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# Economic Analysis of Solid Waste Treatment Plants Using Pyrolysis

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**Abstract:** Municipal Solid Waste (MSW) management is a chronic environmental and economic problem in urban areas worldwide and more specifically in developing countries. Waste-to-Energy (WTE) technologies show a great potential to convert this problem to a revenue source. Pyrolysis is a promising technology and is currently utilized in many regions of the world for MSW disposal and energy generation. The economic value of pyrolysis has been insufficiently evaluated. This paper introduces and discusses the economic value of pyrolysis as MSW management disposal method and energy source. The return period of investments is considered for various pricing policies with respect to end product of process. Hypotheses and conclusions of the model works are briefly reported.

**Keywords:** Waste to Energy, Pyrolysis, Municipal Solid Waste Management

## 1. Introduction

Municipal Solid Waste (MSW) refers to domestic solid waste such as food scraps, paper, cardboard, plastics, clothing, glass, metals, wood, street sweepings, landscape and tree trimmings and general wastes from parks and other recreational areas. The world urban areas generated about 1.3 billion tons of solid waste in 2012. This volume is expected to increase to 2.2 billion tons by 2025. Waste generation rates will more than double over the next twenty years in developing countries. Globally, solid waste management costs will increase from today's annual US $ 205.4 billion to about US $ 375.5 billion in 2025. Cost increases will be most severe in developing countries such as Pakistan [1, 2]. In developing countries, urban MSW is usually a city's single largest budgetary item and it can be a valuable source of biomass, recycled materials, energy and revenue if properly and wisely managed. Several energy recovery or waste-to-energy (WTE) technologies such as pyrolysis, anaerobic digestion (AD), incineration and refused derived fuel (RDF) have been developed in order to generate energy and value-added products in the form of electricity, transportation fuels, heat, fertilizers and chemicals[3,4]. Studies show that WTE can contribute substantially to energy demand especially in heavily populated urban areas [5-13]. Additionally, the WTE environmental value is quite significant with several factors including, but not limited to, greenhouse gas emission reduction, energy saving, landfill area saving, and soil and groundwater protections [14-16].

Pyrolysis is a promising technology and is currently utilized in many regions of the world for MSW disposal and energy generation. The economic value of pyrolysis has been insufficiently evaluated. This paper introduces and discusses the economic value of pyrolysis as MSW management disposal method and energy source. Fast and slow pyrolyses are considered as thermal processes, essential final products are gases, liquid fuel and electricity. Models are proposed to cover and analyze all these products. In these models fast pyrolysis and its products pyrolysis oil is not considered. The paper has three sections:

1) Estimation of income from solid waste
2) Investment calculations
3) Maintenance costs

The estimations were made by considering realistic input values and the return periods for each element were calculated. The models can be used with multi product estimation such as electricity, gas and liquefied gas.

## 2. Estimation of Income from Solid Waste

The capacity of a plant can be determined by considering input solid waste. Typically a person produces MSW at a rate of 0.5 kg to 2.5 kg per day and the waste has carbon content at 20-35 percent[1,2].These numbers are dependent on area, culture and income levels.

The products, defined by Table 1, are electricity, gas and liquid fuel. The reactor may produce these products in pre-defined percentages. Because electricity, gas and liquid fuel can be produced in different percentages, and the system can be designed for one product otherwise the percentages of the products must be defined.

The thermodynamic constants are taken from Cengel and Boles [2014]. The composition and the caloric value of MSW, MSW per capita are taken from Hoornweg and Bhada-Tata [2012]. The part of MSW for pyrolysis is about 15 to 20 percent of the MSW, which varies according to the recycling rates of the MSW; these parameters are defined by Table 2. The population, MSW per capita and the percentage of pyrolysis material dictate the production capacity of the plant.

