Developing a Sustainable Waste Tire Management Strategy for Thailand

Sponsored by the National Science and Technology Development Agency

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Kailyn Connor
Steven Cortesa
Shakhizada Issagaliyeva
Adam Meunier

Orachitr Bijaisoradat
Nachnicha Kongkatigumjorn
Kunathon Wattanavit

Professor Seth Tuler, Co-Advisor
Professor Stanley Selkow, Co-Advisor
Professor Supawan Tantayanon, Co-Advisor

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Submitted by:

Kailyn Connor
Steven Cortesa
Shakhizada Issagaliyeva
Adam Meunier

Submitted to:

Ms. Jiratchaya Duangburong

Co-Authors:

Orachitr Bijaisoradat
Nachnicha Kongkatigumjorn
Kunathon Wattanavit

Project Advisors:

Professor Seth Tuler,
Professor Stanley Selkow
Professor Supawan Tantayanon

Abstract

Thailand's National Science and Technology Development Agency is seeking to develop a successful program to manage approximately 600,000 tonnes of waste tires generated annually in Thailand. This project investigated Thailand-specific issues and options for a viable long-term waste tire management strategy. We evaluated current practices, potential technologies, and successful systems from foreign nations to draw conclusions and make recommendations regarding which technologies are most applicable to Thailand. We made additional recommendations concerning which aspects of a waste tire management system needed to be newly implemented or continued to be used and improved.

Acknowledgments

Our team would like to recognize and thank all of those individuals that have helped us over the past four months on this project. Our project would not have been as successful without their contributions.

First we would like to thank our sponsor the National Science and Technology Development Agency and Ms. Jiratchaya Duangburong for their guidance, input and support on our project. Ms. Jiratchaya was a valuable asset to our team and was essential in helping to arrange and complete our site visits and interviews. We also would like to thank her for taking our team to NSTDA headquarters and giving us an inside look into our sponsoring organization and their missions and goals.

Additionally, we would like to thank those individuals that allowed us to interview them and get a first-hand look at the various waste tire management facilities and their operations. This was a vital part of our research process and we greatly appreciate the insight they were able to provide us.

Finally, we would like to thank our advisors Seth Tuler and Stanley Selkow from Worcester Polytechnic Institute, and our advisor Supawan Tantayanon from Chulalongkorn University. Their feedback on all aspects of our project was very valuable and helped to shape our project. We greatly appreciate their hours spent reading and editing our report. Our project would not be what it is without them.

Executive Summary

Approximately 600,000 tonnes of waste tires are generated annually in Thailand. If improperly disposed of, these waste tires have the potential to harm local environments and negatively affect human health. The most common problems associated with waste tires are open air fires and the creation of mosquito and pest habitats. Tire fires release carcinogens into the atmosphere, threatening public health. They are also are difficult to extinguish. Tire piles create an ideal breeding ground for rodents and mosquitoes, known carriers of illnesses like encephalitis and dengue fever, particularly in tropical climates. To combat the waste tire problem in Thailand, this project's sponsor, Thailand's **National Science and Technology Development Agency** is seeking information for the purpose of recommending successful programs to regulate and manage these waste tires. The **goal** of this project, therefore, was to investigate different options for a viable long-term waste tire management strategy for Thailand.

To accomplish this goal we completed the following **objectives:**

1) Characterize the waste tire problem, existing practices, and potential management strategies specific to Thailand.
- We first focused on obtaining and characterizing Thailand-specific data about problems with waste tires, currently used waste management systems, and potential management strategies.

2) Evaluate waste tire processing technologies based on economic, social, environmental, political, and infrastructural factors applicable to Thailand.
- Using available data, we were able to analyze and evaluate the benefits and disadvantages of commonly used technologies in a feasibility matrix based on economic, social, environmental, political, and infrastructural factors applicable to Thailand. These methods and technologies include landfilling, open dumping and open burning, retreading, reclamation, small-scale application, incineration for energy, and pyrolysis.

3) Evaluate potential waste tire management systems for Thailand based on United Nations Environment Programme guidelines.
- We then evaluated the potential of various waste tire management systems based on guidelines supplied by the United Nations Environment Programme, which highlight the necessary components of a successful waste management program. This involved conducting case study comparisons between Thailand, the United States, and Japan.

4) Develop recommendations for future systems, technologies, and further research.
- Based on our findings, we were able to develop recommendations that will assist the NSTDA in determining which methods for waste tire management should continue to be used and improved, which new methods should be developed and implemented, what information still needs to be gathered, and how to proceed with the collection of that information.

In order to complete our four primary objectives we used a number of different methods. They included conducting interviews with experts on related topics as well as interviews and site visits at several waste tire management facilities in Thailand. Additionally, we created a feasibility matrix in order to analyze and evaluate waste tire processing technologies and used case study comparisons to draw conclusions about Thailand's current waste tire management system when compared to the systems in place in the United States and Japan.

The first step of our project involved identifying the problems that waste tires are creating in Thailand. A number of serious health and environmental concerns are associated with waste tire deposits. Waste tire piles can provide habitats for pests that inhabit the concavities within tires. The rodents and insects that breed within these piles have the potential to spread disease, particularly when waste tire piles are located near urban areas. These pests are known carriers of dangerous illnesses like encephalitis and dengue fever, which tend to be more prolific in nations like Thailand with tropical climates. In addition to this pest problem, large collections of tires can be serious fire hazards. Tire fires spread quickly, emit large amounts of heat, and are difficult to contain or extinguish. Additionally, if openly burned, tires emit large quantities of dangerous chemicals. Open air tire fires release carbon monoxide and carcinogens like benzene, polluting the air with toxic smoke and contaminating the local environment as the ash settles.

Landfilling, the simplest form of waste tire management, reduces these environmental and health issues, but adds others. Though properly landfilled tires will not ignite or provide breeding grounds for rodents, a correctly constructed landfill costs a significant amount of money to build, and additional routine management expenses can become quite costly as well. This "solution" to the waste tire problem is now often considered another form of mismanagement, since tires need special attention in landfills due to their resistance to decomposition and compaction. Additionally, landfilling does not make use of these waste tires as a resource, instead treating them as a waste product.

Disposal of waste tires through open dumping, open burning, or landfilling is a common practice in Thailand, and this management method currently accounts for approximately 63% of all waste tires. However, there are many alternative forms of waste tire management that make use of waste tires in a more economically and environmentally manner. Each of the following methods has its own advantages and disadvantages, which are described extensively in the full length report.

Reusing waste tires for their originally intended purpose is an economical and environmentally conscious option. However, this process can only be applied to waste tires categorized as “repairable waste tires” rather than “scrap tires”.

- **Retreading** repairable waste tires is a highly economical option for waste tire management. Retreading is a safe, efficient process that involves removing the exterior treads on a tire and replacing them with new treads using heat and pressure. This process is similar to the process used in the creation of a new tire, except that it uses only 30-50% of the material that is required for a new tire. Extensive testing has proven that retreaded tires are as safe as new tires when properly inspected and retreaded. This solution can be used repeatedly on a waste tire, continually returning it to the start of the waste tire stream as a “new” tire. Eventually, the tire’s structure breaks down and it can no longer be retreaded. However, there are a number of treatment options for a scrap tire that make use of this waste product as a resource.

Tire-derived aggregate, reclamation, and small-scale projects are viable options that reuse scrap tires in a new application:

- The process of grinding tires into **tire-derived aggregate** is a relatively simple process that can be accomplished using a number of different methods including water jet grinding, cryogenic grinding, and ambient temperature grinding, which produce slightly different variations of crumb rubber. Tire-derived aggregate, or TDA, has a number of applications, including mulch for agricultural purposes, playground mulch, artificial turf filler on athletic fields, backfill in civil engineering process, and as an additive in rubberized asphalt. TDA is especially useful for these applications due to its low cost, availability, durability, light weight, and drainage ability. Recent studies have been conducted that classify tire-derived aggregate as a safe material for these applications, since chemicals leach out of tires at such a low rate.

- **Reclamation** of rubber from tires is another application that uses crumb rubber. This process involves further grinding down rubber into a fine powder and mixing this powder with chemical additives in a process known as “devulcanization”, which breaks down sulfur bonds in the rubber. The reclaimed rubber produced through this process can be reused independently to produce rubber mats, rubber sheets, and rubber tubing. It can also be used as an additive to new rubber products, primarily new tires. This process is economically and environmentally viable, and a reasonably large and successful rubber reclamation industry already exists in Thailand.

- **Small-scale projects** are another productive reuse for scrap tires. This classification includes applications like playground equipment, art projects, and shock absorbers on large vehicles or boats. Though these applications account for only a small percentage of all scrap tires, they are simple and economical uses for the tires that require no infrastructure, planning, or regulation.

All of the aforementioned applications have a limit to their usefulness. Tire-derived aggregate, reclaimed rubber, and small-scale projects are dependent on specific and often limited markets. Additionally, tires used in civil engineering applications or small-scale projects may someday outlive their usefulness, requiring additional processing.

Incineration for energy and pyrolysis are options for waste tire management that can make use of tires at any phase in their life cycle, but are particularly useful for end-of-life tires:

- **Incineration for energy** is a commonly used waste tire management option in many countries with established waste tire management systems. Though this method creates some level of environmental concern due to pollutant emissions, studies have shown that tires produce more energy and fewer pollutants than many fossil fuels when used in the same application. This resource can be used in a number of facilities, including cement kilns, paper mills, and industrial boilers as an alternative to traditional fuels like coal. It can also be used as an additive to coal with little or no effect on emissions. However, it is important to note that proper operating procedures must be followed in order for energy production to be an environmentally viable use for waste tires. If tires are incinerated using poor operating procedures, the environmental damage can be extensive, comparable to open burning.

- **Pyrolysis** is a technology that has significant potential, though it is used much less frequently than incineration for energy worldwide. The process of pyrolysis involves introducing waste tires to a significant amount of heat and pressure, thereby causing the separation of the tire components. Typically, this process produces hydrocarbon gases, carbon black, scrap steel, and "pyrolysis oil", which has similar properties to heavy fuel oil. These products are generally low-grade, and require further refinement prior to reuse. Recent breakthroughs concerning the treatment of these low-grade materials have made pyrolysis a more economically and environmentally viable option. However, balancing the environmental effects of pyrolysis with the potential financial benefits can be a difficult process. Taking shortcuts in the pyrolysis process can lead to higher economic gain, but cause significant environmental harm. Pyrolysis facilities, therefore, need to be highly regulated.

By evaluating the pros and cons of a variety of waste tire management technologies, we have determined that these technologies are all effective strategies for utilizing waste tires as a valuable resource. However, in order for these technologies to be effectively implemented, a full waste tire management system must be established. The United Nations Environment Programme defines the components of a successful waste management program as technologies, policies, institutions, stakeholders, and financial mechanisms. By studying successful waste tire management systems from Japan and the United States and evaluating the similarities and differences between these systems and the current system in Thailand, we were able to draw conclusions about future steps that would positively influence Thailand's waste tire management system.

Technology:

- **Recommendation 1:** Minimize waste tire mismanagement through open burning, open dumping, and landfilling; instead emphasize a multi-faceted approach that involves environmentally and economically viable options.

By shifting the focus of Thailand's waste tire technologies from open burning, open dumping, and landfilling to a combined approach using retreading, grinding for use in civil engineering practices or reclamation, small-scale projects, incineration for energy, and/or pyrolysis, Thailand's waste tire management system will become a stronger source of economic growth and more environmentally sound.

- **Recommendation 2:** Research and develop both emerging and established waste tire management technologies.

By researching emerging and established rubber or waste tire technologies, the National Science and Technology Development Agency will ensure that Thailand establishes and maintains a competitive edge in the waste tire reuse and repurposing industries. The MTECH branch of the National Science and Technology Development Agency already has established programs concerning materials research, making it a good candidate for the creation of a new rubber technology research facility.

Policies:

- **Recommendation 3:** Establish and universally enforce specific policies for waste tires that establish guidelines for the waste tire industry, penalize companies that fail to conform to these guidelines, and create incentives for businesses with environmentally considerate business practices.

Increasing regulation of the waste tire industry will improve business practices, thereby improving the environmental impact of this industry. The creation of incentives for waste tire management companies with positive business practices will promote the growth of this industry in Thailand. It will be important to find a balance so that these regulations improve business practices without significantly inhibiting the growth of the waste tire management industry.

Institutions:

- **Recommendation 4:** Increase cooperation between private sector and regulating institutions.

Increasing the cooperation between regulating agencies and the private sector in the development of new regulations is intended to help mitigate the negative impacts that such regulations will have on the Thai waste tire management industry. By involving members of the private sector, institutions associated with waste tires can gain a better perspective on the needs of waste tire management businesses and make informed decisions on new regulations. As a national organization dedicated to science and technology research and development, the National Science and Technology Agency can act as a catalyst to fuel this cooperation by bridging the gap between regulating institutions like the Pollution Control Department and private industry leaders.

Stakeholders:

- **Recommendation 5:** Expand public participation in the waste tire management system through the use of a public education campaign.

By informing the public about current regulations and future objectives concerning the waste tire management system, the NSTDA can attempt to improve public participation in a program. Through presentations at seminars and conferences, or an advertisement campaign, the NSTDA can directly impact public participation in the collection of waste tires, thereby increasing the volume of waste tires that enter Thailand's waste tire management stream.

- **Recommendation 6:** Further investigate information on public opinions and societal acceptance of a waste tire management system.

Through the use of a large-scale survey or consultations with community leaders, Thailand's regulating institutions can gather information on the current public view of waste tire management options. This information will allow future developments in the waste tire management stream to focus on those options which are most likely to be publicly accepted. A campaign designed to explore public opinions and willingness to participate in a given program will help governing agencies to create a system that is as socially acceptable as possible.

Financing Mechanisms:

- **Recommendation 7:** Improve the current waste tire management stream through the promotion of private sector growth.

Thailand's waste tire stream is currently fueled by the private sector, in that waste tire management companies purchase waste tires from collectors and garages, which in turn purchase waste tires from individual consumers. By promoting private sector growth through the development of an incubator company on the NSTDA campus and recommending the continued use of a free market system, the NSTDA can directly impact the growth of private waste tire management companies. An incubator company would also provide an opportunity for the NSTDA and the Pollution Control Department to test the practicality of new regulations prior to their public establishment.

These recommendations alongside our research report are intended to support the National Science and Technology Development Agency in its development and pursuit of a comprehensive waste tire management program for Thailand.

Through the completion of these recommendations, the following outcomes are expected:

- The minimization of waste tire mismanagement practices, such as open burning, open dumping, and landfilling

- The growth of industries that utilize environmentally and economically viable waste tire management technologies

- The adoption of environmentally responsible business practices in waste tire management industries

- An increase in waste tire recycling rates

- The development of a comprehensive waste tire management system

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Chapter 1: Introduction

Waste tire accumulations pose a threat to public health, safety, and the environment worldwide (EPA, 2010). According to the U.S. Environmental Protection Agency (2010), the most common problems associated with waste tires are open air fires and the creation of mosquito and pest habitats. Difficult to extinguish tire fires can be started within a pile of tires due to the buildup of pressure and heat, arson, or lightning strikes. Open air tire fires release carbon monoxide and carcinogens like benzene, polluting the air with toxic smoke and contaminating the local environment as the ash settles. For every million tires consumed by uncontrolled fire, roughly 55,000 gallons of highly flammable runoff oil can be released into the environment (EPA, 2012). Mosquitoes and rodents are known disease carriers, and tire piles create an ideal breeding ground for illnesses like encephalitis and dengue fever, particularly in tropical climates (Reschner, 2008). This leads to further health and safety concerns when tire piles are deposited near urban areas (*Human Health*, n.d). Additional issues include discarded tires detracting from the aesthetics of a region or occupying large amounts of space in landfills due to the fact that tires cannot be compacted unless they are shredded or otherwise mechanically degraded (EPA, 2010). The hazards associated with waste tires are amplified because of the sheer number of scrap tires discarded per year worldwide. The worldwide generation of waste tires is estimated at 1 billion tires per year (Williams P., n.d). This number is likely to increase, as the global tire market is predicted to grow by approximately 5% over the period of 2011-2015 (*Global Tire Market Report*, 2012).

To manage the hazards associated with waste tires, proper waste tire management has become a necessity, but many nations are currently unable to process the overwhelming amount of waste tires in an environmentally and economically sustainable manner (*United Nations*, 2011). This is the case in Thailand, where the amount of waste tires generated annually has been estimated at between 400,000 and 600,000 tonnes (B. Ou-Udomying, personal interview, January 19, 2013, PCD, 2011). This number has recently increased significantly due to the nation's rapid industrialization. Between 1993 and 2010, the number of motor vehicles sold domestically in Thailand nearly doubled to over 700,000 vehicles, resulting in a dramatic increase in waste tire generation (Tire Automotive Institute, 2011).

Thailand currently has 94 "sanitary" landfill facilities, along with hundreds of open and unrecognized dumpsites (Nokyoo, 2010). According to the Thailand State of Pollution report from 2011, 63% of all waste was improperly disposed of in open dump sites or openly burned (Nokyoo, 2010). There are no municipal solid waste facilities dedicated solely to the purpose of waste tire management in Thailand (Nokyoo, 2010). For waste tires specifically, statistical data from the PCD shows that 63% of this waste is discarded or unaccounted for, 14% is reused as a tire, 20% is reused in another form, and a small 3% is used to create energy (Pollution Control Department, 2012). Statistically, the minority of waste tires generated in Thailand are recycled or repurposed, exhibiting a critical need for the creation of a waste tire management system. Countries with high waste tire recycling and reuse rates tend to have integrated systems for waste management, which typically include regulations and laws, institutions, financial mechanisms, technology and infrastructure, and various stakeholders in the solid waste management chain (UNEP, 2009). Developing systems to properly manage waste tires, though initially costly, can become a profitable undertaking. However, delaying the inevitable need to manage waste tires can cause severe economic loss, as tire fires and open dump sites can cost millions to clean up (EPA, 2010).

Currently, limited statistics exist concerning the management of waste tires in Thailand. Various private companies and governmental organizations have conducted independent research, often producing conflicting results (B. Ou-Udomying, personal interview, January 19, 2013). Inconsistencies exist within the waste tire industry as well, due to the lack of laws specific to waste tires and the low enforcement rate of general waste management policies. The absence of waste tire-specific regulations may contribute to improper practices that could result in environmental or health concerns (B. Ou-Udomying, personal interview, January 19, 2013). Laws concerning the waste rubber industry could establish new standards, improving these issues. This legislation also has the potential to assist in the expansion of a domestic industry which would likely perform well in the world's foremost rubber producing nation (B. Ou-Udomying, personal interview, January 19, 2013). However, information and data concerning Thailand's waste tire practices is generally scattered and sparse.

Our sponsor, the National Science and Technology Development Agency (NSTDA), is seeking to develop recommendations for a waste tire management strategy specific to Thailand. In order to assist the NSTDA in achieving this goal, we identified Thailand's specific needs for a waste tire management program and then assembled information regarding the various methods of recycling, reuse, and disposal of tires. We first focused on obtaining and analyzing Thailand-specific data on the existing waste tire collecting and recycling agencies, along with laws and regulations on waste tire management. Infrastructural, technical and economical details on various waste tire management strategies were obtained during site visits to tire manufacturers, waste tire recyclers, and waste tire regulating institutions. By using the available data and creating a feasibility matrix, we were able to identify the benefits and disadvantages of these strategies and technologies. By comparing the current waste tire management system in place in Thailand to Japan and the United States, two other countries with well-established systems, we were able to identify what current practices in Thailand should remain unchanged, and which need to be further developed and improved.

The evaluation of waste tire management technologies and systems resulted in several findings. We found that Thailand currently disposes waste tires at a higher rate than the United States and Japan, and that the two nations that we used for comparison utilize multiple technologies other than disposal to manage waste tires. We also discovered that Thailand has no regulations specific to the management of waste tires, comparatively few available related statistics, and significantly less interaction between the government and private sector.

These findings were used in the development of recommendations for a fiscally and environmentally sustainable waste tire management strategy in Thailand and allowed us to create an informative website for our sponsor to use as an educational tool. We were able to recommend a number of potential options for waste tire management technologies in Thailand, the establishment of regulations specific to waste tires, and an increase in cooperation between stakeholders, among other recommendations. Ultimately, these recommendations will help the NSTDA to take initial steps toward improved management of waste tires.

Completion of our project's objectives allowed us to assist the NSTDA in determining which methods for waste tire management should continue to be used and improved, which new methods should be developed and implemented, what missing information still needs to be gathered, and how to gather that information.

Chapter 2: Background

In this chapter we will discuss the general importance of waste tire management and the problems caused by improperly discarded waste tires. We outline the necessary components of a waste tire management system. We then present detailed information on the various methods for managing waste tires, including landfilling, incineration for energy, reuse in civil engineering projects and consumer goods, and retreading, followed by a summary of the current solid waste management methods in Thailand. We conclude by identifying the factors and constraints that need to be considered when implementing a waste tire management program.

2.1. Waste Tires as an International Problem

Waste management as a whole is a serious global problem. The United Nations estimates that of the 118 reporting countries, the total municipal waste collected exceeds 1.2 billion tons per year (United Nations, 2011). Waste tires, a significantly problematic municipal waste product, are discarded at an estimated rate of approximately one per year per capita in industrialized nations (EPA, 2010). As the world's population grows and becomes more industrialized, the number of tires produced, and eventually discarded, is growing rapidly. Figure 1 below illustrates the world's rubber consumption, a majority of which is used in the production of tires. Experts predict that the number of automotive and bicycle tires produced in 2015 will reach three billion, which directly correlates to the amount waste tires that will be generated (*Rubber World Magazine*, 2012). The particularly harmful effects of improperly managed waste tires make this small percentage of total waste a significant issue. Waste in general is being generated at increasingly alarming rates, resulting in the increased need for environmentally, socially, and economically conscious waste management strategies on a global level (OECD, 2007).

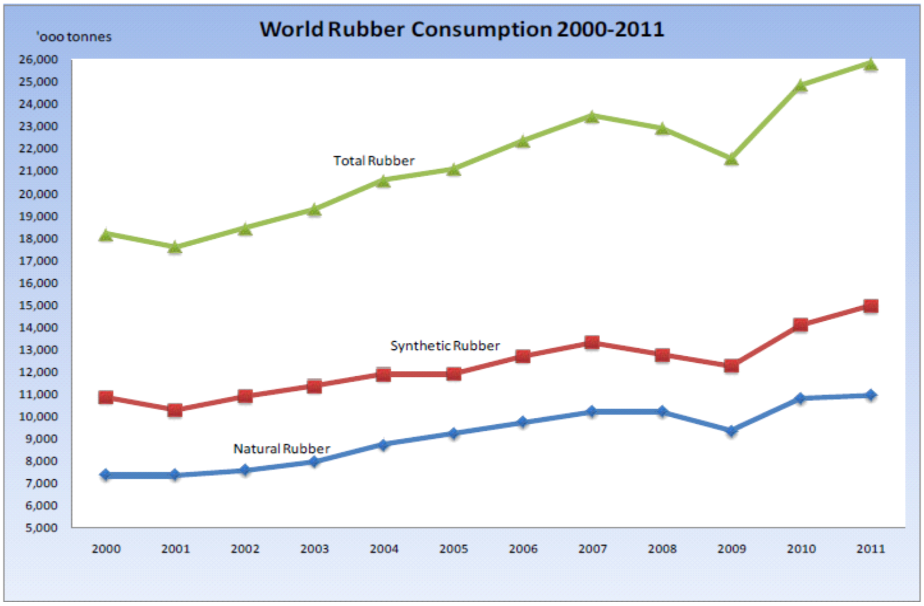


Figure 1 - World Rubber Consumption, 2000-2011 (NR Rubber Statistics, 2011)

As waste management becomes an increasingly important global issue, some waste products are given new life through reuse or recycling programs. In all industrialized nations with readily available statistics, the same pattern emerges of people recycling at an increasing rate (United Nations, 2011). In the United States, for example, recycling expanded from 6.3% of all municipal waste in 1960 to 16% in 1990. In the past two decades, it has jumped to 34% of all waste (EPA, 2012). Similar trends are shown for many other industrialized nations, including all members of the European Union and all Southeast Asian nations with available information, including Thailand (United Nations, 2011). This increase in recycling can be partially attributed to the high cost of landfilling and the fact that reusing materials is cost effective in some situations in comparison to the production of new materials (EPA, 2012). Waste tires have the potential for profitable reuse in a number of applications (Ou-Udomying, 2013). Due to the fact that waste tires are difficult to manage and can cause serious issues makes the development of a waste tire management system a high priority for environmentally conscious agencies worldwide (United Nations, 2011).

The accumulation of waste tires leads to several serious problems, including health and environmental threats from fire or pests, leaching of contaminants from landfills, and aesthetic unsightliness. These problems are all further exacerbated by tires' resilient composition and design. Their durable nature gives them an incredibly long lifespan. Rubber from tires will remain almost indefinitely because only the natural rubber components will break down on their own and this process can take up to 150 years (EPA, 2012). The synthetic components only degrade from mechanical means and no naturally occurring bacteria consume vulcanized rubber (Humphrey, 2003). Appendix A contains further details about the different types of rubber and how it affects the management of waste tires. In the following sections the main problems caused by waste tires will be examined in further detail.

2.1.1. Breeding grounds for insects and rodents

Accumulated waste tires can pose a serious threat to both the environment and human health. Tire piles create an ideal habitat for both insects and rodents. After rainfall, water is trapped in uncovered tires. This stagnant water becomes a breeding ground for various insects, as shown in Figure 2 (EPA, 2012). Mosquito-borne diseases such as encephalitis and dengue fever are a particular problem in tropical climates like Thailand and have been reported around large waste tire piles, creating a greater need for mosquito control (Reschner, 2008).

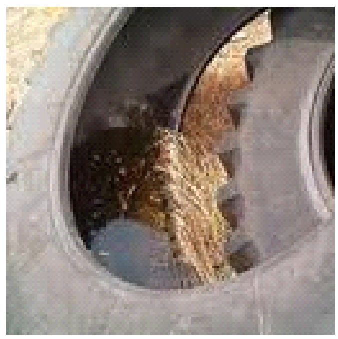


Figure 2 – Water collection in waste tires (San Joaquin County, 2008)

Species that inhabit waste tire deposits can cause additional issues beyond the spread of disease. Waste tire piles that are exported to other nations for repurposing have been known to carry non-native insect species (Ginsberg, n.d). For instance, the species known as the "Asian Tiger Mosquito" was accidentally transported from Japan to the United States in the mid-1980s in shipments of used tires. This species has since become established in at least 23 states and is considered a dangerous, invasive species. Invasive species are often more difficult to control, spread more disease, and cause harm to local ecosystems (Ginsberg, n.d). If elimination of tire piles is not feasible, mosquito abatement programs may be required to suppress mosquito populations within the tire piles. However, other local species, including humans, might be at risk if pesticides or other abatement chemicals are used (EPA, 2012). This task can be problematic and costly.

2.1.2. Fire hazard

When large amounts of tires are improperly stored in unregulated landfills or tire piles, a fire hazard exists. Tire fires emit large amounts of heat and the oily runoff created while burning is highly flammable and can contaminate surface water, groundwater, and soil with lead and arsenic, among other toxins (Reisman & Lemieux, 1997). When tires are burned in an uncontrolled manner, contaminants are formed and released into the air, which is a threat not only to firefighters responsible for extinguishing the fire, but also residents that live in close proximity to the location of the landfill or tire pile. Particulate matter released from improperly burned tires has been proven to settle in lungs, and is especially dangerous to the elderly, children, and people with asthma, heart disease, and allergies (Office of Environmental Health Hazard, 2002). A table of some of the different toxins released in tire fires and the related human health effects is available in Appendix B.

Tire fires can burn for extended periods of time, from several weeks to several months. Tires burn with a higher per-kilo energy output than coal, and the high heat production of tire rubber makes it difficult to extinguish. Exposure to toxic substances at tire fires, fire duration, and site hazards encountered at tire fires all contribute to elevated risks for firefighters (FEMA, 1998). Tire fires can be financially costly as well as dangerous to human health and the environment. For example, one of the most damaging tire fires occurred in September 1999 in Westley, California, shown in Figure 3. Approximately five million waste tires caught fire and burned for 36 days. The Environmental Protection Agency's response cost was about $3.5 million, in addition to cleanup costs which were covered by other related agencies (Shane, n.d).

Figure 3 - Five million tires burning in Westley, CA (Reschner, 2008)

In September 2011, there was a tire fire incident at the Sangserm Machinery Co., Ltd. in Samutprakarn Province, Thailand. The facility housed 10 tonnes of scrap tires in storage which became a volatile fuel source once the blaze started. Firefighters needed two hours to contain the fire to a confined space, and additional time was needed to fully extinguish the fire. Five tire grinding machines were destroyed, along with the majority of the facility. Overall, over 10 million baht (approximately 3 million U.S. dollars) were lost in this incident. This incident highlights both the need for increased regulation of waste tire management facilities and the potential hazard that tires can pose if improperly stored.

2.1.3. Aesthetic Issues

Accumulation of waste tires near residential buildings, business centers, industrial enterprises, road networks, and in natural environments not only can have an adverse effect on human health and safety but can also greatly impact the aesthetic appeal of the region (Roy, 2011). Although the aesthetic unpleasantness of a tire pile does not directly cause harm, it could potentially become a cause of frustration and have an economic cost for local residents. A tire pile detracts from the natural setting of a region, thereby making the location appear less attractive and potentially lowering property values (EPA, 2012). Figure 4 below illustrates how improperly disposed waste tires can detract from the aesthetics of a site.

Figure 4 – Improperly disposed waste tires (The Illahee Community Website, 2009) (Riverkeeper, 2009)

2.1.4. Leaching of toxins

Although waste tires do not directly leach toxins if properly managed in landfills, their presence in landfills has the potential to impact the leaching of other waste products. Leaching is defined as the process of dissolution of harmful chemicals or materials from waste stored in landfills (Kartha, n.d). Laboratory leaching tests on shredded tire samples indicate that when tires are not incinerated, both the metallic and organic components are well below the U.S. Environmental Protection Agency's toxicity characterization leaching procedure standards and that tire shreds show little or no likelihood of being a material hazardous to the environment (Yoon, 2006). However, whole or shredded tires can increase potential health and environmental hazards from other solid waste in landfills. Methane gases can accumulate in the void space within tires, causing them to rise to the surface of the landfill, which may result in damage to the landfill cap and structure (Willard & Smith, 2006). Though tires generally release no pollutants on their own, by damaging the landfill's structure, they can allow other municipal solid wastes stored in the landfill to leach toxins. The dispersion of these toxic chemicals into the surrounding environment is difficult to prevent once the landfill structure is damaged, and can be even more complicated to correct. The composition of municipal solid waste stored in landfills in Thailand can be viewed in Appendix C.

