Using Tyre Derived Fuel: An Analysis of the Benefits

Nhlanhla. Nkosi, Edison. Muzenda, and John. Zvimba

Abstract**—**This paper discusses the socio – economic and environmental benefits of using waste tyre derived fuel. . The paper outlines the uses of waste tyres as an alternative source of energy and various applications that have been implemented internationally, and use these as bench marks for possible solutions in the South African waste tyre problem, as the country gradually adapts to the waste to energy initiatives through governmental, communities and private sector efforts. The method used to compile this paper includes using a triangulation method, which involves literature analysis, site visits and telephonic interviews

Keywords**—**Recycling Markets, Socio-Economical Benefits, Tyre Derived Fuel, Waste Tyres.

I. Introduction

CURRENTLY South African is facing energy and waste challenges. The government and private sector are under pressure to find effective and sustainable remedial measures to these problems. South African policy makers have long been aware that the country was facing impending power shortages. The 1998 White Paper on Energy Policy warned that power shortages would become evident by 2007 and that to avoid a situation of demand exceeding supply, a decision on supply-side investments would need to be made by the end of 1999 [1]. Despite having been forewarned, South Africa now finds itself in a situation of power shortages, load-shedding and power rationing.

The 2012 National Waste Information Baseline Report [2] suggests that in 2011, 108 million tonnes of waste was generated with 55 % being general waste, 1% hazardous waste and the remainder belonging to the unclassified waste class, 90% of this waste was landfilled with only 10 % being recycled. Waste tyre recycling contributed 4% in waste recycling [2]. However, there are possible corrective measures, such as waste to energy initiatives, which can be used to address both waste and energy challenges. This paper outlines the various waste tyre to energy applications utilized by the United States of America (USA) and European countries, and also discusses the benefits of some of these applications in the South African context.

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II. Energy Usage in South Africa

Globally, the rise in individual incomes and population growth is increasing energy demands. This places increasing pressure on both energy supply and the price. Rising international oil prices as well as local transport demands combined with escalating up stream processes (refining and extraction) signals the end of cheap oil.

In early 2008, South Africa experienced a shortfall in power generating capacity which resulted in wide spread power shortages. General awareness and understanding of the value of energy in South Africa has generally been lacking in the past due to historical low energy costs in the country [3].

The primary energy source in South Africa is coal as shown in Fig 1. Based on Fig 1, there has been an inconsistent coal usage pattern over the years, with a significant decline from 79% in 2000 to 71% in 2009. The inconsistency in coal usage was mainly driven by the demand of energy in 2000 from the different sectors as shown in Fig 2. In this regard, both industrial and transport sectors use a significant amount of energy. They also had the highest energy usage during the 2000 financial year compared to other years, thus increasing coal usage. Based on data given in Fig 1 an indication of South Africa's slowness in using alternative energy sources is clearly highlighted, showing the country's great dependence on coal. Since the usage of coal as a source of energy results in serious health and environmental problems, it is imperative that the country must start investing on alternative cleaner sources of energy.

Progress has been made with a range of energy efficiency initiatives such as the South African National Energy Development Institute (SANEDI); a Schedule 3A state owned entity that was established as a successor to the South African National Energy Research Institute (SANERI) and the National Energy Efficiency Agency (NEEA). The key function of SANEDI is to direct, monitor and conduct applied energy research and development, demonstration and deployment as well to undertake specific measures to promote the use of green energy and energy efficiency in South Africa.

