Economic Assessment of Waste Tyres Pyrolysis Technology: A Case study for Gauteng Province, South Africa

Jefrey Pilusa, Mukul Shukla, and Edison Muzenda

***Abstract*—** This study evaluates the viability of pyrolysis technology as a treatment process for waste tyres with the aim of producing alternative fuel and other high value products. A financial model was formulated to evaluate the economic feasibility of this technology as an alternative disposal method. It was discovered that pyrolysis technology becomes more viable when there is guaranteed product off-takes at a given price. Further processing of the crude tyre oil and carbon black is important for production of consistent quality products. Gauteng province alone will require a capital injection of US $59.8 million to setup 14 waste tyres pyrolysis treatment facilities to treat 134,922 tons per annum of waste tyres with a potential investment return and gross margin of 29.79% and 34.59%, respectively. These facilities can produce up to 46.8 million litres per annum of refined tyre derived fuel at cost of $ 0.516/litre and other secondary value add products for local and export markets.

***Keywords*—**Carbon Black, Distillation, Fuel, Diesel, Waste Disposal

I. INTRODUCTION

IT is estimated that 1.5 billion tyres are produced globally per year and majority of these eventually end up as waste tyres contributing a significant portion of the solid waste stream. It was reported that the European Community generated an estimated 4.5 million tons of new tyres in 2010, with 289 million tyres being replaced per year [1]. In the United States, approximately 500 million waste tyres were generated in 2007, with about 128 million used tyres already stockpiled [2]. In Australia, around 52.5 million tyres reached their end of life between 2007 and 2008. Approximately 64% of these tyres went to landfill, or were illegally dumped or stockpiled, while only 13% were recycled [1].

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Disposal of waste tyres and rubber products in South Africa is becoming a growing concern since these products do not decompose easily and they take up a significant portion of landfill space. There are an estimated 60 million (~2.16 million tons) scrap tyres disposed across South Africa, with an additional 11 million (398,000 tons) adding to the stock pile in 2008 [3]. In 2011 alone, 7.25 million new tyres (261,250 tons) excluding mining tyres and belting were sold in South Africa; approximately 55% of these tyres were sold in Gauteng Province. Majority of these tyres are expected to add into the existing waste tyre matrix [4].

The South African government has now recently passed legislation which incorporates a move to turn waste tyres into social, economic and environmental worth. Under the new plan, tyre manufacturers and importers will start paying a levy of $223.20/ton, plus 14% value added tax for any new tyre they introduce into South African market [5]. The funds raised will empower a move to kick start a new industry around the collection, transport and disposal of every waste tyre [6]. By creating income generating opportunities and the researching of new recycling methods, the new legislation will dramatically reduce the quantity of waste tyres across South Africa.

The Recycling and Economic Development Initiative of South Africa (REDISA), as gazetted by the Water and Environmental affairs Minister on the 23 July 2012, has been well received. All tyre producers registered with REDISA must immediately comply with the approved REDISA Integrated Waste Tyre Management Plan (IWTMP) in terms of the Regulation 6(3) of the Waste Tyre Regulations in accordance to the National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008).

There has been great interest in alternative treatment processes for waste tyres, amongst which is the use of pyrolysis technology [7]. Pyrolysis is the thermal degradation of the organic components of the tyres, at typical pyrolysis temperatures of 570^{o}C to produce oil, gas and char product in addition to the recovery of the steel. The yields and quality of these products is determined by the type of reactor used to pyrolyse the feedstock [8]. The fuel oil produced from this process is chemically a complex containing aliphatic, aromatic, hetero-atom and polar fractions [9]. The fuel characteristics show that it has nearly similar properties to diesel fuel and can be used in tests furnaces and internal combustion engines [10]. The oil may be used directly as a fuel, added to petroleum refinery stocks, upgraded using catalysts to a premium grade fuel or used as a chemical feedstock [11]. The gases from tyre pyrolysis are typically composed of C1–C4 hydrocarbons and hydrogen with a high calorific value, of sufficient energy content to act as fuel to provide the heat for the pyrolysis process [12]. The solid char consists of the carbon black filler and also char [13]. The liquid and gaseous fractions obtained are a valuable fuel source; while the solid fraction (char) has the recovery potential of low- grade carbon black or as carbon adsorbent after applying an activation step [14]. The uncondensed gaseous fraction has almost similar properties to synthesis gas as described by Bajus and Olahova, 2011[15] in Table I. These gases can be used as a direct fuel in commercial gas burners or to run fork lift engines. Special attention has been given to the liquid fraction, highlighting its properties as alternative fuel in compression ignition engines [16].