2.2. Waste Tire Management Systems

In order to combat the problems caused by waste tires, an effective waste tire management system is critical. A waste tire management system involves a number of different components. The United Nations Environment Programme provides an extensive report on the definition and establishment of a general waste management program. This program serves as a framework for the structure of our report and provides a basis for our analysis and recommendations (UNEP, 2009). The United Nations highlights five key factors that must be present in order for a new waste management system to be established and have the potential for success. The factors are:

- policies and regulations
- supporting institutions
- proper financial mechanisms
- stakeholder participation
- supporting technologies

The bases for a waste tire management system are the related <u>policies and regulations</u> for waste tire management. Policies and regulations must be well-constructed in order to be effective and must either be accepted by all stakeholders in the program or enforced by associated institutions (UNEP, 2009). The <u>institutions</u> involved in waste tire management can include all regulating establishments, from municipal organizations to federal agencies. These institutions are responsible for the development and enforcement of the aforementioned regulations. The methods for regulating a waste tire management program are further discussed in this chapter under "Political Constraints" (Section 2.5.5.).

The waste tire management system itself must be funded in some way, bringing <u>financial mechanisms</u> into the equation. In countries with successful waste tire management programs, a number of different strategies exist for financing these programs (UNEP, 2009). Information on these strategies can be found in this chapter under "Economic Constraints" (Section 2.5.1.), and they are discussed further in our Results and Analysis Chapter through our case studies of current practices in foreign nations.

The societal aspect of the program must also be established, as an effective waste tire management strategy requires participation from all demographics involved. Consumers who generate waste tires must be willing to assist in the collection of these waste tires. Automobile shops and tire collectors must do their part as middlemen, purchasing or receiving waste tires from consumers, safely storing them, and eventually selling them to businesses in bulk quantities for a profit. Business owners must follow regulations in order for the process to remain environmentally sustainable, and regulators or policymakers must create and enforce policies designed to regulate the actions of other stakeholders. Thailand-specific information regarding current practices and the demographics involved in waste management practices is included in this chapter's section on "Social Constraints" (Section 2.5.2.).

Finally, there are a number of potential technologies associated with waste tire management that must be considered in order to establish a complete system. A description of the primary technologies and practices for waste tire management is included in the following section (UNEP, 2009).

2.3. Waste tire management Technologies

There are multiple methods for waste tire management that, when properly executed, can be both safe and effective. These methods include landfilling, incineration for energy production, pyrolysis, grinding for various purposes, small scale reuse, and retreading. Figure 5 below illustrates the many different paths that a waste tire can take and the various methods that are used to manage these waste tires.

The definitions of "waste" "used" and "scrap" tires used in this paper are derived from the definitions used by the California Department of Resources Recycling and Recovery. This organization defines a waste tire as a tire that is "not intended for use on a vehicle". The category of "waste tire" also includes two subcategories: "repairable waste tires" and "scrap tires". "Repairable waste tire" defines a "worn, damaged, or defective" tire that can be repaired for use in its originally intended purpose. "Scrap tire" defines all "worn damaged or defective" tires that are not repairable tires. A "used tire" is a tire that is no longer mounted on a vehicle but is still suitable for use as a vehicle tire (California Department of Resources Recycling and

Recovery, 2010). This term is interchangeable with "second-hand tire".

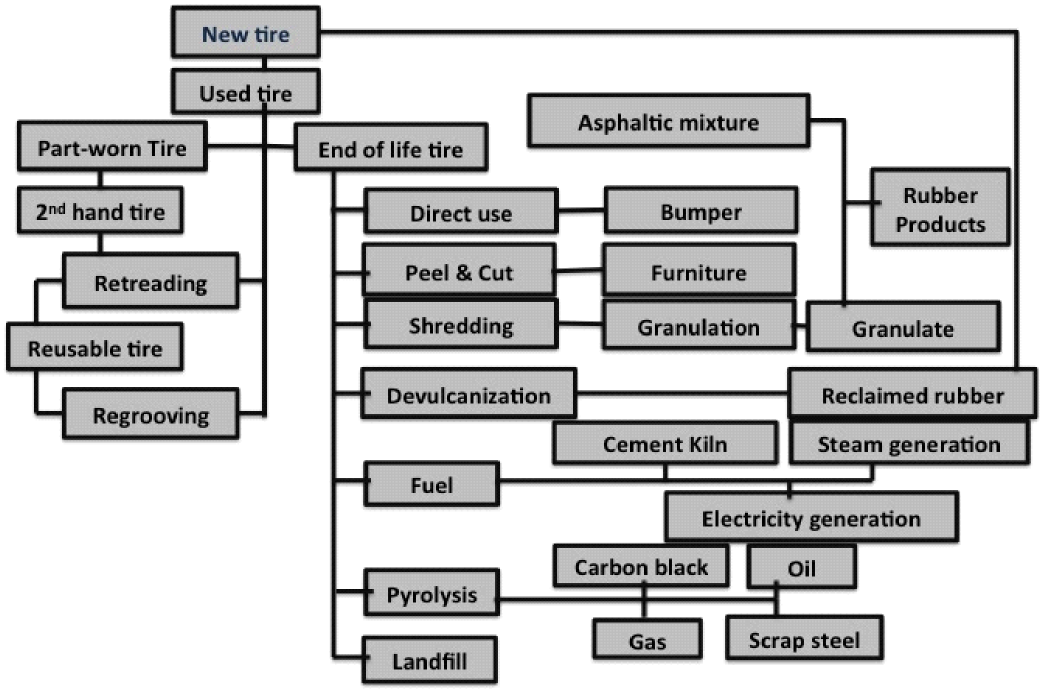


Figure 5 - Potential waste tire management options (Ou-Udomying, 2013)

2.3.1. Sanitary Landfilling

One of the most commonly used methods for waste tire management is landfilling (EPA, 2012). According to the Pollution Control Department, Thailand currently has 94 sanitary landfills (Nokyoo, 2010). Landfills have long been a major part of most waste tire management strategies due to their convenience and relative simplicity (EPA, 2012). However, problems exist with this strategy. Vulcanized rubber from tires can only be broken down by mechanical means, requiring either decades of natural mechanical processes or an abundance of energy in a facility. Additionally, tires can cause problems when stored in landfills, as they take up a large amount of space and can cause issues with landfill covers (EPA, 2012). Furthermore, treating waste tires as a waste product by landfilling does not reclaim anything from the waste tires unlike incineration, repurposing, or retreading.

It is first important to note the difference between sanitary landfilling and open dumping. While both are essentially a mass collection of refuse, landfills are monitored and planned constructs that aim to minimize the environmental and public health effects of solid waste on the local ecosystem. While landfills do not reuse the waste materials in any way, they are advantageous in comparison to open dumps because they have minimal environmental and health impacts when planned, constructed, and monitored as intended.

By contrast, open dumping is a simple process. An open dump is a pit or site where all types of waste are brought and deposited in a collective lot. The environmental impacts of this method are numerous, as are related human health risks. Pollutants from the decomposing waste can leach into the environment, disrupting the local ecosystem or causing health concerns for nearby residents. These under-managed sites can also become breeding grounds for any number of pests, including disease carrying rodents or mosquitoes. Unfortunately, because this is generally the least expensive and most convenient option, opening dumping is actually the final resting place of the majority of Thailand's solid waste, particularly in rural areas (Cherdsatirkul, 2012).

Sanitary landfills, on the other hand, are specifically engineered sites with a set of required equipment, including one or multiple bottom liners, a leachate collection system, a cover, and a natural hydrogeological setting (Ministry for the Environment, 2012). The equipment helps protect any water sources, especially groundwater, from waste contamination. A leachate collection system consists of pipes that are laid along the bottom of the landfill and captures and treats contaminated fluids as they accumulate. A cover is the cap that is located on the top of the landfill, preventing water from permeating and forming leachate (Salman, 2012). Also, in sanitary landfills, waste is compacted each day and covered with a layer of dirt to decrease odor, fire risk, and the risk from insects, rats, mice, birds and other organisms that can transmit disease. Figure 6 below illustrates a detailed cross-section of a sanitary landfill.

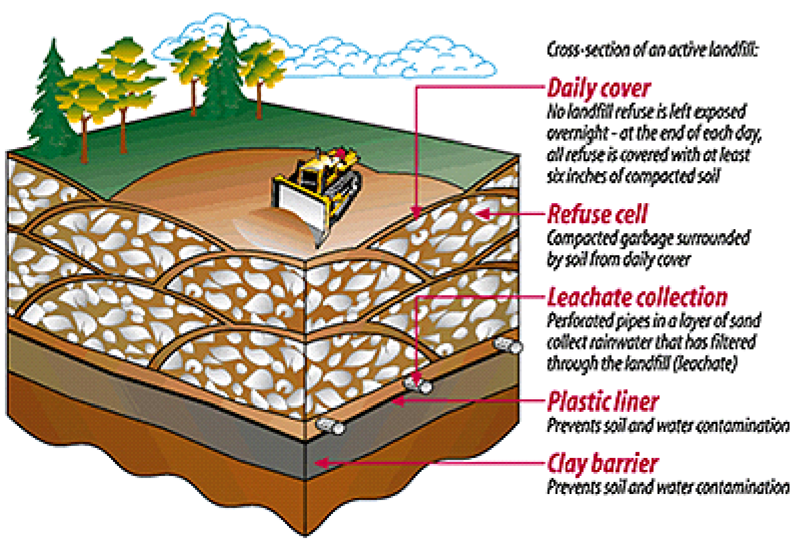


Figure 6 - Schematic representation of a sanitary landfill (South Kent Landfill, 2012).

Monofilling is a more specific type of landfilling that involves a single type of solid waste. This allows for all of the benefits of landfilling, such as containment, while allowing for the possibility of the reclamation of the raw materials contained if future technology and infrastructure can handle the volume. The United States currently uses monofills for a number of materials, including tires (EPA, 2012).

While Thailand does not currently have any operating monofills, it is a fairly established tire waste management method that is more technologically progressive than landfilling (Nokyoo, 2009).

Thirty-five American states allow shredded tires to be placed in landfills (EPA, 2012). However, this can only be carried out after pretreatment and separation, minimizing volume, and allowing for gases to escape safely, which allows a safer waste tire disposal. An example of a landfill that accepts waste tires is the South Kent Landfill in Michigan (Figure 6), which opened in 1982, and is currently approximately 44% full. The landfill was constructed utilizing a single composite liner system, which consists of 10 feet of naturally occurring clay topped by two feet of compacted clay, a plastic liner and two feet of sand for leachate collection. Leachate generated by the landfill is transported daily to a wastewater treatment facility. Methane produced by waste degradation is used to power two engines that currently produce 3.2 megawatts of electricity, enough to provide power to approximately 2,700 homes (*South Kent Landfill,* 2012).

However, when improperly managed, landfills can become prime breeding grounds for pests and often harbor the threat of large tire fires (EPA, 2012). Further, if the waste tires are covered over with fill the degrading tires can release methane, which eventually builds up to dangerous levels beneath the surface. If the cap or the leachate system is not well maintained, water will be trapped in the waste and eventually overflow the landfill sides and pollute the environment (Reschner, 2008). An absent or dysfunctional pipe system can lead to serious environmental and social consequences (Harmony Enterprises, 2011). Due to these dangers, landfilling tires in any form has been banned in all European Union nations since 2006, and regulations on landfilling waste tires are on the rise in other nations (Reschner, 2008). Moreover, with the growth of population and waste tires all over the world, available space for development and construction of new landfills has become severely limited.

2.3.2. Incineration for Energy

Incineration is the most popular method in the United States for energy production from waste tires (EPA, 2012). Almost 130 million shredded scrap tires generated in the United States are used as tire-derived fuel, and 10% to 20% of that fuel is used at industrial facilities alongside conventional fuels like coal (Reisman & Lemieux, 1997).

Waste tire incineration is a method for recovering the material's potential value as energy. Incineration of tires conserves energy by replacing virgin fuel sources, therefore conserving materials acquired from the natural environment (Morris, 1996). Tire derived fuel is actually a more effective source of energy than many commonly used fuel sources. For instance, the energy value of tire-derived fuel is 15,500 BTU/lb., whereas coal produces only 12,750 BTU/lb. (Morris, 1996). Table 1 shows the comparison of energy values of tire-derived fuel (TDF) to other fuels (*Tire Recycling Industry: A Global View*, 2003).

Table 1 - Energy Values of TDF and Other Fuels (Tire Recycling Industry: A Global View, 2003).

Fuel	Energy Values
Coke (Petroleum)	13,700 BTU/lb
Bituminous coal	12,750 BTU/lb
Oil (No.6 fuel oil - 'Bunker C'	151,000 BTU/gal
Natural gas	1,000 BTU/ cu. ft.
Tire-derived fuel	15,500 BTU/lb.

To ensure an environmentally safe incineration process, facilities must be specially engineered. Cement kilns and industrial boilers in United States as well as other incineration plants must meet the emission standards set by the Environmental Protection Agency. Waste tires should be cut into strips, reduced in size, and separated with steel belts and wire components removed in order to ensure proper and safe incineration practices (EPA, 2012). Proper processing also requires elimination of excess air, complete incineration of the mixing fuel components, and prevention of soot generation (Wasniowski, 2003). Moreover, ground tires can also be used as fuel with co-combustion of coal as part of the production of steam, electrical energy, paper, lime, and steel. This co-combustion improves the thermal efficiency of steam boilers and furnaces. Based on the EPA's research, fuel derived by waste tire incineration emits no more pollution than conventional fuels when the technology operates as designed (EPA, 2012). This process is more environmentally considerate compared to coal combustion because it has lower emission of dust, carbon dioxide, nitrogen oxides and heavy metals, with the exception of zinc. Currently, more than 80 facilities in approximately 30 American states incinerate scrap tire material for energy recovery. In 2003, a total of 130 million scrap tires were used as tire-derived fuel in the United States (EPA, 2012). In Thailand, approximately 2.86% of waste tires are incinerated for energy primarily in cement kilns and boilers, which is roughly equal to just over 17 thousand tonnes of tires (PCD, 2011). This technology is primary used by companies including Siam City Cement, TPI and Mahaphant Fibre-Cement Public (Prakaypan, 2013).

Another useful application of tire-derived fuel can be the use of ash and scrap metal wiring that remains. This ash may appear to have no practical value, but it can be extremely useful in concrete production. According to a 2004 study conducted at the Jordan University of Science and Technology, concrete made with up to 10% tire ash had some interesting and potentially beneficial properties (Al-Akhras & Smadi, 2004). The concrete that contained a 10% tire rubber ash mixture had higher compressive strength, flexural strength, and higher thermal resistance than traditional mortar. However, adding tire ash to concrete mixture increases binding time and requires greater water usage. This application for tire ash gives this seemingly useless material a new life as a replacement for sand in mortar mixtures (Al-Akhras & Smadi, 2004).

The states of New England provide an example of how waste tire incineration can be a successful method of waste tire management. These states have been able to use their resources to form a combined effort to manage their collective waste tires (DEP, 2011). Most commonly, the waste tires from each state are burned and used as fuel. Connecticut uses some of New England's waste tires to create fuel in a special tire-to-energy facility. Exeter Energy Limited in Sterling, Connecticut, for example, burns whole and shredded tires, roughly 10.13 million in 2000, and turns it into usable fuel. The plant generates approximately 200,000 megawatt-hours of electricity annually, which is equivalent to conserving approximately 480,000 barrels of oil per year (*Consumers Energy*, 2012). Once the electricity is generated, it is directed along an underground cable system for final sale into the electric grid. There are also three paper mills in Maine that supplement their fuel source with this tire-derived fuel and together the three mills consumed approximately 71,000 tons of TDF in 2000, which equates roughly to 7.1 million passenger tires. Because Connecticut and other New England states no longer permit the landfilling of waste tires, burning tires to create energy is an effective and valuable alternative strategy (DEP, 2011).

However, it is important to understand that tire-derived fuel is not the most environmentally beneficial method for handling waste tires (*Earth Day Update*, 2005). The testing of fuel deriving processes takes place under ideal conditions with excessive air to improve combustion efficiency, artificially controlled burning facility parameters, and burning at TDF levels lower than expected operational levels (Carman, 1997). It is also important to make the distinction between controlled incineration of waste tires and the disorder of uncontrolled tire fires. Incineration does not produce the same adverse effects that unrestrained tire fires cause. When executed correctly, waste tire incineration can be a safe and effective waste tire management method (DEP, 2011).

2.3.3. Pyrolysis

Pyrolysis is the thermal decomposition of an organic material under the exclusion of ambient oxygen. Pyrolysis of the rubber in scrap tires is one of the most reasonable alternatives in terms of environmental protection due to the lack of greenhouse gases produced (Rombaldo, et al., 2008). Pyrolysis of tires can be a more environmentally considerate option for waste tire management compared to incineration or burning of tires, which induces oxidation of hydrocarbons and forms greenhouse gases such as carbon dioxide (CO_2), carbon monoxide (CO), and silicon dioxide (SO_2). Additionally, beneficial products can be obtained from the process shown in Figure 7, including hydrocarbon gases, pyrolysis oil, carbon black, and scrap steel (Wojtowicz & Serio, 1996). The hydrocarbon gases, typically consisting of hydrogen (H_2), hydrogen sulfide (H_2S), carbon dioxide (CO_2), or carbon monoxide (CO), are most often used to fuel the pyrolysis process. The oil produced can be used directly as fuel oil and as a raw material in petrochemical processes (Rombaldo, et.al, 2008). The low-grade carbon black derived from this process can be further treated to obtain high-grade carbon black, activated carbon, or other valuable chemicals such as benzene, toluene, and xylene (Reschner, 2008).

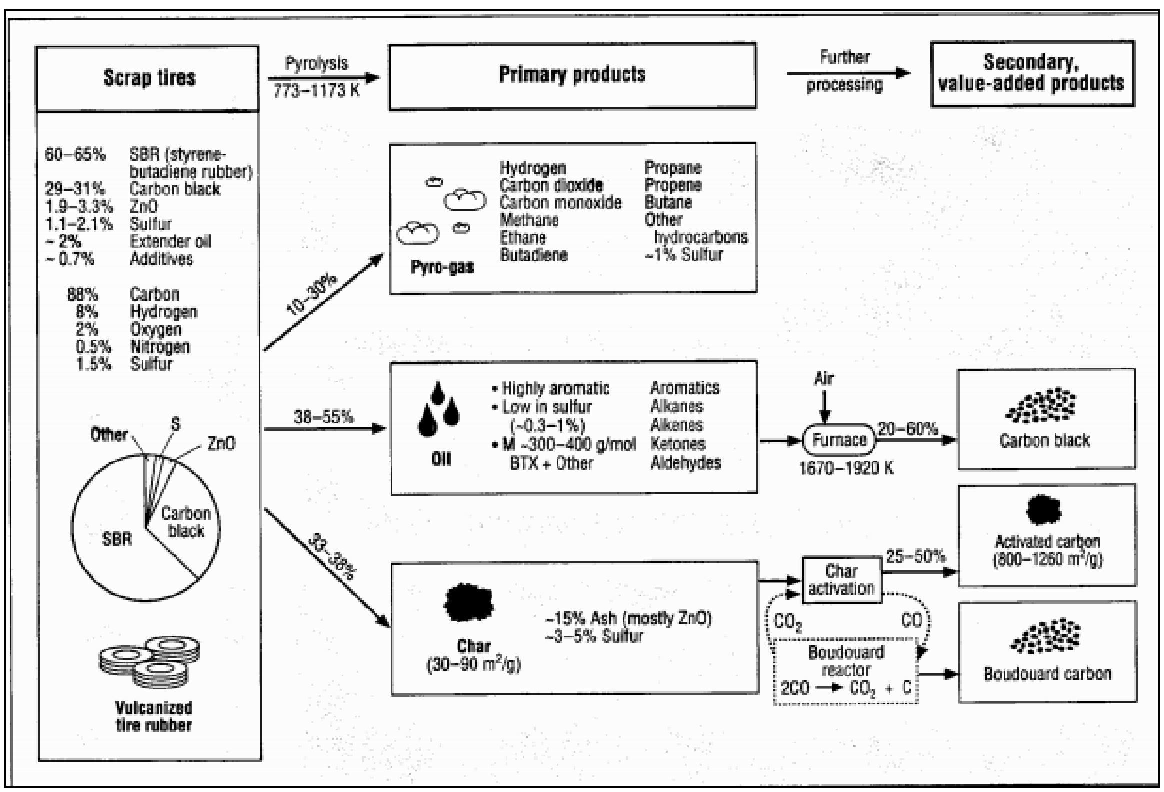


Figure 7 - The products obtained from pyrolysis (Wojtowicz & Serio, 1996).

The percentage of these products can be affected by factors such as temperature, pressure, heating rate, and tire particle size. The conditions of tire pyrolysis are controlled differently depending on the target amount of each product (Roy et al., 1990).

2.3.4. Grinding for reuse in civil engineering applications

Waste tires and their byproducts provide useful materials for use in civil engineering projects. The relatively light weight of waste tires makes them easy to transport and their abundance makes it inexpensive. There are five different grades of ground tires, as shown in Table 2. Tire-derived mulch products have proven especially useful in large-scale construction and engineering ventures.

Table 2 -Standard size of automobile tire mulch in commercial production (Sienkiwicz et al., 2012).

Term	Size (mm)
Cut tires	>300
Shreds	20-400
Chips	10-50
Rubber granulate	0.8-20
Rubber dust	<0.8

2.3.4.1. Grounded as mulch

Tire-derived aggregate (TDA) can be a convenient stand-alone material for some applications. TDA is often used as mulch for agricultural purposes, though its value in this application is questionable due to its lack of weed control (Chalker-Scott, n.d). Other applications harness some of the unique properties of tire-derived aggregate. For instance, use as playground mulch or as artificial turf filler on athletic fields is valuable due to the high durability, drainage ability, and impact cushioning properties. Approximately 40,000 tons of scrap tires were used in 2001 on athletic fields in the United States (EPA, 2012). Though some public concerns about leaching from TDA still exist, these concerns are largely the result of the lack of proper information and the presence of a social stigma regarding tires. Studies have been conducted that classify tire-derived aggregate as a safe material for this application (Chalker-Scott, n.d).

Due to the many different ways that a waste tire can be reused as a product, there are companies throughout the world that have made their businesses out of recycling tires. One company, PermaLife Products, in Oklahoma, uses recycled rubber from tires to make a full line of products. This company was featured on the History Channel in an episode of Modern Marvels in 2007 exhibiting their process of grinding waste tires. Using liquid nitrogen, they freeze the rubber, giving it glass-like fracture properties and allowing it to be broken into small pieces (*Deep Freeze*, 2007). This process, known as cryogenic grinding, is discussed in further detail in Section 2.3.4.4.2. PermaLife

Products manufactures and sells rubber mulch, playground surfaces, rubber stepping stones, tree rings, equestrian arena fill, and other recycled rubber that is used for molded products such as car parts and welcome mats (PermaLife, 2012). This company has been able to take a resource that many people see as a burden and turn waste tires into a line of products that is both safe and environmentally friendly (PermaLife, 2012). Figure 8 below is an example of one of PermaLife's many products.

Figure 8 - St. Jude's Ranch for Children located in Boulder City, NV uses PermaLife Product's playground fill created from recycled tires (PermaLife, 2012).

2.3.4.2. Backfill

Fragmented scrap waste tires is well-suited to repurposing as fill for civil engineering projects. Tire-derived aggregate has a number of uses. These uses, as defined by the American Society for Testing and Materials (ASTM) include: "lightweight embankment fill, lightweight retaining wall backfill, drainage layers for roads, landfills and other applications, thermal insulation to limit frost penetration beneath roads, insulating backfill to limit heat loss from buildings, vibration damping layers for rail lines, and replacement for soil or rock in other fill applications" (ASTM, 2012). Additionally, whole tires or sidewall components removed from tires can be used for a variety of purposes including the construction of retaining walls and drainage projects (ASTM, 2012). Backfilling using waste tires is considered an environmentally conscious practice because contamination or leaching from the material occurs at an inconsequential rate (Humphrey, 2003).

Though flammability is a concern whenever large amounts of rubber based products are present, there have been no instances of tire fires in the dozens of highway construction projects using TDA that have been implemented in the United States in the past two decades (Humphrey, 2003). Additionally, the exothermic reactions that are known to occur within compounded waste tires are only a concern in TDA accumulations greater than three meters thick, and the Civil Engineering Committee approves the use of TDA in applications less than three meters (Humphrey, 2003). TDA is inexpensive, lightweight, and plentiful. Furthermore, use of TDA prevents use of naturally found aggregates, protecting natural resources. Even relatively small-scale projects can provide a new use for millions of waste tires (Humphrey, 2003).

2.3.4.3. Rubberized asphalt

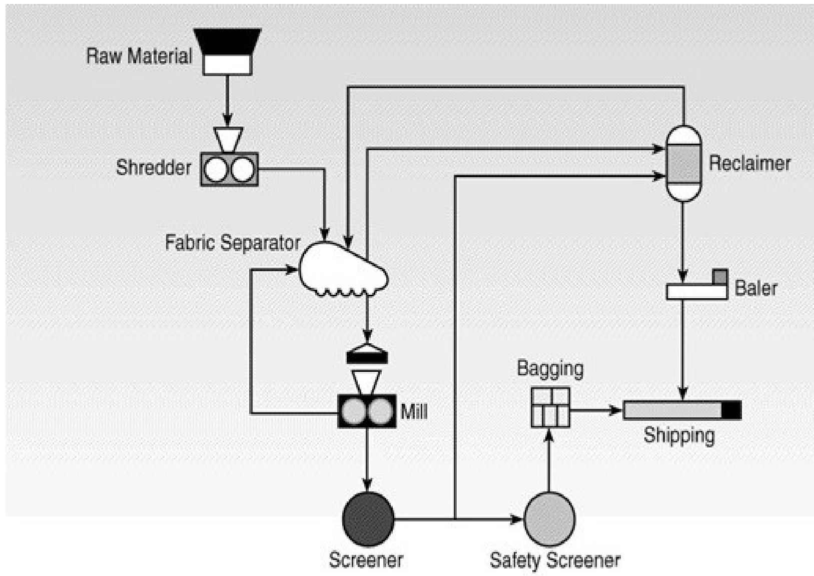
Crumb rubber obtained by shredding waste tires can be reused by incorporating it into asphalt. The benefits and drawbacks to adding waste tire products into asphalt production are still a relatively new research topic. Rubberized asphalt has better skid resistance, reduced fatigue cracking, greater heat and sound insulation, lower density, higher impact resistance, less susceptibility to heat fluctuations, and longer life expectancy than conventional asphalt. However, it is less durable and less ductile. Rubberized asphalt has become increasingly popular in regions with large heat fluctuations, particularly the United States, since the rubber allows the asphalt to shift without cracking from changes in temperature (Ou-Udomying, 2013). Many authorities still disagree on the comparative value of rubberized asphalt contrasted with other basic and inexpensive competitors (Al-Akhras & Smadi, 2004).

2.3.4.4. Methods for grinding

There are four major methods for grinding waste tires: ambient temperature grinding, cryogenic grinding, wet grinding, and high-pressure water jet grinding (Sienkiwicz et al., 2012).

2.3.4.4.1. Ambient temperature grinding

Ambient temperature mechanical grinding (Figure 9) is a process used to grind crumb rubber using shredders, mills, knife granulators, and rolling mills with ribbed rollers. The crumb rubber is grinded repeatedly until it reaches the desired size. Typically, the mulch produced through this method is smaller than 0.3 mm and has a very rough surface. Fibers are separated from the textile cords by pneumatic separators, and steel is separated by electromagnets. This process must use a cooling system to prevent combustion due to the heat produced through the oxidization of rubber grains (Sienkiwicz et al., 2012).



NOTE: Magnets are used throughout the process

Figure 9 - Ambient Grinding Process (Tire Recycling Made Simple, 2012).

Wet grinding is a method developed from ambient temperature mechanical grinding. In order to counteract the large amount of heat produced through ambient temperature mechanical grinding, the product is continuously cooled using a stream of water. This method produces fine rubber dust with grains sized between 10-20 µm which have large specific surface area. This dust is added to mixtures for products with high quality rubber requirements, such as tires (Sienkiwicz et al., 2012).

2.3.4.4.2. Cryogenic grinding

Cryogenic grinding, show in Figure 10, involves the use of liquid nitrogen as a refrigerant to cool down waste tires to a temperature below -80°C. Through this process, the rubber freezes to a glass-like state, and the tires are then broken using hammer mills into small particles. This process is useful for the removal of steel parts and non-claimed rubber particles.

Crumb rubber from the cryogenic grinding process has an angular shape, smooth surfaces and low surface area, so it is often used for applications involving human contact, including playgrounds, soil landscaping, sports surfaces, or asphalt, as shown in Figure 11 (*Tire Recycling Made Simple*, 2012).

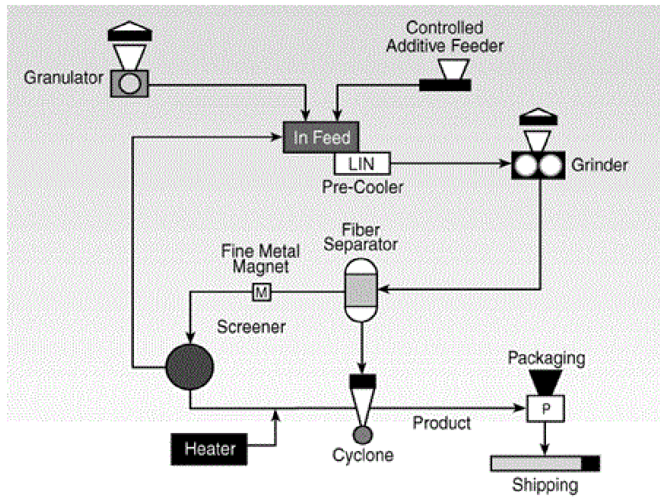


Figure 10 - Cryogenic Grinding Process (Tire Recycling Made Simple, 2012).

