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Tyre Waste Reduction in Hong Kong

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by

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Submitted to:
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Abstract

Hong Kong is a rapidly developing and populated city home to a large number of vehicles, which produce an abundance of tyre waste. The goal of our project was to recommend steps Hong Kong could take towards creating a sustainable waste tyre management system. To accomplish this goal we performed interviews, library research, and traffic observations. Through analysis we arrived at a set of options Hong Kong could apply to better manage their tyre waste.

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We would also like to thank those who helped us with our research: JP Routhier & Sons for providing us with information on tyre recycling in the United States, Mr. Simon Lee of the Hong Kong Environmental Protection Department for an informative interview, Dr. W.G. Wong for information and tours regarding rubberized asphalt, and Jets Technics for a tour of their tyre recycling factories.

Authorship Page

Justin Carmichael, Jared Gesley, Jia Li, and Bradleigh Windsor all contributed to the research and writing of this report. The following is a breakdown of how the report was written for this project.

Justin Carmichael focused his efforts on the background chapter of the report. He also contributed to the results and analysis chapter, and through editing added to the methodology and conclusions chapters.

Jared Gesley performed editing on the entire document, though his focus was on the introduction chapter. He also performed editing on the executive summary.

Jia Li's work was focused on the appendices, as she was responsible for many of the interviews and translations. She also made suggestions involving edits made as a group with the rest of the report.

Bradleigh Windsor was responsible for the initial drafts of the introduction and executive summary, and made some considerable edits to those documents. He also wrote the initial drafts for a large portion of the methodology, results and analysis, and conclusions chapters.

In addition to writing individual sections of this report, Justin Carmichael, Jared Gesley, Jia Li, and Bradleigh Windsor all edited the report for grammar, content, and flow.

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Executive Summary

The invention of the automobile, followed by other motorized vehicles has resulted in an abundance of wastes that can be difficult or hazardous to process. Used oil, refrigerant, and scrap tyres are some examples of major wastes generated from vehicles. Of these, waste vehicle tyres are a bulky and non-biodegradable disposal problem. The Special Administrative Region of Hong Kong, and countries around the world, are looking for an outlet for used vehicle tyres, as scrap tyres contain a large amount of potentially valuable material. In addition, Hong Kong's government is concerned with the space issues created by waste tyres in landfills. Professor C.S. Poon of Hong Kong Polytechnic University (HKPU) has decided to work toward finding a sustainable system for waste tyre disposal and recycling.

In some countries, methods of recycling tyres using innovative technologies are already in practice. For example, the Japanese are able to use whole tyres in concrete for building houses, and the United States has used waste tyres to build rubber based sidewalks, as well as rubberized asphalt. In Hong Kong, some of the waste tyre products have been used to build surfaces for playgrounds, and rubbersoil for use in civil engineering projects. However, many more scrap tyres are being generated annually than are being reused; therefore, Hong Kong needs more viable options for waste tyre management. This project aimed to provide HKPU with steps towards a sustainable reuse and recycling system for scrap tyres.

This HKPU sponsored project was to create a set of recommendations to alleviate the scrap tyre problem. We developed these steps keeping in mind Hong Kong's regulations as well as the residents' respect for the environment.

Our goal was realized via three objectives. Our first objective was to determine the scale of the waste tyre problem in Hong Kong. We determined that

approximately 15,000 metric tons of scrap tyres are produced yearly. We identified present and future tyre management techniques, through online research as well as from private sector companies in Hong Kong. Currently, the only major form of tyre recycling used in Hong Kong is the production of rubberized mats. A very feasible option, which the government is already looking into, is the use of rubberized asphalt in their roads. The only other method Hong Kong uses to manage waste tyres is retreading, done on large government vehicles, on some trucks and minibuses, and on all buses used by the Kowloon Motor Bus Company. We identified legislation used around the world to regulate the number of waste tyres and to promote recycling. Most countries impose a tax on the purchase of new tyres to subsidize the cost of recycling. Britain has banned scrap tyres from landfills and instead has developed monofills or dedicated landfills for excess scrap tyres, to promote the eventual recycling of waste tyres.

By examining Hong Kong's current system for dealing with waste tyres and the models created by other countries, we concluded that Hong Kong should implement five different management techniques to create a sustainable waste tyre management system. First, inspections and maintenance should be more frequent to prolong the lives of tyres. Second, Hong Kong should create monofills to allow for all tyres generated to be recycled at a later time as well as banning tyres from landfills to save landfill space. Third, a tax should be levied on new tyres to fund recycling and reuse efforts. Fourth, the Environment, Transportation, and Works Bureau should use rubberized asphalt in the construction of new roads. Fifth, the use of retreaded tyres should be encouraged, especially by organizations with fleets of large vehicles.

Chapter 1: Introduction

Tyre waste management is a worldwide environmental problem. Billions of waste tyres are produced every year. While there are numerous ways to reduce tyre waste globally, no one method is able to solve the problem, and not every method is viable in all countries. In many countries there is a fee charged to cover disposal costs of waste tyres, so illegal dumping of waste tyres becomes a serious issue. Even in countries with no charge to dispose of waste tyres, illegal dumping is a problem. The current methods of tyre recycling are only practical in those countries with an infrastructure, industry and market that can support tyre recycling.

In the Hong Kong Special Administrative Region (HKSAR) there is a serious problem with waste tyres, because it is a geographically small territory with an extremely large number of vehicles. In Hong Kong there are a lot of private vehicles, even with a public transportation system that is also very widely utilized. Although there are many buses, minibuses, and trucks, the majority of tyres from those heavy vehicles are retreaded. There are more cars and taxis than trucks and buses, so many of the waste tyres produced are from light vehicles. Landfill space is limited in Hong Kong because land is expensive and the active landfills are being filled faster than expected. Stockpiled tyres are a fire hazard and a breeding ground for disease-carrying insects, which in a subtropical city is a relentless problem. Researchers at Hong Kong Polytechnic University (HKPU) are interested in finding ways to manage the waste tyre problem.

There are over a million waste tyres in Hong Kong, all of which could have been recycled using methods that are used in the United States and elsewhere. Currently most tyres in Hong Kong are cut in half and buried, with a small percentage being recycled into rubber mats and stamped products. Hong Kong researchers are

carefully trying to select the best options for tyre waste management in Hong Kong. Researchers began testing rubberized asphalt a few years ago and now the Hong Kong government has begun its own tests, which could lead to its expanded use in the near future. Rubbersoil is one possible solution that has been developed in Hong Kong, but has not replaced conventional materials due to technical problems. Many solutions have been proposed and tested to reduce tyre waste in Hong Kong.

There are many more ways in which Hong Kong could recycle waste tyres, such as uses in civil engineering, like rubberized concrete. Although this technology has been tested in the United States there is still a lot of testing that needs to be done before it can be implemented in Hong Kong. Every solution used in foreign countries has the possibility of being an effective option for waste tyre management in Hong Kong. With few methods currently being employed in Hong Kong, there is a large pool of technologies and methods that potentially could reduce tyre waste but first need to be brought to the attention of Hong Kong's government and private sector. Currently Hong Kong's government manages waste tyres no differently than other waste, but there is potential for environmental improvement through waste tyre management.

The goal of our project was to propose steps towards a sustainable tyre management system for Hong Kong. We accomplished this goal by meeting several objectives. We determined the scale of the waste tyre problem in Hong Kong and what methods are currently being implemented to alleviate the situation. We selected the best possible waste tyre management methods from our research into current methods from around the world. Then we proposed solutions to implement the most effective and feasible options in Hong Kong. We believe that our project has

contributed to alleviating Hong Kong's tyre waste disposal problem and related environmental issues.

Chapter 2: Background

The problem of tyre waste management is a significant problem for many countries. Privately owned vehicles as well as public transportation vehicles, such as buses and taxis, produce thousands of tons of waste tyres every year. In this chapter, we describe basic tyre designs along with possible recycling technologies and methods, and the problems these methods face. We also review government regulations that have an impact on tyre waste management.

2.1 Tyre Manufacturing Techniques

In this section we will give an overview of the methods used to make current motor vehicle tyres. We will also discuss how tyre life can be lengthened through different emerging technologies.

2.1.1 Conventional Tyre Designs

Creating a tyre requires processing rubber, steel, and fabric components separately before combining them into a tyre (Refer to Figure 1) (Rodriguez et al, 2001). The rubber sap is mixed with carbon black, and a variety of chemicals. These chemical components determine the composition and specialty of the tyre along with curing temperature and time (Frederick, 2000).

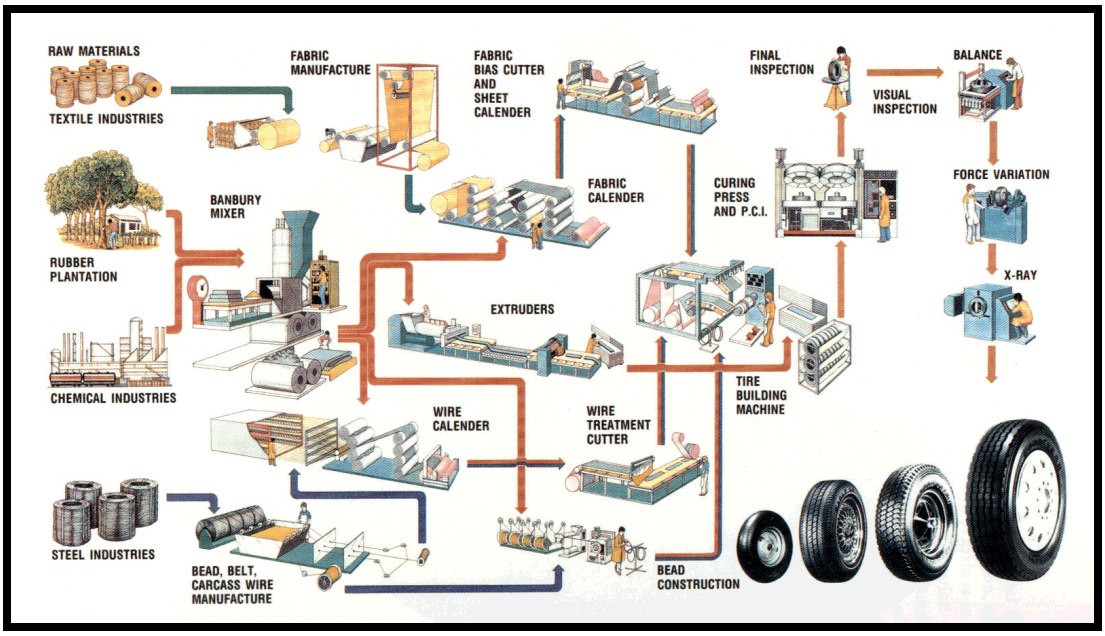


Figure 1 – The tyre manufacturing process (Energy Manager Training, 2004).

There is a fabric component to tyres as well. The fabric, usually nylon, is created separately from the rubber process and wound on a crude rubber carcass in uniform sheets. Steel wires are also wound around the tyre along with steel "beads" (Refer to Figure 2 for a cross section diagram of a tyre). Additional chemicals added with the steel wire help to ensure a proper bond to the rubber (Energy Manager Training, 2004). The tyre at this stage of the process is referred to as a "green" tyre. All the components are there, but the rubber is too soft for use. The rubber is then cured and "vulcanized" with additional chemical components along with heat to create a hard rubber material that has a much longer life on the road (Frederick, 2000).

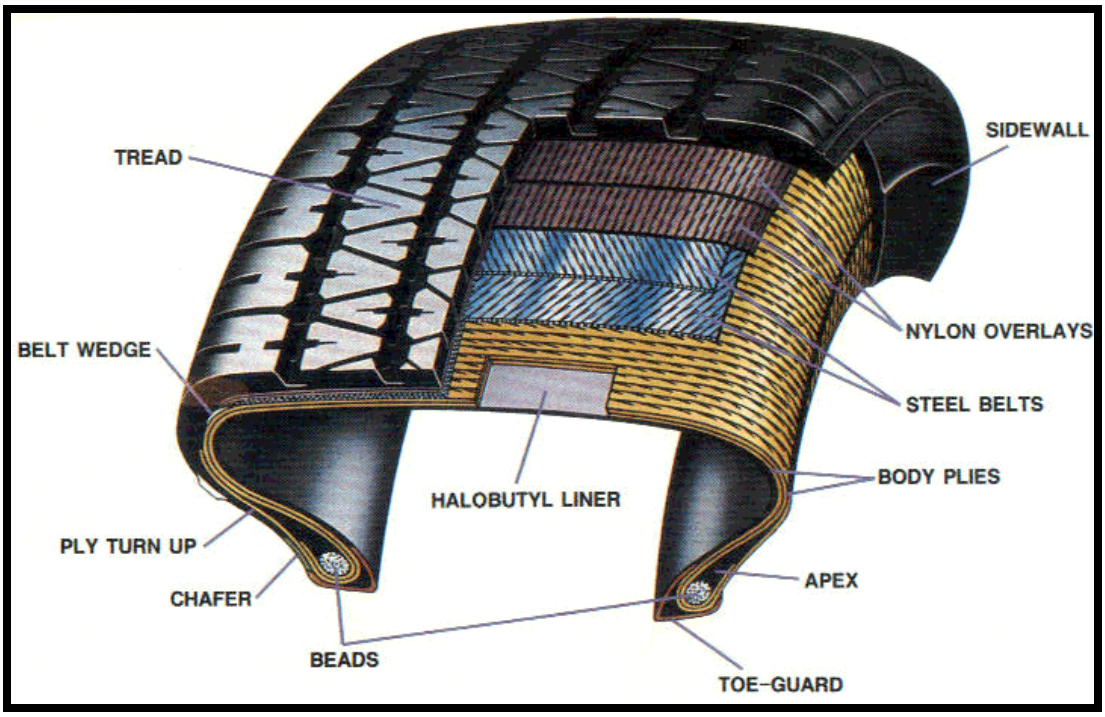


Figure 2 - Cross section diagram of a standard vehicle tyre (Energy Manager Training, 2004).

