End-of-Life Tire Management – Mini Review

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Executive Summary

Whether End-of-Life Tires (ELT) are considered a waste or a resource, they represent a serious problem to be solved world-wide. New Zealand has the third highest rate of car ownership in the world and therefore one of the highest rates of ELT generation on a per capita basis. Of the estimated 6.5 million ELT generated every year they have for the most part occupied precious space in landfills, been used on silage piles and littered the landscape and even waterways. NZ's first regulated tire stewardship scheme (Tyrewise) came into existence in 2022 and it seeks to account for, collect and find solutions for the ELT problem. Since about March of 2021 many of the tires that have been collected from throughout NZ have been used as a fuel substitute to fire cement kilns at Golden Bay Cement Works. At the cement works ELT are simply burned to produce heat to manufacture cement clinker which requires temperature of about 1400 °C. A byproduct of this high temperature combustion process is huge amounts of CO_2 which is a major greenhouse gas. In the future it is expected that process heat intensive industries like cement, paper, steel and milk power manufacture will need to transition to clean energy. This document reviews the various options used internationally to deal with ELT including reuse in roading and civil engineering applications, use as tire-derived fuel for various process heat applications, devulcanization by various means and pyrolysis. The preferred option is pyrolysis which converts the ELT to three valuable product streams including pyrolysis oil, steel and carbon black. Currently, pyrolysis is one of the most widespread practices in Asian countries, while in Europe, the USA, and Latin America the process is gaining more acceptance as it creates favorable conditions for a circular tire economy since the steel, pyrolysis oil and the carbon black can all be used to make new tires. Given the environmental advantages of pyrolysis and the potential to realize a circular tire economy with resource recovery, as well as potentially favorable economics, it is recommended that a full business case be prepared for a large process facility able to deal with the entire annual North Island ELT generation.

1. Introduction

On the 24th of January 2023, the prestigious Security Board of the Bulletin of Atomic Scientists moved the hands of the Doomsday Clock from 100 seconds to midnight to 90 seconds to midnight. Anthropogenic climate change largely driven by the burning of fossil fuels is highlighted as a major existential threat to organized human life on our planet.

An overwhelming consensus has existed for decades within the scientific community, governments, academia and other institutions that global emissions must immediately be reduced to zero if we are to keep the global mean temperature increase to below about 2.0 °C over the next few decades.

To achieve that goal will require significant and immediate reduction in CO_2 and other green-house gases (GHG) from all sources including energy production, agriculture, transportation and manufacturing and waste management. New Zealand has committed itself to 50% reduction in emissions by 2030. It should be noted that climate change, ecosystem destruction and loss of biodiversity are all merely symptoms of human development and a total reliance over more than a century on the burning of abundant and cheap fossil fuels.

New Zealand has one of the highest rates of car ownerships in the world and consequently New Zealanders generate around six million End-of-Life Tires (ELT) per year. That is, about one tire per person per year. Whether one drives an internal combustion engine vehicle or an electric vehicle, ELT will be generated. The rate of tire wear depends on the tire, the vehicle, the road surface, and the manner in which a vehicle is driven.

The biggest sources of metals and other road-related pollutants are abrasion of tires, brake pads and the road surface.[1] By the time an average passenger car tire reaches the end of its life it has lost about 3 Kg of initial mass. The mass is lost as very fine-grained materials (nano- and micro-particulates) known as Tire Wear Particles (TWP).[2]

Modern tires may look simple enough but they are, in fact, complex composite materials comprising several types of cross-linked synthetic and natural rubbers, steel, particulate fillers (silica, carbon black, etc.), chemical additives (sulfur, oils, etc.), and textile and/or metal reinforcements. The Carbon Black (CB) which makes up about 40% of the mass of modern tires is mostly derived from hydrocarbons. To produce one tonne of CB requires about 1.5 tons of fossil resource and vast quantities of water and the process generates about three tons of carbon dioxide.[3] Consequently, these days efforts are being invested in producing CB from sustainable sources.

Orion was the first major specialty chemicals producer to develop and commercialize CB made from renewable feedstocks, such as industrial-grade vegetable oils or other oils derived from waste and residues of biological origin from agriculture or forestry. Orion were also frontrunners to develop and manufacture CB from pyrolysis oils derived from ELT, enabling a tire circular economy.

Without ancillary components such as CB and other fillers tires would last only a fraction of the time that modern tires last. Carbon accounts for about 70% of the total weight of the tire. There is almost 13 - 27 % steel in a conventional passenger car tire.[4]

A passenger car tire can contain up to 1.1 % zinc while heavy vehicles may contain as much as 2.4 % zinc. Total mass of Zn found in Tire Wear Particles (TWP) from the road is lower (0.3–0.4 %). During tire manufacture sulfur is added as a vulcanization agent and zinc oxide (ZnO) as the catalyst. Fillers such as silica (SiO_2), clay minerals and sometimes calcium carbonite ($CaCO_3$) are also added.[5,6]

During use TWP are initially dispersed onto the roads and air and ultimately end up on land and in waterways. Since NZ generates more than six million ELT year, that translates to 18,000 tonnes of material dispersed throughout the countryside every year. A new briefing paper from Imperial College London estimates that in 2021, 52% of all small particle pollution from road transport came from tires and brakes.

It is becoming increasingly appreciated that TWP contribute to air pollution and can have serious deleterious health and environmental effects.[1,7,8] It has been estimated that 30% of microplastics in the environment come from tires.[9] New European Commission Euro 7 standards will be the first in the world to regulate emissions from brakes and tires and set additional limits for particulate emissions from brakes and rules on microplastic emissions from tires. These rules will apply to all vehicles, including electric ones.

Emissions Analytics was founded in 2011 by Nick Molder an Honorary Research Fellow of Imperial College, London, to develop real-world testing methodologies for vehicle emissions including tail-pipe, interiors, tire, brake and other emissions. Emissions Analytics are also putting together libraries of compounds that are released to the environment by vehicles so that we have a better understanding of environmental impacts.

Tires have been designed to be tough and durable and it is this very characteristic that makes them difficult to manage or dispose of at the end-of-life.

The environmentally responsible management of ELT is a challenge that is being grappled with the world over and many approaches can be taken that vary in terms of their environmental impact and costs.

