CANMET Materials Technology Laboratory

Scrap Tire Recycling in Canada

A reference for all parties involved in the tire recycling industry on the options available for end-of-life OTR and passenger tires from an economic and environmental perspective

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by

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ABSTRACT

This report was supported by the Enhanced Recycling Program of Action Plan 2000 on Climate Change (managed by the Mineral Technology Branch, Natural Resources Canada). Data from the provinces and the Canadian Association of Tire Recycling Agencies (CATRA) were collected from August 2004 to February 2005 with the objective of developing a clear picture of tire recovery and recycling in Canada, and the environmental impacts – including greenhouse-gas emissions (GHG) – of current and future practices.

This study of "Scrap Tire Recycling in Canada" shows there is a great market potential for the processing of scrap tires into new applications and value-added products. Thanks to well-operated tire programs in nearly every Canadian province (only Ontario is currently developing its program), scrap tires are now being processed using several techniques.

The biggest market for scrap tires in Canada in 2003/2004 was rubber crumb, which represents more than 40 wt % of the total scrap-tire usage market or more than 100,000 metric tonnes. A further 20 wt % was used as tire-derived fuel (TDF) for either cement kilns or paper mills; 18 wt % was directly processed as moulded products in recycling plants, and 13 wt % was processed as shred. The balance was baled or stored. A total of about 240,000 metric tonnes of scrap tires was processed in Canada in 2003/2004. Approximately 75 wt % of these scrap tires required processing in an ambient or cryogenic recycling plant. Only cement kilns can accommodate whole tires, while some civil engineering applications, like barrier reefs, require no crushing or grinding of scrap tires.

The fibre content in tires varies from product to product, and (especially in scrap tires) the exact composition is never known. According to the available published data on tire composition, the amount of fibre in tires varies from 3 to 5% by weight. Therefore, 7,041 to 11,357 metric tonnes of fibre is available for the waste stream if the fibre can be 100% liberated from the tire. The actual amount might be higher because of contamination with rubber particles.

The steel content in tires also varies from product to product. The amount of steel in tires varies from 10 to 14% by weight, therefore anywhere from 22,714 to 32,708 metric tonnes of steel may be available from end-of-life tires if the steel can be 100% separated from the tire. Statistics

from processors may vary because of contamination with rubber particles or if more passenger tires than truck tires are processed. The exact ratio of passenger tires to truck tires is not known in most processing facilities for scrap tires, therefore the numbers only provide an estimate of the average steel content in the tires.

The recycling of off-the-road (OTR) tires is a big issue in all Canadian provinces; OTR tires include heavy mining tires as well as agricultural and industrial tires. A total of 345,000 OTR tires is reported by the Rubber Association of Canada (RAC) as OTR tires for all of Canada. Due to the high cost of processing these tires, all provinces are searching for feasible options.

Environmental considerations concerning GHG emissions and human health have been evaluated and are summarized in this survey. The whole survey has shown that there is a variety of viable solutions for processing scrap tires. One single solution for Canada is not viable; different processing methods are required to stabilize the market situation.

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1 INTRODUCTION

This project was supported by the Enhanced Recycling Program of Action Plan 2000 on Climate Change (managed by the Mineral and Metals Sector of Natural Resources Canada). Data from the provinces and the Canadian Association of Tire Recycling Agencies (CATRA) were collected between August 2004 and February 2005 with the objective of developing a clear picture of tire recovery and recycling in Canada and the environmental impacts (including greenhouse gas emissions) of current and future practices.

The recycling of tires is not a new technology, but there are many important issues to look at, especially from the viewpoint of protection of the environment. There are four basic choices in dealing with the scrap tire problem. They are commonly referred to as the four Rs (4Rs):

- Reduce,
- Re-use,
- Recycle, and
- Recover.

First in the hierarchy is Reduce, which means that eliminating waste is best for the environment. It is the best method to reduce greenhouse gases, and it also saves natural resources and avoids generating solid waste. Therefore, the “Be Tire Smart” campaign of the Canadian government and the Rubber Association of Canada (RAC) is strongly recommended because it saves a lot of energy and is a benefit for everyone (www.betiresmart.ca).

Although re-use of tires is limited because of safety issues, there is a strong market in retreading tires, and the Rubber Association of Canada is very advanced in supporting the 4Rs hierarchy:

> Truck tire retreading is one of the best examples of extending the viable life and use of a tire. Most commercial truck and aircraft tire casings are retreaded several times before being discarded. Both truck and aircraft tires are specially designed with retreading in mind. The passenger tire market however, is very different and offers little opportunity for retreading except in small niche markets.
>
> It is partly the multi-rubber component structure of a tire that makes it difficult to re-use in new tires. And yet, it is being done. A number of tire companies are now incorporating as much as 5-10% crumb rubber in their new, original equipment quality passenger and light truck tires.
>
> Tire manufacturers, through ever-evolving technologies, have prolonged the life expectancy of automobile and truck tires. Thus the need for new tires is reduced. At the same time, however, automobile manufacturers are selling more new cars. The public, too, can make a useful contribution; it is estimated that tire life can be extended by 30% simply by maintaining proper tire pressures, rotating tires as recommended, keeping wheels properly aligned and practicing good driving habits.[1]

Recovering the rubber and other materials from scrap tires is the biggest market. Most technologies described in this report are based on material recovery and generation of new products.

2 THE TIRE

2.1 TIRE MANUFACTURE

The manufacture of tires is well described in the report: "Effects of Waste Tires, Waste Tire Facilities, and Waste Tire Projects on the Environment"[2], published by the California Integrated Waste Management Board (CIWMB), therefore excerpts from the report are used in this chapter:

> The tire manufacturing process includes the production of rubber and placing additives in the rubber. It also includes the coating of fabrics for the radial belts and bias plies, and integrating them into the rubber.
>
> A tire must safely support a specified load under dynamic conditions with a minimum of power loss, overcome minor obstacles, and provide a reasonable endurance life. In addition, a tire should provide a long wear life, a smooth and quiet ride with good cornering, adequate skid resistance, and traction under various road conditions. A tire is also expected to have a pleasing appearance to complement the vehicle.
>
> The cord and fabric a tire provide for the tires continued structural integrity, increased wear resistance, and road grip. The rubber alone would not provide durability under conditions for which a tire is used. Excessive stress due to carrying large amounts of weight at high speeds in various weather conditions requires tires to be structurally sound. The layers of fabric made from rayon, nylon, and polyester, provide wear resistance and structural integrity. One of the most important factors in maintaining this integrity and wear resistance is the adhesion of the fabrics to the rubber. This is done by placing a steel wire bead around the circumference of both side walls of the tire. This bead is then used to tie on the fabric layers during the tire building. Steel and brass-coated steel may be used in addition to rayon, nylon, and polyester to form the plies. Steel is drawn and twisted in the same fashion as fabric. The configurations of fabric and steel vary with manufacturer and make of tire.
>
> The fabric layers or plies of reinforcing material are firmly adhered to the rubber and must remain effective after the article has been subjected to repeated and varying strains in use. Thus, the tire's durability and its ability to perform under increasingly severe operating conditions is directly linked to the adhesion of the ply material to its adjacent rubber surface.[2]

2.2 TIRE COMPOSITION

Fig. 2-1 shows the construction of a Vredestein passenger tire, and Table 2-1 shows the composition of a typical North American tire[3].

Passenger tires tend to contain more synthetic rubber than natural rubber; truck tires consist of more natural rubber; and off-the-road (OTR) tires, including heavy mining tires as well as agricultural and industrial tires, have nearly no synthetic rubber. The rubber composition may be due to the fact that passenger tires have to meet higher quality standards (low rolling resistance, improved skid resistance and good wear[4]) to succeed in the competitive market. Truck and OTR tires, on the other hand, have to cope with heavy loads and longer distances more than high speed. The fibre content in passenger tires can be as much as 5% of the total tire weight, whereas OTR tires tend to have little or no fibre content and contain about 15% steel.

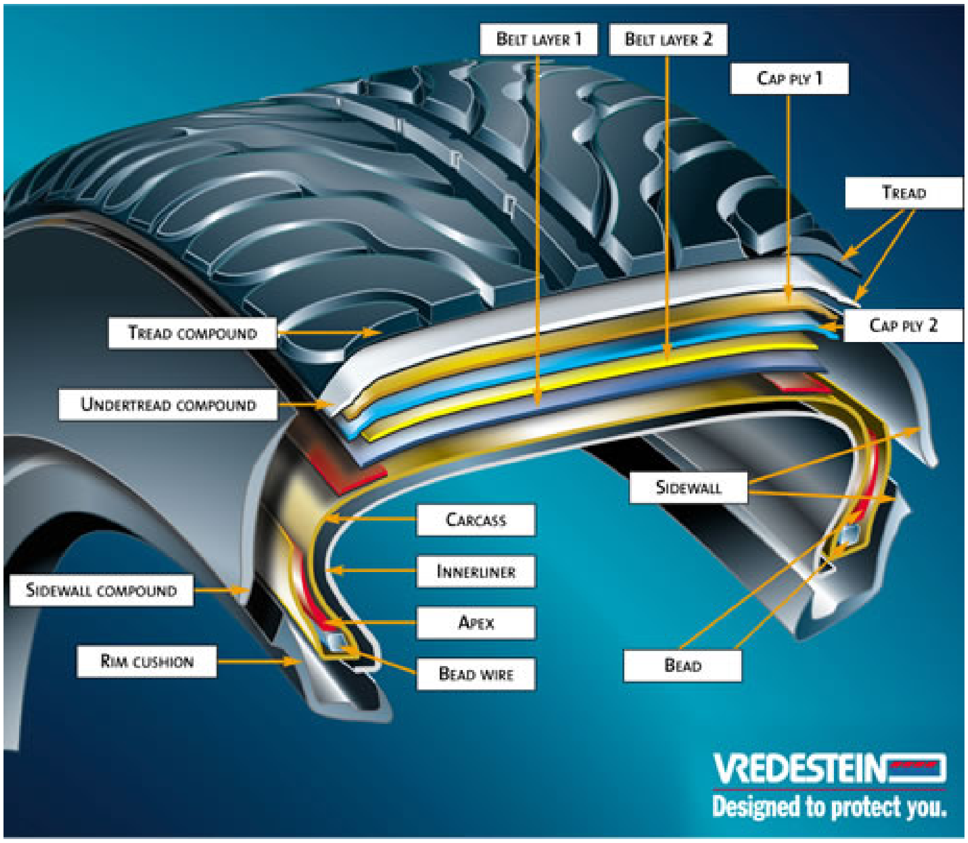

Fig. 2-1. Tire construction[5].

Table 2-1. Typical composition of passenger and truck tires in North America[6].

Composition	Passenger Tire	Truck Tire
Natural rubber	14%	27%
Synthetic rubber	27%	14%
Carbon black	28%	28%
Steel	14-15%	14-15%
Fibre, fillers, accelerators, antiozonants, etc.	16-17%	16-17%
Average weight:	New 11 kg, Scrap 9 kg	New 54 kg, Scrap 45 kg

Exact tire compositions are not known because each company keeps their compositions secret. As a result, all data are assumptions and an average of all tires. Chapter 8 will refer to the environmental impacts of different tire components. According to Phillips, the lifespan of an average passenger tire, if properly inflated and well maintained, can be up to 100,000 miles (160,930 km)[7]. This number seems to be a bit optimistic. The Rubber Association of Canada predicts the lifespan of a well-maintained steel-belted radial tire to be 100,000 km.

In this report, the average weight of a scrap tire is estimated to be 8.2 kg, which is the base for all calculations in this report. There are discrepancies between the provinces, but 8.2 kg is being applied to the entire country.

2.3 MATERIAL DESCRIPTION OF RUBBER, STEEL AND FIBRE

The major component of tires is the rubber. Rubber is produced either from natural sources or from petroleum and natural gas, both of which are discussed below:

2.3.1 Natural Rubber

> The chemical form of natural rubber is a polymer of isoprene (2-methyl-1,3-butadiene). Natural rubber is predominantly sourced from the sap of the Hevea brasiliensis tree. Hevea is a native of the Amazon basin, and until about 1910 the majority of natural rubber was derived from trees growing wild in this region. Since then, plantations have been established around the world[8].

2.3.2 Synthetic Rubber

> There are a number of types of synthetic rubber with various physical and chemical characteristics. Among the most widely used are styrene-butadiene rubbers, ethylene-propylene rubbers, butyl rubbers, acrylic elastomer and silicone rubbers. Like natural rubber, all are polymers, synthetic rubbers are sourced from various hydrocarbons, which are blended and reacted under controlled conditions to form the polymers. More than half of the world's synthetic rubber is styrene-butadiene rubber (SBR) made from styrene and butadiene monomers which are abundant in petroleum. Three quarters of all the SBR made goes into tires[9].

Passenger tires contain more synthetic rubber than natural rubber; in truck tires, the natural rubber content exceeds the synthetic rubber content, and in OTR tires only natural rubber is present.

The rubber polymers in tires are mixed with other components to achieve the best and safest tire performance. The average composition of a tire is given in Table 2-2.

Table 2-2. Basic composition of tire rubber[10,11].

Basic Composition	Examples of Main Compounding Ingredients	Amount (wt %)
Rubber	Natural rubber, synthetic rubber	51.0
Reinforcing agent	Carbon black, silica	25.0
Softener	Petroleum process oil, petroleum synthetic resin, etc.	19.5
Vulcanizing accelerator	Thiazole accelerators, sulfenic amide accelerator	1.5
Vulcanizing agent	Sulphur, organic vulcanizers	1.0
Vulcanizing accelerator aid	Zinc oxide, stearic acid	0.5
Antioxidant	Amine antioxidants, phenol antioxidants, wax	1.5
Filler	Calcium carbonate, clay	

All ingredients of the tire rubber are well combined and there is no way to separate the pure rubber from the additional chemicals. The electron microscope analysis in Fig. 2-2 shows the qualitative analysis of a rubber particle with the chemical composition of additives clearly visible in the rubber matrix.

The main constituents of the particle are identified as carbon (C) and oxygen (O) as expected because of the synthetic rubber. Fillers and additives are identified as fine dispersed components such as: aluminium (Al in Spectra 1 and 4), silica (Si in Spectra 1, 4 and 5), potassium (K in Spectrum 1), zinc (Zn in Spectra 1, 2, 3 and 5), copper (Cu in Spectra 2 and 3) and iron (Fe in Spectra 2 and 3). The fine distribution of particles is clearly visible; it is mechanically impossible to separate them.

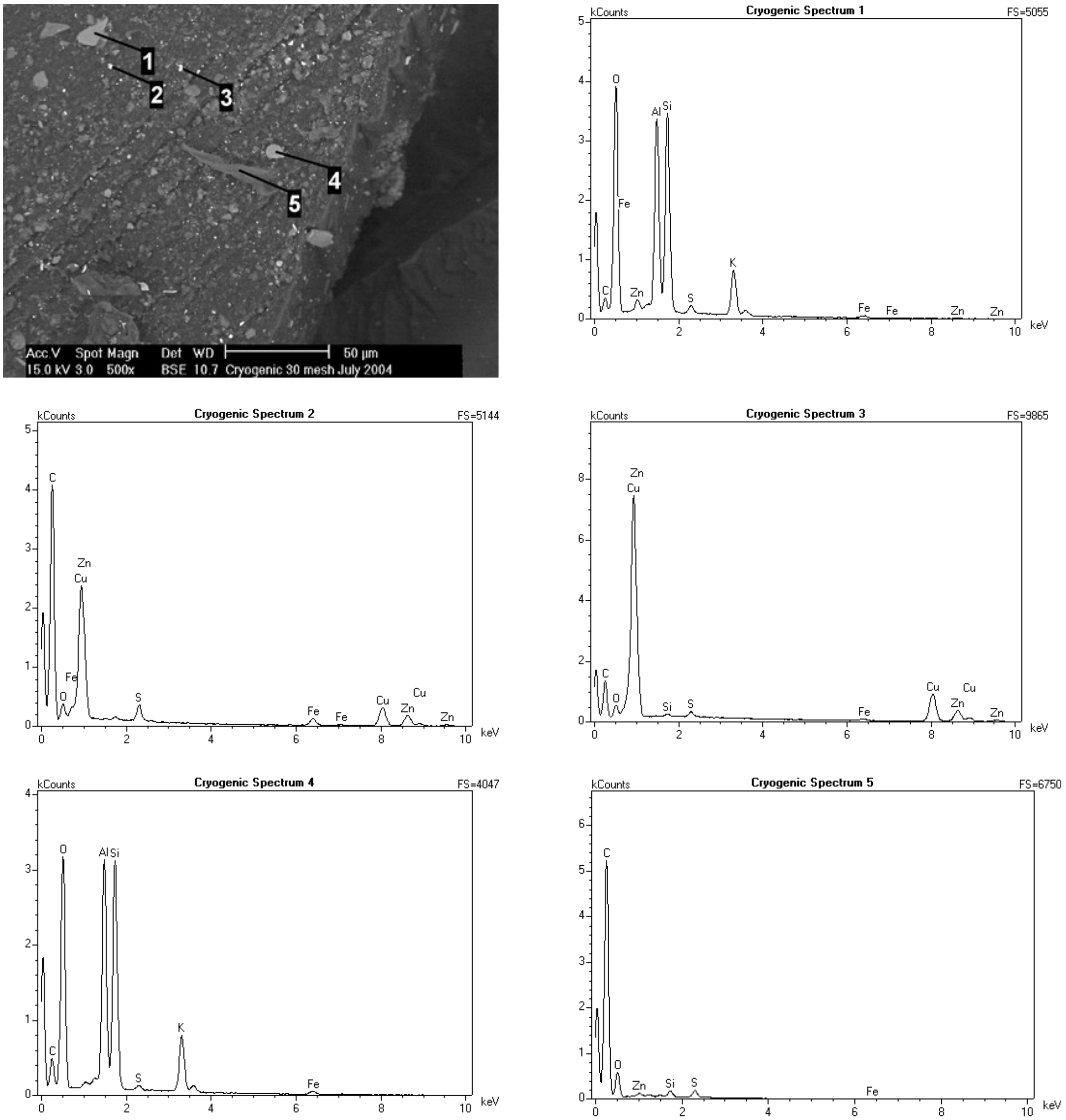

Fig. 2-2. Qualitative analysis of a rubber particle (numbers on the particle refer to spectra numbers)[12].

