Continuous Pyrolysis Technology

A Business Case Study

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Abstract

This project investigates the implementation of continuous pyrolysis technology by Fulton Hogan within New Zealand as a value-add process for end of life tyres. The literature review highlights potential problems including high set-up costs and poor product quality of the end products, oil, gas and char, resulting in limited market options. Many pyrolysis set-ups are deemed economically unviable for these reasons. Market research identifies major retail outlets and tyre collectors within the tyre industry in New Zealand. A report on the potential uses of the recycled end products investigates ways to alter product yield based on requirements, and potential ways to export energy to the grid. The location analysis supports recommendations for Miners Road Quarry in Christchurch and Whitford Quarry in Auckland as sites to build full-sized commercial pyrolysis plants.

Executive Summary

Background and Justification for Project

The Ministry for the Environment is working towards sustainable systems to manage end of life tyres (ELT's). Fulton Hogan has been investigating possible end uses for ELT's. Costs for providing heating fuels for bitumen and asphalt (manufacturing) plants are increasingly high therefore Fulton Hogan's aim is to invest in a system that is both environmentally sustainable whilst both adding value and reducing costs.

This Master of Engineering Management project investigates the disposal of ELT's through a process of continuous pyrolysis. Pyrolysis is the thermal decomposition of materials in a zero-oxygen environment resulting in the production of oil, char (carbon), and gas (syn-gas). Fulton Hogan has developed an alliance with Christchurch based company, CPT, which has built a prototype pyrolysis plant. Fulton Hogan is now at the stage of reviewing the supply chain, logistics, and possible implementation of a full-sized commercial plant.

Phase One: Literature Review

The literature review highlighted some critical points that assisted with determining future progress for the project. The first part, case studies, investigated pyrolysis facilities developed in other parts of the world. Major issues identified included high initial set-up cost and technological issues with creating end products that were of sufficient quality to be profitable. The second part investigated various forms of pyrolysis technology. The third part investigated previous trials of pyrolysis in New Zealand. The final part of the literature review consisted of a review of the 2012 Tyrewise report, commissioned by the New Zealand Government to provide an insight into potential ways to implement a product stewardship scheme for ELT's.

Phase Two: Market Research

Data Collection Tools

Market research formed the main body of the project as it provided critical information on the supply chain of tyres. As the data required information from a wide variety of locations from New Zealand, information was collected via telephone interviews. Other data collection tools used included:

- Internet and literature research
- Email, however direct contact via telephone was shown to be a more successful
- A number of site visits were made and information was collected from qualified personnel on site

South Island Results

The two main tyre collectors in the South Island are Scrap Tyre Movements and Tyre Collection Services, both of whom bail their tyres whole and forward them to Asia for recycling. They are interested in pyrolysis however are limited by funding. These two tyre collectors process a combined total of approximately 500,000 ELT's annually. Market research showed that many ELT's in the South Island go to famers as silage pit covers.

Throughout Canterbury the transfer stations and landfills charge of $6-$35 for ELT disposal depending on the tyre size. In Christchurch, EcoDrop acts as a transfer station for ELT's and other recyclable waste. They collect 800-1000kg ELT's weekly. EcoDrop has potential for providing a source of ELT's for a pyrolysis plant. The Dunedin landfills charge $3.10 per car tyre disposed and $302.50 per tonne for larger quantities. The Dunedin City Council disposal system sends all tyres collected into this landfill.

Market research indicated that the major retailers in the South Island are Bridgestone and Beaurepaires.

- Beaurepaires collects 86,000 ELTs' per annum and uses Tyre Collection Services for tyre disposal. Some Beaurepaires outlets give ELT's away to farmers for use as silage pit covers. Due to knowledge on market share, Beaurepaires is likely to collect more than the estimates 86,000 ELT's.
- Bridgestone collects 195,000 ELTs' per annum. Bridgestone have agreed to supply sufficient quantities for the prototype plant of shredded or chipped tyres. Ideally Bridgestone will also have sufficient supply of ELT's to provide 60 tonnes per week for the proposed South Island based full-sized CPT plant.

North Island Results

Major tyre collectors in the North Island are Tyre Removals Ltd, Pacific Rubber, M.E. Jukes and Sons and J & J Laughton.

- Tyre Removals Ltd services the Auckland area, collecting 180,000 ELT's annually which are shipped to Asia.
- Pacific Rubber provides a tyre collection service for Bridgestone/Firestone and Tony's Tyres north of Rotorua. They collect 300,000 passenger tyres and 104,000 truck tyres annually.
- M.E. Jukes and Sons process 50 tonnes of ELT's annually, all of which are dumped in their own landfill.
- J & J Laughton is a tyre collector that services Rodney, Auckland and the Waikato. They are working alongside Tyregone Processors in the research and development of a tyre pyrolysis plant.
- Carbon Recovery Ltd is a tyre collection and recycling company based in Tauranga. They have agreements with at least a dozen councils in the North Island and around 300 independent tyre retailers.

Major retailers in the North Island are Beaurepaires, Carter's Tyre Service, and Bridgestone.

- Beaurepaires disposes of around 195,000 ELT's annually. Most of the retail outlets in the Auckland area used J & J Laughton for tyre collection and in the Wellington area, Al's Bins Ltd.
- Carter's Tyre Service disposes of approximately 92,000 ELT's annually. Carter's Tyre Service owns 17 Beaurepaires retail stores throughout the North Island.
- Bridgestone disposes of 650,000 ELT's in the North Island. Bridgestone currently holds 40% of the market share for truck tyres nationwide.

The cost to dispose of tyres at landfills across the North Island varies significantly. Car tyres vary from $3-$5 and truck tyres from $10-$15.30. Off-road tyres can cost up to $100 per tyre to dispose of at landfill. Mixed loads of tyres, where the quantity or type is undeterminable, can cost from $324.50-$500 per tonne.

Plastics

There are three recycling companies in Canterbury: Mastagard, Agpac and Comspec. Mastagard has the largest Christchurch based recycling plant, processing 30,000 tonnes of waste annually. Agpac has an agreement with Mastagard for recycling agricultural plastics. Comspec has a recycling plant based in Hornby, with the capacity to process 1000 tonnes of plastic milk bottles annually. The Christchurch City Council has a recycling plant in Sockburn. There are currently no processes in place for energy recovery from plastics in New Zealand.

Phase Three: Report on Potential Uses for the Recycled End Products

The aim of this phase of the project was to show potential uses for the end materials of pyrolysis- oil, gas and char, and ways in which to alter the yield based on requirements. Literature provides ways to increase the yield of oil and gas and reduce the yield of char, by altering the reaction temperature, speed or cooling phase.

The prototype plant will process approximately 54 tonnes of tyres, producing 10,000L of oil, 3,375kg of gas (equivalent to 4,320kg of LPG due to having a calorific value 30% higher than LPG), and 27 tonnes of char per month. The proposed three-line commercial plant will process approximately 270 tonnes of tyres, producing 50,000L of oil, 16,875kg of gas (equivalent to 21,600kg of LPG) and 135 tonnes of char per month.

The end use of oil is limited by the high sulphur and ash content and the viscosity. There are processes that reduce both the sulphur and ash content. There is potential to use the gas in a syn-gas generator to produce energy which can then be used to supply energy to the site and/or exported to the grid. Several companies across Australia have proven that this is possible with the use of pyrolysis of organic biomass. Gough CAT may have options for diesel and gas generators however they have no experience working with used oil. Char is a high energy fuel with a similar calorific value to coal and as such may be co-fired with coal.

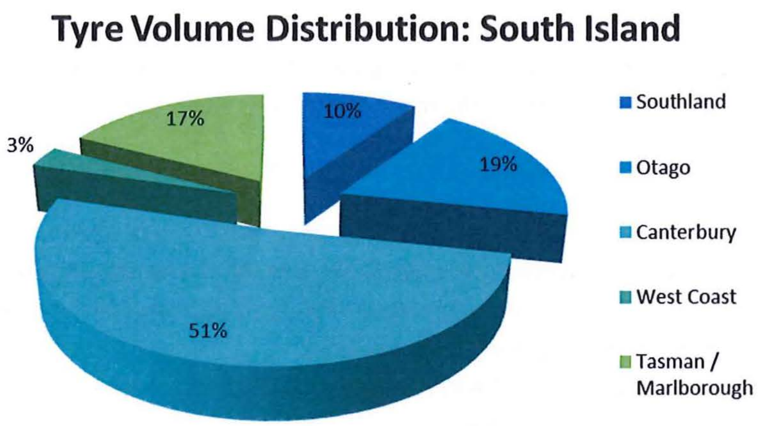
Phase Four: Location Analysis

Constraints Driving Site Selection

When analysing potential sites for a three or five-line operation commercial plant there are various constraints driving site selection. These include the cost, proximity to tyre supply, proximity to bitumen and asphalt (manufacturing) plants, availability of suitable space, and availability of water and electricity.

South Island

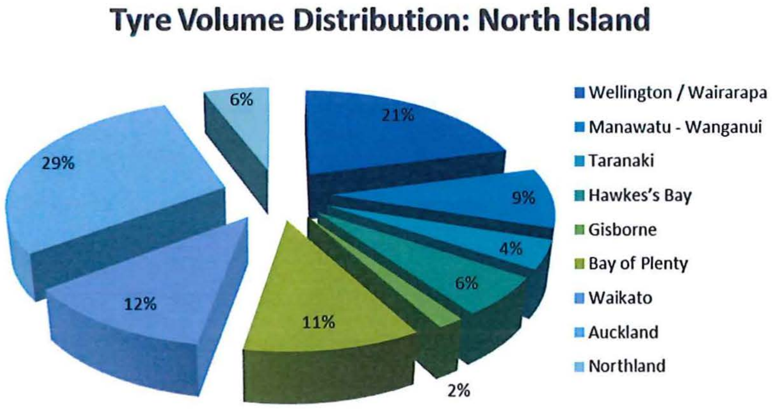
Market research indicates that Canterbury has the highest tyre volume in the South Island with total tyre volume of 150,000 tyres and a total share of 51%.



The sites with the most potential are Pound Road Quarry, Miners Road Quarry, Charlotte Jane Quarry and Coutts Island Quarry. Based on location requirements of proximity to water and electricity as well as available space and ability to gain resource consent, Miners Road has been identified as the most suitable location to develop a full-sized commercial pyrolysis plant. Appleby Quarry, in Nelson, has also been identified as a potential site for a smaller commercial plant.

North Island

Auckland has the highest tyre share with 29%, followed by Wellington with 21%, Waikato with 12% and the Bay of Plenty with 11%.



Auckland's potential site is Whitford Quarry which, due to low development may have sufficient space for a pyrolysis plant. The Auckland area, however, may be restricted due to environmental guidelines. Another potential site is Poplar Lane Quarry in Tauranga. This quarry is highly developed and may not have space for a pyrolysis plant however may be more suitable due to proximity to tyre supply throughout the central North Island and potentially more relaxed environmental restrictions.

Recommendations

Finance has not been included in this project as it is out of scope therefore no recommendations on cost are made in this report. Market research data and literature covered in this report supports the following recommendations for the implementation of continuous pyrolysis technology in Fulton Hogan within New Zealand:

1.0 Fulton Hogan should implement a tyre recycling or energy recovery process to dispose of ELT's.
2.0 Fulton Hogan should support the trial of a prototype pyrolysis plant and, based on the success of that plant, investigate further options for implementing a full-sized commercial plant.
3.0 Initially Fulton Hogan should source all tyres for the prototype plant from Bridgestone.
4.0 Fulton Hogan should source ELT's from tyre retailers and collectors throughout New Zealand, should the implementation of a full-sized commercial pyrolysis plant be deemed a viable option.
5.0 CPT should pay for the transportation of tyres within New Zealand if a full-sized commercial pyrolysis plant is deemed viable.
6.0 Whitford Quarry should be used as a site for a five-line pyrolysis plant in the North Island.
7.0 Miners Road Quarry should be used as a site for a three-line pyrolysis plant in the South Island.

Alternative recommendations that do not involve pyrolysis are:

1.0 Fulton Hogan could use or sell ELT's as tyre-derived fuel (TDF).
2.0 Fulton Hogan could sell rubber crumb for road filling or use as an additive for road surfacing.

Personal Growth Achieved Through Project Completion

I found this project highly valuable, challenging and enjoyable, providing an insight into an industry for which my previous experience was minimal. Lessons learnt through the course of the project supported personal and professional growth and followed on from fundamental topics taught through modules in the MEM course:

1.0 Planning is critical to project completion
2.0 People are willing to divulge valuable information if you ask the right questions and are willing to listen
3.0 It is critical to keep your superior (supervisor/sponsor) updated on project progress
4.0 Recommendations need to be supported by valid research

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Abbreviations

ELT	End-of-life tyre	LDPE	Low-density polyethylene
TDF	Tyre-derived fuel	HDPE	High-density polyethylene
CPT	Continuous Pyrolysis Technology (company name)	PP	Polypropylene

1.0 Introduction

1.1 Background and Justification for the Project

Every year more than one billion end-of-life tyres (ELT's) are disposed of globally. In New Zealand this amounts to an estimated 3.2 million *(MFE, 2004)*. Due to cost and lack of recycling processes in place, many ELT's are disposed of in landfill. This represents a substantial material waste. The materials and processes involved in tyre manufacturing result in difficulty in biodegrading, causing substantial environmental damage through leaching chemicals into the surrounding soil and waterways. Tyres have the tendency to make landfills highly unstable as they are bulky and have the potential for movement even when carefully stacked. Stacked tyres also pose a fire risk and, as burning tyres release highly toxic gasses, can become a serious health risk.

Figure 1.0: Tyre fire in Kuwait, April 2012 *(Alsultan, 2012)*

Some areas of New Zealand have experienced high instances of illegal dumping. This is due to policies implemented by selected landfills that restrict the dumping of whole tyres. As the population increases, the number of vehicles in circulation increases, and therefore so does the number of ELT's.

The Ministry for the Environment is working towards sustainable systems to manage ELT's *(MFE, 2006)*. As a result they are actively encouraging both recycling and the recovery of energy from tyres. Fulton Hogan has been investigating possible end uses for ELT's. Not only do they generate a substantial number of ELT's within Fulton Hogan due to having a high number of fleet vehicles, but they also have strong relationships with external companies who are also researching environmentally and commercially viable ways to dispose of ELT's. Fulton Hogan's aim is to invest in a system that is both environmentally sustainable whilst concurrently adding value and reducing costs within the company.

1.2 Continuous Pyrolysis Technology

Whilst there are a number of different ways that ELT's are recycled around the world, this project investigates the disposal of ELT's through a process of continuous pyrolysis technology (figure 2.0). Pyrolysis is the thermal decomposition of materials in a zero-oxygen environment that prevents combustion or gasification taking place. The end products are oil, char, and synthetic gas (syn-gas). The pyrolysis oil has a similar calorific value as diesel fuel. Char can be upgraded to carbon black which can then be sold on the international market. The syn-gas is high in Hydrogen and Methane and can be used as a replacement for liquid petroleum gas (LPG). All of these end products are of high value as raw materials. Continuous pyrolysis technology as a process has been proven on a pilot plant and as such is deemed to be commercially viable without subsidies *(Hoddinott, 2011)*. Figure 2.0 shows the basic outline of a continuous pyrolysis machine as seen in a design created by a New York based engineer, Tom Nekut *(Nekut, 2008)*.

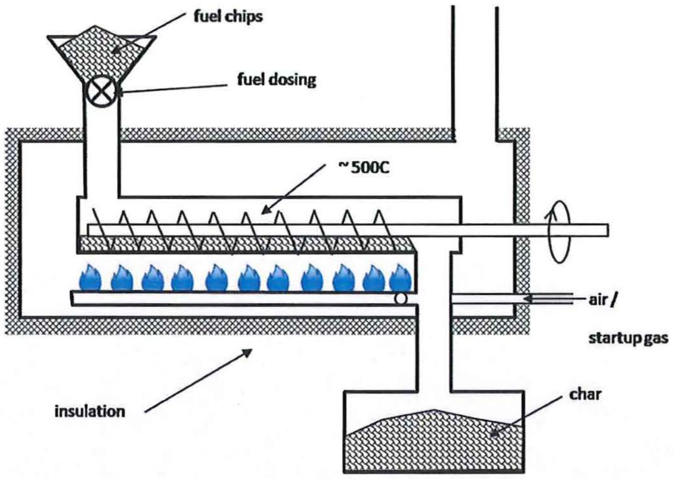


Figure 2.0: Continuous pyrolysis technology *(Nekut, 2008)*

Continuous pyrolysis technology utilises a continuous feed-cycle as opposed to batch pyrolysis which is seen more commonly around the world. It is important to determine the differences seen between the various forms of pyrolysis as research information based on various ways to alter product yield may be affected and/or limited by the technology used. A more in-depth explanation is shown in appendix 1.0.

Many studies conducted on altering product yield are based on batch pyrolysis as these pyrolysis machines are more commonly used *(Pradhan & Singh, 2011; Williams, Bottrill, & Cunliffe, 1998)*. This is critical for the project as phase two investigates ways in which product yield can be altered depending on the required outcome. Whilst there are differences in the technology, many factors remain the same as continuous pyrolysis including:

- Both use a high temperature reactor that utilises combustion with zero oxygen
- Both use a cooling of quenching system to separate the vapours into gas and oil
- Both can be used with the same feedstock (tyres, plastics and organics)
- Both result in the same end products (gas, char and oil)
- In both systems, altering the feedstock alters the product yield
- The energy required for both continuous and batch pyrolysis to drive the reactor comes from LPG or the LTG (liquefied tyre gas) produced during the pyrolysis process

1.3 Description of the Problem

A large number of used tyres and other recyclables are disposed of at landfills every year throughout New Zealand. Fulton Hogan does not have adequate processes in place to deal with the disposal in a way which is environmentally friendly and delivers value for the company. Costs for providing heating fuels for bitumen and asphalt (manufacturing) plants along with other business activities are increasingly high. Fulton Hogan is currently using waste oil at a number of its manufacturing sites but the supply of this heating fuel energy source is now threatened as market users recognize the potential of waste oil as a lower cost energy alternative.

2.0 Development of a Course of Action

The initial stages of the project consisted of developing a plan and charter. The plan developed a clear course of action by identifying the projects objectives, specific steps to achieve the required end results and a schedule for these steps.

2.1 Project Objectives

Aware of the technology behind pyrolysis, Fulton Hogan has developed an alliance with Christchurch based company, CPT (the company is branded after the technology on which it is based). CPT has built a prototype pyrolysis plant that has the capacity to process 300kg of tyres per hour. Fulton Hogan is now at the stage of investigating the supply chain, logistics, and possible implementation of a full-sized commercial plant. Based on the requirements outlined by Fulton Hogan, the project objectives were defined as the following:

- Complete a literature review on pyrolysis and case studies of implementation of pyrolysis plants in New Zealand and in other countries
- Complete market research on the supply chain of tyres within New Zealand
- Complete an analysis of possible locations for implementing full-sized commercial pyrolysis plants within Fulton Hogan in New Zealand
- Investigate options for the end uses of raw materials of pyrolysis
- Produce a report with recommendations for the implementation of continuous pyrolysis within Fulton Hogan in New Zealand

2.2 Steps to Achieve Required Results

The project objectives provided a clear guideline for what was required to complete the project. The full work breakdown structure with specific steps to achieve results can be seen in appendix 2.0.

A literature review was completed to provide background information on the topic of the project. Although it was completed after the project plan and charter, it provided a guideline for developing a course of action on what should be investigated during the market research section. It also provided an insight into possible end uses for the raw materials oil, gas and char, and specifications for a site for the location analysis. The full literature review can be seen in appendix 3.0.

Market research was critical in providing an insight into the supply chain of tyres and the retail market around New Zealand. It also provided information in regards to previous implementations of pyrolysis and other recycling options for tyres.

The report on the potential uses of the recycled end materials was critical in highlighting ways in which the product yield could be altered to give optimum outcomes based on Fulton Hogan's requirements for heating fuels for their bitumen and asphalt (manufacturing) plants. It also gave possible markets where the products not required by Fulton Hogan could be sold.

The last part, the location analysis was important for providing a basis for recommendations around how and where to implement pyrolysis plants within New Zealand.

2.3 Schedule

A schedule was determined based on time allocated for the entire project. Specific tasks were allocated time based on their significance. Market research was given the largest portion of time based on project requirements. Due to the closure of the Fulton Hogan offices through the Christmas period, the location analysis was completed after the report on end uses of raw materials. The full schedule can be seen in the Gantt chart shown in appendix 4.0.

3.0 Phase One: Literature Review

The literature review highlighted some critical points that assisted with determining the future progress for the project. These are summarised in three initial sections: case studies, pyrolysis technology, and evidence of implementation of pyrolysis technology in New Zealand. The final section, an overview of the Tyrewise report, provides information on the ELT market situation in New Zealand. This report was commissioned in 2012 by the New Zealand government. The full literature review is shown in appendix 3.0.

3.1 The Implementation of Pyrolysis Technology: Commercial Case Studies

This section looked at previous examples of pyrolysis within the international market. The research provided vital information on reasons why pyrolysis has not been commercially successful or issues that have arisen during the development of large pyrolysis plants.

- Costs for manufacturing and maintenance of the pyrolysis equipment can be very high *(Samoladaa & Zabaniotou, 2012)*. It appears that a number of companies that have developed pyrolysis plants have sourced external funding for the equipment *(Chang, 2008; Samoladaa & Zabaniotou, 2012)*. Funding is seen as a major barrier for the implementation of pyrolysis technology. The most economically feasible plant size is deemed to be a full-sized commercial plant, with an operating capacity around 140 tonnes of tyres per day. A plant this size costs in the realm of US$5-$7m to build and therefore represents a significant investment *(Islama, Joarddera, Hasana, Takaib, & Haniub, 2011)*.
- Poor design of pyrolysis plants accompanied with technical hurdles result in a high yield of char or a poor quality of product. Char requires further refinery before sale and as such is often dumped *(Uruburua, Ponce-Cuetoa, Cobo-Benitaa, & Ordieres-Meré, 2012)*. A lack in technical expertise is one major reason that pyrolysis plants fail economically *(Samoladaa & Zabaniotou, 2012)*.
- End products char, oil and gas have limited markets due to their chemical composition *(Li, Xu, & Tao, 2010)*. There are difficulties in competing with crude oil due to relatively low prices at present. Rising prices may make pyrolysis more economically viable in the future *(Sienkiewicz, Kucinska-Lipka, Janik, & Balas, 2012)*. A case study based on a plant in China highlights composition issues with the end products, in particular the need to refine the pyrolysis oil before it can be used for fuel therefore reducing any profit made *(Li, Xu, & Tao, 2010)*.
- Government subsidy may be required for the collection of tyres to ensure that the process remains economically viable. This is due to high transport costs associated with moving bulk tyres *(Samoladaa & Zabaniotou, 2012; Chang, 2008)*.
- Legislation barriers exist as pyrolysis in some countries is classed as incineration. Studies show incineration results in increased emissions that negatively impacts the environment. Global commercialisation of pyrolysis may require significant legislative changes *(Samoladaa & Zabaniotou, 2012)*.

3.2 Pyrolysis Technology

Pyrolysis as an economically viable technology has problems due to the quality of the end products. This section of the literature review looked at ways in which the product yield and quality can be altered.

- The oil has been shown to be high in PAH which are carcinogenic, mutagenic and generate increased emissions (soot) on combustion. As such, many pyrolysis companies chose to refine the oil or sell it directly to a diesel refinery *(Williams, Bottrill, & Cunliffe, 1998; Cunliffe & Williams, 1998; Gerald, 2007; Williams & Besler, 1994; Williams & Taylor, 1993; Sánchez, Callejas, Millera, Bilbao, & Alzueta, 2012)*.

- The oil is also very high in sulphur, however this can be reduced. The char is low-grade and therefore needs to be refined in order to produce carbon black or sold for a lower price. Companies may choose to dump it due to being unable to source a buyer *(Williams, Bottrill, & Cunliffe, 1998; Cunliffe & Williams, 1998)*. The gas has limited use due to its chemical composition and is therefore usually used to fuel the pyrolysis reactor *(Williams, Besler, & Taylor, 1990)*.
- Increasing the temperature of the reactor reduces the yield of char and increases the oil and gas yield *(Williams, Besler, & Taylor, 1990)*. This was disproven by a separate study which showed that the char and gas yield increased and oil yield decreased with rising temperatures *(Cunliffe & Williams, 1998)*. This highlights the differences in pyrolysis design and implementation, and reinforces the need for additional research and development.
- Char may be refined to carbon black which will increase its value on the international market therefore making pyrolysis an economically viable process *(Professional Engineering, 1999)*.
- A number of different feedstocks can be used for pyrolysis. This includes tyres, plastics and biomass, although these all produce different end products *(Williams & Besler, 1994; Kanaujia, Sharma, Agrawal, & Garg, 2012; Adrados, de Marco, Caballero, López, Laresgoiti, & Torres, 2012; Pinto, Costa, Gulyurtlu, & Cabrita, 1999)*.

3.3 Pyrolysis in New Zealand

Pyrolysis and other methods of tyre recycling have been researched and in some cases implemented in New Zealand. This section of the literature review investigated case studies of pyrolysis in New Zealand and how successful they were.

- There are records of a Hamilton based company that has built a prototype plant and is looking for funding to expand. Tyregone processors have received government funding of NZ$300,000 for the research and development of a plant in the Auckland area that will have the capacity to process a third of New Zealand's total scrap tyres. Currently the prototype plant processes 2,000 tonnes a year. This could be an issue for Fulton Hogan going forward as they may end up competing directly for a consistent supply of tyres in this area *(Voxy, 2010; MFE, 2011)*.
- Carbon Recovery Ltd. is a company based in Waikato that focusses on shredding scrap tyres and shipping them to Korea to be incinerated as fuel in large cement kilns. They focus on tyre recovery and collection. Carbon Recovery Ltd.'s business strategy is to charge customers for tyres to be removed. This includes large quarry and mining tyres. They also work with councils to clean up illegal dump sites *(Carbon Recovery Ltd, 2012; Enriching the Environment, 2012; Coast and Country, 2012; Q&M, 2010)*.
- Environment Waikato is undertaking a study to look at the possibilities of implementing pyrolysis for the decomposition of organic waste. They have also received government funding for this project *(MFE, 2011)*.
- Recyclotech Industries is a company that is in its initial development stage. They are sourcing a pyrolysis plant from China and are looking for capital investment *(RTI NZ, 2012)*.
- The Ministry for the Environment highlights low landfill costs as the primary barrier for the implementation of recycling processes for scrap tyres. They recommend legislation changes including the possible implementation of an Advanced Disposal Fee (ADF), to be charged to all tyre manufacturers and importers. This money will then be used to fund recycling plants and processes as well as tyre transportation costs *(MFE, 2006)*.

3.4 The 2012 Tyrewise Report

In 2012 the New Zealand government commissioned a report on product stewardship for ELT's in New Zealand *(Tyrewise, 2012)*. This report highlights some issues in regards to tyres and the retail and disposal industry:

- The composition of tyres is predominantly rubber (around 70%) for all tyre types. Weight varies, from 4kg for a motorbike tyre, 8kg for a passenger tyre, and up to 3 tonne for an off-road vehicle tyre. Total ELT's generated in 2011 were 4.8m which equalled around 80,000 tonnes *(Tyrewise, 2012)*.
- 74% of tyres being imported are new tyres, 20% on vehicles and 6% as used tyres *(Tyrewise, 2012)*.
- There are around 1,500 tyre retailers in New Zealand. The average store collects around 400 ELT's every week. Disposal costs at these retailers range from $2.50-$4 for passenger tyres and $6-$16 for truck tyres depending on size *(Tyrewise, 2012)*.
- Pyrolysis could be implemented as a possible end use for ELT's. There are no limits on the types of tyres that can be used in pyrolysis. Based on financial modelling, for a plant to be economically viable it must process around 9,100 tonnes of ELT's annually *(Tyrewise, 2012)*.

3.5 Phase One: Concluding Statement

The literature review identified a large number of ELT's both within New Zealand and around the world that need to be disposed of in an environmentally sustainable way. As a value-add process combined with the potential to generate energy, pyrolysis is an attractive proposition. The literature demonstrated that technology, however, may not have developed to a point where pyrolysis can be implemented in an economically and commercially viable way. Potential end uses for the products (oil, gas, and char) in their raw form, and ways in which to refine these products, are investigated in a later phase of the project.

This phase of the project also provided an insight into the tyre industry within New Zealand and pyrolysis trials that have been undertaken. Pyrolysis and the tyre industry are investigated in the next phase of the project.

4.0 Phase Two: Market Research

Market research was identified as the key part of the project as it provided critical information on the supply chain of tyres. This report covers both the collection of data and recorded results.

4.1 Collection of Data

As the data required information from a wide variety of locations from New Zealand, information was collected via telephone interviews. Other data collection tools used included:

- Internet and literature research to support information collected via interviews including domestic and international examples
- Email however direct contact via telephone was shown to be a more successful
- A number of site visits were made and information was collected from qualified personnel on site

Internet and literature based research was conducted to identify key players in the tyre industry throughout New Zealand and to support information gained in the interviews. Telephone interviews were conducted with:

- 17 Beaurepaires outlets in the South Island and 47 outlets in the North Island
- 20 Carter's Tyre Service outlets (North Island only)
- Bridgestone head office
- Major tyre collectors including:
    - Tyre Collection Services

  - Scrap Tyre Movements
  - Tyre Removals
  - M.E. Jukes and Sons
  - Pacific Rubber
  - J & J Laughton
  - Carbon Recovery
- Other companies involved in the tyre business:
  - EcoDrop

Plastics are not currently an option for use as feedstock for pyrolysis in the prototype plant that CPT has developed due to a lack of research and development, and technical expertise in this area. For this reason, time spent researching the supply chain of plastics has been minimalized to provide an overview of the market in the Christchurch area. The following companies were identified as key players and therefore researched:

- Mastagard
- Agpac
- Compounding Specialists Ltd (Comspec)
- Christchurch City Council

4.2 Results

Data has been separated into three sections – the supply chain of tyres in the South Island, the supply chain of tyres in the North Island, and an overview of the supply chain of plastics within the Christchurch area. The South and North Island are separated as ELT numbers predict that there will be sufficient tyre supply to develop two pyrolysis plants.

4.2.1 South Island: Supply Chain of Tyres

Based on one ELT per person and the most recently released census results, there is an estimated 537,000 ELT's generated annually in Canterbury and just over 1 million in the whole of the South Island.

4.2.1.1 Tyre Collectors

Market research results showed that many ELT's in the South Island go to famers as silage pit covers. For the disposal of large quantities of tyres, there are two main tyre collectors in the South Island:

- Scrap Tyre Movements
- Tyre Collection Services

Cost for tyre disposal by these tyre collectors range from $3-$5.50 depending on location and weight of the tyre. For larger tyres this cost can be as high as $100 per off-road tyre. It is more expensive to dispose of tyres in the South Island due to increased transportation distances and therefore increased costs. There appears to be no tyre collectors operating in Dunedin however Scrap Tyre Movements have been planning on expanding their business south. Currently tyre disposal in Dunedin is processed via the city council rubbish disposal system which sends all tyres to landfill.

Table 1.0 shows the key business activities of the two South Island based tyre collectors. In table 1.0 the column marked 'total ELT's collected refers to information gained directly from the tyre collector. The column marked 'adjusted estimate' refers information based on wider research including retailers and market share estimates. More detail is shown in appendix 5.3 and 5.4.

Tyre collector	Total ELT's collected (annually)	Adjusted estimate	Area servicing	Disposal method	Interest/ knowledge of pyrolysis
Scrap Tyre Movements	300,000	300,000	Nelson through to Temuka	Bale tyres whole and send to Asia	Interested but limited by funding
Tyre Collection Services	104,000	200,000	Canterbury	Bale tyres whole and send to Asia	Interested but limited by funding

Table 1.0: South Island tyre collectors *(based on market research)*

Both Scrap Tyre Movements and Tyre Collection Services provide a service to various city councils throughout the South Island, assisting with general tyre disposal and clean-ups of illegal dump-sites. A clean-up for the new subdivision in Rolleston cost approximately $50,000 and was paid for by the council. A secondary dump was found behind the airport. The collector who had been dumping in this area was held accountable for the costs, which totalled approximately $250,000. These examples highlight the potential market for tyre disposal.