Ad Lansink, a Dutchman, is internationally recognized for developing the original waste hierarchy, or 'Lansink's *Ladder*', and he often gets named '*Father of the waste hierarchy*.' In Lansink's hierarchy (Figure 1) prevention is the most environmentally friendly option and direct disposal in landfills is the least. It is clear that the best way to deal with waste is not to generate it in the first place.

Figure 1. The waste hierarchy as first proposed by Lansink.

Most, but not all, developed countries now view landfills (waste piles and dumps) as the least desirable option for ELT. In fact, tires have been banned from landfills in the European Union for some time.

Permitting landfills today is an extremely expensive exercise and therefore space is precious. The capital and other costs of establishing a landfill in NZ today can easily exceed $100M (NZD). Additional costs are incurred during operation and during post closure. Every effort should therefore be made to reduce volumes of material going to landfill.

In 2020 the amount of stuff generated by humans exceeded all biomass on the planet for the first time.[10] It is increasingly being realized that a linear economic model that starts at resource extraction and ends with waste disposal will not be sustainable since Earth's resources are finite.

The problem with the waste hierarchy applied to ELT is that ELT can just as easily be considered a resource rather than a waste.

In the remainder of this document research and current national and international practices used to deal with ELT will be reviewed and discussed.

2. Current Practice

Globally at present only 3 - 15% of ELT are recycled in some way, 5 - 23% are re-used as retreads, 20 - 30% are stockpiled or go to landfill and 25 - 60% of ELT are incinerated.[11]

The traditional approach for the disposition of the six million tires we generate in NZ every year has been to do little or nothing. At best ELTs have been left to accumulate in piles (Figure 2) around the countryside and/or sent to landfills.

ELT that end up on scrap heaps and landfills pose fire hazards, release pollutants and breed pests like mosquitoes. Heaps of ELT can catch fire easily if ignited by say lightning strikes. Many large fires have occurred at tire dump sites around the world. In NZ a tire pile at the Diggalink yard on Weedons Road, Rolleston, caught fire because of a flare-up of hot ash, which had previously been created by a controlled burn-off at the yard (see here).

Fires involving ELT are difficult to extinguish and can last for several days releasing compounds that are harmful to human health, (*e.g.* dioxins) and polluting the air, soil and water.

At this time the inventories and locations of most ELTs in NZ are not even known.

Figure 2. (a) The tyre dump on a Puketapu Rd property close to Lake Taupo's Kawakawa Bay in 2015. (Source: Marshall, C. Shock as tyre dump mounts near shores of Lake Taupo. *Stuff*, 14-Dec-20) **(b)** Tires at a leased site in Spencer Avenue, Kawerau before some of the tires were removed. The site was leased from Kawerau District Council.

Tyrewise is New Zealand's first regulated product stewardship scheme for recycling used tires and it has taken 20 years to come into existence. Meanwhile tire stewardship schemes have been operating in Scandanavia for at least a decade (Extended Product Responsibility).

Tyrewise seeks to minimize the environmental impacts of ELTs by managing all tires from collection through to processing. Tyrewise concerns itself with the tracking of tires, registration and auditing of participants, as well as incentivizing innovative end uses.

In more recent times NZ has adopted the practice of sending over half the annually generated inventory of ELT to the Golden Bay Cement Works (GBCW). There they are shredded and used as fuel for powering the BGCW cement kiln. The tires effectively replace much of the coal that is used. GBCW claims a reduction in CO_2 emissions through this practice. Simplistically one might categorize this practice as disposal with energy conversion and many consider this practice superior to landfill.

However, the author considers this practice worse than landfill because when one burns tires one is simply converting all carbon in the tire to CO_2 which is the most problematic of the GHGs. We have simply replaced one fossil fuel for another and generated pollution. GBCW should be using a clean fuel such as hydrogen or electricity to heat their kilns. There is a considerable amount of work going on internationally to decarbonize industries reliant on process heat that use fossil fuels including cement manufacture.

GBCW claims reductions in CO_2 emissions because the calorific value of the tires is higher than that of the low rank coal they are replacing them by. Because of the amount of ELT being dealt with in this manner, there will be more discussion of the topic below.

Since the beginning of the industrial revolution the production of goods has proceeded from resource extraction, manufacture, use and disposal in landfills. This linear approach is highly undesirable from a resource and waste management perspective. A far superior approach is a circular economy (Figure 3).

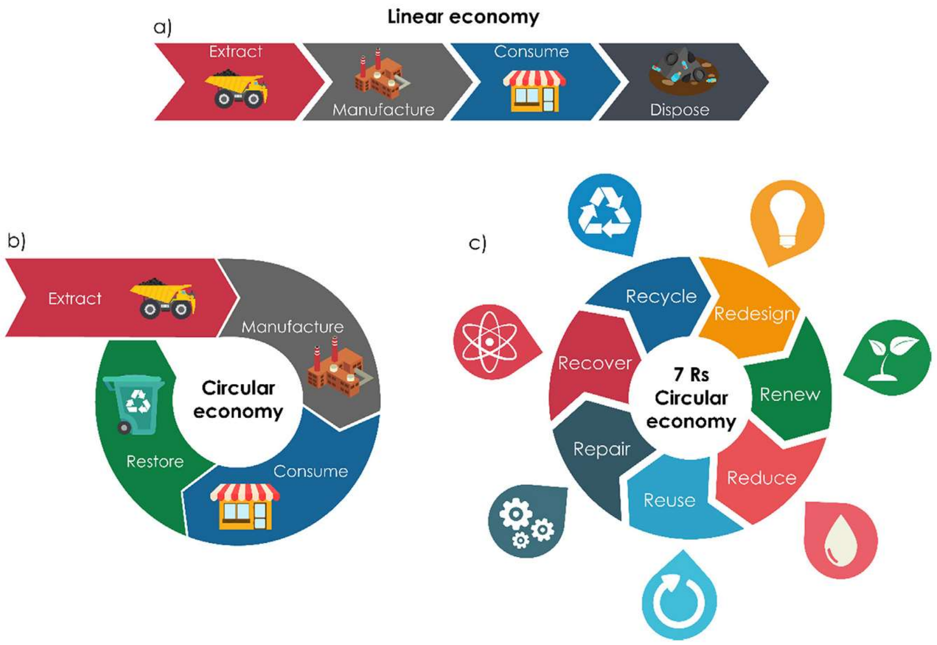

Figure 3. a) Linear and b) circular economy models. c) 7Rs of the circular economy model.[12]

As with most things there are a range of options for dealing with a particular problem and in this document the options for dealing with ELFT will be considered.

