operations as in Figure 1.

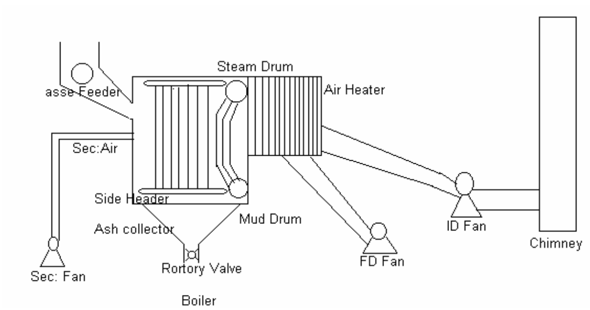

Fig. 3. Flow sheet of boiler- supplied by Pattoki Sugar Mill.

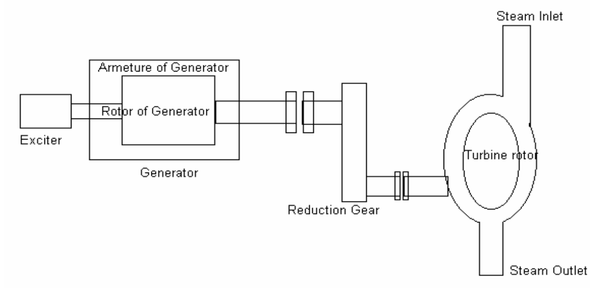

Fig. 4. Flow sheet of steam turbine.

Results of Cost Analysis

The results of cost analysis of all alternative projects are integrated in Table 8 and discussed below.

*Alternative 1 (With Land)***:** The value of BCR in this alternative came out to be 0.15, which was far less than the standard that is 1, NPV was -$ 1,016,403 that was far below zero and PBP was infinite meaning that the investment will be never be recovered. Thus the indicators are quite away from the standards.

Alternative 2(Without Land): The value of BCR in Alternative 2 (without land) turned out to be 0.35, NPV was -$ 349,736 and PBP again infinite. This alternative was slightly better in terms of BCR and NPV but was still not feasible. It was not even worth considering due to infinite value of PBP because of negative annual cash flow. To render it transparently feasible, other factors were thought over. The major factor conceived was the insufficiency of the quantity of solid waste produced in LSE. The situation was checked by designing four more alternative projects at the scale of processing 600 and 1,000 tons of solid waste. These were also evaluated both including and excluding cost of land. The results were as follows:

Alternative 3 (With Cost of Land): When the amount of solid waste was increased to 600 tons/annum and the cost of land was included, the values of indicators came out to be BCR = 0.46, NPV = -$ 643,632 and Payback Period = 18.63 years. This alternative was again not feasible because all the conditions of acceptability were not fulfilled. BCR was less than 1, NPV was negative and at the same time PBP was very large (18.63 years).

Alternative 4(Without Cost of Land): When the amount of solid waste was increased to 600 tons/annum and the cost of land was not included, the values of indicators came out to be BCR = 1.04, NPV = $ 30,535 and payback period = 5.14 years. This alternative made the project feasible because all the conditions of acceptability were fulfilled. BCR was greater than 1, NPV was positive and at the same time.

PBP was small and within the limit of acceptability.

Alternative 5(With Cost of Land): Alternative 5 was looked into at 1,000 scale of processing. It involved the same boiler and same turbine. In spite of the fact that LSE was far away from production of 1,000 tons per annum waste, investigation was done at this scale to provide a base for evaluation at a higher level. Thus, the amount of waste was increased to 1000 tons/annum and the process of calculation was repeated to determine the values of the indicators. The values were BCR=0.7, NPV= -$ 270,862 and payback period = 8.36 years. This alternative was also feasible according to all the criteria cited above. The evaluation was encouraging in the sense that the values were not very far from the criteria of acceptability.

Alternative 6 (Without Cost of Land): The amount of waste was increased to 1,000 tons/year and the process of calculation was repeated to determine the values of the indicators. The values were BCR=1.73 NPV= $ 385,211 and PBP = 2.30 years. This alternative rendered the project most feasible according to all the criterions cited above.