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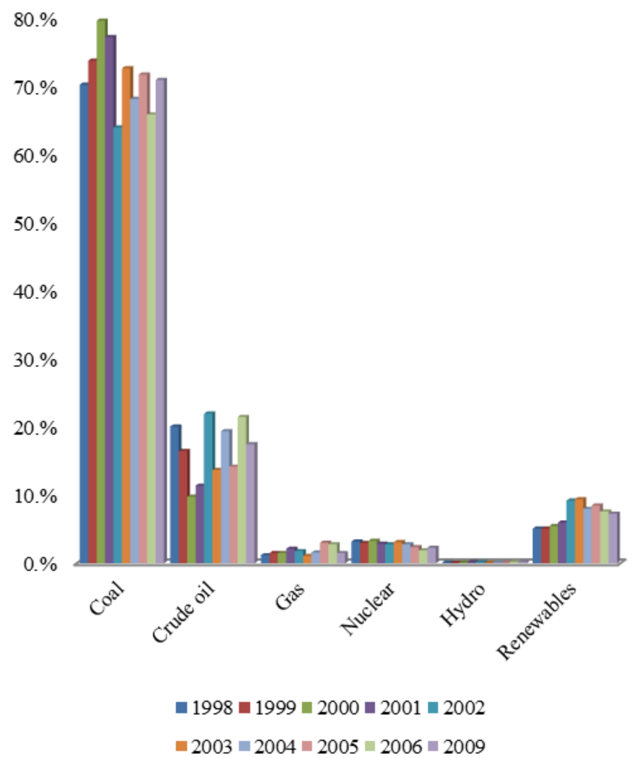

Fig. 1 Primary energy supply in South Africa1998-2009 [4]

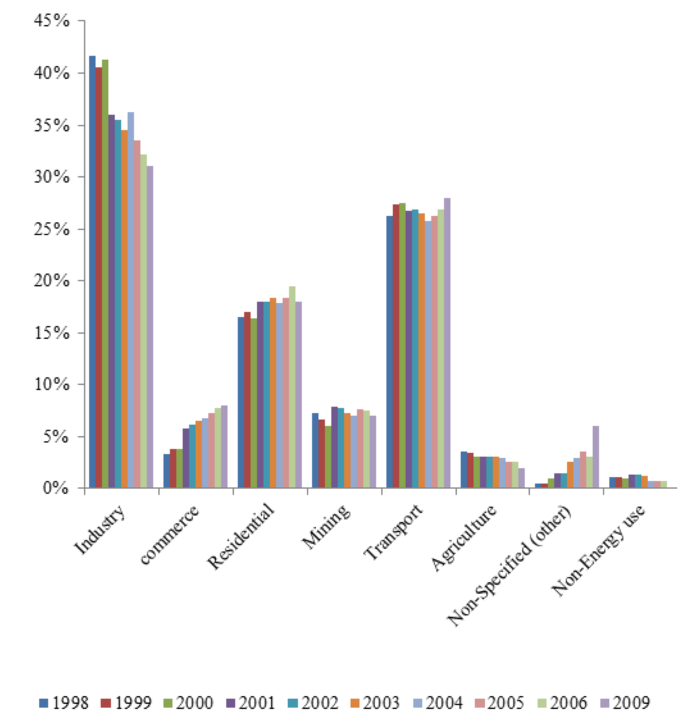

Fig. 2 Energy usage by sector 2006-2009 [4]

SANEDI is involved in numerous institutional research projects and programmes in green energy engineering. This will promote South Africa's development, increase human capacity and eventually lead to commercialization of the intellectual property. Other projects include the Industrial Energy Efficiency Improvement Project, South Africa; the Energy Efficiency Target Monitoring System (EETMS) and the South Africa Germany Energy Project (SAGEN)

Government has promulgated regulations and published supporting documents, namely; green papers; white papers; bills; acts and regulations; international agreements and obligations; guidelines and policies; gazetted notices to aid in the protection of the environment as well as the country's natural resources . For the past ten years extensive research, development and demonstration has been done with the key focus being on research with respect to new technologies as well as the adaptation or evaluation of existing technologies for specific South African conditions such as high unemployment rate. Some of these initiatory steps entail the conversion of waste into valuable and profitable products. Waste to energy processes recover energy in the form of heat and fuel from waste sources. The aim of these initiatives, besides job creation and generating income, is to reduce the volumes of waste going to landfills. Two different methodologies are utilised for this process, namely thermal and no-thermal technologies as shown in Table 1.