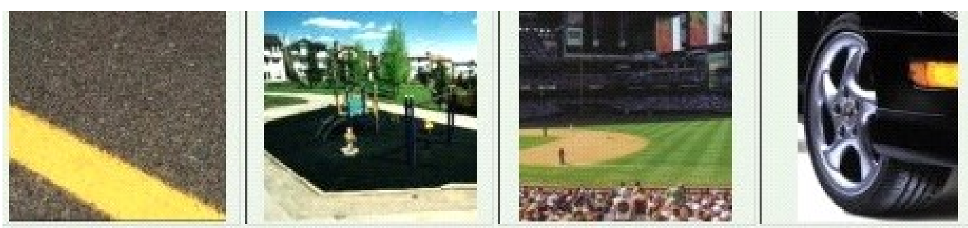


Figure 11 - Applications of crumb rubber particles (Cryogenic Tire Processing System, 2002).

2.3.3.4.3. Water jet grinding

Grinding scrap tires with a water jet is a commonly used method for recycling high resistant, large-size tires from trucks, construction vehicles, and farm tractors. Normally, grinding large-sized tires involves massive grinding machines, which are high energy-consumers. Water jet grinding of tires requires pressure of more than 200 bar to produce high viscosity tire strips. This technique has a variety of advantages. It can be used to separate tire strips from the steel cord, form rubber crumbs from the butyl rubber membrane on the side of the tire, and separate rubber material from the tread and walls. Grinding with a water jet produces very finely ground rubber grains which have large a specific surface area. Moreover, this technique is environmentally conscious, energy-saving, and generates few pollutants and little noise in comparison to other grinding methods (Sienkiwicz et al., 2012).

All techniques mentioned above are useful methods for waste tire treatment. The advantages and disadvantages of each grinding method are summarized in Table 3.

Table 3 - Grinding Techniques (Sienkiwicz et al., 2012).

Method	Benefits	Disadvantages
Ambient Temperature Grinding	-Size of particle not more than 0.3mm -Fiber and steel cannot be separated from each other	-Cooling system required -Possibility of explosion -Higher energy cost
Wet Grinding	-Formed of fine rubber dust with grains size of 10-20 μm	-High cost
Cryogenic Grinding	-Removes steel part and non-claimed rubber particles	-Requires liquid nitrogen
Water Jet Grinding	-Suitable recycling large-size of tires -Can separate steel out and formed crumb rubber from the butyl rubber membrane -Environmentally conscious -Energy saving -Low level of noise	-High cost

2.3.5. Stamped, punched, and cut products

Stamped, punched, and cut products make use of the structural integrity of tires in a variety of ways. Stamped products include mats, coverings, simple furniture, small rubber components and coverings, rubber stamps, ink pads, magnets, shoes, and hundreds of other products. Stamped, punched, and cut products often do not use the entirety of the tire, but generally make use of the majority of the natural and synthetic rubber (RMA, 2012). Though the total number of waste tires has increased recently, the number of bias-ply tires, those tires not containing an internal steel belt, has become progressively more limited. Bias-ply tires are the only tire type considered scrapable for stamped, punched, and cut products. The decreasing popularity of bias-ply tires is due to the increased popularity of radial ply tires, those containing a steel belt, which extend the overall lifespan of a tire, but cannot be reused in this industry. Recent trends point towards a shortage of bias-ply tire rubber in the near future (RMA, 2009). Appendix D contains more detailed information about the composition of the different types of tires.

2.3.6. Small-Scale Applications

Many countries use waste tires to create new products. In contrast to simply eliminating tires through incineration or disposing of them in landfills, treating waste tires as a resource and reusing them can often be more sustainable and beneficial.

2.3.6.1. Playground equipment

Playgrounds are another civil engineering project that can use scrap tires in a variety of applications (EPA, 2012). This includes the use of whole tires in the construction of playground equipment, scrap tire chips as ground cover, and scrap tire matting in the safety surface material (MDE, 2012). Many companies manufacture rubber playground mats as well as granulated rubber for playground fill from waste tires. Once the metal components of a recycled tire are removed from the granulated rubber, it becomes a sand-like material that is a safe alternative to traditional playground materials and is often less expensive (PermaLife, 2012). Whole tires can provide a less dangerous alternative to materials such as sharp metal or wood that splinters and can be used in playgrounds without modifying the tires' state. Whole tires are often a free resource that can be used to make playground equipment such as tire swings, climbing walls, and many other applications (Veerman, 2013).

An excellent example of recycled tire use in playgrounds comes from Thailand. An Australian named Marcus Veerman, founder of a company called PlaygroundIDEAS (formally called Go Play), went to Thailand in 2008 with the idea of involving Thai children in hands-on, community-oriented work (Taylor, 2010). After working with a school to create a new playground, he dedicated himself to this cause. Over the next two years, he was able help create over 45 playgrounds across Thailand. Veerman wanted to use materials that were inexpensive and already available in the community. As a result, he found that local wood, and especially used tires, were very useful resources. However, since local materials are less durable than standard playground materials, he equips the community with the knowledge, resources, and motivation to maintain their new playgrounds over time. Veerman states, "I would rather focus on maintainability as opposed to durability. It's a more sustainable long-term model, even though it seems a bit backwards to us in the West" (Taylor, 2010). He was able to create everything from tire swings, to rubber bridges, to sandboxes, out of the recycled tires. The tires are often painted a bright color, which adds to the character of these unique playgrounds. Figure 12 below is an example of the various playground projects in Thailand. Veerman continues to utilize recycled tires as he builds playgrounds in developing countries all over the world. The PlaygroundIDEAS website contains information about how to build these recycled tire playgrounds, how to get involved in playground building projects throughout the world, and a way to donate to the cause (Veerman, 2013).

Although playgrounds made with recycled tires could not possibly serve as the sole method of waste tire management, it is a simple, relatively inexpensive strategy that benefits playground users and the local communities, as well as providing an outlet for recycled waste tires.

Figure 12 - Marcus Veerman's personal photos of various playgrounds constructed in Thailand that utilized waste tires (Taylor, 2010).

2.3.6.2. Individual tire reuse

Whole tire reuse bypasses the recycling process and reuses the tire in ways other than its original intended purpose. Tires have been reused as tire swings and as playground equipment for decades. Tires can also be reused as containers, gardens, trash bins, sandboxes, and bumpers on large vessels (Texas Commission on Environmental Quality, 2012). While the idea of tire reuse is not a new one, recent efforts to reduce waste, and a little creativity, have yielded many interesting products, structures, and even art from tires, as shown in Figure 13. While individual tire reuse will not be able to remove a noteworthy percentage of tires from the waste stream, it can at least detain a small number of used tires while putting them to reuse.

Figure 13 - Tire Art (How to Recycle, 2012) (Green Art, 2008)

2.3.7. Retreading

Retreading of tires is a process that allows for the majority of a tire to be used again for its intended purpose, while maintaining the necessary stability and traction expected from tires. As a process, it offers companies and individuals the option of saving money, material, and the environment by salvaging the majority of the material in the tire. As an industry, tire retreading is an established and growing part of the recycling process and an effective commercial strategy for saving money (TRIB, 2012).

The tire retreading process is not particularly technologically demanding or expensive especially in comparison to the requirements necessary for the initial manufacturing process of a tire (TRIB, 2012). Economically, the tire retreads cost between 30% and 50% of the cost of purchasing a new tire (TRIB, 2012). The production of one new automobile tire normally needs 22 liters of oil, but for the process of renewing waste tires, only seven liters of oil is needed (EPA, 2012). The retreading process begins with an inspection of a waste tire. The tires are subjected to not only a manual inspection, but also inspection by a shearographer, a type of nondestructive testing machine that uses lasers and lights to quickly scan the surface of the tire while simultaneously gathering necessary information about the condition of the tire (Pride Enterprises, 2010). Accepted tires have their old treads buffed and sanded away, leaving a very smooth and level casing. The amount of rubber byproduct produced in this process is negligible (EPA, 2012). The casing, or the main structural part of the tire without the tread, is then given a new, fresh tread in a process using heat and pressure that is very similar to the original manufacturing process of the tire. Tire serial numbers and model types are kept on record, and it is confirmed that each tire is retreaded to the original radius, crown width, and profile (Pride Enterprises, 2010). This process ensures that the casing and the tread become one single unit and will not shred during use. After an additional inspection, the tire is ready for reuse.

Currently, tire retreading is most popular within the trucking industry where vehicles require a greater number of tires, and the tires are exposed to more pressure, weight, and wear, and therefore must be replaced more often. As a percentage, truck tires are less likely to be rejected due to punctures or mutilation. Truck tires are larger and more expensive than car tires and are more lucrative to retread than automobile tires (Pride Enterprises, 2010). In addition, passenger vehicle tires are rarely retreaded because of the minimal savings offered by retreading. Throughout the late 1990s and early 2000s, tire retreading for passenger vehicle tires progressively decreased due to a closing gap between the cost of retreading and the cost producing a new tire. Only recently, as global costs of newly manufactured tires have increased, has the market begun to rebound (Koeth, 2010). Figure 14 below shows the recent trends of rubber as a commodity.

Figure 144 - Rubber pricing trends ($USD/kg) (Reschner, 2008).

Tire retreading has become increasingly popular in many countries. There are roughly 850 tire retreading plants in North America (TRIB, 2012). Annually, North American businesses and industries net over three billion dollars in retreaded tires, which is a small but significant contribution to the approximately 45 billion dollar North American tire market. Since April of 2000, all government and military vehicles in the United States are required to make use of retreading technology when practical. This not only includes thousands of military vehicles and aircraft, but also government vehicles.

Nearly 80% of all aircraft in the United States are currently using retreaded tires (TRIB, 2012).

In Wittlich, Germany, the leading tire manufacturer, Goodyear Dunlop, has altered their production facility to allow for a new business opportunity in the retreading of truck tires. The company sees retreading as a profitable investment and a strategy for future growth. They have begun to open divisions in the organization that are specifically dedicated to tire retreading (Fleet First, 2011). The company believes that these lines are an important part of the truck division of the company and allows them to better serve their customers' needs. It helps the fleets to reduce operating costs while still using high performance tires. The casings that are used by Goodyear Dunlop for retreading are all thoroughly examined to ensure their suitability for reuse. After the tires are retreaded, they go through the same quality assurance that equivalent new tires would go through. This new business development is a common trend for tire companies and is an important part of the tire recycling process (Fleet First, 2011).

2.3.8. Emerging Technology: Ultrasonic degradation of tires

In a general overview, ultrasonic reclaiming breaks down carbon-sulfur and sulfur-sulfur bonds in cross-linked rubber in tire waste by using high frequency sound waves (Shim, 2002). This process is known to be a continuous process, as opposed to a batch flow process, meaning that more tire waste can be processed over the same amount of time for traditional reclamation techniques (Ou-Udomying, 2013). The few people with knowledge on ultrasonic degradation are seeking patents or have patents pending, and therefore little to no information is available on this method other than the basics of the process. Therefore, little to no other information is publicly available discussing the technology behind this method. This emerging technology is seen by many in the industry to be part of the next generation of tire waste management technology (Ou-Udomying, 2013).

2.3.9. Summary of waste tire management technologies

The waste tire management strategies included in this section are the most commonly used strategies globally (EPA, 2012). Some of these strategies are currently used to varying extents in Thailand, while others are currently unrepresented in Thai industry (Ou-Udomying, 2013). The advantages and disadvantages of each strategy are further evaluated in a feasibility matrix and through the use of case study comparisons of the U.S. and Japan to Thailand in Chapter 4, Results and Analysis.

2.4. Current Waste Management Practices in Thailand

On a national level, Thailand currently has programs in place for managing solid waste in general but not specifically for handling waste tires (Nokyoo, 2010). The Waste Management Bureau of the Pollution Control Department is primarily in charge of the process of waste management.

2.4.1. Solid waste management

Currently, Thailand has a general solid waste management strategy that is built on the principal of the 3R's: reduce, reuse, recycle. The framework for overall waste management includes, "promoting the integrated waste management system to reduce the landfill areas and generate renewable energy; encouraging the cooperation of adjacent local governments for establishment of waste management facilities; and endorsing public and private sectors to participate in waste management projects". The national waste management targets include several separate goals: a waste utilization rate of no less than 30%, waste disposal in engineered practices no less than 40%, and proper management of at least 30% of household hazardous wastes (Nokyoo, 2010).

Thailand's Pollution Control Department (PCD) is planning to implement more waste-to-energy (WTE) recycling strategies. There is an estimated 15.4 million tons of solid waste created every year that contains the equivalent of 3.5 million tons of usable "fuel" that can generate approximately 400 megawatts of electric power. An objective of the department going forward is to create both WTE models for "high potential local governments" as well as "to develop and demonstrate appropriate technologies on WTE through R&D projects and pilot plants" (Nokyoo, 2010). This helps to illustrate Thailand's vision for the WTE future, a vision that could potentially include solid waste incineration, tires in particular, for the creation of an alternative source of energy.

There have been several successful waste management related projects that have been completed throughout Thailand. These projects include the establishment of a municipal solid waste disposal facility in Chiang Mai, an organic waste compost and energy production plant in Rayong, and an incineration plant in Phuket (Nokyoo, 2010). Each of these sites has made significant contributions to the overall solid waste management system, especially in their respective regions. For example, the plant in Rayong is able to generate 625 kilowatts of power from the 70-80 tonnes of organic waste that arrives at the facility daily. The incineration plant in Phuket collects 350-370 tonnes of waste each day and is able to produce 2.5 megawatts of power from 250 tonnes of this waste. Not only are these plants able to eliminate waste in these regions but they are also able to create usable energy from it. The PCD claims that the keys to successful waste management are maximized recycling, good management, efficient technology, proper regulation, and private endorsement (Nokyoo, 2010). These same factors are likely what will lead to a successful waste tire management program in the future.

2.4.2. Current waste tire management strategies and statistics

Although waste tires are included in solid waste programs and regulations, tires are frequently handled differently than other waste. According to the Pollution Control Department, the waste tire management process in Thailand is a "free-market-based system" (PCD, 2011). In Thailand, the typical process of collecting waste tires to be recycled or disposed of first involves an individual bringing their waste tires to a garage. Many garages give a small nominal compensation to the consumer for their waste tires. Once collected at the garage, these tires are often bid on by "tire collectors" who will buy large amounts to sell to reclamation or other tire recycling companies (Ou-Udomying, 2013). These companies are also able to purchase large numbers of scrap tires from leading tire manufacturing companies such as Michelin, Bridgestone, and Yokohama, who sell or give these scrap tires to authorized facilities.

The approximately 400,000 to 600,000 tonnes of used or waste tires generated every year in Thailand are treated in a number of ways. In 2011, the PCD reported that nearly 380,000 tonnes are "disposed or unaccounted for", a category that includes landfilling, open dumping, and open burning, among other unknown destinations. Approximately another 120,000 tonnes were recycled through a variety of means, including reclamation, tire-derived aggregate, and reuse in small-scale projects. About 80,000 tonnes were either retreaded or sold as second-hand tires, and the majority of the remaining 20,000 tonnes were used for tire-derived fuel or pyrolysis applications (PCD, 2011). An analysis of these statistics can be found in Chapter 4: Results and Analysis. The breakdown of used and waste tire distribution can be viewed in Table 4 below.

Table 4 - Thailand Waste Tire Management Statistics (PCD, 2011).

Method	Tonnes of Waste Tires
Disposed	379,500
Recycled	121,000
Reused	81,000
Used as fuel	18,500

2.5. Factors and Constraints of Waste Tire Management in Thailand

There are many economic, social, environmental, infrastructural, and political factors that have an effect on waste tire management. Some of these factors are common to many countries, while others are specific to Thailand. Although some of these factors provide benefits for various waste tire management stakeholders, many can constrain potential waste tire management strategies and their implementation in Thailand. The following sections will provide an overview of the various factors and constraints that will need to be considered when recommending or implementing changes to Thailand's current waste tire management system.

2.5.1. Economic factors and constraints

With any waste management strategy, there are not only costs associated with carrying out the recycling or disposal of waste, but also with creating, implementing, and enforcing the programs. It is essential to consider how a proposed waste tire management program would be funded. In countries with successful waste tire management systems such as the United States and Japan, the government is responsible for funding many of these types of programs, but many companies take responsibility for some of the expenses in order to collect and utilize the resource of waste tires (EPA, 2012). There is a worldwide market for waste tire products, and the companies that require this type of material often do not have their own facilities to create it. Therefore, they have to purchase this scrap tire material from tire recyclers or collect it on their own (RMA, 2012).

In Thailand, financing by private organizations is the primary source of funding for the collection and utilization of waste tires (Ou-Udomying, 2013). Throughout the world, and in Thailand, there are companies that buy scrap tires for various purposes. In most cases, the companies purchase the waste tires and use their own private facilities to turn them into tire-derived aggregate that can be used for various projects. Other companies retread tires for profit. Some facilities focus on producing tire-derived fuel, which they use to create energy for sale or for use in their own factories (DEP, 2011).

Government funding is also an indirect part of the financing for waste tire management in Thailand. It is largely unclear which agencies in the Thai government provide funding for the disposal and recycling of waste tires specifically, since no official waste tire management programs exist. Thailand's overall municipal solid waste management program, which includes waste tires, is operated by the Pollution Control Department that is funded by the Royal Thai Government budget (Nokyoo, 2010). Additionally, each province has a Department of Public Cleansing, which is directly responsible for municipal solid waste collection and disposal. This service is partially funded by fees paid by residents of the province and the remaining expenses are subsidized by the Royal Thai Government (Sakulrat et al., 2002). Regardless of the location, no waste tire management strategy will be effective without proper funding and this economic constraint is a factor that needs to be considered in the evaluation of the proposed strategies.

2.5.2. Social factors and constraints

Waste tire management programs have the potential to create mixed social reactions. The societal reaction to a waste tire management strategy can significantly affect the level of success of the program because of the fact that waste tire producing consumers are the first link in the waste tire management chain. Though some waste tire management strategies are less socially acceptable than others, all have advantages and disadvantages. In addition to the factual pros and cons of these strategies, people have preconceived notions concerning some methods for waste tire management which may or may not be properly informed (Reisman & Lemieux, 1997). It is common knowledge that a variety of reactions should be expected from any change, due to varying personalities or perspectives.

Some solutions, such as retreading, have generally been met with a largely positive response. For example, as discussed previously, the government of the United States has embraced the idea of retreading tires and has begun to use them on all government vehicles. The social acceptance of retreaded tires comes from the obvious benefits of reduced necessary materials, reduced waste, and a safety level equivalent to that of new tires. Additionally, there are few, if any, drawbacks (*Facts about the Industry*, 2011). Evidence suggests that some strategies, like reuse as playground equipment or reuse in civil engineering projects, would also likely meet little opposition. The playground projects created by Marcus Veerman have been greeted with an overwhelmingly positive response (Taylor, 2012), and civil engineering projects, like backfilling for highways, have proven successful in the United States (Humphrey, 2003). The cost effectiveness and small or non-existent environmental impacts of these projects make them publicly acceptable (Humphrey, 2003).

Other solutions, particularly those involving incineration of waste tires, have been polarizing. Since unregulated tire fires are notorious for producing toxic smoke, many people assume that incineration facilities must also release a dangerous level of pollutants (*Greenpeace*, 2012). While tire incineration facilities are clean relative to facilities using natural fossil fuels when they operate as designed, in certain cases, tire facilities do not perform at a standard comparable to their design intent, exacerbating the public concern over the establishment of these facilities (EPA, 2012) (Carman, 1997). On multiple occasions throughout the world, protests against incineration facilities have resulted in a temporary shutdown or permanent relocation (*Greenpeace*, 2012). Through our research, we discovered one instance of a Thai community successfully protesting the operation of a tire incineration facility which was using improper techniques and producing an unhealthy amount of pollutants (Thai Press Reports, 2010).

Along with social polarization on many waste tire management strategies, other issues also need to be addressed in a comprehensive waste tire system. The spread of incorrect information can cause significant resistance to a new program, and once established these resistances are hard to rectify (The Lancet, 2010). Experts on waste management may differ in their opinions on which technology is best for a given situation, as well, causing further division of public opinion. Waste tire management solutions will need to be properly justified and publicized in order for the public reaction to be generally positive (Burgert, 1993).

Willingness of stakeholders to participate in a waste tire management system is often crucial to its success (UNEP, 2009). Participation of all involved demographics is required in order for a given program to work. Consumers who generate waste tires must be willing to assist in the collection process. Automobile shops and tire collectors must do their part as middlemen, purchasing or receiving waste tires from consumers, safely storing them, and eventually selling them to businesses in bulk quantities for profit. Business owners must follow regulations in order for the process to remain environmentally conscious, and regulators or policymakers must create and enforce policies designed to regulate the actions of other stakeholders.

Stakeholders are also more likely to accept and participate in a new system if they are given the opportunity to participate in its establishment (Bovey & Hede, 2001). For example, the location of a new waste management facility may be a cause for concern among local residents, who generally oppose the construction of these facilities in their neighborhood (Ministry of the Environment, 2005). If stakeholders involved in the business of waste tire management are included in discussions concerning new policies, they may be more accepting of these new policies, and the policies may prove more effective as a result. Stakeholder involvement in the establishment of a waste management system can be as important as their involvement in the system itself (UNEP, 2009).

2.5.3. Environmental factors and constraints

There are many environmental issues that are associated with waste tire management. Concerns such as pollution and sustainability are important related environmental factors. If pollution levels are not considered with the management strategy, public health and safety can be placed at risk. Furthermore, the ability of the strategy to be maintained at a steady level without exhausting natural resources is another significant consideration.

Environmental constraints are limited to the geography and climate of a region. Geographic characteristics of a location can inhibit performance of a waste tire management strategy. In Thailand, the tropical climate impacts the effectiveness of many types of waste tire management strategies. For instance, landfilling of waste tires can be negatively affected by higher temperatures. According to the Environmental Monitoring and Assessment Journal, higher methane production rates within landfills can be caused by rapidly degradable organic carbon in waste, combined with high temperature and moisture content in tropical regions (Wangyao et al., 2010). For the same reason, tires float to the surface of the landfill, forming openings and allowing tires to self-combust. Environmental factors are an important consideration when recommending and developing technologies for waste tire management. In order for a method to be considered environmentally feasible, it will need to be environmental conscious and not cause significant harm to the nearby region.

2.5.4. Infrastructural factors and constraints

Any successful waste tire management strategy must have the necessary supporting infrastructure in order to function as intended. Infrastructure can have a significant effect on the ability of tire management facilities to operate at a full capacity, as well as to produce waste tire byproducts competitively. For many types of waste tire management facilities, appropriately sized processing plants with designated space for storage of raw materials, processing sites, and a warehouse for products are essential in order to operate effectively (USITC, 2009). Additionally, certain technologies may require very specific infrastructure that may or may not already exist. Waste tire recycling or reuse in Thailand may face several other types of infrastructural constraints, such as electricity supply, capable drainage systems, and access to transportation networks (Institutional Investor, 1994).

For example, due to the lack of adequate electricity infrastructure in many poorly developed rural parts of Thailand, tire recycling facilities may have to rely on more expensive on-site power generators, which further increases associated costs (Oxford Analytica Ltd., 1990). Thailand also has a persistent problem with flooding that occurs in almost every rainy season, and because the pumping systems often exceed capacity, drainage and flooding occurs along many city roads. This infrastructural issue is something that needs to be considered when constructing any type of facility. Additionally, a new building code is in the process of enforcement, making it mandatory for every building under construction to have its own rainwater storage tank which puts additional requirements on the construction of waste tire related facilities. Infrastructural limitations also include a shortage in Thailand's own ports and terminals for the shipment of products (Institutional Investor, 1994).

Another important consideration about infrastructural constraints is the process of waste tire collection. Collection of waste tires is often more challenging in rural areas that have less convenient access to road networks and longer distances to travel to properly dispose of waste tires. Even when waste tire recycling does take place in rural areas, it can be more difficult for the byproducts to find a market and to transport the recycled goods to cities (Burgert, 1993).

2.5.5. Political factors and constraints

Political factors and constraints encompass all issues related to policies, regulations, laws, and enforcement. In Thailand, political constraints include environmental law and policy as well as the degree to which these are enforced (EPA, 2012). While national laws concerning the disposal of municipal solid waste do exist in

Thailand, there are none that are specific to waste tires (Sakulrat et al., 2002). Additionally, even related laws that would encompass waste tires are only as powerful as the enforcement they receive.

2.5.5.1. Defining waste tires in environmental law

According to Thai law, waste tires fall under the category of municipal solid waste. In the Regulation and Guideline for Solid Waste Management, a document created by the PCD, municipal solid waste in Thailand is described as "any solid waste generated from community activities, e.g. residential household, commercial and business establishments, fresh market, institutional facilities and construction and demolition activities, excluding hazardous and infectious wastes" (Sakulrat et al., 2002). The regulation entitled "Treatment of Waste or Disused Substances" of 1997 clearly lays out which substances are considered hazardous waste. Hazardous substances are flammable, corrosive, toxic, or leachable. In total, approximately 1,000 individual substances are considered hazardous waste. "Treatment of Waste or Disused Substances" also gives explicit guidelines for industrial waste, which may not leave the factory of origin except for detoxification, treatment, disposal, or sanitary landfilling. This regulation is intended to ensure that all waste tires in the municipal waste stream are originating from municipal sources (Zichichi, 2003).

2.5.5.2 Relevant environmental law

Municipal solid waste standards and regulations are dictated by a number of laws and policies. Individual laws and policies can be seen below in Table 5 along with their year and purpose.

Table 5 - Relevant Environmental Laws (WEPA, 2010).

Public Cleanliness and Orderliness Act (PCOA), 1992	Public order banning public dumping or littering in Bangkok Metropolis and Pattaya City. Delinquents are punishable by a fine.
National Environmental Quality Act, 1992	Act promoting citizen participation in environmental quality. Also specifies the responsibilities of the NEB and PCC.
Factory Act, 1992	An overall enormous legislation that, among other

	things, prevents factory or industrial waste from entering the municipal waste stream. Also outlines penalties for violators including revoking of professional licenses, fines, and criminal penalties.
Public Health Act, 1992	Stipulates the responsibilities of local governments in treatment and collection of solid waste.
Policy and Perspective Plan for Enhancement and Conservation of National Environment Quality, 1992 (Enacted in 1997)	Describes plans and goals of Thailand over the next twenty years. More information on this law can be found Chapter 4, Section 4.4..

2.5.5.3. Organizations Involved in the Political Process

There are six main organizations involved in the political process, in addition to the many provincial and other local governments involved. The first of the six organizations is our sponsor, the NSTDA. Additional organizations are all listed in table 6 below with their functions related to municipal solid waste management. Three of these departments, the Office of Environmental Policy and Plan, the Pollution Control Department, and the Department of Environmental Quality Promotion, are subdivisions of the Ministry Of Science, Technology, and the Environment (MOSTE).

Table 6 - Organizations Involved in Municipal Solid Waste Management (Sakulrat et al., 2002).

Organization	**Function**
National Science and Technology Development Agency (NSTDA)	Researches technologies and sponsors the research by private or academic sources.
National Environmental Board (NEB)	Submits environmental law or policy, or amendments to the laws or policies, for approval by the cabinet. Also considers or approves environmental standards for laws proposed in other fields.
Pollution Control Committee (PCC)	Reports on pollution, remediation, and pollution prevention. Proposes measure to control pollution through taxation or standards. Generally reports to the NEB with findings.
Office of Environmental Policy and Plan (OEPP)	A subdivision of MOSTE. Prepares and evaluates policies and plans and also provides guidelines to local governments.
Pollution Control Department (PCD)	A subdivision of MOSTE. Monitors pollution nationwide and prepares policies

	for municipal solid waste management. Also develops methods and technologies to enhance municipal solid waste collection methods.
Department of Environmental Quality Promotion (DEQP)	A subdivision of MOSTE. Collects and runs databases on environmental information. Also promotes public awareness and private enterprise.

Political factors and constraints impact the waste tire systems at all levels, from the national government down to the municipal level. Though this is a collection of all political factors, the majority of them are constraining factors. While these laws should all hypothetically be followed and regulated, information gathered through site visits and interviews does indicate that these regulations may be followed very sporadically with certain companies following all of the environmental regulations and others following few if any. Further information on Thailand's environmental policies can also be found in the Results and Analysis Chapter, in Section 4.4.

2.6. Chapter Summary

Our background research indicates that there are many issues associated with waste tires and that it is a growing problem. However, there are ways to manage waste tires. There is evidence to suggest that Thailand is in need of a specialized waste tire management program to aid their current solid waste management strategies. The many issues associated with waste tires, primarily mosquitoes and rodents, tire fires, and aesthetics cannot be ignored and would be best addressed by utilizing several of the recycling and elimination strategies mentioned. We have identified Thailand-specific benefits and drawbacks for each waste management technologies: including landfilling, incineration for energy, reuse in civil engineering projects and consumer goods, and retreading. By using the UNEP's guide as a basis for our research, we have additionally gathered information concerning the main facets of a successful waste tire management system and their current status in Thailand. Developing recommendations for a complete waste tire management strategy in Thailand requires further examination of each method and evaluation based on economic, social, environmental, infrastructural, and political constraints mentioned in this chapter as well as additional Thailand specific factors.

Chapter 3: Methodology

Thailand is currently faced with the significant challenge of safely managing more than 600,000 tonnes of waste tires per year. Thailand's National Science and Technology Development Agency is seeking information for the purpose of recommending successful programs to regulate and manage these waste tires. The goal of this project was to investigate different options for a viable, long-term waste tire management strategy for Thailand.

To accomplish this goal we completed the following objectives:

1) Characterize the waste tire problem, existing practices, and potential management strategies specific to Thailand.

- We first focused on obtaining and characterizing Thailand-specific data about problems with waste tires, currently used waste management systems, and potential management strategies.

2) Evaluate waste tire processing technologies based on economic, social, environmental, political, and infrastructural factors applicable to Thailand.

- Using available data, we were able to analyze and evaluate the benefits and disadvantages of commonly used technologies in a feasibility matrix based on economic, social, environmental, political, and infrastructural factors applicable to Thailand. These methods and technologies include landfilling, open dumping and open burning, retreading, reclamation, direct use, punched, cut, and stamped, small-scale application, incineration for energy, and pyrolysis.