PBP Scenarios 1 and 2: The results of the two PBP scenarios are integrated with the BCR and NPV values of all six alternatives in Table 12 and 13. A comparison of PBPs of 1 with 2 indicates that in case the cost of land and building is subtracted from total initial fixed investment, then PBP of alternatives 3, 4, 5 and 6 decreases drastically.

5. DISCUSSION

The above evaluations have still a utilitarian value as these make a foundation for planning to exploit this source for disposal of waste and production of electricity. Therefore, on this basis some more alternatives were evaluated to pull it towards feasibility. Alternatives 1 and 2 provided us the basis that as the same boiler which is the major cost component could be used for processing of waste up to 1,000 metric tons per annum as the chances could be there for production of electricity that could meet the institutional demand in economic terms. Thus alternatives 3, 4, 5 and 6 were investigated.

The alternatives 3 including cost of land and alternative 4 excluding cost of land were appraised in sequence to pull the project towards feasibility. Alternative 3 (600 metric ton, cost of land included) turned out to be better than 1 and 2, yet it was also far from the said criteria. Alternative 4 (600 metric ton, cost of land excluded) turned out to be quite feasible and qualified all requisites (BSR 1.04 that was more than 1, NPV $ 30,535 that was positive and PBP nearly five years). All the values were better in case of alternative 5 if the similar alternatives with land cost 1 and 3 were compared but calculated values of BCR (0.77), NPV (-$ 270,862) and PBP (8.36 years) were still away from the standards. These were near the standards indicating that with land alternatives could be pursued further for pulling them towards feasibility by making changes in other parameters.

Alternative 6 (1,000 metric ton, land cost excluded) turned to be the best out of the whole lot. If waste was increased to 1,000 metric ton per annum, then the BCR came out to be 1.73 that was greater than 1, NPV $ 385,211 and PBP was 2.30 years.

From results it is quite clear that if waste is increased the values of BCR, NPV and PBP will undergo a proportionate increase and thus are more favorable for the project acceptability.

Alternative 4 could be exploited to substitute electricity supply to LSE through generators as that could more than compensate this part. The extra electricity produced might be deducted from the purchase from LESCO. In this alternative the target of securing 600 tons per annum solid waste would also be relatively easier.

As far PBP scenarios 1 and 2 are concerned, they present a more realistic picture in the developing countries. For example, if Pakistan is considered in this context, a general observation over here is that people make investments in purchase of land, housing or factory buildings because their prices increase at very high pace up to 10 to 25 years (minimum for concession of excise tax on houses). Thus while evaluating, it doesn't seem pertinent to include their cost in initial investment to calculate PBP, comparison of PBP values in Scenario 1 (Table 8) with those in Scenario 2 (Table 9) indicates that PBP is even halved after moving towards said reality.

The study of impact of inflation on the project evaluation (Table 14) leads to a very interesting outcome. That is alternatives 1 to 3 does not qualify for acceptance while alternatives 4 to 6 (including even the cost of land

and which never qualified before) qualify here after inclusion of inflation adjusted prices. Moreover, BSR and NPV values increase significantly after adjustment (compare values in Table 14 with those in Table 8). This is quite understandable on the basis of the reason that inflation does not mean only an increase in the prices of inputs for making a product; it also implies a similar increase in prices of outputs. Thus if a manufacturing process is taken into account the products it makes for marketing also undergo a proportionate increase. In this sense the product here is electricity. The major determinant of cost of production in manufacturing is the raw material. Here fortunately, there is no raw material cost as solid waste is the material from which thermoelectric power is to be generated. Thus, the inputs responsible for cost increment will be only salaries of workers, maintenance, depreciation, etc. These will undergo less increase as compared to the revenue. That is why highest BSR (2.09) and NPV ($ 757,152) is achieved after inflation adjustment.

The worth of this study is that it will provide the fundamental technology and economics for installation of thermoelectric plants for the supply of electricity to educational institutions located in different places. In big cities like Lahore, the purchase of land rules out any voting in favor of the project but in some small cities or towns where there is ample land to invest, even the land inclusive alternatives may be worth considering.