4.2.1.2 Other Disposal Companies in the Tyre Industry

In Christchurch, EcoDrop acts as a transfer station for ELT's and other recyclable waste. They collect an estimated 800-1000kg of ELT's weekly however it is thought that this may be much higher if disposal price was reduced. More detail is shown in appendix 5.5.

Throughout Canterbury there are a number of transfer stations that accept ELT's. These are collected by tyre collectors or transferred to the Kate Valley Sub-Regional Landfill. The transfer stations and landfill charge $6-$35 for disposal depending on tyre size. As the landfill is not close to Christchurch city the majority of residents wanting to dispose of tyres dispose of them at local garages, workshops or tyre providers. Due to the disposal charge involved, these sites often report tyre dumping after hours.

There are two Dunedin landfills, both of which charge $3.10 per car tyre disposed and $302.50 per tonne for larger quantities. The Dunedin City Council disposal system sends all tyres collected to landfill. More detail is shown in appendix 5.6.

4.2.1.3 Waste Removal Companies

Southern X Press is a South Island based waste removal company that deals with commercial (including agricultural) and residential recyclables including paper, cardboard, plastic and tyres. They are currently investigating implementing a pyrolysis plant for energy recovery from ELT's.

4.2.1.4 Tyre Retail Outlets

Market research indicated that the major retailers in the South Island are Bridgestone and Beaurepaires, both with 17 retail outlets from Southland to Marlborough. Bridgestone has a further 3 stores trading as Tony's Tyre Service. Table 2.0 provides an overview of information recorded through market research. These results are for the South Island only. More detail is shown in appendix 5.1 and 5.2.

Tyre Retailer	Information gathered
Beaurepaires	• Market research showed that Beaurepaires collects an estimated 86,000 ELTs' per annum. Based on market share this figure is likely to be closer to 200,000 tyres. • The only tyre collection company used within Beaurepaires in the South Island is Tyre Collection Services Ltd. • Some retail outlets give their tyres away for silage or dump them in landfill. • A few outlets listed "customers collecting tyres for various uses such as gardening, landscaping or children's play areas" as one end use of ELT's.
Bridgestone	• Bridgestone collects an estimated 195,000 tyres per annum.

	• Fulton Hogan has a relationship established with Bridgestone through the supply of new and re-treaded tyres for commercial vehicles. • Bridgestone have agreed to supply sufficient quantities for the prototype plant of shredded or chipped tyres. Ideally Bridgestone will also have sufficient supply of ELT's to provide 60 tonnes per week for the proposed South Island full-sized pyrolysis plant.
West Coast tyre retailers	• On the West Coast of the South Island tyres have a residual value of around $1. This is due to demand from farmers needing tyres for silage pit covers. • Due to silage usage tyre retailers in this area do not record a significant number of the ELT's that they deal with therefore estimates for the West Coast are likely to be wrong.

Table 2.0: Major tyre retailers in the South Island *(based on market research)*

4.2.2 North Island: Supply Chain of Tyres

The variation in the number of ELT's between a quiet week and a busy week is much higher in the North Island than in the South. According to population estimates there could be around 3.4m ELT's generated annually in the North Island, with 1.5m being in the Auckland area alone, although no accurate records for these figures exist.

4.2.2.1 Tyre Collectors

Major tyre collectors in the North Island are Tyre Removals Ltd, Pacific Rubber, M.E. Jukes and Sons and J & J Laughton. Cost for passenger tyre disposal by these tyre collectors range from $2-3.50 depending on size and weight of the tyre. Larger tyres are priced according to weight.

Table 3.0 shows these tyre collectors and key information on their business activities. More detail is shown in appendix 5.10, 5.11, 5.12, 5.13 and 5.14.

Tyre collector	Total ELT's collected (annually)	Area servicing	Disposal method	Interest/ knowledge of pyrolysis
Tyre Removals Ltd (Auckland)	180,000	Auckland area from Pukekohe to Orewa	Bale tyres whole and send to Asia for material recovery or TDF	In the process of purchasing a batch pyrolysis plant from China
Pacific Rubber (Auckland, Wellington and Kerepehi)	300,000 passenger, 104,000 truck, 50-100 off-road tyres	Regular service for all of North Island and pre-arranged pick-up in the South Island	Bale or process into rubber crumb and sell for industrial/ construction purposes	Interested at the possibility of implementing TDF in New Zealand, no interest in pyrolysis
M.E. Jukes and Sons (Gisborne)	5,000-6,000	Gisborne area only	Dispose of in own landfill	No interest
J & J Laughton (Auckland)	Would not disclose but holds significant market share	Rodney, Auckland and the Waikato	Shred or crumb tyres and sell for horse arenas and sports turfs	Working alongside Tyregone processors in development of a pyrolysis plant in Glendale, Auckland
Carbon Recovery Ltd (Tauranga)	Would not disclose but holds significant market share	All of North Island with pre-arranged pick-ups in the South Island	Send to Asia for use as TDF	Interested at the possibility of implementing TDF in New Zealand, no interest in pyrolysis

Table 3.0: North Island tyre collectors *(based on market research)*

Other smaller tyre collection companies in the North Island are:

- Tyre Disposal Services – Petone, Wellington
- Rubber Solutions Ltd – Upper Hutt
- The Retired Tyre Company – Napier
- Enviro Tyres – a transportation company that collects tyres on behalf of Carbon Recovery Ltd

4.2.2.2 Waste Removal Companies

Various waste removal companies, including Transpacific, Envirowaste, Manawatu Waste and Budget Waste also remove ELT's. In the Wellington area Al's Bins Ltd is widely used for rubbish and tyre removal, taking all ELT's to the Southern Landfill.

4.2.2.3 Tyre Retail Outlets

Major tyre retailers in the North Island are:

- Beaurepaires with 47 retail outlets
- Carter's Tyre Service with 20 retail outlets
- Bridgestone with 41 retail outlets. Bridgestone own a further 18 stores trading under Tony's Tyre Service.

A number of smaller, independent retailers, garages and workshops also exist. Tyres4U is listed as being a major player in the tyre industry however they operate through other retailers, predominantly independently owned stores.

Table 4.0 provides an overview of information recorded through market research for the North Island. Retailers north of Auckland dispose of all tyres in landfill due to the lack of tyre collection services available. There was an attitude associated with these retail outlets that they were not interested in tyre recycling due to cost and availability. More detail is shown in appendix 5.6, 5.7, and 5.8.

Tyre Retailer	Information gathered
Beaurepaires	• Beaurepaires disposes of around 195,000 ELT's annually through 47 retail outlets. • Most of the retail outlets in the Auckland area used J & J Laughton for tyre collection. • The Beaurepaires outlets in the Wellington area predominantly use Al's Bins Ltd, who specialise in rubbish removal and as such takes all tyres to landfill. • Beaurepaires has a similar market share to Bridgestone who dispose of 650,000 ELT's across the North Island. Based on these market figures, it is likely that Beaurepaires (and Carter's) disposes of significantly more than the 300,000 tyres recorded through market research. • Several retail outlets contacted would not disclose or found it difficult to estimate how many tyres they disposed of.
Carter's Tyre Service	• Carter's Tyre Service disposes of approximately 92,000 ELT's annually. • Carter's Tyre Service owns 17 Beaurepaires retail stores throughout the North Island. • They also own Swartz Tyre Ltd in Wanganui and Tunnell Tyres and Garage Ltd in Masterton. • They have recently purchased a further 24 stores in the South Island however these are yet to be re-branded and as such remain in this report as Beaurepaires stores.
Bridgestone and Tony's Tyre Service	• Bridgestone disposes of 850,000 tyres nation-wide, with more than 650,000 tyres being disposed of in the North Island. • All retail outlets in the North Island use Pacific Rubber for disposal of all truck tyres and Waste Tyre Solutions for passenger vehicle tyres. • Bridgestone currently holds 40% of the market share for truck tyres nationwide.

Table 4.0: Major tyre retailers in the North Island *(based on market research)*

4.2.2.4 North Island Landfills

The cost to dispose of tyres at landfills across the North Island varies significantly. Car tyres vary from $3-$5 and truck tyres from $10-$15.30. Off-road tyres can cost up to $100 per tyre to dispose of at landfill. Mixed loads of tyres, where the quantity or type is undeterminable, can cost from $324.50-$500 per tonne. Many of the landfills will not accept whole tyres but require them to be quartered or have the sides cut out of them prior to dumping. This prevents the tyres from floating to the surface and making the landfill unstable. Legislation around the disposal of hazardous waste, including tyres, is currently in the process of shifting towards inhibiting dumping with tyre recycling processes being listed as a high priority.

More detail on landfills in the North Island is shown in appendix 5.9.

4.2.3 Supply Chain of Plastics

Various forms of pyrolysis have been used for the thermal decomposition of plastics *(Adrados, de Marco, Caballero, López, Laresgoiti, & Torres, 2012; Huffman & Shah, 1998; Paradela, Pinto, Gulyurtlu, Cabrita, & Lapa, 2009)*. For this reason there is potential for plastics to be used as a feedstock for the CPT plant providing the team at CPT are able to develop adequate technology.

From 2002-2004 to 2007-2008 the weight of plastic waste increased from 6% to 8% of the total waste stream *(MFE, 2009)*. Each New Zealander uses approximately 36kg of plastic packaging per year and recycles 8.64kg *(Plastics NZ, 2012)*. An estimated 250,000 tonnes of plastic waste goes to landfill every year *(Recycle.co.nz, 2012)*. Many district councils across New Zealand have adopted zero-waste policies with the aim at reducing the amount of plastic and other solid waste going to landfill to zero by the year 2020 *(Snow & Dickinson, 2011)*. These policy changes make recycling options a key goal for all New Zealand individuals and companies. They also create new market spaces within plastic recycling and recovery processes where potential business could be generated.

With the recent initiatives for increasing plastic recycling in New Zealand, 24% of all plastic waste is now recycled. This has risen 46% over the past five years *(Plastics Org NZ, 2012)*. Figure 3.0 shows an increase in production and consumption from 1994 to 2008, but very little increase in recovery. There are currently no processes in place for energy recovery from plastics.

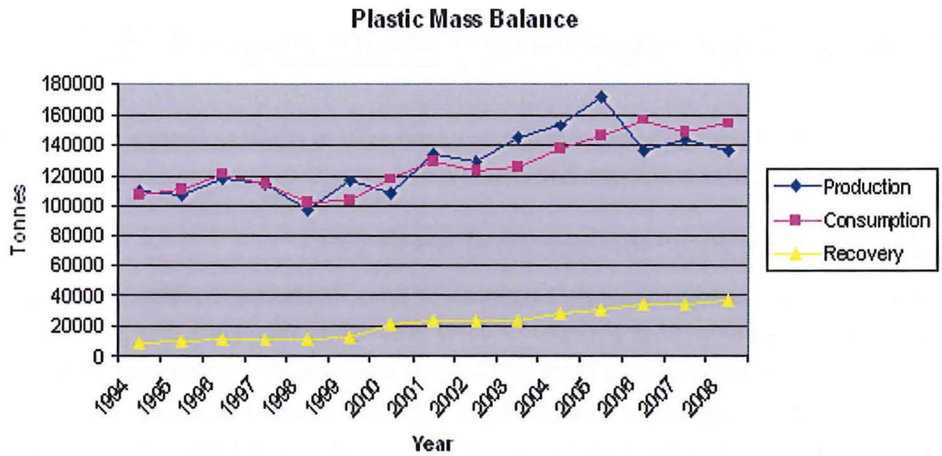


Figure 3.0: Plastic mass production, consumption and recovery from 1994 to 2008 *(Plastics Org NZ, 2012)*

There are two potential targets for energy recovery from plastics:

- Local disposal systems for household plastics – usually PET (1), HDPE (2) and a mixture of hard plastics
- Commercial disposal of films used for transport and packaging – shrink and shroud wrap

Some household plastics are recycled and the remainder goes to landfill at a cost to the council and to the environment. Costs to the council are then recovered through rates. Commercial plastic disposal is charged directly to the company through collection charges or skip hire costs. There are various recycling companies around New Zealand. Those that are Canterbury based have the support of the Sustainable Initiatives Fund Trust (SIFT). SIFT is a Canterbury based publicly funded charitable trust that provides financial support for innovative waste minimisation projects *(SIFT, 2012)*.

There are three recycling companies in Canterbury: Mastagard, Agpac and Comspec. Mastagard has the largest Christchurch based recycling plant, processing 30,000 tonnes of waste annually. Agpac has an agreement with Mastagard for recycling agricultural plastics. Comspec has a recycling plant based in Hornby, with the capacity to process 1000 tonnes of plastic milk bottles annually. These companies have agreements with local councils, major businesses, and farmers for recycling collections throughout the South Island. The Christchurch City Council has a recycling plant in Sockburn which opened in 2009. It separates paper, plastic and glass into bales, sending them to international facilities for recycling. This is used for residential and commercial waste disposed of through the council disposal system. More detail is shown in appendix 5.15.

4.3 Phase Two: Concluding Statement

This phase of the project has provided a clear insight into the supply chain of tyres within New Zealand. It is shown that the tyre collection business has severe restrictions and low profit margin. Tyre collection companies are unable to expand due to existing contracts between retailers and collectors. They are unable to increase profit margins due to high competition. Although there are several tyre collectors in the North Island that have recycling processes in place, such as baling or crumbing tyres for industrial and construction purposes, many pay to send tyres to Asia. This represents space in the market to implement a pyrolysis plant with a clear supply of tyres from these tyre collectors. There is also potential to offer low-cost or free tyre collection directly to major tyre retailers including Beaurepaires, Carter's Tyre Service, and Bridgestone.

Although there may be space in the ELT market to implement a tyre recycling plant such as the proposed CPT plant, the end uses for the recycled products will need to be carefully considered in order to make the project commercially viable. This is further investigated in the next phase of the project.

5.0 Phase Three: Identifying Possible Uses for the Recycled End Products

The aim of this phase of the project was to show potential uses for the recycled materials which are produced from the crumbed or shredded during the pyrolysis process and ways in which to change the potential yield of these products. These end products are oil, gas and char.

5.1 Quantities Produced through Pyrolysis by CPT

The prototype plant will process approximately 54 tonnes of tyres, producing 10,000L of oil, 3,375kg of gas (equivalent to 4,320kg of LPG due to having a calorific value 30% higher than LPG), and 27 tonnes of char per month. The proposed three-line commercial plant will process approximately 270 tonnes of tyres, producing 50,000L of oil, 16,875kg of gas (equivalent to 21,600kg of LPG) and 135 tonnes of char per month. A larger, five-line commercial plant will process 450 tonnes of tyres, producing 83,300L of oil, 28,125kg of gas (equivalent to 36,000kg of LPG) and 225 tonnes of char per month. The approximate percentage breakdown of these products is shown in figure 4.0.

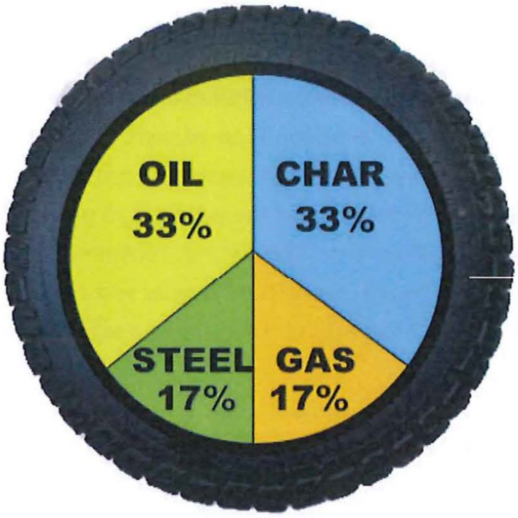


Figure 4.0: Raw materials produced by CPT *(Hoddinott, 2011)*

There are various ways to increase the yield of oil and gas and reduce the yield of char. This includes altering the reaction temperature and speed and the cooling process. The use of pyrolysis oil in the burners at the bitumen and asphalt plants of Fulton Hogan relies heavily on consistency in quantity and quality produced by CPT. There may be issues with the chemical composition of both the gas and the oil. Additives may be used as catalysts to reduce the sulphur content of the pyrolysis oil. More detail on pyrolysis oil, gas and char is shown in appendix 6.0.

5.2 Requirements for the Bitumen and Asphalt Plants

The Christchurch bitumen plant located in Lyttelton requires 6,000L per month of oil. The build of the burner requires low ash content therefore it will be necessary for the pyrolysis oil to the treated prior to use. As the prototype plant has the capacity to produce 10,000L per month there will be an excess of 4,000L of oil. In a three-line commercial plant the excess would amount to 44,000L per month therefore there are further opportunities for sale of or energy generation from the oil.

For bitumen and asphalt plants at various locations around New Zealand the amount of oil required for the burner will vary depending on operating capacity and current usage. There is also potential to use gas in the Fulton Hogan burners however this is dependent on how much gas CPT is able to produce and how much is required for the pyrolysis reactor.

5.3 Potential Markets and Options for Exporting Energy Back to the Grid

Fulton Hogan has been investigating options for exporting energy to the grid as this could reduce on-site energy costs and turn-over a profit. Options include using oil or gas in generators or heating burners, or through co-firing char with coal. More detail on options for exporting energy is shown in appendix 7.0.

5.3.1 Pyrolysis Oil

The end use of oil is limited by the chemical composition – predominantly the high sulphur content, high ash content and the viscosity. Studies have shown that once the sulphur has been removed it is possible to blend the oil with diesel in a ratio of 70/30 (oil/diesel) to produce a fuel that can be used in diesel engines *(Murugan, Ramaswamy, & Nagarajan, 2008)*. Studies have also shown that pyrolysis oil has the potential to become more viscous with time in storage therefore this will need to be monitored during the prototype trial with CPT *(Ringer, Putsche, & Scahill, 2006)*.

5.3.2 Syn-gas

There is potential to use the gas produced in a syn-gas generator to produce energy which can then be used to supply energy for the site on which the generator is established as well as exporting energy to the grid. This is limited by the gas yield produced by CPT. One option is to convert the oil to gas via gasification therefore significantly increasing the gas yield however this is an expensive process due to the equipment required. Several companies across Australia use this set-up with the pyrolysis of organic biomass. Gough CAT has both diesel and syn-gas generator sets available for hire. They do not recommend anything other than pure diesel to be used in their diesel generators due to the inconsistent quality and ash content of used oil which has the potential to cause significant problems with the engine. They have no experience with used oil.

5.3.3 Char

Char is a high energy fuel with a similar calorific value to coal and as such may be co-fired with coal. It also has the potential to be upgraded to carbon black however this incurs significant cost due the technological processes required. Tyre-derived carbon black has also been used as an additive for bitumen and this could be a potential end use within Fulton Hogan. CPT has investigated various options for char. Holcim New Zealand Ltd has agreed to purchase the char at the same cost as coal throughout the trial stages of the pyrolysis plant.

5.4 Examples within Australia

Whilst Australia has several mobile and commercial sized pyrolysis and gasification plants for processing biomass and sewage, they do not have any plants for processing used tyres. Several projects have been or are waiting commissioning and have development plans in progress. The biomass and sewage facilities are designed to generate energy, supplying sufficient energy for the site as well as providing excess that is exported to the grid. Pyrolysis for the thermal decomposition of tyres has been listed as being un-economical and not commercially viable in regards to recycling and energy recovery options for waste within Australia. Further information on pyrolysis in Australia is shown in appendix 8.0.

5.5 Phase Three: Concluding Statement

Although markets exist for the end products of pyrolysis, (oil, gas and char) issues in quality may limit market value. This phase of the project highlights ways in which these products can be altered to increase their value. Examples of organic biomass pyrolysis facilities in Australia show the potential to generate energy. If Fulton Hogan were to implement pyrolysis oil generators, significant site savings would be achieved.

At this stage CPT has made preliminary arrangements to sell the char to Holcim cement for $0.26 per kg, a similar price to coal. The gas will be used to fire the pyrolysis reactor and if there is excess it was be available for purchase for $0.75 per kg. The pyrolysis oil will be sold to Fulton Hogan at $0.55 per litre. This price represents a substantial saving as the current commercial diesel fuel price is around $1 per litre. Further trials will provide information on oil quality and exact quantities that will be produced should a commercial plant be developed. Phase four of the project identities potential sites for a commercial plant.

6.0 Phase Four: Location Analysis

A location analysis was carried out to provide options for implementing pyrolysis within Fulton Hogan. Constraints driving site selection were identified and from these constraints a number of sites were found to have potential. The South Island and North Island data was analysed separately and one site in each island was identified as having the most potential and therefore recommended. More detail on site selection is shown in appendix 9.0.

6.1 Constraints Driving Site Selection

It was established that there are various constraints driving site selection when analysing potential sites for a three or five-line operation commercial plant. These constraints include cost, proximity to tyre supply, proximity to bitumen and asphalt (manufacturing) plants, availability of suitable space, and availability of water and electricity.

6.1.1 Cost

As this project is investigating the implementation of continuous pyrolysis technology in Fulton Hogan, it is critical that the sites are low cost and are easy to access by Fulton Hogan staff and vehicles. Sites already owned or leased by the company will be more cost effective than procuring land that is not. For this reason only sites already in use by Fulton Hogan are investigated in this report.

6.1.2 Proximity to Tyre Supply

Proximity to tyre supply is critical as tyre transportation can be expensive. The large rural areas in the South Island make transportation costs higher than in the North Island. Tyres that are pre-shredded will occupy less space and therefore cost less per unit to transport. It is, however, likely to be more feasible to shred the tyres once they are on-site due to the logistics of transporting a shredding machine. In the trial stages Bridgestone will provide pre-crumbed or pre-shredded tyres which will eliminate the shredding phase of the process.

At this stage, plans recommend that tyre transportation costs are to be covered by CPT, however due to the start-up position of the company, plans will need to be monitored and updated based on progress. Fulton Hogan will be unable to buy reduced price oil if CPT is incapable of funding the tyre transportation. Also increased transportation costs are likely to push up the oil price due to CPT maintaining their profit margin.

6.1.3 Proximity to Bitumen and Asphalt (Manufacturing) Plants

The primary end use of the pyrolysis oil purchased by Fulton Hogan is likely to be as a fuel in the bitumen and asphalt manufacturing plants. For this reason it would be beneficial to have the pyrolysis plant within reasonable proximity to at least one of these plants to reduce costs. Reasonable proximity will be determined on a case-by-case basis and will be subject to the availability of the recommended site.

6.1.4 Availability of Suitable Space

Space and suitable space need to be determined individually. Whilst many of the quarries may have sufficient space to build a pyrolysis plant, the space may not be suitable due to proximity to local residents, existing development and use of the site, the presence of overhead power lines or large transformers, and the ability to gain resource consent. On-site hazards such as the flare (required as an outflow for excess gas) require additional space. Associated hazards are outlined in appendix 9.1.4.

6.1.5 Availability of Water and Electricity

Health and safety requirements and plant operational requirements identify the need for water and electricity on-site. Whilst it is possible to connect these over long distances, due to cost it is beneficial to have them in close proximity to the plant.

6.2 South Island

Market research indicates that Canterbury has the highest tyre volume in the South Island with a total tyre volume of approximately 150,000 tyres and a total share of 51%. This is shown in figure 5.0. The raw data is shown in appendix 9.1.1 and 9.1.2.

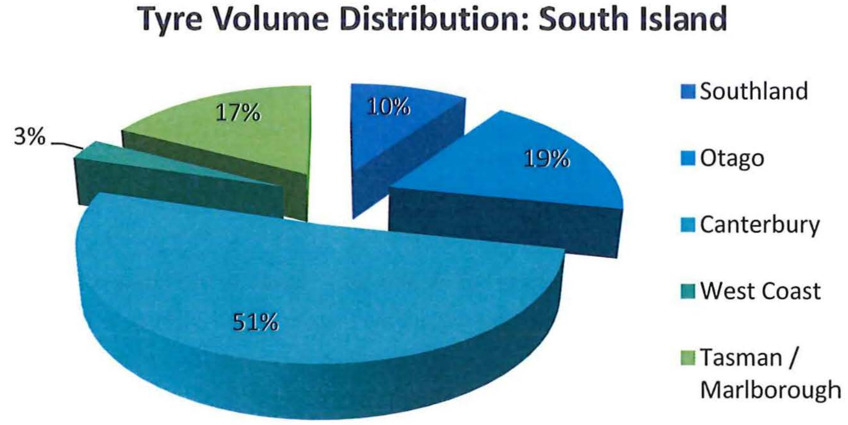


Figure 5.0: Tyre volume in the South Island based on regional distribution *(based on market research results)*

The two main tyre collectors, Scrap Tyre Movements and Tyre Collection Services are both Christchurch based, transporting tyres from a wide area to Christchurch. Both of these collectors currently pay to ship tyres to Asia and therefore represent potential tyre suppliers for a tyre pyrolysis plant in Christchurch.

Based on the location analysis completed the potential locations identified are Pound Road Quarry, Miners Road Quarry, Charlotte Jane Quarry and Coutts Island Quarry. Based on location requirements of proximity to water and electricity, as well as available space and ability to gain resource consent, Miners Road has been identified as the most suited location to develop a full-sized commercial pyrolysis plant. The Miners Road Quarry has an asphalt plant on-site which could potentially directly utilise pyrolysis oil. The nearest bitumen plant is located in Lyttelton at a distance of 28km.

Appleby Quarry, in Nelson, has been identified as a potential site for a smaller commercial plant. The Nelson Plant in Port Nelson is the closest bitumen plant, located 17km away. The Nelson and Marlborough region generates approximately 50,000 ELT's or 17% of the total volume. Due to distance from Christchurch it may be more economically viable to process these tyres within the region rather than transporting them to Christchurch. Otago generates 19% of the total tyre volume however proximity to Christchurch means that transportation costs will not be as high. It is recommended that a Christchurch plant be implemented with regular tyre transportation from Dunedin and the surrounding areas.

6.3 North Island

Auckland has the majority of the tyre share with 29%, followed by Wellington with 21%, Waikato with 12% and the Bay of Plenty with 11%. This is shown in figure 6.0. Raw data is shown in appendix 9.2.1 and 9.2.2.

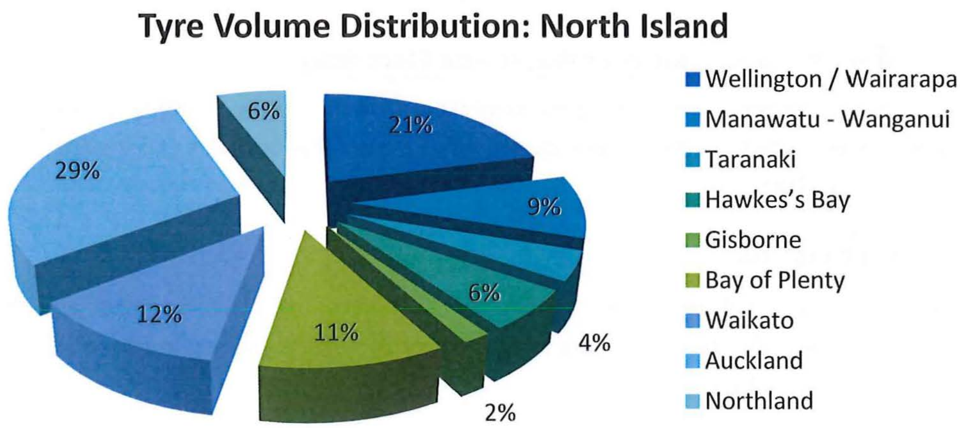


Figure 6.0: Tyre volume in the North Island based on regional distribution *(based on market research results)*

Whitford Quarry, in the Auckland area, offers potential due to proximity to tyre supply, proximity to bitumen and asphalt (manufacturing) plants and space requirements. Auckland Industries, located in Mt Wellington are the closest asphalt and bitumen plants at a distance of 20km from the quarry. The quarry is relatively new and is therefore under-developed. It is also in a rural area that has few local residents. The Auckland area, however, has strict environmental guidelines which may preclude the development of a pyrolysis plant. Another problem with the Auckland area is that the tyre supply from retailers may be very restricted due to established contracts with major tyre collectors in the area.

Poplar Lane Quarry in Tauranga offers potential as a replacement site for Whitford Quarry, should the Auckland area be too restricted. Poplar Lane Quarry is located 16km from Hewletts Road, Mt Maunganui where the bitumen and asphalt plants are located. The Quarry is highly developed and may not have space for a pyrolysis plant however may be more suitable due to proximity to tyre supply throughout the central North Island and slightly more relaxed environmental restrictions.

6.4 Phase Four: Concluding Statement

Based on the requirements for site selection Miners Road Quarry in Christchurch and Whitford Quarry in Auckland are recommended for the development of a full-sized commercial pyrolysis plants. If Whitford Quarry proves unsuitable due to environmental reasons, Poplar Lane Quarry in Tauranga may represent a better option.

The Nelson area has a clean-green image. The area generates a significant amount of ELT's but has no recycling processes in place other than services offered by Christchurch based tyre collectors. There is potential to implement a smaller pyrolysis plant in the area which could not only deal with truck and passenger ELT's but could also provide a solution for off-road vehicle tyres generated from local farm and mines such as Stockton and Spring Creek.

Implementation at any site will be dependent on availability and cost of transportation for tyres, electricity and water supply, availability of suitable space, and ability to gain resource consent.

7.0 Financing the Implementation of Continuous Pyrolysis Technology

Finance has not been included in this project as it is out of scope however a few vital pieces of information add to the overall understanding of the financial situation of the project going forward:

- The prototype plant has been developed and funded by CPT therefore represents limited financial risk for Fulton Hogan. CPT benefits during this initial stage by obtaining a tyre supplier, a site for the pyrolysis plant, a buyer for the oil and potentially a buyer for the gas.
- At this stage the plan is to develop two full-sized commercial plants (one in the South Island and one in the North Island) although this will be reliant on the ability of CPT to raise capital. Based on the one-line prototype plant, a three-line commercial sized plant will cost around NZ$4m to build. A larger five-live plant will cost around NZ$6.5m to build.
- Although not covered within the scope of this project, labour availability and cost may be an issue. CPT however will have the responsibility for providing adequate staff on-site to operate both plants therefore this is outside of the scope of the projects development for Fulton Hogan.
- The implementation of pyrolysis will financially benefit Fulton Hogan in several ways:
    - Pyrolysis oil will be purchased from CPT at a price of $0.55 per litre. This represents a saving of around 50% on the current commercial price of diesel fuel. The pyrolysis oil has potential to be used as a replacement fuel for Fulton Hogan's bitumen and asphalt plants.

  - Pyrolysis oil has the potential to be used to generate energy. This would result in significant savings through the development of a self-sufficient site as well as producing an excess which could potentially be exported to the grid.
  - Pyrolysis will provide an environmentally sustainable way to dispose of ELT's at zero cost therefore representing significant disposal savings. It also has the potential to be used for other waste types such as plastics and organics and to generate positive PR for Fulton Hogan.
- There may be options for Fulton Hogan is purchase shares from CPT should the prototype plant be successful in producing consistent quantities and quality product.

8.0 Recommendations

8.1 Recommendations for the Implementation of Continuous Pyrolysis Technology in Fulton Hogan within New Zealand

This report provides findings that support the following recommendations:

1.0 Fulton Hogan should implement a tyre recycling or energy recovery process to dispose of ELT's.

The cost of tyre disposal indicates room within the market for Fulton Hogan to operate, potentially removing tyres at low or zero cost. This will benefit not only Fulton Hogan, but also tyre retailers. The implementation of tyre recycling or energy recovery is further supported by potential legislation changes proposed to limit tyre dumping in landfill in New Zealand therefore requiring retailers and collectors to find alternative options.