3) Evaluate potential waste tire management systems for Thailand based on United Nations Environment Programme guidelines.

- We then evaluated the potential of various waste tire management systems based on guidelines supplied by the United Nations Environment Programme, which highlight the necessary components of a successful waste management program. This involved conducting case study comparisons between Thailand, the United States, and Japan.

4) Develop recommendations for future systems, technologies, and further research.

- Based on our findings, we were able to develop recommendations that will assist the NSTDA in determining which methods for waste tire management should continue to be used and improved, which new methods should be developed and implemented, what information still needs to be gathered, and how to proceed with the collection of that information.

To complete our investigation of options for waste tire management we adopted a framework for policy analysis (Bardach, 2012). Table 7 below highlights Bardach's Eight Fold Path for Policy Analysis and the associated research objective.

Table 7 - Bardach's Eight Fold Path for Policy Analysis (Bardach, 2012).

Step #	Eightfold Path	Research Objective
Step 1	Define the Problem	1
Step 2	Assemble Some Evidence	1
Step 3	Construct the Alternatives	1
Step 4	Select the Criteria	2
Step 5	Project the Outcomes	3
Step 6	Confront the Trade-Offs	2 & 3
Step 7	Decide	4
Step 8	Tell Your Story	4

The following sections describe the methods that we adopted to achieve each of the objectives listed above.

3.1. Characterize the waste tire problem, existing practices, and potential management strategies specific to Thailand

In order to characterize the waste tire problem in Thailand, we identified the existing practices for waste tire management and potential future strategies. Acquiring and analyzing this information was an essential first step in order to investigate potential options for a long-term waste tire management strategy.

Defining the problem involved locating data related to the various health, safety, and environmental concerns that improperly managed waste tires create in Thailand and the issues caused by existing waste tire management practices. These data include statistics such as the amount of waste tires generated annually in Thailand and the percentage of those waste tires that are reused or recycled. Much of this information was made available through a contact at the Waste Management Bureau of the Pollution Control Department (PCD). This agency provided us with a 2011 report that contains statistics on the utilization and disposal of waste tires in Thailand. Further information can be found below in Table 8, row 1.

The next part of this objective was to determine which current practices for waste tire management are used in Thailand and what alternative strategies are commonly used in other countries. Although our background research discussed many of the methods for waste tire management that are used throughout the world, it was important to gather information on the methods currently used in Thailand and identify which strategies could be implemented in the future. In order to accomplish this task, we conducted interviews at several waste tire management facilities to discover more information on different management technologies including rubber reclamation, pyrolysis, and tire incineration. We were also able to interview experts on pyrolysis at a local university. Personal connections of both our group members and sponsor were extremely helpful when establishing these contacts.

Our first site visit and interview was with Mr. Boonharn Ou-Udomying at his rubber reclamation company, Union Commercial Development. He was able to provide us with information about this technology, including a detailed description of the reclamation process. We also received supplemental information on the types of new technologies that are not currently used in Thailand, such as ultrasonic degradation, as well as statistics on current waste tire management in Thailand. In addition to answering our interview questions, he also provided insight into the overall structure of the rubber industry and the methods for waste tire collection. Further information about this interview can be viewed in Table 8, row 2.

The second site visit and interview was with Mr. Decha Kittisuphaluk at Bangkok Tire Refinery in Chachoengsao province. We obtained information about the company and the pyrolysis process through answers to our interview questions, and a tour of the factory. During the tour, the full pyrolysis process was explained in detail and we were able to see the machinery operating. Additionally, Mr. Decha provided information about the pyrolysis byproduct market. Further information about this interview can be viewed in Table 8, row 3.

Another interview and site visit was conducted at Mahaphant Fibre-Cement with Mr. Wichit Prakaypan. The interview provided us with information about incinerating tires for energy, which the company did until 2010. Information about how the company collected tires for energy production was also obtained. Additionally, we were able to view the incineration facility and see other types of waste products being burned for energy production. Further information about this interview can be viewed in Table 8, row 4.

Finally, Professors Somrat Kerdsuwan and Krongkaew Laohalidanond at King Mongkut's Institute of Technology in Bangkok were interviewed about pyrolysis and incineration of waste tires. Information on the details of those processes and their drawbacks and advantages specific to Thailand were obtained. Furthermore, they provided recommendations for a better waste tire management strategy for Thailand and provided examples of foreign nations with what they considered to be successful waste tire management systems. A summary of this information can be viewed in Table 8, row 5.

To organize the collection of these data, we developed an interview guide template in order to clearly identify questions and record the answers. In addition, prior to each interview, site-specific questions were developed so that questions were tailored for each site. At the interviews and site visits, questions and discussions were recorded on paper. These interviews and the answers received were analyzed and cross-referenced when possible in order to ensure accuracy. The interview guide template and all of the individual interview guides and related responses can be viewed in Appendix E. A site visit spreadsheet was also created to clearly organize and monitor the progress of obtaining and completing site visits and interviews. This spreadsheet, available in Appendix F, contains the name and location of the site, contact information, and final progress of the interview.

Through the completion of our first objective, we were able to identify the specific needs for waste tire management in Thailand and characterize current and potential waste tire management strategies. This information enabled us to begin analyzing commonly used technologies and evaluating potential waste tire management systems.

Table 8 - Objective 1: Site Visit and Interview Information

	Objective 1:				
	Organization	**Type**	**Contact**	**Date**	**Types of information gathered**
1	Pollution Control Department	Government Agency	K’ Nuchanart Leelakahakit	Email-1/16/13	Current statistics: number of waste tires generated annually (600,000), % of each technology used in Thailand, etc.
2	Union Commercial Development Co.	Reclaiming	K' Boonharn Ou-Udomying	Site Visit/ Interview-1/19/13	Reclaiming process information, Current statistics: number of waste tires generated annually (400,000), current technologies used in Thailand
3	Bangkok Tire Refinery Co., Ltd.	Pyrolysis	K’ Decha Kittisuphaluk	Site Visit/ Interview-2/4/13	Pyrolysis process, byproduct market
4	Mahaphant Fibre-Cement Public Co, Ltd.	Incineration	K’ Wichit Prakaypan	Site Visit/ Interview-2/8/13	Incineration, uses of reclaimed rubber at facility
5	KMIT	University	Prof. Somrat Kerdsuwan Prof. Krongkaew Laohalidanond	Interview-1/24/13	Pyrolysis, countries with successful waste tire management practices

3.2. Evaluate waste tire processing technologies based on economic, social, environmental, political, and infrastructural factors applicable to Thailand

Our next objective was to analyze and evaluate the common technologies used for waste tire management. Thailand's waste tire management strategy must balance a number of different constraints and factors in order to be considered feasible. Any potential solution must address the economic, social, environmental, political, and infrastructural constraints and factors outlined in our background chapter. The bases for these constraints were previously known: the solution must be economically and environmentally sustainable, have supporting infrastructure, and be socially and politically acceptable. However, specific constraints within each of these subcategories were discovered through our research in Thailand.

The factors and constraints specific to Thailand could not have been accurately determined without the information that was gained from our site visits. When conducting interviews, questions were constructed so that responses would give us information on the various types of constraints. For example, in order to gain insight on various economic factors related to each type of waste tire management technology, we asked questions about topics such as profitability, cost of facility construction, and future industry growth. At our interview at Union Commercial Development, we were able to obtain information about the cost of the construction of their new facility, as well as information that allowed us to draw conclusions about the profitability and success of the company. At the incineration facility, Mahaphant Plant, we received details about costs and benefits relevant to the facility. In addition, Mr. Wichit Prakaypan presented information on new waste tire technologies, which could lead to growth of the industry. Further information about these interviews can be found below in Table 9, rows 1 and 2.

Gathering information about social factors involved site visits and interviews with companies. Additionally, independent research was conducted on the subject of social psychology. In order to implement and sustain any type of new technology or method for waste tire management, human health and safety must be taken into account, as mentioned in our background chapter. However, it should also be socially accepted in order to be successful. Two of our interviews allowed for the formulation of certain conclusions about social factors related to waste tire management technologies. First, our site visit at the National Science and Technology Development Agency, we asked questions about how the organization publicizes information about new technology they develop. The Agency described the process, which typically includes public forums and brochures. Second, an interview with Marcus Veerman, director of PlaygroundIDEAS, provided with us with insight into what types of projects involving waste tires are widely accepted. These types of responses allowed us to develop recommendations to best suit these communication strategies. Further information about these interviews can be found below in Table 9, rows 3 and 4. In addition to interviews, further independent research was conducted on social acceptance and willingness to adopt changes.

In order to discover information about environmental factors, observations were made at site visits. Interviews at waste tire management facilities did not reveal information specific to environmental constraints or problems due to the companies' inability to discuss this aspect of their operations. However, from observing the various facilities we were able to draw certain conclusions about the environmental impacts of specific technologies. For example, some of the companies were clearly lacking enforcement of environmental policy and were evidently not operating in an environmentally conscious manner. However, some of the other companies appeared to be closely following regulations and exhibited very few negative environmental practices.

These environmental factors also have a political context. Gathering information about political factors involved both site visits and interviews with companies. Additionally, independent research was conducted on the subject of environmental policy in Thailand. To organize the interview process, we employed the interview guide (in Appendix E) to more effectively interview sources. We also used our site visit spreadsheet (available in Appendix F) to clearly organize and monitor the progress of obtaining and completing site visits and interviews related to this objective.

Throughout site visits and interviews, we were able to obtain limited information on various political factors related to each type of waste tire management technology. This is largely due to the absence of laws and regulations specific to waste tires. However, at the interview at Union Commercial Development, Mr. Boonharn discussed the need for regulations specific to waste tire management. The interview conducted with Mr. Wichit Prakaypan at Mahaphant Fibre-Cement provided more information on specific air and water pollution regulations and their enforcement related to waste incineration. Further information about these interviews can be found below in Table 9, rows 1 and 2. Although there are no regulations related to waste tires specifically, there are many laws regarding municipal solid waste, therefore independent research was required in order to investigate in further detail about environmental law in Thailand.

Infrastructural factors are also an important aspect of waste tire management technologies. In order to gain insight on various infrastructural factors related to each type of waste tire management technology, we asked questions about topics such as what materials are required for the process, how large facilities have to be, and what types of machines and technological components are needed. For example, some of our interview questions with Mr. Boonharn provided us with answers about aspects such as the size of the company's two facilities and the equipment necessary for the reclaiming process. Upon interviewing Marcus Veerman of PlaygroundIDEAS, we obtained information about the infrastructure needed to support his playground projects. These data, in addition to supplemental information, allowed us to draw conclusions about infrastructural factors, and take them into consideration while assessing infrastructural requirements for each type of waste tire management technology.

In order to evaluate each of the technologies based on economic, social, environmental, political, and infrastructural factors applicable to Thailand, we developed and utilized a feasibility matrix (see template below in Figure 15). This matrix involves weighing each primary technology against each factor. For each technology, the pros and cons related to each factor were determined and listed. These results were based on information obtained through extensive background research, interviews, and our own observations. Once this feasibility matrix was developed, we used it as a visual aid to evaluate which technologies were most suitable for continued use and development.

After analyzing this organized information in the feasibility matrix, we were able to evaluate and draw conclusions about each type of waste tire management technology. Completion of this objective and the evaluation of potential technologies allowed us to begin analyzing Thailand's current waste tire management system as a whole, leading to our third objective.

		Factor:	**Economic**		**Infrastructural**		**...**
Method:							
Landfilling	Pros						
	Cons						
Incineration	Pros						
	Cons						
...	Pros						
	Cons						

Figure 15 - Feasibility Matrix Template

Table 9 - Objective 2 Information: Site Visit and Interview Information

	Objective 2:				
	Organization	**Type**	**Contact**	**Date**	**Information**
1	Union Commercial Development Co.	Reclaiming	K' Boonharn Ou-Udomying	Site Visit-1/19/13	Economic, environmental and infrastructural factors
2	Mahaphant Fibre-Cement Public Co, Ltd.	Incineration	K' Wichit Prakaypan	Site Visit/ Interview-2/8/13	Economic, environmental, political factors
3	NSTDA	Government Agency	P' Jiratchaya Duangburong	Site Visit-2/6/13	Social factors

		(Sponsor)			
4	PlaygroundIDEAS	Playgrounds	Marcus Veerman	Skype-1/24/13	Social and infrastructural factors
5	Bangkok Tire Refinery	Pyrolysis	K' Decha Kittisuphaluk	Site Visit/ Interview-2/4/13	Environmental factors

3.3. Evaluate potential waste tire management systems based on United Nations Environment Programme guidelines

Our third objective was to evaluate the potential of various waste tire management systems based on guidelines supplied by the United Nations Environment Programme, which highlights the necessary components of a successful waste management program (UNEP, 2009). This evaluation required the analysis of the technologies, policies, institutions, stakeholders, and financial mechanisms of Thailand's current waste tire management system.

In order to provide a basis for evaluating options, we used case study comparisons to show the relationship between existing systems in other nations and the current system in Thailand, permitting us to draw parallels and identify missing components. This method involved conducting independent research on both the United States and Japan, the countries we chose to compare and contrast with Thailand. The United States provided an example of a country with a comprehensive and successful waste tire management system, while Japan provided an example of an Asian country, comparable to Thailand, that is still able to effectively manage waste tires.

These case study comparisons were organized by each component of a waste management system as defined by the UNEP guidelines, as described in Section 2.2.. By illustrating the similarities and differences between individual components of three waste tire management systems, we were able to provide an organized and concise comparison. For example, for the technological aspect of a waste tire management system, we discussed how the United States, Japan, and Thailand use similar technologies for waste tire management, but vary in their comparative usage. Full case studies on both the United States and Japan are available in Appendices G and H respectively. This process helped us to identify best practices in the United States, Japan, and Thailand as well as what components of a waste tire management system are missing or incomplete in Thailand. Ultimately, completing this objective allowed us to proceed to developing recommendations.

3.4. Develop recommendations for future systems, technologies, and further research

Based on our findings from the completion of the combination of the three previous objectives and extensive background research, we were able to develop recommendations that will assist the NSTDA in determining which methods for waste tire management should continue to be used and improved, which new methods should be developed and implemented, what information still needs to be gathered, and how to proceed with the collection of that information.

We developed recommendations for future practices based on what we identified to be successful aspects of other countries' waste tire management systems as well as what technologies are best suited for Thailand. Recommendations were also based on the identification of what strategies have failed in the past and should be avoided. This information was obtained through the completion of the feasibility matrix in conjunction with the case study comparison process. The feasibility matrix assisted us in evaluating each type of commonly used technology for waste tire management and identifying which of the methods are best suited for Thailand. Using this evaluation, we were able to develop recommendations about what types of technologies should be further developed in Thailand, and which types should be minimized. Additionally, the case study comparisons allowed us to identify similarities and differences between Thailand's current waste tire management system, and successful systems in other countries. This resulted in the ability to develop recommendations on which components of Thailand's waste tire management system should be altered or improved, and which components do not require substantial changes.

This objective also involved discovering gaps in information, as well as identifying and recommending how an organization could obtain this information in the future. For example, through our research we recognized the currently limited availability of information specifically related to the evaluation of potential waste tire management systems. Because the development of this missing information is beyond the means and timeframe of this project, we have developed recommendations concerning further research on these topics. These methods will provide an overview of the means of gathering this information when required. For example, we have recognized the limited availability of information on social factors and constraints, and therefore we have developed a questionnaire for private car owners as a means for collecting further information. This questionnaire can be found in Appendix I. We also identify possible inaccuracies in some of the statistics we use due to the unavailability of cross-references. By identifying gaps in our research, we were able to highlight what additional information is necessary in order to continue the development of an improved waste tire management system for Thailand.

By identifying the needs for waste tire management in Thailand, evaluating common technologies based on economic, social, environmental, political, and infrastructural factors, and evaluating potential waste tire management systems based on UNEP guidelines, we developed recommendations regarding waste tire management in

Thailand. The next chapter will present the analysis that is the basis for our recommendations.

Chapter 4: Results and Analysis

This chapter contains the findings of our research including analysis and evaluations. The tools used to aid this process include our comprehensive study of Thailand's waste tire life-cycle stream, a technology feasibility matrix, and case study comparisons.

4.1. Waste Tire Flow in Thailand

The flow chart below (Figure 16) is a result of our findings regarding Thailand's waste tire life cycle stream and will serve as a deliverable for this project. It includes all facets of the flow of waste tires in Thailand, from the creation of the waste tire through its final repurposing or disposal.

As seen in the flowchart, waste tires enter their end-of-life cycle after being brought to local car shops or garages by automobile owners. It was found that the primary technologies for waste tire recycling and reuse in Thailand include heat utilization, tire reclaiming, tire-derived aggregate, and direct use. However, we could not find specific statistics available describing the use of each of these strategies, since the waste tire management report from the Pollution Control Department categorized waste tire management methods as: reused, recycled, used as fuel, and disposed or unknown. Some percentage of end-of-life tires end up in landfills or are dumped openly in less industrialized provinces of Thailand. Although general information concerning disposal, reuse and recycling was available, no specific statistics concerning individual technologies were obtained, and no information on waste tire management was available. Moreover, it is known that export of waste tires is illegal in Thailand. However, through interviews and site observations conducted by our group, we have discovered that selling waste tires to other countries in Southeast Asia is a profitable business (Laohalidanond & Kerdsuwan, 2013) (Ou-Udomying, 2013). Still, no statistics are available concerning the import and export of tires in Thailand (Laohalidanond & Kerdsuwan, 2013).

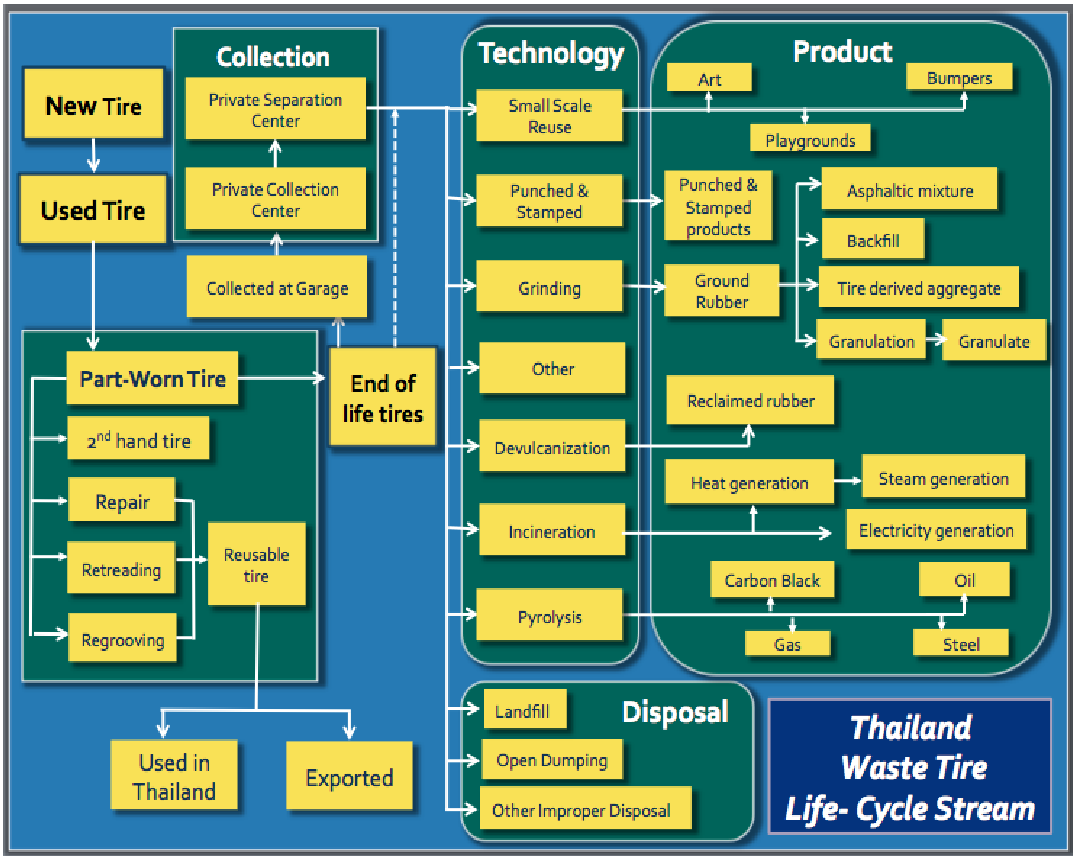


Figure 16 - Thailand Waste Tire Life-Cycle

4.2. United Nations Environment Program guidelines

Though understanding the lifecycle of a tire is crucial to comprehending the complete system of waste tire management, there are other components aside from collection methods and waste tire management technologies that must be addressed. The UNEP has developed guidelines that include five key factors that must be present in order for a new waste management system to be established and have the potential for success. The factors are related policies and regulations and the institutions to support them, proper financial mechanisms, stakeholder participation, and supporting technologies. For evaluation of potential waste tire management systems for Thailand, we adopted the UNEP guidelines as a framework. In this chapter, Thailand's current waste tire management strategies were evaluated using five factors provided by the UNEP in the following order: technologies, policies, institutions, financial mechanisms, and stakeholder participation. A full description of UNEP guidelines may be viewed in Table 10.

Table 10 - UNEP Guidelines (UNEP, 2009)

UNEP Guideline	Description
Technologies	Includes methods of reuse, recycling, and disposal

Policies	Includes laws and acts, regulations, economic instruments (covered under financial mechanisms), and enforcement
Institutions	Includes related governmental agencies
Financial Mechanisms	Includes taxes and fees, levies, subsidies, and support
Stakeholders	Includes waste generators, service providers, private sector, and government

4.3. Findings concerning waste tire management technologies

There are a number of waste tire management technologies currently used in Thailand, many of which are commonly used on a global scale. However, in Thailand, the percentage of waste tires that end up being disposed rather than repurposed is significantly higher than in nations with established waste tire management programs.

Finding #1: In Thailand, waste tires are currently openly incinerated, dumped, and landfilled at high rates in comparison to nations with successful waste tire management programs

Disposal of waste tires through landfilling, open dumping, or open incineration is discussed extensively in the background chapter of this paper. These are all problematic solutions to varying extents, due to the fact that they consume a useful resource without any benefit and have the potential to cause environmental harm. General disposal accounts for approximately 63% of all waste tires in Thailand, though this statistic is not further separated into separate landfilling, open incineration, and open dumping categories (PCD, 2011). The full statistics can be viewed in Figure 17.

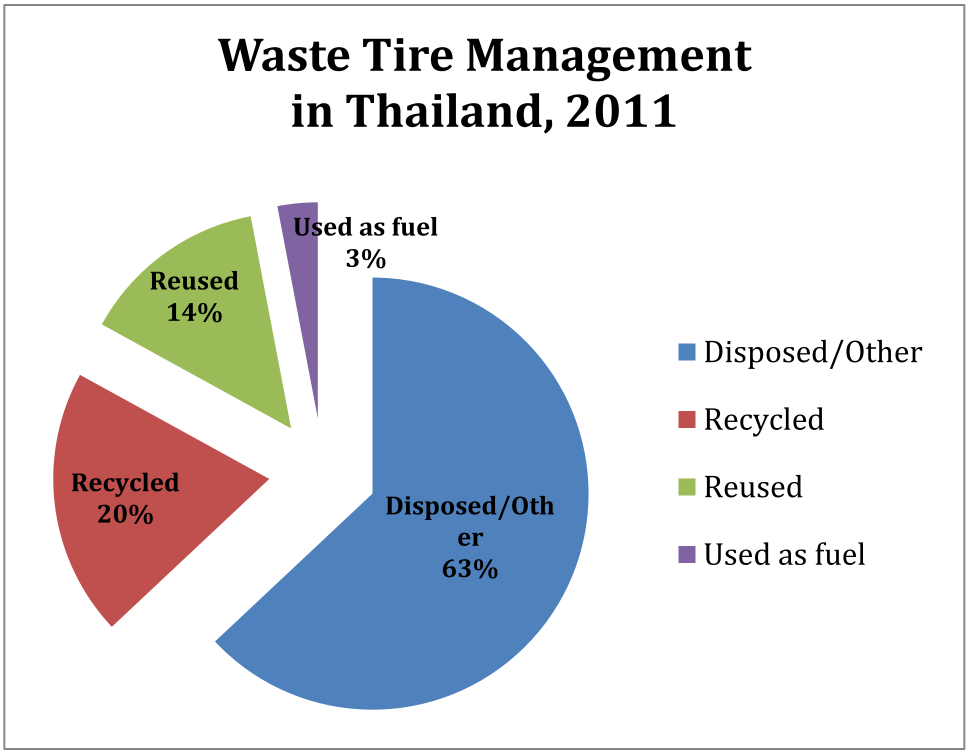


Figure 17 - Waste tires management in Thailand, 2011 (PCD, 2011)

In comparison, the United States and Japan dispose less than 15% and less than 10% of their waste tires, respectively (Japan Automobile Tyre Manufacturers Association, n.d) (RMA, 2011). The majority of the tires disposed in the United States are landfilled, less than 13%, and the only potential source of openly burned or dumped tires is a small 2% of unaccounted for waste tires. Japan's extremely low disposal rate is attributed to the fact that Japan is geographically small and highly industrialized resulting in the need to find alternative end of life uses for waste products and the technological means to support them. Japan also stands to benefit from solutions like reclamation of rubber, since the nation has no domestic rubber production industry (Japan Automobile Tyre Manufacturers Association, n.d). Complete waste tire management statistics of Japan and the United States can be found in Figures 18 and 19 below.

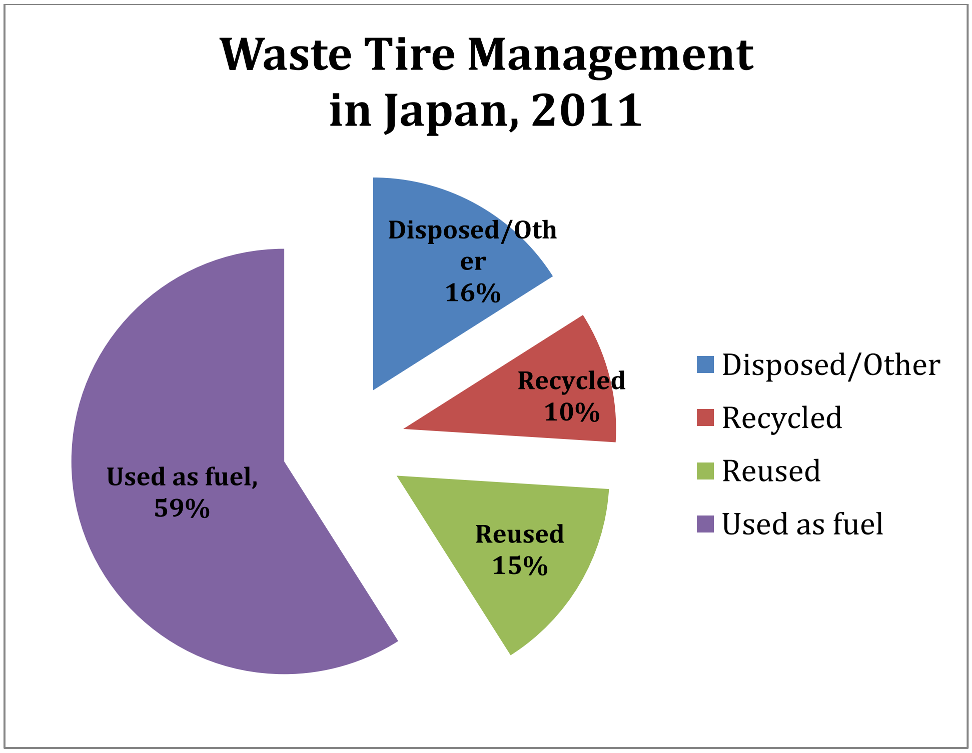


Figure 18 - Waste tire management in Japan, 2011 (Japan Automobile Tyre Manufacturers Association, 2012)

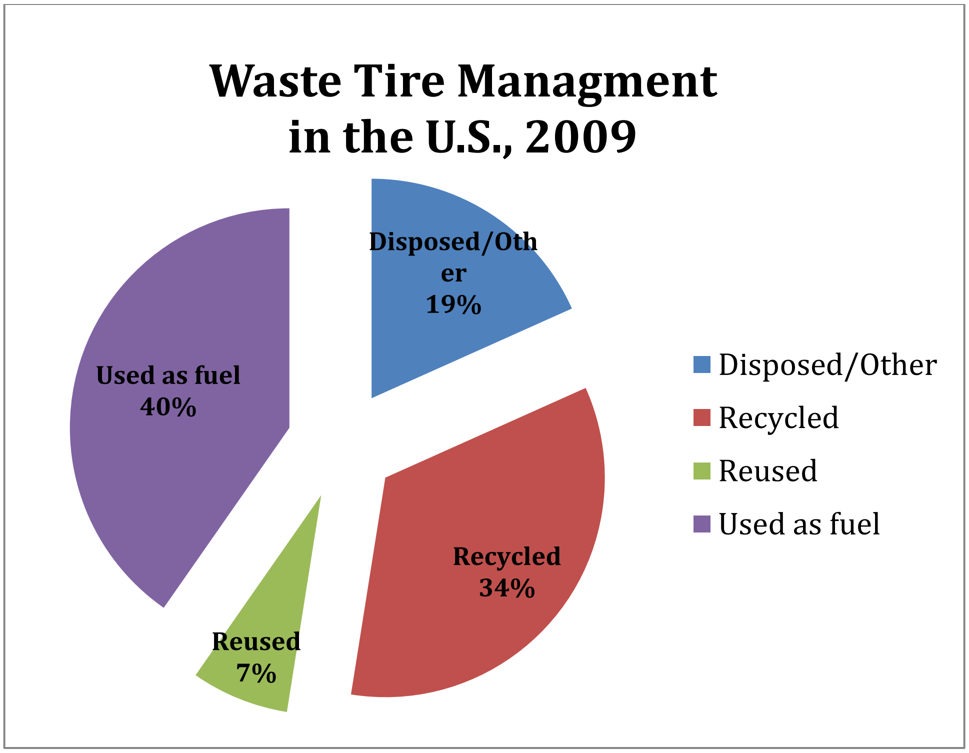


Figure 19 - Waste tires management in USA, 2009 (EPA, 2012)

Finding #2: There are a number of viable waste tire management technologies that could be used at higher rates in Thailand

By evaluating the pros and cons of a variety of waste tire management technologies and as illustrated by practices in Japan, the United States and elsewhere, many technologies are effective for managing waste tires. Several technologies are currently, or have the potential to be, successful in Thailand, such as retreading, grinding for use in civil engineering practices, reclamation, and small-scale projects. Additionally, if further improved in Thailand incineration for energy, and pyrolysis can also be highly effective strategies for utilizing waste tires as a valuable resource. An expansive feasibility matrix detailing our evaluation of all waste tire management methods is available in Appendix J.