Only alternative 6 can completely meet LSE demand. Of course, if considered on classified basis, it can be imagined that the Alternative 4 can be exploited for replacement of partial supplies. It can compensate the supply by LESCO while alternative 6 can meet the demand as a whole. Thus, replacement of supply by LESCO only does not make sense as this will involve two set ups for production. One will be for plant and other for already installed generators. So, to replace both channels, Alternative 6 is suitable as its production more than compensates the total demand. Thus the best alternative thus can be alternative 6.

The question arises how to secure 1,000 metric ton per annum solid waste. The following points are made in connection with the likelihood of this securing:

1. LSE is a fast growing institution with strong chances of its transformation into a university. Its solid waste will also increase proportionately.
2. The villages located near LSE may be investigated for assessment of the waste produced. There is the likelihood that these may be producing waste in the requisite quantity to make up the deficiency. Alternatively, a relationship can be established with Defense Housing Authority (DHA) for supply of solid waste under a social welfare agreement.

Finally, the project can be extended by estimating the solid waste produced at village, town and city levels and subsequent evaluation for thermal power.

6. CONCLUSION

The discussion concludes that producing thermoelectric power from LSE solid waste is not feasible if the land is taken into account. The project can turn out to be feasible if the thermoelectric power plants are set up with 600 or 1000 metric ton per annum solid waste provided LSE can spare a piece of land for installation of the plant. Thus, the project can be pulled towards feasibility by fortification of its solid waste from other sources.

A corollary of the investigation is that the production of thermoelectric power from solid waste goes in favor of the entrepreneur if the impact of inflation is taken into account. Thus, the investor should not hesitate to undertake solid waste based power projects as these will secure their economic future in the corporate sector.

ACKNOWLEDGMENT

Thanks to the executives of Pattoki Sugar Mills: CEO Mian Muhammad Aslam, GM, Mr. Ikram-ul-Haq Sajid, Chief Chemist Mian Abdul Shakoor and Assistant Chief Chemist Mr. Zafar Iqbal for information and help in planning of projects.

REFERENCES

[1] Kyritsis, S. 2000. Proceedings of the 1st World Conference on Biomass for Energy and Industry held in Seville in June 2000.

[2] Audit Commission.-Environment. 2007. Planning and Waste Management Services South Bucks District Council (2007).

[3] Peattie. K. and Hall, G., 1994. The greening of local government: a survey. *Local Government Studies* 20(3): 458.

[4] Worthington, I., Patton, D. and Lindley, I., 2003. Local Authorities, Business and LA21: A study of east midlands sustainable development partnerships. *Local Government Studies* 29(1): 91 – 110.

[5] Alter. H., 1993. The origins of municipal solid waste: Ii policy options for plastics waste management. *Waste Management and Research* 11(4): 319-332.

[6] Alter, H. 1991. The future course of solid waste management in the US. *Waste Management and Research* 9(1): 3-20.

[7] Petts, J., 1994. Incineration as a Waste Management Option [Online], Retrieved January 20, 2009 from http://www.rsc.org/ebooks/archive/free/BK9780854042050/BK9780854042050-00001.pdf.

[8] Olofsson, M., Sahlin, J., Evall, T. and Sundberg, J., 2005. Driving forces for import for energy, recovery in Sweden. *Waste Management and Research* 23(1):3-12.

[9] Kanagawa, 1994. Development of thermoelectric power generation system utilizing heat of combustible solid waste. In *Proceedings of Thirteenth International Conference on Thermo Electrics*, August 30- September 1, Kansas City MO, USA: 314-318.