TABLE I
TYPICAL TYRE PYROLYSIS GAS COMPOSITION [15]

Component		Concentration (vol. %)
CO	Carbon monoxide	47.42
CH_4	Methane	10.70
C_3H_6	Propene	7.80
C_4H_8	1-Butene	7.20
C_2H_6	Ethane	6.70
CO_2	Carbon dioxide	6.50
C_3H_8	Propane	5.70
C_2H_4	Ethylene	4.50
C_4H_6	1,3-Butadiene	1.78
C_4H_{10}	n-Butane	1.70
Molecular Mass(g/mol)		32.9
Latent Heat of Vaporization(kJ/kg)		348.6
Calorific Value(kJ/m^3)		37,000
Gas density (kg/m^3)		1.40
Constant Pressure Heat capacity(kJ/kg.K)		1.3

The main options used for treating waste tyres are through the use of tyres as fuel in cement kilns. Other energy recovery options for tyres include use in power plants and co-incineration [17]. A large portion of tyres are used in material recovery options such as crumb products for the production of rubberised flooring in sports fields and playgrounds, paving block and other rubber application. A significant proportion of the waste tyres are used in civil engineering applications such as road and rail foundations and embankments [18].

The total consumption of Heavy Fuel Oil (HFO) in South Africa was 470 million litres in 2007. Recent data is no longer published due to competition-related concerns. HFO is the lowest cost liquid fuel, and prices are usually determined on a negotiated basis. There are no price regulations for HFO. Globally, the value of HFO has reduced from around the same cost as brent crude oil to around 70% of the brent oil price at the present. One major reason for the decline is a lower demand due to relatively high sulphur content compared alternatives. On this basis, the relative price for HFO is at $ 0.516/liter excluding transportation costs [3]. This is 60% cheaper than commercial diesel and can be sold at much lower price since there is currently no regulations and levies applied on this fuel.

Research has shown that crude tyre derived oil cannot be used as an alternative fuel in diesel engines without further purifications [19]. Murugan *et al.*, 2008 [10] investigated combustion of pure crude tyre derived fuel and its blend with diesel in diesel engines. It was observed that pure tyre derived fuel cannot be used in these engines as an alternative fuel unless it is blended with commercial diesel up to 40% vol. The engine operates efficiently besides the high level of sulphur oxides emissions reported due to the fuel quality. An average of 0.23% by volume in sulphur oxide and other emissions were recorded in the engine exhaust emission fuelled with diesel-tyre derived fuel blend [10].

This is significantly high and will pose a serious environmental challenge if the fuel blend is used in diesel operated vehicles. For this reason, it will be beneficial to use this fuel blend in stationary engines such as diesel generator sets where the resulting emissions can be contained and chemically treated into value added products. The flue gas emissions resulting from combustion of HFO-diesel blends and gas-oil in the generator set and reactor heating source are contained and scrubbed through a gas absorption tower using sodium hydroxide solution [20].

Table II shows typical flue gas composition from combustion of Heavy Fuel Oil (HFO) to prevent further air pollution carbon dioxide can be reacted with sodium hydroxide to form water and sodium carbonate as shown in (1). Due to reaction kinetics favoring sodium carbonate formation in the presence of sulphur dioxide, sodium sulfite is formed as a final stable product (2)

TABLE II
FLUE GAS EMISSIONS FROM COMBUSTION OF WASTE TYRE DERIVED FUEL[21]

Component	Concentration (vol. %)	Emission level (g/kWh)
Suplher Dioxide (SO_2)	0.23%	8.0
Carbon Dioxide (CO_2)	12.5%	296
Nitrogen Oxides (NO_x)	0.003%	0.08
Hydrocarbons(HC)	0.02%	0.18
Carbon Monoxide (CO)	0.01%	0.15
Moisture (H_2O)	10.1%	98
Nitrogen (N_2)	73.6%	1110
Oxygen (O_2)	3.5%	60

$$2\,NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O \qquad 1$$

The initial combination generates sodium-bisulfite ($NaHSO_3$), which is converted to the sulfite by reaction with sodium hydroxide or sodium carbonate [22]. The overall reaction is:

$$SO_2 + H_2O + Na_2CO_3 \rightarrow Na_2SO_3 + CO_2 \quad 2$$

Sodium sulfite is primarily used in the pulp and paper industry. It is used in the production of sodium thiosulphate. Other applications include froth flotation of ores, oil recovery, food preservatives, and making dyes [23]. The current average market price for sodium sulphite is in the order of $20/ton.