Finding #3: Countries with successful waste tire management practices use multiple technologies to manage their waste tires

As shown in Figures 18 and 19 above, Japan and the United States use a variety of waste tire management technologies in order to manage their waste tires. This strategy is advantageous because it lessens a nation's reliance on one waste tire management method while also encouraging innovation and advancement in a range of technologies.

4.4. Findings concerning waste tire management policies in Thailand

This section discusses laws and regulations concerning waste tire management in Thailand. The United Nations Environment Programme identifies policies as one of the key factors of a successful waste management strategy (UNEP, 2009). Currently, no specific laws concerning waste tire management exist in Thailand. Instead, waste tires are defined to be part of municipal solid waste (MSW) and therefore must adhere to corresponding MSW regulations. The composition of municipal solid waste stored in landfills in Thailand can be viewed in Appendix C. However, our site observations and interviews indicate that waste tires are frequently treated separately from solid waste. From our site visits, we learned that tires' physical properties make them difficult to store in sanitary landfills. At the same time, in less industrialized provinces, tires are mostly dumped improperly in nearby forests and roads due to the lack of enforcement and monitoring from local agencies. Additionally, selling tires for either reuse, recycling, or export is much more profitable than landfilling or open dumping. A lack of specific laws and regulations on waste tires makes it harder for the government to keep track of various standards covering every stage of the waste tire management life cycle stream.

Finding #4: Thailand currently has no laws or regulations specific to the management of waste tires

Currently, Thailand has laws and acts in place concerning solid waste management, which by default, encompasses waste tires (Sakulrat et al, 2002). These policies include the Public Cleanliness and Orderliness Act, the Factory Act and the National Environmental Quality Act (WEPA, 2010). A summary of these laws can be found in Table 5 in Section 2.5.5.2., political factors and constraints. In Thailand, the Policy and Perspective Plan for Enhancement and Conservation of National Environment Quality was enacted in 1997. This Plan describes goals of Thailand over 20 years that specifies the desired recycling, collection, and management rates for municipal solid waste. In 1992, Thailand implemented the Policy and Perspective Plan for Enhancement and Conservation of National Environment Quality. This was a twenty-year plan beginning in 1997, and continuing through 2016 (Nokyoo, 2010). Thailand is currently working to reach the goals laid out in this plan. While data is not yet available on the current status of these goals, a number of the plans do concern municipal solid waste as a whole, and therefore waste tires.

The primary sustainable goals of the Policy and Perspective Plan for Enhancement and Conservation of National Environment Quality are:

- To control municipal solid waste management to rate of not more than 1.0kg/capita/day.
- To recover municipal solid waste at the rate of not less than 15% of the total municipal solid waste generated.
- To increase municipal solid waste collection efficiency to 100% in municipalities and to 90% outside municipalities.
- To ensure that each province has a master management plan for sanitary municipal solid waste disposal and every municipality has a proper municipal solid waste disposal system.

Additionally, this Plan highlights relevant system strategies for achieving the desired goals. See Figure 20 below.

- **A Polluter Pay Principle**. This idea is utilized in a number of countries to varying degrees including the United States. This policy would essentially force the party responsible for the generation of the waste to be responsible for treatment or disposal of the waste. This would indirectly discourage polluters from generating waste in the first place, and encourage them to find alternative solutions to their pollution or avoid the creation of pollution is the first place.
- **A buy-back system.** This approach is already used in a number of nations, most notably with car batteries and recently with product packaging. This system keeps used products from becoming waste and saves the company costs on generating new materials. While this approach is generally specific to an individual waste item, it could be implemented with tires since their raw material still has value.
- **Continuous monitoring, investigation and assessment of the problem**, with continual government employee training and education, as well as the promotion of the private sector involvement. While this strategy is broader, it touches on a number of approaches. Continuous, up to date statistics and research can illustrate progress and offer new, innovative solutions. Promotion of the private sector will also help in completing the goals outlined in the *Policy and Perspective Plan for Enhancement and Conservation of National Environment Quality* as well as increasing economic growth. Continuous employee training and education is a further issue of importance for keeping provincial governments on par with national regulations. A municipal solid waste management strategy called the *Solid Waste Expert System* was developed to assist local governments and planning and designing a local waste management strategy.
- **Creation of proper, long-term solid waste management** sites such as sanitary landfills as well as the retrofitting of improperly maintained sites. This approach ensures that waste that no longer has any value as a recycled or reused material is disposed of correctly.

Figure 2020 - Policy and Perspective Plan for Enhancement and Conservation of National Environment Quality in Thailand, 1997 (WEPA, n.d).

There are no laws or regulations in Thailand are specific to waste tires management. However, there are general regulations on air emissions and water pollution standards in Thailand (Prakaypan, 2013). The present situation makes it difficult to monitor the total flow of waste tires, and can, consequently, lead to unmonitored, transboundary diffusion of waste tires (Laohalidanond & Kerdsuwan, 2013). In addition, Thailand lacks local monitoring on various management steps, which prevents the PCD from keeping track of waste transfers between stakeholders in the system, and also overall execution and administration of all policies concerning waste tires (Ou-Udomying, 2013). This may lead to ambiguity in determining current status of the management system and probability and consequences of failure or mismanagement.

Finding #5: Thailand's laws concerning the management of municipal solid waste are comparable to laws in nations with successful waste tire management programs

Though Thailand does not have specific laws concerning waste tire management, this lack of tire-specific laws does not necessarily result in an inadequate waste tire management system. Japan serves as a good example of a country with high waste tire recycling rates, averaging between 85-90%, even though waste tire specific laws do not exist (Tire Recycling Industry: A Global View, n.d). In Japan, waste management law was revised and strengthened in 1997 and 2000 to better control licensing conditions for waste management businesses (Nakamura, 2007). Also, the Japanese End-of-Life Vehicle Recycling Law is intended to improve tire recycling rates.

Thus, Thailand's lack of specific laws related to waste tires does not necessarily mean that successful management of waste tires is inhibited. As seen from Japan's example, waste recycling policies can suffice, if the strategy is enforced and monitored by corresponding agencies, either governmental or private.

4.5 Findings concerning waste tire management institutions

The following findings highlight the lack of systematic data gathering and analysis concerning waste tire management in Thailand. Statistics are important for management, since they allow government or responsible agencies to determine the strengths and weaknesses of current waste tire management practices in Thailand, the number of private or governmental organizations involved, their input, established markets for waste tire products, and identify opportunities for improvement. Having reliable data is crucial to analyzing the relationship between supply and demand, imports and exports, required funding, and profit and loss associated with each one of waste tire management methods. Interaction between regulating organizations and private businesses often leads to the ability to collect more accurate and reliable information (Ou-Udomying, 2013).

Finding #6: No agencies in Thailand are responsible for collecting and reporting statistics concerning waste tire management in Thailand

Typically, the institutions associated with waste tire management are the national, state, and municipal authorities that are responsible for regulating the system. Internationally, these organizations all serve similar roles. The United States agency that is responsible for waste tire management is the Environmental Protection Agency. In Thailand, there is the Pollution Control Department. Japan has the Ministry of the Environment. All of these national organizations are responsible for protecting human health and the environment. There are minor differences in terms of specific policies, but in general these organizations establish regulations designed to reduce or eliminate pollution and human health threats. These institutions are also typically the organizations responsible for data collection and compilation.

In comparison to the United States and Japan, comparatively few statistics concerning waste tire management are available in Thailand. The statistics contained in this report, particularly those concerning processing technologies used in Thailand, were obtained on request from the PCD. These statistics were also significantly less specific than similar statistics publicly available in the United States and Japan. Thailand's waste tire management statistics are divided into the categories of "disposal", which consists of landfilling, open dumping, and incineration, "recycling", which includes reclamation, tire-derived aggregate, and small-scale reuse projects, "reuse", meaning the reuse of second-hand tires or the retreading of waste tires, and "tire-derived fuel" through pyrolysis or incineration for energy. Comparative statistics from the United States and Japan break down these categories much more specifically.

Finding #7: At present, there is limited interaction between regulators and private businesses

During our site visits, we were informed that waste tire management facilities are inspected at least once per year by members of regulating institutions. There appears to be less interaction between the regulating institutions and private companies in Thailand than in either the United States or Japan. In Japan, for instance, the recycling rates are expected to improve further as Japan tightens regulations and strives to improve consumption from end-markets (Tire Recycling Industry: A Global View, n.d). Many people still engage in illegal dumping or illegal transboundary movement of waste in Japan. Local and central governments try to prevent illegal dumping and control the economic gain of those involved in illegal dumping by on-the-spot inspections and administrative penalties (Ministry of the Environment, 2005). Central and local governments realized the difficulty of monitoring municipal waste transfers between different stakeholders within the system, and created a financial mechanism where all stakeholders involved in solid waste management, including average citizens, local businesses, and local governments cooperate (Ministry of the Environment, 2005).

In contrast, Thailand lacks specific information on various management steps, starting from lack of collection centers. Thailand has a scattered waste tire industry structure, where it can be difficult to obtain succinct information on enforcement of laws applying to waste tire management. More attention seems to be paid to bigger corporations or companies in urban areas, where auditors from Pollution Control Department visit two to three times per year and make sure the air and water pollution standards are satisfied (Prakaypan, 2013). However, outside of urban areas and for smaller waste tires recycling companies, enforcement on laws, especially environmental regulations, seems to be sporadic (Laohalidanond & Kerdsuwan, 2013).

4.6. Findings concerning waste tire management financial mechanisms

There are various methods by which waste management systems are funded. We have divided the methods that are commonly used in the United States, Japan, and Thailand into three categories: "user charges", "penalties, fines, and levies", and "private sector participation". Most nations use some combination of these three strategies to fund their waste tire management programs (UNEP, 2009).

Finding #8: There is an established system of funding for Thailand's waste tire management program, funded by the private sector

Through interviews with private company owners and automobile garage owners, we have found that Thailand's waste tire management program is largely funded by the private sector. The willingness of waste tire businesses to purchase waste tires led to the creation of the collection method that is currently used, which involves consumers giving or selling tires to collectors, who then sell these tires to the waste tire management facilities (Ou-Udomying, 2013). Automobile users typically bring their used tires to garages, where they can either leave their waste tires free of charge, or, depending on the garage, they may get credit toward a new tire purchase or monetary compensation. This system is advantageous due to the fact that it rewards consumers or does not charge them for introducing their waste tires into the recycling system, thereby discouraging the open dumping of tires and encouraging recycling. It is also convenient for waste generators because the tires can be collected at the point it is removed from the vehicle (Laohalidanond & Kerdsuwan, 2013).

As a method for comparison, in Japan, waste generators are allowed to contract with private businesses involved in waste collection, immediate treatment, and final disposal. This industry has established a market of 2-4 trillion Yen (approximately 20-40 billion USD), representing 0.4-0.8% Japan's GDP as of 2005 (Ministry of the Environment, 2005).

Finding #9: Regulating agencies currently do not have any publicly available information on incentives or penalties for waste tire management facilities

There are limited associated incentives or penalties for waste tire management facilities in Thailand, and it is possible that additional information about this was not found, as it is not widely distributed nor is it common public knowledge. In comparison, many of the private companies in the United States that deal with scrap tire disposal and recycling receive funding from the EPA as part of the Resource Conservation Challenge, an act that encourages recycling (RMA, 2011). Additionally, the EPA's Small Business Innovation Research Grant Program aims to promote technology innovation and privatization, improving environment and quality of life, creating jobs, increasing productivity and economic growth, and enhancing the international competitiveness of U.S. technology (EPA, 2012).

Penalties, fines, and levies are commonly used in the United States to fund these incentive programs. Depending on individual state regulations and circumstances, the EPA may pursue administrative and civil enforcement for violations of the scrap tire laws and regulations. In more egregious situations, criminal prosecution may be considered by the EPA or local law enforcement officers and prosecutors (EPA, 2012). The penalties for violating any section of laws or regulations relative to the handling and storage of scrap tires in Ohio, for instance, may be prosecuted with a fine of over $10,000 (State of Ohio EPA, 2011). The monetary penalties paid allow for the availability of grants for small business doing innovative research. However, the EPA does not provide funding for businesses using established technologies (EPA, 2012).

4.7. Findings concerning waste tire management stakeholders

Stakeholders' participation in Thailand's waste tire management system is somewhat hard to trace, since no systematic data are available on any private tire recyclers, which are the major industry figures. Thus, tire mismanagement cases are also hard to monitor, and no agency exists to screen active and legitimate participation of stakeholders in Thailand's waste tire management industry.

Finding #10: Information concerning the waste tire management system is less available in Thailand than in nations with highly successful waste tire management programs

Information concerning the waste tire management system is much less available in Thailand than in the United States and Japan. This is likely due to the fact that the systems in the United States and Japan are more structured, meaning that information and statistics are more accurate and readily available. Additionally, Thailand does not seem to have one agency specifically responsible for collecting reliable statistics on waste tires. The Pollution Control Department has estimates, but lacks technology-specific data. In addition, there is no specific division at the PCD or any other involved organization that is responsible for waste tire management specifically, resulting in a lack of focus on this subject. This may also be attributed to the fact that Thailand has no "official" waste tire management system, and that it is driven by the private sector rather than by the government.

Finding #11: Some stakeholders are presently unwilling or unable to participate in the waste tire management system, or may be unaware how to effectively participate in the system

Globally, the types of stakeholders involved in waste tire management are reasonably consistent. In Japan, the United States, and Thailand, the category of waste tire producers is primarily comprised of vehicle owners, with some amount of contribution by tire producers who will scrap low quality tires (EPA, 2011). The collection methods are also somewhat standardized, though collectors in the United States and Japan must be registered, suggesting that waste tire collectors in the United States and Japan are more highly regulated than those in Thailand. The end-of-life facilities are, again, comparable. Though standard operating procedures vary between the facilities, they have the same role in the waste tire management chain.

However, specifically in Thailand, waste tires frequently do not follow the established waste tire management life cycle, instead ending up in unregulated open dumpsites. It follows that waste tire generators are unaware of, unwilling, or unable to participate in the established and more environmentally sound waste tire management stream. The higher percentage of tires that are improperly disposed of in Thailand in comparison to the United States and Japan may be attributed to this lack of public knowledge or willingness to participate.

4.8. Conclusion

The findings, which are based on our independent research, evaluations of various technologies, and case study comparisons, have broadened our understanding of the current waste tire management system in Thailand and the development of successful waste tire management systems. The implications of our analysis will be discussed in the next chapter. The various aspects of Thailand's waste tire management system, as defined by the UNEP, allowed us to draw conclusions based on our findings and present recommendations for our sponsor and other related organizations.

Chapter 5: Recommendations and Conclusions

Based on the findings discussed in Chapter 4 and the independent research presented in the background chapter, our team was able to develop recommendations which will result in sustainable waste tire management strategies in Thailand. The recommendations provided in the chapter were divided into five sections, based on the UNEP's five factors of a waste management system: technologies, policies, institutions, financing mechanisms and stakeholder participation.

5.1 Technology Recommendations

Table 11 summarizes our recommendations concerning the technological component of a waste tire management system in Thailand. The adoption of these recommendations will lead to the increased use of more technologically progressive methods.

Table 11 - Technology Recommendations

Recommendation	Stakeholders	Intended Outcome
Expand the use of technologies that offer maximum economic and social benefit, with minimum environmental drawbacks institutional requirements, and necessary regulation.	NSTDA Private Companies Incubator Companies	Progress toward an overall more sustainable waste tire management system
Minimize the use of waste tires mismanagement methods, notably open dumping and open incineration.	Thai public PCD OEPP NEB	A minimization of all of the negative effects caused by the less technological approaches An overall more sustainable system for waste tire management Elimination of waste tire mismanagement sites
Pursue emerging, progressive technologies which offer cleaner, safer, and more economic results.	Members of Industry NSTDA	Use of more efficient and progressive technologies that also encourage innovation The creation or further

		development of technologies to develop or create safer, cleaner, and more economic options
Develop an incubator company dedicated to sustainable waste tire management on the NSTDA campus.	NSTDA	Model for waste tire management industries Development of one or more waste tire management technologies

Recommendation #1: Minimize the use of landfilling and eliminate the use of waste tire mismanagement methods, notably open dumping and open incineration.

By shifting the focus of Thailand's waste tire technologies away from open burning, open dumping, and landfilling, the waste tire management system will become more environmentally conscious, less economically costly, and more socially accepted. Reduction in the use of these environmentally destructive waste tire management methods will also lead to an increase in available waste tires as a resource for use in the more progressive technologies discussed in Recommendation #2. Information on these management methods can be found in Sections 2.1. and 2.3.1., and information concerning the development of this recommendation can be found in Section 4.3., Finding #1.

Recommendation #2: Expand the use of technologies that offer maximum economic and social benefit, with minimum environmental drawbacks, institutional requirements, and necessary regulation.

The most progressive technologies for waste tire management include retreading, grinding into tire derived aggregate, reclaiming, use as fuel, and small scale reuse. Background research concerning popularly used waste tire management technologies showed that these options are all commonly used in nations with successful waste tire management programs. The subsequent evaluation of these technologies via a feasibility matrix confirmed that these technologies all have the potential for use in Thailand. We have concluded that these are the best options due to their minimal environmental impact, economic viability, social acceptance, low infrastructural needs, and/or regulative simplicity. Through the adoption of these technologies, Thailand stands to gain a new source of economic growth. Recommendation #1 and Recommendation #2 are co-dependent; one cannot be completed without the completion of the other. Information on these technologies can be found in Sections 2.3.2. through 2.3.7., and information concerning the development of this recommendation can be found in Section 4.3., Findings #2 and #3.

Recommendation #3: Research and develop both emerging and established waste tire management technologies.

By researching emerging and established rubber or waste tire technologies, the National Science and Technology Development Agency will ensure that Thailand establishes and maintains a competitive edge in the waste tire reuse and repurposing industries. Emerging technologies such as ultrasonic degradation of tires have great potential for future use, but are not currently developed to the point that they can be effectively used for large-scale waste tire management. See Section 2.3.8. for more information on ultrasonic degradation. The National Metal and Materials Technology (MTEC) branch of the National Science and Technology Development Agency already has established programs concerning materials research, making it a good candidate for the creation of a new rubber technology research facility. This research will be beneficial in a number of ways. First, the publication of reports on emerging technologies could attract investors into funding research, simultaneously accelerating the research process and establishing a market for the new technology. Second, research on the technologies discussed in Section 4.3, Finding #2 could lead to cleaner or more economically beneficial processes. Third, by researching currently used methods, variations between theoretical and practical results may be discovered, which would in turn affect the feasibility of those methods.

Recommendation #4: Develop an incubator company dedicated to sustainable waste tire management on the NSTDA campus.

The NSTDA helps to develop new industries through the use of incubator companies on their campus. Since waste tires are an abundant, inexpensive, and underused resource, we recommend that the NSTDA develop an incubator company specifically dedicated to sustainable waste tire management technologies. This company will promote sustainable growth in the waste tire management industry by serving as a model, and it has the potential to become quite profitable as well. It is important to note that our limited experience with incubator companies means that this recommendation should be further evaluated by the NSTDA. However, many of our findings indicate that further research will help to advance the waste tire management industry in Thailand and that the development of this industry will cause the waste tire collection system to be more effective.

5.2 Policy Recommendations

The following table outlines our recommendations concerning the *policies* necessary for a waste tire management system in Thailand. The adoption of these recommendations will lead to increased regulation and should support growth within the waste tire management industry.

Table 12 - Policy Recommendations

Recommendation	Stakeholders	Outcome
Establish and universally enforce waste tire specific policies that establish guidelines for the waste tire industry.	PCD Thai Society Local Thai Governments Members of Industry	Regulations banning or discouraging waste tire mismanagement A clearer definition of which practices for waste tire management are legal in Thailand Increase of environmental regulation enforcement, particularly outside of urban areas
Establish penalties for companies that fail to conform to newly-formed waste tire management policies and incentives for businesses with environmentally considerate business practices.	NEB PCC Members of Industry	Tax incentives for companies that consistently meet or exceed recommendations or for companies employing the most sustainable practices available Penalties such as fines or license suspensions for policy offenders

Recommendation #5: Establish and universally enforce waste tire specific policies that establish guidelines for the waste tire industry.

Though the recommendation of specific policies is somewhat beyond the scope of our project and the expertise of our team, we suggest that regulating institutions in Thailand take steps to develop, establish, and universally enforce policies specific to the management of waste tires. An analysis of regulations used in different nations as well as information on potential policy topics can be found in Section 4.4, Finding #4. Policies concerning waste tire management should be geared toward the establishment of environmentally, socially, and economically conscious guidelines that all waste tire management businesses must follow. Increased regulation in the waste tire management industry will progress environmentally sustainable business practices, thereby lessening the negative environmental impact of this industry. Additionally, regulating the waste tire management industry intends to promote the growth of companies with sustainable business practices. This project's limited duration did not allow for us to conduct research on specific regulations that could be enforced, and therefore we do not have recommendations on specific new laws. However, many countries with successful waste tire management systems have laws that provide further regulation for waste tire management companies and this is a topic that should be further pursued.

Recommendation #6: Establish penalties for companies that fail to conform to newly-formed waste tire management policies and incentives for businesses with environmentally considerate business practices.

By establishing both negative repercussions and positive incentives for waste tire management companies, policies designed to improve the environmental and social impact of the waste tire management system will likely be adopted more quickly. By offering incentives for companies with positive, technologically progressive business practices, regulating institutions can promote the growth of a progressive industry in Thailand. It is important to note that our research did not include any studies on the incorporation of incentive programs and fines in Thai industry. This recommendation in particular should be reviewed and assessed by a regulating institution with experience in this field. This recommendation is based on the information from Section 4.6, Finding #9, which discusses incentives and penalties in Thailand and the United States.

5.3 Institution Recommendations

The following table outlines our recommendations concerning the regulative *institutions* associated with waste tire management system in Thailand. These recommendations concern the interaction between the public and private sector.

Table 13 - Institution Recommendations

Recommendation	Stakeholders	Outcome
Increase cooperation between private sector and regulating institutions.	NSTDA Private Companies	A combination of research from both the private and government sector, allowing for more progressive technologies to be implemented and utilized An NSTDA-hosted convention for waste tire

		management businesses, encouraging cooperation between the two groups

Recommendation #7: Increase cooperation between private sector and regulating institutions.

Increasing the cooperation between regulating agencies and the private sector in the development of new regulations is intended to help mitigate the negative impacts that such regulations will have on the Thai waste tire management industry. This cooperation would share knowledge of both technical research and market analysis while allowing both parties to still protect their own economic interests such as patents and finances. By involving members of the private sector, institutions associated with waste tires can gain a better perspective on the needs of waste tire management businesses and make informed decisions on new regulations. By combining research from both government and private sectors, research has the potential to progress at a more rapid rate. Though this cooperation between the public and private sectors is intended to enable regulating institutions to make informed decisions that will generate positive reactions in the private sector. An NSTDA-hosted convention, a communication tool commonly used by the NSTDA, on waste tire management could stimulate communication between the public and private sector. Section 4.5. Finding #7 contains information on the findings associated with Recommendation #6.

5.4 Stakeholder Recommendations

The following table outlines our recommendations concerning the *stakeholders* involved in the waste tire management system in Thailand. These recommendations concern societal participation in and acceptance of a new waste tire management system.

Table 14 - Stakeholder Recommendations

Recommendation	Stakeholders	Outcome
Expand public participation in the waste tire management system through the use of a public education campaign.	DEQP NSTDA Thai Society	Increase public knowledge and understanding of the waste tire stream to encourage public participation
Further investigate information on public opinions and societal acceptance of a waste tire management system.	NSTDA Thai Society PCD	A campaign exploring public opinions and willingness in order to create a system as socially efficient as possible

Recommendation #8: Expand public participation in the waste tire management system through the use of a public education campaign.

Since the Thai public is the largest stakeholder in terms of participants, it is imperative that the public is knowledgeable and educated on the problems caused by waste tires as well as the importance of public involvement in the process. By informing the public about current regulations and future objectives concerning the waste tire management system, the NSTDA can attempt to improve public participation in a program. Through presentations at seminars and annual conferences or an advertisement campaign, the NSTDA can directly impact public participation in the collection of waste tires, thereby increasing the volume of waste tires that enter Thailand's waste tire management stream. This recommendation is intended to address the lack of available information and non-participation from the public, which are discussed in Section 4.7., Findings #10 and #11.

Recommendation #9: Further investigate information on public opinions and societal acceptance of a waste tire management system.

Through the use of a large-scale survey or consultations with community leaders, Thailand's regulating institutions can gather information on the current public view of waste tire management options. This information will allow future developments in the waste tire management stream to focus on those options which are most likely to be publicly accepted. A campaign designed to explore public opinions and willingness to participate in a given program will help governing agencies to create a system with maximum social acceptance. A survey should be formulated in order to solve the issues of non-participation or lack of knowledge discussed in Finding #11. This survey would also address the gap in research in this report related to social factors that affect a waste tire management system, helping to further this project's findings. An example of this type of questionnaire, directed toward private car owners, can be found in Appendix I in both English and Thai.

5.5 Financing Mechanisms Recommendations

The table below provides a succinct outline of our recommendations concerning the *financing* of a waste tire management system in Thailand. These recommendations are intended to contribute to increased participation in the waste tire management system and the growth of the waste tire management industry.

Table 15 - Financing Mechanisms Recommendations

Recommendation	Stakeholders	Outcome
Improve the current waste tire management stream	Local Governments Thai Public	Higher tire recycling rates due to monetary incentive

through the promotion of private sector growth in a free market economic system.	Members of Industry	Growth of the waste tire management industry

Recommendation #10: Improve the current waste tire management stream through the promotion of private sector growth in a free market economic system.

Thailand's waste tire stream is currently fueled by the private sector, in that waste tire management companies purchase waste tires from collectors and garages, which in turn purchase or collect waste tires from individual consumers. By promoting private sector growth through the continued use of a free market system, the NSTDA can directly impact the growth of private waste tire management companies. This will subsequently increase the demand for waste tires as a resource in Thai industry, leading to increased incentives for both collectors and waste tire generators. This recommendation may have additional unintended outcomes that have not been discovered through our research due to the limited scope of this project.

5.6 Intended Outcomes

These recommendations alongside our research report are intended to support the National Science and Technology Development Agency in its development and pursuit of a comprehensive waste tire management program for Thailand. These recommendations were all made based off of the information discussed in our findings. An important final note for our recommendations is an overall recommendation of a move towards progress. None of the recommendations can happen over the course of a week or a month. Many of these recommendations must be implemented over a span of years. While it would be ideal to have all of these recommendations implemented immediately, it is more important to be realistic and understand the time and effort that policy change requires. A first step towards any of these recommendations is a move towards progress in waste tire management.

Through the completion of these recommendations, the following outcomes are expected:

- The minimization of waste tire mismanagement practices, such as open burning, open dumping, and landfilling

- The growth of industries that utilize environmentally and economically viable waste tire management technologies

- The adoption of environmentally responsible business practices in waste tire management industries
- An increase in waste tire recycling rates
- The development of a comprehensive waste tire management system

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Appendix A: Types of Rubber

Origin of rubber

Natural rubber comes from the rubber tree (*Havea brasiliensis*), also known as the Para rubber tree. The Para rubber tree belongs to the Euphorbiaceous family, native to the tropical rainforests in South America. This plant species was also discovered in Southeast Asia where vast rubber tree plantations now exist. Presently, Southeast Asia accounts for 97% of the world's rubber supply, with most production coming from Thailand, Indonesia and Malaysia (Davis, 1996) (Li and Fox, 2012). From the statistics provided by the Rubber Research Institute of Thailand, in 2011 more than 3.5 million tons of rubber were produced in Thailand. Three million tons of rubber were exported, and the remainder was used domestically.

Natural rubber (latex) is a milky viscous liquid when extracted from the bark of the rubber tree (*Essential Uses of Rubber Products*, 2011). Crude rubber or isoprene can be obtained from separating and drying the coagulated rubber liquid (Kumar & Nijasure, 1997). Synthetic rubber is also available as an alternative to natural rubber. Synthetic rubber can be made from polymerization of monomers such as styrene, chloroprene, isobutene and 1,3-butadiene (Kumar & Nijasure, 1997). These types of rubber are soft, adhesive and thermoplastic. In addition, they have low tensile strength and low elastic modulus (Kumar & Nijasure, 1997). Due to these properties, natural or synthetic rubber can be made into products such as rubber gloves, shoes, erasers and balloons (*Properties and Uses of Rubber*, 2012). Synthetic rubber is often preferred over natural rubber because synthetic rubber has higher thermal stability and compatibility with petroleum-based products. Furthermore, synthetic rubber can be modified by using different combinations of monomers. Unlike natural rubber, synthetic rubber contains no traces of contaminants, allowing the addition of other materials in order to change its properties (Kumar &Nijasure, 1997). Commonly, additives such as carbon black or zinc[9] can be used to alter the mechanical properties of the product (Kumar & Nijasure, 1997). As a result, synthetic rubber is often used to produce more durable products such as tires, hoses, or belts (Kumar & Nijasure, 1997). Specifically related to this project, for example, changing the percentages of sulfur or additives will produce different types of tires to suit various applications.

Vulcanization

The method of increasing the mechanical strength and elasticity of rubber through the cross-linking of monomers, known today as vulcanization, was discovered by Charles Goodyear in the year 1839. He stumbled upon this process unintentionally by spilling sulfur into liquid rubber on a hot stove (Kumar & Nijasure, 1997). The mixture formed a tough and firm material. Basically, vulcanization is a free-radical polymerization reaction between isoprene and sulfur radicals which forms polyisoprene chain links through sulfur bridges (Figure 1). Before vulcanization, rubber contains 5% sulfur, but the reaction that Goodyear discovered changes the composition to 30-50% sulfur. Cross-linking of rubber through the vulcanization process improves its tensile strength, making the material less adhesive and stiffer. This improves the rubber's thermoplastic property, allowing the product to withstand temperature flux without deformation (Encyclopedia Britannica, 2012). Rubber after vulcanization is ten times stronger than non-cross-linked rubber (*Vulcanization*, 2012). Thus, it is mainly used to produce durable products like tires. See Figure A1 below.