2.3.3 Fibre and Steel

The textiles, or fibre, and the steel present in the tire are used to reinforce the rubber. Such reinforcements can be relatively separate, as in bearings that consist of alternating layers of rubber and steel, or wholly enclosed in rubber, as in the tires. To fulfil their function, the reinforcements should be as inseparable from the rubber as possible[11].

Table 2-3 shows the constituent materials of the tires' body cord and belt cord.

Table 2-3. Materials for body cord and belt cord[13].

	Passenger Tire	**Truck Tire**
Belt Cord	(wt %)	(wt %)
• Steel	99	99
• Aramid	1	1
• Nylon	Trace	Trace
• Fiberglass	Trace	
Body Cord	(wt %)	(wt %)
• Steel		37
• Polyester	98	61
• Nylon		2
• Rayon	2	

> The general function of the textile fibre in tires is to provide stable motor vehicle performance over the required operating conditions. There are several design and operating categories for a vehicle tire. High performance is one example. The composition of fibre has evolved generally from rayon and nylon 6, to nylon 6,6 for medium-performance tires. Polyester terephthlate (PET), polyethylene naphthalate (PEN), and aramid (short form of aromatic polyamide) have been introduced as the fibre components for high-performance tires. They are also used in commercial truck tires[14].

In Europe, a higher percentage of rayon is used due to the high-speed requirements. Rayon is used for its characteristic low expansion, however it is also more costly.

The steel used by the tire industry is ASTM 1070 and above tire-cord quality wire rod to manufacture new tires. Table 2-4 shows an example of an analysis of the additives in the steel.

The steel used in tires has two distinct functions. It is used as steel belting (such as that underlying the tread near the outer diameter of the tire) in some tires, and for the circular metal component (bead) that is encased in rubber at the inner diameter of the tire. The circular metal component assists in sealing the inner diameter against the rim of the vehicle wheel. According to the Rubber Manufacturers Association, a typical passenger-car tire contains about 1.13 kg of steel. Goodyear indicates that there is a total of 0.9 kg of steel in the most popular passenger car tire (P195/75R14) – 0.45 kg of steel in each of the belting and the bead[15].

Table 2-4. Steel analysis (data from Rubber Manufacturers Association, 2004).

Ingredient	Steel belts	Bead wire
Carbon	0.67-0.73%	0.60% min.
Manganese	0.40-0.70%	0.40-0.70%
Silicon	0.15-0.03%	0.15-0.30%
Phosphorus	0.03% max.	0.04% max.
Sulphur	0.03% max.	0.04% max.
Copper	Trace	Trace
Chromium	Trace	Trace
Nickel	Trace	Trace
COATING	66% Copper 34% Zinc	98% Brass 2% Tin

3 TECHNICAL SOLUTIONS FOR SCRAP TIRE HANDLING AND THEIR FEASIBILITIES

This chapter provides an overview of the most common recycling technologies for scrap tires. There are other tire-recycling options, however most of them are in a developmental stage, and other literature might provide more detail[16,17,18,19].

3.1 AMBIENT GRINDING

This grinding process is referred to as ‘ambient’ because all size-reduction steps take place at or near ambient temperatures, i.e. no cooling is applied to embrittle the rubber particles.

In a typical plant layout, the tires are first processed using a preliminary shredder. The tire chips then enter a granulator, where the chips are reduced to a size of less than 10 mm (0.38 in.) in diameter. This liberates most of the steel and fibre from the rubber granules. Upon leaving the granulator, the steel is removed magnetically, and the fibre fraction is removed by a combination of shaking screens and wind sifters.

While there is some demand for the 10 mm rubber granules, most applications call for finer mesh material, typically in the range of 0.6-4.0 mm (5-30 mesh). For this reason, most ambient grinding plants operate a number of consecutive grinding steps. The machines most commonly used for fine grinding in ambient plants are: secondary granulators, high-speed rotary mills, and extruders, screw presses or cracker mills.

Ambient grinding is the preferred technology to produce relatively coarse crumb rubber material – i.e. larger than 0.6 mm (30 mesh)[20]. Rubber particles generated in an ambient recycling plant have a rough surface and tend to be partly devulcanised. Fig. 3-1 shows a rubber particle from a Canadian tire recycler. Some fibre particles are visible in the rubber matrix.

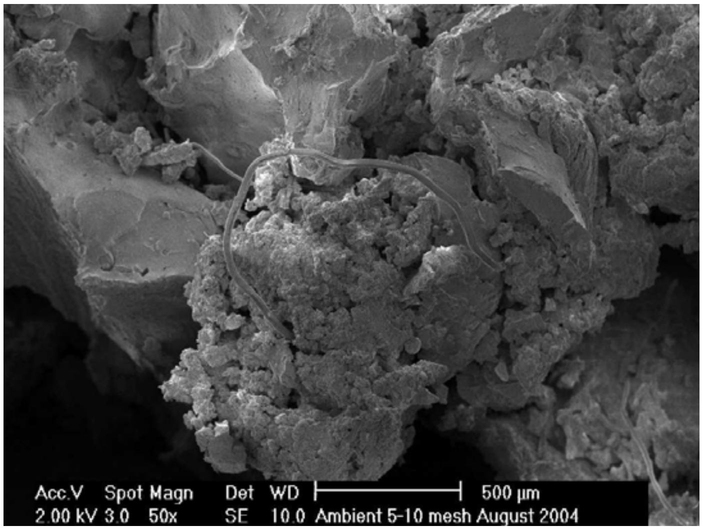

Fig. 3-1. Ambient ground rubber particle[12].

3.2 CRYOGENIC GRINDING

This process is referred to as 'cryogenic' because whole tires, or tire chips, are cooled using liquid nitrogen to a temperature below -80°C (-112°F). Below this 'glass transition temperature', rubber becomes almost as brittle as glass, and size reduction can be accomplished by crushing and breaking. Cryogenic size reduction of rubber requires less energy and fewer pieces of machinery than ambient size reduction. Another advantage of the cryogenic process is that steel and fibre liberation is much easier, leading to a cleaner end product. The drawback, of course, is the additional operating expense for liquid nitrogen (LN2).

A common cryogenic process can begin with preliminary shredding, which is largely the same as in ambient plants. The tire chips are then cooled in a continuously operating freezing tunnel to below -120°C and then dropped into a quickly rotating hammer mill. In the hammer mill, the chips are shattered into a wide range of particle sizes. Because the rubber granules may be damp upon leaving the hammer mill, the material is dried before sorting into well-defined particle sizes. A secondary cryogenic grinding step is required to produce fine rubber powder[21].

The cryogenic process is used when finer rubber particles are required. Due to the embrittlement, the texture of the rubber particles is different from that of the ambient particles. Fig. 3-2 shows an electron microscope image of a rubber particle received from a Canadian tire recycler. The very sharp edges of the particles and less surface area are evident compared with the ambient rubber particle shown in Fig. 3-1.

3.3 DEVULCANISATION AND SURFACE TREATMENT

In chemical terms, devulcanization means returning rubber from its thermoset, elastic state back into a plastic, mouldable state. It is accomplished by selectively severing the sulphur bonds in the molecular structure, thus for this treatment the rubber must already have been separated from the steel and fibre. The devulcanisation and surface treatment for rubber therefore requires previous ambient or cryogenic processing. This processing step enables rubber manufacturers to

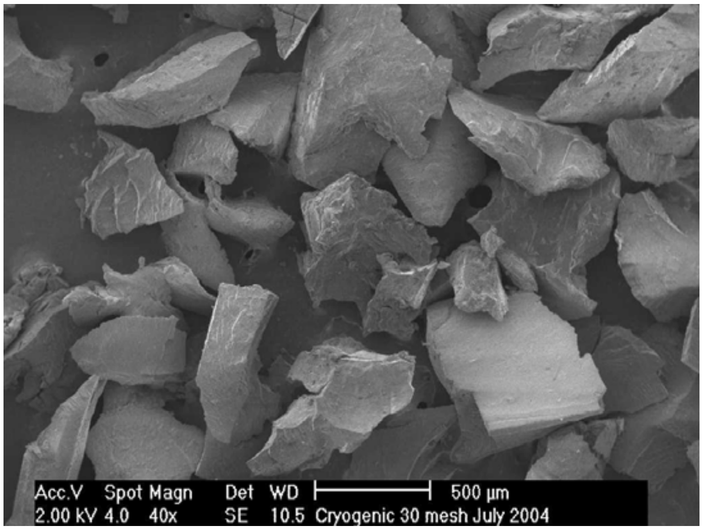

Fig. 3-2. Cryogenic ground rubber particle[12].

use a much larger percentage of recycled material without compromising quality, appearance or performance characteristics. Important devulcanisation methods include:

- Thermal reclaim process,
- Mechanical devulcanisation,
- Devulcanisation with ultrasound and
- Bacterial devulcanisation[20].

In recent years, a number of methods have been developed to chemically treat or modify the surface of the rubber crumb particles. The purpose of this treatment is to increase the adhesion between the rubber granules and the rubber polymer during vulcanization.

Examples of commercial surface treatments are: Vistamer (Composite Particles), Tirecycle (Rubber Research Elastomeric), Surcrum© (Vredestein), Activated Tire Rubber ATR (Texas Encore Corporation), Vestenamer (Hüls AG) and Elastomeric Alloy EA (Technical University of Chemnitz[11]). Surface treatment is usually combined with chemicals to make the recycled rubber surface more reactive with other materials.

The estimated cost of producing devulcanized materials from waste tires is CAD $0.39 to CAD $0.67/kg ± 30%, including the cost of crumb rubber feedstock. This range of production costs is significantly greater than that of virgin rubbers.[22]

3.4 ENERGY RECOVERY – USE AS TIRE-DERIVED FUEL

While uncontrolled tire fires cause substantial air and ground pollution, the incineration of whole tires or tire chips in industrial furnaces is environmentally safe. The calorific value of tire-derived fuel (TDF) exceeds that of coal (Table 3-1), while the sulphur content is in the same order of magnitude or even lower.

Table 3-1. Energy content of fuel[23].

Fuel	Heating Value
Heating oil	42 MJ/kg
Natural gas	38 MJ/m^3
Coal	25 MJ/kg
Wood biomass	20 MJ/kg
Tires	36 MJ/kg
Mixed plastic waste	43 MJ/kg

The use of TDF as a fuel supplement in cement kilns or paper mills in Canada is a viable means of safe disposal of large amounts of scrap tires. The use of TDF in paper mills is restricted to tire shred with most of the steel removed. A paper mill in British Columbia uses hog fuel (wood waste and biomass) as a substitute fuel for natural gas. If the quality of hog fuel is poor (especially in winter), TDF is added to the boiler in fluidized-bed combustion. Due to its high energy content, only 5% of TDF can be co-fired, but it stabilizes the operation of the fluidized-bed boiler. An increase in hog fuel combustion and a decrease in fossil fuel requirements is another benefit when TDF is co-fired[24].

Because the cement industry is the biggest consumer of TDF in Canada, the cement-production process will be described in more detail. There are three cement kilns in Canada currently using TDF: two in Quebec and one in British Columbia. In Quebec, from 1993-2003, 18 million tires have been used to fuel cement kilns. It is estimated that from 2001-2008, approximately 14.5 million used tires from stockpiles and the annual generated stream will be directed to Quebec cement kilns for fuel co-processing. In 2002 the BC cement plant received 270,000 tires, and in 2003 that number increased to 340,000[25].

3.4.1 The Cement Industry – Cement Manufacture[*]

> Cement consists of finely ground Portland cement clinker and additives such as fly ash (from coal firing processes), limestone or calcium sulphate (natural gypsum, anhydrite or gypsum from flue gas desulphurisation). Portland cement clinker is made from a raw material mix mainly consisting of calcium carbonate ($CaCO_3$), silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3). These chemical constituents are supplied by limestone, chalk and clay, as natural raw materials, or by secondary raw materials (e.g. slags). Limestone and chalk are composed of calcium carbonate ($CaCO_3$). The major constituents of clay, which is a natural product of weathering processes, are fine-grained minerals and smaller quantities of quartz and feldspar which constitute residues of the starting material. Clay mineral and feldspar are compounds of aluminium oxide and silicon dioxide with alkalis, such as sodium and potassium. The iron oxide required for melt formation is either contained in the clay minerals in the form of ferrous hydroxide, or added in the form of iron ore or as secondary raw material.
>
> The raw material mix is heated to approximately 1450ºC in a rotary kiln. Decarbonisation finalises until approximately 900°C, and sintering starts at 1200°C. This results in starting materials forming new minerals known as clinker phases (clinker minerals). These are certain calcium silicates, calcium aluminates and calcium aluminate ferrites, which confer on the cement its characteristic features of setting in the presence of water and getting its strength.
>
> The clinker burnt in the rotary kiln is subsequently ground to cement in finish mills, and if necessary further main constituents are added. Calcium sulphate serves to adjust the setting behaviour of the cement in order to obtain optimum workability of the product during concrete production. Apart from cement clinker, substances of silicate, aluminates and calcareous nature represent the remaining main constituents. They either contribute to the setting of the cement or have favourable effects on the physical properties of concrete[26].

To produce one tonne of cement, the following input is necessary:

- 1.6 tonnes of raw material,
- 3.5-4 GJ of energy from fuels, and
- 150 kWh of electrical power [27].

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[*] The text in this section is a direct translation from the original German document (ref 26).

3.4.2 Scrap Tires as TDF in Cement Kilns

Waste products are acceptable fuel for cement kilns providing that their composition is in compliance with local regulations and that no harm to the environment will result from their use. In particular, the content of PCBs, chlorine, sulphur and metal is usually limited in both the solid waste and the emissions.

Carbon and oxygen comprise 88% of tire content, which accounts for its rapid combustion and relatively high heating value. Whole tires contain approximately 30 GJ/tonne of energy, and this increases to 36 GJ/tonne if most of the steel is removed. Compared with the average coal (25 GJ/tonne), a kiln operator can reduce coal consumption by 1.25 kg for every 1 kg of TDF used. An additional advantage of TDF use is its steel portion. A 9 kg passenger tire contains up to 1.36 kg of high-grade steel. The steel can substitute, in part, for the iron requirement in the melt.

Another point of interest is that tires tend to contain less sulphur than most coals. Sulphur in tires ranges from 1.24 to 1.30 wt %. Sulphur in coal ranges from 1.1 to 2.3 wt % or higher, depending on the coal quality. The average coal used in cement manufacturing contains approximately 1.5 wt % sulphur. Emissions data from a variety of kilns in the US have clearly demonstrated a consistent reduction in sulphur and other emissions with the use of TDF. Since all the components of the tires are either destroyed, combined into the clinker or captured in the air pollution device, there is no ash that requires disposal[28].

Using whole tires as TDF can lower operating costs relative to the use of 100% coal. Whole scrap tires can currently be obtained by operating facilities in most Canadian provinces at a positive cost (due to subsidies). The use of scrap tires reduces the amount of coal used and consequently lowers the cost of coal acquisition. Finally, the steel component of the tire can serve as a substitute for the iron thus reducing or eliminating the cost of iron.

3.5 THERMAL CONVERSION TECHNOLOGIES

Thermal conversion technologies are not currently in use in Canada, but efforts are underway to start a recycling plant. The two main technologies are pyrolysis and microwave technology.

3.5.1 Pyrolysis

Pyrolysis is a thermal decomposition of organic material in the absence of air. Typically, the process is performed either in the presence of a flow of inert gas or under vacuum. The main components of tires are elastomers, carbon black filler/reinforcement material and other products such as zinc oxide and steel, as mentioned in Chapter 2.2. Upon heating, the rubber and other organic compounds decompose and are converted into oil and gas. The pyrolysis residue consists of the recovered carbon black filler, inorganic materials and varying proportions of carbonaceous materials formed from the rubber decomposition products. In this report, the vacuum pyrolysis process developed jointly by Pyrovac International and the University of Laval is described. There is no industrial plant operating in Canada, but enough data have been published to give an overview of the process and products. Industrial plants are currently operating in the USA and Europe[16].