[10] Kajikawa, T., 1996. Thermoelectric power generation systems: recovering heat from combustible solid waste in Japan. In *Proceedings*

of Fifteenth International Conference on Thermoelectrics, 26-29 March, Pasadena, USA, IEEE Publications, NJ: 343-351
[11] Kajikawa, T., 1997. Status and future prospects on the development of thermoelectric power generation systems utilizing combustion heat from municipal solid waste. In *Proceedings ICT'97.XVI-International Conference on Thermoelectrics*, 26-29 August, Dresden, Germany, IEEE Publications, NJ: 28-36**.**
[12] Carbo, J., 2006. Colombia: Electric Power Generating Equipment. Bogotá: U.S. Commercial Service and U.S. Department of State, June [Online], Retrieved September 15, 2006 from *http://www.stat-usa.gov/mrd.nsf/*.
[13] Riffat, S.B., 2003. Thermo-electrics: a review of present and potential applications. *Applied Thermal Engineering* 23(8): 913-935.
[14] Dubois, M., Gonzalez, A.M.M., and Knadel, M., 2004. *Municipal solid waste treatment in the EU:* Centre for Environmental Studies, University of Aarhus Finlandsgade, Denmark.
[15] Donelly, C. and Parkman, M., 2006, Leicestershire municipal waste management strategy, best environmental option, strategic assessment. An Environmental Report produced for Lancashire County Council [Online]. Retrieved January 21, 2009. from http://www.lancashire.gov.uk/ environment/lmwlp/pdf/bpeo161104.pdf.
[16] Asian Development Bank. 2001. Guidelines for the financial governance and management of investment projects financed by Asian Development Bank, 1989. Guidelines were reviewed and re-released in November 2001, Publisher ADB.
[17] Asian Development Bank.2003 Guidelines for the Economic Analysis of Projects.

APPENDIX 1

Project Specifications

Project life: 10 years
Financial year: July 1 to June 30
Base year: 2007
Discount rate: 10%

Computation of Solid Waste

Total estimate per day = waste lifted by cleaners + waste lifted by gardeners = 20 ×25×300 = 150,000 + 45,400 = 195,400 kg (25 kg in 20 drums, 300 days/year)

Total area of LSE = 108,088 m^2
Solid waste produced per square meter/ annum = 200,000/108,088 = 1.85 kg
Total number of students and employees in 2006-07 in LSE (full day) = 2,345
Solid waste per head = 200,000/234= 85.28 kg/year.

Total Electric Consumption by LSE

Total consumption = Supply from LESCO + Production from the generators (2006-07) = 730,784
+ 3,847,428/6.5 = 730,784 + 591,912 = 1,322,696 kW.

Computation of Initial Fixed Investment

Land: The current price of land in Defense Housing Authority area where LSE is located was asked from the estate agents in the market. Land requirement and cost is given below.

Total area: 4,047 m^2
Constructed area: 2,529 m^2
Open space: 1,518 m^2
Cost of land/m^2: $ 164.73
Cost of land/acre: $ 666,667

The total cost of land was determined by adding the costs of all above cost elements.

Building: The area of the building was calculated on the basis of the dimensions of the machinery to be installed and was supplied by the executives of Pattoki Sugar Mill. The cost of construction per unit such as square meter was asked from the contractors involved in the construction business.

Cost / m^2 = $ 59.31
Total cost of construction **=** 2,529 × $ 59.31 = $ 150,000

Plant Machinery and Equipment: Detail in Table 3(Appendix 2). The cost of machinery and equipment was worked out from the prices supplied by the machinery manufacturers in Lahore Market and producers of thermo- electric power from solid fibrous wastes.

The contributing elements are shown in Table 3.
Total cost of machinery and equipment = $ 98,833
*Pre-Production Expenditure***:** It had to take one full year to install the plant. Thus, the expenditure involved included salaries of the staff, consultants, etc.

Consultant Fee: $ 3,333/year.
Project Director: $ 5,000/year
Power House In-charge: $ 4,000/year.
Boiler Foreman: $ 3,000/year
Total pre-production expenditure: $ 15,333
Total initial fixed investment (with land): $ (666,667 + 150,000 + 98,833 + 15,333) = $ 930,833

Total initial fixed investment (without land): $ (150,000 + 98,833 + 15,333) = $ 255,833