3. Retreading

The practice of re-treading and reusing tires is certainly higher up on the waste hierarchy than using ELT as fuel. Tire retreading is still practiced in NZ today but to a much lesser extent compared to bygone days. There are various reasons for the decline in popularity. First, modern tires last a lot longer than in days when retreading was more common. Second, a local shop would not be able to fit fresh tread on a worn tire in a way that is more durable and safer than what a major manufacturer can do at its factory. Lastly, even if the tread is fresh, the steel belts and side wall are not. They could be experiencing the effects of aging and environmental wear, and may conceal hidden damage.

4. Materials Recovery (Reuse)

4.1. Civil Engineering Applications

It is possible to use ELT in a range of civil engineering applications as shown in Figure 6. While the use of ELT in such applications is definitely worthwhile, such applications are probably going to account for only a very small fraction of the huge amounts of ELT generated annually.

Figure 6. Source: Anti-scree wall in the Hautes Alpes, France (Aliapur, DR). Artificial turf on playing field, France (Michelin).

4.2. Roading

The resuse of ELT in civil engineering applications seems like a reasonable approach and indeed this is turning out to be quite a common practice world-wide. There is also considerable potential for the use of recovered tire materials in concrete and roading.

Mixing ground ELTs, known as crumb, into asphalt binder is one way to make pavement more environmentally friendly. A 1991 US federal law (the Intermodal Surface Transportation Efficiency Act) required all state departments of transportation (DOTs) to start adding rubber to a prescribed portion of their federally funded roads. However, the technology for doing so was not ready, and the mandate was repealed in 1995. About half of US states have experimented with incorporating crumb into their asphalt mixes, and a handful - like Arizona, California, Florida, and Texas - have led the way in evaluating rubberized roads or building them as standard practice today.

In assessing a process for its environmental merits requires reliable Life Cycle Assessment (LCA) and those that have been undertaken have shown that the use of rubber crumb in roading is favorable.[13]

Figure 4. Source: McElvery, R. Is the road to sustainable asphalt paved with tires? C&EN 2021, 99(7).

https://cen.acs.org/environment/sustainability/road-sustainable-asphalt-paved-tires/99/i7

For now such pavement mixes continue of be investigated with some progress being made.[14]

There is extensive researcher occurring around the world to make asphalt concrete and road paving more sustainable (see here).

Most New Zealand roads are made of *Chipseal* which differs between the North and the South Islands. Chipseal is made of sprayed hot bitumen, or cold bitumen emulsion (bitumen that's sprayed on cold), with crushed stone, known as 'chips', rolled into the surface. It's usually applied to state highways that carry lower traffic volumes (those outside the main urban areas), with the more expensive 'asphaltic concrete' typically reserved for high-traffic state highways. *Asphaltic concrete* (hot mix) is a mixture of bitumen and stones, and is less noisy and harder wearing than chipseal.

The 'chips' in chipseal are small, sharp-edged rocks. In the South Island they come from rivers, while in the North Island they're sourced mostly from quarries. In both cases the rock must be dense, strong and not slippery when it gets wet.

Asphalt concrete is commonly used in the United States and is composed primarily of rocky aggregates and a black, gummy binder that acts as a glue. The binder, a blend of complex hydrocarbons derived mostly from petroleum, generates most of the environmental impact even though it represents just a small portion of the entire mixture. Acquiring, transporting, and refining the binder emits greenhouse gases and volatile organic compounds. During paving, heating the mix of aggregate and binder requires additional energy, producing yet more greenhouse gases and air pollutants. Then, with time, the binder in pavement stiffens from oxidation and begins to crack. As a result, roads demand maintenance and rehabilitation.[15]

Although reuse of ELT in roading seems attractive, it does have some serious drawback, one of which is that it is quite energy intensive.

Like here in NZ, millions of tires reach their functional end-of-life in Australia also and the majority of end up in landfills.

Over the past few years, Fulton Hogan (FH), Australia, has been working on the development of wet blended crumb rubber modified asphalt. FH has recently been certified as a Tyre Stewardship Australia (TSA) Circular Economy Collaborator (Manufacturer) (see here).

A Green Tick for our Sustainable Use of Old Tyre Materials

FH has demonstrated how crumb rubber modified asphalt could be produced with warm mix technologies, lowering production temperatures, VOC emissions, fuming and lowering greenhouse gas emissions.

4.3 Use in Concrete

Internationally, a considerable amount of work is addressing the incorporation of tire aggregate into concrete and evaluating its effect on the properties of this critical building material.[4,16]

Compressive strength of concrete is an important property as regards its use in building industry and initial results appear to indicate that composite materials with acceptable mechanical properties are achievable.

5. Energy Recovery – Tire-Derived Fuel (TDF)

5.1. Cement Manufacture

Tire derived fuel (TDF), one of the leading options for dealing with ELT, is mainly used in cement kilns, but also in thermal power stations, pulp and paper mills, steel mills and industrial boilers.

Table 1. ELT usage as tire derived fuel (TDF). Source: European Tyre & Rubber Manufacturer's Association, Rubber Manufacturers Association and Japan Automobile Manufacturers Association Inc.

	Total ELT (million, (excluding export and retread)	**TDF usage (%)**	**Facilities with TDF utilization**
Europe	250	41	Cement kilns
Japan	80	70	Cement kilns, paper mills, tire factories
US	292	53	Cement kilns, paper/pulp milla, boilers

Cement kilns need to operate at about 1400 °C and are usually fueled by coal and other solid fuels. The tires supplement the coal that is used to power the kilns in places like Golden Bay Cement Works (GBCW). GBCW supplies more than half the New Zealand cement market and is the only local cement manufacturer in the country. Cement manufacture is responsible for 7 - 8% of global carbon dioxide (CO_2) emissions.

As previously mentioned, at the present time up to 50% of the roughly six million ELT generated in New Zealand annually will be used in cement manufacturing at the Golden Bay Cement plant instead of going into landfill (Figure 5).[17]

Minister David Parker has stated that “This innovative project is a win-win-win for the environment. It reduces a significant waste problem, reuses a valuable resource, and reduces carbon emissions by about 13,000 tonnes a year”.