The total market for carbon black is estimated at around 66, 000 tons in 2010. Carbon black is not a single product, and a large range of grades are used in specific applications in order to impart the required properties to the final rubber product [3]. Carbon black grades are determined according to an international ASTM classification. The major multinational tyre companies account for in excess of 80% of the carbon black consumption in South Africa.

Non-rubber applications (e.g. pigments in plastics, inks and paints) account for only around 5% of the market. The average market price for high grade carbon black is in the order of $661/ton and low grade at $273/ton based on the historical import market [24]. The dominant carbon black products in the local market are supplied by Evonik Degussa, which has a local manufacturing plant in Port Elizabeth.

The main aim of this study is to develop an economic model in order to assess viability of pyrolysis technology as an alternative treatment method for waste tyres using Gauteng Province in South Africa as a case study.

II. METHOD

A process flow diagram presented in Fig.1 was developed for pyrolysis of waste tyres in Gauteng Province, South Africa as a benchmark to model the economic feasibility of this technology in South Africa. Gauteng is the smallest province in South Africa, with only 1.5% of the land area but it is highly urbanised and contributes up to 33.9% South African Gross Domestic Product (GDP) valued at R811billion and Johannesburg and Pretoria are located therein. As of 2011, it has a population of nearly 12.3 million (25% of SA population), making it the most populous province in South Africa (Lehohla, 2012). Gauteng province consists of 3 main municipalities which are City of Johannesburg (CoJ), Ekurhuleni (Ekh) and City of Tshwane (CoT) with a total 134,922 tons per annum (tpa) waste tyre generation. The waste tyre distribution and estimated number of tyre pyrolysis treatment plants for each municipality is shown in Table 3 as per population index. Based on the statistical data presented in Table 3, a total of 14 tyre pyrolysis plants each capable of treating 30 tons per day waste tyre/rubber material will be required to handle the waste tyres in Gauteng province.

TABLE III
WASTE TYRE DISTRIBUTION IN GAUTENG PROVINCE, SOUTH AFRICA [25].

Municipality	Distribution	Waste Tyre Generation	No. Plants
CoJ	36.8%	49,651 tpa	5
Ekh	26.8%	36,159 tpa	4
CoT	21.1%	28,333 tpa	3
Other	15.3%	20,779 tpa	2

A. Process Description

The waste tyres will be delivered by an approved waste tyre distributor to a permitted treatment facility where the total mass will be recorded at the weigh bridge facility. The tyres will be offloaded, classified according to size, brand and quantities and stockpiled in accordance to the environmental permitting condition. This system will allow the treatment facilities to have full record of all the tyres treated in terms of their class, size, manufacture and brand.

The tyre rings will be trimmed and cut into halves to extract the reinforcement high tensile steel using a mechanical steel extractor. The steel cords will be baled and sold as a recyclable product. These trimmed tyres will undergo mechanical shredding whereby approximately 10-15mm rubber chips will be produced. The shredded rubber chips will be steam washed, dried and stockpiled before they are fed into a pyrolysis reactor vessel. The steam will be generated using excess heat from the diesel generator set as shown in Fig 1.

The reactor vessel will be initially heated using gas or fuel burners, this heat up the enclosed rubber chips in absence of oxygen to temperatures of about 570^{o}C until gasification occurs. The gasses will be contained and condensed to form Crude Heavy Fuel Oil (CHFO) which will be further fractionated in a distillation column to form light diesel equivalent Tyre Derive Fuel (TDF) and Heavy Fuel Oil (HFO) [26]. The HFO fraction will be blended with low sulphur commercial diesel fuel at 30:70 volume ratios to fuel a diesel generator-set that provides electrical power to all plant machinery. This approach is considered the most economical method for combusting high sulphur HFO since it allows exhaust emissions capture and chemical neutralisation into value added products. The emission from the generator set and reactor fuel burners will be contained and chemically treated through a gas absorption column to produce valuable products such as gypsum and sodium sulphite depending on the type of the alki-solution used. The waste heat rejected by the generator set and reactor cooling will be recovered though a heat exchanger for steam generation which will be used in the plant. Excess uncondensed gas from the process is recycled for process heating using gas burners and a portion of this will be compressed and used as a fuel for fork lift engines. At the end cycle, the reactor vessel is cooled and carbon black and steel remain as by-products. The steel will be baled and sold as a recyclable product whereas the crude carbon black will be further processed in a supper micro mill using process water to wash and facilitate wet grinding. The milled slurry product will be further classified and dewatered as a final product. Based on the waste tyre quantities in South Africa, 30 tons per day plant is considered reasonable for conducting a financial modeling study. A summary of mass balance for this plant is presented in Table V.