TABLE I
WASTE TO ENERGY TECHNOLOGIES

Thermal technologies	Non-thermal technologies
Gasification	Anaerobic digestion
Plasma arc gasification	Fermentation production
Pyrolysis	Mechanical biological treatment(MBT)
Thermal depolymerisation	a) MBT+ Anaerobic digestion
	b) MBT to Refuse derived fuel

Waste tyres have the potential to be utilised as energy source as well an alternative petroleum fuel source. Pyrolysis and gasification are some of the technologies which can be employed to achieve this objective. Waste tyres have become a problem to dispose of due to their non-biodegradable nature and lack of markets of their recycled goods. The waste tyre recycling industry has proven to be unsuccessful in South Africa with only a 4% waste tyre recycling rate being experienced in 2011 and lower in the previous years' [2]. Recycling of waste tyres has the potential to address both environmental and energy challenges as well as contributing to economic growth. The South African government recognizes the conversion of waste to energy in its plans and future strategies [5]. A waste tyre management plan such as the gazetted REDISA Plan, which is awaiting implementation, is expected to address the problem at national level.

III. Tyre Derived Fuel (TDF) Applications

Scrap tyre markets are mature and stable in most developing countries such as the USA. Scrap tyres are recognized as abundant valuable resources and are used in a number of applications, including tyre derived fuels or products. Generally, in South Africa the market for tyre-derived products is much larger than the market for liquid products, such as oil. As given in Table II [6] showing the calorific values for common fuels, TDF has a higher heating value than both coal and wood.

TABLE II
CALORIFIC VALUES OF COMMON FUELS

Fuel	Calorific Value (MJ/kg)
gas	84.7
diesel oil	45.5
scrap tyres	32.5
coal	30.2
coke	26.7
wood	12.4

The following are the existing TDF applications that have been successfully implemented elsewhere, and these can be used as bench marks for the South African scenario in dealing with the waste tyre problem in a beneficial way.

A. Cement Manufacturing

Tyres can be alternatively utilized in cement kilns and power plants. The use of scrap tyres in cement kilns is increasing and is by far the leading thermal technology used for scrap tyres management [7]. When the complete ban of tyres to landfill came into effect in 2006 for most European countries, the use of tyres in cement kilns increased and this was further strengthened by the increase in fossil fuel prices [8]. Most of the leading cement companies such as Lafarge, Holcim, Cimpor, Heidelberg, Taiheiyo, Italcementi, Aalborg Portland, and Castle Cement have plants around the world that are currently co-combusting tyres [7]. Lafarge Cement's overall manufacturing capacity is in excess of 6 million tonnes per annum in the UK with 40% accounting for their domestic market in 2003 [9]. Scrap tyres along with other alternative fuels, such as recycled liquid fuels, form the mainstay of Lafarge Cement's UK strategy to increase its waste tyre utilisation as an alternative source of energy from less than 3% in 1999 to an excess of 20% by 2006 [10].

Local cement companies such as Pretoria Portland Cement (PPC) are also in the investigation stages of incorporating waste tyres as part of their fuel source. This proposed project is however still in the initial stages with full scale implementation expected early 2014 [11].

Cement manufacturing companies use whole tyres and TDF to supplement their primary fuel for firing cement kilns. Several characteristics make scrap tyres, either whole or shredded, an excellent fuel for the cement kiln. The very high temperatures and long fuel residence time in the kiln allow complete combustion of the tyres, without the production of odours or emissions during the combustion process. The ash forms part of the final product and hence there is no waste. The steel component replaces the iron required in cement manufacturing.

The use of tyres in cement kilns results in higher production rates, lower fuel costs and improved environmental quality, considered as advantages, while the only disadvantage is the possible emissions of carbon dioxide (CO_2)[8].