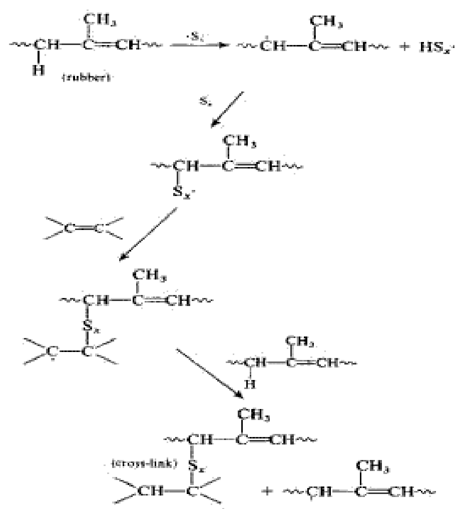

Figure A21 - The Vulcanization Process (Li & Fox, 2012)

To obtain specific products, the process of vulcanization must be carefully controlled. Scorch resistance is the most important factor affecting rubber production. It depends on multiple factors. For instance, the time elapsed before the vulcanization process starts affects the ability of the rubber mixture to be properly mixed and molded. Premature vulcanization causes the rubber product to crack or turn brittle. Additionally, the temperature used should be within the range of 140-180˚C. An accelerator additive is necessary to decrease the extensive time required for this process and to allow the chemicals to react at lower temperatures. This addition must be done properly or the process could be ruined. The most common accelerator used industrially is MBT (2-Mercaptobenzothiazole) (Li & Fox, 2012).

Appendix B: Toxins Released from Tire Combustion

Toxins released through combustion of tires and bodily harm (The Office of Environmental Health Hazard, 2002).

Analyte	No. of Fires Where Meas. Taken	Median Concentration (µg/m3)	Maximum Concentration (µg/m3)	Acute REL (µg/m3)	Target Organ	Chronic REL (µg/m3)	Target Organ
Benzene	21	121	79, 693	1300	Reproductive, Developmental	60	Hematopoietic system; developmental; nervous system
Toluene	21	220	206, 753	37, 000	Central Nervous System Eye; Respiratory Irritation	300	Nervous system; Respiratory system; development
Stylene	14	85	2, 705	21, 000	Eye; Respiratory Irritation	900	Nervous System
Xylones	9	17	3, 809	22, 000	Eye; Respiratory Irritation	700	Nervous System; Eyes
M,p-Xylene	6	76	999			700	Nervous System; Eyes
0-Xylene	10	35	564			700	Nervous System; Eyes
Methylene Chloride	10	8	836			400	Cardiovascular system; nervous system
Chloroform	9	42	1,085			300	Alimentary; kidney; development

Appendix C: MSW Composition

Thailand's municipal waste composition (2007) (Nokyoo, 2011).

Type	Waste Composition (%)
Organic waste	48
Paper cardboard	15
Plastic	14
Glass	5
Metal	4
Others	14

Appendix D: Types of Tires

Structure of tires and tire variety definitions

Rubber tires are a necessary component of nearly every motor vehicle. Typical passenger tires are composed of rubber compounds (47%), carbon black (21.5%), steel (16.5%) and nylon/fiber (5.5%). Sulfur, other basic elements, and additives make up the remainder. There are various classifications of tires based on size and purpose of the related vehicle *(Selecting the Right Tire*, 2012). The following section defines the composition of two major types of tires: biased tires and radial tires. A list of specific tire components and their definitions can be viewed in Appendix K.

A bias tire consists of multiple rubber plies that overlap with each other. Bias tires have ply cords extending diagonally from one tire bead to the other at angles of about 30-40 degrees. Bias type tires are widely used in trucks because they have durable properties (*Bias versus Radial Construction*, 2012).

Radial tires have a cord angle of 90 degree. Layers of cords in radial tires are parallel to each other and combined with stabilizer belts. Radial tires provide better steering control, lower rolling resistance and lower fuel use (*Bias versus Radial Construction*, 2012). See Figures D1 and D2 below.

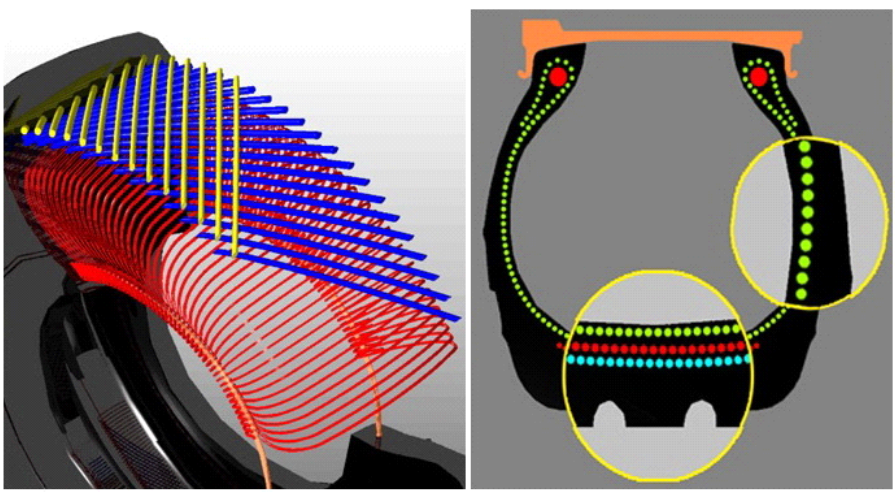

Figure D1 - Radial Tire (*Radial versus Bias Technology*, 2012).

Bias tires and radial tires have their own specific applications for different types of vehicles due to their specific compositions. The table below **s**ummarizes the advantages and disadvantages of bias tires and radial tires and the second table highlights the different components of the two types of tires. See Figure D2 below.

	Advantages	Disadvantages
	• Strong sidewalls, tough casing • Better sidewall puncture resistance • Good lateral stability (hill side work) • Good in rough terrain and off-road • Self-cleaning	• Poor life expectancy (50% of radial) • Lack of flexibility in casing reduces foot print and traction • Tread flexes more, generating more heat

Bias Tire	• Easily repaired • Lower purchase price	and rolling resistance. • Greater rolling resistance and fuel inefficiency • Profile of tire increases soil compaction and reduces traction
Radial Tire	• Good high speed capacity • Longer lasting (Up to 50% longer) • Wear resistant • Low heat build-up • Lower rolling resistance • Better Fuel Economy • Better floatation and larger contact area • Less soil compaction • Better stability and machine handling • Smoother, more quiet ride • Proliferation of tires in the last 10 years has mostly been in radial	• More prone to puncturing • More difficult to repair • Higher purchase price

Figure D2 - Bias and Radial Tires

	Bias	Radial
Tread	√	√
Sidewall	√	√
Chafer	√	√
Liner	√	√
Bead	√	√
Body ply	×	√
Belts	×	√
Cord body	√	×
Breakers	√	×

Figure D3 - Bias and Radial Tire Comparison

Appendix E: Interview Guides

INTERVIEW GUIDE

IQP/SSP Team 1

Developing a Sustainable Waste Tire Management Strategy for Thailand

Orachitr Bijaisoradat · Kailyn Connor · Steven Cortesa · Shakhizada Issagaliyeva · Nachnicha Kongkatigumjorn · Adam Meunier · Kunathon Wattanavit

Site: (Name, Type, Location)	
Date:	
Interviewee: (Name, Title)	
Interviewer(s):	

Question 1: [ ]

Question 2: [ ]

Question 3: [ ]
Etc..

EXAMPLE QUESTIONS

Can you give us a brief explanation of the process of waste tire management at this facility?
Does this facility deal strictly with tires or do you handle other forms of waste?
How do you collect waste tires? What is the source?
What are the local environmental impacts of this facility?
What type of funding does this facility receive?
What are the major benefits of this type of method?
What are the major drawbacks of this type of method?
How many tires are handled at this facility? - annually, weekly, daily
What governmental regulations or laws are placed on this type of waste tire management? Any limits or restrictions?
How many people are employed at this facility?
When did this facility open and why?
How much did it cost to start this company?
What are your plans for the future concerning this company?
Are byproducts produced by this tire management process? Are they used for anything?
How profitable is this company/waste tire management strategy?
Do you have any recommendations concerning other companies we should contact?
What occupation did you have (if any) prior to your entrance into this industry?

INTERVIEW GUIDE

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Developing a Sustainable Waste Tire Management Strategy for Thailand

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Site: (Name, Type, Location)	Union Commercial Development Co. Ltd. Waste Tire Reclaiming, Bangkok
Date:	January 19, 2013 9:30
Interviewee: (Name, Title)	Mr. Boonharn Ou-Udomying
Interviewer(s):	Orachitr Bijaisoradat, Kailyn Connor, Steven Cortesa, Shakhizada Issagaliyeva, Nachnicha Kongkatigumjorn, Adam Meunier, Kunathon Wattanavit

<u>Reclaiming Questions:</u>

Question 1: Is the general composition of different types of tires (i.e. car, truck, motorcycle, airplane) the same?

ส่วนประกอบของยางรถยนต์แต่ละชนิดเหมือนกันหรือต่างกันอย่างไร?

Question 2: Can you give us a brief explanation of the reclaiming process at the facility?

ขอทราบข้อมูลคร่าวๆเกี่ยวกับกระบวนการ reclaiming ในโรงงานแห่งนี้

Question 3: Where do you get the waste tires? How you do get them?

คุณเอายางเก่าที่ไม่ใช้แล้วมาจากที่ไหน ? ด้วยวิธีการใด ?

Question 4: How do you choose the suitable tires waste (type, brand, size) for reclamation?

คุณมีวิธีเลือกยางที่เหมาะสมกับการทำ reclaiming อย่างไร ? ชนิด,ยี่ห้อยาง,ขนาด และอื่นๆ)

Question 5: What raw material do you use in reclamation excepting waste tires? Where do you get the raw material?

คุณมีการใช้วัตถุดิบอย่างอื่นนอกจากยางรถยนต์เก่าแล้วหรือไม่ในกระบวนการ reclamation? และวัตถุดิบเหล่านี้คุณนำมาจากที่ไหน?

Question 6: What governmental regulations or laws are placed on this type of waste tire management? Any limits or restrictions?

มีกฎหมายหรือกฎข้อบังคับ ข้อจำกัด ที่เกี่ยวข้องกับกระบวนการ การจัดการยางที่ใช้แล้วหรือไม่ ?

Question 7: How many tires are reclaimed at Union Commerical Co.Ltd? - Annually, weekly, daily

มีจำนวนยางปริมาณเท่าไรที่ได้เข้าสู่กระบวนการ reclaiming ในโรงงานแห่งนี้ ? รายปี ? รายสัปดาห์ ? รายวัน ?

Question 8: What are the major benefits of tire reclaiming?

อะไรที่เป็นประโยชน์ที่สำคัญของกระบวนการ reclaiming ?

Question 9: What are the major drawbacks of tire reclaiming?

ข้อเสียของกระบวนการ reclaiming คืออะไร ?

Question 10: How profitable is tire reclaiming?

ในกระบวนการ reclaiming มีผลกำไรเท่าไร ?

Question 11: Can the by-product of the reclamation process be used for other application? If yes, in what form?

ผลิตภัณฑ์ที่ได้จากการกระบวนการ reclamation ใช้กับผลิตภัณฑ์อย่างอื่นได้หรือไม่ และในรูปแบบไหน?

<u>General Questions:</u>

Question 12: How much does it cost to construct these facilities initially?

ในการสร้างโรงงานแห่งนี้ใช้งบประมาณเท่าไร ?

Question 13: Have you considered the possibility of other types of tire waste treatments?

คุณได้มีการคิดค้นวิธีการกำจัดยางรถยนต์ในลักษณะอื่นๆบ้างหรือเปล่า ?

Question 14: What do you think about the future of tires waste treatment in Thailand?

คุณคิดว่าในอนาคตการกำจัดยางรถยนต์ที่ใช้แล้วในประเทศไทยจะมีแนวโน้มทางด้านอย่างไร?

Answers:

Question 1: Different types of tires are very similiar in compesition; it is just dependent on the manufactuerer because they have different formulas.

Question 2: They first shred the waste tires and then grind them into dust. Next the dust is put into a “rice cooker”, a machine that applied heat and pressure. When it comes out and they press the resulting compound into sheets, which are then wrapped into a roll, cut, and palleted as mats.

Question 3: They are purchased from “tire collectors” that go to garages and bid on the waste tires. The company purchases the waste tires without the inner lining.

Question 4: Any brand of waste tire is used by the company but only truck, bus, and biased tires (TBB).

Question 5: Chemicals and devulcanizing agents are used to weaken the binding polymers in waste tires but most of the reclamation process is done by mechanical means.

Question 6: None. (See question 14).

Question 7: 25,000 tons of reclaimed rubber is produced each year by the company. 16,000 tons at the Chonburi site and 9,000 tons at this site. This is from 30,000 tons of waste tires.

Question 8: There are many benefits of tire reclaiming:

- The process can produce many products that can be used in several ways such as backfill for asphalt (especially in colder climates), as raw material for making tires (from reclaimed rubber slabs), in tracks and playground mats (from granulated rubber).
- In the past the company has collected tires from dump sites like the forest.
- Reclaming removes waste tires from the waste stream and puts them to a new use.

Question 9: The current process at the facility of ambient mechanical grinding is a batch process and therefore there is a loss of time and energy. Adversely, processes like ultrasonic are a continuous process and are being looked into further for use in the future.
Question 10: It is profitable.
Question 11: Yes, both the steam and carbon black that is produced is reused. The steam that is created from the "rice cooker" process is recycled and used in the machine again as pressure. The carbon black that is generated from the reclamation process can be collected and sold to companies.
Question 12: 15 million baht was invested in 1969 to open the facility. The new facility in Chonburi cost 300 million baht to build last year.
Question 13: Ultrasonic
Question 14: Future Regulations:

Wish→ Thailand shouldn't just produce tires but also take care of the waste (show other countries)

Reality→Company has been trying for 10 years, talked to many government ministries

Additional Presentation Notes:

Boonharn Ou-Udomying

Executive Director of Union Commercial Development Co., Ltd

Chairman of the Rubber-based Industry Club of the Federation of Thai Industries

- Business was started in 1969, first Tire Reclamation facility in Asia
- Saeng Thai Rubber Company (sister company)- manufacturers rubber fenders, hoses, etc.

- Rubber Recycling
  - Cut tires→ small rubber particles
  - Can get steal and fibers
  - Company mostly recycles truck and bus tires
  - Waste tires a problem all over the world- especially in the US (burned; Chicago)
- Rubber Use
  - 60-70% of all rubber goes to tires
  - 15% goes to other car parts
  - 15% goes to gloves, condoms, etc.

- Natural vs. Synthetic Rubber
    - Many different types of synthetic rubber, comes from crude oil
    - Rubber used throughout the world: 40% natural; 60% synthetic
    - Natural rubber is better but more expensive

- Waste Tire Management Methods
    - Peel and cut
        - Flower pots, mud flaps
    - Granulation (Grinding)
        - Ambient Process- mechanical grinding using steel rollers or blades [used at company- takes 3 hours]
        - Cryogenic Process- low temperature freezing using liquid nitrogen with hammer mill to crack frozen tires
            - Popular in Europe
            - Impractical in Thailand's climate- really expensive
        - Uses:
            - Pavement Block→ playground for children (playground mats)
            - Patio surface
            - Tracks→ have to have 30mm of rubber chips (Athletic Association regulation)
            - Asphalt mixture for pavement
                - Beneficial in colder climates→ helps prevent cracking, rubber rebounds
            - Asphalt mixture for pond lining
    - Devulcanization Techniques
        - Chemical and heat [common throughout the world; used in Thailand]
            - Devulcanizing agents + high temperatures + high pressure
            - Like "rice cooker"
            - Slow devulcanization time
        - Ultrasonic [new technology; US]
        - Microwave
        - Biological [takes much longer- 2 weeks]
        - Continued Reactive Process [popular in Europe]

- Reclaimed Rubber Slabs
    - 25% carbon black (reinforcing agent; cheapest way)
    - Raw material for making tires

- Waste Tire Management Throughout the World
    - Thailand
        - Garages buys or collects old tires
        - Collectors bid on waste tires

        - Collectors sell tires to reclamation facilities
        - Often exported to other countries (especially to make pavement)
            - China needs roads made with tires
            - China and Korea buy waste tires for much less in Thailand
    - USA
        - Who pollutes, who pays
        - Consumers pay disposal fee
        - Tire shops pay waste disposal company to collect
        - Waste disposal company pays approved recyclers
    - Europe
        - Indirectly paid by customers
        - Tire manufacturers pay disposal taxes
        - Government agency pays waste disposal company for collecting used tires
        - Waste disposal company pays approved recyclers

- Current Facts About Waste Tire Management in Thailand
    - 400,000 tons of waste tires produced per year
    - Only 50,000 tons are reclaimed
        - 25,000 tons at Union Commercial Development Co., Ltd (biggest company)
        - 25,000 tons at four other facilities combined
    - No regulations regarding waste tire management
    - "People will never pay the fees [to recycle or properly dispose of their tires]"
    - "People love to be paid for their tires"
    - Limited land in Thailand→ rubber trees are being grown instead of food crops
    - People were burning tires to create oil when gases prices were high
    - ATC Garage→ pays customers 200 baht for waste tires if you bought them there
    - Bridgestone Cockpit→ lets people leave waste for free, sells to cement companies, cost covered in price
    - People are brand loyal with tires
    - Never know exact composition of manufactures tires
    - Tires are considered non-hazardous waste
- Tire Production/Reclamation in Thailand
    - Plenty of raw materials
    - Not such a high cost of energy
    - US and Europe can't compete because of labor laws, etc.
    - China has too much competition and costs aren't as cheap as in Thailand

- Union Commercial Development Co., Ltd
    - Talking to major companies like Michelin to use more reclaimed rubber in their tire production
    - Pulls waste tires out of the forest
    - Collects every brand but only TBB- truck, bus, and biased
    - Small tires aren't worth the energy and labor costs
    - Number recycled at facility based on prediction of demand

- By products of process- fiber (nylon nano chips), metal
- Quality of rubber- hard to judge
  - Garbage is collected so it is difficult to judge the quality of the rubber
  - Data collected and used to create range (specification)
  - Manufactures change formula of tires and the range gets wider
- Looking for government to create regulations
  - Ministry of Finance and Ministry of Natural Environment have conflicting vies on what to do about waste tire management
- Looking towards ultrasonic process
- Reclamation is a very common commercial process
- Chonburi facility: 16,000 tons
- This facility: 9,000 tons
- Pollution problem
  - Opening “rice cooker” releases gas, smoke, heat, strong smell
  - The heat it creates is used to make steam and goes back into the “rice cooker”
- 50 million baht was invested in 1969 to open the facility
- The new facility in Chonburi cost 300 million baht to build last year
- Includes building, electricity, land and imported machines
- Future Regulations
  - Wish→ Thailand shouldn’t just produce tires but also take care of the waste (show other countries)
  - Reality→Company has been trying for 10 years, talked to many government ministries

INTERVIEW GUIDE

IQP/SSP Team 1

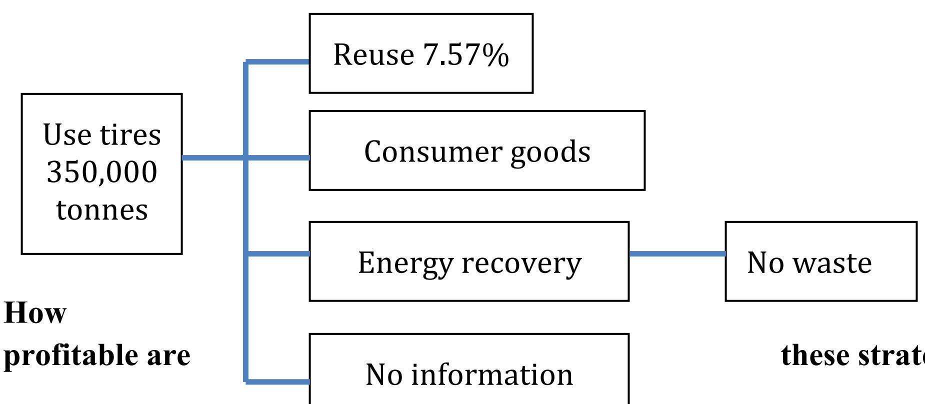
Developing a Sustainable Waste Tire Management Strategy for Thailand

Orachitr Bijaisoradat · Kailyn Connor · Steven Cortesa · Shakhizada Issagaliyeva · Nachnicha Kongkatigumjorn · Adam Meunier · Kunathon Wattanavit

Site: (Name, Type, Location)	Faculty of Engineering, King Mongkut's Institute of Technology North Bangkok (KMITNB), Bangkok
Date:	January, 24, 15:00
Interviewee: (Name, Title)	Mr. Somrat Kerdsuwan
Interviewer(s):	Nachnicha Kongkatigumjorn, Shakhizada Issagaliyeva, Kunathon Wattanavit

1. **Can you briefly describe methods of solid waste incineration/pyrolysis?**

   Municipal Waste Incineration does not usually cover burning of tires. However, tires are burned in cement kilns and boilers in Thailand. From the information obtained in 2011, 7.57% of waste tires are used again, 4.29% are recycled as consumer goods, and 2.86% are incinerated for energy. There is no information on the remaining 83.57%. No information on waste tires export. When conducting research for the Department of Primary Mining, a lot of attention is paid to UK's waste tires management strategy (increased level of recycling and energy recovery, decreased level of landfilling).



2. **How profitable are these strategies?**

   Incineration process in cement kilns is very easy to manage. Not clear, how profitable those strategies are, since only 2.86% of scrap tires are used for energy.

3. **What are the drawbacks of the strategies?**

   No existing laws/regulations on waste tires management. No monitoring of tires collection prevents cement factories/incineration facilities from efficiently purchasing waste tires. No organization exists that is in charge of management and treatment of scrap tires.
   High temperature (1200-1400 °C) and releasing CO_2
   Pyrolysis is very expensive, environmentally inconsiderate, and inefficient. At the end of pyrolysis process, mixed oil is obtained, which has to further be distilled (additional costs and time).

4. **Do you believe these strategies are beneficial for waste tire management?**

   Pyrolysis is not a beneficial strategy for Thailand because it produces a lot of air pollution (toxic gas and greenhouse gas). However, incineration in cement kilns and boilers is. Incineration facilities don't have an established limit to how many tires they can burn a day.

5. **What kinds of byproducts are produced by these processes? Are they used for anything?**

   Waste tires incineration produces carbon dioxide and water, char and low-cost oil. Also, steel parts have to be removed from tires before the process. Pyrolysis requires the use of catalyst that stays behind.

6. **Are they environmentally considerate?**

   When burned at high temperatures in boilers and cement kilns (1200-1400 degrees Celsius), pollution is insignificant compared to pollution resulting from pyrolysis.

7. **Do you foresee pyrolysis becoming more popular than incineration?**

   No, pyrolysis is more of a lab-scale process.

8. **Do you know of tire waste incineration/pyrolysis facilities in Thailand?**

   Siam City Cement, Siam Cement, TPI. No information on boilers. Most MSW incineration facilities do not burn tires for energy/oil; they are governmentally regulated facilities getting rid of waste. Two private incineration facilities also burn waste, but not tires specifically. Cement kilns and boilers use scrap tires to obtain energy.

9. **What governmental regulations or laws are placed on these types of solid waste management? Any limits or restrictions?**

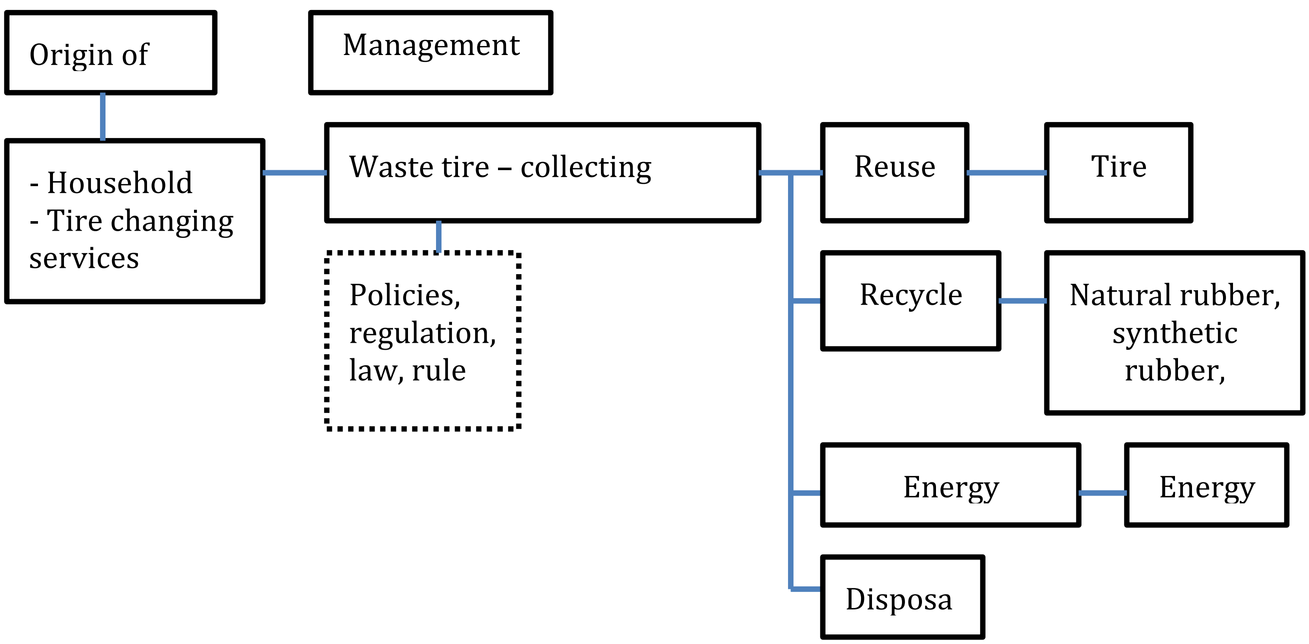
   Only governmental regulations on these types of scrap tires management are concerning air emissions control. Having no clear regulations affects waste tire management badly, making it harder to track the waste tires flow and collect tires from citizens.

10. **Do these methods receive any kind of government funding?**

    No.

11. **Do you have any recommendations concerning other companies we should contact?**

    Cement kilns such as Siam City Cement, Siam Cement, TPI. Most cement companies are located in Saraburi.
    Comments: A collection center would be first required in order to effectively manage tire waste. It is unclear where cement kilns purchase scrap tires from – manufacturers or garages? Manufacturers should be responsible for paying for waste tire management, and tires recycling facilities should be responsible for emissions control. When using scrap tires No information obtained on scrap tires export
    Suggested waste tire management in Thailand:



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Developing a Sustainable Waste Tire Management Strategy for Thailand

Orachitr Bijaisoradat · Kailyn Connor · Steven Cortesa · Shakhizada Issagaliyeva · Nachnicha Kongkatigumjorn · Adam Meunier · Kunathon Wattanavit

Site: (Name, Type, Location)	B-Quik, Premium Garage
Date:	January 15, 2013
Interviewee: (Name, Title)	N/A
Interviewer(s):	Nachnicha Kongkatigumjorn

-Acting as customer-

Question 1: What do you do with the waste tires that you collect and why do you do that?

- There are two ways they are handled at the garage, depending on the customer. One way is the customer keeping them to use, dispose of, or recycle on their own. The other option is for B-Quik to take the waste tires. If collected at the garage then are then sold to retreading manufacturers or other types of waste tire related facilities.

Question 2: Do you pay to collect waste tires?

- No, customers can leave the old tires today**.**

Question 3: How many tires are handled at this facility? - annually, weekly, daily

- Could not provide information.

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Developing a Sustainable Waste Tire Management Strategy for Thailand

Orachitr Bijaisoradat · Kailyn Connor · Steven Cortesa · Shakhizada Issagaliyeva · Nachnicha Kongkatigumjorn · Adam Meunier · Kunathon Wattanavit

Site: (Name, Type, Location)	Phone/Skype, MHMK, Faculty of Science, CU, Bangkok
Date:	January 24, 2013 at 9am
Interviewee: (Name, Title)	Mr. Marcus Veerman
Interviewer(s):	Kailyn Connor, Steve Cortesa, Nachnicha Kongkatigumjorn

1. **Can you briefly describe the process of building playgrounds in Thailand?**

- Difference between up-cycling and down-cycling; up-cycling is when you take a product and turn it into something better than it was intended for
- Connections are really important i.e. the bolts and washers, the main cause of breakages isn't the tires, but because the materials are free they can be easily obtained

2. **What difficulties did you face during the project?**

Weather, keeping the tires dry and the mosquitoes.

3. **What kinds of equipment did you need for the projects? Were there any special skills required?**

Welders, small hand tools and electrical tools, generator

4. **What are your expectations concerning the lifespan of these tire playgrounds?**

- Sun breaks them down
- Of the 40 playgrounds he doesn't know the condition, a few were completely destroyed, not enough backup like money and labor to keep them maintained, wood didn't last for very long
- Should last a long time if other aspects are maintained, there is now an emphasis on maintenance on the company's website

5. **Where did you get the waste tires in Thailand?**

- Drove around to different shops to collect the tires
- Some weeks there would be plenty of tires, others there wouldn't
- Places you can recycle your waste in every town, the ability of people to collect tires
- Would be easy for recycling centers to include tires

6. **Did you have to pay for the materials you used (including tires), and approximately how much did it cost to construct each playground?**

Didn't have to pay for them in most cases, if they did, they didn't have to pay much based on relationship with suppliers.

7. **Did you receive any kind of government funding or funding from private donors in Thailand?**

70% were fully funded by the local organizations, 30% were internally funded.

8. **What governmental regulations or laws did you have to follow while working on these projects? Any limits or restrictions?**

No, Thailand doesn't have a playground standard, some guidelines, there are building standards

9. **Approximately how many tires were used in each playground?**

100 waste tires per playground, 40 playgrounds total.