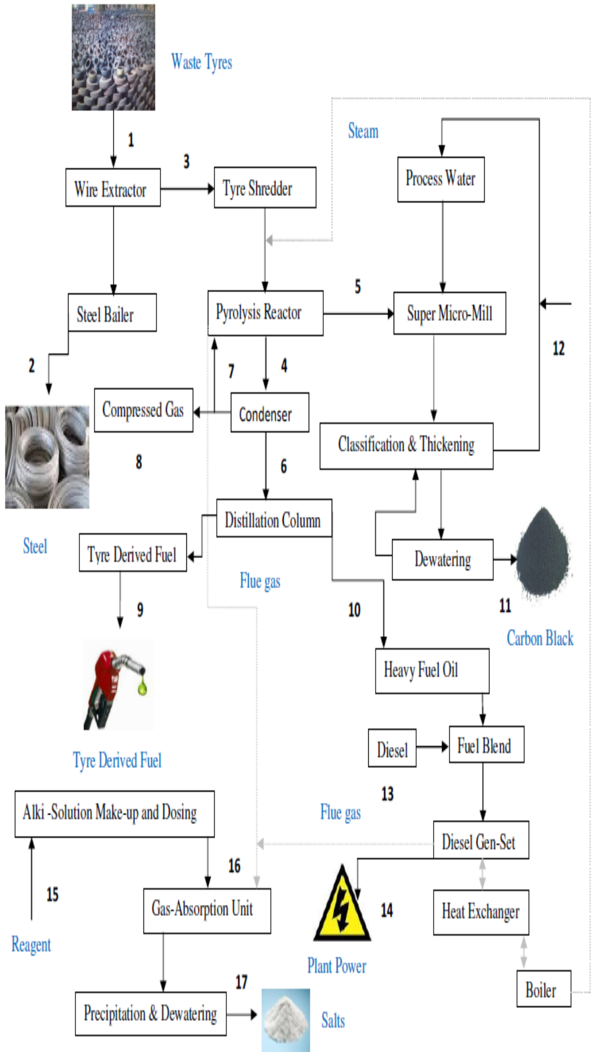

Fig. 1 Proposed Flow Diagram for Tyre Pyrolysis Process.

Table IV presents a costing summary of the proposed waste tyre pyrolysis plant capable of treating 30 metric tons per day of waste tyres. An appropriate process design and layout was considered taking into consideration the availability of waste tyres, environmental impact, product demand and market and applicability of the technology in South Africa. All mechanical and process equipment were specified to the required process duties and their respective electrical requirements and civil loadings. Costing was conducted by defining the most suitable process design specifying all the equipment in the flow sheet and requesting individual pricing from the equipment suppliers. Quotations were obtained from individual equipment suppliers to compile capital cost requirement consisting of material pre-treatment, processing and post-treatment equipment as well as engineering and other services required.

TABLE IV
WASTE TYRE TREATMENT PYROLYSIS PLANT COSTING

Description	**Cost US $**
Steel wire extractor	
Tyre shredder	
Diesel Generator Set	
Weigh Bridge	
Sub-Total Pre-Treatment	**$453,745**
Hot air Furnace c/w Heat Exchanger & Waste Heat Recovery Boiler	
Pyrolysis Reactor	
Gas Liquid Separation Tower c/w Flue Gas Treatment Tank	
Pumps & Tanks	
Interconnecting Pipes & Valves	
Control Unit	
Sub-Total Treatment	**$140,000**
Oil Distillation c/w Condenser	
Carbon Black Super Micro Mill	
Steel wire bailer	
Slurry Handling Plant, Thickener & Filter Press	
Sub Total Post -Treatment	**$2,004,000**
Total Equipment	**$2,597,745**
Environmental Impact Assessment	
Provision for Safety and Health Plan	
Site Establishment	
Structural Design and Plant Enclosure Construction	
Professional Services	
Civils design and Construction	
Electrical design and plant controls systems	
Installation	
Commissioning	
Supervision of installation & commissioning	
Project Management	
Sub Total Engineering & Services	**$1,135,957**
Total Plant Cost Installed	**$3,564,901**
Sub- Total Contingencies	**$534,735**
Total Capital Requirement	**$4,268,437**