***Table 1.*** *Definition of products from the process.*

| ELECTRICITY_PRODUCTION? (YES - NO) | YES | 1 |
|---|---|---|
| PERCENTAGE_OF_ELECTRICITY (0 - 100) | 100 | % |
| GAS_GAS_PRODUCTION? (YES - NO) | NO | 0 |
| PERCENTAGE_OF_GAS (0 - 100) | 0 | % |
| LIQUID_FUEL PRODUCTION? (YES - NO) | NO | 0 |
| PERCENTAGE_OF_LIQUID_FUEL (0 - 100) | 0 | % |

***Table 2.*** *Definition of system parameters.*

| 1_KG_TRASH_CALORIC_VALUE | 2,000.00 | KCAL |
|---|---|---|
| 1_KCAL | 0.001163 | KWH |
| 1_KG_ORGANIC_TRASH_KWH_VALUE | 2.33 | KWH |
| POPULATION | 200,000 | |
| MSW_PER_CAPITA | 1.60 | KG |
| PYROLYSIS_MATERIAL_PERCENTAGE(0–25) | 20 | % |
| PLANT_MATERIAL_DAILY_FOR_PYROLYSIS | 64.00 | TON |

If the plant produces electricity, the income and the power of the plant can be seen on Table 3.

***Table 3.*** *Estimation of the income from electricity production and the power of the plant.*

| EFFICIENCY_FOR_TRASH_PERCENT (80 - 100) | 90 | % |
|---|---|---|
| KWH_PRICE_$ | 0.08 | $ |
| DAILY_ENERGY_FROM_ELECTRICITY | 133,977.60 | KWH |
| INCOME_$_PER_YEAR_FROM_ELECTRICITY | 3,912,145.92 | $ |
| POWER_MW | 5.58 | MW |

The incomes from gas and liquid fuel are presented by Tables 3 and 4, respectively. It should be noted that the calculations are performed per gas or liquid fuel production only.

***Table 4.*** *Estimation income from only gas production during pyrolysis.*

| GAS_EFFICIENCY_PERCENT (80 - 100) | 90 | % |
|---|---|---|
| PRICE_OF_GAS_PER_M3 | 0.35 | $ |
| ENERGY_PER_M3_IN_GAS | 45.00 | MEGAJOULE |
| 1_KWH | 3.60 | MEGAJOULE |
| ENERGY_PER_M3_IN_GAS | 12.50 | KWH |
| AMOUNT_GAS_PER_DAY | 9,646.39 | M3 |
| YEARLY_INCOME_FROM_GAS | 1,243,705.87 | $ |

***Table 5.*** *Estimation income from only liquid fuel production during pyrolysis.*

| LIQUID_FUEL_PODUCTION_EFFICIENCY_PERCENT (80 - 100) | 90 | % |
|---|---|---|
| LIQUID_FUEL_PRICE_PER_LITER | 0.70 | $ |
| OPERATING COST | 0.06 | $ |
| LIQUID_FUEL_PER_TON(100 - 300) | 100.00 | LITER |
| DAILY_PRODUCTION_LIQUID_FUEL | 5,760.00 | LITER |
| YEARLY_INCOME_FROM_ LIQUID_FUEL | 1,345,536.00 | $ |

The efficiency values presented by Tables 3, 4 and 5 depend on the system and the contents of the MSW system and these values vary 80-100 % of the whole pyrolysis material. The prices of electricity, gas and liquid fuel are according to prevailing market values of these commodities. However, the price of electricity is affected by government regulations and subsidies and varies from 3 to 20 US cents. Liquid fuel is produced through Fischer-Tropsch process at a rate of 100 to 300 liters per ton [17-20].

