Study of Potential Scrap Tire Markets in Canada

Canadian Association of Tire Recycling Agencies

Provided to CATRA by Terry Gray
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CANADIAN SCRAP TIRE MARKETS AND ISSUES

PERSPECTIVE

Thirty years ago, virtually all scrap tires generated in North America were landfilled, stockpiled or strewn across the countryside. Entrepreneurs initiated some market development and tire processing in the 1980s, but tire dumping was cheap and didn't require capital investment, so these tire recycling pioneers struggled for survival and many did not win the battle.

Tires began to be recognized as a resource in the 1990s. In addition to basic recycling objectives, a series of major stockpile fires encouraged provinces and states to initiate scrap tire management programs to stop illegal disposal and create markets. Many tire processing methods and equipment components were tried, with mixed results. Market development efforts tested the limits of creativity and "credibility". The long term result has been development of diverse products and a tire processing industry capable of making these products. In a relatively short period of 15 – 20 years, scrap tires have progressed from a disposal liability to a valuable resource with broad market penetration.

Exhibit 1 summarizes the Canadian and US markets for products derived from scrap tires based on the most recent data compiled by CATRA in Canada (2009) and the Rubber Manufacturers Association (RMA) in the US (2011). Most provincial waste tire programs are structured to encourage the highest and best use of tire resources, namely crumb rubber and molded rubber products. These markets currently use over 221,000 tonnes, or 58%, of Canada's waste tires, clearly reflecting program goals. The United States converts 34 million tires (340,000 tonnes) into crumb rubber, but this represents just 11% of its annual generation. Canada and the US have both encouraged use of tire derived aggregate in civil engineering applications, representing 18% of generation in Canada and 6% in the US.

The biggest market difference is in perception and use of tire-derived fuel (TDF) as a supplemental energy resource. TDF is recognized as a viable energy resource in the United States and consumes 50% of annual generation in about 100 facilities across the country. Because of Canada's focus on other markets and historical aversion to use of waste resources for their energy value, only 9% of its tires are used as TDF and some of that is shipped to border areas in the US. RMA estimated that the dramatic increase in baled tire exports from the East and West coasts of the US to China (through Viet Nam) were 6% of generation in 2011, but this is not a substantial issue in Canada. Eleven percent of scrap tires were culled for resale in the US, but used tire resale was not included in Canada's market summary. Miscellaneous smaller markets consume 7% in Canada and 6% in the US.

EXHIBIT1

SCRAP TIRE MARKETS

MARKET	CANADA (2009)		UNITED STATES (2011)	
	TONNES	%	TIRES (MM)	%
CRUMB RUBBER	123,094	32%	22	7%
MOLDED PRODUCTS	98,160	26%	12	4%
CRUMB RUBBER SUBTOTAL	221,254	58%	34	11%
TIRE DERIVED AGGREGATE	68,775	18%	18	6%
TIRE DERIVED FUEL	33,875	9%	153	50%
BLASTING MATS	3,905	1%	0	0%
EXPORTS			18	6%
USED TIRES			35	11%
OTHER	24,115	6%	18	6%
TOTAL MARKET	351,924	92%	276	90%
TOTAL GENERATION	380,990	100%	307	100%

In spite of differences in approach and scale, both countries have established diverse markets consuming 92% of annual generation in Canada and 90% in the US. Canada's performance is even more comprehensive because off-road tires are included in annual generation, but not in the US numbers.

The following sections summarize the characteristics, volumes, benefits, and issues associated with each of these major market segments. Some believe that any market using waste materials is good, while others believe that anything new has to be bad in some way. Objective evaluation of data is generally required to establish practical reality.

CRUMB RUBBER

Within the traditional recycling hierarchy, the highest-value applications for scrap tires use crumb rubber for its specific performance characteristics. To maximize the value of scrap tire resources, tremendous financial, technical, and creative resources have been devoted to developing tire processing technology to make crumb (or ground) rubber and applications to use it. Applications for crumb rubber are normally grouped into the following major market segments:

Athletic/recreational surfaces – Use in artificial sports turf, natural (grass) turf and playground cushioning to protect children when they fall.

Molded and extruded products – Many products, including mats, bumpers, and other creative products.