During the combustion of waste tires in air all the carbon in the tires combines with oxygen to produce CO_2 which is a major GHG. And of course GHGs are what we are trying to prevent reaching the atmosphere since they are the cause of global warming. The author would argue therefore that simply burning a tire is worse than putting them in landfills.

Because of the composition of modern tires considerable ash will be generated and this will need to be disposed of somehow. This deplorable practice of simply burning used tires is not sustainable and must be stopped.

Whether coal or ELT is used to fire cement kilns the result is the belching of copious amounts of green-house gas emissions (CO_2) into the atmosphere. This however is only half of the emissions that come from cement manufacture, the other half of the emissions come from the raw material lime (calcium carbonate) which is converted to CaO and CO_2 during the process. Technical options are being explored for a solution to this half of the emissions equation.

Whilst substituting coal by ELT is certainly advantageous in terms of cost, it is difficult to understand how significant savings in carbon emissions can be made by simply substituting one fossil fuel by another hydrocarbon-derived fuel having a slightly higher calorific value.

Tires have a calorific value of 30 - 40 MJ/Kg which is similar to anthracite coal which has a carbon content of 86% - 97%. Thus, if anthracite coal were used in cement kilns then it would be a superior fuel to ELT. However, if low rank coals are used with lower calorific values then these can have lower carbon contents and more must be used for the same amount of heat (Bituminous coal contains 45%–86%, Sub-bituminous coal typically contains 35% - 45% carbon). As far as the author is aware we are not using high rank coals in New Zealand. However, one would also need to consider other waste flows from the combustion process since waste tire ash would be rich in silica, heavy metals and other chemicals.

Any potential claimed emissions savings possibly come down to the fact that tires contain a significant amount of natural rubber which is considered a renewable material. Whether fossil fuels are used or ELT the result is significant GHG emissions. Better than burning fossil fuels in cement kilns would be to use other clean fuels such as hydrogen for cement manufacture. Alternatively, direct electrical heating (turboheating) should be considered and is being investigated for cement manufacture by companies such as Cemex and Coolbrook.[18] Thyssenkrupp is also actively pursuing turboheating for cement production.

Given that burning tires in cement kilns is not environmentally friendly and is a practice that can hardly be considered sustainable, alternative approaches would be required for dealing with ELT that do not result in emissions, or at least give significant emissions reductions.

In a similar manner to the use of ELTs to power cement kilns they could also be substituted for coal in the blast furnaces of steel plants, pulp and paper plants, industrial boilers and thermal power stations. Once again, all of these uses of industrial heat must be converted to zero-emissions alternatives such as electric arc and industrial furnaces or hydrogen.

5.2. Steel Manufacture - Electric Arc Furnaces

Steelworks equipped with electric arc furnaces provide an almost closed loop recycling possibility for ELT. The method involves applying a quantity of scrap metal into an electric arc furnace, followed by a quantity of tires (shredded or whole). The tires not only add to heat generation but also the act as the reductant as coking coal would do. However, convert carbon monoxide gas is produced which is then oxidized carbon dioxide in the furnace and then released to the environment. In the US, about 1.3 million ELTs are used in this way per year, and a market also exists in Japan. More recently this application has been validated for industrial use in Belgium, France and Luxembourg, and it has the potential for growth in Europe (see here).

Australian company OneSteel has already used old tyres in its commercial steel production processes, keeping more than 11 million tyres out of landfill since implementation (see here).

Tire Derived Fuel

Fletcher Building

Tyrewise

3 million tyres a year used to fuel Whangārei's Golden Bay Cement works

Northern Advocate, 30-Mar-21

Figure 5. Tires sent for co-processing at the Golden Bay Cement Works where both fuel value and materials are recovered.

6. Chemical Devulcanization

A large component of tires are natural and synthetic rubbers (polymers). Rubbers are elastomeric materials that can deform and stretch and recover their original shape. Natural rubber is made from natural rubber latex produced from over 200 plants. In contrast, synthetic rubbers are synthesized as monomers from a variety of petroleum-based hydrocarbons.

To produce rubber suitable for tires, elastomers must go through a complex process known as *vulcanization*, in which the molecular chains of rubber are joined by chemical bonds forming primary crosslinks, thereby producing a three-dimensional molecular network.

Vulcanization was discovered in the mid-1800s by Charles Goodyear, who employed sulfur to form bonds between unsaturated polymer chains found in latex to yield natural rubber. Although other vulcanization techniques (e.g., the peroxidic vulcanization) have been developed in the subsequent years and are today widely employed, the most common vulcanization method is still sulfur vulcanization.

One way of breaking down the rubber therefore is through a devulcanization process which aims to break C-S and S-S bonds of the cross-linked network and reclaim virgin material.

The different methods of devulcanization include chemical, mechano-chemical, ultrasonic, microwave biological, thermo-mechanical, and supercritical CO_2.[19,20] Microwave and ultrasonic devulcanization appear promising because they are dry and eco-friendly techniques that can be easily implemented, allow for high productivity, and yield devulcanized products with good properties.[21]

The chemical method of Zheng *et al.*[22] is also quite promising as the process is relatively simple and yields the polymers that can once again be cross-linked.

None of the methods studied thus far are applied on a commercial scale.

7. Pyrolysis

Currently, pyrolysis is one of the most widespread practices in Asian countries, while in Europe, the USA, and Latin American (LAM) the process is gaining more acceptance as it creates favorable conditions for a circular economy transition (Figure 3).

Pyrolysis of used tires represents an alternative to combustion such as is the case of TDF. Pyrolysis is the process of decomposing materials by heating them in the absence of oxygen or in an oxygen-depleted atmosphere. This is how charcoal is made worldwide.

Pyrolysis is therefore distinct from combustion which simply converts essentially all the carbon in the tire (polymer and carbon black) to CO_2 and other volatile green-house gases. When one pyrolyzes many polymers (plastics), carbon, oil and non-condensable gases are produced that are mostly comprised of H_2 and CH_4. Therefore, pyrolysis results in various potentially valuable products and emissions of GHG is minimized. The carbon yield is dependent on the type of polymer being pyrolyzed and also on the process conditions. For example nylon yields no carbon under typical pyrolysis conditions whereas polyacrylonitrile yields 44% carbon and phenol-formaldehyde yields 52% carbon (Gwyn Morgan Jenkins, Kiyoshi Kawamura in Polymeric Carbons - Carbon Fibre, Glass and Char. 2011).