Tire crumb (0-7 mm) is fed into a pyrolyser, which is 14.6 m long and 2.2 m in diameter. The tire crumb is conveyed by a raking-mixing system circulating over two fixed heating plates. The pyrolysing tire particles remain inside the reactor for approximately 12 min at 500°C, and the pyrolysis pressure is 15-20 kPa. The pyrolytic carbon black (CBp) is cooled in extracting screw conveyors, while the pyrolytic vapours and gaseous products are entrained by the main vacuum pump through a two-stage condensation system. The heavy oil is condensed in the first packed tower, and the lighter oil is recovered at the bottom of the second packed tower. Excess pyrolytic gas is available to generate steam, or it can be burned in a gas turbine. The amount of gas is sufficient to maintain the energy supply for the pyrolysis plant, and the excess gas can be sold. More details on the Pyrovac vacuum pyrolysis plant are available in the literature[29,30].

Yields of a vacuum pyrolysis plant at 500°C and 20 kPa with a capacity of 36,000 metric tonnes are estimated as follows:

- 34 wt % pyrolytic oil 9 (calorific value 43,800 kJ/kg, sulphur content 1.2 wt %),
- 32 wt % pyrolytic carbon black (grade similar to commercial black N300),
- 17 wt % gas (calorific value 46,000 kJ/kg, rich in hydrogen, methane propane, butane),
- 15 wt % steel, and
- 2 wt % fibres[31].

Scrap tire vacuum technology has the potential to recapture the valuable component compounds of tires. For example carbon black, oil and steel can be recycled into various categories of commodity products once a market has been established. A strong research and development program with a special focus on the CBp is also necessary to establish CBp market penetration.

3.5.2 Microwave

One example of Canadian microwave technology is the Patented Emery Microwave Process "Reverse Polymerization™ (RP)" by Environmental Waste International Inc. This technology is to be used for tire reduction and recycling (through product recovery) operations. A pilot plant is operating in Ajax, Ontario. The information about the microwave process in this report was provided by the company itself.

Reverse polymerization is a low-temperature (250-350°C) microwave-induced sublimation process in which reduction occurs in a nitrogen-rich environment, without producing unwanted combustion products; 100% of tire-reduction products are used or recovered. A typical microwave plant has a capacity of 18,000 metric tonnes per year (or 2.2 million passenger tires).

Tires are unloaded or conveyed from inventory, visually inspected for dirt and stones and washed, if required, prior to loading onto a dry feed system consisting of four process lines each capable of reducing 1,500 tires per day. At the dry feed system, air is purged with nitrogen until the nitrogen concentration is equal to that of the reduction tunnel where the tires are being reduced. Each reduction tunnel consists of 10 contiguous chambers, and each chamber is fitted with 15 microwave generators (150 per line) mounted on top of the tunnel. The microwaves engage the scrap tires with energy as they advance along the stainless steel conveyor and are subsequently reduced.

The reduction tunnel is continuously purged with nitrogen and monitored for total oxygen content to ensure safe operation. The hydrocarbon vapours are removed from the reduction chamber through insulated piping exiting the top and center walls. The remaining solid material (steel and carbon black) is removed from the reduction tunnel through a water trap. This ensures that all of the hydrocarbon vapours remain in the reduction tunnel.

At the exit of the reduction tunnel is a series of flexible Radio Frequency (RF) curtains that prevent microwave energy from escaping the reduction tunnel. Located directly after the RF curtains is a motorized rolling crusher that aids in the separation of the carbon from the steel. After the crusher, the conveyor passes out of the reduction tunnel and into water – also an RF trap.

The solid material remaining after the Reverse Polymerization process is carried on the conveyor to the water trap. The water trap has three functions:

- Prevents gases in the reduction chamber from escaping,
- Separates the majority of the carbon black from the steel, and
- Functions as a safe overpressure relief valve in an emergency.

The steel is held on the conveyor by a magnetic field as it descends and passes through the water trap and is then deposited in a bin for recycling. The carbon black is collected from the water trap via scoop conveyor. The remaining carbon is removed from the water trap as slurry using a heavy-duty pump capable of handling solids. The carbon black/water slurry is pumped from the water trap to the closed loop system minimizing the amount of water consumed.

Hydrocarbons from the sublimated scrap tire feed are collected in a series of heated collection pipes and conveyed to a water-cooled condenser. At the condenser, approximately 40% of the hydrocarbons are removed as a light-end, high BTU oil (19,000 BTU/lb or 44,300 kJ/kg). The oil can be considered for further treatment and used as feedstock in another process, or it may be used as fuel supply for surplus energy production. The chemical composition shows a complex mix of C4-C8 hydrocarbons, limonene, xylene, toluene and benzenes; the sulphur content is about 0.85%[32]. After the condenser, the remaining vapour-phase hydrocarbons are passed through a wet scrubber to remove the hydrogen sulphide (H_2S) gas. Sodium hydroxide and sodium hypo chlorite are consumed in the scrubbing process to meet the demands of the system. The gas stream consists of a variety of short-chain hydrocarbons including methane, ethane, propane and butane, and the balance of the gas mixture consists of nitrogen. The gas mixture has a heating value of 58 MJ/m^3.

The non-condensable gaseous hydrocarbons will be used for electricity co-generation. Depending on the efficiency of the co-generation apparatus selected, approximately 2.5 to 3 MW of electricity can be generated from the non-condensable gases.

From 100% tire input, 38% is recovered as carbon black (grade similar to N770/N990), 20% as condensable oil, 32% as non-condensable gas and 10% as scrap steel (grade similar to ASTM 1070)[33].

3.6 RETREADING

The greatest cost in the manufacture of a new tire is the tire body. The tread – the portion of the tire that meets the road – represents a relatively small portion of the total tire cost. Retreading is a process where the tire casing receives a new tread. Not every tire can be retreaded. In order to meet safety requirements, only carefully inspected tire bodies are retreaded. The worn tread is buffed away, and these tire buffings can be used in new applications. They contain nearly no fibre or steel and are therefore a high-value material. The new tread is then bonded to the tire body in a process very similar to the manufacture of a new tire. It is a well-established industry that began in the early 1900s. Passenger cars, aircraft, sand and gravel trucks, delivery vans, farm equipment and earthmovers can all use retreaded tires. For example, 80% of all aircraft tires are retreaded[34].

3.7 DISPOSAL IN LANDFILL

Disposal in landfill is the only solution for used tire disposal if the recycling plant is so far away that the transportation cost and fuel emissions exceed the environmental benefits. In Canada, this may be a (last) option for some territories. All provinces with tire programs are banning landfilling, and most provinces have either cleaned up or are in the process of cleaning up all their landfills. Tires in landfills present fire hazards resulting in dangerous emissions that have mutagenic potential. They are also an excellent breeding ground for mosquitoes that carry the West Nile Virus and are therefore a health hazard. Polyaromatic hydrocarbons were the major emitted products of a simulated tire fire in a study performed by DeMarini et al. in 1994[35], and increased lead and zinc levels were observed. The heat from tire fires also causes some rubber to break down into an oily material like petroleum that can pollute the soil and groundwater.

3.8 FEASIBILITY COMPARISON OF THE TECHNICAL SOLUTIONS

The feasibility of various solutions cannot be compared directly using definitive numbers for each process. Most processes are influenced by many factors including labour costs, transportation, tire supply and product quality. A life-cycle analysis for each technical method of processing tires is required to generate accurate data. This project did not include such detailed analysis, and therefore a general overview is presented.

The market for rubber affects the processing of scrap tires such that higher revenues enable improved processing technologies. Fig. 3-3 shows the North American crumb rubber market in 2003[36].

The pricing of recycled tires is also affected by crumb quality, crumb coloration, purchase quantity, competitive pricing factors, impact of subsidies, and negotiations between producers and end-users. Definitions of quality appear to be quite diverse and are driven by customer specifications unique to different market segments. In general, a “high quality of crumb” means low fibre content (less than 0.5% of total weight), low metal content (less than 0.1%) and high consistency. An accepted level of moisture content is about 1 wt %[37].

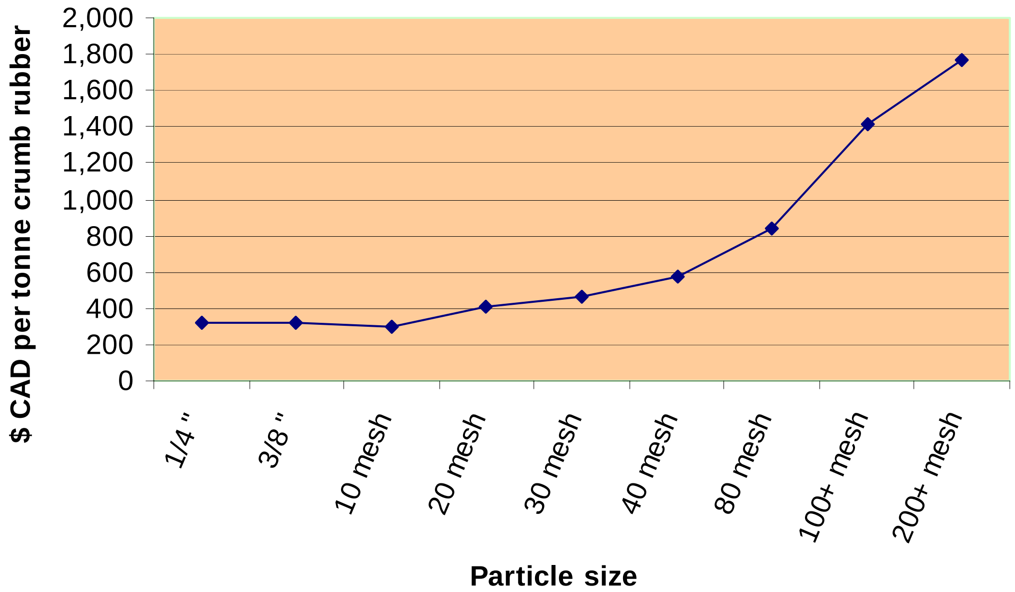

Fig. 3-3. Crumb rubber market in North America 2003[38].

Processing and shredding costs for scrap tires include power, labour, equipment and maintenance costs and can be found in Table 3-2. As shown in this table, the smaller the crumb size, the higher the investment and operating costs. In general, energy, labour, and other variable costs are largely a function of the product particle size, quality and quantity.

No distinction is made between the ambient and cryogenic processing technologies. Cryogenic processing plants have higher investment and provision costs due to the need for liquid nitrogen, but their labour and maintenance costs are lower. Plant location is important because the cost of liquid nitrogen increases when the supplier is not close by. Also, cryogenic plants can produce a larger quantity of fine crumb rubber and get a higher market price. The cost of transportation alone can be estimated at CAD $0.50 per tire[39].

Table 3-2. Potential tire processing and shredding costs[40].

Crumb rubber size	Description	Application	Cost per tonne	Process Rate (tonnes/Hour)
5cm	Clean cut. Ply and bead remains	Cement kilns, Civil engineering	$12	10-12
< 5cm	Minimal wire, cut beads removed by magnets	Industrial, utility, pulp paper mill boilers	$31	7
< 1.25cm	Truly wire free, requires additional shredding equipment	Feed stock for crumb rubber, playground and sport field surfaces	$31 - $68	2-3

Use of scrap tires as TDF in cement kilns or paper mills is financially positive for the processor because it replaces fossil fuel.

Devulcanisation, surface modification and thermal conversion technologies are often affected by high investment costs, but they produce a high-quality product. Their feasibility is a function of the market and the interest of consumers.

Retreading is a very feasible option and probably the most common because it reduces the manufacture of new tires and replaces just part of the rubber on the tire. Unfortunately tires cannot be retreaded forever, and there are limitations due to quality and safety restrictions.

Landfilling is only an option in isolated areas where the transportation costs to the nearest recycler exceeds the benefits of recycling.

4 MARKETS AND NEW APPLICATIONS

This chapter examines the market for products derived from scrap tires. New applications will be described even if they have not yet developed a market. A very detailed description of the North American Market can be found in the report "US Scrap Tire Markets 2003" of the Rubber Manufacturers Association, Washington D.C.[41].

4.1 RUBBER

Rubber crumb accounts for more than 40 wt % of the usage of scrap tires, which corresponds to 13 million Passenger Tire Equivalents (PTE) (or ~100,000 metric tonnes) per year in Canada. Most rubber crumb is produced by ambient or cryogenic grinding, and the particle sizes vary depending on the technology and the demand.

Some typical technical characteristics of rubber from scrap tires are:

- good durability (tire rubber contains carbon black, antioxidants, and UV stabilizers to enhance resistance to wear, chemical decomposition and sunlight);
- moisture absorption (tires and shreds can trap water on the surface and in irregular contours, but they are relatively impervious to actual absorption);
- thermal insulation (rubber is a poor thermal conductor, conversely providing a better thermal insulator than soil or aggregate. Thermal conductivity depends on particle size, reinforcing steel content, compaction, moisture content and other factors);
- vibration insulation (the compressibility of coarse rubber particles allows them to absorb vibrations); and
- acoustic insulation (tire rubber is a poor acoustic conductor, therefore it is a good insulator when used in a configuration with irregular surfaces to further diffuse sound)[42].

The quality of rubber crumb is also influenced by the amount of steel and fibre it retains. The ASTM D-5603-01 defines the standard classification for rubber compounding materials. Because the exact composition of rubber in scrap tires is never known, it is difficult to produce a product with consistent properties and quality. Therefore, a range is normally given for product specifications. The crumb is then used either in new applications or in energy recovery. The possible uses for rubber generated from scrap tires are discussed in the following sections.

4.1.1 Tire-Derived Fuel (TDF)

About 20 wt % of all scrap tires generated in Canada are used as TDF in cement kilns and one paper mill. This equals 6 million PTE (or approx. 49,000 metric tonnes) per year. Most cement kilns use whole tires in their process because their operating temperature is high enough to leave no residues. The steel is required in the cement process (see also section 3.4.1). Due to its high calorific value (approximately 30 GJ/tonne or even higher), TDF is a good substitute for fossil fuels. The combustion must be under control as must the exhaust gas. This is normally the practice in current processes (like cement kilns and paper mills in Canada) where TDF is used.

The standard ASTM D 6700 - 01 “Standard Practice for Use of Scrap Tire-Derived Fuel” gives an overview of the handling of scrap tires as fuel and defines a specific standard[43].

Whole tires, or cut or shredded tires, can be used as tire-derived fuel. Paper mills prefer shredded tires where the steel has already been removed. This increases the total calorific value, but higher costs have to be calculated for the tire processing.

4.1.2 Civil Engineering

Civil engineering applications for scrap tires are gaining acceptance and are expected to experience continued growth in the future. About 13 wt % (3.8 million PTEs per year) of scrap tire usage in Canada is used in civil engineering. Examples of scrap tire use in civil engineering are:

- Erosion control as barrier reefs,
- Tire shreds used in landfill and road construction,
- Highway crash barriers,
- Septic tank leach fields and others.

Tire properties present additional benefits in these applications, such as vibration and sound control, lightweight options for prevention of erosion and landslides, and drainage in leachate systems.

The standard ASTM D 6270–98 “Standard Practice for Use of Scrap Tires in Civil Engineering Applications” provides guidance for testing physical properties and gives data for assessment of the leachate-generation potential of whole or shredded scrap tires in lieu of conventional civil engineering materials. In addition, typical construction methods are outlined[44].

4.1.3 Tire-Derived Products (TDP)

Crumb rubber manufacturing involves extensive processing to further reduce shred size and to remove reinforcing steel and fibre contained in whole tires. Different particle sizes of crumb rubber are used to make a variety of products including lobster cages used in Nova Scotia, playground and other sports surfaces, animal bedding, moulded and extruded products as a blend with plastics, horticultural applications and others. Some processors prefer specific properties of either cryogenic rubber or ambient rubber; some remove the fibres and some do not. It is not always possible to obtain specific information about what is left in the product. The new product will meet specific requirements, and the rest will remain a company secret.

Creation of new tire-derived products shows tremendous potential. Once a product is established on the market, its benefits can be persuasive; sometimes however, it is hard for a new product to find a niche and succeed in the market.

4.1.3.1 Asphalt Rubber

Asphalt rubber is a mixture of 18-22% crumb rubber, asphalt cement and, in some cases, extender oil, which is reacted at elevated temperatures ($\geq$177°C) prior to being mixed with aggregate. Asphalt rubber can be mixed using one of two main techniques: dry or wet. By definition[45], asphalt rubber is prepared using the "wet" process.

In a dry process, crumb rubber is used as part of the aggregate in the hot mix (a mixture of aggregate and hot bitumen) to replace some of the solid fraction; in a wet process, crumb rubber is added to the asphalt/cement mixture at elevated temperatures for a period of half an hour to two hours and then stored until the resulting binder is mixed with the mineral aggregates[46]. Detailed information is available from the State of California Department of Transportation publication "Asphalt Rubber Usage Guide". This guide provides an overview of asphalt rubber materials, components and binder design including the benefits and limitations of these materials[47]. Further information (including environmental considerations) can be found in the "Asphalt Rubber Design and Construction Guidelines" prepared by R.G. Hicks, P.E[48].

Asphalt rubber can be used anywhere conventional mixes are used, although temperatures below 13°C and rainy weather conditions can negatively affect when the product can be placed. In Canada, Ontario has used some asphalt rubber in the Grey County District, and Alberta is testing its behaviour in cold climates[49]. Other provinces are also considering the use of asphalt rubber.