TABLE V
MATERIAL AND ENERGY BALANCE FOR THE 30TPD PLANT

Stream	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Description	**Tyres**	**Steel**	**Tyres Chips**	**Pyrolysis-Gas**	**Crude Carbon Black**	**Crude Heavy Fuel Oil**	**Uncondensed-Pyrolysis-Gas**	**Compressed Pyro-Gas**	**Tyre Derived Fuel-Distilled**
Mass Flow (kg/h)	1,250	125	1,125	667	458	563	97	8	375
Volumetric flow (m^3/h)			0.9	834	1.32	0.63	69	6	0.465
Input Energy (kW)									
Mechanical	85	75	150			110			85
Heating/ Evaporation	89		467.8			120			
Cooling/ Condensation				-68	-99				
Output Energy(kW)									
Thermal				68	99				
Fuel							709.7	57.2	

Stream	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Description	**Heavy Fuel Oil**	**Refined Carbon Black**	**Process Water**	**Diesel Fuel**	**Gen-Set**	**Reagent Solution**	**Flue Gas**	**Sodium Sulphite**
Mass Flow (kg/h)	188	458	229	79	267	98	6,588	126
Volumetric flow (m^3/h)	0.22		0.23	0.09	0.31		13,065	
Input Energy (kW)								
Mechanical		367				15		
Output Energy(kW)								
Electrical					900			
Thermal					200			

B. Treatment Capacity

The technology offer modular pyrolysis reactors capable of treating up to 30 tons per day. Approximately 15 tons per cycle can be processed in a reactor; this will require 1 hour of loading, 4 hours processing and 3 hours of cooling and cleaning. Based on an 8-hour cycle, an average of 8 tons per day can be processed; this is equivalent to 3,750 passenger car tyres per day. The lead time for the supply of a complete pyrolysis plant is 6 weeks ex factory upon confirmation of order. Shipping by sea is approximately 6 weeks and another 11 weeks for installation and commissioning. In summary it will take approximately six months from date of order to an operating plant.

C. Utilities

The treatment plant will require process makeup water for the wet grinding of carbon black, cooling, washing and condensation of gasses to crude heavy fuel oil. This water will be connected onsite via an allocated point to the municipal water supply or process water if available; the daily make-up water required is approximately 11.28 m^3. The pyrolysis reactors will be heated using pyrolysis gas at a consumption rate of $69m^3$/h. Other components such as tyre cutter, shredder, mill drive, compressor plant, heaters, pumps, reactor drive unit as well as control mechanisms requires electrical power of 852.17 kW as presented in Table VI. Fork lift operation will be run by compressed pyrolysis gas at an average consumption rate of $6m^3$/h. The required plant power will be supplied by a generator set fuelled with a blend of diesel-HFO produced from the plant, excess thermal heat rejected from this generator will be capture through heat-exchangers and used for steam generation which will be used to wash and dry the tyres prior to pyrolysis. Electrical power back up will be allowed for general plant lighting. There will also be a consumption of sodium hydroxide (NaOH) to treat the flue gas from the generator set and burner flues gasses at 473 kg per day and cost of $1.36/ ton. Sodium sulphite precipitate resulting flue gas scrubbing is 3 ton per day which attracts a selling fee of around $20/ton.