2.0 Fulton Hogan should support the trial of a prototype pyrolysis plant and, based on the success of that plant, investigate further options for implementing a full-sized commercial plant.

CPT is offering Fulton Hogan the opportunity to trial pyrolysis with a small, low-risk prototype plant prior to implementing pyrolysis on a larger scale. This report highlights the potential that pyrolysis has as a value-add process for tyres and other waste streams. CPT will need to provide trial results with consistent, high-quality oil that can be utilised by Fulton Hogan to make further development viable. Pyrolysis has potential as a value-add process for Fulton Hogan as it could provide oil for the bitumen and asphalt plants as well as further options such as generating energy, leading to significant cost reduction through lower fuel and energy bills.

Support of the prototype plant by Fulton Hogan should be a priority action without which any further development will not be viable due to being unsupported by any evidence of a successful process.

3.0 Initially Fulton Hogan should source all tyres for the prototype plant from Bridgestone.

Bridgestone has a long-standing relationship with Fulton Hogan. They have the capability to supply a consistent quantity and quality of rubber crumb (steel removed) as feedstock. This will enable CPT to determine exact end product yields during initial trial stages. These trial results will provide data for the implementation plan for a full-sized commercial pyrolysis plant should it be deemed viable. The market research data in this report demonstrates that potentially Bridgestone has the capability to supply 850,000 ELT's annually throughout New Zealand should Fulton Hogan implement pyrolysis on a commercial scale.

4.0 Fulton Hogan should source ELT's from tyre retailers and collectors throughout New Zealand, should the implementation of a full-sized commercial pyrolysis plant be deemed a viable option.

The market research data in this report shows that several of the major tyre collectors currently pay to ship ELT's to Asia. Potentially these tyre collectors would be attracted to a local and therefore cheaper method for disposal and therefore may be interested in becoming a supplier for pyrolysis. ELT's can also be sourced from major retailers who are looking for free or low cost disposal. Due to the value-add processes involved in pyrolysis, CPT and Fulton Hogan can afford to under-cut existing tyre collectors. Potential prices for the collection of passenger tyres for pyrolysis could be $0.50- $1.00, which would represent a saving of around $2-$5 per tyre for the retailer. This price would be sufficient to cover transportation costs whilst concurrently offering a large enough margin to entice retailers. Fulton Hogan internally generates a significant number of ELT's annually due to having a large commercial fleet of vehicles which have high usage. These ELT's could also be processed through pyrolysis which would reduce disposal costs for Fulton Hogan.

5.0 CPT should pay for the transportation of tyres within New Zealand if a full-sized commercial pyrolysis plant is deemed viable.

It is recommended that CPT pay for tyre transportation rather than relying on Fulton Hogan to provide this service. At this stage the plan is for CPT to fully own and operate the plants therefore any associated profits and expenses will also be owned by CPT. Potentially CPT could pay Fulton Hogan for a transportation service as they already have commercial vehicles for which they could potentially offer reduced rates.

6.0 Whitford Quarry should be used as a site for a five-line pyrolysis plant in the North Island.

Whitford Quarry offers the most potential as a site in the North Island due to proximity to tyre supply in the Auckland and Waikato regions. Poplar Lane Quarry in the Bay of Plenty is a secondary option should environmental restrictions be too severe in the Auckland area. Due to the large number of ELT's in the upper North Island, a five-line operation is recommended rather than a three-line operation.

7.0 Miners Road Quarry should be used as a site for a three-line pyrolysis plant in the South Island.

Miners Road Quarry offers the most potential for a site in the South Island due to proximity to tyre supply in the Christchurch area and available space on site. Secondary to this site, Appleby Quarry in Nelson may offer potential for a smaller one or two-line pyrolysis plant.

8.2 Alternative Recommendations

1.0 Fulton Hogan could use or sell ELT's as tyre-derived fuel (TDF).

Alternatively, one option beyond pyrolysis is the use of ELT's as TDF in large cement kilns such as Holcim Cement or Golden Bay Cement. This option may be limited due to restrictions on the incineration of tyres however it may have potential due to being an alternative value-add process for the disposal of ELT's. Further investigation in this area would be required prior to implementation.

2.0 Fulton Hogan could sell rubber crumb for road filling or use as an additive for road surfacing.

Fulton Hogan could invest in a value-add process that does not require the decomposition of tyres through pyrolysis or incineration such as crumbing. Rubber crumb offers potential as road filler or for various other industrial uses such as asphalt rubber binder or rubber modified asphalt concrete.

9.0 Ethical Consideration

This project contains information that is highly sensitive therefore steps have been followed to ensure confidentiality is maintained at all times. Consent has been gained from Fulton Hogan to access information used for the purposes of this report with the understanding that an embargo will be put in place following completion.

The technology investigated in this project provides an environmentally sustainable solution with low emissions for ELT's. Ethically and environmentally, this project recommends pyrolysis which has the potential to be of high value to Fulton Hogan.

10.0 Personal Growth Achieved through Project Completion

10.1 Lessons Learnt

Completing this project for Fulton Hogan has taught me a number of important lessons. Lessons learnt include what was planned, what went well and why, and what improvements could have been made:

1.0 Planning is critical to project completion

Although planning was hard work, it was highly valuable as the project progressed. At many points throughout the project I referred back to my plan to make sure that I was on schedule for completion of objectives. Having a full schedule and plan made it less stressful by helping to maintain focus when deviations from the schedule were made due to circumstances outside of my control. Knowing what I had left to complete and how long I had, let me know that the remainder of the project would still be completed within the allocated timeframe.

Improvements: If I had more time allocated for the project plan, I could have completed more background research to support the project planning. During the planning stage I knew very little on the topic of pyrolysis and therefore found it difficult to formulate exact objectives for later phases such as market research.

2.0 People are willing to divulge valuable information if you ask the right questions and are willing to listen

This is one of the biggest lessons that I learnt. Throughout the market research stage I was required to complete over a hundred telephone interviews. Although initially I was nervous about cold-calling companies, I quickly realised that there are a lot of passionate individuals within the industry that are more than happy to divulge knowledge as well as follow-up information via email, providing I asked the right questions and showed a willingness to listen.

Improvements: As market research took significantly longer than anticipated the entire schedule for the project had to be adjusted. Contacting companies and industry specialists takes time therefore in future more time will be allocated for this during the planning stage.

3.0 It is critical to keep your superior (supervisor/sponsor) updated on project progress

Every month I completed a progress report for my sponsor and supervisor. Although I did not appreciate how important these were at the start of the project, I quickly realised that these kept both my sponsor and supervisor updated on what stage I had reached. This meant they could offer support or guidance if required. It also kept their minds at peace, knowing that I was managing the project content and schedule. In support of these progress reports regular email contact was critical to maintain an open channel of communication.

Improvements: Increased email contact with the sponsor and supervisor throughout the entire project would have enabled a more fluid channel of communication. This improved as the project progressed.

4.0 Recommendations need to be supported by valid research

Throughout the course of this project I had to make a number of recommendations to Fulton Hogan in regards to how the implementation of the prototype plant should proceed. All of this was documented in my reports and supported by valid literature and market research data. This information really helped give me a better understanding of the technology and the industry so that I could be confident in my recommendations.

Improvements: I underestimated how critical background knowledge was. Although I put a lot of time and effort into literature research, I feel that there is always room for improvement in this area.

10.2 Reflection on Personal Growth

I found this project with Fulton Hogan extremely valuable as it connected lessons learnt through the year in the MEM course modules to a real-life situation in which I was able to produce real results and recommendations. I really enjoyed the project as it challenged my existing knowledge by placing me in an industry for which I had no previous experience. In this sense I feel I grew, not only personally, but also in my professional capacity.

1.0 Insight into the industry and real-life experience

This project has provided insight into an industry for which I had no prior knowledge. For this reason it expanded my understanding of the industry in which Fulton Hogan operates as well as my knowledge of environmental sustainability. I was able to identify the need for value-add processes that aligned with environmental sustainability within Fulton Hogan. This project provided a deeper understanding of the research and market validation process, taught in the MEM course, with the ability to connect this process to a real-life situation.

2.0 Ability to work and think independently

This project has expanded my ability to work and think independently as I was required to identify crucial questions in regards to the industry, identify key contacts, and produce a solid well-though out report. It also required me to critically process the information received and make valid conclusions. Documentation and reporting was a large part of this.

3.0 Increased communication skills

This project increased my communication skills due to exposure to a number of different individuals with diverse backgrounds across all levels of authority. The project's objectives required direct contact with a number of different departments and areas of business within Fulton Hogan. It also required communication with external companies and, in some cases, communicating project requirements to individuals within Fulton Hogan who would then directly contact external companies.

10.3 Future Actions: What Has Changed For Me

This project has changed the course of my career aspirations. Previously I wanted to work in an environmental role however, although I am still interested in this area, my exposure to Fulton Hogan has shifted this towards becoming a project manager. The ability to plan, schedule, validate, manage and follow through to produce real results is an extremely fulfilling experience.

Through all that I have learnt in this project, I feel that pyrolysis could prove to be highly successful in dealing with ELT's in New Zealand. This has definitely increased my interest in the topic. Going forward I would like the opportunity to be further involved in the implementation of pyrolysis within Fulton Hogan as I think the idea has significant potential. If CPT and Fulton Hogan succeed with this project it will be the market leader for the commercialisation of pyrolysis in New Zealand.

11.0 References

Absolutely Positively Wellington. (2012). Retrieved December 12, 2012, from Wellington Landfill Charges: www.wellington.govt.nz/services/landfill

Adrados, A., de Marco, I., Caballero, B., López, A., Laresgoiti, M., & Torres, A. (2012). Pyrolysis of plastic packaging waste: A comparison of plastic residuals from material recovery facilities with simulated plastic waste. Waste Management, *33(5), 826-832.*

Agpac. (2012). Retrieved December 2012, from Agpac: http://agpac.co.nz/products.php?cid=14&type=P

Alibaba. (2012). Retrieved December 2012, from Alibaba: http://www.alibaba.com/showroom/market-price-for-carbon-black.html

Alibaba. (2013). Retrieved January 4, 2013, from Alibaba: http://www.alibaba.com/showroom/syngas-generator.html

Alsultan, M. (2012, April 17). Retrieved January 2013, from 500px: http://500px.com/photo/6816260

Anthro Terra. (2010). Retrieved January 4, 2013, from Anthro Terra: http://anthroterra.com.au

Arpa, O., Yumrutas, R., & Demirbas, A. (2010). Production of diesel-like fuel from waste engine oil by pyrolitic distillation. Applied Energy, 87*, 122-127.*

Auckland Council. (202). Retrieved December 2012, from Auckland Council: http://www.aucklandcouncil.govt.nz/EN/environmentwaste/rubbishrecycling/Pages/transferstations.aspx

Aydına, H., & İlkılıç, C. (2012). Optimization of fuel production from waste vehicle tyres by pyrolysis and resembling to diesel fuel by various desulfurization methods. Fuel, 102*, 605-612.*

Barron, T. (1992). Tech Trend: Pyrolysis Struggles to Move Off Back Burner. Environment Today, 3*(1), 16.*

Behzadi, S., & Farid, M. (2011). Liquid Fuel from Plastic Wastes in New Zealand. *Auckland, New Zealand: University of Auckland.*

BiG. (2013). Retrieved January 4, 2013, from BiG: http://www.bigchar.com.au

Bio Syngas. (2012). Retrieved January 6, 2013, from Bio Syngas: http://www.biosyngas.com.au

Bradley, D. (2006). European Market Study for BioOil (Pyrolysis Oil) . *Ottawa, Ontario: Climate Change Solutions .*

Business Listing. (2012). Retrieved November 28, 2012, from http://www.finda.co.nz/business/listing/4ynd5v/tyre-recycling-services-ltd/

Carbon Recovery Limited. (2012). Tyre derived fuel. *Retrieved November 18, 2012, from Carbon Recovery Limited: http://www.carbonrecovery.co.nz/tyre-derived-fuel/*

Carbon Recovery Ltd. (2012). Retrieved November 29, 2012, from Carbon Recovery Ltd: http://www.carbonrecovery.co.nz

Carter's Tyre Service. (2012). Retrieved December 2012, from Carter's Tyre Service: http://www.carterstyres.co.nz/

Carterton District Council. (2012). Retrieved December 13, 2012, from Carterton District: www.cartertondc.co.nz/transfer_station-hours

CCC. (2012). Retrieved December 2012, from Christchurch City Council: http://www.ccc.govt.nz/homeliving/rubbish/kerbsidecollection/recycling/recyclingplant.aspx

Chang, N. (2008). Economic and policy instrument analyses in support of the scrap tyre recycling program in Taiwan. Journal of Environmental Management, 86*(3), 435–450.*

Coast and Country. (2012, March). Solution for New Zealand's used tyres. Coast and Country: Horticulture*, p. 20.*

Comspec. (2011). Retrieved December 2012, from Comspec: http://www.comspec.co.nz/

Connell, C. (2010, August 10). They'll be wearing our tyres over there. *Retrieved November 28, 2012, from Stuff: http://www.stuff.co.nz/marlborough-express/news/4008446/They-ll-be-wearing-our-tyres-over-there*

Cunliffe, A., & Williams, P. (1998). Composition of oils derived from the batch pyrolysis of tyres. Journal of Analytical and Applied Pyrolysis, 44*(2), 131–152.*

Duncan, M. (2012). Tyrewise Scoping Report 1. *Tyrewise.*

Dynamotive Energy Systems. (2013). Retrieved January 4, 2013, from Dynamotive Energy Systems: http://www.dynamotive.com/technology/

EcoDrop. (2012). Retrieved November 28, 2012, from EcoDrop: http://www.ecocentral.co.nz/contact

Enriching the Environment. (2012, April). Getting tired of tyres on the farm? Enriching the Environment*, p. 25.*

Euro-Tyre. (2012). Retrieved December 4, 2012, from Euro-Tyre: http://www.eurotyre.co.nz/

Fels, M., & Pegg, M. (2008). A techno-economic and environmental assessment of a tyre pyrolysis plant. *Halifax, Canada: Reported from the Dalhousie University.*

Food and Agricultural Organization of the UN. (2013). Corporate Document Respisitory: Forestry Department. *Retrieved January 17, 2013, from Food and Agricultural Organization of the United Nations: http://www.fao.org/docrep/T0269E/t0269e0c.htm*

Gerald, O. (2000). Tyre-pyrolysis process yields valuable products. Chemical Engineering, 107*(8), 19.*

Gerald, O. (2007, December). New pyrolysis method improves carbon black recovery from scrap tyres. Chemical Engineering, 114*(13), 16.*

Global Renewables. (2012). Retrieved January 2, 2013, from Global Renewables: http://www.globalrenewables.com.au/our-mission/resource-recovery/

Google Earth. (2012, October 19). Retrieved January 10, 2013, from Google Earth: http://www.google.com/earth

Gore DC. (2012). Retrieved December 14, 2012, from Gore DC: www.goredc.govt.nz/refuse

Gough. (2012). Retrieved January 6, 2013, from Gough: http://goughcat.co.nz/power-systems/electric-generators/diesel-powered

Gregoire, C., & Bain, R. (1994). *Techno-economic analysis of the production of biocrude from wood.* Biomass and Bioenergy, 7, *275-283.*

Hoddinott, R. (2011). Retrieved November 2012, from CPT Presentation: http://www.lpga.co.nz/pdfs/Richard-Hoddinott-CPT-presentation-October2011.pdf

Huffman, G., & Shah, N. (1998). *Can waste plastics and tyres be recycled economically? ChemTech December.* American Chemical Society, 23, *34-43.*

Hurunui District Council. (2012). Fees and Charges: 1 July 2012 - 30 June 2013. *Hurunui District Council.*

IPONZ. (2010). Retrieved January 21, 2013, from IPONZ: http://www.iponz.govt.nz/app/Extra/Case/Browse.aspx?sid=634943798414141974

Islama, M., Joarddera, M., Hasana, S., Takaib, K., & Haniub, H. (2011). *Feasibility study for thermal treatment of solid tyre wastes in Bangladesh by using pyrolysis technology.* Waste Management, 31*(9-10), 2142–2149.*

J & J Laughton. (2012). Retrieved December 3, 2012, from J & J Laughton: http://www.tyreshred.co.nz/services.html

Janga, J., Yoob, T., Ohb, J., & Iwasaki, I. (1998). *Discarded tyre recycling practices in the United States, Japan and Korea.* Resources, Conservation and Recycling, 2*(1-2), 1-14.*

Kanaujia, P., Sharma, Y., Agrawal, U., & Garg, M. (2012). *Analytical approaches to characterizing pyrolysis oil from biomass.* TrAC Trends in Analytical Chemistry.

Kuempel, E., & Sorahan, T. (2010). *Views and Expert Opinions of an IARC/NORA Expert Group Meeting, Lyon, France, 30 June - 2 July 2009.* IARC Technical Publication, 42, *61-72.*

Li, X., Xu, H. G., & Tao, Y. (2010). *Comparison of end-of-life tyre treatment technologies: A Chinese case study.* Waste Management, 30*(11), 2235–2246.*

Mastagard. (2012). Retrieved December 2012, from Mastagard: http://www.mastagard.co.nz/mastagard-commercial-services/recycling-services/

McAvinue, S. (2012, August 16). Retrieved December 2012, from Stuff: http://www.stuff.co.nz/southland-times/farming/7473276/Big-jump-in-plastic-recycling-volume

MFE. (2004, January). Retrieved November 2012, from Ministry for the Environment: Waste Management End of Life Tyres: http://www.mfe.govt.nz/publications/waste/management-end-of-life-tyres-jan04/html/page1.html

MFE. (2006, May). Product Stewardship Case Study for ELT's. *Retrieved November 2012, from Ministry for the Environment: http://www.mfe.govt.nz/publications/waste/product-stewardship-endoflife-tyres-may06/html/page4.html*

MFE. (2007). Retrieved December 13, 2012, from Ministry for the Environment: www.mfe.govt.nz/publications/waste/recycling-cost-benefit-analysis-apr07/html/page7.html

MFE. (2009). Retrieved December 2012, from Ministry for the Environment: http://www.mfe.govt.nz

MFE. (2011). Retrieved December 2012, from Ministry for the Environment: http://www.mfe.govt.nz/issues/waste/progress-and-outcomes/waste-minimisation-fund-projects-2010-2011.html

MFE. (2011, March 17). 2010/2011 Waste Minimisation Fund Projects. *Retrieved November 18, 2012, from MFE: http://www.mfe.govt.nz/issues/waste/progress-and-outcomes/waste-minimisation-fund-projects-2010-2011.html*

MFE. (2012). Retrieved December 2012, from Ministry for the Environment: http://www.mfe.govt.nz/issues/waste/disposal-facilities/disposal-facilities-nz-a3-may-2012.pdf

Ministry of Transport. (2012). The New Zealand Vehicle Fleet: ANNUAL FLEET STATISTICS 2011. *Ministry of Transport.*

Murugan, S., Ramaswamy, M., & Nagarajan, G. (2008). Performance, Emission and Combustion Studies of A DI Diesel Engine Using Distilled Tyre Pyrolysis Oil-Diesel Blends. Fuel Processing Technology, 89*(2), 152-159.*

Nekut, T. (2008). Retrieved January 21, 2013, from BioEnergy Lists: Gasifiers & Gasification: http://gasifiers.bioenergylists.org/nekutpyrolyzer0408

Northern Poultry. (2010). Retrieved January 3, 2013, from Northern Poultry: http://www.northernpoultry.com.au/BES.html

NZ Statistics. (2012). 2012 StatsNZ Infoshare Import and Export Data. *Retrieved November 7, 2012, from http://www.stats.govt.nz/infoshare/(S(22mu1xqszysrbj20slcoku45))/TradeVariables.aspx?AspxAutoDetectCookieSupport=1*

Pacific Rubber. (2012). Retrieved December 4, 2012, from Pacific Rubber: http://www.pacificrubber.co.nz

PacPyro. (2012). Retrieved January 2013, from Pacific Pyrolysis Ltd: http://pacificpyrolysis.com/

Paradela, F., Pinto, F., Gulyurtlu, I., Cabrita, I., & Lapa, N. (2009). Study of the co-pyrolysis of biomass and plastic wastes. Clean Techn Environ Policy, 11*, 115-122.*

Peacocke, G., Bridgwater, A., & Brammer, J. (2006). Techno-economic assessment of power production from the Wellman and BTG fast pyrolysis processes. Science in Thermal and Chemical Biomass Conversion: in the Scientific Press.

Petrich, W. (2008). Novel uses for tyre pyrolysis char. United Carbon Corporation*, 455-456.*

Pinto, F., Costa, P., Gulyurtlu, I., & Cabrita, I. (1999). Pyrolysis of plastic wastes. 1. Effect of plastic waste composition on product yield. Journal of Analytical and Applied Pyrolysis, 51*(1-2), 39-55.*

Plastics NZ. (2012). Retrieved December 19, 2012, from Plastics New Zealand: http://www.plastics.org.nz/environmental/recycling/nzrecyclingstatistics/

Plastics Org NZ. (2012). Retrieved December 2012, from Plastics Org NZ: http://www.plastics.org.nz/environmental/recycling/

Pradhan, D., & Singh, R. (2011). Thermal Pyrolysis of Bicycle Waste Tyre Using Batch. International Journal of Chemical Engineering and Applications, 2*(5), 332-336.*

Professional Engineering. (1999). Scrap tyre 'cooking' becomes an economically viable proposition. Professional Engineering*, 9.*

Q&M. (2010, December 30). Green future for old tyres. Q&M*, pp. 32-33.*

Recycle.co.nz. (2012). Retrieved December 2012, from Recycle.co.nz: http://www.recycle.co.nz/problemsize.php

Renewable Oil Corporation. (2013). Retrieved January 4, 2013, from Renewable Oil Corporation: http://www.renoil.com.au

Ringer, M., Putsche, V., & Scahill, J. (2006). Large-Scale Pyrolysis Oil Production: A Technology Assessment and Economic Analysis. *Golden, Colorado: National Renewable Energy Laboratory.*

Roy, C., Chaala, A., & Darmstadt, H. (1999). Vacuum pyrolysis of used tyres end-uses for oil and carbon black products. Journal of Analytical and Applied Pyrolysis, 51*(4), 201-221.*

RTI NZ. (2012). Retrieved November 18, 2012, from Recyclotech Industries (NZ) Ltd: http://www.recyclotech.co.nz/about.html

Samoladaa, M., & Zabaniotou, A. (2012). Potential application of pyrolysis for the effective vaporisation of the end of life tyres in Greece. Environmental Development.

Sánchez, N., Callejas, A., Millera, A., Bilbao, R., & Alzueta, M. (2012). Formation of PAH and soot during acetylene pyrolysis at different gas residence times and reaction temperatures. Energy, 43*(1), 30-36.*

Schwarz, S., Richter, L., & Pirnie, M. (2002). Brightstar solid waste and energy recycling facility: an innovative waste to energy technology. 10th North American Waste to Energy Conference*, 119-135.*

Sienkiewicz, M., Kucinska-Lipka, J., Janik, H., & Balas, A. (2012). Progress in used tyres management in the European Union: A review. Waste Management, 32*(10), 1742–1751.*

SIFT. (2009). Retrieved December 2012, from SIFT: http://www.sift.net.nz/blog/producer-responsibility-in-action-more-on-agpacs-new-baler/

SIFT. (2010). Retrieved December 2012, from SIFT: http://www.sift.net.nz/blog/tag/comspec/

SIFT. (2010). Retrieved December 2012, from SIFT: http://www.sift.net.nz/blog/waste-minimisation-funding-recipients-2010/

SIFT. (2012). Retrieved December 2012, from SIFT: http://www.sift.net.nz/

Snow, W., & Dickinson, J. (2011). The End of Waste: Zero Waste by 2020. *Auckland: Zero Waste: New Zealand Trust.*

Stats NZ. (2012). Retrieved January 2013, from Stats NZ: http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/SubnationalPopulationEstimates_MRYe30Jun12.aspx

T, B., & Skrypski-Mantele, S. (2004). Experience and lessons learned from sewage sludge pyrolysis in Australia. Water Science Technology, 49*(10), 217-223.*

Tauranga City Council. (2012). Retrieved December 13, 2012, from Tauranga CC: www.tauranga.govt.nz/council-services/rubbish-recycling/disposal/transfer-stations.aspx

The Crucible. (2012). Retrieved January 3, 2013, from The Crucible: www.thecrucible.com.au

Tyre Collection Services Limited. (2012). Retrieved November 27, 2012, from Tyre Collection Services Limited: http://tyrecollections.co.nz/

Tyrewise. (2012). Scoping Report 1: Investigation into the collection and disposal of used tyres in New Zealand and internationally. *Tyrewise Working Group.*

Unapumnuk, K., Keener, T., Lu, M., & Liang, F. (2008). Investigation into the removal of sulfur from tyre derived fuel by pyrolysis. Fuel, 87*(6), 951-956.*

Uruburua, A., Ponce-Cuetoa, E., Cobo-Benitaa, J., & Ordieres-Meré, J. (2012). The new challenges of end-of-life tyres management systems: A Spanish case study. Waste Management.

Visy. (2012). Retrieved January 2, 2013, from Visy: http://www.visy.com.au

Voxy. (2010, Jan 28). Kiwi Inventors Create "No 8 Wire" Global Pollution Solution -- In A Shipping Container! *Retrieved Nov 2012, from Voxy: http://www.voxy.co.nz/national/kiwi-inventors-create-quotno-8-wirequot-global-pollution-solution-shipping-conta/5/36615*

Waste Tyre Solutions. (2010). Retrieved December 5, 2012, from Waste Tyre Solutions: http://www.wastetyres.co.nz/services_recycling.htm

Williams, P., & Besler, S. (1994). Polycyclic aromatic hydrocarbons in waste derived pyrolytic oils. Journal of Analytical and Applied Pyrolysis, 30*(1), 14-33.*

Williams, P., & Taylor, D. (1993). Aromatization of tyre pyrolysis oil to yield polycyclic aromatic hydrocarbons. Fuel, 72*(11), 1469–1474.*

Williams, P., Besler, S., & Taylor, D. (1990). The pyrolysis of scrap automotive tyres: The influence of temperature and heating rate on product composition. Fuel, 69*(12), 1474–1482.*

Williams, P., Bottrill, R., & Cunliffe, A. (1998). Combustion of tyre pyrolysis oil. Trans IChemE, 76*, 291-301.*

Appendices

Appendix 1.0 Pyrolysis Technology

1.1 Continuous Pyrolysis Technology

A provisional patent has been filed on 09/02/2010 under reference 583184 by Richard Grant Hoddinott for a 'continuous pyrolysis process' *(IPONZ, 2010)*. The international classifications are C10G 1/10 – from rubber or rubber waste, and B09B 3/00 – destroying solid waste or transforming solid waste into something else. The patent covers the unique technology developed by the team at CPT including a continuous process as opposed to the standard batch pyrolysis commonly seen elsewhere. Although continuous pyrolysis is not a new technology, CPT has developed a pyrolysis plant that due to several technological differences offers improved processes and end products.

The exact specifications for the pyrolysis machine designed and created by CPT will remain a trade secret and therefore is not covered in this report. One advantage of continuous pyrolysis is a higher processing capacity due to a continuous feed-cycle into the reactor. Labour costs are also reduced due to an automatic feeder, with only one or two engineers required on-site for operating the machine. Generally continuous pyrolysis is more energy efficient than batch pyrolysis.

1.2 Batch Pyrolysis

Batch pyrolysis is most commonly found in China and India and is regarded as a technologically viable form of pyrolysis which has been shown to be successful through trials and commercial enterprises. Emissions can be a problem with low cost batch pyrolysis plants due to cost-cutting methods used in manufacturing. Batch pyrolysis, as opposed to continuous pyrolysis which is fully automated, requires manual labour to input shredded tyres into the reactor. These tyres are then heated for a set period of time (depending on feedstock and required output), the end products are extracted and then the process restarts with tyres being fed once more into the reactor.

Figure 7.0 shows the process of batch pyrolysis. The tyres enter the reactor then pass through three sets of condensers before exiting as gas, char and oil. In this example an electric heater is shown as the reactor, however the majority of pyrolysis machines utilise gas to achieve the high temperatures required for complete decomposition of the feedstock.

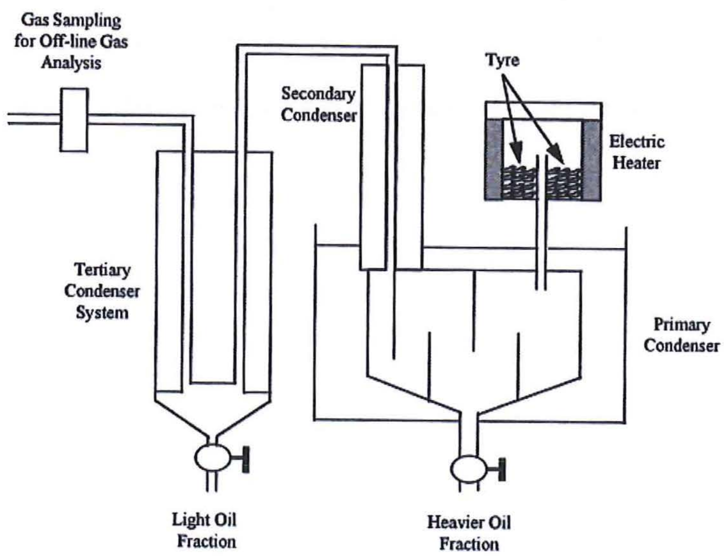


Figure 7.0: Example of a batch pyrolysis machine *(Cunliffe & Williams, 1998)*

1.3 Other Methods of Pyrolysis

There are various other methods for pyrolysis which offer a variety of results depending on feedstock and technological and manufacturing capability. Various forms include:

- Fluidised bed reactor – simple to design and construct, consisting of a feed hopper, fluid bed reactor, a condenser train (where the gasses and oils are formed) and a packed bed. They have good heat control and heat storage capacity. Fluidised bed reactors are ideal for wood and organic bio-waste processing and generally give high oil to solid waste ratios. The rate at which the feedstock is heated can be a limiting factor with this design.
- Biotherm reactor – fluidised sand in the reactor ensures fast rapid heating. After the products are separated in the reactor, they enter into two sequential cyclones which remove the majority of the char. Following this the gases are rapidly cooled to produce gas and oil. The gas is recycled back into the reactor.
- Conical reactor – a form of continuous pyrolysis which results in high gas yield. They have higher processing capacity due to being continuous and have improved ability to decompose solids that are difficult to breakdown via a fluidised bed reactor.
- Rotating cone pyrolysis reactor – mainly used for the decomposition of organic bio-waste. The pyrolysis reactor uses hot sand in the reactor which is introduced at the bottom of the cone mixed with the bio-waste. A rotating motion moves the mixed material up towards the top of the cone under pressure. Vapours then exit via the top of the cone and a cooling phase separates out the gas from the oil. The char remains mixed with the sand and exits separately to the vapours.

Appendix 2.0: Work breakdown structure

Figure 8.0: Work breakdown structure *(excerpt from project plan)*

Appendix 3.0: Literature Review

3.1 Implementation of Pyrolysis Technology (Case Studies)

3.1.1 Feasibility study for thermal treatment of solid tyre wastes in Bangladesh by using pyrolysis technology *(Islama, Joarddera, Hasana, Takaib, & Haniub, 2011)*

Topic: Investigates cost estimations of plant builds based on production capacity
Relevance: HIGH – directly relates to the implementation of continuous pyrolysis technology as a commercial process

This article highlights the feasibility of using pyrolysis technology in Bangladesh to turn whole used tyres into their materials – Oil, char, steel cords, and gas. Tyre pyrolysis liquids have a high gross calorific value (CGV) of around 41-44 Mg/Kg which increases their potential to replace conventional fuels. The resultant liquids also provide a potential supply of light aromatics such as benzene, toluene, and xylene which have a higher value on the market than the raw oils. Char has the potential to be processed and refined to produce carbon black, an essential material used in the production of bitumen and other concretes.