Crumb rubber obtained from tires has been beneficial in paving as an elastic binder additive. Thus, asphalt rubber provides improved mechanical properties, increased pavement durability, reduced reflective cracking and reduced fatigue resistance. Further, there are safety benefits as well because asphalt rubber pavement provides safe surfaces with good surface friction. Reduced splash and spray under wet conditions are also reported, and reduction in tire noise has also been demonstrated (e.g., a reduction of 3-5 dB). Savings in energy and natural resources result from the reduced thickness of the asphalt rubber pavement layers. When properly designed and constructed, less maintenance is necessary and overlays need not occur as often. Because thinner layers of hot mix can be used and the pavement lasts longer, the asphalt rubber pavement is generally more cost effective than conventional materials over 80% of the time for an analysis period of 30-40 years.

4.1.3.2 Rubber-Plastic Blend

Using crumb rubber in rubber-plastic blends involves a technology to modify the surface of the rubber particle; not all rubber, therefore, is devulcanised. The outer few molecular layers of rubber particles have to be enabled in order for them to combine with other polymers, like plastics. Because rubber is a thermoset polymer, it can't simply be melted down and moulded into new products as can some plastics. Heating above a critical temperature causes rubber to decompose. Untreated crumb rubber can bond physically, but not chemically or molecularly; this leads to lower performance specifications. It takes up to 233 MJ/kg of energy to manufacture new polymers, but just 4.7 MJ/kg to make a surface modified rubber, such as Vistamer™[50]. Higher processing costs for surface modification will be recovered through the energy savings in manufacturing virgin polymers. Surface-modified particles comprise as much as 40 wt % in shoe soles, moulded epoxy coatings, solid cast polyurethane industrial wheels and polyurethane tires for wheelchairs.

Blends from recycled rubber and thermoplastics have properties close to those of thermoplastic elastomers. Additional advantages of the new material are its lower specific weight (than rubber) and the environmental benefits from the recycling properties as a thermoplastic[51].

The automotive industry is also a growing market because up to 20 wt % of a car consists of plastic or rubber. Rubber-plastic compounds have good properties and are feasible alternatives to prime plastic products that are already available on the market. A company providing such products in Canada is NRI Industries in Toronto. They have achieved significant energy savings in their production process for automotive parts using rubber-plastic blends[52].

4.1.4 Other

Based upon limited market history and potential, devulcanized tire rubber can be expected to find uses in moulded goods, binders for plastics, and applications needing a smooth surface finish. Examples of product areas are footwear soles, rubber sheeting, car mats, and inner liner compounds. Potential uses of devulcanized rubber of especially high quality and performance include tire tread and sidewalls, but this high level of quality has not been demonstrated. Surface devulcanization technologies (for example, chemical and mechanical) appear destined, in the near term, to produce low- or medium-quality devulcanized rubber material[22].

Up to 5 wt % of recycled rubber can be used in manufacturing new tires. The percentage is limited due to quality and safety issues. In 2004, the Integrated Waste Management Board of the state of California published a very detailed report on this topic[53]. In a study conducted by Continental Tire North America (CTNA) for the North Carolina Division of Environment and Natural Resources (NCDENR), CTNA formulated compounds with up to 13.6% recycled content but concluded the tires may not be commercially viable due to reduced tread life and wet traction, as well as higher rolling resistance. Finally, other factors such as economics (transportation, energy cost, low price of virgin rubber, etc.), supplies, and crumb rubber quality limited recycled-content to about five percent.

The consensus in the industry is that up to 5% recycled content in new tires can be reasonably accommodated. However, the addition of crumb rubber into a virgin compound increases the internal heat generation and thereby increases rolling resistance. The use of crumb rubber is therefore limited to the non-flexing areas of tires.

Some barriers to the growth of crumb rubber use as recycled-content in new tires are:

- Inefficient collection, sorting, and processing technologies for waste tire material,
- Lack of standardized quality control procedures at processing facilities,
- Consumer perceptions of poor tire quality due to recycled content,
- Cost of transportation of crumb rubber to final destinations such as tire manufacturing plant, and
- High dynamic performance requirements of treads limit amount of recycled content.

4.2 STEEL

The composition and properties of the steel in the bead of a tire conforms to AISI 1070 or better. For instance, one European manufacturer of steel tire cord (Bekaert) produces normal- and high-tensile- strength grades of steel cord containing, respectively, 0.725 and 0.825% carbon, 0.525%

manganese, 0.23 and 0.21% silicon, 0.01 and 0.006% sulphur, 0.008% phosphorus, and trace amounts of copper, chromium, and nickel[54].

> Another significant marketing issue is the alloy content of the tire steel. Most obvious is the bronze coating on bead wire and brass coating on belt wire. The high-tensile belt wire can be made from grades 70 to 80 carbon steel that might contain other metals such as magnesium. Foundries with very tight specifications on selected metals, such as copper (in the tire wire coatings), will not use tire wire. Among other reasons, steel coatings are used to protect the parent steel from corrosion and to promote adhesion of steel cord to the tread. The properties of steel used in tires are subject to research and modification. For example, one research project involved the evaluation of new coatings for cord steel used in tires, including those composed of zinc cobalt, nickel cobalt, or both[14].

Bead wire is generally lower-carbon steel than belt wire and has a thicker gauge. Belt wire is composed of cords of very thin, high-tensile wire that has been wrapped and twisted. This provides stability and strength to the tire tread and sometimes, particularly in trucks, to the body of the tire as well. Ambient grinding can be used to strip out tire belt cords cleanly. Another method of separating tire steel cord is the cryogenic process. This freezes the material and breaks it apart quite cleanly with a hammer mill. The belt wire is said to look like steel wool after final processing in a cryogenic operation. Clean, recovered steel belt wire may have a high value for some customers because of its high tensile strength[14].

Thermal processing of waste tires is one method of recovering steel with little or no rubber contamination. For example, Helzer has conducted research on recovering clean bead steel using a new pyrolytic process, as well as the effect of using various amounts of this recovered steel in the manufacture of cast iron[55]. The recovered tire steel was found to be an appropriate recycled feedstock for the production of gray iron, but not for ductile products because of its high sulphur content.

Several different types of steel fibre recovered from waste tires were evaluated as concrete-reinforcing materials in research conducted in the United Kingdom (UK)[56]. This research was funded by the Dept. of Trade and Industry in the UK, and only preliminary results are currently available. Several different types of steel fibre fractions were prepared and tested as alternative steel reinforcing in the manufacture of structural concrete. Two methods of steel recovery were employed: (1) size reduction (which resulted in some rubber contamination in the steel fraction), and (2) melting away of the rubber and recovery of clean steel. According to the authors, the second method of recovery (melting) produced good quality concrete. The recovered steel fibres had similar properties to those of conventional reinforcement steel fibres on the market.

> Currently, the steel recovered from waste tires is usually an inconsistent low-quality material that gains acceptance in the scrap steel markets during periods of high demand, losing market share when the market is oversupplied. Moreover, tire-derived steel’s rubber content, low density, difficulty in being compacted, and alloy coating make the steel fraction unsuitable for many applications. Another drawback is the scrap’s lack of uniformity, which can vary from shipment to shipment in regard to rubber content, source of steel (bead, body, or belt wire and mixtures), alloying (bronze or brass), form (chopped, shredded), and compression level (loose, compacted, or briquette)[14].

4.3 FIBRE

Very little market demand has been identified for fibre generated as a consequence of crumb rubber production. The chief reasons are substantial contamination of the fibre by rubber particles, lack of proven cleaning technology to produce high-quality fibre, mixed composition of the fibres (mixture of polyester, rayon, and nylon fibres), and particle size and shape of fibres. Few fibre users and manufacturers have any experience with tire-derived fibres in particular, or more broadly with mixtures of comparable fibre types.

Very little information was found regarding uses and markets for fibre recovered from waste tires. Two research studies[57,58] report on the recovery and use of “micronized” tire fibres as filler for polymer mortars. The micronized fibres were a mixture composed mainly of polyester, rayon, and nylon fibres. This work is currently at the R&D stage, however preliminary studies have yielded positive outcomes with regard to using tire fibre as mortar filler material.

Potentially relevant to the recycling of textile belting from waste tires, cord-yarns (used in the manufacture of tires) have been studied on a laboratory scale for use as reinforcing material for recycled polypropylene (PP) material[59]. Fibres are of interest as reinforcing material because they improve the properties of recycled PP resin over those of conventional, recycled PP material. The research found that modification of the yarn fibres using electron beam technology, along with other treatments, was necessary in order to achieve the desired level of bonding between the fibres and the PP matrix.

Fibre TDF has currently the largest market for tire-derived fibre because it can compete with conventional fuels such as natural gas, oil and coal. Fibre as a heat source has a potential calorific value in the same range as rubber TDF with essentially no sulphur. However, its water content may reduce its effective calorific value, and in either loose or baled forms, it may not be compatible with customers’ feed-delivery systems[14].

Synthetic fibres can be added to concrete for reinforcing purposes. One of the benefits that fibre confers is sound deadening, however the fibre length is a major commercial hurdle. Processors did not indicate that the fibre coating added for rubber adhesion was a limitation in concrete[14].

NRI Industries in Toronto is reported to be the only manufacturer of rubber products that adds fibres to its products. NRI continues to develop new products for the automotive industry and elsewhere, and it has the resources to develop new rubber products using tire-derived fibre additives.

4.4 OTHER

Other materials are retrieved from the thermal decomposition of scrap tires – such as pyrolysis and microwave as described in chapter 3.5. These products are:

- Oil,
- Gas, and
- Carbon Black.

The quality of these products varies depending on the technology used in their generation. Since there is no market at this moment in Canada, it is difficult to describe a standard for these products.

5 TIRE PROGRAMS IN THE CANADIAN PROVINCES AND TERRITORIES

Active tire recycling programs are currently operating in Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland and Labrador, Nova Scotia, Prince Edward Island, Quebec, Saskatchewan and the Yukon. The Province of Ontario is implementing its system at the present time. Table 5-1 provides an overview on the tire programs in the Canadian provinces including time frames and levies in the provinces.

Table 5-1. Tire program in the Canadian provinces.

Province	Tire program exists	Responsibility	Tire levy[1]
British Columbia	since 1991	Ministry of Environment, Lands and Parks	$ 3 on all tires
Alberta	since 1992	Tire Recycling Alberta (TRA)	$ 4 on all tires
Saskatchewan	since 1995	Saskatchewan Scrap Tire Corporation	$ 3.50 up to $ 50 depend on tire size[2]
Manitoba	since 1992	Manitoba Tire Stewardship Board	$ 2.80 on all tires
Ontario	program in process	Ontario Tire Stewardship Board	$ 4 on all tires or $ 6 on commercial tires
Quebec	since 1993	Recyc Quebec	$ 3 on all tires
New Brunswick	since 1996	New Brunswick Tire Stewardship Board	$ 3 on PT or $ 9 on Truck tires
Nova Scotia	since 1997	RRFB Nova Scotia	$ 3 on PT or $ 9 on Truck tires
Prince Edward Island	since 1999	Island Waste Management Corporation	$ 2 on all tires
Newfoundland and Labrador	since 2002	Multi-Materials Stewardship Board	$ 3 on PT or $ 9 on Truck tires

[1] Levy on Passenger Tires and truck tires less than 24.5 inches
[2] including OTR tires
PT = Passenger tire

The Yukon Territory is the only Canadian territory with a tire program. It was implemented in 2003, and a levy of $5 is collected on all new tires less than 24.5 in. diameter. Currently, Yukon tires are transported to Alberta for recycling.

Table 5-2. Scrap tire generation 2003 (data from Rubber Association Canada).

Province	in % by province	collected PTE	weight in metric tonnes
British Columbia	10.11%	2,800,000	22,960
Alberta	8.66%	2,400,000	19,680
Saskatchewan	3.97%	1,100,000	9,020
Manitoba	3.25%	900,000	7,380
Ontario	37.18%	10,300,000	84,460
Quebec	29.24%	8,100,000	66,420
New Brunswick	2.89%	800,000	6,560
Nova Scotia	2.53%	700,000	5,740
Prince Edward Island	0.72%	200,000	1,640
Newfoundland and Labrador	1.44%	400,000	3,280
Canada	100.00%	27,700,000	227,140

Table 5-2 shows the estimated generation of scrap tires in Canada. The numbers are based on each tire sold in the country. It can be estimated that one new tire refers to one generated scrap tire. Also the population of the country might be an indicator for the generation of scrap tires. Referring to Table 5-3, there is a population of nearly 32,000,000 citizens in the whole country (including the territories), which is quite close to the generated number of scrap tires of 27,700,000 PTEs.

Table 5-3. Population in Canada[60] (Statistics Canada).

Province / Territory	Population 2004
Alberta	3,201,895
British Columbia	4,196,383
Manitoba	1,170,268
New Brunswick	751,384
Newfoundland and Labrador	517,027
Nova Scotia	936,960
Ontario	12,392,721
Prince Edward Island	137,864
Quebec	7,542,760
Saskatchewan	995,391
Northwest Territories	42,810
Nunavut	29,644
Yukon Territory	31,209
Canada	31,946,316

5.1 ALBERTA

5.1.1 Tire Program and Regulation

Tire Recycling Alberta (TRA), a division of the Alberta Recycling Management Authority [former Tire Recycling Management Association of Alberta (TRMA)], is a not-for-profit association that operates as a Delegated Administrative Organization under the auspices of the Alberta Minister of Environment. It allows industry and stakeholders to participate in environmental stewardship initiatives that protect the quality of air, land and water.

Tire Recycling Alberta is directly accountable to the Minister of Environment, and reports annually on the fulfillment of its legislated mandate through its three-year Business Plan, its Annual Budget and its Annual Report.

In September 1992, a $4/tire Advance Disposal Surcharge was put into practice to fund initiatives to reduce, and eventually eliminate, scrap tire stockpiles within the province. Implemented in 1996, the Tire Recycling and Management Alberta Regulation 206/96 (consolidated up to AR 170/2001) authorizes Tire Recycling Alberta to levy the Advance Disposal Surcharge, which is to be used to provide or pay for any or all of the following:

- Establishment and administration of a scrap tire waste minimization and recycling program;
- Education programs for the scrap tire waste minimization and recycling program;
- Expenditures incurred in the collection, transportation, storage, processing and disposal of scrap tires;
- Research and development activities related to scrap tire management; and
- Promotion and development for marketing the products of scrap tire recycling.

The tire recyclers are paid for performance based on the number of tires that are successfully recycled and used. There are no loans, loan guarantees, start-up grants or bailouts[61].

There are no regulations regarding stockpiling, landfilling or burning scrap tires.

5.1.2 Data

Through a major stockpile-reduction program conducted by Tire Recycling Alberta, there are currently no large accumulations of scrap tires in the province. Stockpiles are cleaned up as required by Tire Recycling Alberta and are removed by recyclers/processors on instruction.

Data on the recycling of scrap tires (3,474,744 PTE) received from the province of Alberta is about 1,000,000 PTEs higher than the published data from the RAC (2,400,000 PTE). The difference may reside in the fact that Alberta has eliminated stockpiles, therefore the supply of scrap tires was higher than the annually generated scrap tires, which may explain the discrepancy.

Table 5-4. Scrap-tire usage in Alberta.

Recycling 2003/2004	in wt %	in PTE	in metric tonnes
Manufactured Product	17.09	593,766	4,868.88
Rubber Crumb	29.41	1,021,826	8,378.97
Civil Engineering	53.50	1,859,152	15,245.05
Total	100.00	3,474,744	28,492.90

5.2 BRITISH COLUMBIA

5.2.1 Tire Program and Regulation

The Financial Incentives for Recycling Scrap Tires (FIRST) program began in June 1991. The FIRST program is an example of a first-generation industry-stewardship program. It is funded by consumers and administered by government. There is no involvement of the tire industry, other than retailers[62].

The Ministry of Environment, Lands and Parks initiated the FIRST Program in 1991 after the introduction of a $3 levy on the sale of new tires in British Columbia. It was established by the ministry to address concerns that scrap tires were posing environmental and human health risks.

The Sustainable Environment Fund was created to assist in directing money collected through environmental levies and waste permit fees toward a variety of provincial environmental protection programs. The Ministry of Water, Land and Air Protection administer the Sustainable Environment Fund and Treasury Board sets the overall revenues and expenditures for the fund each year during the government budget process.

Financial assistance available from the program consists of a transportation credit designed to assist the movement of scrap tires from generators anywhere in the province to the nearest eligible processor registered in the program, and a processing/end use credit.

Stockpiling tires is generally not permitted, but there is no specific regulation. In some regional districts, landfilling of tires is banned, and open burning is banned through regulation. In general, burning is not allowed at landfills[63].

5.2.2 Data

Stockpiles may be cleaned up through incentive credits, where eligible. As of November 2004, there is one private stockpile containing approximately 69,000 PTEs that is gradually being depleted.

Data on the recycling of scrap tires (3,456,843 PTE) from British Columbia are higher than the published data from the RAC (2,800,000 PTE). This may be because British Columbia is cleaning up all stockpiles, therefore the supply of scrap tires was much higher than the annually generated scrap tires.

Table 5-5. Scrap-tire usage in British Columbia.