TABLE VI
ENERGY REQUIREMENTS FOR A 30 TPD WASTE TYRE PYROLYSIS PLANT

Heating	677.15 kW
Mechanical Energy	852.17 kW
Cooling/Condensation	(366.56) kW
Plant Energy Requirements (combined)	**1,530.00 kW**
Energy Efficiency	**76%**
Available Fuel Energy	767 kW
Generator set Output	900.0 kW
Total Supply	1,666.8 kW

III. RESULTS AND DISCUSSION

This economic model was based on 5-year project life, 8-hour working shift for 3 shifts in a day and 25 working days per month as set out be the National Department of Labour. The model assumptions are summarised in Table VII. The plant units cost was based on South African Rand with an exchange rate of R10.30: US$1 (base date 10 July, 2013). A 100% senior debt funding was used with a total interest rate of 9% per annum to calculate the senior debt repayments taking into account company tax rate and value-added tax of 29% and 14% respectively. A straight-line depreciation method was applied over a 5-year period. Senior debt repayment of $1,159,477 was calculated over a 5-year debt repayment period at 9% per annum, as presented in Table VIII. An average inflation rate of 7.2% per annum was used to calculate the inflation indices of products, material and services. The costing also allowed for fixed and variable costs, including 5% per annum maintenance fee as a percentage of installed equipment cost, and a management fee of 3% per annum of revenue, as presented in Table X.

The figures presented in this study are order of magnitude estimates based on desktop studies. Detailed studies will be required for a more accurate costing exercise. Detailed cost calculations were conducted for a mobile plant of 30 ton waste tyres per day production capacity and with a total capital investment $4,268,437.00. This amount includes the equipment purchase consisting of the following equipment list as indicated in Table IV, environmental impact assessments (EIAs), Record of Decision (ROD), and site establishment. The expected revenue stream will be from variable end products such as refined carbon black, steel, and tyre derived fuel sodium sulphite. The operating costs as calculated in the model comprise labour requirement, input costs and plant equipment maintenance.

Four revenue streams were identified as tyre derived fuel, refined carbon black, high tensile steel and sodium sulphite. The recommended selling prices of the revenue streams presented in Table VIII were set at minimum and can be increased to increase profitability. The variable includes cost of diesel fuel at ($1.28/L), electricity at $0.13/kWh, process water ($0.34/m^3), bulk bags (US$4.87/ton) and sodium hydroxide ($1.36/ton) and the fixed cost includes equipment maintenance, insurance, and technical and operational staff as shown in Table IX.

Material and energy balances were conducted to quantify utilities and products on a yearly basis. These were linked to the input unit costs in order to calculate the actual treatment cost per unit mass of waste grease taking into account factors such as depreciation, debt repayments, fixed and variable costs. Fig. 2 represents the cash flow projections over a 5-year period, with revenue, total cost, free operating cash flow at 28.79% internal rate of return and 34.59% gross margin. Based on this costing, the plant will yield a positive free operating cash flow of $44, 147 between years 2 and 3 and the total treatment cost of $220/ton of waste tyres.

TABLE VII
ASSUMPTION USED AS A BASIS FOR MODELING

Description	Units	Value
Annual Working Hours	Hrs/yr	8760
Plant Estimated Downtime	Hrs/yr	1560
Plant Available Time	Hrs/yr	7200
Actual Plant Capacity	Ton/hr	1.25
Exchange Rate	R/$	10.3
Project Period	Yrs	5.0
Depreciation Period	Yrs	5.0
Capital Financing Period	Yrs	5.0
Bank Lending Rate	% per annum	6%
Margin on Investment	% per annum	3%
Debt	% capital	100%
Equity	% capital	0%
Bank Finance Fee	% on debt	2%
Actual Annual Production	Tons/yr	9,000
Available Plant Capacity	Tons/yr	10,950
Actual Production	Tons/day	30
Input Cost		
Cost of Bulk Bags per Ton Carbon Black	$/ton	4.87
Electricity Cost	$/KWh	0.13
Diesel Fuel Cost	$/L	1.28
Water Cost	$/ m^3	0.34
Cost of Sodium Hydroxide	$/ton	1.36
Power Requirement	kWh/hr	2,360
Electrical Power Consumption	kWh/hr	2.39
Diesel Consumption	m^3/hr	0.09
Water Consumption	m^3/hr	0.47
Output Cost		
Sale of Sodium Sulphite	$/ton	20.00
Sale of Tyre Derived Fuel	$/L	0.52
Sale of Refined Carbon Black	$/ton	273.55
Sale of Steel Wire Scrap Metal	$/ton	66.28

TABLE VIII
FINANCING SUMMARY OF 30 TPD WASTE TYRE PYROLYSIS PLANT

Period in years	5	
bank lending rate	6.0%	
Margin on investment	3.0%	
Total rate	**9.0%**	
Financing Period (yrs)	**0**	**1…n=5**
Advanced (US $)	$ 4,137,579	-
Repaid (US $)		($ 1,159,477)
Interest portion(US $)	$ 372,382	$ 405,897
Cash flow - Senior debt (US $)	-	($ 1,159,477)
Capital outstanding (US $)	**$ 4,509,962**	**$ 3,756,381**