The article discusses the use of a fixed-bed fire-heating pyrolysis reactor with price comparisons for the implementation of a pilot plant (3.6 tonnes a day), a small commercial sized plant (36 tonnes per day), and a full-sized commercial pant (144 tonnes per day). The production costs included the capital and operating costs for collection and shredding of tyres, on-going pyrolysis running costs, the costs incurred separating steel from char, and the processing of emissions required to conform to environmental standards. This was compared to the profit that would be made from the sale of the raw materials. The results showed that the most economically feasible plant size was the full-sized commercial plant. This was due to the significant amount of crude pyrolysis oil that this sized plant was able to produce.

This article highlights case studies of plant costs around the world as shown in table 5.0. Capacity refers to the amount of tyre waste that can be processed. The differences shown in costs were largely down to the vast variations in quotes from equipment manufacturers.

Existing plant/Feasibility study	Capacity	Cost to Build	Notes
Shanghai Greenman pyrolysis plant	25 tonnes/day	US$2.5m	Actual plant build
Taiwan pyrolysis plant		US3.5m	Actual plant build
Dalhousie University study of a pyrolysis plant	30 tonnes/day	US$3.0m	*(Fels & Pegg, 2008)*
Feasibility Study Committee (a number of universities)	100 tonnes/day	US$4.863m	*(Huffman & Shah, 1998)*
Biocrude pyrolysis plant (for the degradation of wood waste)	100 dry tonnes of wood/day	US$7.23m	*(Gregoire & Bain, 1994)*
Biocrude pyrolysis plant	36 dry tonnes of wood/day	US$3m	*(Peacocke, Bridgwater, & Brammer, 2006)*
Biocrude pyrolysis plant	144 dry tonnes of wood/day	US$5m	*(Peacocke, Bridgwater, & Brammer, 2006)*

Table 5.0: Estimated and actual costs for the manufacture of a pyrolysis plant *(Islama, Joarddera, Hasana, Takaib, & Haniub, 2011)*

The article included a diagram of a conceptual plant, as shown in figure 9.0. The tyres are cleaned with compressed air and shredded to a size of 4cm³. They are then dried prior to entering the reactor tube for pyrolysis. Solid residue extracted from the reactor is a mixture of char and steel. The steel is separated from the char through a magnetic separator. The average rate of pyrolysis gas generated is 12,000 L/min. These are pushed out to the condenser, which then separated the gas from the oil. The gas is compressed and re-used for the reactor part of the process. The oil is pumped into storage tanks and sold.

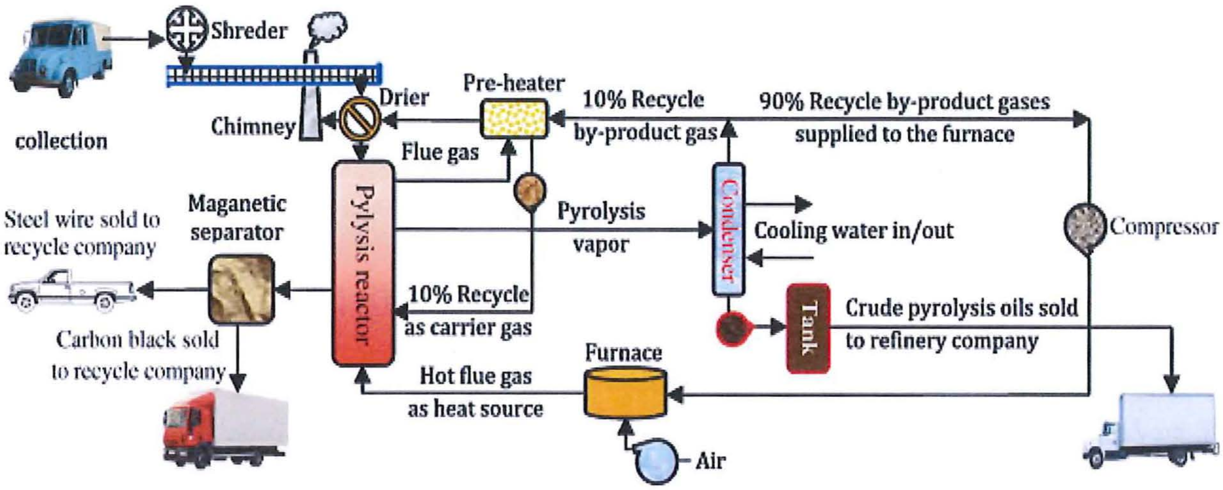


Figure 9.0: Conceptual design of a pyrolysis plant *(Islama, Joarddera, Hasana, Takaib, & Haniub, 2011)*

Steel and char are estimated to represent a total of 45 wt% and can be sold for around US$75 per tonne. The oil is valued at an estimated US$400 per tonne *(Fels & Pegg, 2008)* in Bangladesh. The production cost per tonne of pyrolysis oil is shown in table 6.0.

Plant size	Production capacity	Production cost per tonne
Pilot plant	3.6 tonnes a day	321
Small sized commercial plant	36 tonnes a day	193
Full-sized commercial plant	144 tonnes a day	136

Table 6.0: Estimated production cost per tonne of pyrolysis oil *(Islama, Joarddera, Hasana, Takaib, & Haniub, 2011)*

There will be a degree of uncertainty in these price estimates due to fluctuations in the market for pyrolysis oil. The paper concludes that if 64,000 metric tonnes of tyres are processed by pyrolysis annually the import bills would reduce by 29,400 tonnes (205,000 barrels) of oil, 6,400 tonnes of steel and 22,400 tonnes of coal for Bangladesh. The implementation of pyrolysis plants would also dramatically reduce the impact of waste tyres on the environment.

3.1.2 Tech trend: pyrolysis struggles to move off back burner *(Barron, 1992)*

Topic: New York based pyrolysis plant established for processing plastics, cardboard and rubber
Relevance: Medium to high – deals with problems around implementation of pyrolysis

This article discusses why pyrolysis for the decomposition of tyres has failed to take off despite the need to find an economically viable and environmentally friendly way of disposing of tyres. It lists the hurdles for pyrolysis as:

- Poor design of the pyrolysis plants
- Over-inflated expectations
- Technical hurdles

It uses New York based **Wayne Technology, Inc.** as an example of a company that have successfully developed and built a commercial pyrolysis plant (interestingly little information exists as to whether this plant was a success or whether it still exists). It was opened to process 50 tonnes daily of plastic, cardboard and rubber (scrap tyres) in order to reclaim oil and gas as raw materials. The company claims to have overcome many of the technical hurdles that were seen in earlier prototypes. Temperature of the kiln is stated as being 700°F or higher and produces an estimated 120 barrels of oil per day. The gas produced is used to refuel the pyrolysis plant. The char is not used but is sent to landfill. The company claims to be able to process a mix of industrial waste, minimising the need to separate it into categories.

The article also mentions several other plants:

- **Seko/Warwick Corp., Meadville, Pa**: Plant that produces 100 gallons of number 2 grade oil, 4,800 cubic feet of gas, 80lbs. steel, and 800lbs. char per 1 tonne of tyres processed.
- **Resource Technology Corp. (RTC), Wyo:** Processes only scrap tyres and reclaims between 28-30% oil per tyre volume.
- **PTO Inc., Springdale, Ark:** A plant that produces 9.36lbs. char from each 20lb. tyre. This plant is developed to maximise the char yield.

The article concludes that new technology needs to be developed to process the char in order to produce a high grade carbon that can be used as a replacement for coal. The technology exists but is not advanced enough to be of much use in a commercial situation.

3.1.3 Tyre-pyrolysis process yields valuable products *(Gerald, 2000)*

Topic: A plant in California has been developed for continuous pyrolysis technology
Relevance: Low - no detail in article, only highlights the importance of the process for the extraction of raw materials for resale

This article briefly outlines the importance of products that can be produced from pyrolysis as fuel gas, carbon black and steel wire. A company in California, Union Nature Co., have developed a prototype plant that has been tested at a rate of 6,000 tonnes of scrap tyres per year, but can process a total of 20,000 tonnes per year. The plant is fed with whole tyres that are then pyrolysed at 315-540°C. A bentonite-based catalyst is used in the process to keep the temperature down and absorb some of the sulphur from the gas. The carbon black and steel is separated at the end of the process. 15% of the gas produced is used for the reactor and the remainder is sold for fuel. The company claims to be able to recover the capital invested in the plant within three years of operation, based on a gas price of US$2 per million Btu for gas, US$100 per tonne for steel, and US$200 per tonne for the carbon black.

3.1.4 Economic and policy instrument analyses in support of the scrap tyre recycling program in Taiwan *(Chang, 2008)*

Topic: Implementation of scrap tyre recycling in Taiwan
Relevance: Medium – highlights reasons why implementation of pyrolysis plants has problems but relatively unrelated to New Zealand environment

This article covers the implementation of a continuous pyrolysis technology plant in Taiwan, focussing on the 1990's when there were four major tyre recycling firms using pyrolysis technology in the country. Scrap tyre recycling in Taiwan was introduced due to large piles of tyres building up in residential and commercial areas. These stock piles represented environmental, public health and aesthetic problems. They were not only fire hazards, but also a breeding ground for disease vectors such as rodents and insects.

Pyrolysis represented challenges as the initial set-up of equipment was expensive and required significant overseas investment and technical expertise. The plants showed unstable economic returns on the raw materials so were not highly regarded as being successful. Table 7.0 shows the plants and their capacity per month.

Plant	Start-Up Year	Capacity	Service District
1	1997	3000 tonnes/month	Keelung, Taipei, Ilan, Hualien
2	1993	2300 tonnes/month	Taipei, Taoyuan
3	1995	300 tonnes/month	Taichung
4	1994	300 tonnes/month	Pingtung, Taitung

Table 7.0: Pyrolysis plants in Taiwan in the 1990's *(Chang, 2008)*

Problems exist in Taiwan due to the low government subsidy offered as support for the recycling companies, resulting in lower profits for the scrap tyre collectors. The subsidies are not based on weight or size of tyre, but rather on unitary value, making the process for deciding subsidiary value highly irregular and inefficient. The service districts restrict competitiveness between the plants as tyre collectors are restricted to supplying one plant. The article recommends different methods for management of subsidiary programmes including the removal of the service districts in order to drive up prices for whole scrap tyres.

3.1.5 Potential application of pyrolysis for the effective valorisation of the end of life tyres in Greece *(Samoladaa & Zabaniotou, 2012)*

Topic: Implementation of pyrolysis in Greece with positives and negatives
Relevance: HIGH – relevant to the implementation of pyrolysis in a commercial sized scheme

This article focuses on the drawbacks and solutions of pyrolysis and potential ways to implement it in Greece. The amount of end-of –life tyres (ELT's) in Greece was 40,000 tonnes in 2010. It discusses the use of pyrolysis to break down ELT's to their raw materials. Composition is shown in table 8.0.

Composition (wt%)	USA (passenger)	USA (truck tyre)	EU (passenger)	EU (truck)
Natural rubber	14	27	22	30
Synthetic rubber	27	14	23	15
Carbon black	28	28	28	20
Steel	14-15	14-15	13	25
Fiber, fillers, accelerators, antiozonants etc.	16-17	16-17	14	10
Biomass (ASTM D6866)			17-20.3	28.6-29.7

Table 8.0: Used tyre composition for passenger and truck tyres *(Samoladaa & Zabaniotou, 2012)*

No large scale commercial pyrolysis plant exists in Greece although this paper recommends implementation of this technology to deal with the large amount of ELT's that currently have no use. The recycling plants that currently exist are shredding plants which produce steel, fibre and rubber granules. The barriers for pyrolysis are listed as:

- Lack of product standardisation
- Lack of markets for sale of products especially carbon
- Legislative barriers (as it is considered incineration)
- Public acceptance

In 2004 a Joined Alternative Management System (JAMS) was established with the aim of implementing ways to manage the disposal of ELT's in an environmentally safe and economical way. It has the participation of 83 tyre importers and manufacturers, and 63 car importers. The article highlights this as an important step that will assist in the implementation of tyre pyrolysis.

Pyrolysis produces oil, gas and char which varies based on operational conditions and the reactor used. Gas and oil comprise half the net weight of the raw materials produced have energy content similar to that of conventional fuels. Figure 10.0 shows the product breakdown.

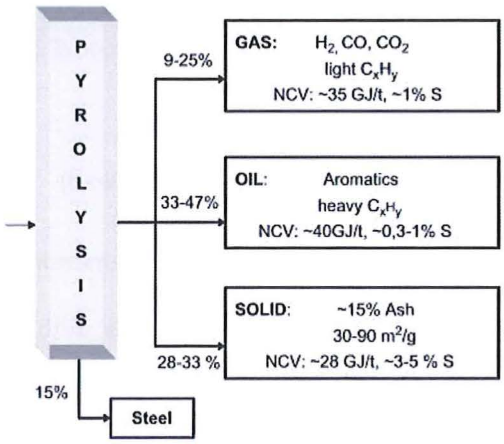


Figure 10.0: Pyrolysis mass and energy balances *(Samoladaa & Zabaniotou, 2012)*

The char is of low commercial value due to being a mixture of different types of carbon black. Processes for upgrading the char to carbon black is now considered to be economically viable due to market demand. The pyrolysis oil can be used as feedstock for the pyrolysis plant, used directly as a fuel, or added to petroleum refinery feedstocks. Due to the high sulphur content (1.35%-1.5%) they can be used as a replacement for No 6 fuel oil. The economic viability of a pyrolysis plant depends on several factors. These include:

- Product resale price
- Plant production capacity
- Total production cost
- Capital investment
- Tipping fee

It is unlikely that a plant will be built unless the costs are less than that those required for the build of an incinerator. However with the development of the polluter responsibility system across Europe pyrolysis is becoming an increasingly attractive proposition. The need to implement a way to supply tyres to the plants at low cost or free of charge is necessary to reduce on-going running costs. Table 9.0 shows a SWOT analysis for the pyrolysis of ELT's.

STRENTHS • Reduced air emissions • High efficiency and energy self-sufficient • Potential marketable products • Almost zero wastes • Funding availability (green activity) • Raw material availability (tyres) • Pyrolysis plants are compact in comparison to incineration plants • Existing collection system in Greece • Existing legislation	**WEAKNESSES** • High investment • High operation cost • New technology – new commercial application therefore lack in product standardization • Economic viability has only been proven in large scale commercial plants (>20,000 t/yr) • JAMS low interest
OPPORTUNITIES • Extensive research expertise • High added value process (waste into product) • Minimise/eliminate abroad recovery	**THREATS** • Public scepticism • Lack in environmental standards and Best Available Technologies (BAT)

• Well-developed legislative frame • Funding opportunities through dissemination programmes • Zero national competition (niche market) • Increase energy independence	• Unstable economic environment • Unproven and unstable market for end products • Confused legislation frame (pyrolysis is considered incineration)

Table 9.0: SWOT analysis for pyrolysis of ELT's *(Samoladaa & Zabaniotou, 2012)*

The main advantages of pyrolysis are listed as:

- Low energy consumption (pyrolysis gas covers process energy required)
- Environmental emissions of the plant have low SO_x concentration
- Pyrolysis is cleaner than incineration or combustion plants (lower emissions and operating temp)

The article says: "These particularly low emissions can be effectively further decreased using a combined pyrolysis-combustion process for the elimination of the non-condensable poly-aromatic compounds and tar components".

3.1.6 The new challenges of end-of-life tyres management systems: A Spanish case study *(Uruburua, Ponce-Cuetoa, Cobo-Benitaa, & Ordieres-Meré, 2012)*

Topic: Implementation of recycling plants in Spain
Relevance: Medium – relates to pyrolysis (thermolysis) implementation

There are two plants in Spain that utilise thermolysis, the thermal degradation of scrap tyres into their raw materials. One plant has a capacity of 16,500 tyres per year and the other has a capacity of 500 tyres per year. These amounts are relatively unsubstantial compared to the amount of tyres that are processed via shredding annually in Spain. Economic studies completed show that thermolysis offers no clear advantage over other recycling methods due to the use of the end products. There is a lack of public support for the recycling of ELT's. Spain has developed a clear system for paying for the collection of ELT's with a minimum recovery for payment of 100 tyres. Various measures are in place to develop environmentally friendly processes and policies in the tyre industry such as expanding the life of tyres and implementing new processes to re-groove and re-tread worn tyres, therefore reducing the number of ELT's annually.

3.1.7 Progress in used tyres management in the European Union: A review *(Sienkiewicz, Kucinska-Lipka, Janik, & Balas, 2012)*

Topic: Implementation of tyre recycling in the EU
Relevance: Medium – relevant to different options for tyre recycling, no detail on pyrolysis

The EU has passed legislation to prevent the stockpiling of tyres in landfills and is encouraging recycling. Figure 11.0 shows the activity of tyre suppliers and recyclers based on extended producer responsibility whereby the manufacturers and importers of the tyres either maintain the responsibility of managing used tyres or they can pass the responsibility to a not-for-profit organisation that is expressly appointed for the task.

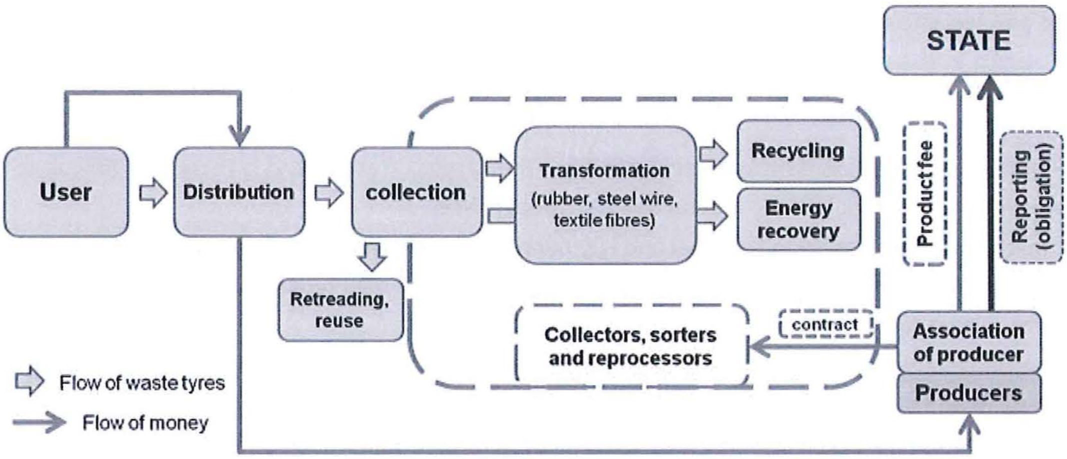


Figure 11.0: Activity of organisations recovery/recycling tyres in the EU *(Sienkiewicz, Kucinska-Lipka, Janik, & Balas, 2012)*

Legislation in the EU states that these not-for-profit organisations must file annual reports stating the effects of their activities. They are also taxed if they are unable to meet their recovery and recycling targets. This policy is highly effective, with the recovery rate of tyres reaching 96% in 2010 compared with 72.2% for paper and 58% for plastics. The article states that Japan has a recovery rate for tyres of 91% and the USA 89%. In 2010 38% of used tyres were sent for energy recovery and 40% for material recycling.

The article discusses the use of pyrolysis for the decomposition of used tyres. The raw products of the process include:

- Fly ash, soot, charred remains of oxides and sulphides of zinc, silica and steel
- Gas rich in hydrogen, carbon monoxide and dioxide, aliphatic hydrocarbons, hydrogen sulphide
- Liquid rich in aromatic hydrocarbons and oils with a high calorific value

The article states that commercial scale pyrolysis plants have failed on a significant scale primarily due to the high costs of installation and servicing of the plant and uncompetitive prices of the end products. It is becoming more widely accepted and researched due to increasing technology, rising energy costs and petroleum based fuel costs and the increasing need to find suitable management for the disposal of used tyres. The article recommends grinding and shredding tyres as more economically viable methods for disposing of used tyres.

3.1.8 Comparison of end-of-life tyre treatment technologies: A Chinese case study *(Li, Xu, & Tao, 2010)*

Topic: Supply chain and implementation of ELT recycling in China
Relevance: HIGH – relevant to the supply chain of ELT's for recycling and the process of pyrolysis

This paper highlights the supply chain of tyres for recycling and energy recovery as seen in China. Collectors of ELT's have established working relationships with tyre collectors and offer a door-to-door service for garages, retailers, and individuals. These pay a nominal fee to the customers (unlike many countries where the user pays for the tyres to be taken away). The recyclers then pay a fee to the collectors.

This paper discusses the options for ELT's as ambient grinding, devulcanisation, pyrolysis and illegal tyre oil extraction. It shows that pyrolysis is the best treatment option with the highest net benefit. It is a relatively environmentally benign technology although still has a degree of toxicity due to air emissions. China has developed a new pyrolysis technology called "Minute-negative pressure pyrolysis" in which the tyres are granulated and fed into a reactor at temperatures of between 480-700°C and pressure of between 0.01-0.04 MPa. This results in the production of char, gas and oil. Problems associated with pyrolysis in this case study include:

- The combustion gas is difficult to separate from the gaseous fraction and is therefore difficult to sell. As such it is fed back into the reactor as a fuel for pyrolysis.
- The char is separated from the steel and is ground and packed and sold as low-grade carbon black. It is generally deemed no economically viable to refine this to high quality carbon black which would have a much larger market.
- The oil cannot be used directly as diesel due to its chemical composition and is therefore sold to diesel manufacturers for purification. It has low retail value due to this reason.
- The pyrolysis equipment requires high investment during the initial stages of development.
- Likely only to be economically viable in full-sized commercial plants.

3.1.9 Discarded tyre recycling practices in the United States, Japan and Korea *(Janga, Yoob, Ohb, & Iwasaki, 1998)*

Topic: Tyre recycling practices in the US, Japan, and Korea
Relevance: Low – reports on need to implement recycling but does not recommend pyrolysis

Stockpiled tyres globally represent problems due to providing a breeding site for mosquitos which spread disease as well as representing a fire hazard. In the US common practice is to shred the tyres, which reduces transportation costs by 30-60% due to a reduction in volume of up to 75%. Shredder companies charge between US$19-$75 per tonne of tyres. Pyrolysis is largely unsuccessful due to unfavourable economies. Pyrolysis oil is similar to crude oil but requires refining which adds cost. Current low prices for crude oil make pyrolysis uneconomical. Char as a by-product is difficult to dispose of and has little retail value.

In Japan and Korea there is more importance placed on the recycling of tyres. Japan utilises the combustion of tyres in cement kilns to produce a fuel oil. This is deemed a better option that pyrolysis as there is no residue to be disposed of in landfills. Korea has a lack of legislative support and although they have cement kilns with the capacity for combustion, these are not widely used. The US has the largest problem due to significant stockpiling of tyres that need to be remedied.

3.2 Pyrolysis for the Decomposition of Tyres and Other Recyclables

3.2.1 Combustion of tyre pyrolysis oil *(Williams, Bottrill, & Cunliffe, 1998)*

Topic: Investigates the composition of pyrolysis oil
Relevance: No relevance to the implementation of the plant or supply chain, however relevant to the technology of continuous pyrolysis technology for the decomposition of tyres

This paper analyses the properties of the oil produced through the pyrolysis of tyres. This includes the calorific value, elemental analysis, and carbon, sulphur, nitrogen and hydrogen content. These properties were compared to the oil properties of the petroleum-based fuel diesel. The oil contents are shown in table 10.0.

Content	Total wt% of pyrolysis oil	Total wt% of diesel oil
Sulphur	1.45	0.2
Nitrogen	0.4	0.05
Carbon	88	87.1
Hydrogen	9.4	12.6
Ash	0.002	0.01

Total PAH	9.2	3.1
Calorific value	**42.1 MJ kg^{-1}**	**46.0 MJ kg^{-1}**

Table 10.0: Total wt% of contents of pyrolysis oil and diesel oil *(Williams, Bottrill, & Cunliffe, Combustion of tyre pyrolysis oil, 1998)*

Sulphur is of importance as high sulphur content results in sulphur oxide emissions when the oil is burnt as a fuel. The sulphur level in the tyre pyrolysis oil was similar to that found in a light to medium fuel oil. Total PAH (polycyclic aromatic hydrocarbon) represents a health hazard due to being highly carcinogenic and mutagenic. This means that precautions will need to be taken when handling the oil. Increased PAH also increases the production of soot and other emissions when the fuel is combusted. This may limit the potential for the oil to be used as a fuel without further processing before use.

Pyrolysis of the tyres resulted in a total char content of 46.8 wt% and steel of 12.9 wt%. The gases produced were mostly hydrocarbons, with lower amounts of carbon dioxide and monoxide also being recorded. Oil yield from the plant resulted in a total of 24 wt% and total gas yield was 23.9 wt%. For this experiment the char was rated as the highest priority so the conditions of the reactor were optimised for the production of char. Williams et al. discuss other studies which have produced a total oil yield of up to 58 wt%. The process for optimising the production of oil and gas include a very hot reactor for a short time period with rapid quenching in order to allow the pyrolysis gasses and vapours to condense before secondary reactions breaks down the higher molecular weight material into gas. Char production comes at the expense of oil production but can be sold at a much higher retail value if the right buyer is found.

3.2.2 The pyrolysis of scrap automotive tyres: The influence of temperature and heating rate on product composition *(Williams, Besler, & Taylor, 1990)*

<u>Topic</u>: Investigates the effect of high temperatures on the production of raw materials from tyre pyrolysis
<u>Relevance</u>: No relevance to the implementation of the plant or supply chain, however relevant to the technology of continuous pyrolysis technology for the decomposition of tyres. Conditions for increasing the oil yield is important as this is the most sought after raw material in the process for Fulton Hogan.

This paper investigates the process of pyrolysis for the decomposition of tyres. Williams et al showed that raising the temperature in the reactor reduced the amount of solid waste and increased the amount of gas and oil. This increase was noted up to a maximum temperature of 600°C after which the change to yield was minimal. At this point the raw materials produced were shown to be 55% oil, 10% gas and 35% char. The rate of heating and cooling also effected the production of raw materials. The gases that were produced from the process were Hydrogen, Carbon Monoxide, Carbon Dioxide, Butadiene, Methane and Ethane. An increase in temperature also resulted in a decrease in aliphatic fractions and an increase in aromatic fractions.

3.2.3 Composition of oils derived from the batch pyrolysis of tyres *(Cunliffe & Williams, 1998)*

<u>Topic</u>: Chemical composition of pyrolysis oil
<u>Relevance</u>: Medium to high - discusses the various uses of end products of pyrolysis

This paper shows that gas yield increased as the temperature increased, and oil yield decreased. Char content decreased with increased temperature, from 40% at 500°C to 36% at 900°C. Total yield as alternative temperatures is shown in table 11.0.

Final Temperature (°C)	Char yield (wt %)	Oil yield (wt %)	Gas yield (wt %)
450	37.4	58.1	4.5

475	37.3	58.2	4.5
500	38.3	56.2	5.5
525	37.8	56.9	5.2
560	38.1	55.4	6.5
600	38.0	53.1	8.9

Table 11.0: Yield of tyre pyrolysis products *(Cunliffe & Williams, 1998)*

The composition results showed that the pyrolysis oil had similar properties to that of a light petroleum fuel oil. Limonene was shown to be a major component of the oil representing 3.1 wt% at a temperature of 450°C and decreasing to 2.5 wt% at 600°C. Limonene is a product used in industrial solvents, resins, and adhesives, a dispersing agent for pigments, and as a fragrance in cleaning products.

The concentration of PAH and lighter aromatic hydrocarbons was determined. Increased temperature resulted in an increase in the aromatic content of the pyrolysis oil. The total PAH level increased from 1.5-3.5 wt% as the temperature was increased from 450-600°C. PAH is critical due to fuel PAH tending to form particulates upon combustion. PAH have been shown to be most likely to form soot. Unburned fuel PAH can also be deposited on soot formation through combustion and therefore enter the atmosphere. A significant number of these compounds have been shown to be highly carcinogenic which can make the handling of this oil difficult if found in high quantities. PAH that has been tested positive for being carcinogenic or mutagenic includes:

- Chrysene
- Trimethylphenanthrene
- Tetramethylphenanthrene
- Phenanthrene
- Methylphenanthrene
- Methylfluorene

All of these are found to varying degrees in pyrolysis oil depending on the feedstock for the reactor. They also showed that PAH increases with secondary reactions at moderate to high temperatures and with increased time spent in the reactor hot zones. The article also highlights the presence of high concentrations of volatile hydrocarbons that could potentially have high value that would therefore offset the costs of tyre disposal. These include xylene, toluene, indene and styrene.

The pyrolysis oil is suggested as an alternative to conventional fuel oil, being easy to handle, store and transport therefore making it unnecessary to place the pyrolysis plant near to a fuel recycling plant. It can also be used as a chemical feedstock. Pyrolysis oil has a high calorific value of between 41-44 MJ Kg^{-1}.

3.2.4 Scrap tyre 'cooking' becomes an economically viable proposition *(Professional Engineering, 1999)*

Topic: Changes in the process of pyrolysis result in outputs of raw materials
Relevance: Medium to low - not much detail contained in article

This article provides a brief overview of a study that has been completed at Leeds University. The study conclusions are that improved pyrolysis has resulted in an increase in the quality of the char to produce a high quality carbon as one of the end raw materials of the process of continuous pyrolysis technology. This means that the carbon can be sold for a higher price therefore making pyrolysis a more economically viable process for the decomposition of scrap tyres. The team at the university also improved the quality of the oil to maximise the quantities of limonene and xylene. Limonene is a much sought after industrial solvent. The article claims that the reason continuous pyrolysis technology has not taken off is due to the quality of the resultant raw materials and therefore their commercial value.

3.2.5 New pyrolysis method improves carbon black recovery from scrap tyres *(Gerald, 2007)*

Topic: Improvements in the process of pyrolysis to improve the quality of char to carbon black
Relevance: Low - no detail in article

This article discusses the proposed implementation of two plants, modelled on a prototype built in North Dakota, US. The proposed plants utilise a new technology which improves the quality of char to produce a high quality carbon black that has a high retail value. The prototype currently processes only 10 tonnes of tyres a day. The article discusses the current process for continuous pyrolysis technology which requires the plant to run at a very high temperature (750°F). This is a problem as it results in the production of oil and gas that has very high quantities of PAH, which is highly carcinogenic and is therefore difficult to handle. Delta-Energy has developed a new process that uses lower temperatures that aims to reduce PAH levels and improve the quality of the char.

3.2.6 Study of co-pyrolysis of biomass and plastic wastes *(Paradela, Pinto, Gulyurtlu, Cabrita, & Lapa, 2009)*

Topic: Changes in yield and product composition in relation to temperature and reaction time
Relevance: Medium - lots of detail on the process of continuous pyrolysis technology but none on implementation of continuous pyrolysis technology as a commercial plant

This article looks at the use of plastic in the pyrolysis of Pine in order to improve the efficiency of the process. It enables a higher output of liquids and lower output of solids (char). The resultant oil has similar properties seen in fuel oil, the gas was of superior quality to that of producer gas, and the solids had higher heating values than some coals.

A faster reaction time resulted in:

- Increased gas production that had higher alkane content
- Increased liquid production that had higher aromatic content

A higher reaction temperature resulted in:

- Decrease in total liquid yield
- Increase in total solid and gas yield
- Increase in alkane content of gas product

An increase in pressure in the reaction process resulted in:

- Increase in aromatic content of liquid product

These changes in yield and product composition are important when commercialising the process to produce raw materials that can be sold to meet specifications.

3.2.7 Aromatization of tyre pyrolysis oil to yield polycyclic aromatic hydrocarbons *(Williams & Taylor, 1993)*

Topic: PAH levels in pyrolysis oil derived from scrap tyres
Relevance: Medium - shows further study of pyrolysis oil having high PAH

This article reports results of the analysis of pyrolysis oil from the decomposition of tyres. The study shows significantly higher PAH levels than found in diesel oil – over 10%. Carcinogenic PAH including benzopyrene, chrysene and fluoranthene were found in significant concentrations. These represent a significant health hazard. The PAH levels increased with higher temperatures.