2.1.2 Unconventional Tyre Designs

Tyres can be manufactured with a significantly longer lifespan using unique modern technologies. The increased life span of the tyres may contribute significantly to waste reduction. Two notable techniques have been developed in the past decade that can enable the tyre to have a longer life before needing to be discarded or recycled. The names of these two techniques are Zero Pressure and PAX System (Michelin Inc, 2006).

Zero Pressure

Zero pressure is a unique system that allows drivers to keep driving up to 50 miles at 55 mph even when there is no air inside the tyres (Michelin Inc, 2006). The zero pressure technique along with the included low tyre pressure monitoring system allows the tyre to properly maintain air pressure and therefore reduce the wear on the tyre tread (Michelin Inc, 2006).

PAX System

With the PAX system, the tyre wheel is made of steel or steel alloy (Michelin Inc, 2006). The diameter of the wheel is wider than an equivalent standard wheel. Most of the tyre designs use inflation pressure to hold the tyre to the rim, which makes the tyre separate easily from the rim when a flat occurs at high speed. However, the design of a PAX system wheel actually improves its grip when vertical loads are applied to the tyre. The repairable tyre and reusable support ring can provide a longer life for tyres. Additionally, these tyres have shorter and more flexible sidewalls, which can reduce rolling resistance by reducing tyre roll. This also helps to prolong the life of the tyre.

By using these unique designs, tyres can be made to last longer, thereby reducing tyre waste (Michelin Inc, 2006). By implementing these technologies into Hong Kong's transportation infrastructure it may be possible to slow the accumulation of tyre waste, though it is uncertain whether these methods will be cost effective. Furthermore, it is unknown if these tyres will complicate recycling or retreading procedures due to their unique design and composition.

Summary

Each material that goes into a tyre has value by itself. Steel can be melted down, and pure rubber is easily recyclable, but the problem lies in the fact that all these materials are strongly bound and mixed together with a mix of potent chemicals that makes separation a difficult and costly process. For this reason tyre recycling is not an easily profitable business (Rodriguez et al, 2001). We will outline several recycling methods in the next section that have had varying degrees of success.

2.2 Recycling

Eventually, all tyres become unsafe to use even though the majority of the material used to make the tyre is still present. Retreading, or the addition of a new tread to an old tyre, can be performed on heavy vehicle tyres several times over before these tyres also become unsafe. Therefore, recycling is an integral part to tyre waste management around the world. The recycling techniques described below are several of the possible solutions for the recycling of waste tyres in Hong Kong.

2.2.1 Shredded Rubber

Most recycling processes require the tyres to be shredded before further processing (Clark, Meardon, & Russell, 1993). Shredding allows for much more efficient transportation of tyre waste, as it can reduce the volume of the tyres by about 75%. Tyre shredding also eliminates many of the problems associated with above ground storage in stockpiles. The tyre shreds do not allow water to build up and become breeding grounds for insects, and the volume reduction allows for much more efficient use of land. Of course the problems with fire hazards still remain.

Shredding Equipment

Tyre shredding equipment is moderately expensive and consumes lots of power. The tyre as a whole is first shredded to two-inch shreds. These shreds, about the size of the palm of your hand, are not too useful by themselves other than the volume reduction as they still contain the metal wires from the tyre (Lundin, personal communication, November 28, 2006. See Appendix D). These shreds are put through additional shredding equipment to reduce the size of the shreds to about one inch. During this last shredding process the metal wires from the tyre are removed by magnetic means. A rotating magnetic drum draws the metal wires out of the shreds

and into a separate pile (see figure 1). This metal wire has not found much use in industry in the United States as it contains too much rubber to be processed for scrap metal as it is. As a result, there are stockpiles of this metal wire in the United States (see Appendix D).

Figure 3 - Whole tyre shredding teeth on the left, and the rotating magnetic drum for separation of metal wires on the right.

Uses

Once most of the metal wire is removed from the rubber the shreds become much more useful. Shredded rubber from tyres has found uses ranging from plant mulch to highway bedding. In the United States the most common use for tyres is for fuel; tyre rubber has a fuel value about equal to that of coal, although some sources claim a greater fuel value (Farrell, 1999b). Although the process is not an environmentally friendly recycling method, the waste from the burnt tyres, which includes steel slag from the belts, can be used in creating concrete (Clark, Meardon, & Russell, 1993).

The civil engineering applications for tyre shreds are numerous. The chips can be used as a highway bedding (Hylands & Shulman, 2003), insulation material, sound barrier, and as a "sorptive" (a process that can filter some heavy metals) drainage layer (Edil, Park, & Kim, 2004) to name a few such applications. The use of the tyre

shreds often can lead to prolonged life of roads, and the implementation is usually very cost effective (Clark, Meardon, & Russell, 1993).

Crumb Rubber

The tyre shreds can be processed to even finer levels. This product, called crumb rubber, is almost entirely devoid of contaminant wire and material. Unfortunately the methods for producing crumb rubber are complex and expensive. One method is to cryogenically freeze the rubber shreds and mechanically pound them to break them into finer pieces, removing the fibers and metal wire thereafter (Brown, 2002). Other methods exist for creating crumb rubber without the need for cryogenic temperatures, but it is unknown if these are cost effective (Anthony, 1999). This rubber product can be processed into such items as shoe soles, industrial mats, and playground tiles (Steuteville, 1995).

2.2.2 Uses for Whole Tyres

Tyres do not need to be shredded to find use. Whole tyres have found a variety of uses in civil engineering projects as well (Hylands & Shulman, 2003). When strategically placed on hillsides or beaches, tyres can help fight erosion. Though unsightly, it may be the best option for areas with little capital to spend processing the tyres. Boats can use tyres as bumpers. A stack of tyres covered in fiberglass has been found to make an effective highway barrier as well (Clark, Meardon, & Russell, 1993).

If tyres are linked together and placed on the ocean floor they can form an artificial reef (Rowe, 2002). In the past, artificial reef projects using waste tyres were prone to problems of tyres washing ashore in large numbers. This is often either due to strong ocean currents or poor reef construction. Care must be taken to ensure the binding material that holds the tyres can withstand the salty ocean environment;

otherwise the material will corrode and release the tyres creating an environmental disaster. If done properly tyre reefs can form a great natural habitat for fish and other organisms.

Whole tyres can also be burned for fuel directly without the need for shredding or processing, though this requires existing kilns to be modified (Clark, Meardon, & Russell, 1993). These modifications to accommodate whole tyres can be expensive and problematic due to the accumulation of incombustible products. If the whole tyres are burned the ash contains lots of carbon material and steel slag which can also be used in civil engineering applications such as mixing with concrete.

2.2.3 Rubber Asphalt

Rubber asphalt is an interesting application of tyre waste. Used to coat the top layer of roads, rubberized asphalt contains at least 15% reclaimed tyre rubber by weight. The rest of the asphalt is composed of regular asphalt cement and additives (Rubber Pavements Association, 1998).

Besides the great benefit of recycling tyres, rubberized asphalt has plenty of advantages over regular asphalt. These include reduced pavement thickness, absorption of traffic noise (up to 85% has been noted), and longer road life. About 2,000 tyres are recycled per “lane mile”. The road life can be dramatically increased which can help save costs in the long run. Furthermore, rubberized asphalt can be recycled, used in diverse climates, and the emissions at the processing plant are similar to that of regular asphalt (Rubber Pavements Association, 1998).

Costs

There are initial costs associated with rubberized asphalt. The processing equipment is a significant investment, though once set up regular equipment can be used to apply the asphalt to the road. Processing the waste tyres to create a fine

powder is also an expensive process that must be taken into consideration. The components of the asphalt must be carefully controlled and the temperatures closely monitored, else the quality of the asphalt will decrease substantially (Rubber Pavements Association, 1998). According to the Rubber Pavements Association there are five issues that prevent rubber asphalt from gaining wide acceptance:

1. Formerly a patented process prevented industry development. Last patents expired in 1992.
2. Long held in "experimental" status.
3. "If it ain't broke, don't fix it" mentality. Many state highway departments prefer to use old materials and methods.
4. ISTEA mandate for use caused political fallout. RPA does not support mandates. A-R should be used by free choice based on its superior qualities.
5. "Impostors" (processes with non-reacted rubber additives) often lead to failures associated with A-R. F. Some specialized equipment is required.

(Rubber Pavements Association, 1998)

Rubberized asphalt roads may be a viable option for Hong Kong. The significant number of tyres used in the process could make a significant contribution towards the goal of reducing tyre waste.

2.2.4 Pyrolysis

Pyrolysis is a unique method for recycling tyres. The process is essentially heating without the presence of oxygen, and when performed on complex organic materials pyrolysis will break the material down into such things as oil, char, and gases. Laboratory research has shown that when applied to a tyre the process has the potential to produce approximately one gallon of oil, seven pounds of char, three pounds of gas, and two pounds of steel and ash (Clark, Meardon, & Russell, 1993).

Due to the complexity of the process, there are many unresolved issues. Technologies have to improve to increase the efficiency of the pyrolysis process as well as the processing of the products. According to the EPA, there are no pyrolysis

plants operational in the United States as of 2007. The building costs are too high, and "the products of tire pyrolysis have limited marketability due to their low quality compared to virgin materials" (Environmental Protection Agency, 2007). Another problem with pyrolysis is in regards to research. Until recently most of the research done was through corporations and proper scientific methods were not always followed. For example, before attempting a large scale process, researchers have to test the technology with smaller reactors and rubber samples. These samples often did not include all the constituents of the tyre, such as the metal wires and fibers. This could drastically affect the outcome of the experiment. Additionally, the reactors must be brought to full steady state operation before sampling of gases and oils, which sometimes was not done. Proper research could lead to better reactor designs (Rodriguez et al, 2000).

The pyrolysis process is very sensitive to the initial conditions and the steady state temperature of the reactor. Research has shown that the temperature of the reactor determines the chemical composition of the products, as well as the ratio between solid and gaseous products (Rodriguez et al, 2000). If a two stage process is used where gas is passed through a catalyst, it has been found that the catalyst temperature determines the concentrations of the different gases produced (Williams & A.J., 2002). The gases produced contain valuable natural gases such as propane. The oils, which can be burned for energy directly, also contain a number of chemicals with high commercial value. One such chemical produced in high concentrations is "limonene", which has a high industrial value (Williams, 1999). The solid product, char, can be processed into a product similar to low grade activated carbons (Cunliffe & P.T., 1998), useful for filtering heavy metals and other contaminates from water or

for creating inks (Williams, 1999). Refer to Appendix H for information on the chemicals produced by tyre pyrolysis.

There may be many obstacles preventing the use of pyrolysis presently, but the option must be kept in mind as technologies are constantly improving and the world's oil supply is constantly being depleted.

Using these techniques it is possible to substantially reduce tyre waste in Hong Kong. However, these are neither all encompassing nor the final solution. Tyre waste in Hong Kong will likely require a combination of these as well as other techniques.

2.3 Government Regulations

One of the key factors in determining the management of tyre waste is legislation. If proper legislation is enacted, tyre waste can be recycled in an environmentally friendly manner, while overzealous legislation may lead to illegal dumping.

United States

In the United States there is no federal legislation governing the disposal of waste tyres. The legislation is instead left to the discretion of the individual states (EPA, 2006). As a result there are differences among states and their laws on tyre disposal, although there is legislation shared amongst most of the states. As of 2004, thirty-seven states have banned burying whole tyres due to problems such as creeping (tyres slowly rising to the surface of the landfill), and nine have gone so far as to ban tyre shreds from the landfills. Thirty-five states also have collection fees, while five don't allow fees due to illegal dumping. Twenty-one states have also created dedicated scrap tyre funds, and nineteen have created market development incentives for recycling (Rubber Manufacture's Association, 2004).

Some states still allow large stockpiles, thereby providing a breeding ground for disease-causing insects and a fire hazard. However, those stockpiles are also readily available for recycling, unlike tyres buried in landfills. The United States also has relaxed emissions regulations that allow for the burning of tyres, so that method of waste management is most common (Lundin, personal communication, November 28, 2006. See Appendix D). For a breakdown of the recycling methods used in the United States in 2003, refer to Figure 4.

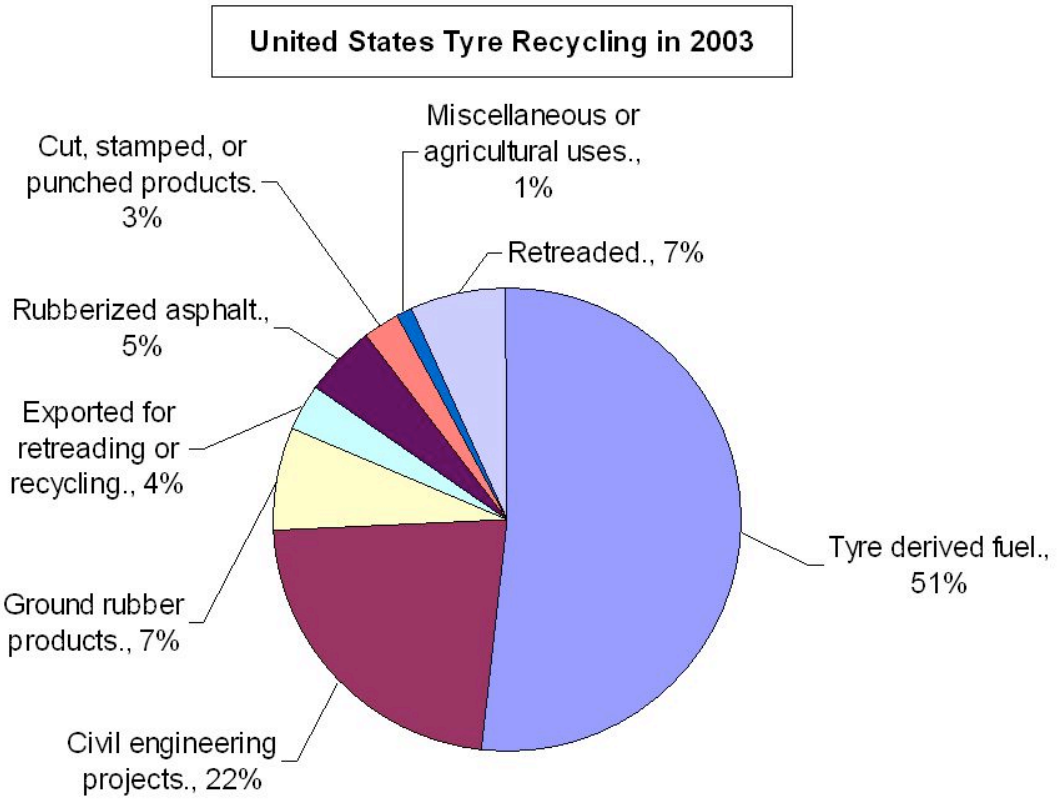


Figure 4 - Uses of recycled tyres in the United States for 2003. This graph is compiled from statistics found at the following source: (Environmental Protection Agency, 2007).