Computation of Operating Cost

Raw material cost: As raw material was the solid waste to dispose of its cost was zero.
Cost of electricity = Minor cost of electricity was to be involved in the initial running of the plant. The electricity would be self supplied within the set up when the plant would be functional. Thus, it was neglected.
Cost of water: Some cost of water was to be there along with its pre-treatment in the beginning. After the facility would be functional, steam condensate would be recycled without any pre-treatment. Thus, cost of water was neglected.
Labor cost: The nature and number of employees engaged to run the plant along with their salaries is computed in Table 4 (Appendix 2).
Maintenance cost: The maintenance cost was calculated at the rate of 10% of the purchase price of machinery and equipment. Thus, maintenance cost = $ 9,883.
Depreciation: Both plant machinery and equipment were depreciated on straight line basis at the rate of 10% of the purchase price. Depreciation cost = $ 9,833.
Total operating cost/year = $ (21,800 + 9,883.33 + 9,883.33) = $ 41,567.

The operating cost was calculated as in Table 5 (Appendix 2), while that was discounted to the Base year as in Table 6 (Appendix 2).

Assumptions and Computation of Expenditure in Future Years

Apart from the initial investment, no other capital expenditure was assumed over the project life under consideration. The operating cost in the base year (2007 - 2008) was zero. However, it was subject to alter with changes in labor cost, operating capacity, etc. Pattoki Sugar Mill Thermoelectric Plant was assumed to work at 80% of its capacity and its runners did not intend to increase it in the future. At the time of enquiry, the optimal plant capacity was said to be 80% which allowed for desirable level of efficiency needed to produce electric power. It was predicted that the salaries of labor were subject to an increase of 15% after every three years, while the utilities were to an increase of 10% per year.

Computation of Benefits

The calorific value of waste (polyethylene bags, papers, card boards and plastic bottles, etc) was assumed in between the values of bagasse (17,937 kJ) and furnace oil (42,202 kJ) per kg. Thus, the calorific value of waste was averaged as 30,069 kJ. Calculation of kWs of electricity produced from 200 metric ton of waste is given below.

Weight of solid waste: 200 m. ton/year
Calorific value: 30, 069 kJ
Live steam temp: 600^{o}C- 650^{o}C
Live steam pressure: 70 – 80 kg/cm²
Fuel steam ratio: 1: 7

a. Steam produced from available fuel: 1400 metric ton /year
b. Turbine for electricity generation: Multistage condensing turbine with LT generator (400 Volt)
c. Steam consumption per kW by turbine: 5 kg /kW
d. Electricity produced: 280,000 kW/year
e. Electricity produced: 32.40 kW/hr

Return per year = $ 280,000×0.10833 =$ 30,333
Total revenue return per year = $ 30,333
Electric power produced per year = 2 80,000 kW
Price of electricity/kW = $ 0.10833
Steam produced = 0.1620 tons/hr

Scrap Value of the Machinery and Equipment

The scrap value of the machinery and equipment at the end of the project life was estimated at 10% of the purchase price. Therefore, the worth of the asset at which it can be sold would be $ 9,883.

Benefits Discounted to the Base Year

The revenue returns from thermoelectric plant were in the form of constant periodic cash flows of $ 30,333 per year. The total receipts after discounting at 10% were calculated by applying annuity tables. Thus, present value received constantly per annum for 10 years at 10% discount rate was 6.14457 (from annuity tables).

Present value of $ 30,333received constantly per annum for 10 years at 10% discount rate: $ 30,333* 6.14457 = $ 186,385.

Computation of B/C Ratios, NPV and PBP

Alternative 1: (With Land)

$$\text{B/C Ratio} = \frac{\text{PV of Benefits}}{\text{PV of Cost}} = \frac{190{,}196}{1{,}206{,}599} = 0.15$$

NPV = $ (190,196-1,206,599) = - $ 1,016,403.

$$\text{PBP} = \frac{\text{Total Investment in Year 1}}{\text{Annual Cash Flow}}$$

PBP was evaluated for two scenarios for the reason that the overall trend about the land and building in Pakistan is that its price always increases with time. Thus, here assumption made is that it does not depreciate and is cash in hand.

Scenario 1:

Total investment in year 1 (all costs included):
= Total initial fixed investment – scrap value or

Total investment in year 1 with land and building:
= $ (930,833-9,883) = $ 920,450

Total investment in year 1 without land:
= $ (264,167-9,883) = $ 253,783

Annual cash flow = total revenue return- operating cost.