10. **Do you have any recommendations concerning tire playgrounds in or near Bangkok that we could visit?**

WPI did a playground project in Klong Toei a few years ago.

11. **Was the public and local community supportive of your efforts?**

Yes, the local community that the playground benefited was supportive and appreciative of the playground. The public and various part suppliers were often willing to donate materials such as waste tires, bolts, and wood.

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Developing a Sustainable Waste Tire Management Strategy for Thailand

Orachitr Bijaisoradat · Kailyn Connor · Steven Cortesa · Shakhizada Issagaliyeva ·
Nachnicha Kongkatigumjorn · Adam Meunier · Kunathon Wattanavit

Site: (Name, Type, Location)	Mahaphant, Saraburi
Date:	February, 8, 10:00
Interviewee: (Name, Title)	Mr. Wichit Prakaypan
Interviewer(s):	Nachnicha Kongkatigumjorn, Shakhizada Issagaliyeva, Kunathon Wattanavit, Adam Meunier, Orachitr Bijaisoradat

Incineration Questions:

Question 1: Can you briefly describe methods of tire waste incineration in cement kilns?

Mahaphant has not incinerated tire waste for energy since 2010. However, future plans involve the use of shredded tires for civil engineering projects.

Question 2: Does the process result in any byproducts? Are they used for anything?

Incineration of waste tires is not environmentally considerate, since it releases toxic pollutants if maintained improperly. It also takes away from the aesthetic attractiveness of the facility because of the heavy some it produces. The production at the Mahaphant company is intended to reduce the impact on the environment, using closed-system production scheme (recycling of byproducts).

Question 3: **What are the major benefits of using waste tires for energy?**

It releases large amounts of heat

Question 4: **What are the major drawbacks of using waste tires for energy?**

Heat fluctuations are hard to control when waste tires are burned, and that affects the quality of the production. Moreover, waste tires might be more expensive compared to other type of fuel available at the facility (biomass, dust, wood chips, paper).

Question 5: **Is the general composition of different types of tires (i.e. car, truck, motorcycle, airplane) the same? Does Mahaphant only reclaim certain brand tires?**

No, tires are shredded before being transported to the facility, so the brand/composition doesn't matter.

Question 6: **What governmental regulations or laws are placed on this type of waste tire management? Any limits or restrictions?**

The Mahaphant Company has its own quality control system, in addition to the Pollution Control Department control. Air pollution standard is 10 ^{PM}, and 100 mg/m^3. Water pollution is regulated by PCD, as well.

Tire Fiber Questions:

Question 7: **How many tires are [were] used at Mahaphant for tire fiber production? - Annually, weekly, daily**

10 tons/month

Question 8: What are the major benefits of using waste tires fiber/waste tires for energy?

When waste tires fiber is being used, it helps fill the hollow cement, making it sound proof, flexible and strong, still keeping the product within reasonable weight range.

Question 9: **What are the major drawbacks of using waste tires fiber?**

Tires are known to be highly flammable. A building would not pass fire safety tests, if the walls contained flammable tire fiber. Instead, tire fiber is only used for doors and windows for now, and new technologies are being developed.

Question 10: **Where do you get the waste tires? How you do get them?**

A private company that collects and shreds tires has an agreement with Mahaphant. It gets tires from a network of facilities (garages, manufacturers). It is much harder to have an agreement with a large tire manufacturer, since more paperwork and time is required. Local agency does not only effectively collect tires, but also shreds them before selling.

Question 11: **What governmental regulations or laws are placed on this type of waste tire management? Any limits or restrictions?**

The Mahaphant Company has its own quality control system, in addition to the Pollution Control Department control.

Question 12: **How well are those enforced?**

An auditor from PCD visits the facility 2-3 times a year. A report to the PCD has to be submitted by the facility management.

General Questions:

Question 13: **How many people are employed at Unionpattanakit co.Ltd and Saengthai Tire Production co.Ltd facilities in Thailand?**

3900 people at the entire facility, and within those, about 60 people working in the Research and Development Center of Mahaphant.

Question 14: **How large are these facilities?**

400 square acres

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Developing a Sustainable Waste Tire Management Strategy for Thailand

Orachitr Bijaisoradat · Kailyn Connor · Steven Cortesa · Shakhizada Issagaliyeva · Nachnicha Kongkatigumjorn · Adam Meunier · Kunathon Wattanavit

Site: (Name, Type, Location)	Bangkok Tire Refinery (BTR)
Date:	To be determined
Interviewee: (Name, Title)	Mr. Decha Kittisuphaluk
Interviewer(s):	Orachitr Bijaisoradat, Steve Cortesa, Nachnicha Kongkatigumjorn

Question 1: How long have this facility been operating under your leadership?

Ans This facility has been operating for 4 years

Question 2: Can you give us a brief explanation of the pyrolysis process at the facility?

Ans 1. Put the end of life tires (unused tires) into a closed furnace.

2. Provide the heat to the furnace using firewood as fuel until the tires melt to be oil vapor

3. Condense the oil vapor to liquid oil, then allow the oil to cool down for storage.

Question 3: Does the process produce any byproducts? Are they used for anything?

Ans There are byproducts. 1. Steel wires – for steel 2. Carbon black – for energy

Question 4: Does the byproducts have any affect towards the environment?

Ans The byproducts MAY affect the environment when the management is not good

Question 5: What governmental regulations or laws are placed on this type of waste tire management? Any limits or restrictions?

Ans From my knowledge, there are no direct laws or regulations concerning used tires (ELT), but there are regulations for building a facility.

Question 6: How many tires undergo pyrolysis at a typical amount in this facility? - Annually, weekly, daily

Ans Currently BTR uses approximatelyy 2000 tonnes per month. (working days – 25 days a month)

Question 7: Where do you get the waste tires? How do get them?

Ans There are salesmen who come to sell old tires to the facility.

Question 8: How do you choose the suitable tire waste (type, brand, size) for pyrolysis?

Ans We select only passenger car tires, truck tires, large-size truck tires (6 or 10 wheel trucks)

Question 9: Do waste tires have to be pretreated before the pyrolysis process takes place?

Ans We don't have to pretreat the tires. We differentiate the tires by weight.

Question 10: What are the major benefits of pyrolysis?

Ans Pyrolysis helps dispose and reduce the large amount of end-of-life tires. It is also economically beneficial.

Question 11: What are the major drawbacks of pyrolysis?

Ans Pyrolysis may effect the environment when the process is not well managed.

Question 12: How profitable is pyrolysis?

Ans For 5 years, the company gained about 10% profit per year on average.

<u>General Questions:</u>

Question 13: How many people are employed at Bangkok Tire Refinery facility in Thailand?

Ans About 130 people.

Question 14: How much does it cost to construct these facilities initially?

Ans Overall investment for construction is about 100 million baht.

Question 15: How much does it cost to run a typical production facility annually? What percentage of this cost is dedicated to pyrolysis?

Ans BTR uses approximately 150 million baht per year (100%).

Question 16: Have this facility/you thought of other tire waste treatments? Or other ways to improve the current pyrolysis method?

Ans We are still considering the possiblities from government support, thesis and research from universities (if any) to improve/use new technologies. The company is also consulting with a company from the US about reversing tires to raw materials for tire manufacturing.

Question 17: What do you think/expect about the future tire waste treatment in Thailand?

Ans There should be an increase in waste tire management in Thailand due to the increasing amount of automobile use. waste tire management requires a lot of invesment (expensive). Therefore, the government should support and control the waste management as a system to reduce the amount of "hard to dispose" waste and recycle the waste to the most useful product.

Additional Presentation Notes:

Machinery:

- Imported from China; cheap labor and machine cost

- Machine parts were separated before imported to Thailand
- The machine was adapted by engineers to increase safety and to make it suitable for pyrolysis
- Uses 400-800 degree Celsius for the whole process

Raw material:

- Firewood
    - 1.3 – 1.4 baht per kg
- Tire
    - Depends on the economy *There are no fixed price of the tires; depends entirely on the salesperson
    - 2 types of tires 1) Defected tires from tire manufacturer, 2) End of life tires
    - Tires can be either shredded (2.10 baht/kg) or whole tires (1.60 baht/kg)

Environment:

- BTR wants to make the pyrolysis process as safe as possible towards the environment and health, especially issues with carbon black
- They need better waste water treatment
- Want to use high technology to solve environmental problem
- Local people does not like the facility to be built due to production of dust/ash/carbon black and smell

Product:

- Stove oil 38-45%
    - The stove oil produced is not as viscous as the real stove oil. Therefore, customers have to adapt their machines to be suitable for using this type of oil.
    - The testing quality of oil use ASTM standard
    - Produces about 700,000 liter/month
- Carbon black 35%
    - Sold to other companies which further processes the carbon black to coal
- Steel wire 10%
- Gas 10%
    - Sulfur, propane (protane) and methane and others
    - Bad odor
    - Can be converted to gas engine but produces only 1kW per batch
    - Can be converted to turbine energy but it is a low quality gas, so machine will break down after about 6 months.

    - Cannot be used for energy during pyrolysis process because it is not safe and may explode.

Current co-operating companies:

- 3rd world countries i.e. Malaysia and Vietnam
    - less industrial regulations compared to Thailand – allows tire import (Thailand only export)

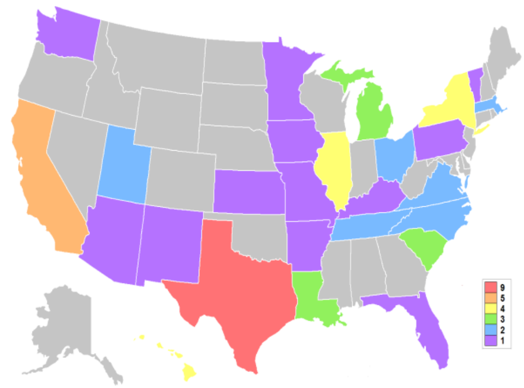
Appendix F: Site Visit Spreadsheet

Company / Organization	Type	Coordinator / Contact	Location	Information	Target Group	Availability
Pollution Control Department (Waste Management Bureau)	Government	K'Nuchanart Leelakahakit	92 Soi Phahon Yothin 7 Phahon Yothin Road Sam Sen Nai Phayathai District Bangkok 10400 E-mail : lnuchanart@yahoo.com Tel: 02-298-2411	Research report	Primary	Provided data about waste tires in Thailand (in Thai) via E-mai on 11 Jan 2013
Union Comercial Development, Co. Ltd.	Reclamation rubber + Production of tires	K'Boonharn	Head office : 95/34 2nd fl. M.8 Suptawee Home Factory Watkhusand Rd., NailKlong Bangphakot, Pra Samuhchedi, Samutprakan 10290 (Manufacture :Chonburi)	Site visit/ Interview Expert	Primary	Site visited on 19 Jan 2013, 9:30am-12pm
NSTDA	Government Agency	P' Jiratchaya Duangburong	Thailand Science Park	Site visit/Interview	Primary	Attended meeting and site visit on 6 Feb 2013, 9am-12pm
Thamasat University	University	-	Rangsit Campus	Site visit/Interview	Primary	Recommended we contact Prof.Somrat at KMITNB
Chulalongkorn University	University-pyrolosis	Prof. Dr. Sirirat Jitkarnka	Chulalongkorn University	Interview	Primary	Private research, info not available
KMITNB	Future solid waste management	Prof. Somrat Kerdsuwan Prof. Krongkaew Laohalidanond	Faculty of Engineering KMINBT Email : somrat_k@yahoo.com Tel : 083-5055119 (Secretary- K'Bo)	Interview	Secondary	Interview conducted on 24 Jan 2013, 3pm-4:30pm
B-Quik	Premium Garage	Unknown	Lotus department store, Kallaprapurk (กัลปพฤกษ์)	Interview	Secondary	Interviewd as customer on 15 Jan 2013
Leng Yoo Long (เล้งอยู่ลั้ง)	Private Garage	Vichien Tansuwanont	Thonglor	Site visit/ Interview	Primary	Phone interview available at any time
PlaygroundIDEAS	Playgrounds	Marcus Veerman	Austrailia	Skype Interview	Secondary	Interviewed 24 Jan 2013, 9am-10am

Mahaphant Fibre-Cement Public Co, Ltd.	Incineration/ Cement Kiln	K' Wichit Prakaypan	59 Moo 12 Saraburi-Lomsak Rd., K.M. 16, Chongsarika, Pattananikorn Lopburi, 15220 Tel: 036-638888	Site visit/ Interview	Secondary	Site visited 8 Feb 2013
Siam Cement	Incineration/ Cement Kiln	-	99 Moo 9 and 219 Moo 5 Mitraparb Rd., K.M. 129-131 Tamban Tabkwang, Amphar Kangkoy, Saraburi 18260 Tel: 036-240930	Site visit/ Interview	Primary	Could not visit in time
Bangkok Tire Refinery (BTR)	Pyrolysis	Mr. Decha Kittisuphaluk	777 Moo. 9 Tambon Samrong, Amphur Plangyaow, Chacheng Sao 24190 Tel: 083-502200	Site visit/ Interview	Secondary	Site visited on 4 Feb 2013, 9:30am-12pm
Michelin	Retreading/ Manufacturing	K'Rangsarit	252 Phaholythin Rd. Samsaen Nai, Payathai, Bangkok 10400 Thailand Tel : 02-619-3000 Email : Jugsujinda.rangsarid@th.michelin.com Tel : 089-8112642	Report and research/ interview	Primary	Sent interview guide and proposal summary. No response.
Bridgestone	Production of tires	-	Saraburi	Interview	Secondary	Could not contact
Cement Thai NakornLuang co. Ltd	Convert tire to cement	-	Column Tower 7th-12th Fl. 199 Ratchadapisek Rd., Klongtoey, Bangkok 10110, pr@sccc.co.th	Site visit/Interview	Secondary	Could not contact

Appendix G: U.S. Case Study

United States Case Study



With over 80% of all waste tires being either recycled or repurposed, the United States of America serves as a prime example of a country with an effective waste tire management system (EPA, 2012). It includes all of the elements that the United Nations claims are required for a waste management system including, policies, institutions, financing mechanisms, technology, and stakeholder participation (UNEP, 2009). Figure G1 below illustrates the percentage of waste tires utilized relative to the amount generated in the United States.

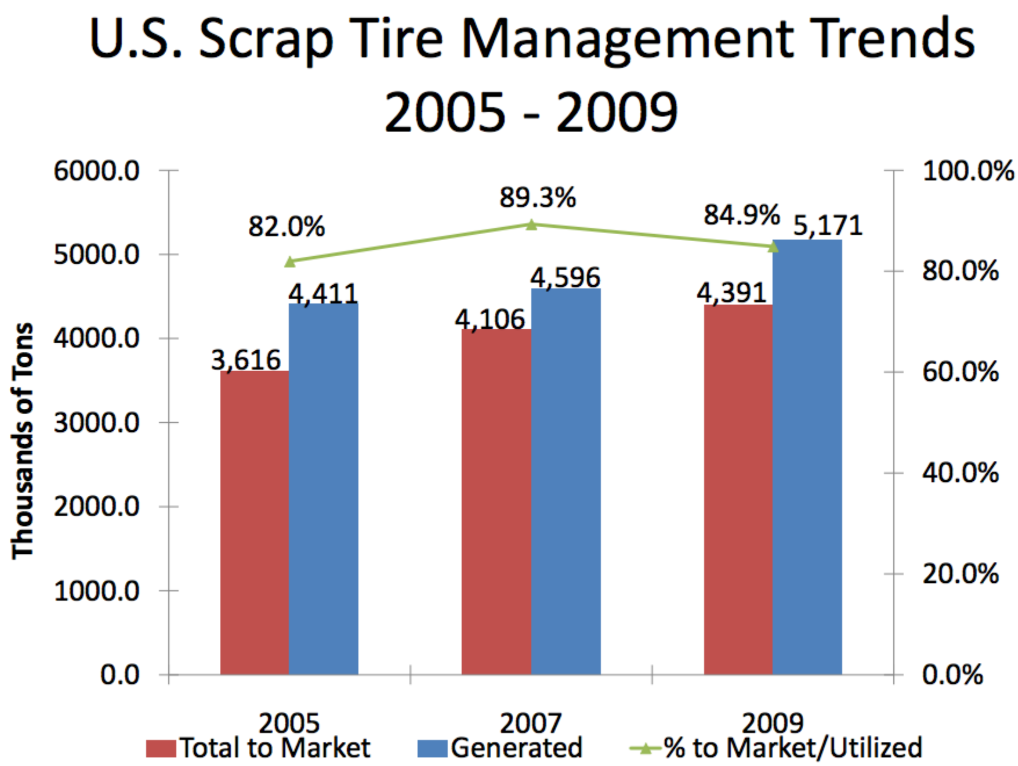


Figure G1 – U.S. Scrap Tire Management Trends 2005-2009 (U.S. Scrap Tire Management Summary, 2011).

Stakeholder Participation

In the U.S., the waste tire industry is divided into 4 main sections of stakeholders: consumers, generators, collectors, and processors. Scrap tires are generated by "consumers" who are the original users of the product. The used tires are then collected by "generators", which includes retailers, municipalities, consumers, and junkyards. The "collectors" then transport the tires to the "processors". Finally, the "processors" turn the waste tires into materials that can be used by the end-markets (Tire Recycling Industry: A Global View, n.d). The industry structure is shown below in Figure G2.

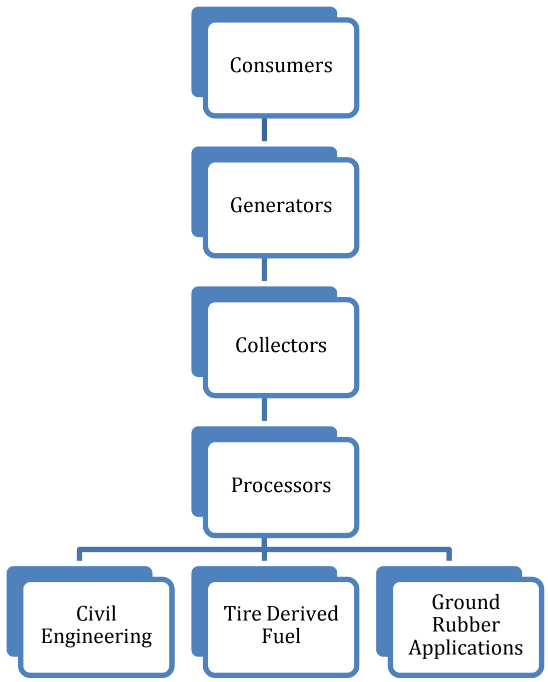


Figure G2 – U.S. Waste Tire Industry Structure (Tire Recycling Industry: A Global View, n.d).

Institutions

United States governmental laws and regulations support the growth of the American scrap tire recycling industry (Tire Recycling Industry: A Global View, n.d). While government support has been instrumental in the growth of the industry, it is not consistent across states. Stewardship programs exist in different states, helping to educate the public about illegal dumping and enforce anti-tire dumping laws (EPA, n.d). Local agencies are usually responsible for tire pile cleanup, allowing local citizens to drop off limited numbers of tires at recycling centers.

United States end-markets for scrap tire products is said to be one of the largest in the world (Tire Recycling Industry: A Global View, n.d). State agencies and local municipalities make large use of scrap tires generated, including playground and park applications and rubberized asphalt. The federal government purchases large amounts of scrap tires products and follows purchasing guidelines applicable throughout the U.S. (EPA, n.d). EPA has established the Comprehensive Procurement Guideline (CPG) program as continuing effort to promote the use of materials recovered from solid waste

(EPA, n.d). This program contains various information on recycling-content products marketing, including details on all specific products available, and 8 overview Product Resource Guides along with a mechanism to suggest a product (EPA, n.d).The main end-markets for scrap tire products in the United States are tire-derived fuel, civil engineering applications, ground rubber, and punched and stamped products (Tire Recycling Industry: A Global View, n.d).

Primary Technologies

The primary waste tire recycling technologies that are used in the United States include incineration for tire-derived fuel, grinding for tire-derived aggregate, and use in civil engineering products (Tire Recycling Industry: A Global View, n.d). Landfilling is also a method that is used frequently in the United States, despite knowledge of this strategy's flaws. Only 8 states have no restrictions on placing scrap tires in landfills, while 38 states ban whole tires from landfills, and 17 states allow processed tires to be placed into monofills (U.S. Scrap Tire Management Summary, 2011). A monofill is a landfill, or portion of a landfill, that is dedicated to one type of material (EPA, n.d). Monofills are preferable to above ground storage of tires in piles, due to fire hazards and human health hazards; however, they are mostly used where no other markets are available and municipal solid waste landfills do not accept tires (EPA, n.d). The percentages of U.S. scrap tire disposition for 2009 can be seen in Figure G3 below.

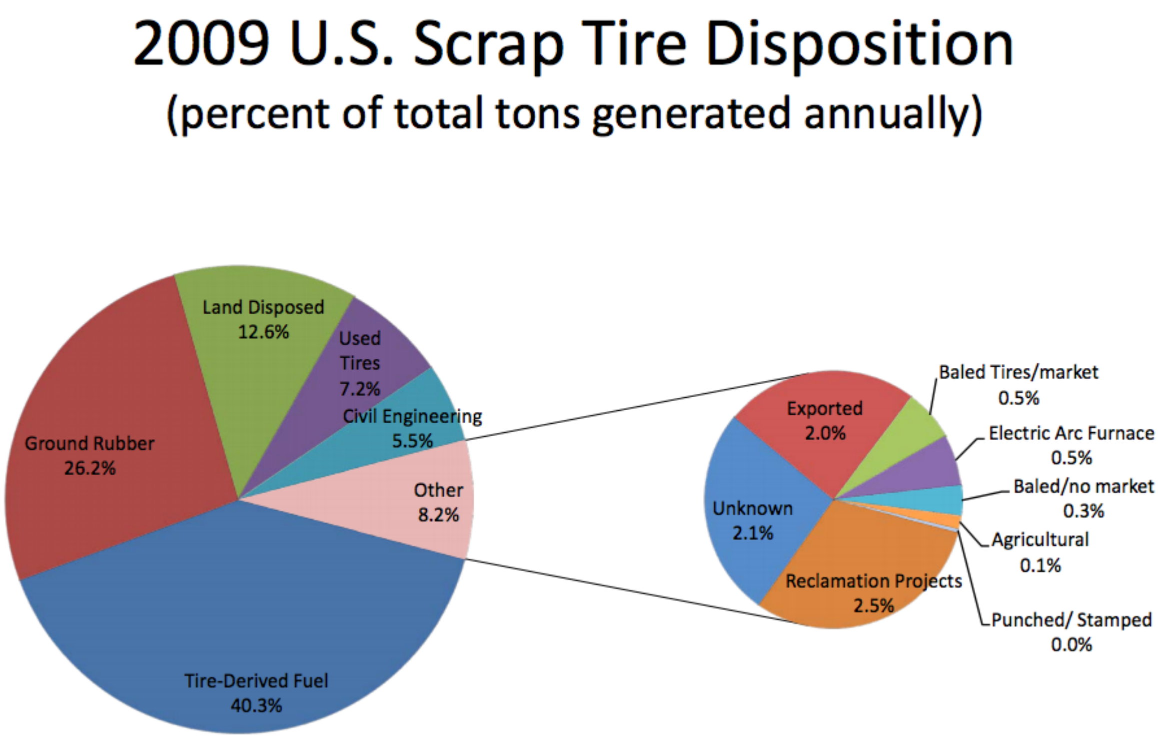


Figure G3 - Waste Tire Management Technologies used in the United States (2009) (U.S. Scrap Tire Management Summary, 2011).

Tire-derived fuel (TDF) as a method of scrap tire management is significantly more popular than other methods in the U.S. and accounted for 48% of total recycled tires in 2009 (U.S. Scrap Tire Management Summary 2005 – 2009, 2011). At the end of 2003, 89 U.S. facilities burned TDF on a regular basis, 43 of which are cement kilns, 17 pulp and paper mills, 13 coal-fired power plants, and 15 industrial boilers or waste incinerators. Based on over 15 years of experience with more than 80 individual facilities, the U.S. Environmental Protection Agency recognizes that the use of tire-derived fuels is a viable alternative to the use of fossil fuels (Tire Incineration, n.d). Tire-derived fuel continues to be the largest management method for scrap tires in the United States. As of 2006, state and local environmental agencies have approved the use of TDF at 48 plants in 21 states (EPA, 2012). Figure G4 below highlights the trends for TDF in the United States.

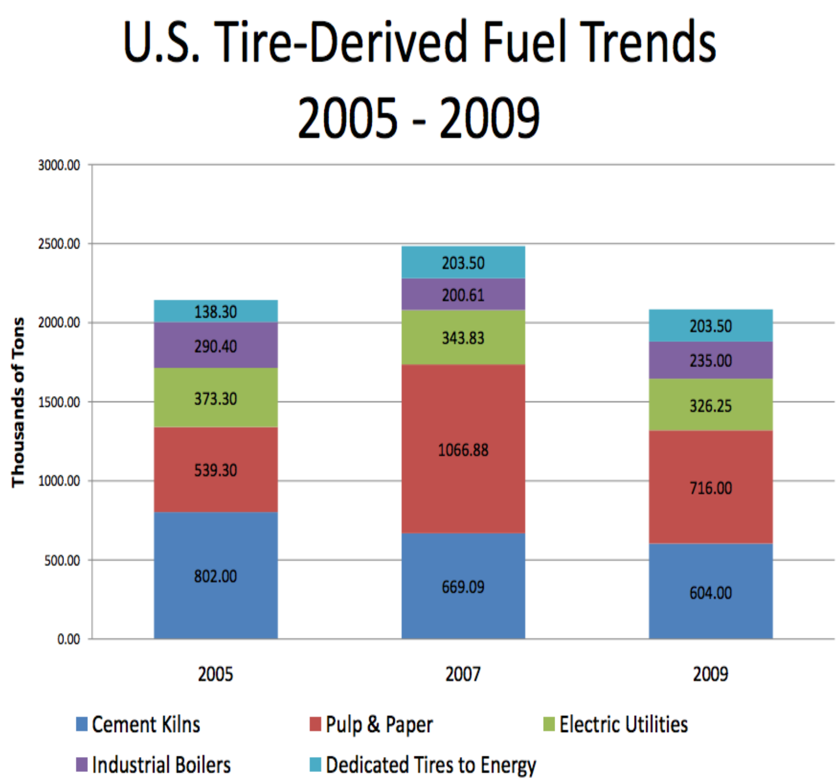


Figure G4 – U.S. Tire-Derived Fuel Trends 2005-2009 (U.S. Scrap Tire Management Summary, 2011).

Civil engineering applications remain one of the main uses of scrap tires in the United States. Mainly, scrap tires are used for lightweight fills, drainage layers for landfills and aggregate for septic tank leach fields (Tire Recycling Industry: A Global View, n.d). 39 states approve tire shreds for civil engineering applications. Tire derived aggregate (TDA) is used primarily in New York, California, South Carolina, North Carolina, Minnesota, Virginia and Ohio (Scrap Tire Markets In the United States 9th Biennial Report, 2009). The more prevalent uses for TDA are as a medium in septic fields (North Carolina and South Carolina), road construction (Minnesota) and in landfill construction in Virginia, Ohio and New York (Scrap Tire Markets In the United States 9th Biennial Report, 2009). Civil engineering applications have grown faster than any other application over the last five years and are expected to grow further (Tire Recycling Industry: A Global View, n.d).

Ground rubber is another prominent use of waste tires in the United States. 29.25% of total scrap tires produced in the U.S. was used for making ground rubber in 2009 (Scrap Tire Markets in the United States: 9th Biennial Report, 2009). The major applications for ground rubber include asphalts/sealants, molded and extruded products, sports surfacing, new tire manufacturing, surface modification, animal bedding and horticultural applications (Tire Recycling Industry: A Global View, n.d). The bulk of the ground rubber is generally used to produce molded products, sports surfacing and asphalt/sealants. Trends from 2005- 2009 (as seen in Figure G5 below) show a steady increase in the U.S. ground rubber market and these trends are expected to continue (U.S. Scrap Tire Management Summary, 2011).

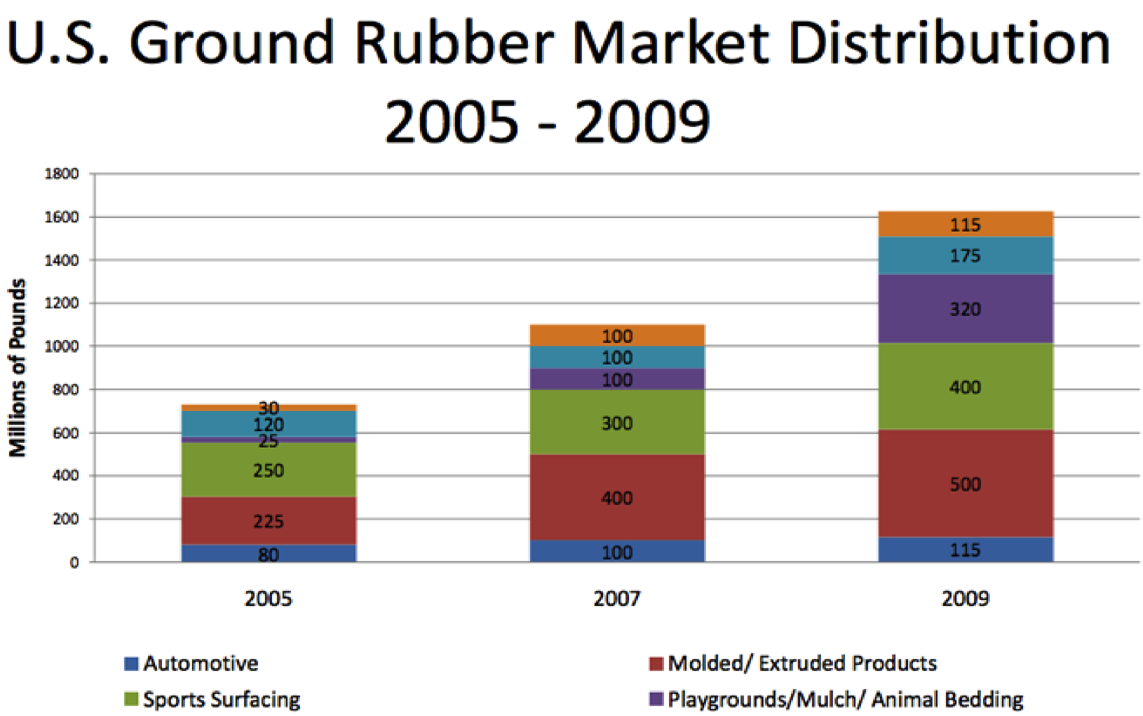


Figure G5 - US Tire-Derived Fuel Trends 2005-2009 (U.S. Scrap Tire Management Summary, 2011).