3.2.8 Polycyclic aromatic hydrocarbons in waste derived pyrolytic oils *(Williams & Besler, 1994)*

Topic: PAH levels in pyrolysis oil derived from wood and solid waste
Relevance: Medium - shows further study of pyrolysis oil having high PAH

This article shows increased levels of PAH in pyrolysis oil derived from wood waste, municipal solid waste, and rice husks. The levels were significantly higher than those found in diesel oil and increased proportionally relative to increased temperature and reaction time. The PAH found in the oil consisted of naphthalene, fluorene and phenanthrene. Carcinogenic and mutagenic PAH were also found in the pyrolysis oil.

3.2.9 Analytical approaches to characterizing pyrolysis oil from biomass *(Kanaujia, Sharma, Agrawal, & Garg, 2012)*

Topic: Chemical composition of pyrolysis oil from a variety of feedstocks
Relevance: Medium - highlights the large scope of feedstock that could be used for pyrolysis

This article highlights the use of pyrolysis for the degradation of a number of different agricultural residues and forest biomass. This includes:

- Barley (straw and hulls), rice husk, wheat straw, corn (stalks, leaves, and husks)
- Coconut and peanut shells, fruit bunches and pulps (apricot and peach pulp)
- Waste furniture and wood
- Foliage crops
- Tea waste, bagasse, rapeseed cake
- Algal biomass

The pyrolysis oil that is produced varies depending on feedstock and reactor conditions. The acidity of it is usually in the range of pH2-4 due to the organic acids present (mainly acetic and formic acids). This is important because low pH levels can make it difficult to transport and store for long periods of time. The article stresses the importance of a refinery process to produce oil that can be used as a reliable fuel source. It also mentions the economic implications that it has on the process of pyrolysis.

3.2.10 Formation of PAH and soot during acetylene pyrolysis at different gas residence times and reaction temperatures *(Sánchez, Callejas, Millera, Bilbao, & Alzueta, 2012)*

Topic: Formation of soot containing PAH as an emission from the combustion of diesel oil
Relevance: Low- article does not discuss pyrolysis oil but relates to PAH of diesel oil

This article discusses the formation of soot from the combustion of diesel oil as a result of the PAH content of the oil. PAH content in the soot was higher when the oil was combusted at higher temperatures. At lower temperatures the PAH content of soot was very low. The article also discusses PAH to be highly carcinogenic and mutagenic and as a result is hazardous to health through inhalation.

3.2.11 Pyrolysis of plastic wastes. 1. Effect of plastic waste composition on product yield *(Pinto, Costa, Gulyurtlu, & Cabrita, 1999)*

Topic: Plastic feedstock (polyethylene, polystyrene, and polypropylene) on resulting end product

Relevance: Medium – article is relevant to the pyrolysis of different plastics

This article highlights the importance of pyrolysis as an economically viable way of disposing of plastic waste. Product yield depends on the composition of the plastic feedstock – polyethylene (PE) increases the alkane content, polystyrene (PS) increases the aromatic content, and polypropylene (PP) increases the alkene content. This article suggests the optimum temperature for the thermal decomposition is 430°C at an initial pressure of 0.41 MPa increasing to 3.5 MPa. The optimum time in the reactor is 20 minutes. All plastics are washed and ground before pyrolysis. PE led to the highest gas yield. Both PS and PP increased the octane number of the resulting end product.

3.2.12 Pyrolysis of plastic packaging waste: A comparison of plastic residuals from material recovery facilities with simulated plastic waste *(Adrados, de Marco, Caballero, López, Laresgoiti, & Torres, 2012)*

Topic: Pyrolysis of plastics that are rejected from the recycling waste stream due to chemical composition
Relevance: Medium – article is relevant to the pyrolysis of a mixture of plastics

This article discusses the pyrolysis of a mixture of different plastics that cannot be recycling due to composition and therefore end up in landfill or being incinerated. In this article red mud, a by-product of the aluminium industry is used as a catalyst in the reactor. This mixture resulted in higher solid and gas yield and significantly lower oil yield.

3.2.13 Performance, emission and combustion studies of a diesel engine using distilled tyre pyrolysis oil-diesel blends *(Murugan, Ramaswamy, & Nagarajan, 2008)*

Topic: Pre-treated pyrolysis oil blended with diesel creating a fuel that diesel engines can run off
Relevance: HIGH – relevant to options for the use of pyrolysis oil

Murugan et al. showed that tyre-derived pyrolysis oil can be blended with diesel oil to produce a fuel that can be used in diesel engines. The maximum concentration at which the four stroke single cylinder air cooled diesel engine ran properly was at 70/30 pyrolysis oil/diesel. Prior to blending the pyrolysis oil was desulphurised and then distilled through vacuum distillation. Issues with long-term use of pyrolysis-diesel blended fuel may include carbon deposits and oil ring sticking as a result of the higher viscosity of the fuel.

3.3 Pyrolysis Technology in New Zealand

3.3.1 Kiwi inventors create "no 8 wire" global pollution solution – in a shipping container! *(Voxy, 2010)*

Topic: Implementation of continuous pyrolysis technology plant in Hamilton, New Zealand in 2010
Relevance: HIGH – directly relates to continuous pyrolysis technology project and could represent direct competition

Article about three chemical engineers who have developed a pyrolysis plant in Hamilton. Working under the company name Tyregone Processors the article reports that they were looking for government support for the project. The plant runs off the gas that it produces and is therefore self-sufficient. The article claims that the technology has been world-patented and that three of these plants would have the capacity to process New Zealand's entire supply of scrap tyres (about 5m annually). The Director of the company, Chris Newman, recommends the implementation of a tariff for all tyre importers as opposed to the current system whereby garages charge customers for the disposal of used tyres. The company and prototype plant has the support of University of Auckland Faculty of Engineering Professor Mohammed Farid and has been inspected for quality.

It is currently backed by private investors. The other two engineers involved in the project are Hamish Hamilton and Roger Monkton.

The plant operates at around 650°C inside a 40ft container. All gas produced is redirected back into the reactor, the oil is recommended to be used for industry, heating and energy generation. The char and steel is separated and resold as raw materials.

Note: The article has an attached comment from a reader that states that they have developed a new pyrolysis technology called CPL (closed and continuous pyrolysis system at low temperature) that operates at 300°. The name attached to the comment is: John 0211335217.

3.3.2 Carbon Recovery Ltd website *(Carbon Recovery Limited, 2012)*

<u>Topic</u>: Website for recycling tyres into tyre chips for the production of tyre-derived fuel overseas
<u>Relevance</u>: Low – relates to recycling tyres but not pyrolysis

This website belongs to company that focusses on processing whole tyres down into tyre chips in the Waikato region. The company uses a machine that has been imported from the US called a Columbus McKinnon. The tyre chips are then sent overseas to Korea where they are mixed with coal, wood or gas in a 10/90 ratio and used as fuel source for concrete, power plants or paper mills. The website highlights a review undertaken in the UK by the (UK) Environmental Agency that recommends the incineration of tyres in cement kilns over the dumping of whole tyres or chips in landfill. The kilns fire at temperatures reaching 1800° and produce a fuel with a calorific value of between 26 and 34 GJ per tonne which is similar to that of coal. The website says that the company will collect tyres from retailers, transfer stations and illegal tyre dumps and process them into fuel with the aim to feed the fuel back into the energy grid. It appears that the project is not yet in place but is looking for funding. The company has been covered in a number of media reports. These are outlined below.

3.3.2.1 Getting tired of tyres on the farm? *(Enriching the Environment, 2012)*

This article covers the start-up of the company, Carbon Recovery Ltd, and their tyre recycling programme called 'Tyre Back'. The company has set up a free phone, 0800868473, which has had immediate response from farmers wishing to dispose of old tyres sitting around their farm or property. Estimates are that there are as many as 50m tyres sitting around the countryside unused or illegally dumped which are leaching chemicals into the soils and providing a breeding ground for mosquitos. The company is charging a transport fee for removing the tyres.

3.3.2.2 Solution for New Zealand's used tyres *(Coast and Country, 2012)*

This article says that every day New Zealanders dispose of around 11,000 tyres which are sent to landfill, illegally dumped or sent overseas. Re-treading has decreased in popularity in recent years. The New Zealand Waste Strategy and the Waste Minimisation Act 2008 support the implementation of tyre recycling. Carbon Recovery Ltd has spent the last ten years researching tyre recycling and has purchased a chipping machine in order to send tyre chips overseas. They provide a nationwide tyre collection service to individuals as well as councils (to recover illegally dumped tyres).

3.3.2.3 Green future for old tyres *(Q&M, 2010)*

This article discusses the company, Carbon Recovery Ltd, which has been established by Owen Douglas. It covers the company activities as covered above and the need to implement procedures in New Zealand to deal with end of life tyres. Carbon Recovery will target quarry and mining operations, contractors, tyre retailers, and council transfer stations. They will charge a collection fee of $30 for a tyre up to 50kg and up to $250 for large mining tyres. It currently stores all collected tyres in an old quarry. The shredder is capable of chipping 12 tonnes of tyres an hour.

3.3.3 Recyclotech Industries (NZ) Ltd *(RTI NZ, 2012)*

Topic: Company in Auckland that is looking to implement pyrolysis
Relevance: HIGH – could be direct competition for tyre collection if they do import a plant

This website is owned by a company that aims to help develop and commercialise waste management business opportunities in the waste industry. It is yet to establish a tyre processing plant but is in agreement with Chinese manufacturers for the purchase of a pyrolysis plant to turn scrap tyres into carbon char, steel, and oil. It claims that the high temperature and zero oxygen environment of the reactor prevents the formation of PAH and dioxins. The website claims that the advantages of pyrolysis include:

- Removes 99% of the problematic waste associated with scrap tyres
- Creates high-value by-products
- The method reduces the CO2 footprint and water usage (as cooling water is recycled)
- The gas produced is recycled and used in the pyrolysis plant
- The project is deemed 'Green' and is financially viable (proven overseas)

The website has been created as a way to inform potential investors and lists the company as being Auckland based.

3.3.4 Ministry for the Environment *(MFE, 2011)*

Topic: Funded studies for the minimisation of waste around New Zealand
Relevance: HIGH – relevant to pyrolysis and research already implemented in New Zealand

This website looks at different waste management actions that have been put in place and, in some cases, funded by different organisations and governing bodies. Those relevant to this project include:

- **Tyregone Pyrolysis Plant, Investigation and Development**: This company has received funding of NZ$300,000 from the Waste Minimisation Fund (WMF). The WMF is a fund run by the Ministry for the Environment. This funding was allowed for the expansion of an existing pyrolysis plant in the Auckland region. The plant aims to process 2,000 tonnes a year which would otherwise go directly into landfill.
- **Environment Waikato**: This study is being conducted by Environment Waikato to look at pyrolysis as a way to create value from organic waste. They have received funding from the WMF of NZ$159,000 to develop a pyrolysis plant and test it for use with organic waste in order to produce biochar and energy.

3.3.5 Liquid Fuel from Plastic Wastes in New Zealand *(Behzadi & Farid, 2011)*

Topic: Small scale prototype pyrolysis machine built for the breakdown of plastics
Relevance: Medium– relevant to pyrolysis, but only on a very small scale and no plans to upgrade

This report is written by two lecturers at the University of Auckland. It discusses the possible uses of pyrolysis to break down plastics that may not be recyclable. It also suggests pyrolysis for the breakdown of waste tyres, coal and petroleum residues, biomass and other lubricating or heavy oils. The resultant products are oil, gas and solid. The variables in the process include the plastics that are used, the temperature that the reactor is heated to, and the catalyst that is used for the reaction. It outlines a pyrolysis project that has been created by the University using the plastics PP, LDPE, HDPE, and a mix of all three. The temperature is set between 400-600°C for a period of 45-60 minutes. PP generated the highest oil yield however it was more than 50% light oil and only 20% heavy oil.

3.3.6 Ministry for the Environment: Product Stewardship Case Study for ELT's *(MFE, 2006)*

Topic: An overview of the situation surrounding ELT's in New Zealand currently
Relevance: Medium – does not recommend pyrolysis directly but does discuss the importance of researching possible end uses for tyres with an emphasis of recycling

Although this section on the website for the Ministry for the Environment is slightly out of date as it is written in 2006, it highlights some important factors for the stewardship of ELT's within New Zealand that is still relevant. This includes the following points:

- There are approximately 30 dedicated tyre collectors in New Zealand, nine of which offer shredding services. One of these, J&J Laughton is the only one who recovers steel and produces rubber granules. 95% of all tyres collected by these companies are disposed of via shredding or quartering. Resource consents for the collectors indicate that they can only store whole tyres for a maximum of two years before disposal. Tyre collection is also undertaken by waste companies.
- Tyres are used for silage pit covers by farmers. They are also used (at much lower quantities) for arena surfacing, matting, toys, garden mulches, retaining walls, and for other engineering applications including road surfacing. Current estimations are that only 25% of used tyres are used in these ways and the remainder 75% is sent to landfills. Approximately 300,000 tyres are illegally dumped every year. The Basel Convention restricts the movement of hazardous waste outside of the country of origin to a dumping ground offshore. This includes all scrap tyres. It emphasises the importance of recycling the tyres locally.
- Golden Bay Cement in Whangarei and Holcim Cement in Westport are two sites where tyres could be disposed of as fuel for the kilns. As whole tyres can be used for fuel in kilns, this will save time shredding or quartering.
- Pacific Steel is highlighted as a potential user of scrap tyres. They have trialled the use of tyres as an alternative use for Activated Carbon and as an energy source. Half a million tyres could be disposed of for this use.
- Significant environmental barriers exist for the disposal of tyres. Overseas trials have shown that they can be incinerated at very high temperatures without unacceptable emissions. In Australia, burning tyres as a fuel source in cement kilns is common practice.
- Cost is a secondary barrier for the disposal of tyres. Landfill represents the cheapest option for disposal and therefore all other options have difficulty being shown as economically viable. The only way to change this is to increase the cost to landfill tyres or to pass legislation preventing it.
- An Australian study showed the following results. Barriers to alternative ELT's end uses were as follows:
    - Cheap landfill pricing
    - Unsupportive public procurement policies
    - Private sector inertia in other uses
    - Lack of consistent and reliable ELT supply
    - Lack of regulation
    - Distance from collection point to ELT end-users
    - Competition from raw materials priced low

- Concern by regulators over the heavy metal leachate
- Operational difficulty in burning tyres
- Negative public perception of burning tyres
- Health and safety issues

- The MFE suggest the possible implementation of an advanced disposal fee (ADF) at the point of manufacture and import. This would potentially generate funds for the development of higher-value reuse options alongside supplementing transport costs of getting the tyres to the recycling plants. The implementation of an ADF has benefits and negatives associated with it. The MFE also recommends the implementation of tyre tracking to report the movement of all tyres.

3.4 Tyrewise Summary of Supply Chain and Possible Uses of ELT's Within New Zealand *(Tyrewise, 2012)*

3.4.1 Supply Chain of Tyres in New Zealand

The major companies involved in the import of new and used tyres are Bridgestone/Firestone and Goodyear/Dunlop followed by Tyres4U, Michelin and a number of smaller companies *(Tyrewise, 2012)*. The majority of tyres imported into New Zealand are made in Japan, where low-cost labour and resources make for an ideal climate for manufacturing. There are no tyre manufacturers in New Zealand following the closure of the Bridgestone/Firestone factory in 2010.

3.4.1.2 Categories of Tyres Imported into New Zealand

Tyrewise categorises tyres in New Zealand into eight categories *(Tyrewise, 2012)*. These are listed in table 12.0 along with their average weight per tyre. Note that the weight is lower for used tyres due to general rubber wear throughout the life of the tyre. Off-road tyres range in weight from 3kg to 3tonnes and an average of 200kg per tyre has been taken due to this vast difference in sizes. The majority of tyres used in aircraft are re-treaded and disposed of overseas and therefore are not relevant for the purposes of this project.

Tyre Category	New Tyres: Weight (kg)	Used Tyres: Weight (kg)
Motorbike	4.75	4.0
Passenger	9.5	8.0
Light to Medium Commercial	19.0	16.0
Truck and Bus	47.5	40.0
Industrial (i.e. Forklift)	34.0	28.0
Tractor	77.0	64.0
Off-road (Grader, Earthmover, Forestry)	220.0	200.0
Aircraft	18.0	14.0

Table 12.0: Average weight and categories of new and used tyres in New Zealand *(Tyrewise, 2012)*

3.4.1.3 Composition of Tyres Imported into New Zealand

Tyres are composed of rubber, steel and textile. Carbon black is incorporated into the rubber during the manufacturing stage and is one of the key end raw materials from CONTINUOUS PYROLYSIS TECHNOLOGY. Table 13.0 shows the relevant percentages and weight of these raw materials.

Tyre Category	Rubber %	Rubber kg	Steel %	Steel kg	Textile %	Textile kg
Motorbike	70%	2.8	18%	0.7	12%	0.5
Passenger	72%	5.7	21%	1.7	6%	0.6
Light/ Medium Commercial	69%	11.1	25%	4.0	5%	1.0
Truck and Bus	68%	27.2	32%	12.8	0%	0.0
Off Road (Grader, Earthmover, Forestry)	70%	140	30%	60	0%	0.0

Aircraft	70%	9.8	10%	1.4	20%	2.8

Table 13.0: Breakdown of raw materials relevant for recycling of tyres in New Zealand *(Tyrewise, 2012)*

3.4.1.4 Quantity of Tyres Imported into New Zealand

The majority of tyres entering New Zealand enter as new tyres as shown in figure 12.0. These figures are based on the assumption of:

- Five tyres per car, motorhome, and Ute (four plus one spare)
- Two tyres per motorcycle
- Four tyres per tractor
- Five tyres per commercial vehicle weighing under 1500kg (89% of commercial vehicles)
- Fourteen tyres per commercial vehicle weighing over 20,000kg (5% of commercial vehicles)
- Corresponding estimates for vehicles weighing between 1500kg and 20,000kg based on size relationship to wheel estimate

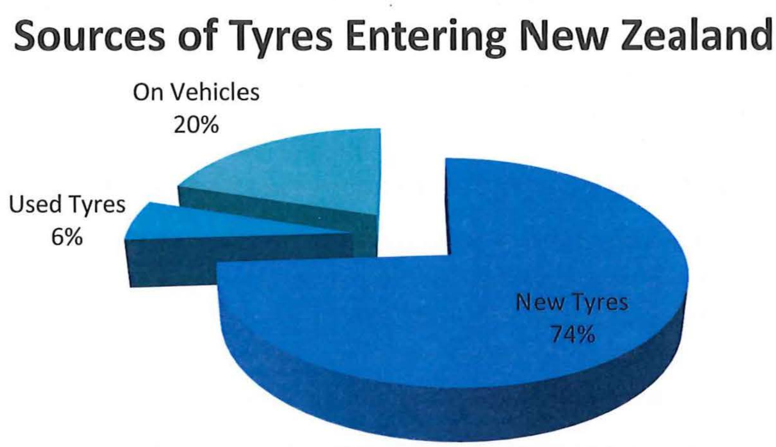


Figure 12.0: Breakdown of sources of tyres entering New Zealand in 2011 *(NZ Statistics, 2012)*

These measurements provided an estimate of around 4.8m tyres entering New Zealand every year. Based on these figures estimates as to total weight of tyres entering New Zealand can be made. As shown in table 14.0, passenger tyres account for the majority of the 80,608 tonnes of tyres.

Tyre Category	Av Used Weight (kg)	New Tyres Imported	Used Tyres Imported	Tyres on Vehicles	Total Tyres (Units)	Total Weight (Tonnes)
Motorbike	4.0	138,916		34,192	173,108	692
Passenger	8.0	2,666,530	211,493	830,955	3,708,978	29,672
Light to Medium Commercial	16.0	5,292	6,338	74,610	86,240	1,380
Truck and Bus	40.0	496,077	33,050	21,518	550,645	22,026
Industrial	64.0	30,015		14,768	44,783	2,866
Tractor	28.0	88,636	28,763	-	117,399	3,287
Off Road	200.0	102,849	132	-	102,981	20,596
Aircraft	14.0	3,997	2,377	-	6,374	
	TOTAL UNITS	3,532,312	282,153	976,043	4,790,508	
			TOTAL ESTIMATED TONNES OF TYRES			**80,608**

Table 14.0: Estimated total weight of tyres entering New Zealand based on 2011 figures *(Tyrewise, 2012)*.

3.4.1.5 Sources of End of Life Tyres in New Zealand – Potential Suppliers for CPT

The majority of tyres in New Zealand for passenger, light to medium commercial vehicles, and trucks have their tyres changed at garages and tyre suppliers therefore these places have the highest number of end of life tyres that need to be disposed of. Other secondary sources include the following:

- Tyres being removed from imported cars that are not up to standard. Stricter import duties have resulted in a drop of used cars being imported. From 2003 to 2011 the number of cars dropped from 169,771 to 84,028 *(Tyrewise, 2012)*.
- Car scrapyards and vehicle wreckers who must dispose of the used tyres that cannot be resold prior to scrapping the vehicle. In 2011 a total of 145,000 *(Ministry of Transport, 2012)* vehicles were scrapped totalling 725,000 tyres, only of which some can be resold.
- Truck tyres are re-treaded between two and four times depending on the tyre and its usage. Re-treading businesses in the North and South Island classify approximately 10% of all tyres as unfit for re-treading *(Tyrewise, 2012)*. These tyres then need to be disposed of.
- Farmers have a source of used tyres for various purposes including covering silage pits. These are discarded when they are no longer needed *(Tyrewise, 2012)*.
- Illegal dump sites around the country could provide a source for ELT's with support from local councils for the clean-up of these areas. Auckland Council pays $50,000-$100,000 every year for the clean-up of illegal dump sites *(Tyrewise, 2012)*.

3.4.1.6 Tyre Retailers

There are around 1500 tyre retailers in New Zealand *(Tyrewise, 2012)*. This includes:

- 98 Beaurepaires and 22 Goodyear service centres owned or franchised by Goodyear/Dunlop
- 54 Firestone/Bridgestone stores and 22 Tony's Tyre Service stores owned by Firestone
- 125 Firestone dealerships
- 300 Tyre4U independent dealerships

Disposal costs for passenger tyres at these retailers range from $2.50-$4 and truck tyres from $6-$16 depending on size. It was shown that tyres are also dumped at these places overnight, which then moves dumping responsibility onto the retailer. An average store collected around 400 ELT's a month. In the Auckland area Goodyear and Tyres4U send many of their tyres to J&J Laughton's (for rubber crumbing). Firestone and Tony's Tyre Service send tyres to Pacific Rubber.

Total money collected from customers for tyre disposal for 2011 for Goodyear/Dunlop and Firestone/Bridgestone was $2.2m and the actual money spent on disposal was $2.1m. This was a total of 618,000 tyres during this period.

3.4.1.7 Tyre Re-treaders and Processors of ELT's

There have not been any tyre re-treaders for passenger vehicles since 2007 due to re-treading being economically unviable. This has significantly increased the number of waste tyres by a measure of 3 to 4 fold. Tyre processors that were interviewed felt that their tyre supply was not sufficient and was limited by the large number of ELT's still going to landfill *(Tyrewise, 2012)*.

- Pacific Rubber (Auckland) crumbs truck tyres for use as a construction material. The larger crumbs are used for the construction of synthetic sports fields. The smaller crumbs are used in the construction industry for adhesives, resins and rubberized asphalt. Pacific Rubber (Paeroa) cut and shred tyres for the civil engineering industry. Uses include retaining structures, road foundations, feed-out pads and drainage mediums.

- Carbon Recovery Ltd (Waikato) chip tyres and send them to Korea for use as a tyre-derived fuel. They are limited by their supply of ELT's.
- J&J Laughton's (Auckland) shred, chip and granulate tyres for the civil engineering industry. Uses include land erosion control, sub base in roading, surface water diversion, embankment retention, sports turf management, horse arena surfaces, backstops for firing ranges, and silage pit covers. They also send tyres to Asia for energy recovery.
- Tyregone Processors (Auckland) are established next to J&J Laughton's and are in the development stage of a pyrolysis reactor. They have not yet been able to provide a successful commercial plant.

Figure 13.0 shows a breakdown of the end use pathways for ELT's in New Zealand in 2011.

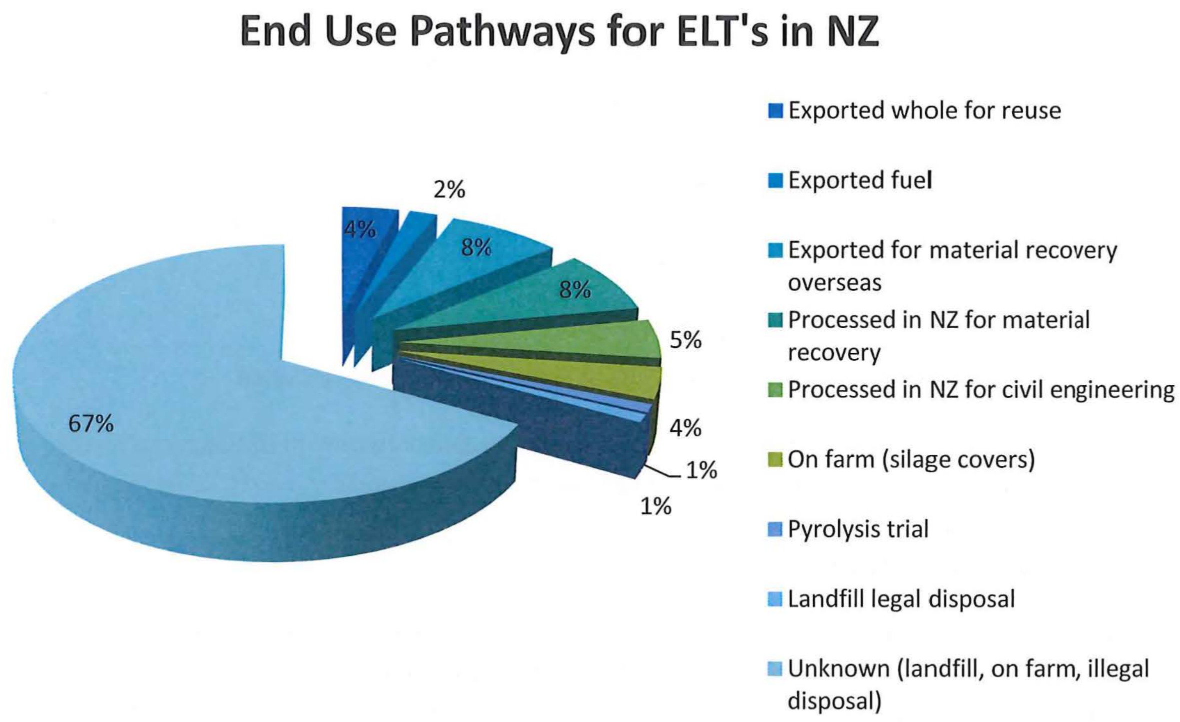


Figure 13.0: End use pathways for ELT's in New Zealand for 2011 *(Tyrewise, 2012)*

3.4.1.8 Tyre Exporters

A number of collectors ship tyres overseas to Africa, Asia or the Pacific Islands. In 2011 138,475 were shipped overseas, with 109,294 going to Vietnam *(Tyrewise, 2012)*. Reclaimed rubber was shipped to Australia and New Caledonia to be used for the construction of artificial turf. This amounted to 10,200kgs *(NZ Statistics, 2012)*.

3.4.1.9 Issues in New Zealand

The main problems in New Zealand appear to be that tyres are still being seen as rubbish that needs to be disposed of rather than their value as a raw material. A change in legislation to support recycling will assist in altering this. The high fee for disposal only aids in supporting illegal dumping and the collection fee paid to tyre collectors and processors is seen as extravagant to individuals and companies. If value add processes could be put in place for ELT's then this disposal fee could be dramatically reduced or completely eliminated.

3.4.2 Options for Alternative Uses of ELT's

80,000 tonnes of ELT's are generated annually in New Zealand with only a fraction being diverted from dumping to a beneficial use such as for recycling. One of these options outlined is pyrolysis.

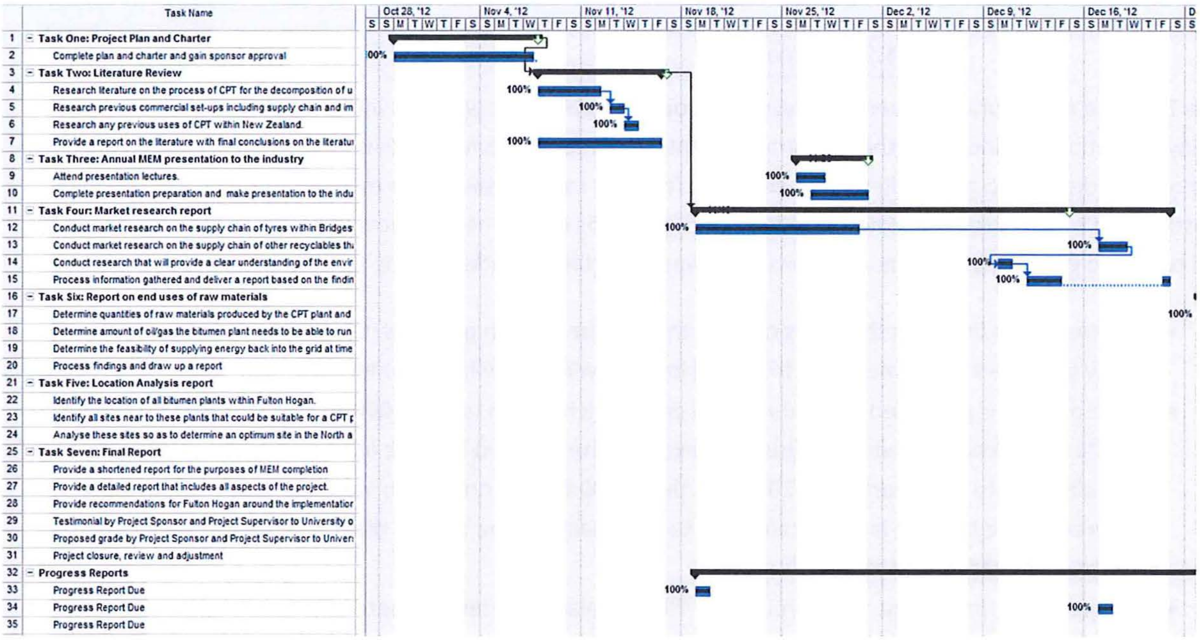
3.4.2.1 Pyrolysis

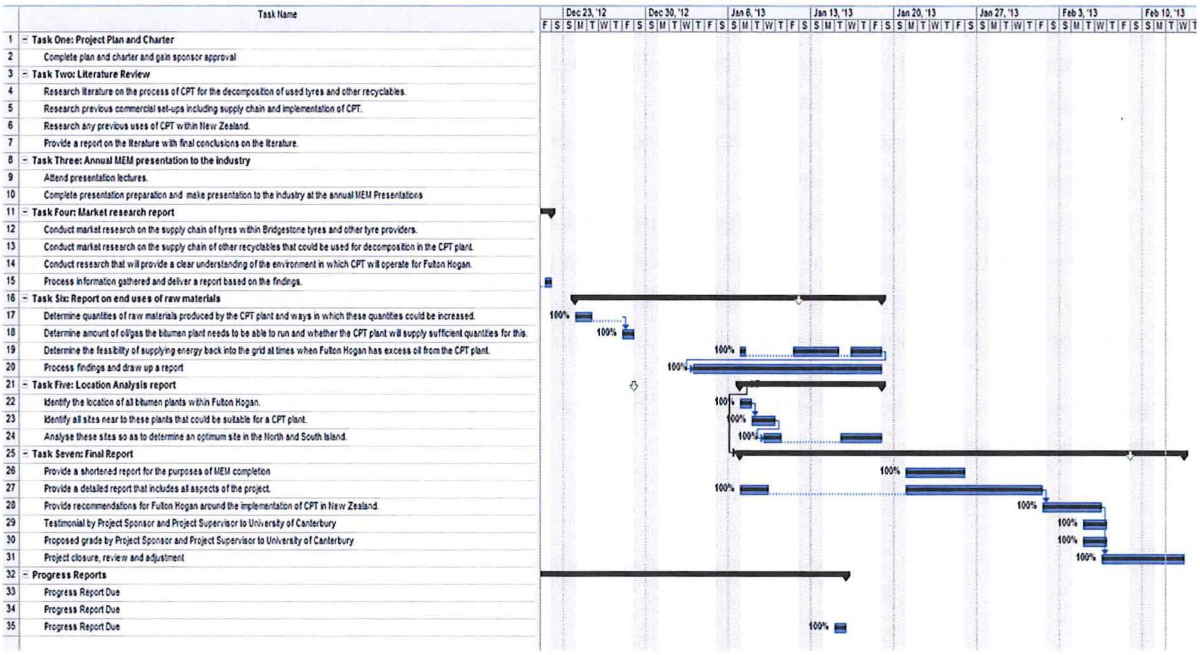
The Tyrewise report briefly covers pyrolysis as an option to break-down tyres into gas, oil and char. The oil has many potential uses including the industrial solvents and alternative fuels. Trials have been undertaken to mix the oil with diesel to create a diesel blended fuel. The char can be used in the manufacturing of ink, paint, dye, plastics, and rubber products. Energy derived from pyrolysis can be used to power onsite generators or can be fed back into the pyrolysis plant. An assessment was undertaken to identify the viability of pyrolysis:

- There are no limits on the types of tyres that can be used in pyrolysis. Older tyres that are more worn may produce a lower yield due to having lower raw material for input into the plant.
- The process is predicted to produce 30% char, which would total 24,000 tonnes if all 80,000 tonnes of ELT's were processed via pyrolysis. This exceeds the demand for char in New Zealand and the balance would need to be exported. In 2011 less than 1000 tonnes on carbon was imported into New Zealand therefore the balance is significant. Due to the quality of the carbon black it is difficult to secure long-term contracts for the export.
- There is no precedent for pyrolysis in New Zealand therefore there has been no environmental analysis completed on emissions or environmental hazards.
- Reklaim have conducted a financial analysis that has shown that for a plant to be commercially and economically viable it will need to process 175 tonnes a week or 9,100 tonnes per year. This accounts for 11.37% of total ELT's in New Zealand.
- It is deemed not possible to determine prices for oil, gas and char due to fluctuating markets and inconsistency in product quality.
- Tyrewise highlights the potential to feed energy back into the grid with pyrolysis.
- It is thought that the implementation of pyrolysis in New Zealand would lead to the development of medium to high level skilled jobs in the industry due to new technological skills required. The development of support services would also be required to make a commercial plant sustainable.