B. Pulp and Paper Industry

The pulp and paper industry uses tyre-derived fuel as a supplement to wood waste, the primary fuel used in pulp mill boilers. The technology has been in continuous use in the United States since the early 1980s. The heating value of the wood waste fuel ranges from about 8,334.5 to 9,495 kJ/kg on a dry basis. Tyres facilitate uniform boiler combustion, and help overcome some of the operating problems caused by fuels with low heat content, variable heat content and high moisture content. The consistent heating value, low moisture content of TDF and its low cost in comparison to other supplemental fuels make TDF an attractive fuel in the pulp and paper industry. One of the key advantages for using TDF in the pulp and paper industry is that it reduces emissions and increases combustion efficiency. It also lowers energy costs and improves product quality [12].

citations consecutively in square brackets [1]. The sentence punctuation follows the brackets [2]. Multiple references [2], [3] are each numbered with separate brackets [1]–[3]. When citing a section in a book, please give the relevant page numbers [2]. In sentences, refer simply to the reference number, as in [3]. Do not use "Ref. [3]" or "reference [3]" except at the beginning of a sentence: "Reference [3] shows ...." Unfortunately the **PSRCENTRE** document translator cannot handle automatic endnotes in *Word*; therefore, type the reference list at the end of the paper using the "References" style.

C. Industrial Boilers

In industrial boiler application, combustion of tyre TDF generates energy in the form of steam and/or electricity, replacing other fuels such as coal. This also reduces pollution. TDF combusted industrial boilers emit less oxides of sulphur and nitrogen compared to coal. TDF operated systems offer higher heating value, lower emissions, competitive cost, and ability to create stable operating conditions in the boilers. This makes the use of TDF attractive in power generation. However, TDF is not compatible with all boilers as clumping and clogging can also occur. Also, if the metal in waste tyres is not recovered, it causes disposal challenges.

Countries like USA have had successful and growing tyre derived fuel applications as shown in Fig. 6. The cement kiln as well as the pulp and paper industry has seen the most significant growth due to the favourable benefits such as cost saving, high heating values, low moisture content and minimal emissions that TDF offer. Developing countries, such as South Africa can adapt the same strategies to deal with their increasing waste tyre problem.

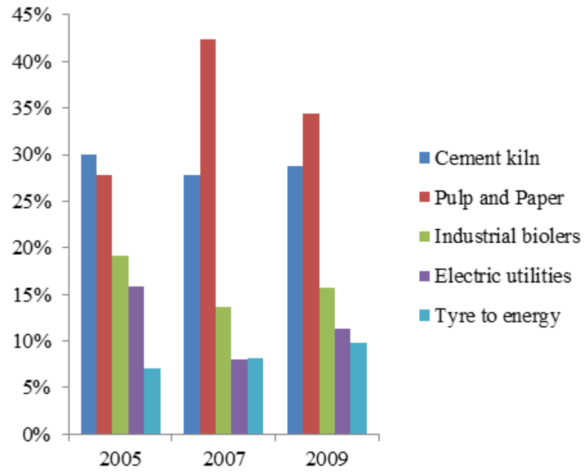

Fig. 3Tyre derived fuel trends in USA

D. Tyres-to-Energy Facilities

The vast quantities of worn-out tyres discarded every year are a source of renewable energy. This potential is wasted when waste tyres are landfilled, taking up valuable air space and posing environmental challenges. The conversion of waste tyres into valuable energy is being highly considered in developing countries such as South Africa. Tyres have high energy value, hence pyrolysis and electricity generation.

There are 544 waste-to-energy plants in Europe while there are 86 recorded in the United States in 2012 [13],as given in Fig. 4.

In South Africa, both the government and the private sector are involved in small waste to energy initiatives. In this regard, the government has proposed the utilisation of landfill gas at Durban's Bisasar Road Landfill Site. Bisasar Road is Africa's largest landfill site, and one of only three landfill sites in Durban with a full permit [14]. The Bisasar Road waste management facility includes an active landfill which accepts up to 3,300 tonnes of all types of waste per day. The project involved the installation of spark ignition engine generators to generate 4 MW initially increasing to 6.5MW at present. There is the potential to expand this capacity to 8MW in the coming years [15]. In addition to government participation, there are individual companies such as Carbon Consult & Engineering which convert solid Bio-mass fuels to produce tar-free gas for electricity generation and / or heating applications. The biogas plant is self-contained, efficient and reliable alternative source of convenient energy. It is one of the most cost-effective solutions to uplift non-grid and remote areas, where it may be difficult to obtain liquid fuels or where the costs thereof are too high, but where bio-mass material is readily available. Currently existing systems range from 120 to 850 Norm Cubic Meter tar-free gas production per hour, producing 50 to 400 kVA electricity [16]. A growth in such projects and initiatives will aid in the reduction of coal utilization as South Africa's main power source.