= $ (30,333 – 2,494,000) = -$ 415,667

Scenario 2:

Total investment in year 1
= Total initial fixed investment- cost of land and building- scrap value

Total investment in year 1 without land and building = $ (930,833 – 666,667 - 150,000 -9,883) = $ 104,283.

Annual cash flow = total revenue return- operating cost as above.

Annual cash flows are consolidated and shown in Table 8 and 9 (Appendix 2)

Framework of Alternative Projects

The framework bases are reported in Table 7 and the results in Table 12 and 13 (Appendix 2) that also present two scenarios for PBP. While computing, some common requisites were not included. For example, the steam boiler as it remained the same at scale of processing from 200 to 1000 metric ton /year and also the fuel value, which was also the same as the composition of the fuel was the same.

APPENDIX 2

Table 1: Solid waste produced at different sites of LSE.

Sites	Basis of measurement	Solid waste produced per day (kg)	Solid waste produced per month (kg)	Solid waste produced per year (kg)
main cafeteria	8 bales, each 15-16 kg/day	8×15.5 =124	124×26 =3224	3224×12=38688
canteen 1	1 rubbish bin, waste 10 kg	10×1= 10	10×26=260	260×12=3,120
canteen 2	4 rubbish bins waste 5 kg each	5×4= 20	20×26=520	520×12=6240
canteen 3	1 rubbish bin, waste 20 kg	20×1= 20	20×30 =600	600×12=7,200
hostels	3 rubbish bins 20 kg in each and One 20 kg rubbish bin from hostel mess	20×3=60 20×1= 20	60×30 = 1,800 20×30 = 600	1,800×12 = 21,600 600×20 = 7, 200 Total = 28,800
libraries	One rubbish basket 5kg, 50 printer paper and books boxes every 3 months. Each box = 1kg	1×5 = 5	5×26 = 130 50×0.33×1=16.5 Total = 146.5	146.5×12=1758
computer laboratories	2 rubbish bins waste 5 kg each	5×2=10	10×26=260	260×12=3,120
administration and teacher's offices	Reported as a component of overall waste	---	--	- --
photocopying room	1 box that is full with 10kg waste	0.83	0.83×26 =21.6	21.6×12=259.9
lawns and plantations	1 bale each 25 kg	4×25 = 100 10×25=250	100×30=3000 250×30=7,500	3000× 10=30,000 (For 10 months) 7,500×2=15,000 (For 2 months of fall)
Hedges	12 times a yr	20×20=400	-	400
		Total solid waste per annum, kg		134,586

Table 2: Electricity and diesel bills and power consumption of LSE over time.

Sr. No.	Year and point of time	Fuel and power consumption (kW)	Electricity bills ($)	Diesel Bills ($)
1	June 2004-05	$ 9,778	$ 57,735	-
2	June 2005-06	$ 13,983	$ 82,211	$ 31,502
3	June 2006-07	$ 12,180	$ 75,467	$ 64,124

Table 3: Plant machinery and equipment.

Plant Machinery and Equipment	Capacity	Quantity	Cost-$
Steam boiler	2 metric ton /hr	1	$41,667
Water treatment plant	1 metric ton /hr	1	$1,667
Feed water storage tank	25 metric ton	1	$1,333
Multi stage turbine	100 kW/hr	1	$16,667
Electric pumps	-	6	$833
Distribution panel	-	1	$833
Transformer	-	1	$10,833
Vehicle (truck)	-	1	$25,000
		Total	$98,833

Table 4: Breakdown of labor and labor cost, US $.

Labor	Number	Salary per employee	Salary per month
Boiler/turbine attendant	3	$117	$351
Boiler/turbine helper	3	$83	$249
Turbine foreman	1	$250	$250
Water treatment plant labor	2	$100	$200
Electrician	3	$117	$351
Transport of waste to storage	5	$83	$416
		Total	= $1,817/month
			= $21,800/year

Table 5: Total operating cost over years.