The report also looks at other options for ELT's however they are not relevant to this study on the implementation of pyrolysis.

Appendix 4.0: Gantt Chart Showing Project Schedule





Appendix 5.0: Market Research Raw Data

5.1 Beaurepaires stores throughout the South Island

Location of Store	No. of Tyres (per week)	Tyre Collector Used	Additional Notes
Nelson	250-300 4wd, commercial, car	Tyre Collection Services Ltd	
Richmond	100-150	Tyre Collection Services Ltd	
Christchurch – Hornby	105 car and light truck (4wd)	Tyre Collection Services Ltd	
Christchurch – Northwood	90 car and light truck (4wd)	Tyre Collection Services Ltd	
Christchurch – Sydenham	80 car and light truck (4wd)	Tyre Collection Services Ltd	
Christchurch – City	100-120 mostly car	Tyre Collection Services Ltd	
Darfield	100-120	All to farmers for silage	
Rangiora	50	All to farmers for silage	
Ashburton	60-100	Silage and Tyre Collection Services Ltd for excess	
Timaru	200-300	All to farmers for silage	
Alexandra	60	Silage and excess removed by Beca (to landfill)	Mainly car and 4wd tyres
Dunedin – Andersons Bay	100-125	Silage and Dunedin City Council disposal system	
Dunedin – City	50-100	Shred, put in skip, taken to landfill	Wide variation on numbers week to week
Oamaru	80-100 all car tyres	All to farmers for silage	
Queenstown	80-100	To a recycling company for rubber re-use	Did not name recycling company
Gore	100-200	Silage and excess to landfill	Mostly car tyres
Invercargill – Deveron St	Would not comment	Silage	Company did not want to discuss details at all
Total tyres:	**Average: 1852 per week; 86,304 per year**	**One company, silage and landfill used**	

Table 15.0: Beaurepaires stores throughout the South Island, with total tyres disposed of and tyre collector used *(based on phone interviews with all retailers)*

Although the Darfield outlet of Beaurepaires gave all their tyres to farmers for silage, the manager knew about a tyre recycling company based in Rolleston (Tyre Collection Services Ltd). He was aware of the need to dispose of tyres responsibly and commented that if farmers no longer required tyres for silage they would look into options for recycling. Some of the retail outlet managers had no problem with disposing of tyres in landfill and had no interest in options for recycling.

The manager of the Queenstown outlet commented that Beaurepaires did not make any money from tyre disposal. He said that he did not support the use of tyres for silage pit covers and did not think that Beaurepaires did either due to the on-going negative effects on the environment such as leaching of chemicals into the soil. The manager knew of J & J Laughton in Auckland and mentioned that they provided a tyre collection service for many Beaurepaires outlets throughout the North Island.

The manager of the Gore outlet of Beaurepaires discussed a scrap metal yard in Mataura, owned by Jeff Thacker, which reportedly has a working pyrolysis plant on the premises. This plant produces char, gas and oil and the owner has the capability to feed energy back into the grid. The manager of the outlet was unable to provide details on this plant and I was unable to locate any information on the company or owner.

5.2 Total tyres in the South Island disposed of by Bridgestone annually

Region	Passenger Tyres	Truck Tyres	Total Tyres
Nelson / Marlborough	27,000	2,750	29,750
West Coast	8,000	950	8,950
Canterbury	93,000	6,900	99,900
Otago	34,000	2,400	36,400
Southland	18,000	2,600	20,600
TOTAL TYRES	**180,000**	**15,600**	**195,600**

Table 16.0: Total tyres disposed on by Bridgestone annually *(based on figures provided by Bridgestone)*

5.3 Scrap Tyre Movements

An interview conducted with Andrew Dick, the owner of Scrap Movement Tyres highlighted some important factors to be taken into account when looking at the supply chain of ELT's:

- Many tyres are illegally dumped around Christchurch. A clean-up for the new subdivision in Rolleston cost approximately $50,000 and was paid for by the council. A secondary dump was found behind the airport. The collector who had been dumping in this area was held accountable for the costs, which totalled approximately $250,000. Mr Dick commented that it was common practice for tyre collectors to try and invent ways to dispose of tyres which costs them less.
- Tyres get dumped in rental properties around the city. Residents who are keen to make some money will charge around $1 a tyre then dump them on the property. When the tenancy is up, the landlord is then left to pay for the disposal. Mr Dick has been involved in a number of rental property clean-ups which generally cost around $300-$400 per site.
- Farmers have problems with tyres being dumped on their land. The cost for disposal is not covered by the council as it is private property.
- The council is making money from tyres being disposed of in landfills. It seems there may be slight reluctance to support legislation changes around tyre recycling due to this. This comment is purely opinion based.
- Mr Dick felt that Tyrewise's recommendation to add an advanced disposal fee (ADF) to all tyres being imported into New Zealand would be a good step towards a change in attitude over the end use of scrap tyres.

Although the information on what Scrap Tyre Movements was going to do with tyres in the near future was deemed to be commercially sensitive, Mr Dick did comment that he had been in China for the past two weeks looking at pyrolysis machines. He said that it was difficult to implement pyrolysis here due to the high equipment costs. Whilst in China, he has been in contact with a developer from India who processed 12,000 tyres or around 100 tonnes a day with the use of ten pyrolysis machines bought from the Chinese factory. This man was in China to purchase two more machines to increase production of char and oil which he could then sell for a profit. Mr Dick was adamant that the oil produced from the pyrolysis machines was of high quality and could be burnt as diesel.

Mr Dick had applied for a grant from the New Zealand Government for the purchase of a pyrolysis machine but was declined due to being in direct competition with another tyre processor. He was told that "the government cannot be seen to be giving money to a company that is in direct competition with another".

Following this he had discovered that his competitor had applied for a grant and put an application forward to prevent this from happening. Mr Dick commented that he felt that making a pyrolysis machine here in New Zealand would not provide the same results as importing one which already had proven technological success in terms of processing and product quality.

5.4 Tyre Collection Services

An interview conducted with the manager from Tyre Collection Services outlined the following:

- Tyre Collection Services collects around 2000 tyres a week. This totals approximately 104,000 annually. Most of these are from passenger vehicles, but the company deals with all types of tyres. This figure was provided by the company but subsequent research shows that this may be well below the real number of ELT's processed by the company (they service Bridgestone who have around 200,000 tyres to dispose of annually).
- Economic viability was a massive issue for the company. The tyres are baled whole because chipping or shredding machinery to separate out steel and different grades of rubber is expensive. They are sent to Vietnam because this is both cheaper and more environmentally friendly than dumping them in a local landfill. They felt that it would be detrimental to their business if they were to be seen sending tyres to landfill. They had been looking at other options such as pyrolysis, but machinery cost was too high. On-going maintenance of this machinery was not seen to be an issue.
- The manager relayed that there are no restrictions on how long tyres can be stored for in New Zealand. Tyre Collections Services stores theirs out in the open in a fenced yard. They hold the tyres until the exchange rate is at a point where it is beneficial for them to be exported.
- The manager was aware that the government was in the process of passing legislation to prevent tyres going to landfill, but this was at least 18 months away.
- Around half the tyres they collect are used for silage pit covers in farms throughout the South Island.
- Tyre Collection Services is in direct competition with Scrap Tyre Movements.

5.5 EcoDrop

An interview with John Ross, General Manager, provided an overview of their practices:

- EcoDrop uses Tyre Collection Services to collect and dispose of their tyres. This company runs a weekly collection of tyres from all three of their collection points. Every week they have between 800-1000Kg of tyres collected.
- Most of the tyres that they have to dispose of are passenger vehicle tyres, but they also have a few truck tyres. They do not deal with larger commercial vehicles, such as off-road or grader, as they are difficult to move and costly to dispose of.
- In the past, EcoDrop has given tyres to farmers for use as silage pit covers, but due to a drop in demand, this practice was no longer done. Farmers tend to access tyres directly from tyre collection yards.
- Mr Ross thought that all tyres that were collected were recycled, but was unsure of the exact use. He said that recycling tyres was more active now than it had ever been and fewer tyres were dumped at landfill than they used to be.

Mr Ross indicated that EcoDrop would be very interested in a company or process that would remove the tyres free of charge from their collection sites.

5.6 South Island Landfills

There are twenty-two landfills in the South Island and three additional ones on the Chatham Island (figure 14.0). Prices at landfills around the South Island for passenger vehicles vary from $3.10-$6 and for truck tyres $13-$35. Green Island and Waikouaiti landfills in Otago charge $302.50 per tonne for mixed tyres.

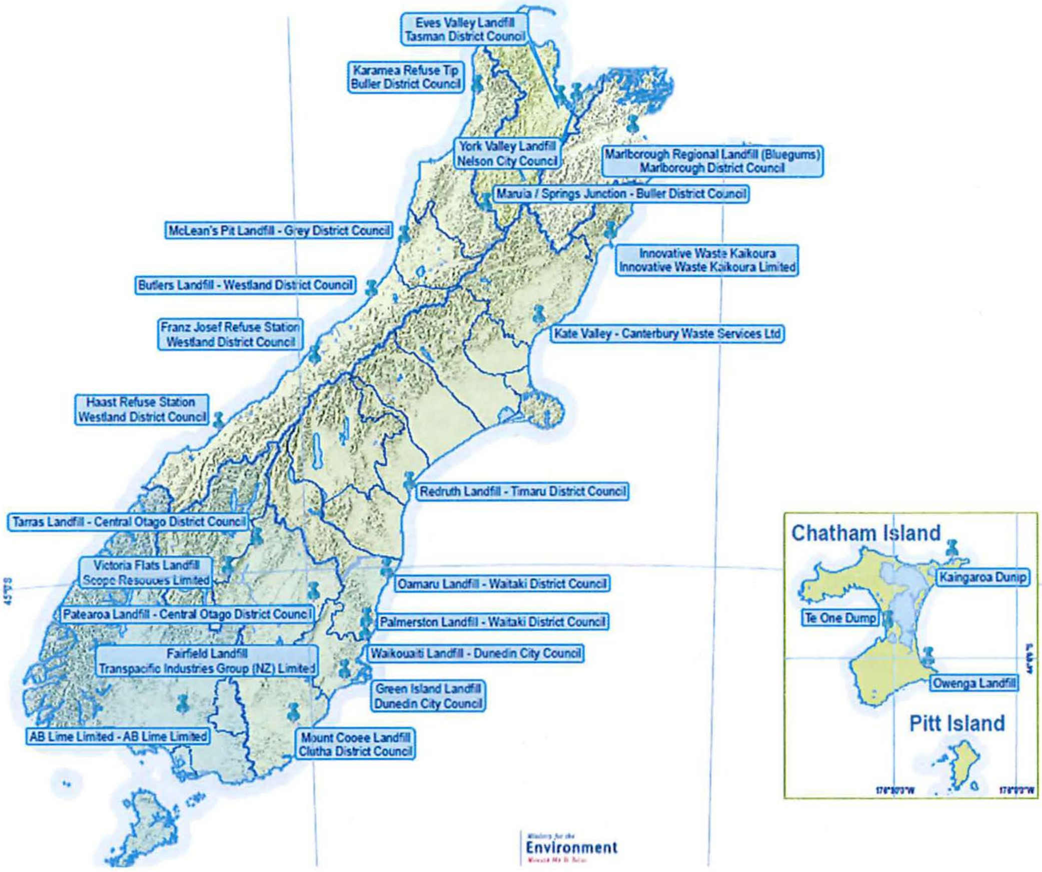


Figure 14.0: Waste disposal facilities in the South Island, New Zealand *(MFE, 2012)*

All landfill in Christchurch goes to the Kate Valley Sub-Regional Landfill. Many landfills around New Zealand have now banned the disposal of whole tyres, but will still take shredded or quartered tyres. The charges for tyre disposal at Kate Valley are outlined in table 17.0.

Tyre	Disposal Cost (per tyre)
Car tyre (on and off the rim)	$6.00
4WD tyre	$7.00
Truck tyre	$12.00
Tractor tyre	$35.00

Table 17.0: Tyre disposal charges for Kate Valley Sub-Regional Landfill *(Hurunui District Council, 2012)*

The disposal charges are the primary reason that many tyres are dumped at garages and tyre providers, during hours in which businesses are closed, and in illegal dumping sites across the country. These dump sites are then left to be cleaned up by the council at a cost to the tax payer.

5.7 Beaurepaires (Independent to Carter's Tyre Service) stores in the North Island

Location of Store	No. of Tyres (per week)	Tyre Collector Used	Additional Notes
Dargaville	10-20	Landfill	
Kaikohe	20-25	Silage and excess to landfill	

Kaitaia	Unable to estimate	Silage and excess to landfill	
Kawakawa	25-50	Customers take for gardens and excess to landfill	
Kerikeri	Unable to estimate	Silage, customers take for gardens, and excess to landfill	
Whangarei	100-120	Landfill	
Auckland – City	80	Landfill	
Auckland – Albany	100-140	J & J Laughton	
Auckland – Browns Bay	50	J & J Laughton	
Auckland – Clendon	35-40 mostly car	Landfill	
Auckland – East Tamaki	70-80	J & J Laughton	
Auckland – Glen Innes	90 mostly car	J & J Laughton	
Auckland – Glenfield	100 mostly car	J & J Laughton	
Auckland – Greenlane	80-100 car and 4wd	J & J Laughton	
Auckland – Grey Lynn	40-60	J & J Laughton	
Auckland – Henderson	150	Landfill	
Auckland – Howick	50-100	Landfill	
Auckland – Kingsland	200	J & J Laughton	
Auckland – Manukau City			Disconnected
Auckland – Mt Roskill	150	J & J Laughton	
Auckland – New Lynn	80	J & J Laughton	
Auckland – Newmarket	90-140 busy period, 60-100 quiet period	J & J Laughton	
Auckland – Takanini	Unable to provide totals	J & J Laughton	
Auckland – Takapuna	60	J & J Laughton	
Auckland – Waiuku	20-25	Landfill	
Warkworth	100	Landfill	
Rotorua	100-140	All to farmers for silage	
Tauranga – Cameron Rd	20-100	Pacific Rubber	
Tauranga – Durham St	200-300 car and 4wd	Pacific Rubber	No truck tyres
Whakatane	60	To farmers for silage and excess to landfill	
Hamilton – Anglesea St	100	Pacific Rubber	
Hamilton – Te Rapa Rd	30-80	Waikato Tyre Shredding	
Hamilton – Pukete Rd		Waikato Tyre Shredding	Would not disclose amount of tyres
Matamata	Unable to provide totals	Council rubbish collection	
Te Awamutu	40-60	Tyre Savers	Collected every 3 months, shredded and recycled
Taumarunui	100	During silage season tyres are taken by farmers, rest of the year they are stockpiled on site	Landfill won't take tyres
Hastings	140-150	Pacific Rubber	7,500 last year
Napier	60-120	Retired Tyre Company	Varies a lot depending on demand
Waipukurau	90-100	Retired Tyre Company	5,000 last year
Paraparaumu	130	Tyre Disposal Services	
Porirua	80-100	Al's Bins Ltd	Pays $800-1200 monthly
Upper Hutt	180-200	Tyre Disposal Services	

Lower Hutt	50	Al's Bins Ltd	Mostly car and 4wd tyres
Wellington – Victoria St	70-160	Al's Bins Ltd	Also removes any rubbish
Wellington – Central	80	Al's Bins Ltd	
Wellington – Newtown			Manager would not discuss
Wellington – Thorndon Quay	80-200	Al's Bins Ltd	
Total Tyres:	**Average: 3750 per week; 195,000 per year**	**7 different collection companies**	

Table 18.0: Beaurepaires (Independent to Carter's Tyre Service) stores in the North Island, with total tyres disposed of and tyre collector used *(based on market research results)*

Phone interviews showed that more managers in the North Island than in the South Island did not want to discuss details on which tyre collector they used or how many tyres they processed weekly or annually. The manager of the Warkworth outlet discussed his intention to purchase a pyrolysis plant in the future depending on available cash flow. He felt this would be the most economically viable way to dispose of tyres. Currently he sends all tyres to landfill however he was aware that this would not be possible if legislation were to change. Tyre Savers is a Hamilton based company that specialises in trucks and trucking equipment. They also act as a tyre dealer and offer tyre repairs. Although the retail outlet at Te Awamutu listed them as the tyre collector for their ELT's, Tyre Savers are not listed as a tyre collection company.

5.8 Carter's Tyre Service

Location of Store	No. of Tyres (per week)	Tyre Collector Used	Additional Notes
Mt Wellington	30-40 car and truck	J & J Laughton	
North Harbour	60 car, 70 truck	J & J Laughton	
Silverdale (Trading as Beaurepaires)	50-60 car, truck and off-road	J & J Laughton	Mainly larger tyres – truck and off-road.
Pukekohe	100 car and truck	J & J Laughton	
Whangarei	60-70 car and truck		
Hamilton	100-120 car and truck	Enviro Tyres (for Carbon Recovery)	
Morrinsville	60-100 car and truck	Pacific Rubber and Enviro Tyres. Also sent some tyres to Waikato Tyre Shredding.	Mainly uses Pacific Rubber and to farmers for silage covers.
Mt Maunganui (commercial)	30-55 truck and off-road	Enviro Tyres (for Carbon Recovery)	
Mt Maunganui (retail)	60 car and light truck	Enviro Tyres (for Carbon Recovery)	
Rotorua (Trading as Beaurepaires)	110 car, 50 truck	Pacific Rubber	
Taupo	200 car and truck	Pacific Rubber	
Tokoroa	100 car and truck	Pacific Rubber	
Gisborne	40-50 car and truck	The Retired Tyre Company	Owner: Shane Donaldson
Hastings	70 car and truck	Pacific Rubber	
Pahiatua	35 car, 25 truck	Tyre Disposal Services	
Masterton (Trading as Tunnell Tyres and Garage Ltd)	100 car and truck	Tyre Disposal Services	In silage season all tyres go to farmers
Te Kuiti	50 car and truck	Enviro Tyres (for Carbon Recovery)	Stated Enviro Tyres dispose of in landfill
New Plymouth	120-130 car, 130 truck	Enviro Tyres (for Carbon	

		Recovery)	
Wanganui (Trading as Swartz Tyres Ltd)	100-150 car and truck		Shred their own tyres and dispose at landfill
Palmerston North	75 car and truck	Rubber Solutions Ltd	
Wellington	25 car, 15 light truck, 20 heavy truck	Tyre Disposal Services	
Total Tyres:	**Average: 1850 per week; 92,600 per year**	**5 different companies used**	

Table 19.0: Carter's Tyre Service stores with total tyres disposed of and tyre collector used *(based on market research results)*

Whilst some retailers felt that it was important to recycle tyres and were proud to discuss how their tyres were being used, others were not concerned with them being dumped in landfill and had not looked at any other options or companies for use in disposal. The manager at the retail store in Whangarei discussed the importance of using a tyre collector that did not send tyres to Asia to be incinerated in kilns due to the level of pollution generated from this practice. This store sends their tyres to a company that crumbs the tyres and uses them to make synthetic sports fields and children's play areas. Tunnell Tyres and Garage Ltd in Masterton discussed the use of tyres by the Masterton regional council in the retaining walls of the local river banks. The manager of this store was proud that none of their tyres go to landfill and said that during that during the silage season all the tyres that they get go straight to farmers for use as silage pit covers. The retail store in Morrinsville also gave a lot of tyres to farmers during silage season. One retail outlet discussed the increasing trend of the use of truck tyres as exercise equipment, particularly for rugby players.

5.9 Total tyres in the North Island disposed of by Bridgestone annually

Region	Passenger Tyres	Truck Tyres	Total Tyres
Northland	40,000	2,400	42,400
Auckland	178,000	6,650	184,650
Waikato	57,000	10,500	67,500
Coromandel	5,000	700	5,700
Bay of Plenty	54,000	10,700	64,700
Taranaki	26,000	1,700	27,700
Gisborne	8,000	1,250	9,250
Hawkes Bay	38,000	2,350	40,350
Central North Island	17,000	1,700	18,700
Wairarapa	13,000	800	13,800
Kapiti Coast	22,000	750	22,750
Manawatu / Wanganui	47,000	3,850	50,850
Wellington	112,000	1,700	113,700
TOTAL TYRES	**617,000**	**45,050**	**662,050**

Table 20.0: Total tyres disposed on by Bridgestone annually *(based on figures provided by Bridgestone)*

5.10 Landfills in the North Island

Auckland council accepts tyres at transfer stations around the city. These are shredded prior to disposal in landfill. The majority of tyres left at council transfer stations in the Auckland area are collected by J & J Laughton. Prices for the disposal of tyres at transfer stations are outlined in table 21.0.

Tyre	Disposal Charge
Car tyre (on and off the rim)	\$3.20
Truck tyre	\$9.90
Tractor tyre	\$15.30
Loader tyre	\$49.30

Table 21.0: Tyre disposal charges for Auckland based transfer stations *(Auckland Council, 202)*

The Wellington landfill (Southern Landfill) is located on Landfill Road, off Happy Valley Road between Brooklyn and Owhiro Bay. The charges for tyre disposal are shown in table 22.0.

Tyre	Disposal Charge
Car tyre	$4.00
Truck tyre	$10.00
Tractor tyre	$10.00
Tyres only, unconfirmed number: car	$324.50 per tonne, min charge $32.50
Tyres only, unconfirmed number: truck/tractor	$371.80 per tonne, min charge $37.20
Tyres only, unconfirmed number: off-road	$411 per tonne, min charge $41.10
Tyres only, unconfirmed number: mixed	$411 per tonne, min charge $41.10

Table 22.0: Tyre disposal charges for the Southern landfill *(Absolutely Positively Wellington, 2012)*

Tauranga landfill sends all tyres to Carbon Recovery Ltd to be shipped overseas and used as TDF. The charges for all transfer stations are listed in table 23.0.

Tyre	Tauranga Transfer Stations
Car tyre	$5.00
4wd tyre	$8.00
Truck tyre	$15.00
Tractor	$100.00

Table 23.0: Tyre disposal charges for Tauranga transfer stations *(Tauranga City Council, 2012)*

In total there are twenty-seven landfills in the North Island. These are shown in figure 15.0.

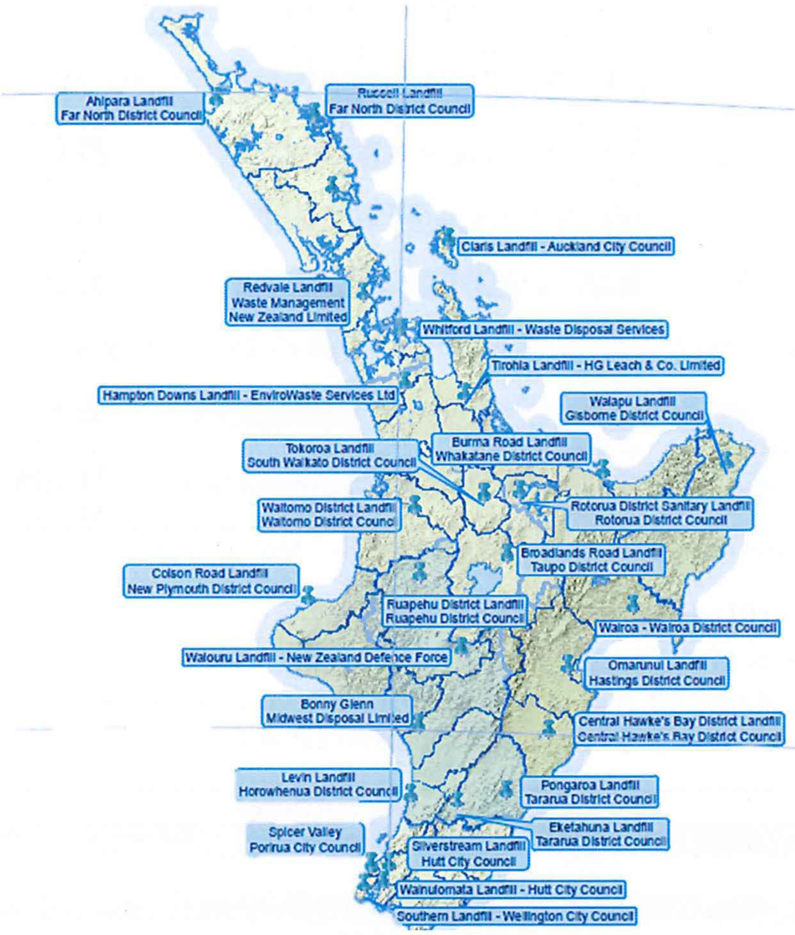


Figure 15.0: Waste disposal facilities in the North Island, New Zealand *(MFE, 2012)*

5.11 Tyre Removals Ltd

An interview with Rod Lovegrove, Director of Tyre Removals, highlighted the following:

- Tyre Removals process around 180,000 tyres annually. They are restricted by the tyre supply in the Auckland region. Due to high competition from existing tyre collection companies that already hold contracts with major retailers and councils throughout the North Island, Tyre Removals are unable to expand their business further.
- They are in the process of purchasing a batch pyrolysis plant from China. This will provide raw materials which potentially can be sold therefore increasing revenue. They had developed sufficient technology to reduce sulphur content of the pyrolysis oil, and are in the process of working on developing a solution to deal with PAH and other toxic components.
- Mr Lovegrove was aware of a trial pyrolysis plant at Tyregone Processors but had heard that it had not been successful.

5.12 Pacific Rubber and Waster Tyre Solutions

Pacific Rubber has a processing plant in Takanini (Auckland) as well as depots in Wellington and Kerepehi, Waikato. They do regular collections in the following places in the North Island:

- Waikato: Te Awamutu, Cambridge, Waitomo, Raglan, Otorohanga
- Coromandel: Thames, Coromandel town, Whangamata, Whitianga, Pauanui, Paeroa, Waihi
- Bay of Plenty: Katikati, Tauranga, Mount Maunganui, Te Puke, Whakatane, Rotorua, Tokoroa
- Taupo: Taupo, Turangi
- Hawkes Bay : Hastings, Napier, Wairoa, Waipukarau
- Taranaki: New Plymouth
- Wanganui and Manawatu: Palmerston North, Wanganui, Levin, Feilding
- Wairarapa: Masterton, Greytown
- Wellington: Wellington, Kapiti Coast , Hutt Valley, Porirua

They will also do pre-arranged collections throughout the South Island in Marlborough, Nelson, West Coast, Canterbury, Otago and Southland. An interview with Alan Copsey, the general manager provided the following information on Pacific Rubber:

- Pacific Rubber dissolved their subsidiary company, Waste Tyre Solutions, 12 months ago. The main company, Pacific Rubber, now deals directly with all tyre collection orders.
- Pacific Rubber processes around 400 truck tyres a day, amounting to 104,000 annually.
- They process around 300,000 passenger tyres a year. Alternatively to crumbing, passenger tyres are also bailed and used for retaining structures, drainage, and concrete reinforcement and on farms as silage pit covers.
- Pacific Rubber processes 1-2 large off-road vehicle tyres a week, amounting to 50-100 per year. These tyres are sold to farmers for use in culverts or are shredded.
- Pacific Rubber does not send any tyres to Asia for recycling, but have looked at options for using tyres as Tyre-derived Fuel (TDF) here in New Zealand. Mr Copsey mentioned that if legislation passed supporting the use of TDF in New Zealand, Pacific Rubber would be interested in processing their tyres this way as a method to create energy from ELT's and therefore generate increased profit.
- They have arrangements for the collection of tyres from:
    - Firestone/Bridgestone retail stores throughout the North Island, including a number of independently owned Bridgestone stores.
    - Beaurepaires retail stores throughout the North Island (now owned by Carters).

- A number of independent garages and retail stores including Euro-Tyre in Auckland *(Euro-Tyre, 2012)*. No further details were given on these retailers.
- Various councils throughout the North Island. Mr Copsey did not go into detail on which councils they worked with.
- Although they do pre-arranged collections for the South Island these are not very frequent due to increased prices as a result of transportation costs.

- Pacific Rubber was not interested in pyrolysis technology due to equipment cost and lack of technological proof that the process was successful in producing quality end products.

Mr Copsey also mentioned that Bridgestone was in contact with a company looking at the implementation of a tyre recycling plant in Christchurch, but did not have any details on this. He thought that this recycling plant may be pyrolysis but could not confirm this.

5.13 M.E. Jukes and Sons

An interview with Laurie, the General Manager, provided the following information:

- M.E. Jukes and Sons processes between 40-50 tonne of tyres annually. These are a mixture of truck, commercial, and passenger tyres.
- They have an arrangement with the council to collect tyres from transfer stations in the area, shred them and then dispose of them in their own landfill.
- M.E. Jukes and Sons provide a collection service for all tyre retailers, suppliers, garages and workshops in the Gisborne area.
- They have no interest in recycling and have not looked into any other options for the disposal of tyres. The local council supported M. E. Jukes and Sons process for removing and dumping tyres.
- Laurie was not aware of any other tyre collector or processor operating in the area.