European Union

The European Union (EU) is as experienced in dealing with tyre waste as the United States. Tyre waste legislation in the EU has become much more stringent in

the past decade. The Community Waste Strategy (CWS) of July 2006 promotes the prevention, recovery, and minimization of the disposal of waste (European Tyre and Rubber Manufacturers' Association, 2006a). The CWS also enacts a mandatory take-back of all “end-of-life” products to the producer. The CWS also covers restrictions on the shipment of waste. Waste tyres are not considered hazardous but can still be taxed on import and export.

Another key document is the “Directive on the Landfill of Waste” of April 1999. The legislation enacted by this document effectively bans all waste tyres from the landfills (European Tyre and Rubber Manufacturers' Association, 2006a). Whole tyres were banned on July 16, 2003, while all shreds were banned on July 16, 2006. Any waste tyre product used in the engineering of the landfill is exempt from these laws (European Tyre and Rubber Manufacturers' Association, 2006a).

Like the United States the EU has lenient emissions requirements and waste tyres are burned for fuel. In 2004, 31% of all waste tyres were burned, up from 14% in 1992 (European Tyre and Rubber Manufacturers' Association, 2006c). This happens despite costly modification to the cement kilns required to burn the tyres.

Hong Kong

Hong Kong is a very special case because of its unique history as a center of commerce, and it is still transitioning from being a British colony to being an integral part of China. Despite the difficulties in making the transition Hong Kong has passed and enforced some laws that govern environmental issues. The government imposes a tax on exported waste, with the exception of waste that is going to be recycled (HKEPD, 2005).

These countries, such as Britain, provide excellent benchmarks for how the Hong Kong government can be involved and help. Legislation is not the only factor that must be taken into account when assessing waste management methods; sociopolitical factors play an important role in determining the best management method for Hong Kong as well.

2.4 Sociopolitical Factors

An important concern in implementing any type of tyre waste management technology is sociological and political factors. A country cannot successfully control any type of waste product without an educated and informed population. Public support for recycling and reuse technologies depends on how informed people are about environmental issues.

Sociological Factors

Hong Kong and the United States have different environmental attitudes and beliefs. Hong Kong's legislation and the residents' concern for their environment likely is due to the pollution that comes from Mainland China, which is not nearly as regulated as Hong Kong (HKEPD, 2005). The majority of Hong Kong's residents are ethnic Chinese with approximately one-half of them being born in mainland China, so their concern for Hong Kong's environment may be due to experience with the serious problems across the border. Surveys show that the majority of people in Hong Kong consider air pollution to be a serious problem (Martinsons et al, 1997). The environmental attitudes of people in Hong Kong depend strongly on the demographic in question. The older or less educated people tend to think less of the environment, while the females and more educated individuals surveyed have stronger environmental attitudes (Lai et al, 2003). There exists very little awareness to tyre

waste issues, because tyre waste is a relatively small problem in comparison to air pollution and other municipal wastes.

Any recycling technology that contributes to pollution should be considered as a less favorable option even if within regulations. Tyre derived fuel is an unfavorable option based on both legislative and sociological factors. The pollution created in making and using tyre derived fuel would not be acceptable in Hong Kong. Also, the limited space in Hong Kong makes it difficult to build a factory.

Political Factors

Hong Kong is listed as having the world's highest economic freedom rating (Gwartney, 2006) by several comparisons. The government has very little impact on business, because legislation or other means of government intervention is generally frowned upon. Any recycling method that relies on government legislation, subsidies, or any form of intervention would be unfavorable for the investors in Hong Kong, who prefer free market incentives (John So, personal communication, February 5, 2007. See Appendix H).

2.5 Summary

Due to the complicated structure and composition of tyres, recycling is very troublesome. Despite this, there are many methods that have been proven in several countries to be profitable. Based on existing laws and regulations, some of these options, such as tyre derived fuel were found not to be feasible in Hong Kong. Sociopolitical factors further reduced the options, although there are still numerous recycling methods available that need to be analyzed. The objectives and the methods we implemented to determine the most effective solution for Hong Kong will be outlined in the subsequent chapter.

Chapter 3: Methodology

The main goal of our project was to propose a sustainable tyre management system for Hong Kong. The project had three major objectives. First, we identified the scale of the problem in Hong Kong. Second, we identified presently used and possible future tyre waste management schemes in Hong Kong. Third, we identified legislation that Hong Kong could adopt to increase the number of waste tyres being reused and recycled.

3.1 Identify the scale of the problem

We identified just how much tyre waste there is in Hong Kong. The methods that we used to identify the magnitude of the problem of waste tyres in Hong Kong were—archival research, such as government websites, and interviews with professors and government officials.

3.1.1 Determining Hong Kong's waste problem

By doing research in local libraries, we were able to get more reliable information specific to Hong Kong, such as the government data, on the number of tyres imported and the volume of waste produced. The Hong Kong Polytechnic University and University of Science and Technology libraries contained reports and papers on waste tyres, which we used to collect data on methods used in Hong Kong. We were also able to determine the volume of tyre waste produced in comparison to municipal waste in Hong Kong.

3.1.2 Observation of Hong Kong's major roads

By observing the traffic on some of Hong Kong's major roads, in Sham Shui Po, we were able to determine which types of vehicles are the most heavily used. Though this could not be done in a controlled manner leading to representative data,

we observed enough traffic to gain an insight into the general composition of traffic. We observed three major roads, on different days and different times of the day, for half an hour each, recording the number of each type of vehicle observed.

3.2 Identify the present and possible future methods of tyre management

Hong Kong has several temporary measures in place to deal with the waste tyre problem. By evaluating these methods, as well as those used in other countries we were able to determine which methods might be the most effective.

3.2.1 Jets Technics

Jets Technics is a company that uses waste tyres to make rubber mats for playgrounds. Through an interview with the owner, we were able to get more detailed information on their practices, and the volume of tyre waste that they could handle. We also inquired about what they view as the greatest obstacle to tyre management, and how this may be resolved. We concluded the interview by asking if they plan to broaden their business and consume more tyres. This interview gave a good perspective into the efforts of the private industry towards recycling.

3.2.2 Public transportation companies

Due to the dense population in Hong Kong, public transportation is a major method of travel. Therefore public transportation companies are a significant contributor to the waste tyre problem in Hong Kong. Everyday there are thousands of double-decker buses, mini-buses, taxis, and trucks driving on the streets. The larger tyres on public transportation vehicles consume more space in the landfill than small vehicle tyres. We interviewed the KMB bus company, and various transportation vehicle drivers to gain the private sector's perspective on waste management and their

perception of the problem. Through these interviews we determined their practices for tyre maintenance and methods of disposal or retreading.

3.2.3 Search for possible recycling methods

We performed case studies on different countries and regions through research both online and in print. These countries included the United States, Europe, Japan, and China. By researching business journals online we found methods of recycling proven to be profitable, and other articles online outlined particularly innovative methods of recycling. Additional interviews in Hong Kong substantiated these methods of recycling.

3.3 Identify current and possible future legislation for waste tyre management in Hong Kong

In order to determine whether a possible solution to the tyre waste problem could be implemented in Hong Kong, we needed to identify current laws and possible additional regulations that could be introduced.

3.3.1 Interview professors

It was relatively easy to find the available information regarding waste legislation in Hong Kong, but the information was not specifically on waste tyre management. Professor C.S. Poon of HKPU's Civil and Structural Engineering Department has been researching waste management with respect to civil engineering applications. Other professors in Hong Kong have provided specialized applications of recycled waste tyres. They are experienced with the laws that would affect implementation of new recycling methods in Hong Kong and through interviewing them we were able to obtain valuable information on methods of recycling that they have been researching and the factors that affect the methods of recycling.

3.3.2 Legislation in other countries

Some countries such as Japan have effectively promoted green technologies and recycling technologies, while other countries have a long history of dealing with tyre waste. Through government websites we were able to identify their laws, which affect tyre waste. We studied Japan's legislative system due to similarities with Hong Kong that include a geographically isolated area with a high population and severely limited land. We included the United States due to their experience with the tyre waste, even though the similarities with Hong Kong are few. The European Union, including Britain, has extensive legislation in place governing the disposal and recycling of waste tyres. This system was also studied and contrasted against the other regions and countries.

3.4 Summary

Once the scale of the scrap tyre problem was determined, appropriate management methods were considered, and the legislation and policy that would be required to implement those methods was examined. We reviewed all of the current methods of disposal and recycling of scrap tyres in Hong Kong. We also looked at the methods for scrap tyre disposal and recycling used in different countries. These solutions work within the laws and regulations of the individual countries. In the next section we will discuss the methods that would work within the laws and regulations of Hong Kong.

Chapter 4: Results and Analysis

In this section we will present the results of our data gathering in Hong Kong. Having determined the scale of the problem we were able to single out methods of recycling that were capable of dealing with the volume of tyres, while rejecting measures too expensive to be used with the volume of tyres available. We then analyzed the options applicable to Hong Kong by contrasting possible techniques of waste tyre recycling with legislation both present and applicable in the future.

4.1 Scale of the Waste Tyre Problem in Hong Kong

Through an interview with Mr. Simon Lee (Appendix E) of the Hong Kong Environmental Protection Department (EPD), we determined the scale of the problem with waste tyres in Hong Kong. We found that while waste tyres are a very small percentage of the total waste in Hong Kong, almost nothing is currently done to prevent their accumulation in landfills. The EPD estimates that there are approximately 18,000 tons of waste tyres dumped annually in the landfills, by a 2005 estimate. EPD estimates also put waste tyre accumulation at 50 tons per day. Unfortunately, the only action taken to alleviate the problem with waste tyres is legislation requiring all waste tyres to be split in half before burial in the landfill. The tyres are buried with the rest of the trash, not in a monofill, a separate burial site for waste tyres only, and therefore cannot be collected for recycling at a later date.

Mr. Lee also informed us of a resource that deals with the statistics of motor vehicles. In this source, government records and surveys are detailed, and most notable is a breakdown of the different kinds of motor vehicles. To our surprise, we found cars and taxis make up the largest percentage of all motor vehicles (see Figure 5).

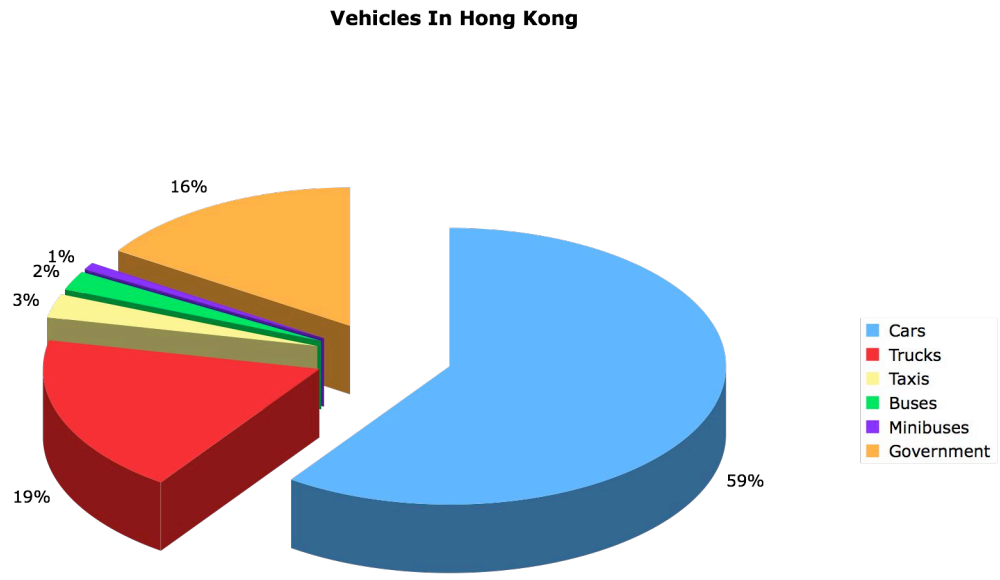


Figure 5 - A breakdown of all registered vehicles in Hong Kong, showing cars to be the most substantial percentage of registered motor vehicles (Hong Kong Transport Department, 2006).

Unfortunately, the government records and surveys say little on which vehicles are the most commonly used. Through interviews with transportation vehicle drivers we determined the use of minibuses, buses, and taxis are immensely greater than that of private vehicles, with some drivers driving for 20 hours a day. Taxi drivers have told us they change their tyres every five or six months (See appendices J through N for interviews with drivers). We also performed direct observation of the road traffic in Hong Kong (See Figure 6) to determine the level of use of these vehicles, to substantiate the government data (See Appendix O). Though this is not a scientifically valid survey due to limitations with time, the data we acquired suggests private cars should not be disregarded.