Rubber modified asphalt and sealants – Addition of crumb rubber to asphalt binder to improve highway performance characteristics, including pavement life.

Tires/Automotive – Use of ground rubber from scrap tires in manufacturing some new tires, in the rubber compounds used to retread worn tires, and in molded automobile parts.

Export – Ground rubber sold to markets in Europe and the Far East from North America.

The percentage of ground rubber used in each of the major market segments in the United States during 2011 is shown in Exhibit 2, based on estimates made by the U.S. Rubber Manufacturers Association (Ref. 1). Data for Canada is not available, but would be expected to be similar. Canada probably has higher percentages in molded/extruded products and less in asphalt and automotive applications.

INSERT PIE CHART SHOWING

EXHIBIT 2: U.S. Ground Rubber Market Distribution, 2011

Athletic/recreational – 23%
Molded/extruded – 31%
Asphalt – 18%
Automotive – 5%
Export – 4%

Source: U.S. Rubber Manufacturers Association

ATHLETIC AND RECREATIONAL SURFACES MARKET

Athletic and recreational surfaces currently represent one of the largest markets for crumb rubber in North America. This market segment encompasses a wide variety of applications and additional variations within them. The following discussion briefly summarizes the two largest applications within this market segment: synthetic sports turf and playground safety surfacing.

Synthetic Sports Turf

Natural grass is a traditional sports field mainstay, but heavy usage of grass fields leads to turf failure, athletic injuries, and unattractive field appearance. In addition, standing water during wet weather can prevent use of grass fields and cause field damage. Good grass surfaces require routine watering, fertilizing, and turf replacement, resulting in significant maintenance costs. Damaged grass surfaces may contribute to injuries when the ground is hard, muddy, or loses traction. Awareness of costs associated with maintenance and injuries has led to development of alternatives.

Initial synthetic sports surfaces were developed for indoor arenas where the absence of sunlight prevented use of natural turf. One of the early examples was the Astrodome in Houston, Texas, which caused the trademarked name Astroturf to become a general description for an early generation of artificial playing surfaces. More sophisticated systems that use ground rubber were developed in the 1990s. These advanced turf systems were initially applied in high-profile American football stadiums used by professional and university teams but are now in broad use on a wide range of sports fields at all levels of play in Canada and the US.

<u>Description</u>

The current generation of artificial sports turf uses 7.6-cm (3-inch)-long strands of green polyethylene embedded in a porous backing to form a carpet-like structural framework for the turf system. The carpet is spread over a sophisticated drainage system capable of removing rain water rapidly and is in-filled with silica sand, ground rubber, or layers of each. A schematic representation of the FieldTurf Tarkett design is shown in Exhibit 3.

INSERT EXHIBIT 3 – FieldTurf Tarkett Synthetic Turf Schematic

The result is an attractive turf that drains water rapidly and is capable of withstanding comparatively heavy use. The polyethylene grass-like blades add containment to the ground rubber, and the rubber provides cushioning while the combined synthetic turf system bears the physical forces of athletic activity. Each manufacturer has variations intended to offer technical or economic advantages. An example of an American football field is shown at the right. .

INSERT EXHIBIT 4 – SYNTHETIC TURF - CANADIAN EXAMPLE

Current Market Status

Synthetic sports turf installations range from large stadiums to smaller municipal playing fields. The turf has been installed for international football, American football, field hockey, baseball, other sports, and practice facilities. The North American market grew rapidly to an estimated 1,000 field installations in 2008 and hundreds more in Europe, according to the Synthetic Turf Council (www.syntheticturfcouncil.org). The market has decreased to about 800 fields annually during the 2009 to 2011 period due to a combination of technical issues and poor economic climate.

A Canadian company, FieldTurf Tarkett, was one of the earliest manufacturers of synthetic sports fields and has played a major developmental role in this increasingly competitive market. Some of these turf systems have been tested and approved by the Fédération Internationale de Football Association (FIFA, the International Federation of Association Football in Zurich, Switzerland) for their grass-like performance.