Years	Calculations (US Dollars)	Operating Cost-US $
2007-08	$0	$0
2008-09	$21800+$19767	$41,567
2009-10	$21800+$19767	$41,567
2010-11	$21800+$19767	$41,567
2011-12	$25070+$19767	$44,837
2012-13	$25070+$19767	$44,837
2013-14	$25070+$19767	$44,837
2014-15	$28831+$19767	$48,597
2015-16	$28831+$19767	$48,597
2016-17	$28831+$19767	$48,597
2017-18	$33155+$19767	$52,922

Note: Operating cost = cost of (labor +utilities and chemicals + maintenance and depreciation), $.

Table 6: Total operating costs discounted at 10% to the base year, $.

Years	Calculations (US Dollars)	Operating Cost (US Dollars)
2007-08	0	$0
2008-09	$41567*0.909091	$37,788
2009- 10	$41567*0.826446	$34,353
2010-11	$41567*0.751315	$31,230
2011-12	$44837*0.683013	$30,624
2012-13	$44837*0.620921	$27,840
2013-14	$44837*0.564474	$25,309
2014-15	$48597*0.513158	$24,938
2015-16	$48597*0.466507	$22,671
2016-17	$48597*0.424098.	$20,610
2017-18	$52922*0.365543	$20,404
Total Operating Cost		$275,767

Table 7: Bases and requisites of different alternative projects.

Alternatives	1	2	3	4	5	6
Solid waste-/year, metric ton	200	200	600	600	1,000	1,000
Cost of land	Included	Excluded	Included	Excluded	Included	Excluded
Live steam temperature, ºC	600- 650	600-650	600- 650	600-650	600C^{o} -650	600-650
Live steam pressure, kg/cm²	70–80	70–80	70–80	70–80	70–80	70–80
Fuel steam ratio	1:7	1:7	1:7	1:7	1:7	1:7
Steam produced/year, metric ton	1400	1400	4200	4200	7,000	7,000
Multistage turbine	light duty	light duty	light duty	light duty	heavy duty	heavy duty
Steam consumption/kW	5 kg/	5 kg/	5 kg/	5 kg/	5 kg/	5 kg/
Electricity production/kW/year	280.000	280.000	840.000	840.000	1,400,000	1,400,000
Steam produced /hr, metric ton	0.1620	0.162	0.486	0.486	0.81	0.81
Electricity produced/hr	32.40 kW	32.40 kW	97.22 kW	97.22 kW	162 kW	162 kW

Table 8: Total inflation adjusted operating cost over years.

Years	Operating Cost	Inflation Rate	Calculation	Inflation Adjusted Operating Cost
2007-08	$0	0	Year of Installation	$0
2008-09	$41,567	8%	$41567*1.08*1.04	$46,688
2009-10	$41,567	8%	$41567(1.08)$_{2}$*1.04	$50,423
2010-11	$41,567	8%	$41567(1.08)$_{3}$*1.04	$54,457
2011-12	$44,837	8%	$44837(1.08)$_{4}$*1.04	$63,440
2012-13	$44,837	8%	$44837(1.08)$_{5}$*1.04	$68,515
2013-14	$44,837	8%	$44837(1.08)$_{6}$*1.04	$73,996
2014-15	$48,597	8%	$48597(1.08)$_{7}$*1.04	$86,618
2015-16	$48,597	8%	$48597(1.08)$_{8}$*1.04	$93,548
2016-17	$48,597	8%	$48597(1.08)$_{9}$*1.04	$101,032
2017-18	$52,922	8%	$52922(1.08)$_{10}$*1.04	$118,824

Note: Operating cost = cost of (labor +utilities and chemicals + maintenance and depreciation), $.

Table 9: Inflation adjusted operating cost discounted to base year.

Years	Calculations (US $)	Operating Cost(US $)
2007-08	$0	*$0*
2008-09	$46688*0.909091	$42,443
2009- 10	$50423*0.826446	$41,672
2010-11	$54457*0.751315	$40,914
2011-12	$63440*0.683013	$43,330
2012-13	$68515*0.620921	$42,542
2013-14	$73996*0.564474	$41,769
2014-15	$86618*0.513158	$44,449
2015-16	$93548*0.466507	$43,641
2016-17	$101032*0.424098	$42,847
2017-18	$118824*0.365543	$45,812
Present Value of Total Operating Cost		$429,419

Table 10: Inflation adjusted cash flows over years.