5.14 J & J Laughton

J & J Laughton were not willing to give an interview, stating that the information that was requested was commercially sensitive. They would also not comment on the progress of Tyregone Processors in the development of a pyrolysis plant on the J & J Laughton site in Glendale. Research provided the following information:

- J & J Laughton shred their tyres into two grades: primary shred and secondary shred.
    - Primary shred is very course and is used for leachate drainage, bank retention, as back-fill in retaining walls, and as landfill cover.
    - Secondary shred is much smaller, 99.9% steel free and can be used as a rubber crumb. Uses include artificial sports grounds and children's play areas. It can also be mixed with bitumen for use in roading.
    - Their shredding machine has the ability to be adjusted to generate different chip or granule size depending on requirements.
- They were unable to establish a relationship that covered the whole of the Tyres4U business as the stores are independently owned and therefore all stores deal with their ELT's differently.
- In total J & J Laughton provide a tyre collection service for around 200 regular customers including retail outlets, garages, wreckers, re-tread plants and resource recovery centres.

5.15 Carbon Recovery Ltd

A number of companies around the country that have large incineration kilns have been approached by Carbon Recovery Ltd in the attempt to sell EPT's as TDF to fuel their kilns. Coalcorp, Genesis Power, Golden

Bay Cement, Holcim Cement, Pan Pacific, Kinleith Pulp, and Huntly Power Station were amongst those that did not show enough interest in the business venture to implement it. Golden Bay Cement were interested but required a guaranteed supply of 20,000 tonnes of ELT's to be able to run their burners. This was difficult for Carbon Recovery Ltd to manage due to the number of tyre collectors, who are direct competitors, acting as constraints on consistent tyre supply. Without this supply there was no benefit of funding the alterations that would need to be made to the burners in order to use TDF, which was estimated to be around NZ$1-$2m.

An interview with Ray Austin highlighted some important factors in regards to the scrap tyre business:

- Ray Austin claimed that some tyre collectors are illegally exporting tyres to China where they are being burnt in uncontrolled kilns. Due to the nature of these kilns the resultant emissions are highly toxic to the atmosphere and surrounding environment. The tyre collectors chose to use these incineration companies as they pay for the tyres. He emphasized that tyres used as TDF in controlled kilns is one of the safest, most productive ways to dispose of ELT's and the resultant emissions were negligible.
- One tonne of rubber chips is equivalent to 1.6 tonnes of coal and can be used interchangeably providing the burner or kiln has the correct modifications made to it.
- 65% of the global pool of ELT's was currently being used as TDF, mostly in cement kilns. The steel content in the tyres oxidises as very high temperatures, forming a fine powder that when mixed with the cement, creates a higher quality cement.
- Ray Austin was convinced that tyre pyrolysis was not an economically sound solution for the disposal of tyres. He stated a number of reasons for this including:
    - Studies from a number of trial plants in the US that had not been successful. He was unaware of any large commercial plants that had been successful economically.
    - Melbourne University had run a number of trials on the pyrolysis of plastics, to a total cost of AU$30m, but had been unsuccessful in producing a consistently successful pyrolysis plant that could be developed to commercial size.
    - The end product char was very low-grade and therefore had a limited market and low value.
    - The end product oil was high in sulphur and needed treatment before using as a combustion fuel. Ray Austin ordered a sample of oil from the pyrolysis plant in China and had it tested at Marsden Point Refinery in New Zealand. Results showed very poor quality with high levels of PAH and other toxic compounds.
    - The pyrolysis plants were highly dangerous due to very high temperatures, poor design and poor build quality. He agreed that it appeared that China may have improved their technological knowledge of pyrolysis but that these improved plants were hard to come by, still had associated dangers, and were very expensive.

Carbon Recovery Ltd indicated that they are currently involved in looking at the possibilities of building their own kiln. This would be used to burn ELT's as TDF to generate energy to feed back into the grid. They were also interested in using plastics as TDF for the same purpose. Ray Austin was confident that this would be a successful venture.

5.16 Information gathered on the supply chain of plastics

5.16.1 Mastagard

Mastagard is Canterbury's largest locally owned recycling and waste collection plant. Valued at NZ$5m based in Bromley, Christchurch, it processes 30,000 metric tonnes of waste annually including paper, cardboard, plastics, polystyrene, timber and steel. The company has fleet of transport vehicles that covers the South Island. Mastagard processes both plastic film and rigid plastic including:

- Bottles, buckets, pallets
- Garden furniture/hoses, plant pots
- Children's toys
- Crates and storage containers, hard plastic tubes
- Petri dishes

All plastics are recycled into a reusable pellet which is then used to make composite lumber, lawn and garden products, pallets, crates, containers, piping, automotive parts, and plastic bags. Mastagard represents significant competition in the recyclables market due to their free drop-off site at Wilsons Road, Christchurch and their involvement with product stewardship for plastics and other recyclable waste.

5.16.2 Agpac

Agpac focusses on plastic supply and recycling for the agriculture, viticulture, horticulture and environmental industries. They supply polythene and textile products such as wraps, twines, covers, mesh and sustainable plastic products. Agpac has a dedicated plastic recycling programme, Plasback, which is product stewardship accredited and provides solutions for recycling for the agriculture industry. They provide recycling in six different streams of plastic:

- Stream One: silage wrap, pit covers, and small low density polyethylene (LDPE), feed bags, shrink wrap and pallet covers.
- Stream Two: Polypropylene feed, seed and fertiliser bags.
- Stream Three: High density polyethylene (HDPE) containers from 1-60L.
- Stream Four: High density polyethylene (HDPE) drums, 100 and 200L.
- Stream Five: Vineyard nets and HDPE monofilament nets.
- Stream Six: Twine – Polypropylene twines from farms and orchards.

Plasback has been developed with cost in mind, as low landfill prices are not a deterrent for dumping all waste. The scheme has financial support from SIFT. Through the Plasback scheme the average dairy farmer can recycle all silage film for approximately $100 per annum. The scheme has been so successful it has been expanded into Australia and is currently growing at a rate of 40% per annum. The collected plastic is turned into a plastic resin and exported to Australia and Korea. They also have an agreement with Mastagard for local recycling in the Christchurch area.

Currently only 10-20% of agricultural plastics are recycled. Government product stewardship schemes aim at increasing this to 100% *(SIFT, 2009)*. Total collection figures for Plasback throughout New Zealand are:

- Southland and Otago: 87 tonnes in 2010-2011 season increased to 168 tonnes in 2011-2012
- Canterbury, West Coast and Tasman: 192 tonnes collected in 2010-2011 season increased to 197 tonnes in 2011-2012
- Waikato: 200 tonnes collected in 2010-2011 season increased to 239 tonnes in 2011-2012
- Northland: 19 tonnes collected in 2011-2012 season

- Taranaki: 54 tonnes collected in 2011-2012 season *(McAvinue, 2012)*

5.16.3 Compounding Specialists Limited (Comspec)

Comspec is a Hornby based recycling plant that opened in 2009 with the capacity to process 1000 tonnes of plastic milk bottles annually. One tonne of plastic milk bottles is approximately 110,000 bottles *(SIFT, 2010)*. The development of the Comspec plant will mean that no plastic milk bottles will be shipped offshore to Asia, but instead turned into plastic resin in Christchurch. This will also reduce costs for companies buying resin for industrial and agricultural purposes.

Comspec had financial support from SIFT during the development of their processing plant.

Appendix 6.0 Pyrolysis Oil, Gas and Char

The prototype plant will process approximately 54 tonnes of tyres, producing 10,000L of oil, 3,375kg of gas (equivalent to 4,320kg of LPG due to having a calorific value 30% higher than LPG), and 27 tonnes of char per month. The proposed three-line commercial plant will process approximately 270 tonnes of tyres, producing 50,000L of oil, 16,875kg of gas (equivalent to 21,600kg of LPG) and 135 tonnes of char per month. A larger, five-line commercial plant will process 450 tonnes of tyres, producing 83,300L of oil, 28,125kg of gas (equivalent to 36,000kg of LPG) and 225 tonnes of char per month.

6.1 Oil

6.1.1 Quantities produced by CPT and required by Fulton Hogan for commercial purposes

The prototype plant will produce approximately 10,000L per month through processing 54 tonnes of tyres (based on 300kg per hour, 8 hours a day, 4.5 weeks per month). The three-line commercial plant will process 270 tonnes of tyres therefore producing 50,000L per month of oil.

Currently Fulton Hogan supplies 1,300,000L a year or 108,330L per month of used oil to Tegal. Tegal is equipped with burners that can handle the high ash content of the oil produced through pyrolysis, however the full sized commercial plant will not have the capacity to produce sufficient supply to meet Tegal's demands. CPT would need to process 585 tonnes of tyres per month to reach this demand. Fulton Hogan currently supplies other used oil from the Canterbury region to meet Tegal's requirements. This oil, once filtered, has sufficient quality required for the smooth running of their burners.

Pyrolysis oil, generated by CPT, has yet to be proven in terms of quality and quantity although CPT has suggested a treatment process to reduce the sulphur and ash content. Polycyclic Aromatic Hydrocarbon (PAH) levels may also be an issue due to producing soot and being potentially carcinogenic however PAH will need to be further investigated once quality and quantity has been established.

6.1.2 Options for storage

On the Lyttelton bitumen plant site Fulton Hogan has the capacity to store:

- One tank with a holding capacity of 550,000L of used oil, currently in use with oil collected through ROSE – filtered prior to delivery to Tegal
- One tank with a holding capacity of 600,000L of used oil, currently in use with oil collected through ROSE – filtered prior to delivery to Tegal
- Two quarantine tanks with a holding capacity of 25,000L each, currently in use with Light Fuel Oil (LFO). LFO is suitable for use in liquid-fuel burning equipment without pre-heating and is currently used in the burners at the Lyttelton bitumen plant.

It is suggested that the two quarantine tanks could be used to hold pyrolysis oil as it will need to be tested and treated prior to use. LFO is more expensive than oil and therefore it is predicted that it will not be imported long-term. Tyre-derived pyrolysis oil has similar composition to LFO *(Cunliffe & Williams, 1998)*. Ideally the pyrolysis oil would be treated and used in the Lyttelton bitumen plant as a reduced price replacement for LFO. This is entirely dependent on proven high quality of oil and guaranteed on-going supply.

A further option, which should be considered in the event of the development of a full-sized commercial plant, is to build storage tanks for the pyrolysis oil on site. Ideally this will also have the capacity to store gas and char. The optimum size for this storage facility would be in the region of 300,000L which would be sufficient for six months' supply of pyrolysis oil.

6.1.3 Options for blended fuels

One study showed that tyre-derived pyrolysis oil can be blended with diesel oil to produce a fuel that can be used in diesel engines. The maximum concentration at which a four stroke single cylinder air cooled diesel engine ran properly was at 70% pyrolysis oil, 30% diesel. Prior to blending the pyrolysis oil was desulphurised and then distilled through vacuum distillation. Issues with long-term use of pyrolysis-diesel blended fuel may include carbon deposits and oil ring sticking as a result of the higher viscosity of the fuel *(Murugan, Ramaswamy, & Nagarajan, 2008)*.

Fulton Hogan currently has a scheme in place to trial blended biodiesel with diesel in their fleet vehicles. During this scheme a specially-developed fuel blending pump was installed with the assistance of the EECA. This pump enables different blends of biodiesel depending on the vehicle requirements and could potentially be used in the blending of pyrolysis oil and diesel.

6.1.4 Options for removing sulphur from pyrolysis oil

Various options exist for removing sulphur from tyre pyrolysis oil. These include:

- Adding calcium hydroxide as a catalyst during the reaction process has been shown to reduce the sulphur content of the oil by up to 34.25%. The use of 10% strength sulphuric acid reduced the sulphur content by up to 75.27% therefore the combined use of calcium hydroxide and sulphuric acid resulted in a reduction of sulphur by 83.75% *(Aydına & İlkılıç, 2012)*.
- Adding calcium oxide (lime) with a ratio of 2% during the reaction process has been shown to decrease sulphur content *(Arpa, Yumrutas, & Demirbas, 2010)*.
- Altering the temperature has been shown to affect sulphur content. The lowest sulphur content was recorded at a temperature of 550°C. This is shown in figure 16.0. The maximum oil yield was shown at 500°C *(Aydına & İlkılıç, 2012)*.

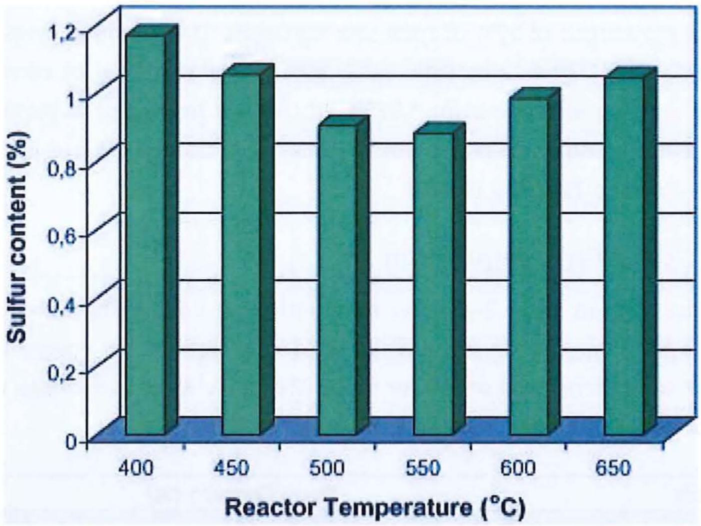


Figure 16.0: Reaction temperature and sulphur of pyrolysis oil in a fixed bed reactor *(Aydına & İlkılıç, 2012)*

- One study showed that the maximum desulphurisation occurred at a temperature of 600°C, with a result showing 53% less sulphur than results recorded at a temperature of 350°C *(Unapumnuk, Keener, Lu, & Liang, 2008)*.

6.1.5 Total oil yield and options for increasing yield

The CPT plant produces an oil yield of around 30%. Studies have shown that this can be increased to a maximum yield of 58% *(Williams, Bottrill, & Cunliffe, 1998; Pradhan & Singh, 2011)*. Oil production in pyrolysis as a fraction of the total yield can be increased in the following ways:

- The CPT prototype plant runs at 500°C. Various studies have shown that increasing the temperature of the reactor increases the total yield of oil and gas and reduces the yield of solid waste *(Williams, Besler, & Taylor, 1990)*. This needs to be trialled as other studies on batch pyrolysis show that any temperature increases beyond 500°C reduces the yield of oil *(Cunliffe & Williams, 1998; Aydına & İlkılıç, 2012)*.
- A study on the pyrolysis of bicycle tyres showed the optimum temperature for oil production through pyrolysis to be 600°C *(Pradhan & Singh, 2011)*. In this study, lower temperatures resulted in incomplete decomposition of tyre mass and therefore increased solid residue (char).
- Faster reaction time at increased temperatures with sudden cooling to prevent secondary reactions can increase oil production however this may only be a viable option for batch pyrolysis. CPT runs their reaction time for approximately 45mins. Flash pyrolysis (2 minutes) have been shown to produce very high oil yields however this is used primarily in the pyrolysis of biomass as lower reaction time is required for complete decomposition.
- For the pyrolysis of plastics a faster reaction speed at a lower temperature increases the oil yield. An increase in pressure within the reactor also increases oil yield *(Paradela, Pinto, Gulyurtlu, Cabrita, & Lapa, 2009)*. The recommended temperature is 430°C at an initial pressure of 0.41 MPa increasing to 3.5 MP. The optimum time in the reactor is 20 minutes *(Pinto, Costa, Gulyurtlu, & Cabrita, 1999)*.

6.2 Gas (syn-gas)

6.2.1 Quantities produced by CPT

The prototype plant has a gas output of 17% of total raw materials. One tonne of tyres produces 62.5kg of Liquefied Tyre Gas (LTG). As the LTG has a calorific value 30% higher than that of conventional LPG, this is equivalent to 80kg of LPG. In the prototype plant 3,375kg of LTG will be produced (equivalent to 4,320kg of LPG) per month. In a three-line commercial plant, which process 270 tonnes of tyres per month, 16,875kg of LTG will be produced (equivalent to 21,600kg of LPG).

6.2.2 Gas composition

Analysis for the gas can be seen in table 24.0. This is critical when identifying potential uses for the gas produced. The level of methane may be an issue when looking at options for energy generation as newer generators run on gas with a methane level of 70% or more. There are ways to increase the level of methane by reducing some of the other gases however this will be done at additional cost.

Component	Total Content (%)
Hydrogen	30.0 +/- 2%
Methane	48.0 +/- 2%
Ethane	3.5 +/- 0.5%
Ethylene	4.5 +/- 0.5%
Propane	1.0 +/- 0.2%
Propylene	3.0 +/- 0.5%
C4 hydrocarbons	1.0 +/- 0.2%
C5 hydrocarbons	4.5 +/- 0.5%
C6 hydrocarbons	3.0 +/- 0.5%
C7 hydrocarbons	1.5 +/- 0.5%

C4 hydrocarbons	1.0 +/- 0.2%

Table 24.0: Component analysis for gas produced through pyrolysis by CPT *(Hoddinott, 2011)*

6.2.3 Options for increasing gas quantities through pyrolysis

Gas yield can be increased in the following ways:

- Several studies have shown that a hotter reactor increases the oil and gas yield *(Williams, Bottrill, & Cunliffe, 1998; Williams, Besler, & Taylor, 1990)*. A rapid cooling will reduce the majority of this gas to liquid form however the use of a slower cooling method will result in secondary reactions further breaking down the oil into gas therefore maintaining a high gas yield.
- One study showed that the optimum temperature for gas production was 600°C, producing 8.9 wt% gas. At 450°C the oil yield was 4.5 wt% *(Cunliffe & Williams, 1998)*.
- For the pyrolysis of plastics, a faster reaction time increases the gas yield. A higher temperature increases both the char and gas yield whilst also increasing the aromatic content of the gas *(Paradela, Pinto, Gulyurtlu, Cabrita, & Lapa, 2009)*. The presence of polyethylene during pyrolysis of plastics generates the highest gas yield *(Pinto, Costa, Gulyurtlu, & Cabrita, 1999)*.

Increasing the temperature may change the chemical composition of the gas – increasing the aromatic fractions and decreasing the aliphatic fractions.

6.2.4 Further options for increasing the quantities of gas

Another option to increase the quantity of gas produced is via the use of gasification. This process coverts pyrolysis oil into syn-gas however this will require further equipment and significant processing therefore the cost increase is high. The advantage of this method is that it does not rely on altering existing technology supplied by CPT and therefore may be more achievable.

6.3 Char (Solid Output)

6.3.1 Quantities produced by CPT

The char produced through pyrolysis is a high-energy content solid fuel and has a calorific value of 28.75 MJ/kg. The prototype plant will produce approximately 27 tonnes per month of char, to be bagged up in one tonne holding bags. In a three-line commercial plant this will amount to 135 tonnes per month. Initially this will be disposed of in landfill until a suitable buyer can be sourced. CPT will aim to reduce the quantity of char produced due to the limitations of the New Zealand market for char.

6.3.2 Options for reducing char quantities through pyrolysis

Solid waste can be reduced in the following ways:

- Increasing the reaction temperature during pyrolysis will reduce the char yield *(Paradela, Pinto, Gulyurtlu, Cabrita, & Lapa, 2009; Williams, Besler, & Taylor, 1990)*. This will increase the liquid and gas component and therefore decrease the solid component of the output.
- Increasing the speed of the reaction will decrease the amount of char produced. Slow pyrolysis results in product yield of around 30% oil, 35% char and 35% gas. Fast pyrolysis with rapid cooling results in around 75% oil, 12% char and 13% gas *(Ringer, Putsche, & Scahill, 2006)*. These results are based on the pyrolysis of biomass and are dependent on feedstock type and moisture content.
- For the pyrolysis of plastics a lower temperature will decrease the char content of the raw materials *(Paradela, Pinto, Gulyurtlu, Cabrita, & Lapa, 2009)*.

6.3.3 International market of char and carbon black

The char that the CPT prototype plant currently produces is low-grade with a high amount of impurities such as silica, zinc and sulphur, and therefore has limited market options. The pyrolysis of whole scrap tyres results in the solid residue being a mix of char and steel however the steel is easily separated through the use of magnets. In the initial stages of the CPT trial this will not be an issue as the rubber supplied by Bridgestone has no steel in it.

The option of further processing to produce a high quality carbon black exists although due to the advanced nano-carbon upgrading process and technological know-how required this incurs significant additional costs. This would however greatly expand market options and value for the char.

- The international price for carbon black ranges from US$100-$3620 per metric tonne depending on supplier and quality of product *(Alibaba, 2012)* as shown in table 25.0.

Supplier	Product Type	Price (US$)
Ganzhou Eastern Dragon Household Articles Factory	Wood based activated carbon black	1700-2000
Gaocheng Baoli Plastic Products Co Ltd	Carbon black N220, N330, N550, N660, N774	800-1000
Hebei Baili Industry Trade Co Ltd	Carbon black N220, N330, N550, N660	800-1200
Hebei Baoqi Import & Export Co Ltd	Carbon black N220, N330, N550, N660	700-1000
Hebei Eminent Chemical Technology Co Ltd	Carbon black N220, N330	600-1100
Hebei Hanxing Chemical Co Ltd	Carbon black N220, N330, N550, N539, N990 (for rubber)	1700-2100
Henan Lianxing Foreign Trade Co Ltd	Carbon black N220, N330, N550, N660	700-1000
Henan Premtec Enterprise Corporation	Carbon black N220, N330, N550, N660	800-960
Shanghai Weivi Industrial Co Ltd	Carbon black N220, N330, N339, N550, N660	950-1250
Shanxi Xinsheng Coking Gas Co Ltd	Carbon black N220, N330, N339, N375, N550, N660, N774	900-1000
Taian Yonghe Chemical Co Ltd	Conductive carbon black for cable	600-3800
Tianjin Huayuantianyou Chemical Products Trade Co Ltd.	Carbon black N220, N330, N550, N660	480-780
Wuhan Hanhyu International Import and Export Co Ltd	Carbon black P180, N220, N330, N550, N660 for tyre tread and fuel (smokeless fuel)	100-1000
Wuhan Xuyadi Chemicals Co Ltd	Carbon black N220, N330, N550, N660	800-1000
Yucheng Jinhe Industrial Co Ltd	Carbon black N220, N330, N550, N660	750-900
Zhengzhou Blue Ribbon Industry Corporation Ltd	Carbon black N220, N330, N550, N660	600-700
Zhengzhou Glory Enterprise Development Corporation	Carbon black N220, N330, N550, N660	900-1000
Zhengzhou Meikewote Trade Co Ltd	Carbon black	3450-3620
Zhengzhou P&B Chemical Co Ltd	Carbon black N220, N330, N550	600-700
Zhengzhou Sigma Chemical Co Ltd	Carbon black N220, N330, N550, N660	650-700
Zichuan Antou Alum Factory	Carbon black N115, N220, N234, N326, N330, N375, N550, N660, N770, N774, N880, N900	950-3593

Table 25.0: Suppliers and price of various product types associated with carbon black *(Alibaba, 2012)*

The codes in table 25.0 refer to the different grades of carbon black which have different road-wear abrasion and particle size when used in the manufacturing of tyres. Carbon black also has various other applications such as industrial rubber goods, conveyor belts and fan-belts. An overview of these uses is shown in table 26.0.

Type	Description	Particle Size (nm)	Tensile Strength (MPa)	Road-wear Abrasion	Uses
N220	Fine active carbon black	24-33	23.1	1.15	Due to high wear and resistance used for tyre treads and re-treading, industrial rubber goods and conveyor belts
N330	Fine active carbon black	28-36	22.4	1.00	Due to high strength and wear good resistance used for solid tyres, agricultural tyres, conveyor belts, industrial rubber goods and fan-belts
N550	Medium-dispersion, medium-active carbon black	39-55	18.2	0.72	Due to high extrudability and high tear resistance used for tyre carcass and tubing, profile extruded goods, industrial rubber goods, seals and hoses
N770		70-96	14.7	0.60	Tyres (tyre ply compound and bicycle tyres) and other rubber industries, ink and paint colorant
N880		180-200	12.6	-	Printing ink, water-based coatings and spun dyed fiber colorant pastes
N990	Low active grade of carbon black (similar to char)	250-350	9.8	-	Used for conveyor belts, as an inactive filler for tyres (tyre body and inner compound), industrial rubber goods, and for carbon graphite materials

Table 26.0: Carbon black code with relative particle size, strength and uses *(Alibaba, 2012)*

Global demand for the product is predicted to rise 4.3% in 2013. It is commonly sold as fine black granules or in powder form and is primarily used in the manufacturing of tyres and rubber related goods. It has wide uses including:

- Ceramic and cosmetic pigment
- Coating pigment
- Ink pigment – photocopier and laser printer toner
- Plastic and rubber (natural and synthetic) pigment – tyres and tyre tubes, cables, seal rings, tape, and general plastic manufacturing

One study showed that char as a raw material may be used as an extender in adhesives, coatings and cement. As much as 7% char can be added to vinyl or rubber cement resulting in lower material cost whilst maintaining the same physical and chemical properties *(Petrich, 2008)*.

The International Agency for Research on Cancer (IARC) states that "Carbon black is possibly carcinogenic to humans" (Group 2B carcinogen) and attributes upper respiratory tract discomfort as one symptom of short-term exposure *(Kuempel & Sorahan, 2010)*.

6.3.4 Local market options for char

As char is a high energy fuel with a similar calorific value to coal, it can be co-fired with coal to produce a more environmentally-friendly fuel source. The calorific value of coal and various other commercial fuels compared to pyrolysis char is shown in table 27.0.

Fuel	Calorific Value (MJ/kg)
Anthracite	31.4
Hard coal	29.3
Lignite	26.7
Coal briquettes	29.3
Heavy fuel oil	42.6
Middle fuel oil	43.1
Light fuel oil	43.5
Gas oil (diesel oil)	45.6
PYROLYSIS CHAR	**28.75**
PYROLYSIS OIL	**42.82**

Table 27.0: Various commercial fuels and corresponding calorific value *(Food and Agricultural Organization of the UN, 2013)*

The cost effectiveness of this is an issue as coal is relatively cheap to purchase. Based on information gathered from Solid Energy it is unlikely that it will be possible sell the char for a lower price than coal. Char will need to have a pricing point that ensures the venture remains commercially viable. Large companies that use coal as a raw material for their burners such as Fonterra or Goodman Fielder may be interested in co-firing as an option. This will need to be investigated further.

Roy et al showed that tyre-derived carbon black can be used as an additive for road bitumen *(Roy, Chaala, & Darmstadt, 1999)*. This is one potential use for char within Fulton Hogan.

Appendix 7.0 Options for Energy Generation

7.1 Options in Regards to Orion

Orion provides 30 minute data for the last 12 months which gives an accurate cost based analysis on how much can be saved through exporting energy to the grid. This information was accessed and passed on the site engineers who will establish the possibilities for power generation through the use of used oil.

Orion controls who can export energy back into the grid. Preferably they will enable exportation however this will only be during the control period, from the 1st May to 31st August, when electricity demand is high. Orion will potentially pay the exporter $146-$147 per kW hour during this period. Throughout the remainder of the year the generator will be used singularly to supply energy for the site on which the generator is located therefore representing significant electricity savings. Two separate ICP's (connection points) located at Miners Road are highlighted as possibilities for power exportation within the Christchurch area. There are two connection points as the power bills for the quarry and asphalt plant are separated. These ICP's require further investigation to establish the possibilities for power exportation.

7.2 Gough CAT *(Gough, 2012)*

Gough CAT lease generators for the purposes of generating energy with diesel however they advised that they cannot run their generators on used oil or oil that has high sulphur or viscosity. Tony Hamilton, division manager as Gough, advised that it is very difficult to get clean-burning used oil that can be used in the generators and as such did not recommend anything other than diesel. The diesel generators have power ratings from 13,000-17,460kW and are emission compliant with most worldwide regulations. Gough CAT has generator sets for lease that run off syn-gas therefore this could be one potential option for energy generation if CPT can provide sufficient syn-gas. These generators operate on a variety of gasses including natural gas, digester gas, landfill gas, biogas, wellhead gas and propane. They have power ratings from 65-6,520kW.

7.3 Syn-gas for Energy Generation

Syn-gas has been used in other commercial facilities around the world as a way to generate energy. This can then be used to either supply power for the site or fed back into the grid. Companies that have successfully used syn-gas for energy generation include:

- Brightstar (SWERF), Australia – syn-gas is converted via modular energy-generator sets
- UR-3R, Australia – waste disposal facility which uses a digester to extract syn-gas
- Pacific Pyrolysis, Australia - all oil is converted into syn-gas for energy generation
- The Crucible Group, Australia – has a working prototype plant with generator but further development is dependent on funding
- Renewable Oil Corporation, Australia and Canada – via a gas turbine which can generate energy with syn-gas or pyrolysis oil

Australia does not have any fully operational commercial-sized tyre pyrolysis facilities. They have several demonstration plants with plans to build larger ones dependent on funding and environmental resource consent. Australia also has several large pyrolysis plants for the processing of other materials such as biomass and sewage. Pyrolysis for the thermal decomposition of tyres has been listed as being un-economical and not commercially viable in regards to recycling and energy recovery options for waste within Australia. This is due to the limited end uses for the raw materials produced. A complete overview of pyrolysis in Australia can be seen in Appendix 8.0.

There is potential for Fulton Hogan to generate energy with the use of the syn-gas produced through pyrolysis however it is dependent on the technological capabilities of CPT. Currently the CPT prototype pyrolysis plant does not provide sufficient yield of syn-gas for use in a gas generator. Ways to increase syn-gas production are shown in section 1.2.3. Syn-gas energy generators can be imported from China (table 28.0).

Company	Generator Type	Price (US$)
Camda Generator Work Co. Ltd	Syn-gas/diesel generator set 20kw-500kw	13,000-160,000 per set
Fuan Hengli Machinery Electrical Co. Ltd	Diesel/syn-gas generator set 305kw/381KVa	36,000-39,000 per set
Fuan Wonyong Electrical Machinery Co. Ltd	Cummins syn-gas/diesel generator set 1500/1800 rpm	1,000-50,000 per set
Guangxi Yulin Excellent Power Generator Equipment Co. Ltd	Syn-gas generator set 15kw	100-1,000 per set
Guangzhou Kanghai M&E Equipment Co. Ltd	MAKE syn-gas generator set with a Sino-American Cummins engine	1,000-80,000 per set
Shengli Oilfield Shengli Power Machinery Group Company Ltd	500GF1-RG syn-gas generator set	170,000-220,000 per set
WeiFang Guanghui Agriculture Machinery Co. Ltd	Syn-gas generator set 10kw-300kw	10,000-50,000 per set

Table 28.0: Some options for the procurement of a syn-gas generator *(Alibaba, 2013)*

7.4 Oil for Energy Generation

Fulton Hogan has been investigating the options for using pyrolysis oil for energy generation. Issues surrounding this include:

- The oil is very viscous – this makes it difficult to be used in a diesel engine generator. Blending it with diesel may be a solution for this problem. Studies have shown that blending it at a proportion of up to 70/30 (pyrolysis oil/diesel) will enable sufficient consistency for the smooth operation of a diesel engine *(Murugan, Ramaswamy, & Nagarajan, 2008)*.
- The oil is high in sulphur and ash – CPT has been working on ways to reduce the sulphur content of the pyrolysis oil.
- The oil may contain other toxins which could affect the ability for it to be used for energy generator – further testing will need to be carried out by CPT during the trial period to determine the consistent chemical composition of the pyrolysis oil.

Studies have shown that pyrolysis oil is unstable and increases in viscosity with age during storage *(Ringer, Putsche, & Scahill, 2006)*. As combustion burners and fuel injection systems are designed to operate with fuel that is consistent this may pose significant technological challenges for the use of pyrolysis oil as a combustion fuel. This may be something that needs to be monitored by CPT during the trial period. Pyrolysis oil can be co-fired with coal as a high energy fuel source for kilns and burners *(Bradley, 2006)*. Various tests have been completed to determine the feasibility of using pyrolysis oil as a fuel in generators and engines:

- 2006: Pyrolysis oil was used as a replacement for Heating Oil #2 in a furnace in an aluminium plant in Baie Comeau, Quebec.
- 2006: Pyrolysis oil was used as a replacement for combustion fuel oil #6 (Bunker C) in a greenhouse application at Great Lakes Greenhouses Inc. in Leamington, Ontario. This test was run successfully for a period of four hours.
- 2005: Pyrolysis oil was successfully converted to syn-gas via a process of gasification at the research institute Forschungszentrum Karlsruhe in Germany.