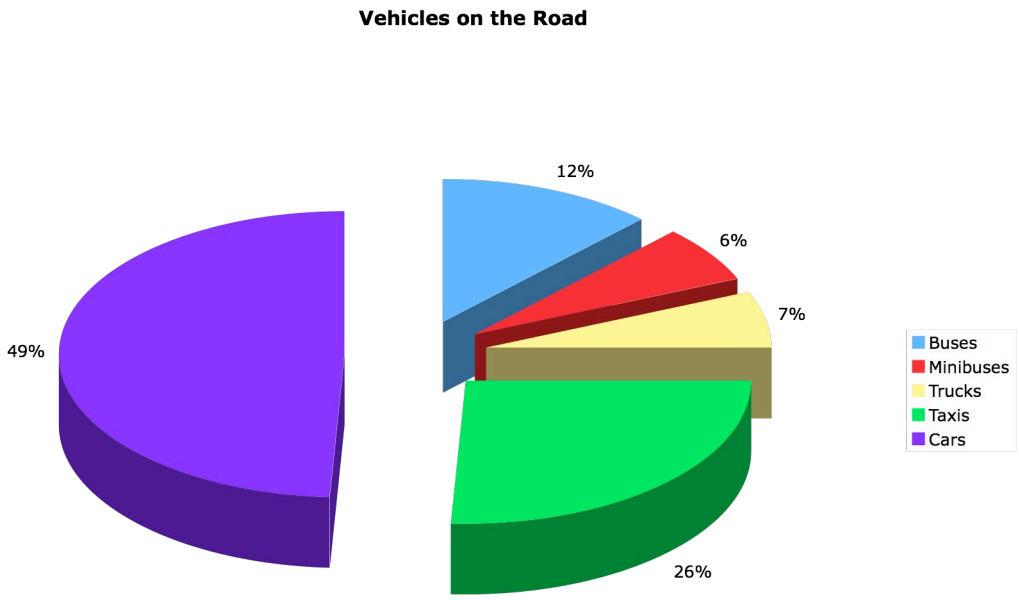


Figure 6 - Use Vehicles observed on major Hong Kong roads (See Appendix O).

As shown in Figure 6, taxis comprise a considerable percentage of observed traffic, meaning the tyre waste from taxis will be considerably more than other vehicles. The vehicles observed on the roads the most is the passenger car, which is surprising due to the extensive public transportation system in Hong Kong. The data suggested that small cars and taxis contribute the most to tyre waste.

Another significant source of waste tyres is trucks, especially small trucks. However, our data was not conclusive so we were not able to determine the exact percentage of waste tyres generated annually by the small trucks. Trucks make up about ten percent of the vehicles in Hong Kong and through interviews we determined that not all of them use retreaded tyres.

Illegal dumping is also a problem due to the fees associated with tyre collection and splitting prior to burial. Mr. Lee informed us that approximately 4,000 tons of tyres are illegally dumped every year. Tyre collection companies will often

dump tyres illegally, being unaware of how severe the fines are if they are caught. One garage we interviewed stated they did not realize how severe the fines were until they read in the papers how one company caught dumping two tyres was fined several thousand Hong Kong dollars. It is apparent that illegally dumped tyres are a significant percentage of the waste tyres produced, and create further problems since municipal workers have to locate and dispose of these tyres. Illegal waste dumps can often be seen in remote areas of Hong Kong, such as by ports or under bridges away from residential areas (See Figure 7).

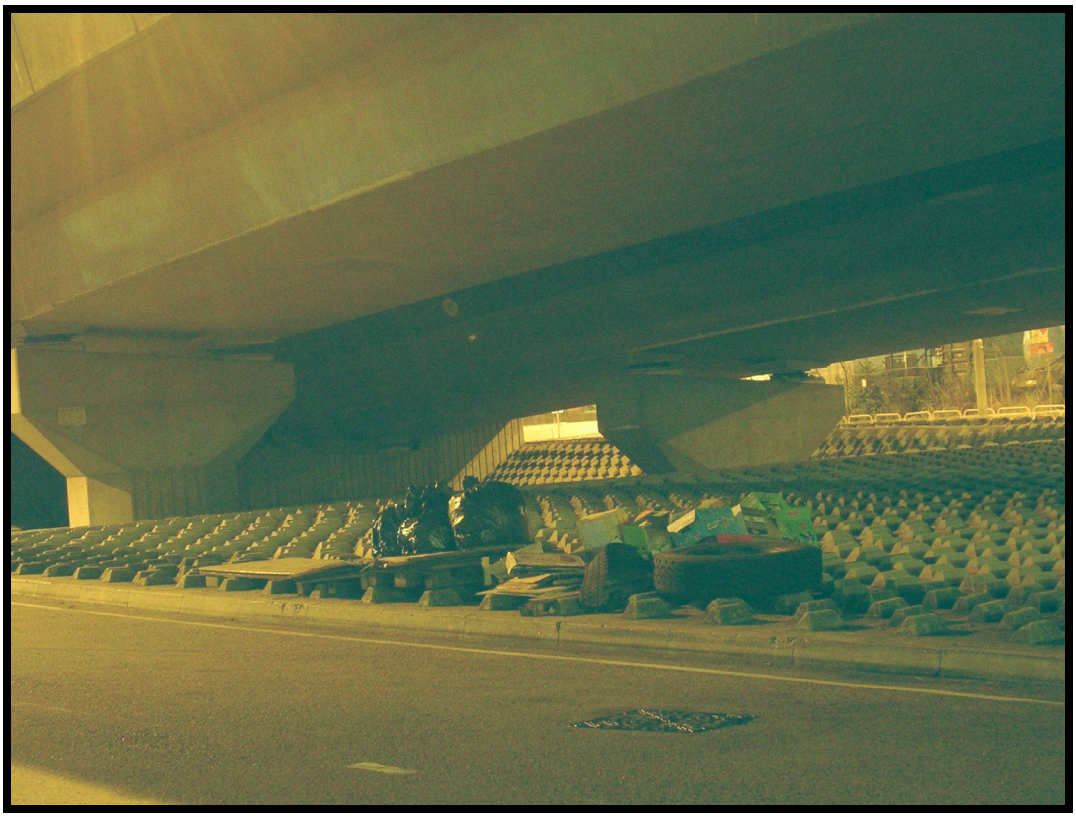


Figure 7 - Waste tyres and other trash seen under a bridge in Sham Shui Po, Hong Kong.

4.2 Recycling Techniques

We have identified numerous techniques for tyre recycling, however not all are feasible in Hong Kong. Recycled rubber mats and stamped rubber products are the only tyre products currently being used commercially in Hong Kong, although Mr. Lee informed us of pilot projects in Hong Kong dealing with artificial reefs and

rubberized asphalt, as well as a pilot project involving pyrolysis (See Appendix E). Due to the stringent emissions regulations any form of disposal involving the combustion of tyre rubber cannot be implemented in Hong Kong.

Recycled Rubber Products

A company based in Hong Kong, Jets Technics, has developed particularly innovative ways to recycle tyres to create useful products. During a tour of Jets Technics, John So informed us that by using custom designed machinery protected by intellectual property rights they can shred tyres economically and produce a variety of shreds (See Appendix H). By combining these shreds with polymers and pressing or heating them they can create products such as factory floor coatings, athletic surfaces, rubber bricks, racing tracks for horses, and tiles for playgrounds (See Figure 8).

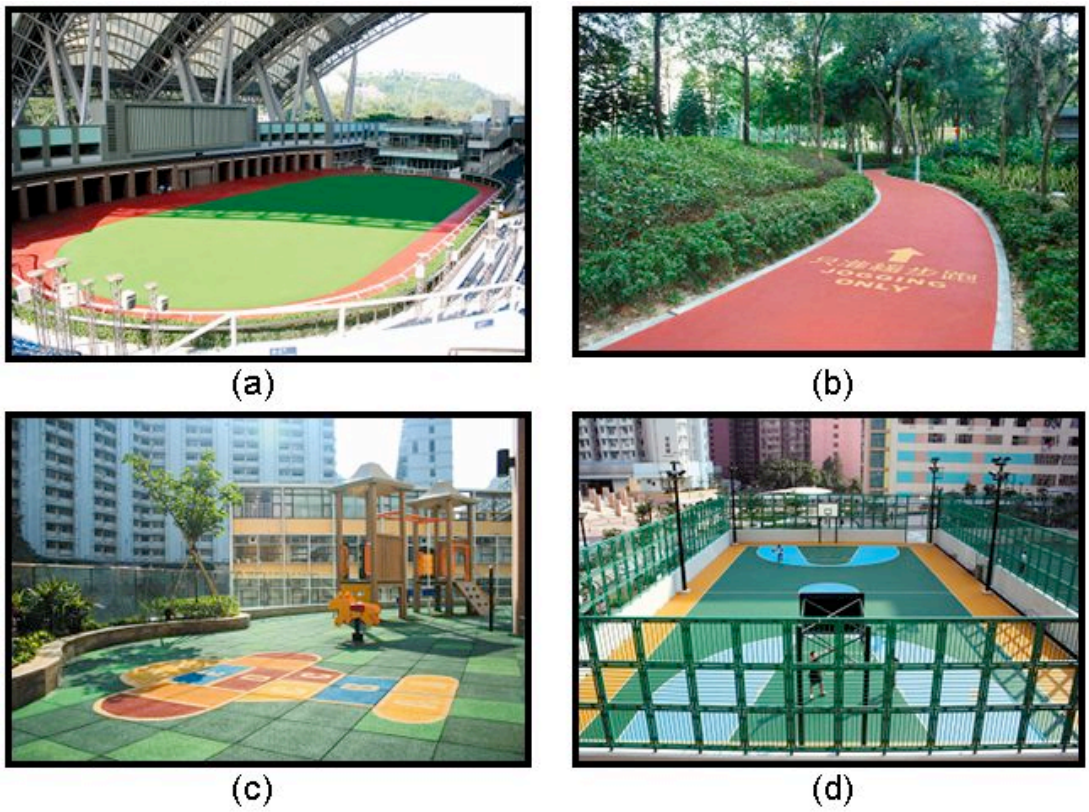


Figure 8 - Examples of Jets Technics products created from recycled tyres. A horse racing track can be seen in (a), a park path in (b), (c) is a playground, commonly seen in Hong Kong, and (d) is an example of an athletic surface. Photos courtesy of John So (Jets Technics).

Jets Technics demonstrates that it is possible for recycling to be a profitable business. The company started with two employees, and now has over 300 working at several plants. In recycling the tyres their motivation went beyond helping the environment but also "to use the cheapest raw material". Currently they are paid by some companies to remove tyres, but they believe others are following their example and project that within ten years they will have to pay for their tyres. Furthermore, they mention difficulty in getting a steady supply of tyres in Hong Kong, with most of the tyres being forced into landfills without being made available to the private sector. Some new rubber products are planned for the future, including highway noise barriers created from tyre rubber.

Tyre Reefs

Hong Kong's Agriculture, Fisheries, and Conservation Department (AFCD) began several artificial reef projects in 1998. Eric Yau answered several of our questions through email correspondence (See Appendix I). He told us that these reefs aim to promote the growth of various organisms, providing a boost to the natural environment and in turn increasing the fish population. The AFCD is testing several materials, including "redundant steel and wooden vessels, pre-fabricated concrete modules, redundant marine concrete structures, biofilters (pre-fabricated fibre-glass sheets of high surface area ratio to volume) and natural quarry rocks". The tyre reefs are built off a steel-based frame and linked together with nylon straps which are inert to ultraviolet light and sea water (See Figure 7).

Figure 9 - A tyre reef unit prior to submersion, showing the nylon straps and base. Photo courtesy of Eric Yau (See Appendix I).

Each tyre reef unit uses a significant number of tyres. The pilot projects have already used 37,500 tyres to date. The artificial reefs are also periodically checked to perform "quantitative underwater fish surveys". The tyre units show significant growth and stability, as can be seen in Figure 8.

Figure 10 - A submerged tyre reef showing considerable growth.

Despite the quality of the tyre reefs, the AFCD studies show that natural quarry rock piles and biofilters make the best reefs. For this reason, the AFCD has no future plans to use tyres in the creation of artificial reefs. Please refer to Appendix I for more information regarding tyre reefs.

Rubberized Asphalt

The Hong Kong Highway Department has expressed interest in using rubberized asphalt and has developed a pilot program to test the viability of the most accepted and tested process of creating rubberized asphalt, the Arizona process, developed by Arizona State University. According to Dr. Wong of the Civil Engineering Department of Hong Kong Polytechnic University, the test phase of this project, currently underway, is to ensure the Arizona process is suitable for Hong Kong despite the extensive testing in the United States (See Appendix G). The Civil Engineering Department of Hong Kong Polytechnic University, the Hong Kong

Environmental Protection Department, the Hong Kong Environment, Transportation, and Works Bureau and others are heavily involved in the project. As of January 2007 the rubberized bitumen is imported from mainland China and processed in existing machinery in Hong Kong. There is a test road built at the future site of the Hong Kong Eco-Park, and this road is also currently being expanded (See Figure 9). Testing will continue for one year, and based on these results the government will decide whether or not to use rubberized asphalt on a larger scale.

Figure 11 - A rubberized asphalt road being constructed at the Hong Kong Eco-Park (also currently under construction).

Pyrolysis

Mr. Lee of the EPD also informed us that Hong Kong has had pilot programs testing the viability of pyrolysis, but these programs have shown pyrolysis not to be

cost effective. Presently, there are no projects involving tyre pyrolysis and there are no future plans to test any methods of tyre pyrolysis (See Appendix E).

Retreading

There are two companies in Hong Kong that retread truck tyres. The bus company, KMB, informed us through email communications that they retread their own bus tyres regularly (See Appendix M). These companies retread the tyres approximately three times before they are no longer useable. The retreaded tyres are half the price of new tyres, however, they do not last as long. They do not make retreaded tyres for small vehicles in Hong Kong, which is likely due to the consumer perception that retreaded tyres are not as safe.

4.3 Model Legislation

The United States, Britain, Australia, and Japan all have legislation regulating the disposal of waste tyres. One of the most effective methods for increasing recycling is to ban the disposal of waste tyres in landfills. Hong Kong currently does not do this, however according to Mr. Lee they do require tyres to be cut in half prior to being dumped into the landfills (See Appendix E). Currently there is no other legislation directly governing the disposal of waste tyres.

Other legislation affects the disposal or recycling of tyre waste. For example, the emissions regulations in Hong Kong effectively ban any burning of waste tyres. Dr. Wong informed us that even the emissions from heating rubberized asphalt mix must also be taken under consideration (See Appendix G). Furthermore, Mr. Lee told us that laws governing the export of waste make shipment to the mainland for processing prohibitively expensive. Currently scrap tyres are viewed as a waste

product in Hong Kong so as such they are subject to all the fees imposed on waste, but the reality is that scrap tyres are in fact a source of raw materials.

The British have implemented a scheme to control waste tyres. They have banned waste tyres from landfills and created monofills for the tyres to be stored in. They also use scrap tyres in a variety of their civil engineering projects and have a highly developed infrastructure for the recycling of scrap tyres.