Recycling 2003/2004	in wt %	in PTE	in metric tonnes
Tire Derived Product (TDP)	81.15	2,805,189	23,002.55
Tire Derived Fuel (TDF)	18.85	651,654	5,343.56
Total	100.00	3,456,843	28,346.11

5.3 MANITOBA

5.3.1 Tire Program and Regulation

In 1992, the Manitoba government instituted a $3 levy on all tires sold in the province for use on licensed vehicles or trailers. In April 1995, the Tire Stewardship Board was established to work with stakeholders to develop solutions to scrap tire management problems in Manitoba. The program is funded by tire consumers through the retail industry. In 2000, the government of Manitoba "removed and retained" the P.S.T. portion of tire levy, and the board now receives $2.80 on all tires sold[64]. The Waste Reduction and Prevention Act and the Tire Stewardship Regulation 33/95 provide the authority to declare scrap tires as designated materials, and it allows the Board to collect a tire levy on new tires to establish a fund and a management program administered by the Board.

5.3.2 Data

With the tire program, all landfills and stockpiles have been cleaned up. There is one landfill considered to collect OTR tires that are not levied through the program but are recycled in the USA. Due to the high cost, not all OTR tires can be recycled, and they must be stored somewhere.

Table 5-6 shows 1,475,538 PTEs[64] compared with a figure of 900,000 from the Rubber Association of Canada.

Table 5-6. Scrap-tire usage in Manitoba[64].

Recycling 2003/2004	in wt %	in PTE	in metric tonnes
Moulded products	13.34	196,868	1,614.32
Shred	71.75	1,058,660	8,681.01
Tire Derived Fuel	12.44	183,504	1,504.73
Blasting mats	2.27	33,495	274.66
Cut Products	0.20	3,011	24.69
Total	100.00	1,475,538	12,099.41

5.4 NEW BRUNSWICK

5.4.1 Tire Program and Regulation

New Brunswick's Tire Stewardship Board (NBTSB) was established in 1996 and includes four directors representing the industry and two representing the provincial Department of Environment and the local government.

The NBTSB is an organization that allows industry and stakeholders to be accountable for scrap tire environmental stewardship initiatives. A not-for-profit association, the NBTSB is responsible for fulfilling the legislative mandate, the Clean Environment Act (o.c. 96-739) provides the authority for the NBTSB to make scrap tires a designated material.

New Brunswick Regulation 96-82 under the Act, allows the Board to establish and administer a scrap tire management program. The program includes distribution management, supply, use, storage, collection, transportation, recycling, processing, disposal and other tire and scrap tire handling.

In addition, the Regulation provides the authority to levy $3.00 per tire with rim size 8-17 in., as well as levy of $9.00 per tire with rim size greater than 17 in. to a maximum of 24.5 in. for advance disposal surcharge. Furthermore, the Regulation stipulates that the Board may establish a fee for tires with a rim size exceeding 24.5 in. and may vary the fee according to size, usage or other classification[65].

5.4.2 Data

Stockpiles are cleaned up, and there is just one stockpile left at the processors site that contains about 450,000 PTEs.

Table 5-7. Scrap-tire usage in New Brunswick[65].

Recycling 2003	in wt %	in PTE	in metric tonnes
Crumb Rubber	1.48	11,891	97.51
Fabricated Products (TDP)	95.84	770,637	6,319.22
Collected by retailer	100.00	804,079	6,593.45
Total Recycled	97.32	782,528	6,416.73

Table 5-7 shows 804,079 PTEs[65] collected by retailers for recycling compared with the number from the RAC of 800,000. In this case, the data match with the number of recycled tires. New Brunswick has recycled a total of 782,528 PTEs, which corresponds to the RAC data.

5.5 NEWFOUNDLAND AND LABRADOR

5.5.1 Tire Program and Regulation

On April 1, 2002, government regulation for the Used Tire Recycling Program in Newfoundland and Labrador placed a ban on disposal of tires in municipal waste disposal sites and provided residents with an environmentally safe way to dispose of tires. Retailers must remit a levy to the Multi-Materials Stewardship Board (MMSB) of $3 on new tires with a rim diameter of 17 in. or less, and $9 on new tires with a rim diameter between 17 in. and 24.5 in.

The MMSB (a Crown agency of the Department of Environment and Conservation) is responsible for the operations of the Used Tire Recycling Program, and it is currently collecting tires from retailers, municipal waste disposal sites, and highway depots operated by the Provincial Department of Transportation and Works and storing them in privately owned and operated storage yards on the island portion of the province.

5.5.2 Data

All 400,000 scrap tires generated annually are collected in selected drop-off sites. Upon accumulation of approximately 1,200 tires at any designated drop-off site, MMSB will remove and transport them to one or more of the designated privately owned and managed industrial yards on the island. The tires will be stored securely at those locations in full compliance with all regulatory requirements established by the Department of Environment and Conservation and the Fire Commissioners Office until markets for them are identified by MMSB. Since there is currently no recycler in the province, all tires are stored.

Table 5-8. Scrap-tire usage in Newfoundland and Labrador.

Recycling 2004	in wt %	in PTE	in metric tonnes
on storage yards	100	400,000	3,280.00

5.6 NOVA SCOTIA

5.6.1 Tire Program and Regulation

The Province of Nova Scotia appointed the Resource Recovery Fund Board Inc. (RRFB) as administrator of the Used Tire Management Program, which came into effect January 1, 1997.

The RRFB was established in 1996 under the Solid Waste-Resource Management Regulations to pursue five mandates:

- to develop and implement industry stewardship programs;
- to fund municipal or regional diversion programs;
- to develop and operate a deposit-refund system for beverage containers;
- to develop education and awareness of source reduction, reuse, recycling and composting; and
- to promote the development of value-added manufacturing in the province.

The RRFB Board of Directors is comprised of three appointees from the Minister of Environment and Labour (one of which must serve as Chair), one appointee from the Union of Nova Scotia Municipalities, one appointee from the seven Regional Waste Management Authorities, and between two and ten industry appointments. Currently there are twelve seats on the board.

An environmental fee of $3.00 is applied at the point of retail sale on all new passenger car tires. The same fee is applied to all light truck tires not exceeding 17 in. rim size and a fee of $9.00 is applied to all highway truck, tractor and trailer tires not exceeding 24.5 in. rim size.

5.6.2 Data

There were 912,000 PTEs collected and recycled in 2003/2004. With a scrap tire recovery rate of 86% and 6.3 million tires diverted from landfills, there are no major stockpiles left in the province.

Table 5-9. Scrap Tire Usage in Nova Scotia.

Recycling 2003/04	in %	in PTE	in metric tonnes
Crumb rubber	70.00%	638,400	5,234.88
Fibre	20.00%	182,400	1,495.68
Steel	10.00%	91,200	747.84
Total	100.00%	912,000	7,478.40

5.7 ONTARIO

5.7.1 Tire Program and Regulation

Ontario was the first province in Canada to implement a tire program. In 1989 the province introduced a $5 tire tax program, but in 1993, Ontario rescinded this program.

In June 2002, the Ontario legislature passed the Waste Diversion Act to promote reduction, reuse and recycling of waste. This act establishes a multistakeholder board, Waste Diversion Ontario (WDO), that is tasked with developing, implementing and operating diversion programs for designated wastes in accordance with the act. In March 2003, the Minister of Environment passed Ontario Regulation 84/03, which describes and defines “used tires” as a designated waste under the act. In June 2003, Ontario Tire Stewardship (OTS) was created as a new industry funding organization, and it submitted a plan for the scrap tire program to the Minister. The plan is applied to all tires that are either produced in the province or enter the province to be sold. Clean-up activities of existing stockpiles are also included as “Off-the-Road” tires in future phases of the OTS operations.

In September 2004, WDO approved the Scrap Tire Diversion Program for Ontario submitted by the OTS. WDO will submit the proposal to the Minister of Environment for final approval.

5.7.2 Data

Table 5-10 is based on an estimate of the OTS and shows the figures that were presented in their submission for a new Scrap Tire Program in Ontario. It is estimated that 12,407,00 PTEs were available for recycling in 2002. The RAC published a number of 10,300,000 PTEs in 2003 for scrap tires generated.

Table 5-10. Scrap-tire usage in Ontario.

Recycling 2002	in wt %	in PTE	in metric tonnes
Export USA	30.00	3,722,000	30,520.40
Crumb Rubber	42.60	5,285,000	43,337.00
Fabricated Products (TDP)	6.45	800,000	6,560.00
Civil Engineering	6.45	800,000	6,560.00
Landfill	8.06	1,000,000	8,200.00
Non-verifiable Diversion	6.45	800,000	6,560.00
total	100.00	12,407,000	101,737.40

5.8 PRINCE EDWARD ISLAND

5.8.1 Tire Program and Regulation

In 1999, the PEI government incorporated the Island Waste Management Corporation; this is a legislated, government-run program with a mission to collect and process all scrap tires on PEI. Prior to its inception, PEI imposed a $2 tire levy – the lowest levy on tires in Canada – and they are considering increasing it to $3 or $4. They are also negotiating with the province of Nova Scotia to recycle the tires from PEI in Nova Scotia. Currently most tires are baled and used in civil engineering applications.

5.8.2 Data

Table 5-11 shows the estimated number of scrap tires generated in 2004. All of the tires were baled.

Table 5-11. Scrap-tire usage on Prince Edward Island.

Recycling 2004	in wt %	in PTE	in metric tonnes
Baled tires	100.00%	140,000	1,148.00

5.9 QUEBEC

5.9.1 Tire Program and Regulation

The first program to reuse and recycle scrap tires in Quebec was initiated in 1993. This was funded by RECYC-QUEBEC – a state corporation that was established in 1990. In 1999, a tire levy was legislated. The seven-member Board of RECYC-QUEBEC is composed of government appointees from municipalities, non-profit organizations, industry, education and technical sectors. The mission is to encourage industry to recycle scrap tires, to prevent stockpiling and landfilling of tires, to clean up all existing tire stockpiles, to assist industry in creating viable business opportunities and to improve the environment for future generations. A $3 levy is in place for all tires under 24.5 in. rim size and 48.5 in. overall diameter.

New legislation bans stockpiling and will clean up existing stockpiles by the end of 2008. Burning and landfilling are now banned by legislation. Permits and bonds are now required to stockpile tires. The elimination of 12 large and 604 small private stockpiles with 25 million PTEs comes under a credit program in effect until December 2008. As of July 1, 2004, four large and 495 small sites, totalling over 10 million PTEs have been cleaned up.

5.9.2 Data

In 2003, 6,693,049 PTEs were recycled (Table 5-12) by 18 processors: 2 TDF, 2 die cut, 1 shred, 3 crumbers, and 10 producers of moulded products. Products include blasting mats, rubberized asphalt, sealants, carpet underlay, mats, sport surfaces, car parts, barricades and soundproof panels. The RAC figures are 8,100,000 PTEs in 2003. That means that about 1,400,000 PTEs are unaccounted for. The figure for Ontario is higher; perhaps more tires from Quebec are exported to Ontario than the other way around. Export to the USA is also a possible factor.

Table 5-12. Scrap-tire usage in Quebec.

Recycling 2003	in wt %	in PTE	in metric tonnes
Crumb Rubber	76.00%	5,086,717	41,711.08
Tire Derived Fuel (TDF)	24.00%	1,606,332	13,171.92
Total	100.00%	6,693,049	54,883.00

5.10 SASKATCHEWAN

5.10.1 Tire Program and Regulation

The Saskatchewan Scrap Tire Corporation (SSTC) Program was initiated in 1996. Through the Environmental Management and Protection Act, and the Scrap Tire Management Regulations in

1998, the authority was provided to declare scrap tires a designated material. The SSTC is a non-governmental management agency that is comprised of independent stakeholders who represent the industries involved with, or affected by, the scrap tire issue. A multi-stakeholder board composed of ten individuals oversees the stewardship of scrap tire management in the province of Saskatchewan.

The Saskatchewan program incorporates a multi-tiered levy system, which includes passenger car tires, medium truck tires, agricultural tires and large off-road/mining tires. The predisposal levy is collected on the sale of all new tires and varies from $3.50 (passenger tire) to $50 for OTR tires. Saskatchewan is the only province that has implemented a levy on OTR tires.

5.10.2 Data

In 2003, 1,459,232 PTEs were recycled in Saskatchewan (Table 5-13). The Rubber Association of Canada assumed scrap tire generation of 1,300,000 PTEs. Saskatchewan is using their surplus of the program to clean up all the landfills in the province. There were still 158 landfills to be cleaned up in 2004. Since 1999, 115 landfill sites have been cleaned up under the program.

Table 5-13. Scrap-tire usage in Saskatchewan.

Recycling 2003	in wt %	in PTE	in metric tonnes
Crumb Rubber	53.00	773,393	6,341.82
Steel and Fiber	29.00	423,177	3,470.05
Civil Engineering	6.00	87,554	717.94
Manufactured Products (TDP)	1.00	14,592	119.66
Other (OTR, rings, tubes)	11.00	160,516	1,316.23
Total	100.00	1,459,232	11,965.70

5.11 THE TERRITORIES

5.11.1 Northwest Territories

There is no tire program and no documentation on the generation of scrap tires in the Northwest Territories.

5.11.2 Nunavut

There is no tire program and no documentation on the generation of scrap tires in Nunavut.

5.11.3 Yukon

The Yukon Territory is the only Canadian Territory with a tire program. It was implemented in 2003, and a levy of $5 is collected on all new tires less than 24.5 in. diameter. The estimated number of scrap tires generated is 35,000-40,000 PTEs of which 90% originate in the capital, Whitehorse; 7,000 PTEs are assumed to be in landfills. All tires are shipped to Alberta for processing.

5.12 THE CANADIAN ASSOCIATION OF TIRE RECYCLING AGENCIES

The exchange of scrap-tire information has become a very useful tool to assist processors and the program to become more efficient. The Tire Stewardship Board was instrumental in establishing the Canadian Association of Tire Recycling Agencies (CATRA). This association was established to facilitate information exchange between Canadian scrap tire program boards and to assist their program managers in the efficient operation of their programs as all provincial agencies have some similarities and differences, and are evolving at different rates. The agencies have monthly conference calls and annual meetings to exchange information. It is not only a very cost-effective and useful communications method but it also mirrors established associations in the US and Europe. CATRA is now involved in the national/international approach to solving the numerous scrap tire issues.

Each of the existing tire programs in the provinces came on line at different times over the past decade. While sharing some similarities, they have developed in various ways to respond to different circumstances. Some operate as a component of the provincial government while others focus on a stewardship model, with industry stakeholders sharing responsibility through an external Board of Directors. Regardless of their approach, each jurisdiction offers key experience and expertise within the flexible CATRA system.

Beyond its focus on information exchange, CATRA can also serve as an umbrella organization to address tire recycling issues with inter-provincial or national ramifications. Joint research activity involving various participants may also be undertaken. Other areas for potential collaboration include national and international communications on Canada’s approach in this rapidly changing field.

In recent years, the Canadian industry as a whole has emerged as an international leader in the manufacture of quality ‘value-added’ products from recycled tires. Compiling research data on such advances, and ensuring easy access to this information, remains CATRA’s constant goal. Additional information is available on the CATRA website (www.catra-online.ca).

5.13 SUMMARY

The data presented above by province are collected below and show an overview of the scrap-tire generating and processing situations in Canada. Differences and discrepancies are shown and described. Ontario is the only province currently without a tire program, therefore this number is an estimate of the scrap tires availability for processing.

Table 5-14 shows all collected data of processed scrap tires in Canada. A comparison with published RAC data and the population in each province is presented in Table 5-15.

Table 5-14. Processed scrap tires in Canada.

Province / Territory	in % by province	processed PTE	weight in metric tonnes
Alberta	11.14	3,474,744	28,492.90
British Columbia	11.08	3,456,843	28,346.11
Manitoba	4.73	1,475,538	12,099.41
New Brunswick	2.51	782,528	6,416.73
Newfoundland and Labrador	1.28	400,000	3,280.00
Nova Scotia	2.92	912,000	7,478.40
Ontario	39.76	12,407,000	101,737.40
Prince Edward Island	0.45	140,000	1,148.00
Quebec	21.45	6,693,049	54,883.00
Saskatchewan	4.68	1,459,232	11,965.70
Yukon	0.11	35,000	287.00
Canada	100.00	31,200,934	255,847.66

Table 5-15. Processed and generated scrap tires in Canada in comparison with the population.

Province	PTE processed	PTE generated (RAC)	Population	PTE proc./gen.
Alberta	3,474,744	2,400,000	3,201,895	1.45
British Columbia	3,456,843	2,800,000	4,196,383	1.23
Manitoba	1,475,538	900,000	1,170,268	1.64
New Brunswick	782,528	800,000	751,384	0.98
Newfoundland and Labrador	400,000	400,000	517,027	1.00
Nova Scotia	912,000	700,000	936,960	1.30
Ontario	12,407,000	10,300,000	12,392,721	1.20
Prince Edward Island	140,000	200,000	137,864	0.70
Quebec	6,693,049	8,100,000	7,542,760	0.83
Saskatchewan	1,459,232	1,100,000	995,391	1.33
Canada	31,200,934	27,700,000	31,842,653	1.13

The last column in Table 5-15 indicates the ratio of processed tires to generated tires. Only Quebec, New Brunswick and Prince Edward Island are processing fewer tires than they are generating. There are a few explanations for this fact.