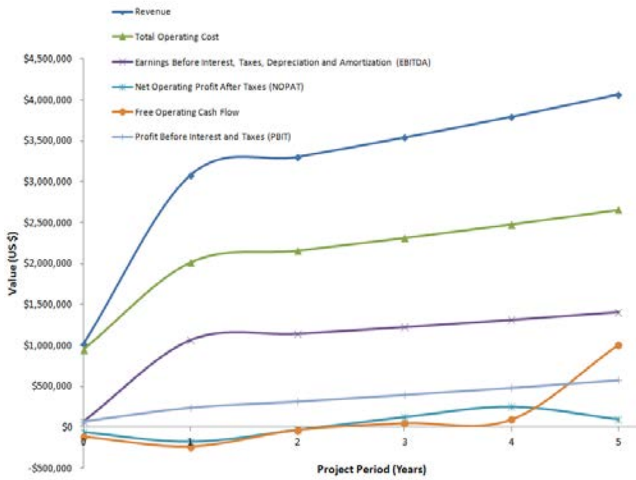

Fig.2: Cash Flow Projections for a 30 tpd Waste Tyre Pyrolysis Treatment Plant

TABLE IX
REVENUE SUMMARY OF A 30 TPD WASTE TYRE PYROLYSIS TREATMENT FACILITY

Period -Yrs	**0**	**1…n=5**
Sale of tyre derived fuel		
	$ 516 /m^3	$ 553 / m^3
	$ 557,895	$ 1,852,736
Sale of refined carbon black	$ 273/ton	$ 293 /ton
	$ 360,720	$ 966,720
Sale of Sodium Sulphite	$ 20/ton	$ 21 /ton
	$ 7,284	$ 19,521
Sale of steel wire scrap metal	$ 66 /ton	$ 71/ton
	$ 23,860	$ 63,944
Total Revenue	**$ 1,014,475**	**$ 3,076,370**

The earnings before interest, taxes, depreciation, and amortisation (EBITDA) of a project give an indication of the operational profitability of the business. It is defined by considering a project's earnings before interest payments; tax, depreciation, and amortization are subtracted for any final accounting of its income and expenses [22]. Depreciation is often a very good approximation of the capital expenditures required to maintain the asset base, so it has been argued that EBITA would be a better indicator. The gap between the project revenue and total operating cost represents the gross margin. A uniform increase on the revenue, EBITDA and operating cost (OPEX) is observed, and this is influenced by the fact that year 0 consisted of plant construction, installation and commissioning, resulting in reduced plant utilisation. A slight uniform annual increase in PBIT, EBITDA, OPEX and Revenues is linked to the 7.2% annual inflation rate used in the model. A common trend between the free operating cash flow and net operating profit after tax (NOPAT) is observed during the first three years of the project. A positive free cash flow is realised in year 3, which attracts income tax, resulting in reduced NOPAT. Between years 4 and 5 there is a steep increase in free operating cash flow and a rapid decline in NOPAT as a large portion of the positive cash flow is exposed to income tax. It is expected that there will be a steadily growing NOPAT and stable free operating cash flow immediately after year 5 due to an end cycle of the senior debt repayment. Fig. 2 shows a great investment potential in waste tyre pyrolysis technology, since the raw material is a waste material and can be procured at no cost. A debt-equity funding structure can also be considered whereby international technology suppliers and investors can provide a debt portion of the investment at an agreed return.