4.4 Summary

Hong Kong has experience with various recycling methods for scrap tyres through comprehensive trial programs and private companies. Jets Technics is a shining example of how industry can help the environment through recycling and at the same time make a profit. The rubberized asphalt test projects have so far been successful and all indications show the material will be suitable for Hong Kong's environment. This indicates the possibility of wider implementation, which would both improve the highways and reduce tyre waste.

Although the government's tyre reef program was moderately successful, the alternative materials were far more successful and tyres are no longer used. Tyre pyrolysis has been studied and found to be too expensive for implementation in Hong Kong, so no studies on tyre pyrolysis currently exist.

Based on what we have discovered we will now draw conclusions and make suggestions for further research.

Chapter 5: Conclusions

There is no simple solution to Hong Kong's waste tyre problem; therefore several steps are proposed in order to alleviate the waste tyre problem. Through analysis of methods and systems used in other countries and the data gathered in Hong Kong we suggest the following steps be taken to aid Hong Kong in its goal of reducing tyre waste.

1. Maintain vehicles and tyres to extend tyre life.
2. Create monofills for waste tyres and ban tyres from landfills.
3. Levy a tax on new tyres.
4. Use rubberized asphalt.
5. Maximize the use of retreaded tyres.

If the Environment, Transportation, and Works Bureau, were to require more frequent inspections on all passenger cars, not merely cars that are older than six years, then the wear to tyres could be reduced by maintaining wheel alignment. Taxi cars should be inspected at least once a year due to their extensive use. The new inspections would force people to better maintain their vehicles and tyres, prolonging their life. Private vehicles comprise sixty percent of all the vehicles in Hong Kong so despite the fact that private cars are not driven as many miles as trucks and buses, the scrap tyres that they generate annually is not negligible. Many truck and bus companies already use retreaded tyres, so the only way to reduce the number of tyres being dumped into the landfills is through reducing the number of private tyres being dumped.

Creating monofills of tyres is essential to scrap tyre reclamation and recycling. Currently most waste tyres in Hong Kong are mixed in landfills with all other waste;

this prevents the tyres from ever being retrieved and recycled. Creating a monofill makes tyres available for future use.

Once there is an operational monofill then waste tyres should be banned from regular landfills, as was done in Britain. This prevents valuable material from being disposed of where it is inaccessible. This ban will also help to alleviate the burden on the three landfills in Hong Kong. Due to the relatively small volume of waste tyres generated yearly only a small parcel of land would be needed to create a monofill.

Levying a tax or disposal fee onto the cost of new tyres would provide revenue to support recycling. The income from the tax could cover costs such as waste tyre transportation, monofill management, rubberized asphalt and private industry that recycle waste tyres into products. With an increase in the cost of new tyres, retreaded tyres become even more economical.

Using rubberized asphalt in the construction of new roads and highways could provide the largest outlet for waste tyres. For a small increase in price the roadway lasts longer, creates less sound pollution and uses approximately one thousand waste tyres per lane mile.

Retreaded tyres are as safe as new tyres and cost half as much. With the ability to retread heavier tyres three or four times the life of a tyre can be doubled. This reduces the number of tyres requiring disposal. By encouraging retreading Hong Kong can reduce the waste tyre problem and save money. Some truck drivers are still unaware of the savings associated with retreaded tyres, or they are misinformed that retreads are not safe tyres.

The implementation of these steps would be a good start for Hong Kong to create a sustainable tyre waste management system. Although these steps temporarily alleviate the problem, more work still needs to be done. More research needs to be

done on different recycling methods, such as pyrolysis, to see if it would be an option for Hong Kong in the future. With this additional research Hong Kong should be able to continue to address its tyre waste problem.

References

Ahmed, I. (1993). *Use of waste materials in highway construction*. William Andrew Publishing/Noyes. Online version available at: http://www.knovel.com/knovel2/Toc.jsp?BookID=188&VerticalID=0

This book describes the uses of various waste products in highway construction. It touches on tire waste, "crumb rubber", and also on furnace ash product (from burning tires, possibly).

Anthony, W. S. (1999). Turning old tires into new products. *Agricultural Research. 47,* 23.

This article describes a new method for separating crumb rubber from the fiber components in tires. The article also touches on uses of these products, as well as profit margins.

Aoyagi-Usui, Midori, Vinken, Henk, & Kuribayashi, Atsuko (2003). Pro-environmental attitudes and behaviors: an international comparison. *Human Ecology Review*. *10*, 23-31.

This journal article provides an international comparison on environmental behaviors. The countries studied include the Asian countries of Japan, Bangkok, and Manila contrasted against the United States, the Netherlands. The research may not have taken enough countries into consideration, and China isn't included in the study.

AUTh School of Engineering, (1999). Tyre wear: tyre and particle composition. Retrieved February 4, 2007, from AUTh School of Engineering Web Site Web site: http://vergina.eng.auth.gr/mech0/lat/PM10/Tyre%20wear-tyre%20and%20particle%20composition.htm

This website reviews a few journal articles on the chemical and structural composition of tyres. Some of the tables are fairly informative.

Bignozzi, M. (2006). Tyre rubber waste recycling in self-compacting concrete. *Cement and Concrete Research, 36(4), 735-739.*

This journal article studies various mixtures of tire waste and concrete. It compares compressive strengths with known values for different types of concrete.

Blumenthal, M. (1997). Growing markets for scrap tires. *BioCycle. 38*, 53-56.

In this article the tire derived product market for the year of 1996 is analyzed. 1996 was an excellent year for the environmentally friendly use of tire waste

products, and the article discusses the various uses, and then breaks down the categories so the reader can see which use was the most prevalent.

Blumenthal, M. (2002). Scrap tire recycling markets update. *BioCycle. 43*, 58-62.

This article, about four pages in length, talks at length about the various markets for tire derived products. It discusses tires in road construction, tire derived fuel, and other markets.

Brown, C (2002) Best practices in scrap tire and rubber recycling. *Resource Recycling, 16(12), 21.*

This article focuses on recycling technology, comparing different methods of creating crumb rubber and more. It discusses the differences between ambient and cryogenic processing of tires

Chan, Ricky (2001). Determinants of Chinese consumer's green purchase behavior. *Psychology & Marketing*. *18*, 389-413.

This journal article, written by a professor of HKPU, analyzes the purchasing behavior of Hong Kong residents with regards to green products. It provides some insight into the sociopolitical values of Hong Kong Chinese residents.

Clark, C., Meardon, K., & Russell, D. (1993). *Scrap tire technology and markets*. Park Ridge: Noyes Data Corporation. Online version available at: http://www.knovel.com/knovel2/Toc.jsp?BookID=92&VerticalID=0

This book is one of the most useful resources on scrap tires available. Several hundred pages in length it touches on just about any topic, from basic tire technology, to recycling technology, and to markets, laws, and government regulations. A downside is the book is very focused on the US market, not going into the markets/laws in other countries.

Cunliffe, Adrian M., & Williams, Paul T. (1997). Composition of oils derived from the batch pyrolysis of tyres. *Journal of Analytical and Applied Pyrolysis*. *44*, 131-152.

This journal article provides information on the composition of oil from pyrolysis at different temperatures. Includes tables on elemental composition as well as chemical analysis.

Cunliffe, A.M., & Williams, P.T. (1998). Properties of chars and activated carbons derived from the pyrolysis of used tyres. *Environmental Technology*. *19*, 1177-1190.

This journal article discusses research into the properties of the carbon obtained through tyre pyrolysis. The authors treat the carbon and test its use as an activated carbon, and do tests on particle surface area.

Earth Link. (2000). Scrap Tires and Recycling. Retrieved January 14, 2007, from Earth Link Technology Enterprises Web site: http://www.earth-link.com.hk/tire1.htm

This webpage gives an overview of tire recycling which gives no new or interesting information, but goes on to another section talking extensively about rubber soil technologies.

Edil, T. B., Park, J. K., & Kim, J. Y. (2004). Effectiveness of scrap tire chips as sorptive drainage material. *Journal of Environmental Engineering 130,* 824-831.

This journal article tests tire chips as a drainage and absorptive material material through both tank and field tests. It concluded the tire chips can absorb volatile organic compounds and is a good drainage material.

Energy Manager Training, (2004). Energy Manager Training. Retrieved February 8, 2007, from Tyre Web site: http://www.energymanagertraining.com/tyre/tyre.htm

This website provides some information, though not all referenced. The pictures and diagrams provided on tyre manufacturing technology are very valuable. The pictures include a diagram of the factory process along with a cross section of tyres. The discussion also includes an in-depth explanation of "vulcanization", though a knowledge of chemistry would help in understanding.

Environmental Protection Agency, (1999). State tyre legislation and funds. Retrieved January 18, 2007, from State Scrap Tire Programs Web site: http://www.epa.gov/epaoswer/non-hw/muncpl/tires/scrapti.pdf

A 200 page reference from the US EPA on the tire programs for each state. The information is segregated by state then organized into tables. Provides information on legislation, state funding sources, state contact information, and more.

Environmental Protection Agency. (2006). Management of scrap tires. Retrieved Dec 2, 2006 from http://www.epa.gov/epaoswer/non-hw/muncpl/tires/index.htm

This is the central government page on waste tire management. It briefly covers many of the issues around waste tires. With links to many government reports and statistics it is a central location with many of the facts especially concerning government actions and laws.

Environmental Protection Agency, (2007). Management of scrap tires. Retrieved February 11, 2007, from Basic information Web site: http://www.epa.gov/epaoswer/non-hw/muncpl/tires/basic.htm

This website provides an overview of the waste tyre problem in the United States with updated statistics. The site also provides plenty of links for more information.

Environmental Protection Agency, (2007, January). Management of Scrap Tires. Retrieved January 31, 2007, from Pyrolysis Web site: http://www.epa.gov/garbage/tires/science.htm

This website provides some updated statistics on tyre pyrolysis with some additional links.

European tyre and rubber manufacturers' association, (2006a, March 17). End of life tyres. Retrieved February 11, 2007, from European legislation impacting end of life tyres Web site: http://www.etrma.org/public/activitieseoflteuleg.asp

This website provides an overview of the legislation governing used tyres in the European Union. The site provides links to the actual documents if you'd like to read them yourself.

European tyre and rubber manufacturers' association, (2006b, April 18). End of life tyres. Retrieved February 11, 2007, from Retreading Web site: http://www.etrma.org/public/activitieseofltretre.asp

This website provides some statistics on retreading in the European Union, along with some basic information on retreading and EU legislation.

European tyre and rubber manufacturers' association, (2006c, July). End of life tyres. Retrieved February 11, 2007, from Use as an alternative fuel Web site: http://www.etrma.org/public/activitieseofltrecov.asp

This website provides information on how common it is to burn tyres in the EU, and the legislation governing the burning. The site also provides some information regarding the costs of converting a cement kiln.

Farrell, M. (1999a). Building sustainable recycled tire markets. *BioCycle. 40*, 50-53.

This article talks about the value of tire derived fuel, but also discusses regulations and incentives towards tire recycling imposed in various US states.

Farrell, M. (1999b). Funding innovative uses for scrap tires. *BioCycle. 40*, 61-64.

This article gives further examples of the uses of scrap tires in civil engineering. It discusses tracks made from tire rubber, new tires made from old ones (for carts, etc.), as well as now interesting civil engineering projects being undertaken by a few states.

Frederick, James S. 2000. International Labour Association. Retrieved February 8, 2007, from Tyre Manufacturing Web site: http://www.ilo.org/encyclopedia/?doc&nd=857200086&nh=0

This website provides an article on tyre manufacturing. The article was written as an account of a tour, with first hand experience with one particular operation. The page includes some useful diagrams and photos.

Gray, K. (1998). Shredded tire market options. *BioCycle. 39*, 52-54.

This article doesn't give too much new information that isn't given in other articles (such as tire markets in civil engineering projects). It does however talk about the equipment uses to shred tires and how they run into problems shredding

tires, because tires were made to be so resilient. The machines often need to be rebuilt and maintained after about 300,000 tyres.

Gwartney, J., & Lawson, R. (2006). *Economic Freedom of the World: 2006 Annual Report*.Published Online: The Fraser Institute.

This book, published online, provides information on Hong Kong's economy. It provides a useful comparison of free markets on page 13, with Hong Kong listed as the top free economy.

Hong Kong Environmental Protection Department (HKEPD). (2005). Waste. Retrieved December 3, 2006, from Hong Kong's Environment Web site: http://www.epd.gov.hk/epd/english/environmentinhk/waste/waste_maincontent.html

This website, rub by the Environmental Protection Department of Hong Kong, gives an abundance of information on the waste problem in Hong Kong. The sire provides information on incentives, plans, and legislation.

Hylands, K, & Shulman, V. (2003). *Civil engineering applications of tyres*. Berkshire, UK: TRL Limited.

This book is filled with lots of information. It talks about basic tyre technology, recycling technology, civil engineering uses, and more. The diagrams, tables, and pictures are very helpful as well.

Jang, J. (1998). Discarded tire recycling practices in the United States, Japan and Korea. *Resources, Conservation and Recycling, 22(1-2), 1.*

This article compares tire recycling methods in various countries. Discusses some methods of tire recycling, along with the hazards of tire stockpiling.

King County Environmental Purchasing Program. (2006, February). King County. Retrieved January 14, 2007, from Tire-Rubber Material and Products Web site: http://www.metrokc.gov/procure/green/rubber.htm

This website talks about the tire recycling program in King County, Washington State United States. This county has some very innovative uses for tires that other publications have failed to mention, such as the tire beds. The website also talks about tire use in highway construction. At the bottom of the page is contact information and further references.

Keown, Charles (1988).Risk perceptions of Hong Kongese vs Americans. *Risk Analysis*. *9*, 401-405.

This journal article provides a comparison between the risk perceptions of Americans and Hong Kong Chinese. The risk analysis includes such things as nuclear weapons and smoking but also touches on environmental risks such as fertilizers, DDT, and forms of electrical power generation. The article is somewhat antiquated and may not be representative of modern day Hong Kong.

Lai, Julian C., & Tao, Julia (2003). Perception of environmental hazards in Hong Kong Chinese. *Risk Analysis*. *23*, 669-684.