- First the published data of the Rubber Association is an estimate of the number of scrap tires generated based on their knowledge and the data available from tires sold in the provinces. Therefore the numbers don’t have to be exact in theory and practice. New Brunswick for example, with a ratio of 0.98, is therefore in the range of a typical assumption error and is considered marginal.

- Second the comparison with the population of the provinces gives another indicator for the generated scrap tires. It is known that each person generates approximately one scrap tire. In the case of Prince Edward Island, the ratio of PTE processed/generated looks much better if the population is considered. Even the province of Quebec has a better ratio because the population in the province is less than the estimated number of scrap tires.

- Third, there is always a gap in the numbers of tires whose fate is unknown and are not part of the statistics. Especially Ontario and Quebec, with the largest populations of the country, have the highest potential of “losing” tires. Ontario and Quebec represent about 60% of the scrap tires generated in Canada.

6 MATERIAL FLOW FROM SCRAP TIRES IN CANADA

6.1 PASSENGER AND TRUCK TIRES

Passenger and truck tires are part of the tire programs in the provinces and Yukon Territory but are not recycled separately, therefore the data include both passenger and truck tires without differentiation. Tires from the Yukon Territory are included in the data from Alberta where they are processed.

6.1.1 Rubber

Table 6-1 shows tire usage in all provinces. Table 6-2 illustrates the distribution of scrap tire usage in Canada (in weight percent) based on the data collected during this survey as seen in Table 6-1.

Table 6-1. Tire usage in Canada 2003/2004.

Province	Tire Usage in PTE					
	Moulded Products	Crumb	Shred	Tire Derived Fuel	Baled / Stored	Total
Alberta *	593,766	1,021,826	1,859,152	0	0	3,474,744
British Columbia	2,805,189	0	0	651,654	0	3,456,843
Manitoba **	230,363	0	1,061,671	183,504	0	1,475,538
New Brunswick	770,637	11,891	0	0	0	782,528
Newfoundland and Labrador	0	0	0	0	400,000	400,000
Nova Scotia	0	638,400	0	0	0	638,400
Ontario ***	800,000	5,285,000	800,000	3,722,000	1,000,000	11,607,000
Prince Edward Island	0	0	0	0	192,293	192,293
Quebec	0	5,287,509	0	1,405,540	0	6,693,049
Saskatchewan	14,592	773,393	87,554	0	0	875,539
Canada	**5,214,547**	**13,018,019**	**3,808,377**	**5,962,698**	**1,592,293**	**29,595,934**

* Shred includes Civil engineering applications
** Moulded Products include blasting mats
*** Tire Derived Fuel is equivalent to Export USA

Table 6-2. Scrap-tire usage in Canada 2003/2004.

Scrap Tire Usage in Canada	in wt %	in PTE	in metric tonnes
Moulded Products	17.62	5,214,547	42,759
Crumb	43.99	13,018,019	106,748
Shred	12.87	3,808,377	31,229
Tire Derived Fuel	20.15	5,962,698	48,894
Baled / Stored	5.38	1,592,293	13,057
Total	100.00	29,595,934	242,687

6.1.2 Fibre

The fibre content in tires varies from product to product. Especially in scrap tires, the exact composition is never known. The potential mass of fibre in the waste stream of scrap tires was based on estimates of the fibre content in tires. From the available published data on tire composition, the amount of fibre in tires varies from 3 to 5 wt %. Thus a range can be given for the mass of fibre available from tire processing if the fibre can be completely separated 100% from the tire. Air separators and screening systems can separate the fibre. Table 6-3 shows the estimated mass of fibre for each province.

Table 6-3. Potential mass of fibre generated from scrap-tire processing.

Province	Min fibre in metric tonnes	Max fibre in metric tonnes	Reported tonnes for fibre from provinces
Alberta	610.08	984.00	
British Columbia	711.76	1,148.00	4,132.86
Manitoba	228.78	369.00	
New Brunswick	203.36	328.00	
Newfoundland and Labrador	101.68	164.00	
Nova Scotia	177.94	287.00	1,495.68
Ontario	2,618.26	4,223.00	
Prince Edward Island	50.84	82.00	
Quebec	2,059.02	3,321.00	
Saskatchewan	279.62	451.00	574.81
Canada	7,041.34	11,357.00	

Only three provinces in Canada report fibre mass. Reported data is close to calculated data for the province of Saskatchewan only. Nova Scotia and British Columbia have a much higher actual mass for fibre. This may reside in the fact that the separation of rubber from fibre is never 100%. The rubber is the most valuable product and must be kept clean and at a high quality, so the processor will lose some rubber particles attached to the fibre. Currently the fibre is mostly a waste product and has no quality restrictions, but the fibre was not contaminated by enough rubber to account for the discrepancy shown in Table 6-3. Another reason may be that passenger tires tend to contain more fibre than steel as published by most tire suppliers and manufacturers. For example, the tire recycler Western Rubber in British Columbia processes 70 wt % passenger tires and 30 wt % truck tires. They weigh everything entering and leaving the plant, and their figures show fibre output double that of steel. That disputes the official published tire composition with 4 wt % fibres and up to 15 wt % steel. Both products show very little contamination with rubber particles.

6.1.3 Steel

The steel content in tires also varies from product to product. For the potential mass of steel in the waste stream of scrap tires, the possible steel content in tires was estimated. According to the available published data on tire composition, the amount of steel in tires varies from 10-14 wt %, therefore a range can be determined for the mass of steel retrievable from tire processing if the steel can be completely isolated from the tire. Steel can be easily removed by magnetic separators. Table 6-4 shows the estimated mass of steel for each province.

Table 6-4. Potential mass of steel generated from scrap-tire processing.

Province	Min steel in metric tonnes	Max steel in metric tonnes	Reported tonnes for steel from provinces
Alberta	1,968.00	2,833.92	
British Columbia	2,296.00	3,306.24	2,296.04
Manitoba	738.00	1,062.72	
New Brunswick	656.00	944.64	
Newfoundland and Labrador	328.00	472.32	
Nova Scotia	574.00	826.56	747.84
Ontario	8,446.00	12,162.24	
Prince Edward Island	164.00	236.16	
Quebec	6,642.00	9,564.48	
Saskatchewan	902.00	1,298.88	2,682.45
Canada	22,714.00	32,708.16	

The three provinces that report fibre mass also report steel mass. The figures for estimated and reported steel mass are in better agreement than those for fibre mass. The reported tonnes of steel in the province of Saskatchewan are double the estimated mass. The ratio of passenger tires to truck tires is unknown. Truck tires tend to contain more steel than passenger tires, but the ratio is not considered in these calculations. British Columbia and Nova Scotia report a number in the range of the estimated mass of steel.

6.2 OFF-THE-ROAD (OTR) TIRES

Off-the-Road (OTR) tires are an important issue in all Canadian provinces. The number of OTR tires generated will be estimated by province. The collected data are unreliable due to a lack of information on OTR tires. Only one province (Saskatchewan) has implemented OTR tires in its program. All other provinces can only provide estimates of the number of OTR tires or no number at all. Information from the Rubber Association of Canada indicates that nearly 50% of all OTR tires originate in the western provinces, 23% are assumed to originate in Quebec and 23% in Ontario. The balance of 4% is assumed to originate in the Atlantic provinces. The RAC estimates that a total of 345,000 OTR tires are generated per year in Canada[66].

Table 6-5 shows the OTR tire data collected. Most provinces provided the data in unit numbers. If no additional information about the weight of the OTR tires was given, an estimate of 500 kg per OTR tire was used. No data could be provided for Newfoundland/Labrador. Anthony Stock, a tire recycler from British Columbia who is involved in OTR tire recycling, provided estimated numbers for Ontario, Quebec and the Territories[67].

Table 6-5 shows a lack of information on the generation of OTR tires. The number of OTR tires buried in landfills is even higher, but only one province in Canada (Nova Scotia) has published the number of OTR tires in landfills.

Table 6-5. Estimation of OTR-tire generation in the Canadian provinces.

	OTR tires	
Province	in units	in metric tonnes
Alberta	24,050	19,210
British Columbia	55,500	12,420
Manitoba *	30,000	15,000
New Brunswick **	4,000	2,000
Newfoundland and Labrador	no data	no data
Nova Scotia ***	15,700	7,850
Ontario	no data	18,000
Prince Edward Island	very few agricultural tires	-
Quebec	no data	10,000
Saskatchewan	1 % of total scrap tire processing	120
Territories	no data	10,000
Canada	**129,250**	**94,600**
Canada (estimates from RAC)	**345,000**	**172,500**

* annually sold
** annually generated
*** including all OTR in landfills

7 RECYCLING OF OTR TIRES

The recycling of OTR tires is a big issue in all provinces in Canada. OTR tires include heavy mining tires as well as agricultural and industrial tires. Saskatchewan ships OTR tires to the USA to a recycler who uses the tires as TDF. Other provinces, including Alberta and Manitoba, are also making major efforts to develop new options for recycling. Transportation costs to the USA are quite high, therefore a local solution for processing OTR tires would be preferable.

Except in Saskatchewan, OTR tires are not included in the provincial tire programs, therefore no fee is collected for the tires. This means that there are no incentives for processors who recycle OTR tires. Agricultural and industrial OTR tires can be processed as truck tires due to similar size and composition, but heavy mining tires need special equipment for processing. Because of the large size and difficult handling, the processing costs for OTR tires are much higher than those for passenger tires; OTR tire processing costs are in a range of $200 per metric tonne or even higher depending on the tire size[68], which is at least four times higher than the processing costs for passenger and truck tires.

An innovative solution for recycling OTR tires is to modify them for use as water tanks, a road base for temporary roads, or feed bunks and other livestock items. The sidewalls are cut off the large tires forming a tank or bunk 20-30 in. tall, depending on the size of the tire. Most of the tanks have a poured cement bottom. The cut sidewall makes an excellent windbreak fence[69].

OTR tires from the mining industry have a rubber content of nearly 100% natural rubber. This is a high-value natural resource and should be recovered. If the tread is peeled off an OTR tire, the buffings are pure rubber with no steel or fibre contamination and can be used for retreading OTR tires. This is very feasible in the case of a 15 ft tire weighing 1,400 kg and a new tire cost of approximately CAD $40,000. Retreading OTR tires costs about half the cost of manufacturing a new tire, but the lifetime of retreaded OTR tires is reduced by 20%. Safety and quality issues must also be met and have to be taken into account depending on the future use of the tire[70]. Due to severe operating environments, OTR tires utilize the highest and most advanced levels of available technology.

Rubber crumb (lower quality) generated from OTR tires can be used as TDF, and the steel from OTR tires is mainly recovered as bead from the scrap tires and can be recycled as normal scrap steel.

8 ENVIRONMENTAL CONSIDERATIONS AND HUMAN HEALTH

All material used in tire manufacturing and scrap-tire processing including the transportation of the material has an impact on the environment and human health. To determine all possible impacts, a full life-cycle assessment would be required for a tire and a scrap tire. This survey cannot provide full life-cycle assessments, therefore a summary is provided with the information that was available to the public. Table 8-1 shows a broad description of (scrap) tire components and their potential impacts on the environment. The processing technologies and their role in the reduction of GHG emissions and the impacts on human health are described below.

8.1 MATERIAL RECOVERY

A major market for the use of rubber crumb is surfacing. Public concerns include environmental toxicity of leaching and possible release of carcinogens. The concern is highest if the rubber crumb is used in playgrounds. Once released to the environment, metals ions associated with a tire's composition are relatively mobile and can migrate to ground and surface waters through soil leaching and runoff, but in most cases the concentrations of metals that leach from tires and tire chips are very minute. Consequently, the impact of metals from tire leaching in the environment is relative small.

Metals leached from tire stockpiles have been studied and analyzed (California Integrated Waste Management Board, 1996). This study showed that aluminium, cobalt, selenium and zinc had higher concentrations in tires than in coal. Other metals have been determined to have levels below those of coal. A long-term study by Malek et al. [71] conducted on tires immersed in seawater concluded that, after 42 years, tires constructed of polyisoprene and immersed at a depth of 80 ft showed very little degradation. Analytical tests on the tires determined that the tire rubber absorbed water equal to 5% of its mass. Concentrations of rubber, carbon black, sulphur, zinc oxide, mercaptobenzothiazole, and stearic acid in the tires were within ±10% of the levels that would be found in the original tire composition. Antioxidants were also analyzed in the tires, but any loss of these compounds could not be confirmed. The iron bead was also analyzed, and trace metals were detected indicating that the bead was a mild steel; no oxidation appeared to have occurred. More details on these studies are available on the California Integrated Waste Management Board (CIWMB) website (www.ciwmb.ca.gov).

A study in Alberta was undertaken to evaluate the environmental hazards of tire crumb for use in public playgrounds[72]. The health hazard for children, if any, associated with the use of tire crumb in playgrounds depends on the presence of an intact pathway of exposure and direct contact with chemicals that may be present in tire crumb. This exposure may occur through skin contact or via ingestion. Inhalation of volatile constituents is not a plausible route of exposure because no volatile compounds would be expected to remain in the shredded crumb. The report concluded that *"there was little potential for an exposure sufficient to cause adverse health effects in children"*[73]. As well, ingestion of tire crumb on the ground is not likely. Tire crumb does not contain chemicals with high vapour pressures. Therefore, exposure via inhalation was deemed inconsequential and the resulting hazard negligible. Dermal exposure was deemed to be unlikely and thus presented a low overall hazard.

Table 8-1. Potential environmental impacts of materials used in tires[73].

Material	Source	Application	Potential impacts
Natural rubber	Natural rubber is predominantly obtained from the sap of the Hevea Brasiliensis tree.	The proportion of natural rubber to total rubber has been declining steadily over the past several decades and currently makes up about 30% to 40% of the total rubber used.	Loss of habitat in tropical forests - there are approximately 9.5 million ha of rubber plantation. Impacts of agricultural practices on local environments. Impacts from transportation to markets. Impacts from processing including odour.
Synthetic rubber	All of synthetic rubber are made from petrochemicals.	This makes up approximately 60 to 70% of the total rubber used.	Resource depletion of petroleum. Energy consumption, emissions and waste during manufacture.
Steel cord and beading including the coating materials and activators, copper/tin/zinc/cromium	The steel is premium grade and is only manufactured in a limited number of plants around the world due to the high quality requirements.	Steel is used to provide rigidity and strength to the tires. In a passenger tire steel cord makes up to 15% by weight.	Impacts during production and transportation. Leaching of metals during disposal. Issues with difficulty in recycling.
Other reinforcing fabrics	Predominantly sourced from petrochemicals.	Used for structural strength and rigidity. Makes up about 5% of a radial tire.	Impacts during production and transport.
Carbon black	Generally sourced from petroleum stock.	Imparts durability and wear resistance and resistance to degradation. Makes up about 28% of a passenger tire.	Impacts during production and transport.
Zinc oxide		Zinc is added to provide resistance to UV degradation, control vulcanisation and enhance blending. Zinc oxide makes up about 1.2% of a passenger tire.	Impacts during manufacture and disposal. Impacts due to leach/emission from waste tires.
Sulphur (incl. Compounds)	Sulphur is used to vulcanise the rubber.	Makes up about 1% of a passenger tire.	Impacts during production. Impacts during combustion for energy recovery.
Other additives and solvents: age resistors, processing aids, accelerators, vulcanising agents, softeners and fillers	The other additives are used in the various rubber compounds to modify handling manufacturing and end-product properties.	The additives makes up about 8% by weight of a passenger tire.	Impact associated with manufacture and transportation. Emissions during manufacture. Impacts associated with use and disposal of the solvents. Emissions from tires in use, during recycling and in final disposal.
Recycled rubber	Recovered from used tires or other products.	Used in same rubber compounds in the manufacture of new rubber products and retread materials.	Impacts from energy use in production.

Addressing the risk of tire crumb contaminating surface or groundwater:

> "Chemicals leaching from relatively fresh tire crumb may present a moderate toxic threat to aquatic species if the runoff is not diluted. However, this toxic activity is quickly degraded by natural processes, presumably by conversion of the chemicals responsible to non-toxic products. Given that undiluted runoff is not likely and that three months is an outside estimate of the duration of toxicity, it is doubtful that tire crumb would present a significant risk of contamination in receiving surface waters or groundwater."[73]

The energy content in a passenger tire (PT) is about 260 MJ/PT, so the necessary energy required to process tires to crumb should not exceed this limit in order for crumbing to be environmentally feasible. The energy consumption of various grinding and shredding operations is shown in Table 8-2. The energy used to manufacture a new tire is 103 MJ/kg which can translate to greenhouse gas (GHG) emissions of 6.9 kg CO_2 per kg tire manufactured[74]. These emissions can be reduced by replacing virgin synthetic rubber with recycled rubber depending on the processing method. To produce new synthetic rubber, an additional 90 MJ/kg is needed. Even if cryogenically ground rubber is reused as material in new tires, an energy saving is obvious, and its level depends on the percentage of rubber replaced.

Table 8-2. Energy consumption of various grinding and shredding operations[26].