***Table 6.*** *The incomes from the sale of recyclables, biochar, carbon credit, gate (tipping) and brown water.*

| **RECYCLABLE_SALES_PER_TON_$** | **0.00** | **$** |
|---|---|---|
| PERCENTAGE_OF_RECYCLABLE (0 - 20) | 0 | % |
| DAILY_AMOUNT_OF_RECYCLABLE | 0.00 | TON |
| YEARLY_RECYCLABLE_SALES_$ | 0.00 | $ |
| BIO_CHAR_$_PER_TON | 0.00 | $ |
| PERCENTAGE_OF_CHARCOAL (0 - 2) | 0 | % |
| DAILY_AMOUNT_OF_CHARCOAL | 0.00 | TON |
| YEARLY_BIO_CHAR_SALES_$ | 0.00 | $ |
| CARBON_CREDIT_$_PER_TON | 0.00 | $ |
| PERCENTAGE_FOR_CARBON_CREDIT (0 - 100) | 0 | % |
| DAILY_AMOUNT_OF_CARBON_CREDIT | 0 | TON |
| YEARLY_CARBON_CREDIT_$ | 0.00 | $ |
| GATE_(TIPPING)_FEE_$_PER_TON | 0.00 | $ |
| PERCENTAGE_OF_GATE (TIPPING) (90 - 100) | 0 | % |
| DAILY_AMOUNT_OF_GATE (TIPPING) | 0.00 | TON |
| YEARLY_GATE_(TIPPING)_FEE_$_ | 0.00 | $ |
| BROWN_WATER_$_PER_TON | 0.00 | $ |
| PERCENTAGE_OF_WATER (0- 80) | 0 | % |
| DAILY_AMOUNT_OF_BROWN_WATER | 0 | TON |
| YEARLY_INCOME_BROWN_WATER_$ | 0.00 | $ |

The incomes from of recyclables, biochar, carbon credit, gate (tipping) and brown water are presented in Table 6. The sale values can be determined through the agreements with local municipalities. The percentage of recyclable( 0-20); charcoal percentage ( 0 – 2 ), carbon credit percentage ( 0 - 100 ), tipping percentage (90 – 100) and percentage of water ( 0 – 80 ) are all dependent on the content of the MSW.

# 3. Total Income

Total income is estimated by adding these incomes which are possible if the sale of these products are present. The income from one tone of household waste (*trash*) can be estimated. In this calculation, only the sale of electricity is considered; if gas and liquid fuel are also to be produced and their production rates are as per Table 1.

***Table 7.*** *Total income.*

| **TOTAL_INCOME_YEARLY_$** | **3,912,145.92** | **$** |
|---|---|---|
| INCOME_OF_PROCESSED_ONE_TON_TRASH_ | 33.49 | $ |

# 4. Investment Calculations

The list of equipment is determined by considering the amount of the trash and the capacity necessary equipment, see Table 8. The system uses slow pyrolysis [22] where the obtained gas product runs electric generators; Table 8 is set for only electricity production. Equipment for fuel liquefiers which uses Fischer–Tropsch process [17, 19] and gas filters are not considered. The dryers are required to eliminate moisture in MSW [23], and finally the moisture is used for water production. The exhaust gases are used in dryers to increase the efficiency of the system. The other components are MSW sorting unit, waste handling unit, de-sulfurization unit, gas filters and granulation system. The other components of the capital investments are civil works, engineering design, installation and commissioning. This needs rewriting, very confusing.

***Table 8.*** *List of the major items of the plant.*

| **CAPITAL INVESTMENT** | | | |
|---|---|---|---|
| **ITEMS** | **Pcs.** | **Unit Price USD** | **Total Price USD** |
| SYSTEM EFFICIENCY | 0.9 | | |
| DAILY CAPACITY OF PYROLYSIS REACTOR, TON | 24 | | |
| PYROLYSIS SYSTEM | 2 | 2,000,000.00 | 4,000,000.00 |
| DAILY CAPACITY OF DRYING UNIT, TON | 70 | | |
| DRYING SYSTEM | 2 | 250,000.00 | 500,000.00 |
| DAILY CAPACITY OF CONDENSER, TON | 70 | | |
| CONDENSER | 2 | 300,000.00 | 600,000.00 |
| DAILY CAPACITY OF MSW PRESORTING, TON | 100 | | |
| MSW PRESORTING | 2 | 400,000.00 | 800,000.00 |
| DAILY CAPACITY OF WASTE HANDLING, TON | 200 | | |
| WASTE HANDLING | 1 | 400,000.00 | 400,000.00 |
| DAILY CAPACITY OF DE-SULFURIZATION UNIT, TON | 200 | | |
| DE-SULFURIZATION | 1 | 350,000.00 | 350,000.00 |
| DAILY CAPACITY OF GAS GENSET, TON | 24 | | |
| GAS GENSET | 2 | 1,000,000.00 | 2,000,000.00 |
| DAILY CAPACITY OF GAS FILTER UNIT, TON | 24 | | |
| GAS_FILTER | 0 | 350,000.00 | 0.00 |
| DAILY CAPACITY OF LIQUIFIER UNIT, TON | 24 | | |
| LIQUIFIER | 0 | 3,000,000.00 | 0.00 |
| DAILY CAPACITY OF GRANULATION UNIT, TON | 24 | | |
| GRANULATION SYSTEM | 1 | 250,000.00 | 250,000.00 |
| CIVIL WORKS | 1 | 1,000,000.00 | 1,000,000.00 |
| PROJECT AND ENGINEERING | 1 | 500,000.00 | 500,000.00 |
| INSTALLATION AND COMISSIONING | 1 | 1,000,000.00 | 1,000,000.00 |
| TOTAL | | | 11,400,000.00 |