This article studies the risk perception of various demographic groups in Hong Kong. Risks are diverse and include things such as radioactive fallout, tidal waves, and air pollution, amongst others.

Martinsons, Maris G., So, Simon K.K., Tin, Cathy, & Wong, Donna (1997). Hong Kong and China: emerging markets for environmental products and technologies. *Long Range Planning*, *30*, 277-290.

This journal article provides some insight into the green purchasing behavior of Hong Kong residents, and some of the factors leading to this behavior.

Merritt, N. J, Redmond, W.H., & Pearson, M. M. (2005). Government and market mechanisms to provide alternatives to scrap tire disposal. *Journal of Nonprofit & Public Sector Marketing*. *13,* 151-178.

This assesses state imposed fees and incentives towards tire recycling and disposal, as well as general government regulations (determined via abstract – couldn't find full article on the web).

Michelin, Inc. (2004). Michelin(R) Pax(R) System. Retrieved December 3, 2006, from Michelin(R) Web site: http://www.michelinman.com/difference/innovation/paxsystem.html

This website describes Michelin's innovative PAX® Tire system, which is a unique way of improving automobile reliability and tire life.

Michelin, Inc. (2006). Zero Pressure (TM). Retrieved December 3, 2006, from Michelin(R) Web site: http://www.michelinman.com/difference/innovation/zeropressure.html

This website describes Michelin's new tire system which allows relatively safe driving when the tire loses pressure. These tires are also more efficient and longer lasting than normal tires.

Miller, C. (2006). Scrap tires. *Waste Age*, *37(9)*, 72.

This one page article summarizes US statistics on scrap tires for the year of 2003. It cites its sources if further information is desired.

NEA. (2006, May). Singapore National Environment Agency. Retrieved January 14, 2007, from RECYCLING PLANTS IN SINGAPORE Web site: http://www.nea.gov.sg/cms/rcd/Local%20Recycling%20Plants.pdf

This website provides a list of some recycling plants in Singapore. The list provides some basic information on the material being recycled (tires are easy to locate in a column), as well as the method of recycling and contact information for

the plant. The contact information sometimes included other websites and email addresses.

Niemeyer, Shirley, Heiden, Kathleen, Grisso, Bobby, & Woldt, Wayne. (2005). Managing wastes: tires. Retrieved January 30, 2007, from HealthGoods Web site: http://healthgoods.com/Education/Environment_Information/Solid_Waste/managing_wastes_tires.htm

This website provides a very general overview of scrap tires. It cites some sources, which may be the only thing useful for the report.

Pyper, Wendy (2004). A heap of great returns. *ECOS*, *118*, Retrieved January 30, 2007, from http://www.publish.csiro.au/?act=view_file&file_id=EC118p22.pdf

This article discusses an Australian innovator's method for recycling tyres, and his company Molectra. The three stage process of chemical treatment, grinding, and microwave energy is discussed along with how the products are used. The last page also discusses the profitability of the technology by citing some actual numbers. Provided an email for contact.`

Rodriguez, I, Laresgoiti, M, Cabrero, M, Torres, A, Chomon, M, & Caballero, B (2000). Pyrolysis of scrap tyres. *Fuel Processing Technology*, *72*, 9-22.

This journal article provided in depth information about tyre pyrolysis. The article explains how processes in the past for studying tyre pyrolysis were often flawed and problematic, and often the sample put in the reactors weren't representative of the entire tyre. The article performs pyrolysis on a carefully selected piece of tyre and compares the resulting oils, gases, and char at different temperatures of pyrolysis. Very informative article.

Rowe, Mark (2002, May 15). Dumped on. Retrieved February 4, 2007, from Guardian Unlimited Web site: http://www.guardian.co.uk/waste/story/0,12188,747921,00.html

This news article provides more general knowledge on the tyre waste problem in the UK, but also includes some commentary by an expert. This discussion includes burning tyres, and tyre reef projects.

Rubber Manufacture's Association. (1999). State legislation table. Retrieved January 18, 2007, from State Scrap Tire Fees and Point of Collection Web site: https://www.rma.org/publications/scrap_tires/index.cfm?PublicationID=11124

This website was linked to from the US EPA, and provides information on each state's tire collection fees, including the money collected and who collects it.

Rubber Manufacture's Association. (2004, November). State legislation. Retrieved January 18, 2007, from Table of State Legislation of Scrap Tires Web site: https://www.rma.org/publications/scrap_tires/index.cfm?PublicationID=11121

This website was linked to from the US EPA, and provides fairly up to date information on each state's legislation in an easy to read table.

Rubber Pavements Association. (1998, May). Frequently asked questions. Retrieved January 14, 2007, from Main Page Web site: http://www.rubberpavements.org/

This website provides an abundance of information regarding rubber pavement technology in an attempt to promote the technology. The various links include an insightful FAQ, as well as links for further information and contacts.

Steuteville, R. (1995). Puncturing the scrap tire problem. *BioCycle. 36,* 51-53.

This expands on some uses of scrap tires, citing statistics from the early 90s. About one page in length.

Willard, P., & Smith, E. D. (2006). Waste tire recycling: environmental benefits and commercial challenges. *International Journal of Environmental Technology & Management 6*, 362-374.

This article focuses on recycling efforts made by the state of California, as well as projects by the US Army corps of Engineers (determined via abstract as well).

Williams, Paul (1999, November 22). University Of Leeds. Retrieved January 30, 2007, from High Value Products from Scrap Tyres Web site: http://www.leeds.ac.uk/reporter/443/tyres.htm

This website discusses the tyre pyrolysis technologies being developed at the University of Leeds in the UK. The technologies and research lead to some interesting finds, such as the composition of tyre pyrolysis oil contains valuable chemicals such as "limonene".

Williams, P.T., & Brindle, A.J. (2002). Catalytic pyrolysis of tyres: influence of catalyst temperature. *Fuel*. *81*, 2425-2434.

This journal article describes research into the effect of the temperature of a zeolite catalyst on gas composition from tyre pyrolysis. The paper shows what gases are produced as a result of modifying the temperature. By using a catalyst they show a degree of control over the output gas, which has important commercial implications.

Yang, G. (1993). Recycling of discarded tires in Taiwan . *Conservation And Recycling , 9(3), 191-199.*

This looks at the 30 year old tire recycling program in Taiwan, with an emphasis on the 80s. It also discuses the government regulations and recycling methods (only found the abstract for this article).

Appendix A: Hong Kong Polytechnic University (HKPU)

Hong Kong Polytechnic University (HKPU) is a non-profit organization. It is one of the finest universities in Hong Kong, and provides higher education not only to Hong Kong people, but also to people around the world. The HKPU has a motto, "To learn and to apply, for the benefit of mankind" (HKPU, 2006). HKPU believes that one of its missions is to carry out research of an applied nature relevant to community needs.

HKPU consists of a council, court, president and offices of the president, officers and senior management of the University, senate and its academic structure (HKPU, 2006). It has 26 academic departments, including 12,313 full-time and 2,284 part-time students. It is the largest UGC-funded tertiary institution in Hong Kong in terms of number of students.

There are two major sources of income for HKPU. The first one is the tuition collected from students, which is used to provide education for the HKPU students. Another source of income is funding research by Hong Kong government and cooperation (HKPU, 2006). As HKPU believes in their missions, they think they are responsible to help in solving the problems occurring in Hong Kong society.

Wasted automobile tires have been a major issue in Hong Kong for a long time because there are a huge number of cars driving on streets but the amount of available space is limited. This way of disposal of the wasted tires not only use up a lot of free space, but also create a lot of pollution, which damages both the environment and human's health. As one of the finest universities in Hong Kong, which provides high education, HKPU is responsible to help the community to solve this issue.

Through the funding from government and private companies, HKPU is equipped with modern research laboratories (HKPU, 2006). HKPU also has a large database of most research that has been done around the world.

There is no other organization in Hong Kong that works on the problem of waste vehicle tires.

APPENDIX B: Interview Protocol for Tire Recycling Plant Employee

1) How long has JP Routhier & Sons, Inc been in the tire business?
2) What parts of the tire do you manage to recycle?
3) What is the most significant source of your scrap tires?
4) What tire derived product do you make the most of?
5) Who buys your tire derived product?
6) Do you create any tire derived fuel?
    a. If yes, who generally finds a use for this fuel?
7) What are some hazards involved with the recycling process?
8) How do you create tire derived fuel?
9) How do you separate the steel from the tire?
    a. What is done with this steel?
10) What are your products used for?
11) What is the most common use?
12) About how many tires do you deal with on a daily basis

Appendix C: Interview with Bobby Lundin, Tire Recycling Plant Employee of JP Routhier & Sons, Inc.

13) How long has JP Routhier & Sons, Inc been in the tire business?

JP Routhier & Sons, Inc. has been operating this particular plant since 1989.

14) What parts of the tire do you manage to recycle?

This facility manages to create one inch shreds, which are used in that form for either creating crumb rubber, or burned directly. The steel wire in the tire is magnetically separated, but steel companies believe there is too much rubber mixed with this product to create steel, so it sits in piles for the time being.

15) What is the most significant source of your scrap tires?

The tires come in from a variety of places on a daily basis.

16) What tire derived product do you make the most of?

This facility makes one inch chips.

17) Who buys your tire derived product?

Anyone who wants to create crumb rubber from the one inch shreds, and also use the shreds directly for fuel.

18) Do you create any tire derived fuel?

Yes

a. If yes, who generally finds a use for this fuel?

Paper mills generally burn the product for fuel.

19) What are some hazards involved with the recycling process?

The machines that shred the tires are obviously a hazard, and you have to be careful for the steel wire, but otherwise the process is safe.

20) How do you create tire derived fuel?

The one inch shreds can be burned directly as they are, since the metal wire is removed magnetically.

21) How do you separate the steel from the tire?

The two inch shreds are further shredded to one inch shreds. As these are rolled down a conveyor and into a pile a rotating magnetic drum catches the metal wires and puts them into a separate pile.

a. What is done with this steel?

As stated, the metal wire isn't used at the moment. The piles of the steel wire will remain for the most part until a better method of removing the steel from them is created.

22) What are your products used for?

Once further processed into crumb rubber there are a variety of uses. The crumb rubber can create excellent fields for football or soccer, by placing the crumb rubber underneath the turf. The crumb rubber can be used for lots of things requiring rubber. The unprocessed chips can be used in highway development directly.

23) What is the most common use?

This company primarily uses the chips either for fuel or for civil engineering type projects, such as the aforementioned highway developments projects. About how many tires do you deal with on a daily basis?

24) About how many tires do you deal with on a daily basis

The tires come in daily in large volumes. The tires come in a variety of sizes, and while the regular car tires can be placed directly on the treadmills the larger tires have to be cut using hydraulics prior to loading on the conveyor belts. Some tires also come in with unused treads and are resold.

APPENDIX D: Interview with Simon Lee, officer of Environmental Protection Department in Hong Kong

Interview at the Environmental Protection Department
Environmental Infrastructure Division
Waste Reduction Group
Representatives: Simon LEE Environmental Protection Officer

Current Statistics:

Q: How many tyres are in the landfills?
A: Due to the number of landfills and the fact that there is no charge for dumping waste tyres it is difficult to gain an accurate figure. Also they keep track of tyres by weight measuring the amount in metric tons. Through sampling the EPD estimates that in 2003 approximately 15,000 tons. In 2004 approximately 14,000 tons and in 2005 18,000 tons.

Q: How many tyres are stockpiled?
A: The land space in Hong Kong is so limited and there are no fees for dumping so not only is there no space for stockpiling there is no reason to.

Q: How many tons of tyres are disposed of on a daily basis?
A: Fifty tons per day.

Q: How many tyres are exported?
A: No tyres are exported while whole, but there is one company that is trying to export crumb rubber to the mainland.

Q: How many private vehicles are there?
A: Approximately 370,000 cars of which 18,000 are taxis.

Q: How many heavy vehicles are there?
A: Approximately 120,000.

EPD Activities:

Q: What is the EPD currently doing to regulate the disposal of waste tyres?
A: The EPD is not specifically imposing any regulations, however the landfills require that all tyres be cut atleast in half before being dumped and thosewho dump tyres must get a permit. This creates a lot of illegal dumping, approximately 4,000 tons a year, because people do not want to pay to cut tyres in half.

Q: Are there any options that you have explored that were too impractical?
A: Companies have looked into pyrolosis, but found that there is not a large enough supply of tyres for it to be feasible. The EPD however performs studies prior to implementing any regulations that would affect the disposal of waste tyres, so as to avoid costly mistakes.

Q: What are your plans for the future?
A: A producer responsibility scheme is going to be implemented. To gain funds to help supplement the costs of recycling waste tyres. However, we are not in charge of that so we cannot go into great detail about it. There is a report posted on the EPD website at http://www.epd.gov.hk/epd/msw/.

Waste tyre uses:

Q: Is it practical in Hong Kong to create rubbersoil, rubberized concrete, rubber mats, tyre reefs, tyre derived fuel, or pyrolosis?
A: Currently there are 11 projects involving rubbersoil, such as roadwork, slope work, and subbase. However, this technology is still in its infancy so before it can become a widely accepted technology it needs to be proven.

Also rubbersoil is a patented technology so there is no competition. Hong Kong is also conducting studies on rubberized concrete as a possibility for reuse. The company Jets Technics is one of the largest manufacturers of rubber mats in Hong Kong and they are very profitable. Hong Kong also has some pilot programs in using waste tyres for artificial reefs through the Agricultural and Fishery Departement, though these methods at most will consume one years worth of tyres. The PRC scheme may allow for a full scale tyre reed project in Hong Kong in the future. Pyrolysis is very expensive though several companies have looked into it.

Laws and Legislation:

Q: What current laws regulate the disposal of waste tyres?
A: There are no laws that directly regulate the disposal of tyres. Landfills are required to apply for a permit when discarding tyres, and they are required to split the tyres in half for burial.

Q: Is there any planned legislation to regulate tyre disposal?
A: Yes, Hong Kong is looking into tyre collection and disposal fees, amoungst other legislation governing the transportation and export of tyre waste.