This will also create competitiveness among power generating ventures, thus giving the country various options of power generation.

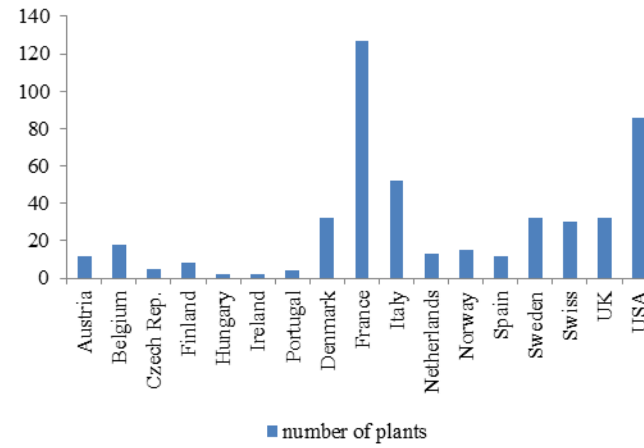

Fig. 4Waste to energy plants across developed countries [13]

The TDF market is expected to grow further with the development of standard specifications. These facilitate the standardization of product, lower emissions compared with traditional fuels such as coal, rising energy costs of traditional fuels as well as increased acceptance of TDF. However, environmental groups have adopted a hostile attitude towards TDF [17]. In addition, natural gas is becoming a major competitor and these two factors could slightly hamper growth prospects. With improvements in recycling rates, establishment of a formal waste tyre industry structure and government initiatives, demand from end use-markets looks set to grow further.

IV. Waste Tyre Pyrolysis Markets

Over the last two decades there has been a growing interest in using tyre-derived fuels. Initially this interest was driven by concerns for potential shortages of crude oil, but in recent years the ecological advantages of alternative fuels have become an even more important factor. Tyre derived-oil can be easily transported and stored. However, the properties of waste tyre-oil also result in several significant problems during its use as a fuel in standard equipment such as boilers, engines and gas turbines. Poor volatility, high viscosity, coking, and corrosiveness are probably the most challenging and have so far limited the range of its applications [18].

A. Tyre Derived Oil Applications

Waste tyre pyrolysis produces gaseous products such as synthesis gas. This gas can be used for fuel, electricity, and chemicals. PGL systems can generate an oil-based liquid containing up to 30-50 % of the tyre feedstock [19].

Chemical feed stock: Pyrolysis of waste tyres produces gases such as benzene; toluene and xylenes which are very important chemicals. They are used as primary feed stocks to produce plastics, resins, fibres, surfactants, dyestuffs and pharmaceuticals, and long-chained alkyl benzenes that can be used as surfactants. Xylenes are important industrial chemicals. O-Xylene is used as a phthalic anhydride to produce plasticizers and dyes, m-xylene derivatives are used on polyesteric resins and fibre industries and p-xylene derivatives on polyesteric fibres as well. Toluene has a wide range of applications and it is mostly used for pesticides, dyestuffs, surfactants and solvents production [20].

Industrial and commercial: The liquids obtained are dark brown coloured products, resembling petroleum fractions. The main oil product produced by pyrolysis technology is the fuel oil that is widely used for industrial and commercial purposes [18]. Pyrolysis of scrap tyres produces oil that can be used as liquid fuels for industrial furnaces, foundries and boilers in power plants due to their higher calorific value, low ash, residual carbon and sulphur content. Pyrolysis oil is an effective substitute for diesel, heavy fuel oil, light fuel oil or natural gas in industrial, commercial and residential boilers. Furnaces and boilers are devices commonly used for heat and power generation. They are usually less efficient than engines and turbines but they can operate with a great variety of fuels ranging from natural gas and petroleum distillates to sawdust and coal/water slurries and oil seems. For a fuel to be suitable for boiler application, it should have consistent characteristics, provide an acceptable emission level and be economically feasible.