Particle size of crumb rubber	MJ/PT
Tire shreds	0.5
5 x 5 cm pieces	2.5
2.5 x 2.5 cm pieces	16
Granules (0.6-1.2 cm)	40-50
Cryogenically ground crumb	100

8.2 ENERGY RECOVERY

Replacement of fossil fuels is an important eco-efficiency driver in the cement industry because it reduces fuel costs, use of natural resources and CO_2 emissions. Scrap tires can be completely destroyed in cement kilns for a variety of sound technical reasons. The combination of extremely high temperatures, a positive oxygen atmosphere and a relatively long gas residence time (4 to 12 s at the elevated temperatures) assures the complete combustion of the scrap tire. This complete combustion precludes products of incomplete combustion or black smoke or odours being released from the stack[28].

> "Scrap tires can be considered as alternative fuels; however they contain more zinc and cadmium, but less mercury and arsenic than fossil fuels. Stack emission measurements at a cement manufacturing plant indicate cleaner processing when scrap tires are used as alternative fuel. Although the stack emissions of zinc and iron increase, emissions of mercury are significantly reduced, as well as those of cadmium and tellurium. There is a strong shift from the gaseous phase to the particulates, which is much easier to control."[75]

Additionally, the use of TDF is a low-cost NO_x reduction option. In Canada, scrap tires are used as tire shreds in a paper mill. The environmental benefit of the use of scrap tires in a paper mill can be considered as neutral. It uses energy for the crumbing of scrap tires, but as a result the overall impact of TDF in a paper mill is approximately CO_2/GHG neutral (higher CO_2 emissions from TDF compared with natural gas are offset by the reduced natural gas CO_2 emissions due to the use of extra hog fuel). Cement kilns can use tires from stockpile or landfill clean-ups, which is a beneficial use of scrap tires because they are difficult to recycle mechanically due to their older age and contamination with dirt.

For the cement industry, an example from CBR HeidelbergCement Group (a cement company in Belgium) shows the environmental benefits of replacing 10% of their energy demand with rubber tires in the cement clinker process. Less depletion of fossil resources is required resulting in a benefit of 390 MJ (or approximately 15 kg coal) per tonne of clinker. With fewer emissions, savings of 2.4 kg CO_2 per tonne of clinker are achieved. The depletion with steel causes 2 kg of mainly ferrous resources[76].

A survey from Australia compares energy generated and greenhouse gas emissions between tires and other fuels[9]. Table 8-3 shows the conclusions of the survey. Using tires as fuel can reduce the CO_2 emissions when compared with coal. They have higher CO_2 emissions than oil and natural gas. Assuming that the energy content in a passenger tire is 260 MJ/PT, and the energy needed to manufacture a new tire is about 974 MJ/tire, the energy savings are about 27%.

Table 8-3. Comparison of energy and greenhouse gas emissions[9].

	Energy	Greenhouse Gas emissions	
Fuel	GJ/t	kgCO_2/t	kgCO_2/GJ
Tire shred with majority of steel removed	32	2,391	75
Whole tires	27	2,080	77
Thermal coal	27	2,430	90
Brown coal	10	922	95
Oil	46	3,220	70
Natural Gas	39	1,989	51

8.3 THERMAL DEGRADATION

Pyrolytic units are expected to have minimal air-pollution impact because most of the pyrolytic gas generated in the pyrolysis process is burned as fuel. Additional pyrolytic gas may be vented to a flare system. Assuming complete combustion, the decomposition products of the pyrolytic gas are water, carbon dioxide, carbon monoxide, sulphur dioxide, and nitrogen oxides. The benefit of thermal-conversion technologies for greenhouse gas reduction cannot be provided as a definite number. The energy benefit is calculated as the substitution of other energy, which can be generated by the combustion of coal, gas, oil etc. The reduction of CO_2 produced is based on the kind of fossil fuel used to generate the energy. As fossil fuel consumptions vary between provinces, each province must calculate their own benefit. That is not part of this survey.

Table 8-4 shows an average composition of the products of a pilot pyrolysis plant and a pilot microwave plant. Additional information can be found in section 3.5.

No external energy source is required. In fact, both technologies generate a surplus of energy such that more than half of the energy generated during the process can be provided to other consumers. For example a microwave plant with a capacity of 18,000 metric tonnes of scrap tires per year produces approximately 1730 kWh/year. With half of the energy needed for the process, 865 kWh/year (or 240,470 GJ) can be sold to the market. A pyrolysis plant with a capacity of 36,000 metric tonnes of scrap tires per year can generate 2880 kWh/year in energy. With 1336 kWh/year energy needed for the process, 1544 kWh/year (or approximately 430,000 GJ) can be sold to the market. These figures are based on assumptions related to the pilot plants, and variations may be possible.

The benefit of thermal-conversion technologies for greenhouse gas reduction cannot be provided as a definite number. The energy benefit is calculated as the substitution of other energy, which can be generated by the combustion of coal, gas, oil etc. The reduction of CO_2 produced is based on the kind of fossil fuel used to generate the energy. As fossil fuel consumptions vary between provinces, each province must calculate their own benefit. That is not part of this survey.

Table 8-4. Products received from a pyrolysis or microwave plant.

	Pyrolysis		Microwave	
	in metric tonnes	in wt %	in metric tonnes	in wt %
Tire Input	36,000	100	18,000	100
Carbon Black (CB)	11,655	32	6,840	38
Condensible Oil	12,250	34	3,600	20
Non-condensible Gases	5,975	17	5,760	32
Scrap Steel	5,400	15	1,800	10
Fibre	720	2	included as ash in CB	

An additional benefit of thermal-conversion technologies lies in the fact that they produce carbon black. Depending on the impurities in the carbon black produced by a pyrolysis or microwave plant, there can be a benefit of up to 1.2 tonnes CO_2 per tonne input if it is used instead of virgin carbon black.

8.4 RETREADING

A comparative ecological evaluation of a retreaded tire with a new tire poses certain methodological problems. A retreaded tire and a new tire are not equivalent products because it is not technically possible for a retreaded tire to simultaneously obtain the same level of safety, durability, handling and service life as the base product – a new tire. For example the rolling resistance of a retreaded tire is at least 3% higher than that of a new tire. On the other hand, comparing the manufacture of a new tire to that of a retreaded tire reveals that a new tire has a much greater impact on the environment than a retreaded tire and the potential GHG emissions are 1.8 times that of a retread[77]. While 974 MJ are needed to manufacture a new passenger tire, only 400 MJ are needed to manufacture a retreaded tire. This corresponds to energy savings of 41% and can lead to a CO_2 reduction of 27 kg CO_2 per retreaded tire, depending on the energy source[73].

Table 8-5 gives an overview of oil savings attributed to tire retreading. The synthetic rubber contained in the tire is petroleum based, therefore oil is used in the manufacturing process.

Table 8-5. Oil savings attributed to tire retreading[78].

Tire	Oil saved per tire (litre)
Passenger tire	17
Light truck tire	36
Medium and heavy truck tire	63

With higher rolling resistance, the retreaded tire may use more fuel during its lifetime and thus presents a disadvantage over a new tire. In addition, the lifetime of a retreaded tire may be reduced by 20% relative to that of a new tire. The total ecological effect of a high-quality retreaded tire exhibiting a moderate increase in rolling resistance over a new tire can be said to be virtually neutral.

8.5 DISPOSAL

Stockpiling whole tires creates two significant hazards: mosquitoes and fires. Due to their shape and impermeability, tires managed in stockpiles tend to hold water for long periods of time. This stagnant water provides an ideal breeding ground for mosquitoes and sites for mosquito larvae development. Tire stockpiling has contributed to the introduction of non-native mosquito species as used tires are imported from other countries to Canada. These new mosquito species are often more difficult to control and spread more disease.

Stockpiling whole tires also poses a significant fire hazard. Tire fires, some of which may be started intentionally, generate large amounts of heat and smoke and are difficult to extinguish. This is due to the fact that tires, in general, generate more heat energy by weight than coal; and there is a 75% void space in a whole waste tire, which makes it difficult to either quench the fire with water or cut off the oxygen supply. Some tire fires have burned continuously for months.

The landfilling of whole tires consumes a large volume of landfill space because the tires are relatively incompressible and 75% of the space a tire occupies is void. This void space provides potential sites for gas collection and harbouring of rodents. In landfills, waste tires capture explosive methane gas and "float" upward sometimes shooting to the surface with tremendous force and piercing the landfill cover. The primary advantage to landfilling whole tires is that processing costs are avoided.[2]

Storing scrap tires in a landfill or a stockpile generates no GHG emissions because the tires are extremely slow to decompose. But a landfill or stockpile fire is an environmental hazard of great concern because toxic gases are released to the environment. This should be avoided.

> "The organic products of incomplete combustion are present in emissions from all combustion processes and, in general, have been found to be carcinogenic in humans and rodents and to be mutagenic in bacteria and mammalian cells. The mutagenic emission factor for the open burning of tires was 3-4 orders of magnitude greater than that for the combustion of oil, coal, or wood in utility boilers; it was most similar to values for the open burning of wood and plastic. Open burning, regardless of feedstock of fuel, appears to result in greater mutagenic emission factors than does controlled combustion as in various types of incinerators or boilers[41]."

The emissions from stockpile tire fires affect not only the atmosphere but also the land and groundwater due to the liquefaction of the rubber during the combustion process. In addition, water on tire fires often increases the production of pyrolytic oil and provides a mode of transportation to carry the oils off-site and speed up contamination of soils and water.[79] Air emissions from open burning of tires include pollutants such as particulates, carbon monoxide, sulphur oxides, oxides of nitrogen, volatile organic compounds, polynuclear aromatic compounds, dioxins, furans, hydrogen chloride, benzene, polychlorinated biphenyls; and metals such as arsenic, cadmium, nickel, zinc, mercury, chromium and vanadium. In open-fire situations, these emissions can represent significant acute (short term) and chronic (long term) health hazards. These health effects include irritation of the skin and eyes, central nervous system depression, respiratory effects, and cancer[80].

8.6 TRANSPORTATION

Transportation of scrap tires to a processing plant plays an important role in regions located far away from the nearest processor. Table 8-6 gives an overview of the energy used in transport tasks, and Table 8-7 shows the maximum transport distance before the energy from transport exceeds the energy recoverable from scrap tires.

Table 8-6. Energy used in transport tasks[9].

Transport mode	MJ/tonne km	kg CO_2/tonne km
Light commercial	5.0	0.350
Rigid truck	3.5	0.240
Articulated truck	1.4	0.095
Rail	0.5	0.035
Sea	0.3	0.022

Table 8-7. Transport distance before the energy from transport exceeds the energy recoverable from scrap tires[9].

Transport mode	Distance in km
Light commercial	5,400
Rigid truck	7,714
Articulated truck	19,286
Rail	54,000
Sea	90,000

These calculations have also to be taken into account if the total greenhouse gas benefits are estimated for specific processing options. They may vary from province to province in Canada.

8.7 SUMMARY AND RANKING OF PROCESSING METHODS

This section will summarize all the above-mentioned technologies and make a recommendation, which might be subjective and is not presented as the only solution. There may be different opinions, and perhaps not every solution is suitable for every Canadian province, but it will present an overview of the best available environmentally friendly solutions for recycling scrap tires. Table 8-8 summarizes the preferred processing methods in scrap tire recycling.

Table 8-8. Ranking of processing methods in scrap tire recycling[81].

Rank	Processing Method	Examples
1	Use **PRODUCT** for its originally intended purpose as long as possible.	Design rubber compound and tire geometry for maximum durability. Keep tire properly inflated at all times to ensure maximum service life. Reuse partly worn tires. Retread tire casings.
2	Use **MATERIAL** for its originally intended purpose.	Grind scrap tires into crumb rubber, separate steel and fibre. Sell rubber as raw material (includes devulcanisation and surface treatment)
3	Use whole scrap tires for energy recovery.	Burn whole scrap tires as fuel supplement in cement kilns.
4	Use mechanically processed tires for energy recovery.	Tire chips added to coal as fuel supplement in power plants, paper mills, cement kilns, etc.
5	Alter the chemical structure of scrap tires and use the products for energy recovery.	Pyrolysis, Microwave
6	Storage for possible recovery at a later time.	Monofilling
7	Disposal without any current or future use.	Landfilling

> "A tire should be used as a tire as long as possible to avoid, whenever possible, the early replacement with a new tire. With proper inflation the rolling resistance will be optimal which can minimize fuel consumption and extend the lifetime of a tire. Under-inflation of a tire by 20% reduces the lifetime of the tire by 15,000 km and increases fuel consumption by 4%. The combustion of one litre of fuel releases 2.4 kg CO_2 to the environment, thus a reduction of 1.5 million tonnes CO_2 emissions can be achieved each year if all Canadian tires are proper inflated[82]."

Well-maintained tires are best for the environment. Retreading can extend the lifetime of a tire because usually the tread of a tire is rubbed off, but the tire casing is still good. Once the quality and safety standards can no longer be met, the tire becomes scrap and has to be processed as such.

The next step is material recovery and reuse for its originally intended purpose. Rubber crumb can be used either in new tires or in other rubber products such as those described in Chapter 4.1.3. There are many possibilities, and each of them has its own benefits for the environment. Rubber asphalt for example does not really replace other materials used in the paving process, but it improves the properties of the asphalt, therefore less rubber modified asphalt is used than conventional asphalt because the layer thickness is thinner. Also a road surfaced with rubber asphalt lasts longer and needs less maintenance saving raw materials over a longer period of time. Only the effects on human health of fumes generated during a construction of rubber pavement are not yet known.

Rubber crumb can be treated with surface modification or devulcanisation to generate a higher quality product with new properties offering additional applications for the rubber market. The benefit for the environment is less due to the additional energy used for the process.

Using whole tires as TDF in cement kilns is beneficial for the environment because they replace fossil fuels and recover the material steel as well. The steel is required for cement formation and eliminates the need to add steel. The energy savings are less than those of material recovery and rubber crumb because more energy is needed to produce new synthetic rubber. If recycled rubber replaces synthetic rubber, the energy benefit can be twice that of TDF depending on the process, where the rubber crumb is used and how much virgin rubber is replaced.

Less GHG reduction is achieved in using shredded tires for energy due to the energy needed to process the tires to shred or crumb.

Pyrolysis and microwave are ranked 5th because of uncertainty about a market for the products generated from these technologies. There is definitely a huge benefit in GHG savings, but to verify these figures it would be necessary to have an operating plant in Canada. Hopefully this situation will change in the near future.

Storage of scrap tires and landfilling is the last option for processing scrap tires and should be avoided anywhere. There is always a fire hazard, and the negative impact on the environment and human health is too high. Chapters 3.7 and 8.1 have presented information on the hazards of landfilling tires. If only landfilled, the tires have nearly no impact on the GHG emission because they hardly decompose and keep the carbon fixed forever (as long as there is no fire).

9 SUMMARY

This study of “Scrap Tire Recycling in Canada” shows a great market potential in the processing of scrap tires into new applications and valuable products. The times of illegal stockpiling and burning of tire stockpiles and landfills seem to have become part of history. Thanks to well-operated tire programs in nearly each Canadian province (only Ontario is currently developing its program) scrap tires are now being processed using several techniques.

Tire programs in the Canadian provinces came on-line at different times over the past decade. While possessing some similarities, they have developed in various ways to accommodate their different circumstances. Some operate as a component of the provincial government concerned, while others focus on a stewardship model, with industry stakeholders sharing responsibility through an external Board of Directors. All tire programs have implemented a tire levy and use this levy to fund the collection and processing of the scrap tires into valuable products. The Tire Stewardship Board was instrumental in establishing the Canadian Association of Tire Recycling Agencies (CATRA). This association was established to facilitate information exchange between scrap tire program boards and to assist Canadian scrap tire program managers in the efficient operation of their programs as all provincial agencies have some similarities and differences, and are evolving at different rates.

The “be tire smart” campaign of the Canadian government and the Rubber Association of Canada encourages Canadian tire consumers to avoid generating waste by keeping their tires properly inflated which saves energy because it uses less fuel and extends tire lifetime.

Tires consist mainly of natural and synthetic rubber (up to 40 wt % combined), carbon black (28 wt %), steel, fibre, fillers, accelerators, antiozonants, etc. Passenger tires tend to have more synthetic than natural rubber, truck tires consist of more natural rubber, and OTR tires contain nearly no synthetic rubber. This may be due to the fact that passenger tires have to meet higher quality standards (low rolling resistance, improved skid resistance and good wear[5]) to succeed in the competitive market. Truck and OTR tires, on the other hand, have to cope with heavy loads and longer distances more than operating under high speed conditions, and natural rubber can withstand much higher workload demands than synthetic rubber. Also, while OTR tires tend to contain little or no fibre and about 15 wt % steel, the fibre content in passenger tires can be up to 5 wt % of the total tire weight. Exact tire composition is not known because of company secrets.

The biggest scrap-tire market in Canada in 2003/2004 was rubber crumb, which represents more than 40 wt % of the total scrap tire usage market or more than 100,000 metric tonnes. A further 20 wt % was used as Tire-derived Fuel (TDF) for either cement kilns or paper mills, 18 wt % was directly processed as moulded products in recycling plants, 13 wt % was processed as shred and the balance was baled or stored. A total of about 240,000 metric tonnes of scrap tires was processed in Canada in 2003/2004. Approximately 75 wt % of the scrap tires required processing in an ambient or cryogenic recycling plant. Only cement kilns can accommodate whole tires while some civil engineering applications, like barrier reefs, require no crushing or grinding of scrap tires.