Additionally alterations to the fuel injection system and burner within a diesel engine may allow the engine to run on 100% pyrolysis oil however the ash content will need to be reduced prior to use.

Appendix 8.0 Pyrolysis in Australia

The Australian market for renewable energy is different to New Zealand due to initiatives in place to ensure that 20% of electricity within Australia comes from renewable sources by 2020. The scheme will run until 2030. This initiative allows government grants for companies researching and developing renewable energy therefore driving innovation within the industry. New Zealand has a large portion of electricity being supplied by hydro-power therefore there is no pressure on the industry to drive or support pyrolysis and gasification projects.

8.1 ESI Enersludge *(T & Skrypski-Mantele, 2004)*

ESI Enersludge is a pyrolysis facility based in Perth that processes sewage sludge into a solid fuel (char) and a liquid biofuel (oil). The plant was developed in the late 1990's and has the ability to process 25 dry tonnes per day. The oil accounts for approximately 30% of the raw materials produced. The end products are utilised within the plant: the char is used in the drying of sludge within the facility, and the oil and gas are used to generate energy which is fed back into the grid.

8.2 Brightstar - SWERF *(Schwarz, Richter, & Pirnie, 2002)*

The Brightstar Solid Waste and Energy Recycling Facility (SWERF) is a municipal waste to energy facility using pyrolysis technology based in NSW. Built in 2003, SWERF cost AU$137m to develop and build. The facility is owned and operated by Energy Developments Ltd (EDL), a US company that has a number of waste gasification projects in operation in Australia, Taiwan, Greece, the US and the UK. The SWERF has the capacity to process up to 75,000 metric tonnes per year. Outputs of the pyrolysis are char (40 wt%) and syn-gas. SWERF has gasification technology in place to reform the char into syn-gas which is then used to fuel the pyrolysis process. Any left-over char is then sent to landfill. Energy generation is completed with syn-gas (as a replacement for LPG) via modular energy-generator sets as shown below in figure 17.0. The output is around 700kW hours per tonne of feedstock.

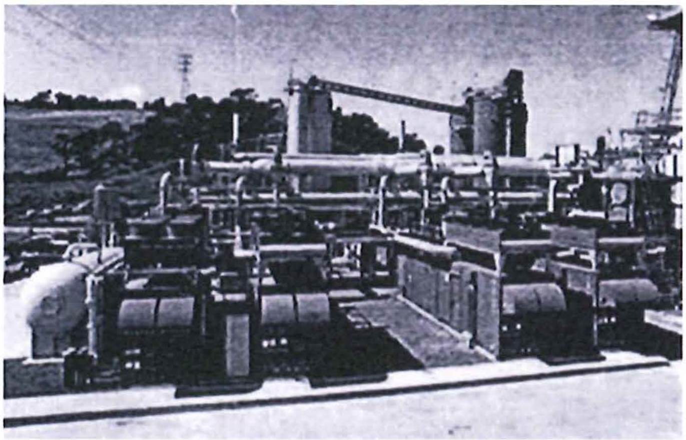


Figure 17.0: SWERF modular energy-generator sets *(Schwarz, Richter, & Pirnie, 2002)*

8.3 UR-3R *(Global Renewables, 2012)*

UR-3R does not use pyrolysis however they are important in waste management in Australia. One of their business activities is the processing of liquid waste through a digester which allows the extraction of syn-gas. The syn-gas is then combusted to produce 'green electricity'. Some of this electricity is used to power the UR-3R plant and the remainder is fed back into the grid.

If CPT were able to produce sufficient syn-gas through the pyrolysis of waste tyres this could provide opportunities for combustion and therefore electricity generation in a similar way to UR-3R. It may be possible to alter the pyrolysis technology created by CPT to maximise the production of syn-gas over oil. UR-3R's business model for this could provide vital information for Fulton Hogan in regards to the implementation of feeding energy back into the grid.

8.4 Visy *(Visy, 2012)*

Visy has 30 recycling plants across five Australian states, two of which are pyrolysis plants: Visy Pulp and Paper Mill in Tumut, NSW and Visy Paper Mill in Gibson Island, Brisbane. Although both these plants utilise pyrolysis technology, it is very different to continuous pyrolysis technology. The plant in Tumut cost AU$400m to build and has the capacity to process 800,000 tonnes of paper, cardboard and wood biomass waste per year. It runs a fluidised bed pyrolysis reactor which produces black liquor as a high energy fuel source and syn-gas. The black liquor is then used to power the recovery boiler which takes 670 tonnes of black liquor a day. Steam from the boilers is then fed into a steam turbine which produces 20MW of power. The power is mostly used within the facility and the rest is fed back into the grid. The syn-gas is also re-used within the plant.

8.5 Pacific Pyrolysis – PacPyro *(PacPyro, 2012)*

PacPyro is in developmental stages. The company has built a prototype plant in Somersby in NSW which has the capacity to process 300kg per hour of non-food biomass material into biochar for agriculture and horticulture use. It also produces syn-gas which is used in the pyrolysis reactor. Biochar can be used as a green fuel source due to its calorific value of between 18-31 MJ/Kg. It has sulphur content similar to that of black coal (~0.02%). The prototype plant is set-up to power a 200kW power generator that is established on-site and subsequently provides power for the site as well as feeding energy back into the grid. Any oil produced during the pyrolysis process is converted into syn-gas to be used in energy generation. PacPyro is currently seeking between AU$2.2-4m to develop and build a full-sized commercial plant, which will have the capacity to process 2 tonnes of waste, on the outskirts of Melbourne. Estimates indicate that this plant will have an energy output of between 6,400-40,000 MWh per annum depending on feedstock volume, type and moisture content.

8.6 The Crucible Group *(The Crucible, 2012)*

The Crucible Group operates a pyrolysis plant near Kalannie, WA for the processing of wheat and straw waste (timber industry bio-waste) into biochar and gas. The prototype plant commissioned in 2008 has the capacity to process between 10,000-40,000 tonnes of bio-waste. Planning for the full-sized commercial plant, which will have the capacity to process 100,000 tonnes of bio-waste, includes the use of gas for energy generation which will then be fed back into the grid. The biochar produced is sold as a soil enhancer. The Crucible Group built a prototype plant in Vales Point which provided adequate results for the development of the full-sized commercial plant to be built near Kalannie in 2013. The Crucible Group has patented technology but is dependent on available funding for the development of the plant near Kalannie.

8.7 BiG Char – Black is Green *(BiG, 2013)*

Black is Green is a mobile pyrolysis unit capable of processing 1 tonne of biomass per hour in a continuous feed process. Operating in Mackay, Central Queensland, the company, BiG, has established a relationship with Renewable Carbon Resources Australia for marketing the technology and the biochar produced. BiG sells biochar for use on gardens as a soil enhancer. BiG is currently in the process of building three commercial-sized biochar facilities, to be commissioned in 2013.

8.8 Anthro Terra Pty Ltd *(Anthro Terra, 2010)*

Anthro Terra uses biomass pyrolysis to generate biochar for agriculture. The company is primarily involved in research relating to biochar and is affiliated with a number of academic and government research groups. Anthro Terra has three mobile units (150 kg/hr), one unit able to be relocated (350kg/hr) and one larger, fixed plant (500-2,000 kg/hr). The main purpose of the pyrolysis equipment is for the generation of char and as such they do not use the gas directly for energy generation. Instead the gas produced is combusted during pyrolysis and there are processes in place to store, export or utilise the heat produced in an external heat engine.

8.9 Renewable Oil Corporation *(Renewable Oil Corporation, 2013; Dynamotive Energy Systems, 2013)*

Renewable Oil Corporation is a company based in Victoria, Australia. It is in the developmental stage of building a pyrolysis plant for the processing of biomass. Renewable Oil Corporation currently has a full-sized commercially operating plant in Ontario, Canada, that processes 65,000 tonnes of dry mass per year. The Ontario plant uses fast pyrolysis from which one tonne of wood biomass will yield 300L of finished fuels. 70% of the raw material produced through fast pyrolysis is oil. This oil is then used in a variety of ways including:

- As a raw material – the unprocessed pyrolysis oil is used as a fuel for the generation of renewable energy and heat in gas turbines and boilers. It has been trialled as a fuel for slow speed diesel engines but is not currently in use this way.
- Processed via hydro-reforming – this enables the upgrading of the pyrolysis oil to a variation of hydrocarbon liquids. In hydro-reforming hydrogen is added to the pyrolysis oil in a reactor and water, methanol and acetic acid are removed. The resulting fuel has an energy content that is 90% that of diesel and is therefore completely interchangeable with other hydrocarbon fuels. An optional second stage of hydro-treating further upgrades the fuel by adding hydrogen and removing oxygen. Three different products are produced through these two stages: Jet Fuel, Naphtha and Diesel.
- Sold for use in other markets – extraction of industrial resins, solvents, food flavourings and other natural chemicals.

The Renewable Oil Corporation alongside the Orenda Aerospace Corporation (Canada) has developed a fully operational gas turbine that is specially designed to run on either syn-gas or pyrolysis oil. Two tonnes of pyrolysis oil can generate 2.7MWe of base load power. It also produces thermal energy which can be used as a waste boiler heater or can be recovered as steam. The steam can be used to boost the power output to 4MWe. Larger versions of the generator have been created which can generate up to 25MWe on a continuous basis. The plant also produces char which is upgraded to charcoal in forms including cooking briquettes or metallurgical reductants.

8.10 Biochar-Energy Systems Pty Ltd *(Northern Poultry, 2010)*

Northern Poultry Cluster Ltd formed Biochar-Energy Systems for the commercialisation of pyrolysis on poultry farms. Biochar-Energy Systems is a small company that manufactures pyrolysis machines for the purpose of turning poultry litter into biochar. A commercial sized plant would have the capacity to process 200-500kg per hour of poultry litter.

8.11 Bio Syngas *(Bio Syngas, 2012)*

Bio Syngas is an Australian based company researching the process of gasification for the processing of agricultural biomass into energy. Whilst gasification differs to pyrolysis the end products char and syn-gas are similar to that of pyrolysis. Bio Syngas has a business strategy to develop multiple small scale power plants (1.5-25MW) which will supply electricity to a few specific customers. They are in the process of developing a commercial plant in Wagga Wagga which will produce 6MW through biogas.

Appendix 9.0: Location Analysis

9.1 South Island Data

9.1.1 Tyre Volume by Location

Table 29.0 shows tyre volume by location based on market research results (estimates only). Figure 18.0 gives an indication as to the proportion of tyres in each location. Bridgestone has a further 195,000 ELT's in the South Island which are only shown in the regional breakdown due to available information. They use Tyre Collection Services for the disposal of tyres, a Christchurch based company, and therefore all ELT's from Bridgestone will be disposed of via Christchurch.

Location	Tyre Volume (per annum)
Invercargill	Volume not disclosed
Gore	7,800
Dunedin	9,750
Alexandra	3,120
Queenstown	4,680
Oamaru	4,680
Timaru	13,000
Ashburton	4,160
Christchurch (incl. Rolleston and Rangiora)	28,340
Nelson	20,800
TOTAL TYRE VOLUME	96,330

Table 29.0: Tyre volume in the South Island by location *(based on market research results)*

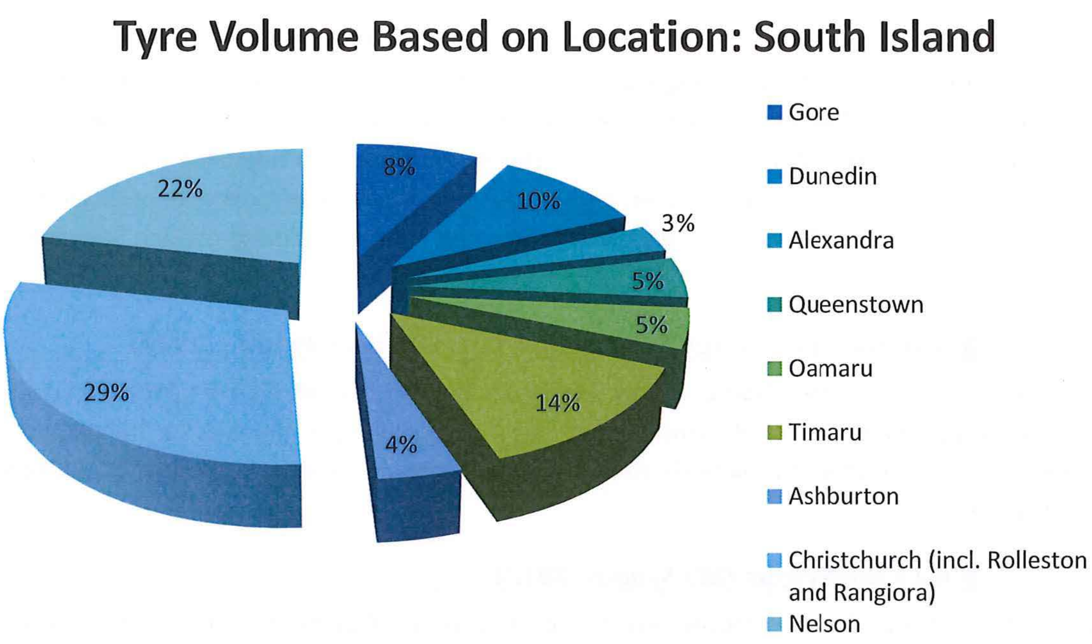


Figure 18.0: Tyre volume in the South Island based on location *(based on market research results)*

9.1.2 Tyre Volume Based on Regional Distribution

Table 30.0 shows tyre volume by region. As shown in these results the largest volume by region is in Canterbury and the second largest is in Tasman. Included in this is ELT's disposed of by Bridgestone.

Region	Tyre Volume (per annum)	Tyres Volume - Bridgestone (per annum)	Total Tyre Volume (per annum)
Southland	7,800	20,600	28,400
Otago	17,550	36,400	53,950
Canterbury	50,180	99,900	150,080
West Coast	No figures	8,950	8,950
Tasman / Marlborough	20,800	29,750	50,550
TOTAL TYRES	**296,330**	**195,600**	**291,930**

Table 30.0: Tyre volume in the South Island by region *(based on market research results)*

Figures may be wrong for the West Coast region as many retailers do not record tyre figures due to tyres being collected by farmers and used as silage pit covers on farms.

9.1.4 Plant Requirements

The South Island based plant will be a 3 line commercial plant. The plant will have specific requirements including electricity, water and space however the design of the plant and development of the site will be dealt with externally by CPT and therefore is not covered in this report. Considerations for health and safety requirements for high risk areas include:

- **Heat**: Flammable area, gas heaters, steam, hot pipes, hot material, LPG bottles and gas flare – potential for fire, explosion, personal injury and burns
- **Bulk Hazardous Storage Area**: Char, gas and oil – potential for spills, fire, explosions, burns, environmental issues
- **Moving Machinery**: pumps and augers – potential for crushing, being struck by, or getting lacerations from equipment
- **Gas System**: potential for fire, explosion, personnel injury and burns

Due to these issues guards and safety zones are to be implemented and observed at all times when on site. Safety zones impact space requirements for the plant.

9.1.5 Fulton Hogan Bitumen and Asphalt Plants – South Island

Fulton Hogan has a number of bitumen and asphalt plants located throughout the South Island. These are located at the following sites:

- Invercargill
- Dunedin
- Alexandra
- Cromwell
- Timaru
- Ashburton – asphalt only
- Christchurch
- Greymouth
- Blenheim – asphalt only
- Nelson

Based on recommended locations and proximity to asphalt and bitumen plants, potentially a Christchurch based pyrolysis plant could be developed to provide oil for the plants in Christchurch, Ashburton and Timaru. A Nelson based pyrolysis plant could potentially provide oil for the two bitumen plants in the Nelson area, as well as asphalt plants in Nelson and Blenheim.

9.1.6 Potential Sites

Christchurch has four potential sites that could be used for a pyrolysis plant: Pound Road Quarry, Miners Road Quarry, Coutts Island Quarry and Charlotte Jane Quarry in Lyttelton.

9.1.6.1 Pound Road Quarry

The prototype plant will initially be set-up at a site proposed on the Pound Road Quarry. This site meets all requirements for electricity, water and space. The base that the plant is to be built on must also be suitable. Space may be an issue for a larger commercial-sized plant therefore it is recommended that this will be developed at a separate site should the trial be successful. Figure 19.0 shows an aerial view of Pound Road Quarry *(Google Earth, 2012)*.

Figure 19.0: Pound Road Quarry *(Google Earth, 2012)*

Figure 20.0 shows the space requirements for the proposed prototype plant to be installed at Pound Road Quarry.

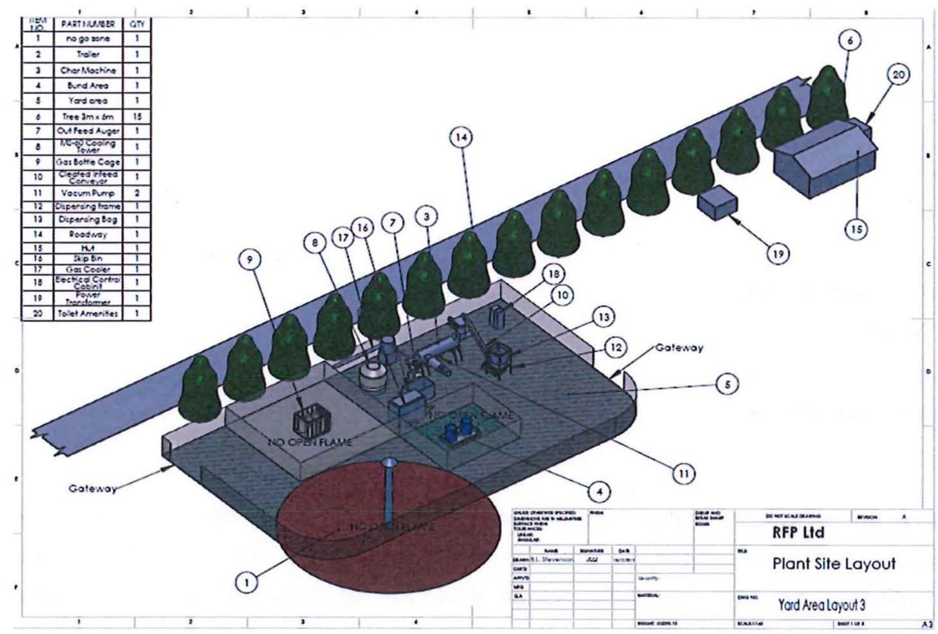


Figure 20.0: Prototype plant site layout *(sourced from CPT, 2012)*

9.1.6.2 Miners Road Quarry and Asphalt Plant

The proposed site due to availability of requirements such as water, electricity and space is Miners Road Quarry. The site also contains the Miners Road Asphalt Plant which potentially could be an end use for the pyrolysis oil and syn-gas generated by CPT. Options for exporting energy at this site are being investigated. Figure 21.0 shows the Miners Road Quarry *(Google Earth, 2012)* as the recommended site for the full-sized commercial plant to be built.

Figure 21.0: Miners Road Quarry *(Google Earth, 2012)*

9.1.6.3 Lyttelton Bitumen Plant – Charlotte Jane Quarry

Due to the facilities available at the Lyttelton Bitumen Plant (figure 22.0) for storage of used oil, this site could represent an ideal place to locate a generator. Due to space restrictions however it is not an ideal site for a pyrolysis plant to be located. Used oil transportation is already in place through ROSE which could offer potential transportation for the pyrolysis oil.

Figure 22.0: Lyttelton Bitumen Plant *(Google Earth, 2012)*

9.1.6.4 Appleby Quarry

Appleby quarry is a small alluvial quarry and therefore may not be suitable for a pyrolysis plant due to space restrictions and close proximity to the river. The quarry is shown in figure 23.0. If a pyrolysis plant for the upper South Island were to be developed, a site investigation would need to take place with potential locations beyond quarries being investigated.

Figure 23.0: Appleby Quarry, located beside the Waimea River, Nelson *(Google Earth, 2012)*

9.2 North Island

9.2.1 Tyre Volume by Location

Table 31.0 shows tyre volume by location based on market research results (estimates only). Bridgestone has a further 650,000 ELT's in the North Island which are not specified by location but by region only.

Location	Tyre Volume (per annum)
Wellington (incl. Upper and Lower Hutt)	33,020
Porirua	4,680
Paraparaumu	6,760
Masterton	5,200
Pahiatua	3,120
Palmerston North	3,900
Wanganui	6,500
Taumarunui	5,200
New Plymouth	13,520
Waipukurau	4940
Hastings	11,180
Gisborne	7,020
Whakatane	3,120
Rotorua	14,560
Tauranga	16,120
Mount Maunganui	5,330
Taupo	10,400
Te Kuiti	2,600
Tokoroa	5,200

Te Awamutu	2,600
Kihikihi	2,600
Hamilton	13,780
Morrinsville	4,160
Pukekohe	5,200
Auckland	85,800
Silverdale	2,860
Warkworth	5,200
Dargaville	780
Whangarei	9,100
Kaikohe	1,170
Kawakawa	1,950
Kerikeri	Volume not disclosed
Kaitaia	Volume not disclosed
TOTAL TYRES	**297,570**

Table 31.0: Tyre volume in the North Island by location *(based on market research results)*

Figure 24.0 shows the tyre volume across the North Island by location. This gives an indication only as tyres generated by Bridgestone are not included in these results.

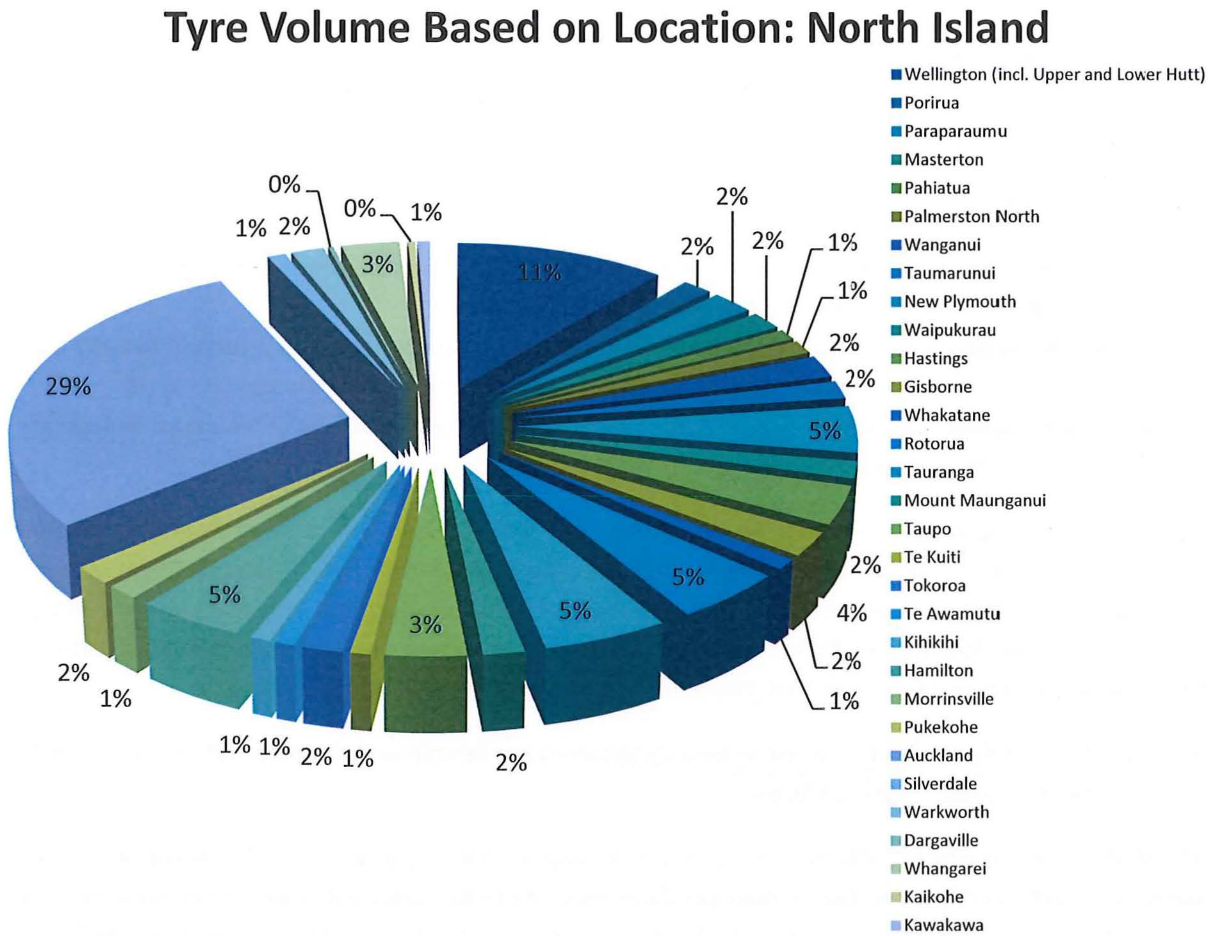


Figure 24.0: Tyre volume in the North Island based on location *(based on market research results)*

9.2.2 Tyre Volume Based on Regional Distribution

Table 32.0 shows tyre volume by region. The Auckland region has the largest annual tyre volume as expected by the population distribution throughout the North Island. The Wellington region has the second largest tyre volume followed by Waikato and the Bay of Plenty.

Region	Tyre Volume (per annum)	Tyres Volume - Bridgestone (per annum)	Total Tyre Volume (per annum)
Wellington / Wairarapa	49,660	150,250	199,910
Manawatu - Wanganui	18,720	69,550	88,270
Taranaki	13,520	27,700	41,220
Hawkes's Bay	16,120	40,350	56,470
Gisborne	7,020	9,250	16,270
Bay of Plenty	39,130	64,700	103,830
Waikato	41,340	73,200	114,540
Auckland	99,060	184,650	283,710
Northland	13,000	42,400	55,400
TOTAL TYRES	**897,570**	**662,050**	**959,620**

Table 32.0: Tyre volume in the North Island by region *(based on market research results)*

9.2.3 North Island Tyre Collection Market and Recommended Locations

9.2.3.1 Auckland and Waikato

Auckland also has the largest population base with 1,507,700 (as of June 2012) and the largest share of tyres therefore it is an obvious primary choice to locate a pyrolysis facility. As a region however it may represent significant problems based on other specifications including space and ability to gain resource consent due to high environmental restrictions. The Auckland tyre market may also be restricted due to retailer agreements with tyre collectors in the area.

Major tyre collectors in the Auckland area are:

- **Tyre Removals Ltd** (Auckland), disposing of around 180,000 tyres annually – currently bale and send to Asia but in the process of importing a pyrolysis plant
- **Pacific Rubber** (Auckland), processing around 300,000 passenger tyres and a further 104,000 truck tyres annually – crumb all tyres and sell as crumb or bales for industrial purposes within NZ
- **J & J Laughton** (Auckland) – currently crumb and sell for horse arenas and other industrial purposes, also currently investing pyrolysis with Tyregone Processors

Tyre Removals Ltd represents potential for partnership within the Auckland area as they currently pay to send all tyres to Asia. Partnering with them would enable free tyre disposal within New Zealand without incurring export costs. Moving fast on any potential agreements with Tyre Removals Ltd may prevent them importing a pyrolysis plant therefore allowing Fulton Hogan the first mover advantage with pyrolysis in the North Island as well as a guaranteed supply of tyres from this collector and the retail outlets that they service.

J & J Laughton and Pacific Rubber would be unlikely to form a partnership or agreement with as they currently have commercial use for all tyres collected.

The Waikato region also has a large share of the tyre volume with a total share of 12%. There are no tyre collectors based directly in this region however close proximity to Auckland and market research shows that the majority of retailers are serviced by Auckland-based tyre collectors or Carbon Recovery in the Bay of Plenty. A number of retailers in this area dispose of tyres by giving them to farmers to use as silage pit covers.

9.2.3.2 Tauranga and the Bay of Plenty

The Bay of Plenty has a significant portion of ELT's for the North Island with a total share of 11% (based on market research results). It may offer more advantages than the Auckland and Waikato area as environmental guidelines will not be as restricting. It has sufficient proximity to both Auckland and Waikato to offer relatively cheap transportation for tyres should a pyrolysis facility in the Bay of Plenty area be developed.

Major tyre collectors close to this area are:

- **M. E. Jukes & Sons** (Gisborne), disposing of 40-50 tonnes (around 5000 tyres) annually into landfill
- **Carbon Recovery Ltd** (Tauranga), did not provide estimates however are a major player and likely to be in similar size to Pacific Rubber – bales and sends all tyres to Asia for use as TDF

Both M.E. Jukes & Sons and Carbon Recovery Ltd offer potential for partnership or agreements for tyre disposal. M.E. Jukes & Sons may be difficult to deal with as an interview with the company highlighted that they had little or no concern for recycling and were content with disposal in landfill. They also have their own landfill therefore are not liable to pay charges relating to local landfill costs. They offer a full rubbish disposal service and are not dependent on tyre collection and disposal.

Carbon Recovery Ltd may be interested in an agreement to supply tyres for pyrolysis. They have been investigating the development of a kiln to burn ELT's as TDF however this is dependent on resource consent and funding and is therefore not likely to be developed in the near future. They have agreements with at least 12 councils throughout the North Island and consequently offer substantial potential for this project.

9.2.3.3 Wellington and the Wairarapa

Wellington and the Wairarapa have the second largest share of tyres with a total share of 21%. Although there are several tyre collectors in the area, none of them offer an integrated service for retail outlets through Wellington. Al's Bins appears to be the largest service provider, removing both rubbish and tyres for disposal in the Southern Landfill.

9.2.5 Fulton Hogan Bitumen and Asphalt Plants – North Island

Fulton Hogan has bitumen and asphalt plants at the following locations in the North Island:

- Wellington
- New Plymouth
- Gisborne
- Mount Maunganui
- Tauranga
- Hamilton
- Auckland
- Whangarei

Based on number of ELT's generated, potential locations include Wellington, Auckland and Tauranga:

- An Auckland based pyrolysis plant could service the bitumen and asphalt plants in Auckland, Hamilton, Whangarei, and Mount Maunganui.
- A pyrolysis plant based in Tauranga could service Auckland, Hamilton, Mount Maunganui and Gisborne.
- A Wellington based pyrolysis plant would be restricted due to access issues as it would only be in close proximity to the asphalt and bitumen plants located in Belmont, Lower Hutt.

9.2.6 Potential Sites

Wellington does not have any quarries in close proximity therefore it is not an ideal location as space for resource consent will be an issue. Potential sites include Whitford Quarry in Auckland and Poplar Lane Quarry in Te Puke, Tauranga.

9.2.6.1 Whitford Quarry

Whitford Quarry is located in Whitford-Maraetai Road in Auckland (figure 25.0). The quarry's primary resource is 'greywacke' rock, which is extracted, crushed and sold as aggregate. Based on standard quarry site facilities, this site should have sufficient requirements for electricity, water and space however this will need to be investigated further. Development of a full-sized commercial plant will depend on resource consent. Auckland Industries, located in Mt Wellington would be the closest asphalt and bitumen plants at a distance of 20km from the quarry. Whitford quarry shows significant potential as it is a relatively new quarry and is therefore under-developed.

Figure 25.0: Whitford Quarry *(Google Earth, 2012)*

9.2.6.2 Poplar Lane Quarry

Poplar Lane Quarry (figure 26.0) is located in Te Puke, Tauranga. It is larger and more developed than Whitford Quarry and therefore may not have space for a pyrolysis facility. The area to the right of the quarry (in figure 26.0) is a commercial development and therefore is not accessible to Fulton Hogan. Poplar Lane Quarry is located 16km from Hewletts Road, Mt Maunganui where the bitumen and asphalt plants are located.

Figure 26.0: Poplar Lane Quarry *(Google Earth, 2012)*