Use as automobile fuel: High viscosity, delayed ignition time, lower heating value, corrosion and solid content hinder the utilization of pyrolysis oil in combustion devices. Work has been done on the improvement of pyrolysis oil for use in modern combustion devices [21, 22, 23, 24 and 25]. This research has found that pyrolytic oils require preliminary treatments such as decanting, centrifugation, filtration, desulphurization, and hydrotreating before use as fuels. not singular.

Bi-fuelling or blending: Viscosity and sulphur content of crude TDO influence engine performance and emissions, hence affect the use of tyre derived pyrolysis oil as a blending fuel. The high viscosity of the fuel leads to problems over time such as carbon deposit. The high carbon residue content and high viscosity arise from large molecular mass and chemical structure of the oil. The high carbon residue is responsible for heavy smoke emissions. The treated pyrolytic oil could be used alone or blended with other fuels such as CIMAK-B10 diesel fuel, which is basically 10% biofuel and 90% fuel [26]. The addition of pyrolytic oil to this kind of diesel fuel reduces the viscosity of the resulting blend. Consequently, the atomization will be improved, ensuring a complete burnout of the fuel. Based on its fuel properties, tyre-derived pyrolytic oil can be considered a valuable component for use with conventional fuels.

B. Tyre Derived Oil Applications

Studies have reported the possibility of using the tyre char as a substitute of industrial grade carbon black (CB) which is more economical compared to carbon black produced primarily from petroleum. Basically, the two main uses of tyre chars are reinforcing filler and an adsorbent. Activated carbon is used extensively as an adsorbent for the removal of contaminants in the treatment of water and wastewaters.

Commercial activated carbon derived from carbonaceous material such as various ranks of coal (peat, lignite, bituminous and anthracite) and wood are relatively expensive and the manufacturing requires intricate activation procedure to generate well defined surface properties [27]. It is therefore necessary to consider other carbonaceous waste materials abundantly available, such as waste tyres.

90% of the CB produced in the world is used for rubber compounding with the tyre industry making up to 70% [28]. Most of the carbon black is manufactured to meet specific requirement and demands a high price. Commercially produced CB is in the form of fluffy powder, which consists almost entirely of elemental carbon. The size and shape of the CB aggregates are principal features that influence the performance of the material as a reinforcing agent. Some of the properties of the CB that are used to characterize and grade the material are particle size, surface area, aggregate size and aggregate morphology. The CB used in the rubber industry contains over 97% elemental carbon whilst specialist application CBs may contain over 99% carbon. Table 3 shows the various grades of carbon black and their applications.

TABLE III
GRADES, PROPERTIES AND USES OF CARBON BLACK [29]

Type	ASTM	Average particle diameter (nm)	Primary properties and uses
Super abrasion	N110	17	High reinforcement; used in special and off-road tyre products for which high abrasion is required.
Intermediate Super abrasion	N220	21	High reinforcement and tear strength, used in passenger, off-road and special tyres for which good abrasion resistance is required.
High-abrasion	N330	31	Medium-high reinforcement, low modulus, high elongation, good flex, tear and fatigue resistance; used in tyre tread, carcass and sidewall compounds, motor mounts, weather mounts, weather-stripping and bicycle tyres
Fast-extruding	N550	53	Medium-high reinforcement, high modulus and hardness, low die swell and smooth extrusion; used in tyre inner liners, carcass and sidewall compounds and hose and other extruded goods
General purpose	N660	63	Medium reinforcement and modulus, good flex and fatigue resistance, low heat build-up; used in tyre carcass, inner liners and sidewalls, sealing rings, cable jackets, hose and extruded goods
Semi reinforcing	N762	110	Medium reinforcement, high elongation and resilience, low compression set; used in mechanical goods, footwear, inner tubes and floor mats
Medium	N990	320	hysteresis and tensile strength, high elongation and loading capacity; used in wire insulation and jackets, mechanical goods, footwear, belts hose, gaskets, O-rings and tyre inner liners

Traditionally, carbon black has been used as a reinforcing agent in tyres. Nowadays, as a result of its unique properties, its uses have extended to pigmentation, ultraviolet (UV) stabilization and conductive agents. It is used as a conductive agent in high performance products such as tyre and industrial rubber products, high performance coatings, inks, activated carbon and briquettes.