Types of Rubber:

Q: What types of scrap rubber are used in Hong Kong?
A: There is a project to export crumb rubber as a resource, and the highway department is open to proposals though they haven't used rubbersoil technologies yet. There is a company that uses tyre rubber to make rubberized asphalt, though it's currently only used in mainland China. This company hasn't been too successful yet but may be expanded to doing work in Hong Kong. Goldbond is the company in Hong Kong that makes rubberized asphalt.

Q: How do you remove the steel from the tyres?
A: The metal bands from the tyres are removed mechanically. The rest of the

metal wires are removed magnetically after shredding and separated into another pile.

Expenses:

Q: How could the government cover the start up costs for recycling techniques?
A: Even if the government subsidizes companies it's difficult because there is not enough waste tyres. The special conditions of Hong Kong must be taken into account. The production of tyres isn't high and the Hong Kong government doesn't like to apply too many regulations. The technology must be sustainable and commercially viable. Playground mats and simple uses of tyre rubber are viable but technologies such as pyrolysis take up too many resources. As such, small applications of tyre waste is the main plan of action for the PRS.

APPENDIX E: Phone interview with Lau Tit Chu, Owner of Man Lee Hang Tyre & Battery Company

1) What is your name?
   Lau Tit Chu. I am the owner of Man Lee Hang Tyre & Battery Co. Ltd.
2) How long has your company been in the business of collection tyres?
   We have been in the business of collecting tyres for 29 years.
3) How many tyres do you collect on a daily and yearly basis?
   We average about 100 tyres on a daily basis and so about 36,500 on a yearly basis.
4) What kinds of tyres are collected?
   We collected all kinds of tyres.
5) What percentage of vehicle tyres or bus tyres is collected?
   It is about 40% small size tyres, 30% middle size tyres and 30% large size tyres.
6) Do you ever collect a fee for the disposal of tyres?
   Yes. We charge $3 for small size tyre, $8 for middle size and $15 for large one. The fee also depends on the distance we need to go to collect the tyre, the weight of the tyre and how dirty it is.
7) After the tyre is collected, what is done with it?
   After we collect the tyres, we cut them into halves. We then will send them to the landfill directly by truck, but we need to fill out a form for the EPD before we send them. We need to apply for a license to collect the tyres every season.
8) Do you have any plans for change in the future either with collection fees or more environmental procedures?
   Recently we do not have any plans because we are short of laborers.
9) Where do the tyres come from?
   Sometimes people come to our company with their tyres directly, and sometimes people will call us to ask about the fees. If they agree with the price, we will go to their place and collect the tyres.

Appendix F: Interview with Dr. Wing Gun Wong, Civil Engineering Professor from Hong Kong Polytechnic University

The EPD is currently building their first test road with rubberized asphalt. Eco-Park is the chosen location as it already is to be a new center of recycling in Hong Kong. The EPD is using a method called Arizona concrete after professors from state universities.

HKPU began researching rubberized asphalt 3 years ago. Professor Wong and others visited Arizona to review this technology. Wong was hesitant at first but then he was shown two roads, one rubberized asphalt and the other standard asphalt both under similar conditions. After ten years of wear and tear the rubberized asphalt still looked new while the "other is cracked all over the surface." When tested by Arizona the concrete actually outperformed expectations.

Professor Wong began researching this technology and its applications in Hong Kong. Although the Arizona mixture works, Hong Kong has its own design criteria and requires a different mixture for maximum performance. Approximately one and a half years ago a privately financed road was constructed using a rubberized asphalt mixture that was more refined for Hong Kong. Wong has submitted many papers to the Highway and Environmental Protection Departments to try and get rubberized asphalt roads to be constructed.

There is a company in mainland China that recently completed a mixing plant and will use a copy of the Arizona process, which has already been thoroughly tested. The differences between standard and Arizona processes are very few. The mixture must be kept 10 degrees Celsius hotter, a separate tank must be installed and mixing blades must be strengthened. The tank is to hold the rubberized cement before it is

mixed into batches of concrete. The increase in temperature and the strengthened blades are to cope with the thicker viscosity or higher resistance.

The EPD has already looked into the environmental releases and determined they are within acceptable levels. The increased costs are “very minimal” compared to standard materials. Once a market and an industry are established the cost is very low. Rubberized asphalt also lasts longer, which offsets the initial cost. 20 million Hong Kong Dollars, over 150 million USD is the approximate startup cost for plant to turn tyres into crumb and refined rubber

Rubberized asphalt can be mixed for up to one day to increase strength and reduce on site compaction. It can also be made and poured on site without any mixing. Costs in Hong Kong are still high, especially compared to China or the USA where there is a large market, industry and already has rubber asphalt mixing plants started.

Rubberized asphalt is used in the top 2-4 inches of the road. It replaces conventional binding materials in bitumates. Costs too much for entire concrete of road, but still receives advantageous affects for being laid on the top. Scrap tyres perform better than rubber that was created for use in asphalt.

In Eco-Park the Highway and Environmental Departments will be testing the road with non-destructive equipment. The road will be reviewed directly after be created and every four months afterwards. EPD is now in a hurry to use rubberized asphalt and is testing the Arizona mix in Hong Kong. “EPD is in a rush”-the Arizona concrete “may not be applicable”-the Arizona mix “may not be the best mix” for Hong Kong’s design criteria. While the EPD is rushing forward, the Highway Department is responsible and is requiring more testing before implementation.

Highway Department “must make everything certain”, need market, test data, and real road data before using in Hong Kong

Since the British left the people have more freedoms which results in more complaints. The noise around Hong Kong tends to be just above the acceptable level and noise pollution is becoming more and more of an issue. Rubberized asphalt has a significant effect on sound created between tire and road. Rubberized asphalt lowers the sound produced by 3-5 decibels, which lowers the noise created to below acceptable levels.

The future plan for rubberized asphalt will share costs between the Highway and Environmental Departments. Phase 1 will use the Arizona mix and will be tested to provide data for Hong Kong. It will start just after the New Year and last for one year. Phase 2 will possibly use a mixture designed for Hong Kong.

Investors just recently built a large rubberized concrete mixing plant in Hong Kong, which will lower the costs for future projects.

Mainland China has very high standards for construction projects. Although they are maintained for national or high level projects the local authorities don’t follow code because of high costs.

Appendix G: Tyre pyrolysis: gas, oil, and char composition

Pyrolysis gas compositions (vol.%) and GCV

Pyrolysis Temperature	**400 ºC**	**500 ºC**	**600 ºC**	**700 ºC**
Methane	4.4	19.8	20.0	20.0
Ethene	4.3	9.4	9.7	8.9
Ethane	4.5	9.1	9.0	8.1
Propene	4.1	6.4	6.5	4.5
Propane	4.4	4.4	4.1	3.2
Butene	30.8	17.5	17.9	16.0
Butane	6.1	3.8	4.0	3.8
Pentene	3.7	2.8	3.6	2.1
Pentane	12.8	4.8	3.8	4.6
Hexene	2.2	1.1	0.9	0.9
Hexane	5.1	1.7	1.6	1.6
CO	4.2	4.8	6.5	10.4
CO_2	10.7	9.4	8.8	11.4
SH_2	2.6	5.1	3.6	3.9

source: Rodriguez, I, Laresgoiti, M, Cabrero, M, Torres, A, Chomon, M, & Caballero, B (2000). Pyrolysis of scrap tyres. 72, page 18.

Concentration of light aromatic hydrocarbons in tyre derived pyrolysis oils (ppm)

Volatile hydrocarbon	Tyre pryolysis temperature (°C)					
	450	475	500	525	560	600
Benzene	<5	55	770	2950	70	605
Toluene	2250	3200	6095	17 740	7770	5070
Ethylbenzene	250	235	120	405	370	190
1,2-Dimethylbenzene	2780	3190	3345	5710	5875	3530
1,4-Dimethylbenzene	2750	2665	3620	6880	8350	3120
Styrene	1205	1705	1950	3545	3635	1915
1,3-Dimethylbenzene	920	1020	1325	2450	2570	1040
Trimethylbenzene	840	825	1255	1085	1285	820
Trimethylbenzene	1050	1265	1670	1240	1530	1200
Trimethylbenzene	1550	1350	2370	2320	3210	1450
Methylstyrene	730	570	1090	1145	1590	715
Trimethylbenzene	1075	1070	1325	1295	1395	1095
4-Methylstyrene	730	570	1090	1145	1590	715
Trimethylbenzene	370	440	490	675	320	330
Methylstyrene	6020	6025	7630	8865	9030	6950
Limonene	31 320	30 330	29 010	28 965	24 590	25 130
Indene	2190	2630	3175	3090	3105	1560

source: Cunliffe, Adrian M., & Williams, Paul T. (1997). Composition of oils derived from the batch pyrolysis of tyres. Journal of Analytical and Applied Pyrolysis. 44, page 146.

Properties of tyre derived pyrolysis chars

	Temperature of Pyrolysis (°C)					
	450	475	500	525	560	600
Proximate analysis						
(Wt% as received)						
Moisture content	0.5	0.4	0.4	0.4	0.3	0.4
Volatiles	3.0	2.7	2.8	2.8	2.6	2.3
Ash content	11.7	11.6	11.9	12.4	12.3	12.1
Ultimate analysis						
(Wt% dry ash-free)						
Carbon	93.3	94.8	90.6	95.0	94.6	95.9
Hydrogen	1.1	0.9	0.9	1.1	0.8	0.8
Nitrogen	0.7	0.7	0.7	0.9	0.9	1.1
Gross CV (MJ kg^{-1})	30.5	30.7	30.5	30.0	30.6	30.2
Sulphur content (wt%)	2.4	2.6	2.3	2.6	2.4	2.3
Toluene discoloration	93.9	98.2	99.6	99.9	100.0	100.0
(% transmission)						

source: Cunliffe, A.M., & Williams, P.T. (1998). Properties of chars and activated carbons derived from the pyrolysis of used tyres. Environmental Technology. 19, page 1181.

Appendix H: Interview with Jets Technics on Monday, February 5, 2007

Representatives: So Tat Wing, Chairman
John So, Director Assistant
Winnie Chan, Director Assistant

Q. How long has Jets Technics been recycling tyres in Hong Kong?
A. The business was started approximately twenty years ago by Mr. So Tat Wing, and they originally produced playground safety mats.

Q. How many waste tyres per year can you recycle?
A. We cannot give you a definite answer.

Q. What range of products can you manufacture here at this facility?
A. They have two facilities. One simply grinds down rubber tyres. The other can make a range of rubber products, as well as plastic products.

Q. Who do you manufacture your products for? The government or private industry?
A. They manufacture for both, but primarily work on government projects as they started the company manufacturing for the government, such as parks.

Q. How many people do you currently employ?
A. Between the office and two manufacturing plants they employ approximately 300 people.

Q. Where do the waste tyres that you use come from?
A. They try and get waste tyres from wherever they can. They collect tyres from the bus companies as well as other sources, and we even saw a conveyor belt that they were recycling. They also recycle their own products.

Q. How do the tyres come to you, whole, shredded, crumb?
A. The tyres come whole and from their they create shreds and crumbs as per their needs.

Q. Do you pay to receive the tyres?
A. Currently they do not pay to receive the tyres, in fact some companies even pay Jets Technics to collect tyres, but they predict that within the next ten years they will have to pay for tyres, because of the increase in demand.

Q. Are the tyres that you use primarily small tyres or larger heavy vehicle tyres?
A. They use all sorts of tyres ranging in size from small go-kart tyres to large truck tyres.

Q. How do you plan to expand your operations here in Hong Kong?

A. They are looking into new products, such as rubber noise barriers and other products, also they are working on marketing their products in other countries, such as China Japan and Europe.

Q. Is there any competition for recycled waste tyre products in Hong Kong or elsewhere?

A. There are other companies that manufacture rubber products around the world, but Jets Technics feels that they bring the best quality at the best price.

Q. Have you looked into rubber railroad mats for cars to drive on?

A. They know the markets for scrap tyres. At the moment they are sticking with their products because they would have to do a lot of R&D in order to consider such a product.

Q. Have you looked into other rubber products such as rubbersoil?

A. This question was not asked, as it was not pertinent.

Q. Are there currently any laws that limit or help your operations?

A. No, and they like it that way. They would prefer competition so that the industry can grow. They would like for the government to have as few regulations as possible.

Q. Is there anything done in other countries such as in Europe that you want to adopt?

A. This question was already answered.

Q. Do you receive any government subsidies?

A. No, they do not receive subsidies nor do they want them. They feel that if the government is going to help one company then they must help all the companies.

We began at their main office, where we were given a brief introduction to their company and some of our questions were answered. They informed us that it was very difficult at first, because the people of Hong Kong were not familiar with their product or anything similar. One of their biggest contracts to date is the stable for the Beijing Olympics. They also make a product called JRex, which is a product made from recycled plastic and wood chips. Polymer safety mats come in 3 thicknesses 45, 75, and 110 millimeters. The bottom layer is scrap tyre pieces and the top layer is a polymer. The polymer is a selling point as it can come in a range of colors.

They enjoy being able to rent land at a discounted rate as land in Hong Kong is extremely expensive. They also believe that banning waste tyres from landfills could help their business as well as the industry and market grow.

A lot of power is required to shred tyres and the maintenance costs are high. To overcome energy and maintenance problems they need to specially design machines by themselves. At first they didn't have enough power, but through R&D they were able to come up with an efficient way to shred tyres. This is a patented technology. There is a lot of R&D of before they can get it to the market, but the market is needed first. Eco-purchasing. It's not necessary to label with Green product, because the product is very good. Customers are not standard consumers, so they don't care that the product is Eco, more focused on if it can perform as well as the conventional materials.

The technology requires many components, which were developed in house and they set very high standards. They don't produce any reports, because the R&D team is constantly improving their technology. The timber is broken into just one type of shape in order to perform properly in the plastic wood, long thin strips about one inch long. There are huge nails in the pallets that they use to make JRex, so they have a specialized machine to remove the nails. He is able to improve the lifespan of his machines by removing all contaminates first. The Minister of the Environment came to ask the cost of a factory, but a factory cannot be started with just money it requires experience.