TABLE X
OPERATIONAL COST ESTIMATION ON 30 TPD WASTE TYRE PYROLYSIS PLANT

Period (Years)		**0**	**1….n=5**
Fixed Cost			
Maintenance	5.0%	-	$ 221,774
Total annual Salaries		$ 352,593	$ 683,212
Supervisors two (2)	$ 237,277	$ 118,638	$ 254,360
Shift Operators nine (9)	$ 332,187	$ 166,094	$ 356,105
Admin Assistant	$ 46,506	$ 46,506	$ 49,855
Cleaners	$ 21,355	$ 21,355	$ 22,892
Total Salaries	$ 637,325		
Management fee	3%	$ 29,054	$ 88,591
General Overhead		$ 214,725	$ 76,117
Auditing Fees	$ 1,754	-	$ 1,881
Security	$ 5,847	$ 5,848	$ 6,269
IT	$ 6,549	-	$ 7,021
Insurance	1%	$ 41,376	$ 44,355
Signage & Postage	$ 389	-	$ 418
Stationery	$ 584	$ 292	$ 627
Legal Fees	$ 2,144	$ 2,144	$ 2,299
Furniture	$ 17,543	$ 17,544	-
Power Connection fee	$ 11,695	$ 11,696	-
UIF & Skills Levy	1%	$ 3,526	$ 6,832
Entertainment	$ 409	-	$ 438.83
Recruitment	20%	$ 127,465	-
Telephone	$ 584	$ 585	$ 627
Travel & mileage	$ 3,508	$ 3,509	$ 3,761
PPE	$ 1,481	$ 741	$ 1,588
Sub-Total Fixed Cost		**$ 596,372**	**$ 1,069,694**
Variable Cost			
		$ 0.13/kWh	$ 0.14/kWh
Electricity cost		$ 888	$ 2,380
		$ 1.28/L	$ 1.37/L
Diesel cost		$ 343,592	$ 920,825
		$ 0.34/m^3	$ 0.37 / m^3
Water cost		$ 460	$ 1,233
		$ 1.36 /ton	$ 1.46/ton
Sodium Hydroxide Cost		$ 77	$ 207
		$ 4.87/ton	$ 5.22 /ton
Bulk Bag Cost		$ 6,426	$ 17,223
Sub-Total Variable Cost		**$ 350,555**	**$ 939,488**
Total Treatment Cost		**$ 268 /ton**	**$ 223 /ton**

Approval of the REDISA Integrated Waste Tyre Management Plan (IWTMP) by the national Minister of Environmental Affairs in terms of the Regulation 6 (3) of the Waste Tyre Regulations and in accordance with the National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008) allows REDISA to be in a position to collect up to $88.9 million per annum in the form of a tyre levy in order to support local entrepreneurs in waste tyre recycling initiatives such as pyrolysis and crumbing with the aim of job creation, human capacity building and environmental management. Gauteng Province requires a total capital investment of $59.8 million to erect 14 of the 30-tons-per-day treatment facilities across four major municipalities in the province.

IV. Conclusion

Waste tyre pyrolysis technology is one of the proven technologies that can be applied as an alternative method for the treatment and disposal of waste tyres and rubber products. The use of crude tyre derived fuel as a direct fuel for any combustion system is not recommended due to the high level of contamination and high sulphur content. Refining of crude tyre derived oil through a de-sulphurising distillation process is important in ensuring the production of clean low-cost fuel. Carbon black post-treatment via super micro-milling and classification helps to produce various grades of high quality carbon black for the local and export market. The heavy fuel fraction of the distillate can be used only with a low sulphur diesel blend in stationary combustion units such as generator sets and boilers fitted with emission neutralization systems. The refined tyre derived fuel is suitable for use in conventional diesel engines with blends of up to 1.5:1 volume ratio, tyre derived fuel-diesel. Chemical treatment of flue gases from the combustion of heavy fuel oil results in the production of valuable sodium sulphite. The application of pyrolysis technology to the treatment of waste tyres was found to be economically feasible when considering a 30 tpd plant capacity with a required capital investment of US $4.27 million with a potential investment return and gross margin of 29.79% and 34.59%, respectively. These facilities will produce an alternative 46.8 million litres per annum of refined tyre derived fuel for application in diesel engines at the cost of $0.516/litre and other secondary value-added products for local and export markets. This use of this alternative fuel by the municipalities will not only reduce the fuel bill, but offset the dependency on fuel derived from natural resources such as petroleum oil. This fuel can be used as diesel additive by municipal-owned public transport such as buses, waste collection vehicles, and generator sets to run municipal waste water works and pump stations. There is no doubt that the availability of waste tyres and the product off-take market are the key drivers for the successful operation of waste tyre pyrolysis technology.

Acknowledgment

The authors are grateful to the National Research Foundation of South Africa, Departments of Mechanical and Chemical Engineering for supporting the research. The authors are also indebted to the Faculty of Engineering and the Built Environment of the University of Johannesburg for conference support. The authors are also grateful for the assistance provided by Prof. Craig McKenzie in language editing and manuscript proof reading.

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