Policies and Financing

Waste tire management is primarily controlled and monitored by state governments. Currently, 48 states have laws or regulations specifically dealing with scrap tires (EPA, n.d). Most states have laws concerning which institutions fund waste tire management programs, who may handle scrap tires, and how the market for scrap tires products should be developed further. Moreover, each state has regulations on licensing or registration requirements for scrap tire haulers, processors and some end user, as well as manifests for scrap tire shipments (EPA, n.d). In addition, many states collect fees on scrap tires, generally ranging from $0.50 to $5.00 depending on the size of the tires. Fees are usually collected to fund scrap tire management programs, stockpile cleanup, help local communities establish market programs, create licensing/enforcement systems, and host tire collection programs/amnesty events (EPA, n.d). Some scrap tire fees may also offer grants or loans to scrap tire processors and end users of tire-derived materials. Many local agencies provide funding for events like amnesty days where any local citizen can bring a limited number of tires to a drop-off site free of charge (EPA, n.d).

California is as an example of a state with a particularly successful waste tire management program. To further strengthen waste tire management strategy in the state, the Legislature passed Senate Bill 876 in 2000 to augment the California Tire Recycling Act (Tire Recycling Industry: A Global View, n.d). The new legislation covers:

- Development of technical standards and permit requirements for waste tire facilities.
- Registration of used and waste tire haulers.
- Enforcement actions against illegal tire facilities.
- Investigation into used and waste tire hauler and waste tire facility/storage complaints.
- Research and development supporting markets for tire-derived products.
- Technical and financial assistance to local governments.
- These programs are funded by a $1.00 per tire fee collected on the retail sale of new tires (California Scrap Tire Briefing Sheet, n.d).

As a whole, the United States has been successful in recent years in their reduction of waste tire stockpiles. Much of this is due to many states such as New York, Alabama, and Michigan that mandate the elimination of large stockpiles.
The results of the strategies discussed above may be viewed in the following chart (Figure G6):

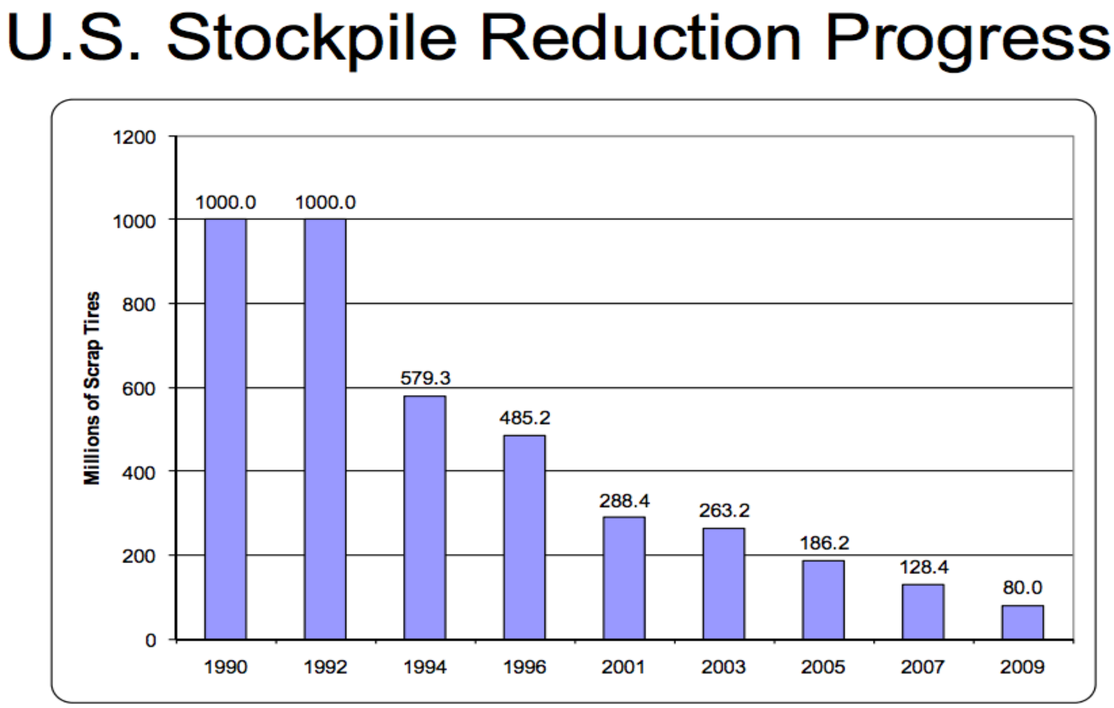
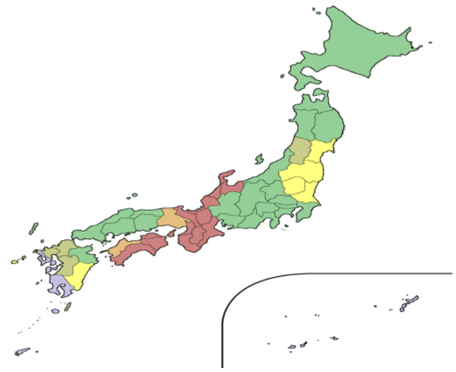


Figure G6 - U.S. Waste Tire Stockpile Reduction (1990-2009) (U.S. Scrap Tire Management Summary, 2011)

Appendix H: Japan Case Study

Japan Case Study



Japan provides an example of a waste tire management system in a country that is comparable to Thailand. Japan, like Thailand, lacks specific laws related to tire waste, and the waste tire industry is largely unregulated. However, despite the lack of regulations, Japan is still able to have a very high recycling rate for used tires. Recycling is given utmost importance in Japan since land is at a premium and as such there is no space available for landfills (Tire Recycling Industry: A Global View, n.d). As a result, scrap tire recycling rates in Japan are very high. The total recycled volume of 2011 was 900,000 tons and the recycling rate was 90%, decreased by 1% from 2010.

Stakeholder Participation

Stakeholder participation varies slightly in Japan compared to Thailand and different terminology is used. Individual consumers typically dispose of used tires at "dealers" which includes tire retailers, tire shops, car dealers, service and gas stations, and car repair shops (Tire Recycling Industry: A Global View, n.d). The "dealers" supply the scrap tires to the "contractors" that both collect and transport the tires (Japan Automobile Tyre Manufacturers Association, n.d). Consumers such as car, truck, and bus companies typically dispose of their scrap tires directly to the "contractors", bypassing the "dealers" since higher volumes are involved (Tire Recycling Industry: A Global View, n.d). Tires from end-of-life vehicles are disposed of by "contractor" companies directly to reutilization and disposal companies. Figure H1 below is a schematic representation of waste tire collection system in Japan.

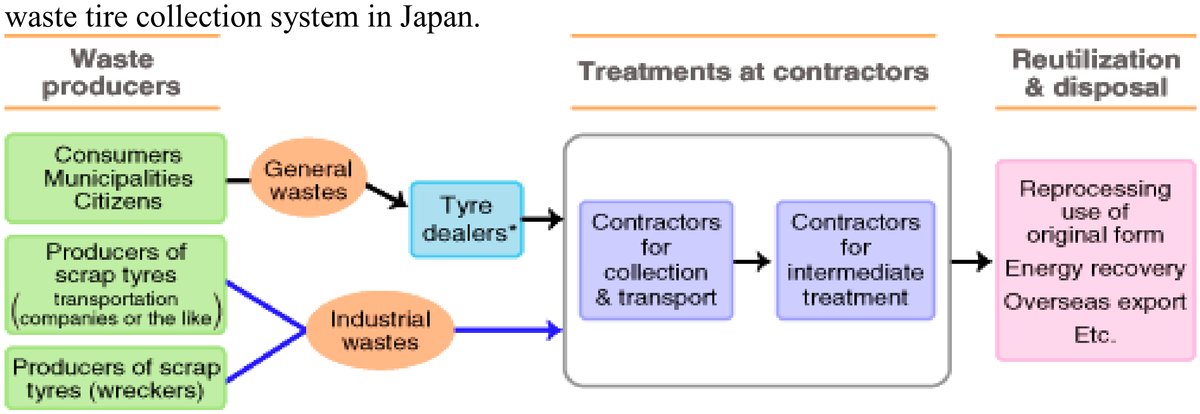


Figure H1 - Japan Waste Tire Flow (Japan Automobile Tyre Manufacturers Association, n.d)

Institutions

Many types of institutions are involved in both the collection and regulation of waste disposal in Japan. Local governmental entities helps to remove the waste tires that are dumped illegally, and receives support from the Japan Automobile Tyre

Manufacturers Association or the Waste Management Foundation (Japan Automobile Tyre Manufacturers Association, n.d). The Japan Automobile Tyre Manufacturers Association, which includes Bridgestone Corporation, Sumitomo Rubber Industries, Ltd., The Yokohama Rubber Co., Ltd., Toyo Tire & Rubber Co., Ltd., Nihon Michelin Tire Co., Ltd, is an independent association that mainly conducts research on production, distribution, consumption and trade of the automobile tires, as well as plans and promotes policies concerning safety and environmental preservation (Japan Automobile Tyre Manufacturers Association, n.d). Japan Waste Management & 3Rs Research Foundation's goal is to manage various problems of waste in Japan and implement recycling programs by gathering information from governmental, industrial and private sectors (Japan Waste Management & 3Rs Research Foundation). Furthermore, several groups of major companies in other industries, such as cement and automobile industries play an important role in waste management in Japan (Nakamura, 2007).

Primary Technologies

In 2011, about 38% of the generated scrap tires by weight were used for heat utilization purposes, primarily in paper manufacturing (Japan Automobile Tyre Manufacturers Association, n.d). An additional 8% of the total scrap tires produced was used for heat utilization in the cement industry. However, usage of scrap tires as fuel in the cement industry has declined from 148 thousand tons in 2007 to 77 thousand tons in 2011 (Japan Automobile Tyre Manufacturers Association, n.d). The fall is mainly due to the decline in the number of public works being executed and usage of other waste as fuel. Use of scrap tires as fuel in boilers declined due to regulatory pressures: 11 thousand tons in 2007 compared to 6 thousand tons in 2011 (Japan Automobile Tyre Manufacturers Association, n.d). The usage of scrap tires as fuel is likely to fall further as Japan comes under pressure to reduce its greenhouse gas emissions as part of the Kyoto Protocol and newer market applications of scrap tires are introduced (Tire Recycling Industry: A Global View, n.d).

Crumb rubber is used in rubber or plastic products, and mixed with other materials to make new products, including plastic floor mats and adhesives. It can also be mixed with asphalt as an additive to make cement products (J.-W. Jang et al, 2008). This is expected to grow further in the future as the tire-derived fuel market continues to decline and the industry tries to promote scrap tire recycling and alternative end-markets (Tire Recycling Industry: A Global View, n.d).

In addition, lack of available space for landfilling causes the export of waste tires to remain high every year.

Policies and Financing

Japan has no specific laws regarding scrap tire recycling. The issue has always been dealt with as part of solid waste recycling (Tire Recycling Industry: A Global View, n.d). For instance, Ministry of the Environment has taken several measures to prevent illegal dumping (Nakamura, 2007). "The manifest system" was introduced in Japan to all industrial waste in 1998, and it enables dischargers to trace their waste in each process of waste management. In addition, licensing conditions for waste management businesses were revised and strengthened as part of Waste Management Law in 1997 and 2000 (Nakamura, 2007). The Japanese End-of-Life Vehicle Recycling Law is intended to improve tire recycling rates. The recycling rates are expected to improve further as Japan tightens its regulation and tries to improve consumption from end-markets (Tire Recycling Industry: A Global View, n.d).

Japan has a long-running co-operative program that co-opts tire manufacturers, government agencies and other industry players for scrap tire recycling. Even though there are no specific regulations governing emissions from burning scrap tires, the waste tire management emissions are expected to meet the broader emission regulations issued from time to time (Tire Recycling Industry: A Global View, n.d).

Statistics

Scrap tire generation is likely to be flat in the wake of stagnant automotive demand. Industry growth rates in Japan are likely to taper off due to peaking of recycling rates and the lack of any significant stockpiles.

The industry is too dependent on tire-derived fuel and there is a need to develop other end-markets. The tire-derived fuel market has been declining for the past few years but has been offset by a rise in exports. Any substantial fall in exports could lead to a supply glut in the domestic market resulting in a fall in prices. See Figure H2 below.

				2007	2008	2009	2010	2011		
				tons	tons	tons	tons	tons	distribution(%)	2011/2010(%)
Kind of recycling	Domestic	Reuse	Retreaded tyre bases	37	38	46	48	50	5	104
			Reclaimed & powdered rubber	111	106	83	97	97	10	100
			Other uses	17	10	7	1	1	1	100
			Subtotal (A)	165	154	136	146	148	15	101
		Heat utilization	Paper manufacturing	328	339	349	388	377	38	97
			Chemical factories	12	24	11	9	32	3	356
			Cement calcining	148	141	112	95	77	8	81
			Steel manufacturing	40	39	28	30	31	3	103
			Gasification furnace	42	48	48	49	45	5	92
			Tyre manufacturing	18	19	18	23	20	2	87
			Boilers	11	12	9	8	6	1	75
			Metal refining	8	2	1	1	1	1	100
			Subtotal (B)	607	624	576	603	589	59	98
	Export		Used tyres	148	146	142	147	152	15	103
			Cut tyres	32	11	6	8	10	1	125
			Subtotal (C)	180	157	148	155	163	16	105
Total recycling (A+B+C)				952	935	860	904	900	90	100
Reclamation				11	8	3	4	2	1	50
Others				101	113	87	89	96	10	108
Subtotal (D)				112	121	90	93	98	10	105
Total used tyres (A+B+C+D)				1,064	1,056	950	997	998	100	100

Figure H2 – Uses of tire waste in Japan (Japan Automobile Tyre Manufacturers Association, n.d)

Appendix I: Questionnaire

Waste Tire Management of Private Car Owners

แบบสอบถามเกี่ยวกับการบริหารการจัดการยางรถยนต์ที่ใช้แล้ว

Age (อายุ)**: ( )** 18 - 25 ( ) 26 - 35 ( ) 36 - 45 ( ) 46 - 55 ( ) 56 - 65 ( ) 66 - 75

Sex (เพศ)**: ( )** Male (ชาย) ( ) Female (หญิง)

Education (การศึกษา**):**

Occupation (อาชีพ**):**

Location (hometown) (ที่อยู่**):**

1) How many tires does your household generate per year? * Include any tires that are no longer exploitable and are replaced
   ในครอบครัวของคุณ ใช้ยางล้อรถยนต์จำนวนกี่เส้นต่อปี? * รวมถึงยางล้อรถยนต์ที่ไม่ได้ใช้แล้ว

- ( )0
- ( ) 1 - 2
- ( ) 3 - 5
- ( ) > 5

2) What kind of vehicle do you have?
   คุณมียานพาหนะประเภทใดบ้าง?

- ( ) A truck

  รถบรรทุก
- ( ) A motorcycle

  มอเตอร์ไซค์
- ( ) A passenger car

  รถยนต์ส่วนตัว
- ( ) Multiple kinds (please specify)

  อื่นๆ โปรดระบุ

3) Where do you take the used tires? * Include any facility, such as car shop, recycling company or a landfill
   คุณทำอย่างไรกับยางที่ใช้แล้ว?

- ( ) Keep them on my property

  เก็บไว้ที่บ้าน
- ( ) Take them to a recycling facility/local landfill

เอาไปขายให้ร้านรับซื้อของเก่า

- ( ) Dump in a nearby stockpile

  เอาไปทิ้ง

- ( ) Sell to a shop

  ขายให้ร้านขายยาง

- ( ) Make something out of them

  เอายางไปประยุกต์เป็นอย่างอื่น

- ( ) Else:

  อื่นๆ

4) What is the best tire recycling option, in your opinion? * Indicate the method that is most sustainable/profitable to your knowledge
   ในความคิดของคุณ คุณคิดว่าการรีไซเคิลยางวิธีไหน เป็นวิธีที่ดีที่สุด? *วิธีที่ยั่งยืนและได้รับผลประโยชน์

- ( ) Incineration for energy

  เผายาง

- ( ) Reuse in civil engineering projects

  นำกลับมาใช้ในโครงการที่เกี่ยวกับวิศวกรรมโยธา

- ( ) Reuse in consumer goods

  นำกลับมาใช้ในสินค้าอุปโภคบริโภค

- ( ) Retreading to make new tires

  นำกลับมาทำเป็นยางใหม่

- ( ) Devulcanization

  ปฏิกิริยาการทำลายพันธะเคมีของโครงสร้างตาข่ายสามมิติ (โครงสร้างร่างแห)

- ( ) A combination of those (please specify)

  เอาวิธีต่างๆมารวมกัน

- ( ) I do not think it is safe to recycle tires

  การนำยางมารีไซเคิล อาจจะไม่ปลอดภัย

- ( ) Else:

  อื่นๆ

5) Do you consider waste tires a problem in your community?
   คุณคิดว่าขยะยางได้สร้างปัญหากับชุมชนรึเปล่า

- ( ) Strongly agree

  เห็นด้วยอย่างยิ่ง

- ( ) Agree

  เห็นด้วย
- ( ) Neutral/Do not know

  เฉยๆ
- ( ) Disagree

  ไม่เห็นด้วย
- ( ) Strongly disagree

  ไม่เห็นด้วยอย่างยิ่ง

6) Have you ever had problems getting rid of your waste tires? * Indicate all that apply
   คุณมีเคยปัญหากับการกำจัดยางรถยนต์หรือไม่

- ( ) Some shops do not pay much for tires

  ร้านบางแห่งรับซื้อยางรถยนต์ในราคาถูก
- ( ) It is too far from my house to take my tires to a shop

  ร้านรับซื้อยางรถยนต์อยู่ไกลเกินไป
- ( ) My tires are not accepted by a facility

  ร้านหรือบริษัทไม่รับซื้อยางรถยนต์ของผม/ดิฉัน
- ( ) I do not know where to take them

  ผม/ดิฉันไม่ทราบว่าต้องนำยางรถยนต์ไปขายต่อที่ไหน

7) How do you rate your experience of dealing with tire shops? *Please provide comments

- ( ) Very easy

  ง่ายมาก
- ( ) Moderately easy

  ง่าย
- ( ) Slightly easy

  ค่อนข้างง่าย
- ( ) Difficult

  ยาก

8) Are you aware of the environmental pollution caused by injudicious management of waste tires? *Please provide comments
   คุณตระหนักถึงมลพิษทางสิ่งแวดล้อมที่เกิดจากการกำจัดอย่างผิดวิธีหรือไม่

- ( ) Strongly agree

เห็นด้วยอย่างยิ่ง

- ( ) Agree

เห็นด้วย

- ( ) Neutral/Do not know

ไม่รู้

- ( ) Disagree

ไม่เห็นด้วย

- ( ) Strongly disagree

ไม่เห็นด้วยอย่างยิ่ง

9) Do you know any legislation or legal framework governing management of waste tires? *Please provide comments
คุณเคยได้ยิน หรือทราบถึงข้อกำหนด และกฎหมายเกี่ยวกับการบริหารจัดการและการกำจัดยางรถยนต์ที่ใช้แล้ว

- ( ) Strongly agree

เห็นด้วยอย่างยิ่ง

- ( ) Agree

เห็นด้วย

- ( ) Neutral/Do not know

เฉยๆ

- ( ) Disagree

ไม่เห็นด้วย

- ( ) Strongly disagree

ไม่เห็นด้วยอย่างยิ่ง

10) Do you think proper utilization of waste tires can create new job opportunities? *Please provide comments
คุณคิดว่าการบริหารจัดการและการกำจัดยางรถยนต์ที่ใช้แล้วด้วยวิธีที่เหมาะสมมากขึ้น
จะสามารถสร้างรายได้และโอกาสการสร้างงานใช้ชุมชนได้หรือไม่

- ( ) Strongly agree

เห็นด้วยอย่างยิ่ง

- ( ) Agree

เห็นด้วย

- ( ) Neutral/Do not know

เฉยๆ

- ( ) Disagree

  ไม่เห็นด้วย
- ( ) Strongly disagree

  ไม่เห็นด้วยอย่างยิ่ง

11) Do you think the existing waste tire management programs in Thailand are effective? *Please provide comments
    คุณคิดว่าการบริหารจัดการและการกำจัดยางรถยนต์ที่ใช้แล้วด้วยวิธีที่ใช้อยู่ในปัจจุบัน มีประสิทธิภาพมากหรือน้อยเพียงใด

- ( ) Strongly agree

  เห็นด้วยอย่างยิ่ง
- ( ) Agree

  เห็นด้วย
- ( ) Neutral/Do not know

  เฉยๆ
  - ( ) Disagree

  ไม่เห็นด้วย
  - ( ) Strongly disagree

  ไม่เห็นด้วยอย่างยิ่ง

Appendix J: Feasibility Matrix

		Factor:	**Economic**		**Infrastructural**		**Environmental**		**Social**		**Political**
Method:											
Open Dumping/ Open Burning	Pros		• Free of cost		• Requires no infrastructure and minimal space		None		• Convenient		None
	Cons		• Material from waste tires remains unused- lost potential • Can be very costly to remediate • Can decrease nearby property values		• Uses space that could be used for something else		• All potential environmental issues are maximized by lack of containment		• Detracts from the aesthetic appeal of the region		• Extremely difficult to monitor and regulate due to frequency of occurance
Landfilling	Pros		• No additional transportation is necessary • Facility does not need to purchase tires		• Can handle large volumes of tires • Can be established in rural environments • Does not require advanced technology • Generally accepts all tires		• More environmentally safe than open dumping • Pollutants contained under ideal conditions • Centralized destination for waste		None		• More easily regulated due to lack of complicated processes
	Cons		• Landfills may charge a deposit fee • Tires may cause expensive damage to landfills • Contamination caused by landfill damage is expensive to clean up • Material from waste tires remains unused- lost potential • Landfills are expensive to develop and maintain • High transportation cost due to rural location • Additional maintenance costs added due to potential		• Landfills eventually fill up • Takes up a lot of space • Complicated construction is needed to prevent pollution • Expensive, daily maintenance is required • Generally must be located in rural areas		• Tires can cause damage to the landfill, allowing other MSW to leach toxins		• Tires can cause damage to the landfill, allowing other MSW to leach toxins and create negative health effects • Detracts from the aesthetic appeal of the region		• Lack of regulations makes proper management difficult to enforce

			damages caused by tires								
Incineration (for energy)	Pros		• Energy is produced • Entirety of material is consumed or useful for other applications (cement) • Replaces other expensive fuels		• Tires are completely eliminated, so there is no longer a need to store or transport them		• If properly maintained, fewer emissions than coal and many other fuel sources		None		• Some regulations regarding emissions
	Cons		• Expensive facility • High cost for proper maintenance of controlled environment • Can be more expensive to burn than other types of waste • Rural location of facilities leads to high transportation costs • Cost of purchasing waste tires		• Expensive facility to build • High cost for proper maintenance of controlled environment • Generally must be located in rural areas due to societal resistance		• If improperly maintained, dangerous levels of emissions (clarify)		• Negative health effects caused from improperly managed facilities • Social stigma regarding incineration of tires		• Regulations encompass only specific pollutants • Air quality is difficult to monitor and standards are difficult to enforce •Proper management difficult to enforce

Pyrolysis	Pros		• Produces separated byproducts which can be reused as fuel or sold		• Potential for urban/suburban location if operated in an environmentally responsible manner		• If managed correctly, few pollutants are produced • Separates all components of tire • Eliminates waste		None		• Some regulations regarding emissions
	Cons		• Very expensive procedure if environmentally conscious • Expensive facility • Low quality products • Need to frequently replace machinery • Large facility requires extensive space • Difficult to be both profitable and environmentally responsible		• Expensive facility to build • Rural location of facilities leads to high transportation costs		• Requires a lot of energy • When poorly maintained creates a lot of pollutants • Carbon black produced and scattered • Toxic greenhouse gas released from process • Bad odor • Furnace burns wood to operate machine, using a natural resource		• Produces bad odor that can negatively impact local residents		• Lack of regulations makes proper management difficult to enforce
Retreading	Pros		• Reuses tire for intended purpose • Tire can be repaired and resold multiple times • Uses less material than making new tire • Quick, inexpensive process in comparison to construction of new tire with same result • Less expensive for consumers		• Inexpensive facility, potentially smaller scale in comparison to some other methods due to low cost of machinery • Potential for any environment (rural or urban) • Requires very similar to technology to the manufacturing process		• Requires less material than manufacturing a new tire • When done properly, same quality as a new tire • Recycles materials, extended use • Reduces the need for new rubber production		• Less expensive than new tires for consumers		• Self-regulating, requires less direct enforcement by government agencies
	Cons		• Typically only performed on large tires due to low profits from smaller automotive tires • If a larger percentage of tires are retreaded, new tires will be less valuable, and sales of new tires could potentially		• Insignificant infrastructural disadvantages		• Other solution required once tire can no longer be retreaded		• Many people believe that retreaded tires are of a lower quality • For automobiles, retreaded tires costs are about equal to that of a new tire, dissuading people from choosing retreading		• Lack of regulations makes proper management difficult to enforce

			decrease								
Grinding (Reclamation)	Pros		• Profitable, established industry in Thailand • Makes use of generally overlooked material • Multiple markets for product • Less need for new rubber allows for more land to be dedicated to food production, etc.		• Successful examples exist in Thailand, providing models for future facilities		• Reduces the need for new rubber production • Recycles • Could reduce the land needed for new rubber production • Heat produced from process can be recycled to create steam to fuel the process again		• Potential lower cost of rubber products due to inexpensive reclaimed rubber		• Self-regulating, requires less direct enforcement by government agencies • Professional society within the industry allows for more accurate information gathering
	Cons		• Growth of reclaimed rubber industry may affect rubber production industry • Cost of purchasing waste tires • High energy cost • Moderate machinery and facility purchase & repair costs		• Expensive facility and machinery • Machine maintenance is expensive and frequent • Need waste treatment machinery in order to reduce pollutants		• If improperly maintained, chemicals used in process can diffuse into the environment • Process separates carbon black which negatively affects the environment if spread • Possible release of pollutants if unregulated • Releases gas, smoke, heat, and strong odor		• Possible pollutants causing negative health effects for facility employees and local residents if improperly maintained		• Sporadic enforcement of solid waste pollution regulations
Grinding (Direct use)	Pros		• Can be used in many applications (track & field etc.) • Quick and inexpensive • Can control process (mulch size) • Does not consume material, leaving end-of-life applications viable		• Comparatively simpler machinery is needed for initial process		Few/No pollution produced; no use of chemicals		• Produces products for many application that consumers benefit from (e.g. sports fields)		• Requires minimal regulation
	Cons		• Machinery is expensive • Need different machinery for different mulch sizes • Cost of		• Frequent maintenance is required due to high wear on machinery		• Insignificant environmental disadvantages		• Insignificant social disadvantages		• Sporadic enforcement of solid waste pollution regulations

			purchasing waste tires								
Punched, cut, stamped	Pros		• Inexpensive process • Is already an established, profitable market in some countries		• Simple technology		• Few pollutants produced		• Consumers benefit from a functional product		• Requires minimal regulation
	Cons		• No known established market in Thailand • Cost of purchasing waste tires		• Minimal preexisting infrastructure		• Insignificant environmental disadvantages		• Insignificant social disadvantages		• Sporadic enforcement of solid waste pollution regulations
Small-scale applications	Pros		• Tires are often donated • Low transportation cost due to local availability • Does not consume material, leaving end-of-life applications viable • Replaces other, more expensive materials		• Simple technology • Requires minimal infrastructure		• Few pollutants produced		• Can directly benefit local communities (e.g. playgrounds)		• Requires minimal regulation
	Cons		• Low number of tires repurposed • Typically not profitable		• Insignificant infrastructural disadvantages		•Waste tires will eventually re-enter waste stream		• Insignificant social disadvantages		• No regulations on quality control for commercial products

A Microsoft Excel version of this feasibility matrix can be found at:
https://sites.google.com/site/bkk13tires/

Appendix K: Glossary of Tire Components

Glossary of tire components (*Radial Versus Bias Tire Construction*, 2012).

bead
: A bundle of bronze-coated high tensile strength steel wire strands which is insulated with rubber. The bead is considered the foundation of the tire; attached to the steel rim of the tire.

belts
: Layers of steel cord wires located between the tread and the body ply. Typical tires may contain anywhere from 2 to 5 belts. The steel wire of the belts runs diagonally to the direction of motion. The belts increase the rigidity of the tread and the cut resistance of the tire. They also transmit the torque forces to the radial ply and prevent cutting, cut growth and cracking.

body ply
: A single layer of steel cord wire, running from bead to bead laterally to the direction of motion. The design is called “radial”. The body ply is a primary component restricting the pressure which ultimately carries the load. The body ply also transmits the forces (torque, torsion, etc.) from the belts to the bead and eventually to the rim.

breakers
: Sometimes referred to as *belts*. The breakers provide protection for the cord body from cutting and increase tread stability which resists cutting.

chafer
: Increases the overall stiffness of the bead area, thereby increasing the durability of the bead area and preventing deflection or deformation. It also assists the bead in transforming the torque forces from the rim to the radial ply.

cord body
: Also known as the *carcass*. It consists of layers of nylon plies. The cord body confines the pressurized air within the tire, which supports the tire load and absorbs shocks encountered while the tire is in service. Each cord in each ply is completely surrounded by resilient rubber. These cords run diagonally to the direction of motion. They transmit the forces from the tread down to the bead.

liner
: An integral part of all tubeless pneumatic tires. It covers the inside of the tire from bead to bead and prevents the air from escaping through the tire.

sidewall
: A protective rubber coating on the outer sides of the tire. It is designed to resist cutting, scuffing, weather checking, and cracking.

tread
: Consists of specially compounded rubber which can have unique characteristics ranging from wear resistance, cut resistance, heat resistance, and rolling resistance. The purpose of the tread is to transfer the forces between the rest of the tire and the ground.