Appendix I: Interview with Hong Kong's Agriculture, Fisheries, and Conservation Department on Hong Kong's Tyre Reef Project

Representative: Eric Yau AFCD Employee

Q. When was the tyre reef project started?
A. The tyre reef projects was started in 1998.

Q. What other materials are used besides tyres?
A. Other materials include redundant steel and wooden vessels, pre-fabricated concrete modules, redundant marine concrete structures, biofilters (pre-fabricated fibre-glass sheets of high surface area ratio to volume) and natural quarry rocks.

Q. What have been the results of the project so far?
A. The project shows that our ARs are effective in enhancing marine resources in terms of fish and invertebrate communities.

Q. If other materials are used, what materials seem to be the most effective? In comparison to the tyres?
A. Biofilters and natural quarry rock piles.

Q. How many tyres are used in the tyre reefs?
A. A total of 37,500 has been used in the making of 400 tyre reef blocks.

Q. How are the tyres bound, and in what geometry?
A. The tyres are bound together on a steel-based frame with nylon straps and buckles which are inert to sea water and UV lights. The completed tyre block will form a pyramidal shape (similar to a Toblerone chocolate bar).

Q. How do you check the performance of the reefs?
A. We check the ARs by conducting quantitative underwater fish surveys as well as qualitative surveys of the reefs.

Q. What are your future plans involving the use of tyre reefs?
A. As tyre reefs do not show to the best AR materials (in Hong Kong context), we have no future plans involving the use them.

Appendix J: Interview with Lik Hang Tyre & Battery Company

Q. What do you do with waste tyres that you remove from vehicles?
A. We send the tyres to a refuse collection point in Sham Shui Po.

Q. Do you need to pay to send the waste tyres to the collection point?
A. No. It is free.

Q. What kind of vehicles do you sell tyres for?
A. We sell tyres only for small vehicles, such as taxies and private cars.

Q. What brands of tyres do you sell?
A. We sell only name brands, such as Michelin, Bridgestone and Yokohama.

Q. Do you offer retreaded tyres?
A. No. There are no companies in Hong Kong that produce retreaded tyres for small vehicles.

Q. On average how many tyres do you sell per month?
A. We sell about 200 tyres per month.

Q. Hong long do tyres usually last?
A. Usually on taxies the front tyres will wear out in about six months and private cars the tyres will last about two or three years.

Q. Do you charge customers for disposing of their tyres?
A. No.

Appendix K: Interview with Wah Kee Tyre & Battery Company

Q. What kind of vehicles do you sell tyres for?
A. We sell tyres for both trucks and small vehicles.

Q. Do you offer retreaded tyres?
A. Yes. We offer both new and retreaded tyres for trucks, but only new tyres for small vehicles.

Q. What is the difference in price new tyres and retreaded tyres different?
A. New tyres are about twice the price of retreaded tyres.

Q. Where do you get the retreaded tyres?
A. We get them from Wah On Tyres Retreading Company. We can either send them the old tyre to be retreaded or buy the retreaded tyres directly.

Q. What do you do with your waste tyres?
A. We send them to either be retreaded or to the refuse collection point in Sham Shui Po.

Appendix L: Interviews with Minibus Drivers in Kowloon Tong and Diamond Hill

Q. Do you own this minibus or does a company own it?
A. The bus is owned by a company. (There are many minibus companies in Hong Kong)

Q. How far do you travel daily?
A. We do not keep track but the bus runs 18 hours a day, at a max speed of 50 km/hr. (480 kilometers a day counting for stoppage time and assuming speed of 30 km/hr)

Q. Do you check your air pressure regularly?
A. Yes daily.

Q. Do you use retreaded tyres?
A. In Diamond Hill they used retreaded tyres in the back.
In Kowloon Tong they used all retreaded tyres.

Q. How often do you have to change your tyres?
A. Diamond Hill: every 3 to 4 months for retreads and 4 to 5 for new tyres.
Kowloon Tong: every 1 to 2 months

Q. Where do you get your tyres changed?
A. A garage, but not a specific garage.

Appendix M: Kowloon Motor Bus Company

九龍巴士（一九三三）有限公司
九巴服務 日日進步 THE KOWLOON MOTOR BUS CO. (1933) LTD.

Our Ref: CSE/ENQ-inf/242/2007

15 February 2007

Ms Li

Email: jiali@wpi.edu

Dear Ms Li

Information on KMB

Thank you for your recent facsimile regarding your interest in tyre retreading at KMB.

Our company runs a tyre retreading workshop, which retreads some 33,000 used tyres every year. Between 50 to 60 per cent of bus tyres that are in use on more than 4,000 KMB buses every day are retreaded tyres. As each tyre can generally be retreaded several times, the life of a tyre can be extended by up to two years through retreading. As part of our routine maintenance procedures, the air pressure of tyres, which are filled with regular air, is checked regularly.

Also, you may wish to visit our homepage ***www.kmb.hk*** to view our publication, 'KMB's Effort in Environmental Protection', which covers key facets of our environmental policy.

Thank you for your attention.

Yours sincerely

Andrew Ho
Senior Manager, Customer Service
Customer Service Department

香港九龍荔枝角寶輪街九號
9 Po Lun Street, Lai Chi Kok, Kowloon, Hong Kong.
Tel: (852)2786 8888 Fax: (852)2745 0300
Website: www.kmb.hk

Appendix N: Interview with Que Fung Automobile Store

Q. How many tyres do you change everyday?
A. It is about 24 to 25.

Q. Do you offer retreaded tyres?
A. We offer retreaded tyres for trucks only.

Q. Where do you get your retreads from?
A. We call the retreading company and they come to pick up the tyres. After they are retreaded, they return them to us.

Q. What do you do with your waste tyres that can no longer be retreaded?
A. Sometimes we send to the waste tyre collection place directly, and sometimes we call the used tyres disposal company and they come to pick them up.

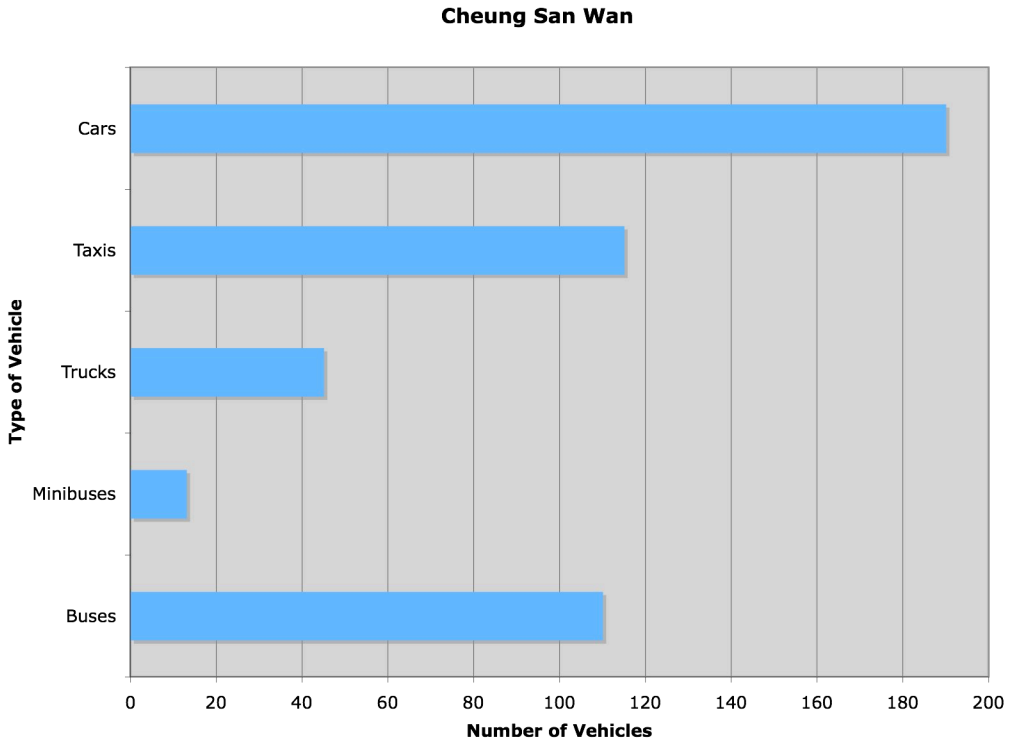
Q. Do you need to pay them for picking up the waste tyres?
A. Yes.

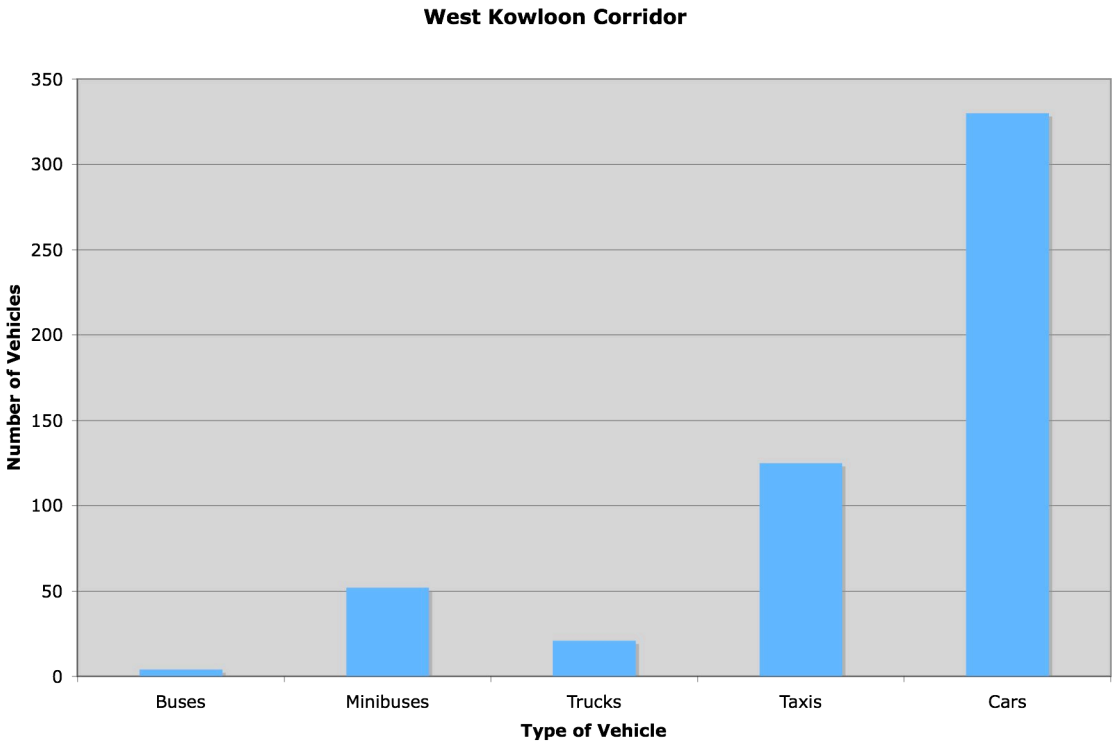
Q. How much do you need to pay for a tyre?
A. Usually, it is about $1 to $2 for a tyre. We need to pay more if the tyre is really old and dirty.

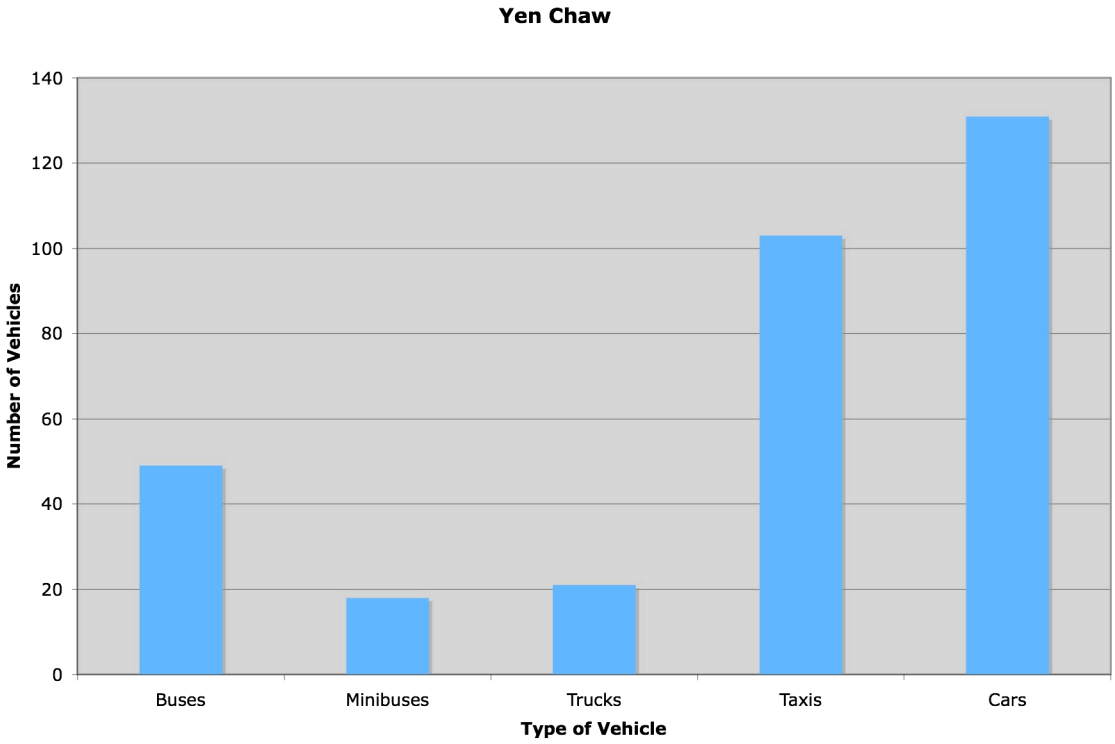
Q. Have you ever heard of any illegal dumping in Hong Kong?
A. Yes. More than ten years ago, someone dumped two tyres on the street and got fined a couple thousand dollars. We wouldn't consider dumping the tyres due to these prohibitive fines.

Appendix O: Observation of Traffic in Sham Shui Po

On different days of the week we observed traffic patterns on three different streets in the Sham Shui Po area. We counted individual vehicles for thirty minutes, and excluded motorcycles and government vehicles. Below are charts of our findings.







While this data cannot be viewed as representative of all of Hong Kong it suggests that cars are probably a substantial contributor to the number of waste tyres in Hong Kong.