Years	Cash Flows	Inflation Rate	Calculation	Inflation Adjusted Cash Flows
2007-08	$0	0	Year of Installation	$0
2008-09	$30,333	8%	$30333*1.08*1.04	$34,070
2009-10	$30,333	8%	$30333*(1.08)2*1.04	$36,796
2010-11	$30,333	8%	$30333*(1.08)3*1.04	$39,740
2011-12	$30,333	8%	$30333*(1.08)4*1.04	$42,919
2012-13	$30,333	8%	$30333*(1.08)5*1.04	$46,352
2013-14	$30,333	8%	$30333*(1.08)6*1.04	$50,061
2014-15	$30,333	8%	$30333*(1.08)7*1.04	$54,065
2015-16	$30,333	8%	$30333*(1.08)8*1.04	$58,391
2016-17	$30,333	8%	$30333*(1.08)9*1.04	$63,062
2017-18	$30,333	8%	$30333*(1.08)10*1.04	$68,107

Table 11: Discounted inflation adjusted cash flows.

Years	Inflation Adjusted Cash Flows	Discount Factor	Discounted
2007-08	$0	0	$0
2008-09	$34,070	0.909091	$30,973
2009-10	$36,796	0.826446	$30,410
2010-11	$39,740	0.751315	$29,857
2011-12	$42,919	0.683013	$29,314
2012-13	$46,352	0.620921	$28,781
2013-14	$50,061	0.564474	$28,258
2014-15	$54,065	0.513158	$27,744
2015-16	$58,391	0.466507	$27,240
2016-17	$63,062	0.424098	$26,744
2017-18	$68,107	0.385543	$26,258
		Total inflation adjusted revenues	$285,580

Table 12: Computation of results of evaluation of alternatives- Scenario 1.

Alt.	PV of Benefits, $.	PV of Costs, $	BCR	NPV $.	Initial Investment- $	Annual Return, $	PBP, Years
1	$190,196	$1,206,599	0.15	-$1,016,403	$920,950	-$11,233	Infinite
2	$190,196	$539,933	0.35	-$349,736	$254,283	-$11,233	Infinite
3	$562,967	$1,206,599	0.46	-$643,632	$920,950	$49,433	18.63
4	$562,967	$539,933	1.04	$30,535	$254,283	$49,433	5.14
5	$935,738	$1,206,599	0.77	-$270,862	$920,950	$110,100	8.36
6	$935,738	$539,933	1.73	$385,211	$254,283	$110,100	2.30

Table 13: Computation of results of evaluation of alternatives- Scenario 2.

Alt.	PV of Benefits, $	PV of Costs, $	BCR	NPV, $	Initial Investment, $	Annual Return, $	PBP, Years
1	$190,196	$1,206,599	0.15	-$1,016,403	$104,283	-$11,233	Infinite
2	$190,196	$539,933	0.35	-$349,736	$104,283	-$11,233	Infinite
3	$562,967	$1,206,599	0.46	-$64,449	$104,283	$49,433	2.10
4	$562,967	$539,933	1.04	$30,535	$104,283	$49,433	2.10
5	$935,738	$1,206,599	0.77	-$270,862	$104,283	$110,100	0.94
6	$935,738	$539,933	1.85	$385,211	$104,283	$110,100	0.94

Table 14: Computation of results of evaluation of inflation adjusted alternatives.

Alt.	PV of Benefits-$.	PV of Costs-$	BCR	NPV-$
1	$294,144	$1,360,253	0.21	-$1,066,108
2	$294,144	$693,586	0.42	$399,442
3	$865,304	$1,360,253	0.63	-$494,949
4	$865,304	$693,586	1.24	$171,718
5	$1,450,738	$1,360,253	1.06	$90,485
6	$1,450,738	$693,586	2.09	$757,152