Tyre and Industrial Rubber Products: Carbon black act as both a filler and as a strengthening or reinforcing agent, in rubber products such as tyres. It is used in inner-liners, carcasses, sidewalls and treads depending on specific performance requirements. Carbon black is also used in many industrial rubber products, such as belts, hoses, gaskets, wiper blades and conveyor wheels.

High Performance Coatings: Carbon black provide pigmentation, conductivity, and UV protection for a number of coating applications such as in automotive (primer basecoats and clear coats), marine, aerospace, decorative, wood, and industrial coatings.

Inks: Carbon black for pigmentation contains more oxygen than normal carbon black to improve the dispersion and flow characteristics. Carbon black enhances formulation and flexibility in meeting specific colour requirements. Carbon black has higher tinting strength than iron black and organic pigments. It is widely used for paints as well as newspaper, printing and India inks.

Activated Carbon: Activated carbon is a collective name for a group of porous carbons, which are manufactured either by the treatment of carbon with gases or by the carbonization of carbonaceous material with simultaneous activation by chemical treatment. Activated carbon can be prepared from many carbonaceous materials such as municipal and industrial wastes [30 and 31], forest and agricultural by-products [32 and 33]. Waste tyres are a source of activated carbon because of their high carbon content. Several studies have reported on the production of activated carbon from waste tyres [30, 31, 34 – 40]. Table 4 shows the various types and size of activated carbon as well their applications.

TABLE IV
Various Activated Carbon Applications and Sizes

Type	Average size	Application
Powder	>100mm (diameter 15-25 mm)	Liquid phase applications
		Flue gas treatment
Granular	0.5 - 4.0 mm diameter	Gas phase application
		Water treatment
Pellet	4-7 mm diameter, 5-15mm length	Gas phase application

Briquettes: Briquettes are a block of flammable matter used as fuel to initiate and preserve a fire. Briquettes have a wide variety of uses from household to industrial applications. This type of fuel has not been fully exploited as fuel has been abundantly available in the past. However, with the current fuel shortage and rising prices, government, private sector and communities are searching for affordable alternative fuels such as briquettes. Briquettes can potentially offer the following benefits over traditional fuels (firewood and charcoal); uniformity and standardisation, can be tailored to a particular usage, namely long burning time, stove types, smoke and ash levels among others as well as the fact that they are economically cheaper than coal, wood and other fuels, particularly if they are made from waste materials such as waste tyres.

Two key markets for briquettes are likely to be households and small scale industrial applications. The household market comprises of individual consumers who need fuel for cooking and heating. Briquettes can be a great substitute for charcoal and coal. Key benefits include reducing household fuel bills and long-lasting burning. The industrial market can use briquettes for small scale energy requiring processes. Briquettes can be more economical, healthy and environmentally friendly.

The briquettes are particularly recommended for boilers (steam generation), food processing industries (distilleries, bakeries, canteens, restaurants and drying), textile process houses (dyeing and bleaching), agro-products (tobacco curing, tea drying, oil milling), clay products (brick kilns, tile making, pot firing) and domestic cooking and water heating [41].

C. Tyre Derived Steel Wire Applications

There are limited studies on the application of scrap steel produced from waste tyre pyrolysis. It is believed that the scrap steel would be similar to its original quality if the pyrolysis temperature is kept below 600^{o}C. Whereas, increasing the pyrolysis temperature would cause damage to the steel due to carbonization or other possible chemical reactions [18]. Scavengers recover steel wire from waste tyres and sell to recyclers for income.

V. CONCLUSION

International trend show that other options for waste tyre utilization exist besides landfilling. These waste to energy options can address both environmental and energy challenges. As a positive outlook, South Africa is also on trend in considering some of these methodologies for the amending of its energy shortage, with support from both the government and private sector.

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