The pyrolysis of tires yields essentially three product streams including steel from the reinforcement, fuel oil (condensable gases) and a char that is rich in CB but also contains inorganics (Figure 7).

As a result, pyrolysis is considered by many to be something of a missing link between the management of ELT and the tire industry because it provides a bridge from a linear to a circular economy model.[23] As a consequence the process is being intensively studied and reviewed.[24-26]

Figure 7. Products from the pyrolysis of waste tires.

The carbon-rich char recovered during the pyrolysis process contains a high concentration of mineral ash, consisting of the additives (primarily silicate compounds and zinc components) that accounts for up to 20 percent of this CB. This material is often referred to as pyrolytic CB, or CBp.

Due to the presence of these other mineral components questions arise as to suitability of this material as a feed for the production of new tires. Many studies have therefore investigated the feasibility of upgrading this material to one that could be a superior feed material for new tire manufacture.[27]

Aside from significant scientific interest, several projects are currently in progress worldwide. The EU-founded *BlackCycle Project* is being coordinated by Michelin and aims to create, develop, and optimize a full value chain from ELTs to secondary raw materials (SRMs) through pyrolysis, in which they are expected to be used to develop new ranges of tires.

The Fraunhofer Institute for Building Physics IBP has recently developed a simple process for separating pure carbon black from the minerals in the ash and allowing the recovered CB (rCB) to be reused in the production of new tires.

One tire Manufacturer, Continental Tires, expects to use 100% rCB in its new tire production process by 2050 (Figure 8).

Klean Industries Inc. ("Klean") has recently partnered with City Circle Group ("CCG") to build a fully integrated, continuous tyre pyrolysis plant to recover carbon black and biofuel in Melbourne Australia (see here).

Press Release, 12-Sep-2023

Continental Uses Recovered Carbon Black in Solid Tires

- Solid tires from Continental's tire plant in Korbach now contain carbon black recovered from end-of-life-tires
- Recovered carbon black reduces use of fossil raw materials and CO2 emissions
- By 2050 at the latest, Continental aims to use 100 percent sustainable materials in its tire products

Figure 8. At Continental's tire plant in Korbach, Hessen, recovered industrial carbon black (rCB) is being added to newly produced Super Elastic solid tires, thus reducing the use of fossil materials and cutting CO_2 emissions.

Therefore the pyrolysis process opens the way for complete resource recovery.

The pyrolysis oil (fuel oil) produced in the process could be used in farm machinery or to fire the pyrolysis plant itself. Recently researchers[28] have demonstrated that it is possible to produce CB from spent tire derived-oil that has comparable quality to commercial CB.

The oil could also be used as a raw material for the synthesis of other chemicals (e.g. limonene, benzene and its homologues), or it could be upgraded to become a fuel for vehicles.[29,30]

BASF are working on a project referred to as ChemCycling® which aims to manufacture products from chemically recycled plastic waste on an industrial scale. BASF cooperates with technology partners, who use pyrolysis to transform plastic waste (either mixed plastic waste or end-of-life tires) into a pyrolysis oil. The oil is fed into BASF's production network (Verbund) at the beginning of the value chain, thereby saving fossil resources.

Aside from the production of rCB suitable for use in new tire manufacture, CB has many other commercial uses including as a soil amendment, as a reinforcing filler, as a pigment in coatings.

It is also important to emphasize that since the yield of carbon is at least 30% by weight, a considerable proportion of carbon in the tire is fixed during the pyrolysis process as opposed to being released to the atmosphere.

It is also possible to treat the CB product to produce Activated Carbon (AC) which is an even more valuable product.[31]

Recent LCA of various methods for dealing with ELT have shown that pyrolysis saves significant CO_2 emissions (see here).[32] LCA proves that pyrolysis not only closes the recyclable material loop, but also saves more CO_2 emissions than all currently used, common recycling processes for ELT. Pyrolysis reduces CO_2 emissions by 72% while burning of scrap tires in cement plants saves 42% and waste-to-energy power plants save only 6%.

8.1. Costs of Turn-Key ELT Pyrolysis Plants

Nowadays there appear to be a relatively large number of process engineering firms operating in the resource recovery and recycling sphere that are able to supply turn-key ELT pyrolysis plants (Table 1).

Table 1. Incomplete list of vendors of turn-key tire pyrolysis plants.

	Company	URL
1	Beston Machinery Company Ltd	https://www.bestongroup.net/pyrolysis-plant/pyrolysis-tyre-recycling-plant/
2	Doing Renewable Energy Equipment Co., Ltd	http://www.china-doing.com/
3	Mingjie Environmental Equipment	https://www.mingjiegroup.com/products/products_9_1.html
4	Niutech	http://en.niutech.com/tire2fuel/
5	Klean Industries	https://kleanindustries.com/tyre-pyrolysis-plant/
6	Pyrum Innovations	https://www.pyrum.net/
7	Metso	https://www.metso.com/portfolio/tire-pyrolysis/
8	Elysium Nordic	https://elysiumnordic.com/
9	Huayin Group	https://www.huayinenergy.com/
10	Enviro	https://envirosystems.se/
11	Enerpat	https://www.enerpatrecycling.com

On 22-May-22 I received a quote from Beston Machinery Company Ltd for $82,800 USD (FOB) for a small plant that can process the 40,000 or so ELT generated annually in the Whakatāne district (Appendix 1). It should be noted that the quoted plant does not seem to include a shredder.

Obviously, the plant needs a location in which to be installed and also ancillary equipment such as fork lifts and so forth.

I have also received an estimate for a much larger plant capable of processing up to half of New Zealand’s annual ELT generation (ca. 3 million) from a large multinational company called Metso (https://www.metso.com/portfolio/tire-pyrolysis/).

Metso has an Australian office and claims to be a frontrunner in sustainable technologies, end-to-end solutions and services for the aggregates, minerals processing and metals refining industries globally.

Metso has a pyrolysis flowsheet developed for a pilot plant to produce a pelletised carbon product, oil similar to diesel, and a process gas with heating value similar to propane.

The Metso standard plant size is able to process 3.3 million passenger car tires per year and according to Ian Dunn, who is the Senior Manager, Ferrous & Heat Transfer, Asia Pacific, a turn-key plant would cost about $30M.

Clearly more detailed specification and costings of plant and equipment would be necessary.