The fibre content in tires varies from product to product, and, especially in scrap tires, the exact composition is never known. According to the available published data on tire composition, the amount of fibre in tires varies from 3 to 5% by weight. Therefore, 7,041 to 11,357 metric tonnes of fibre are available for the waste stream, if the fibre can be 100% liberated from the tire. The actual amount might be higher because of contamination with rubber particles.

The steel content in tires also varies from 10 to 14% by weight; therefore anywhere from 22,714 to 32,708 metric tonnes of steel may be available from end-of-life tires if the steel can be 100% separated from the tire. Statistics from processors may vary because of contamination with rubber particles or if more passenger tires than truck tires are processed. The exact ratio of passenger tires to truck tires is not known in most processing facilities for scrap tires, therefore the numbers only provide an estimate of the average steel content in the tires.

The feasibility of different solutions cannot be determined by comparing definite numbers for each process. Most processes are influenced by many factors such as labour and transportation costs, tire supply and product quality. The pricing situation is also affected by crumb quality, crumb coloration, purchase quantity, competitive pricing factors, impacts of subsidies, and negotiations between producers and end-users.

The recycling of OTR tires is a big issue in all Canadian provinces; OTR tires include heavy mining tires as well as agricultural and industrial tires. Information from the Rubber Association of Canada has shown that nearly 50% of all OTR tires originate in the Western provinces, 23% in Quebec and 23% in Ontario; the balance of 4% is assumed to originate in the Atlantic Provinces. A total of 345,000 OTR tires is reported by the RAC as OTR tires for all of Canada. Due to the high costs of processing these tires, all provinces are searching for feasible options.

Environmental considerations concerning GHG emissions and human health have been evaluated and are summarized in this survey. Under-inflating a tire by 20% results in a reduced lifetime of 15,000 km and 4% higher fuel consumption. The combustion of one litre of fuel releases 2.4 kg CO_2 to the environment, thus a reduction of 1.5 million tonnes CO_2 emissions can be achieved each year if all Canadian tires are proper inflated.

Comparing the manufacture of a new tire with the retreading of a scrap tire, a new tire has a much greater impact on the environment than a retreaded tire. The potential for GHG emissions is 1.8 times that of a retread. With 974 MJ of energy needed to manufacture a new passenger tire and only 400 MJ needed to manufacture a retreaded tire, this corresponds to energy savings of 41%.

Material recovery and reuse for its originally intended purpose is highly recommended. Rubber crumb can be used either in new tires or in other rubber products. Because the energy content in a passenger tire (PT) is about 260 MJ/PT, the energy to process tires to crumb should not exceed this amount to be environmentally feasible. The energy used to manufacture a new tire is 103 MJ/kg, which translates to GHG emissions of 6.9 kg CO_2 per kg of tire manufactured. Replacing virgin synthetic rubber with recycled rubber, depending on the processing method, can reduce these emissions.

Energy recovery is another option for processing scrap tires. When burned as fuel, tires produce higher CO_2 emissions than oil and natural gas, but lower emissions than coal.

Thermal conversion technologies like pyrolysis and microwave technology can definitely reduce GHG emissions. Unfortunately there is no operating plant in Canada to verify the numbers from the two Canadian pilot plants, and no market has been established for the carbon black generated during the process.

Storing scrap tires in a landfill or a stockpile generates zero GHG emissions because the tires are extremely slow to decompose, but a landfill or stockpile fire is a serious environmental hazard because uncontrolled gases are released to the environment. This should be prevented.

The whole survey has shown that there is a variety of viable solutions for processing scrap tires. One single solution for Canada is not viable. Different processing methods are required to stabilize the market situation. One market can become saturated and then other options might be feasible. Some technologies might not be efficient for all scrap tires and depend on the type and quality of the scrap tires. Landfill clean-ups do not provide the best source of high-quality crumb, and energy recovery in a cement kiln might be a better solution. Each technology has to be considered and evaluated for the specific product.

10 FUTURE WORK AND RECOMMENDATIONS

During the survey, a lack of data monitoring OTR tire management was noted – only Saskatchewan has implemented OTR tire recovery into their program. A levy on OTR tires will be implemented in most provinces in the coming years. Due to the high processing costs for OTR tires, funding may be required beyond the tire levy fees.

Recycling must be promoted so that products generated from scrap material are perceived as value-added products, not “waste” material. The public must be educated about the benefits of recycling; for example, using tires as TDF in cement kilns or paper mills provides economic and environmental advantages and is not just “burning tires”.

Environmentally friendly technologies need to play a bigger part in the marketplace. Most new technologies struggle in the beginning because they do not have enough funding to compete against older, more established technologies. For example, pyrolysis and microwave technology have to bring a new product to the market, such as recovered carbon black which is comparable to virgin carbon black. Industry, however, is reluctant to show interest in this product.

Calculations on GHG emission reduction in this report have shown that there is a potential of CO_2 reduction in scrap tire recycling but more work is required to provide more accurate numbers. More attention has to be focussed on the life-cycle assessment of scrap tires.

ABBREVIATIONS

CATRA	Canadian Association of Tire Recycling Agencies
FIRST	Financial Incentives for Recycling Scrap Tires
GHG	greenhouse gas
kg	kilogram (equals 2.2 lbs)
MJ	mega Joule
MMSB	Multi-Materials Stewardship Board
NBTSB	New Brunswick's Tire Stewardship Board
OTR	Off-the-Road Tires
OTS	Ontario Tire Stewardship
PT	Passenger Tire
PTE	Passenger Tire Equivalent (1 PTE = 8.2 kg)
RAC	Rubber Association of Canada
RMA	Rubber Manufacturer Association
RRFB	Resource Recovery Fund Board Inc.
TDF	Tire-derived Fuel
TRA	Tire Recycling Alberta (former TRMA)
TRMA	Tire Recycling Management Association of Alberta
SSTC	Saskatchewan Scrap Tire Corporation
WDO	Waste Diversion Ontario
US $ 1	converts to CAD $ 1.23 (January 26th, 2005)

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LITERATURE

[1] www.rubberassociation.ca, December 2004

[2] Effects of Waste Tires, Waste Tire Facilities, and Waste Tire Projects on the Environment, Report from California Integrated Waste Management Board (CIWMB), Publication Number 432-96-029, California 1996

[3] www.rma.org, November 2004

[4] Dunn, J.R., Jones, R.H., Automobile and Truck Tires Adapt to Increasingly Stringent Requirements, Elastomerics, July 1991, pp 11-18

[5] www.vredestein.com, December 2004

[6] www.rma.org, November 2004

[7] Phillips, M., The Trouble with Tires, Recycling today, March 1998, www.recyclingtoday.com

[8] http://en.wikipedia.org/wiki/Rubber, January 2005

[9] Atech Group, A National Approach to Waste Tyres, Commonwealth Department of Environment, ISBN 0642 54749 1, Australia, June 2001

[10] Information from the Rubber Association of Canada, 2004

[11] Asplund, J., Scrap Rubber – An Unpredictable Waste or a Useful Raw Material, RAPRA Technology Ltd., Seminar: Rubber in the environmental age – Progress in recycling, 1996, ISBN 1859570917

[12] Analysis were done in August 2004 at Natural Resources Materials Technology Laboratory

[13] Modern Tire Dealer, 2002 Fact Book Statistics," <www.mtdealer.com/fbstats/0102_12.pdf>

[14] Assessment of Markets for Fiber and Steel Produced from Recycling Waste Tires, Report from California Waste Management Board (CIWMB), Publication Number 622-03-010, California 2003

[15] The Goodyear Tire and Rubber Company, 1144 E Market St, Akron OH 44316, "Scrap Tire Recovery," October 9, 2001, p. 20

[16] Juniper Consultancy Services Ltd., Emerging Solutions for Recovering Value from Scrap Tyres – Technology options and market opportunities, Juniper report, 2004, www.juniper.co.uk

[17] Yamaguchi, E., Waste tire recycling, http://www.p2pays.org/ref/11/10504/, August 2004

[18] http://www.entire-engineering.de/str/en.html, December 2004

[19] Rapra Technolgy Ltd, Dufton, P., End-of-Life Tyres – Exploiting their Value, A Rapra Industry Analysis Report, UK 2001, ISBN 1-85957-241-3

[20] Reschner, K., Scrap Tyre Recycling – Market Overview and Outlook, Waste Management World, Vol. 3 Number 4

[21] http://www.entire-engineering.de/str/en.html, December 2004

[22] Evaluation of Waste Tire Devulcanisation Technologies, Report from California Integrated Waste Management Board (CIWMB), Publication Number 622-04-008, California 2004

[23] Archer, E., Klein, A., Whiting, K., The Scrap Tyre Dilemma – Can Technology Offer Commercial Solutions?, Waste Management World, Vol. 3 Number 1

[24] Duo, W., Karidio, I., Cross, L., Ericksen, B., Combustion and Emission Performance of a Hog Fuel Fluidized-Bed Boiler with Addition of Tire-Derived Fuel, Paprican Research Report PRR 1625, Canada, December 2002

[25] Personal information from Cement Association Canada, August 2004

[26] Verein deutscher Zementwerke e.V., German cement industry, Environmental data 2001, Germany

[27] Data provided from Heidelberg Cement Group, July 2004

[28] The Use of Scrap Tires in Cement Rotary Kilns, Scrap Tire Management Council, 1992

[29] Roy, Ch., Darmstadt, H., Carbon Blacks Recovered from Rubber Waste by Vacuum Pyrolysis – Comparison with Commercial Grades, Plastics, Rubber, Composites Processing and Applications 27 (1998)

[30] Roy, Ch., Chaala, A., Darmstadt, H., The Vacuum Pyrolysis of Used Tires – End Uses for Oil and Carbon Black Products, Journal of Analytical and Applied Pyrolysis 51 (1999), pp. 201-221

[31] Roy, Ch., Plante, P., De Caumia, B., Oil and Carbon Black by Pyrolysis of Used Tires, International Conference Sustainable Waste Management and recycling, Kingston University, London, Canada 2004

[32] Norton, D., et al., Microwave Processing of Organic waste, International Conference on Incineration and Thermal Treatment Technologies, Philadelphia, 2001

[33] Provided data from Mike Vocilka, Environmental Waste International, Ajax, Ontario, August 2004

[34] International Tire and Rubber Association Foundation Inc. (ITRA), Understanding retreading, Guideline, 2001

[35] De Marini, D., et.al., Mutagenicity and Chemical Analysis of Emissions from the Open Burning of Scrap Rubber Tires, Environmental Science and Technology 1994, 28 pp. 136-141

[36] Exchange rate for the CAD to US$ was estimated at: 1 US $ = 1.23 CAD (26th January, 2005)

[37] Duffey, M.R., Sunthonpagasit, N., Scrap Tires to Crumb Rubber: Feasibility Analysis for Processing Facilities, Resources, Conservation and Recycling 40 (2004), p. 281-299

[38] Scrap Tire and Rubber Users Directory 2004, 13th Edition, Recycling Research Institute, Scrap tire news, USA

[39] Harmonized Economic Instruments for Used Tires, Canadian Council of Ministers for the Environment, Apogee Ref.:363 CCME, 1994, Canada

[40] Considerations for Starting a Scrap Tire Company, Rubber Manufacturers Association, RMA Special report GEN-060, 2004, USA

[41] Available on the website www.rma.org

[42] Designing Building Products made with Recycled Tires, Report from Integrated Waste Management Board (CIWMC), Publication Number 433-04-008, June 2004, California, USA

[43] ASTM International, ASTM D 6700 – 01, Standard Practice for Use of Scrap Tire-Derived Fuel, Edition 2001, USA

[44] ASTM International, ASTM D 6270 – 98, Standard Practice for Use of Scrap Tires in Civil Engineering Applications, Reapproved Edition 2004, USA

[45] ASTM D 6114, Standard Specification for Asphalt Rubber Binder, 2001

[46] Navarro, F.J., et al, Thermo-Rheological Behaviour and Storage Stability of Ground Tire Rubber-Modified Bitumens, Fuel 2004, article in press May 2004

[47] State of California Department of Transportation, Asphalt Rubber Usage Guide, California 2003

[48] Hicks, R.G., Asphalt Rubber Design and Construction Guidelines, prepared for Northern California Rubberized Asphalt Concrete Technology Center and the California Integrated Waste Management Board, California, 2002

[49] Schulz, A., Asphalt Rubber in Alberta 2002-2004 – What have we learned? Presentation at Rubber Recycling 2004, Rubber Association of Canada, Banff, 2004

[50] Riggle, D., Finding Markets for Scrap Tires, Biocycle March 1994, pp. 41-55

[51] Michael, H., Scholz, H., Mennig, G., Blends from Recycled Rubber and Thermoplastics, Kautschuk Gummi Kunststoffe Vol.52 No 7-8/99, pp. 510-513

[52] Schnekenburger, M., Scrap Tire Rubber in Manufactured Parts, Presentation at Rubber Recycling 2004, Rubber Association of Canada, Banff, 2004

[53] Increasing the Recycled Content in New Tires, Report from California Integrated Waste Management Board (CIWMB), Publication Number 622-04-001, California 2004

[54] Bekaert Group, 2003

[55] Helzer, S.C., “A Recovery Method for Tire Bead as Cast Iron Charge Material,” 1994 <http://fp.uni.edu/rrttc/grants/project.asp?ProjectID=142>.

[56] Pilakoutas, K. and R. Strube, “Re-use of Tyres Fibres in Concrete,” *Proceedings of the International Symposium on Recycling and Reuse of Used Tyres*, R.K. Dhir, M.C. Limbachiya, and K.A. Paine (eds.), Thomas Telford, University of Dundee, Dundee, UK, 2001, pp. 225–236

[57] Bignozzi, M.C., Saccani, A., Sandrolini F., New Polymer Mortars Containing Polymeric Wastes. Part 2. Dynamic Mechanical and Dielectric Behaviour, *Composites Part A: Applied Science and Manufacturing*, Elsevier Science (Amsterdam, Netherlands), 2001, pp. 205–211

[58] Bignozzi, M.C., Saccani, A., Sandrolini F., New Polymer Mortars Containing Polymeric Wastes. Part 1. Microstructure and Mechanical Properties, *Composites Part A: Applied Science and Manufacturing*, Elsevier Science (Amsterdam, Netherlands), 2000, pp. 97–106

[59] Czvikovszky, T., Hargitai, H., Electron Beam Surface Modifications in Reinforcing and Recycling of Polymers, *Nuclear Instruments and Methods in Physics Research B*, Elsevier Science (Amsterdam, Netherlands), 1997, pp. 300–304

[60] Statistics Canada, www.statcan.ca, November 2004

[61] Tire Recycling Alberta, Alberta Business Plan 2003/2004

[62] http://wlapwww.gov.bc.ca/epd/epdpa/ips/tires/, July 2004

[63] http://www.catraonline.ca/bc/stockpiles.html, November 2004

[64] Manitoba Tire Stewardship Board, Annual Report 2003/2004, Winnipeg

[65] New Brunswick Tire Stewardship Board, Annual report 2001

[66] Phone call with David Lamb, Rubber Association of Canada, February 2005

[67] Personal information from Anthony Stock, Target Recycling Inc., British Columbia, February 2005

[68] Heck, M., OTR “Off the Road” Tire Recycling, Rubber Recycling 2004, Rubber Association of Canada, Banff 2004

[69] Scrap OTR’s Spin their Way into Other Uses, Scrap tires News June 2004, USA

[70] Ramshaw, D., Tyres, Chains and Handlers, Mining Magazine 1995, p.237-244

[71] Malek,K., Stevenson, A. Effect of 42 Year Immersion in Sea-Water on Natural Rubber, Malaysian Rubber Producer’s Research Association, Hertford, Engl. Journal of Materials Science, Vol 21 No1, January 1986

[72] Birkholz, D.A., Belton, K.L., Guidotti, T.L., Toxicological Evaluation for the Hazard Assessment of Tire Crumb for Use in Public Playgrounds, Journal of the Air & Waste Management Association, Vol. 53 July 2003, pp 903-907

[73] UK Environment Agency, Tires in the environment (undated)

[74] This calculation is based on data from Australia where most energy is supplied by fossil fuel power plants (the majority coal power plants). The scenario for Canada differs from province to province.

[75] Mukherjee, A.B., Kaantee, U., Zevenhoven, R., The Effects of Switching from Coal to Alternative Fuels on Heavy Metals Emissions from Cement Manufacturing, Proc. Of the 6th Int. Conf. on the Biochemistry of trace elements, p. 379, Guelph, Canada, 2001

[76] CBR Cement, Environmental Report, 2001, Belgium

[77] Life Cycle Assessment of a Car Tire, Continental AG, Hannover Germany, 1999

[78] Data received from American Retreaders Association, 1996

[79] Transportation Research Record, Geoenvironmental and Engineering Properties of Rock, Soil, and Aggregate, Transportation Research Board, Washington D.C. Library of Congress catalog card no. 92-25598

[80] Air Emission from Scrap Tire Combustion, EPA report 600/R-97-115, October 1997

[81] Information from Kurt Reschner

[82] www.betiresmart.ca, January 2005