## 5. Operating Expense

Operating costs can be seen in Table 9, where the yearly profit and payback periods are also presented. The costs of the operation are payments of electricity, miscellaneous maintenance, water treatment, salaries, lubrication, and cost on unseen expenses.

***Table 9.*** *Operating expenses.*

| OPERATING EXPENSES | | | |
|---|---|---|---|
| | **Unit Cost USD** | **Daily Cost** | **Annual Cost** |
| ELECTRICITY COST_@_365_DAYS | 0.03 | 3,000.00 | 32,850.00 |
| GENSET MAINTENANCE | 2 | 18,000.00 | 36,000.00 |
| GAS_FILTER_MAINTENANCE | 0 | 20,000.00 | 0.00 |
| LIQUIFIER_MAINTENANCE | 0 | 20,000.00 | 0.00 |
| DRYER MAINTENANCE | | | 60,000.00 |
| CONDENSER MAINTENANCE | | | 30,000.00 |
| WATER TREATMENT | | | 30,000.00 |
| PYROLYSIS UNIT MAINTENANCE | | | 157,500.00 |
| SALARIES | | | 200,000.00 |
| OTHERS | | | 50,000.00 |
| MSW PRESORTING MAINTENANCE | | | 22,000.00 |
| HANDLING MAINTENANCE | | | 1,800.00 |
| GAS GENSET LUBRICATION COST | 2 | 24,000.00 | 48,000.00 |
| TOTAL | | | 668,150.00 |
| GROSS PROFIT | | 2,299,784.72 | USD/YEAR |
| PAYBACK PERIOD | | 4.96 | YEAR |
| | | 59.48 | MONTHS |

The water may have some odors and these odors may be avoided by odor control technologies which are widely available on the market. Since only electricity is produced in this scenario, the cost of maintenance of gas filters and liquefiers is not withstanding.

## 6. Various Scenarios and Return Period

The important variables profit and return period for investment are the sale price of electricity and population; the various cases are presented by Table 10 and can be extended further. In these scenarios, the income from recycling, charcoal, carbon credit, tipping and produced water are not considered. If these incomes are to be taken into consideration, the profit and return period of the investment will be shortened considerably.

***Table 10.*** *Various scenarios.*

| POPULATION | PRICE OF ELECTRICITY, $/kWh | PROFIT $ | RETURN_PERIOD, YEAR |
|---|---|---|---|
| 200,000 | 0.08 | 3,189,245.92 | 3.57 |
| 300,000 | 0.08 | 5,074,118.88 | 2.95 |
| 200,000 | 0.10 | 4,145,382.40 | 2.75 |
| 300,000 | 0.10 | 6,511,973.60 | 2.30 |

## 7. Conclusion

MSW is a chronic problem in urban areas. WTE technologies such as pyrolysis can be utilized to convert this problem to a revenue source if properly managed and implemented. This paper presented an economic analysis of the Pyrolysis technology as an MSW management option. The analysis showed that the determining factor in WTE investment is the selling price of electricity. However, more comprehensive scenarios can be developed where electricity, gas and liquid fuel production are considered with their selected production percentages.

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