9. Conclusion

Pyrolysis appears to be the environmentally superior solution for dealing with ELT although it is harder to say that technological maturity has been reached without conducting further due diligence.

Numerous manufactures supply commercial turn-key plants and they would need to be thoroughly evaluated prior to making any commitments. One would need to understand very well the operational history of operations in other parts of the world.

Considering that one of the advantages of pyrolysis is the generation of potentially valuable product streams, considerable effort would need to be devoted to assessing the economics.

Scandinavian Enviro Systems has produced an interesting you tube video of their patented pyrolysis process that operates at full-scale in Åsensbruk, Sweden (https://www.youtube.com/watch?v=WToX36026DE). There potential customers can apparently view and study their process.

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Appendix 1

Following is a quotation from *Beston Machinery Company Ltd* for a small-scale ELFT pyrolysis plant capable of processing the ELT generated annually in the district of Whakatāne. The total cost for the plant is $82,800 USD (FOB).

Note that the quote does not include a shredder.

QUOTATION

* 该图仅为示意效果图，部分产品及配置情况请以最终设计或实物为准。
* This drawing is only a schematic effest drawing. Some products and configuration should be based on the final design or physical object.

BLJ-6 PROPOSAL

PYROLYSIS PLANT

QUOTE NO.	BESTON094
QUOTE	Mar 22, 2022
DATE	Apr 6, 2022
SALES REPRESENTATIVE	Joshua
EMAIL	joshuasun@bestongroup.com
PHONE	+86 18569982306 (whatsapp & wechat)

Beston(Henan) Machinery Co., Ltd.

NO.99,Daxue Road,Zhengzhou,ChinaDATE
0086-371-55181866
www.bestongroup.com

Contents

Could any of these situations be a problem in your

- Waste tires all over places!
- No place for plastic!Bury or Burn? No!
- Polluted Oil sludge left to be cleaned?

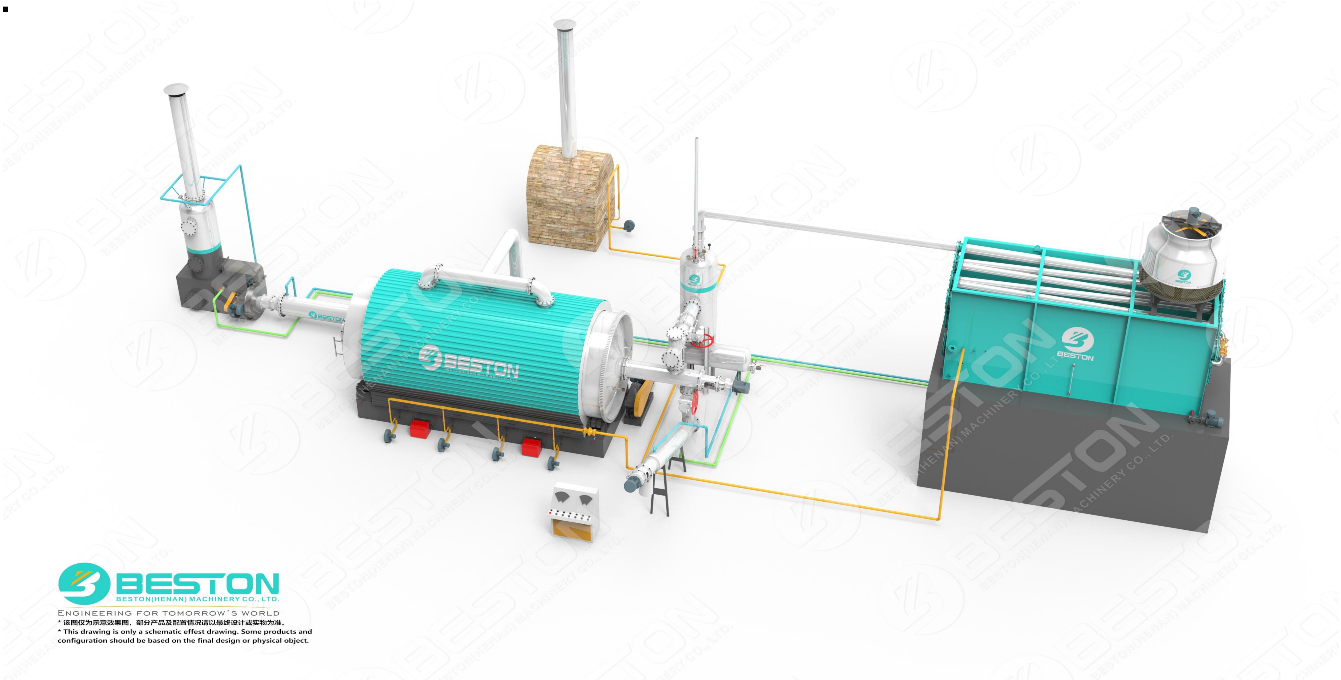
Turn waste into money!

Beston (Henan) machinery Co., Ltd.

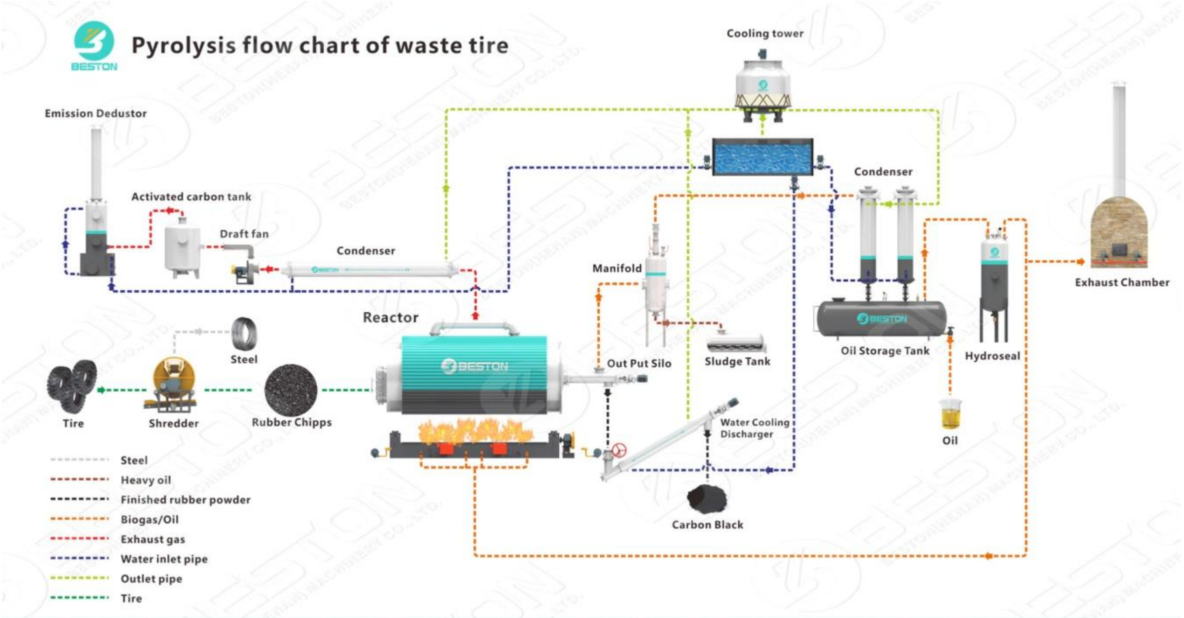
was founded in 2013. We are professional in manufacturing all kinds of waste recycling equipment. In 2018, the branch of Beston Machinery was founded in Romania. Now we have 8 overseas branches and more than 60 overseas after-sales services personnel. All the plants we supply has the certification of ISO and CE. We promise the quality of all plants we sell to every customer and welcome people from all over the world who have the intention to change the world by waste recycling to contact us.

Recycling waste tire plastic to fuel oil small pyrolysis plant can turn waste tyre to fuel oil with latest pyrolysis technology. Pyrolysis is the thermal decomposition of materials in the absence of oxygen. In the case of the pyrolysis of rubber tyres, the rubber degrades under high temperatures and long-chain hydrocarbons in rubber are broken down into compounds with shorter carbon chains in the reactor, yielding oil, gas, wire steel and carbon black.

3D Layout



The flow chart



SLUPPY SCOPE

- Waste tire and plastic recycling machine
- Waste tire/plastic oil and waste engine oil
- Distillation machine

Economical analysis of BLJ-6

Beston (Henan) Machinery Co., Ltd.

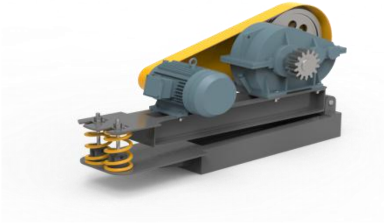
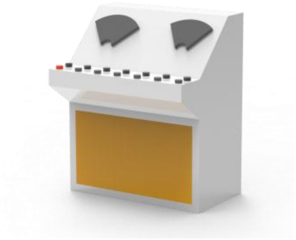
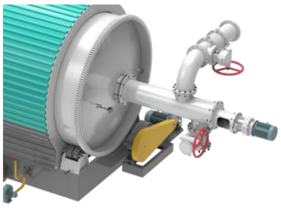
Analysis of BLJ-6 Pyrolysis Plant To Process Waste Tyre

Material	Tyre	6MT/Day	$46/MT	
Fuel	Pyrolysis oil	100kg/Day	$0/kg	
Electricity Pyrolysis	42.4KW (70%)	18Hour	$0.14/KWH	Daily consump 534kwh
Labor	6 person	1 day	$15/person/day	
Pyrolysis oil	45% oil yield	2.7MT	$410/ton	
Carbon black	30% yield	1.8MT	$50/ton	
Steel wire	15% yield	0.9MT	$150/Ton	

Daily Input					
Items	**Unit**	**Consumption**	**Unit price**	**Total**	**Remark**
Tyre	Ton	6	$46.00	$276.00	
Pyrolysis oil	KG	100	$0.00	$0.00	
Electricity Pyrolysis	KWH	534	$0.14	$74.76	
Labor	Person	6	$15.00	$90.00	
Total				**$440.76**	
Daily Output					
Items	Unit	Quantity	Unit price	Total	Remark
Pyrolysis oil	Ton	2.7	$410.00	$1,107.00	
Carbon black	Ton	1.8	$50.00	$90.00	
Steel wire	Ton	0.9	$150.00	$135.00	
Total				**$1,332.00**	
Daily Profits					
Output - Input	$891.24				
Month Profits (25 working days)		$22,281.00			
Annual (10 Months)		$222,810.00			

Key Machine Parts List

NO.	Items	Unit	Quantity	Remark	Photo
B01	casing	set	1	Φ2260*3600*1.8mm (Q235b carbon steel)	
B02	reactor	set	1	Φ2200*6000*16mm (Q245r boiler steel)	
B03	manifold	set	1	Φ700*2000*6mm (Q235b carbon steel)	
B04	heavy oil tank	set	1	Φ600*1500*6mm (Q235b carbon steel)	
B05	Oil condenser oil tank hydro-seal	set	1	(Q235b carbon steel) 5800*2260*2500	
B06	connect Pipe for flue	set	1	Φ320*2300*4mm (Q235b carbon steel)	

B07	draft fan	set	1	7.5kw	
B08	de-dusting device	unit	1	Ø426*3000*4mm (Q235b carbon steel) Ø900*2000*6mm (Q235b carbon steel) 1500*1000*1000mm (6mm thick) (Q235b carbon steel)	
B09	speed reducer	set	1	5.5KW	
B10	electric control board	set	1	Normal	
B11	1st carbon discharger	set	1	Ø420*2600*6mm with 4kw motor (Q235b carbon steel)	
B12	burner base	set	1	(Q235b carbon steel)	

B13	flue tube condenser	set	1	ϕ426×6000 (Q235b carbon steel)	
B14	2ed carbon discharger	PC	1	Ø320*5000 5.5kw (with condenser) (Q235b carbon steel)	
B15	water tank (cooling tower)	set	1	Tank Built in client place (concrete&brick) Cooling tower: 60Kg/H, 3KW	
B16	Pyrolysis oil burner	set	2	300,000Kcal	

Technical Parameters

ITEM	CONTENTS
24-capacity	2-4 MT
Operating pressure	Constant pressure
Maximum Height	9 meters
Reactor rotate speed	0.4 turn/minute
Workers	4-6(2 groups)
Land area	30m*12m*8m
Electricity consumption	37.85kw/h
Water consumption	1-2m^3/day
Fuel(pyrolysis oil)	240kg

Quotation

Item	Data	Quantity
Pyrolysis Plant	FOB(Qingdao) price: 82,800 **USD**	set
Packing	1*40FR+1*40HQ+1*20GP	/
Delivery	35 Working Days	/
Loading Port	Qingdao China	/
Payment	50% T/T in advance, 50% T/T before delivery	/
Price Validity	15 days from Quote	/

What services can Beston offer?

Installation and Training

Engineer for installation guiding, testing, commissioning and operators training.

Installation period

Anticipated period is for 40 working days.

Installation Charges

Client cover engineer’s round-trip tickets+ board and accommodation + phone calling charge andrelated basic daily expenses, as well as engineer salary (100USD one day one person site service/ 50USD per day online instruction).

Warrantee

12 months guaranteeOn-site servicesRegular phone call visitingsWhole life time maintenance and wearing parts supply

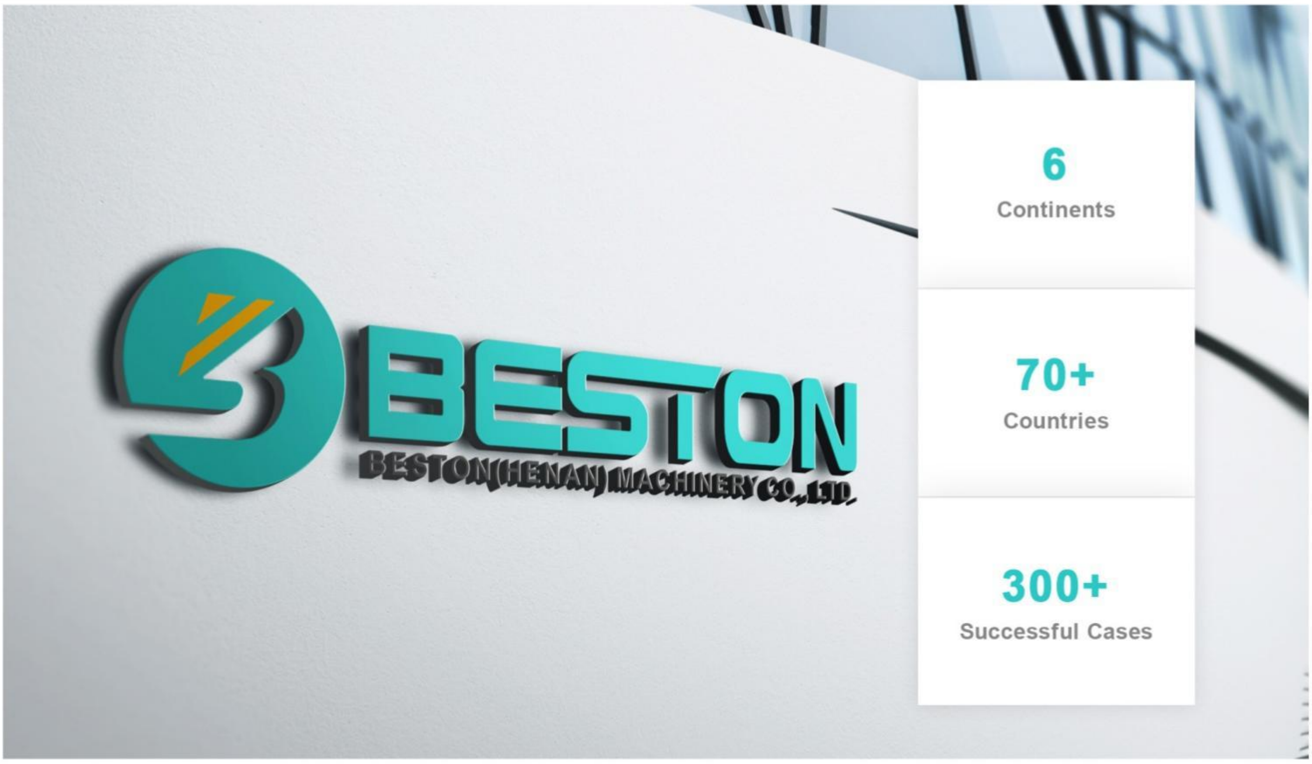
Self-prepared material

Items	Unit	Quantity	Remarks
water pool 40m3	/	1	according to actual place
oil tank 20m3 (suggested)	/	1	
Ø50 galvanized pipes	meter	not fixed	
Other materials			
Items	Unit	Quantity	Remarks
electricity wires	Meter	not fixed	according to actual place
12# U steel	Meter	not fixed	reinforcement
Foundation for reactor			
Items	Unit	Quantity	Remarks
steel plate （500*500*10）	Piece	4	reactor base
steel plate（1300*500*10）	Piece	1	speed reducer base
Ø16 reinforced bars	Meter	35	If the bottom of the cement cushion layer is compacted with 37-lime lime soil and the thickness is not less than 200mm, it is not necessary to use threaded steel bars during construction.
Ø10-Ø12 reinforced bars	Meter	140	
C30 concrete	M³	4.5	
Tools required			
Items	Unit	Quantity	Remarks
Crane	Set	1	capacity 15-25 tons
forklift	Set	1	capacity 5-10 tons
Planometer	Set	1	
welding machine	Set	3	
Scaffold	Set	1	
impact driller	Set	1	
oxygen cutting device	Set	1	
Cutter	Set	1	
Wrench	Set	not fixed	according to requirement
Hammer	Set	1	
Pliers	Set	1	
Workers required			
Items	Unit	Quantity	Remarks
workers for civil construction	Person	4	2 masters 2 assistants
workers for welding	Person	3	Professional worker
Plumbers	Person	2	Professional worker
Electricians	Person	2	Professional worker

Beston Successful Installation Cases

Contract date: 2019.8	Project Location: Nigeria
Model: BLJ-16	Input Material: Waste Tire

Contract date: 2019.10	Project Location: Zimbabwe
Model: BLJ-6	Input Material: Waste Tire



6
Continents

70+
Countries

300+
Successful Cases

More advanced in technological innovation

Stricter in more durable

More assured in professional guidance

More professional in environmental protection and energy saving

More cost-effective in economic performance

More comprehensive in scope of applications


Schedule of Registration

ISO 14001：2015

Beston (Henan) Machinery Co., Ltd


SGS

Test Report


SGS

ORIGINAL

Analysis Report


UDEM

CERTIFICATE

ATTESTATION

CERTIFICATE OF MACHINERY DIRECTIVE