Ground Rubber Requirements

Each of the major synthetic turf systems uses ground rubber as the primary infill material surrounding the green polyethylene fibers. The type and size of the ground rubber vary depending on the turf manufacturer. Some use primarily cryogenic ground rubber produced by freezing shredded rubber before it is fractured in a high-speed hammermill, a machine that pulverizes the rubber into fine particles. The resulting product has smooth sides and tends to flow easily when applied to a sports field. Others use "ambient" rubber, produced in a series of shear and compression equipment at ambient temperatures. This product tends to have a more irregular surface shape with a more cohesive consistency. A "crambient" product made by a primary cryogenic process followed by secondary ambient processing to yield hybrid performance characteristics is also used.

Particle size requirements for ground rubber also vary by turf manufacturer. The most common distributions of particle sizes for sports fields are 14-30 mesh and 10-14 mesh. "Mesh" is a term used to describe size and is equal to the number of holes per inch that the material can pass through. The specifications also generally require removal of virtually all reinforcing fabric and wire in scrap tires. Experience has shown that proper quality control of the ground rubber is critical for proper performance of synthetic turf.

Approximately 3 pounds of ground rubber are generally used per square foot of synthetic turf, depending on the manufacturer, design, and desired surface characteristics. As a result, the estimated 1,000 new fields in North America with an average size of about 7,500 square meters (80,000 square feet) used about 110 million kilograms (240 million pounds) of ground rubber in 2008, but probably less than 90 million kilograms in 2011. This is still one of the largest individual ground rubber markets. Industry participants feel that the market has further potential for growth as technical perceptions are resolved, but short term market direction will depend on availability of capital funding in difficult economic times for many US school districts. Canadian synthetic turf and crumb rubber manufacturers are major participants throughout North America.

Application Benefits and Issues

Virtually any product has advantages and disadvantages, and questions are commonly raised about new products. Synthetic sports turf manufacturers claim their products offer the following advantages versus traditional grass turf:

- *Injury/Health* - Synthetic turf remains consistent under varying weather, use, and maintenance conditions. According to a National Collegiate Athletic Association (NCAA) study that compared injury rates during the 2003-2004 academic year, the injury rate during practice was 4.4 percent on natural turf and 3.5 percent on synthetic turf (Ref. 2). Other studies indicate that frequency of injury is similar for both surfaces, but that the severity of injuries is worse on natural grass turf. There are more head, neural, and ligament injuries on natural grass, while there are more epidural, muscle trauma, and temperature-related injuries on synthetic turf (Refs. 3, 4).

- *Economics* – Synthetic turf's higher initial cost is offset by reduced maintenance associated with water, fertilizer, pesticides, cutting, turf replacement, and manpower. In some cases, budget, knowledge, and the availability of labor may limit proper maintenance of grass fields.

- *Availability* – Traditional turf may not be used for play without sustaining expensive damage when it is wet, limiting use of these facilities. Conversely, synthetic turf drains rapidly, allowing use quickly after heavy downpours. In addition, synthetic turf can reportedly tolerate up to 3,000 hours of use per year, about four times more use than natural turf, allowing the facilities to be used more heavily for different sports.

These factors fueled its early growth. Some questions have also been raised about the synthetic turf system. The following is a brief discussion of major issues and the status or conclusions based on available data.

- *Elevated Turf Temperature* – The particles of black rubber and colored synthetic turf blades absorb light energy and become warmer than ambient temperatures. Limited data shows surface temperatures of 49 ^{o}C to 65 ^{o} C (120^{o} to 150^{o} F) on hot sunny summer days with ambient temperatures of about 35 ^{o} C (95 to 100^{o} F). Other surfaces also tend to exceed ambient temperatures, even cement roadways and light-colored sand on beaches. The New York State Department of Environmental Conservation conducted a study in 2009 indicating that surface temperatures of synthetic turf are warmer than natural grass or sand, but that differences in wet bulb globe temperatures that more accurately reflect actual heat stress were similar, with minimal impact on athletes (Ref. 5). Customer reactions have ranged from no concern to limiting use during peak temperature times or using a water spray to cool the surface before use (Ref. 3). This is less of an issue in Canada's moderate summers than in the southern US.

- *Metals Leaching* – Tire rubber contains zinc, sulfur, and small quantities of other materials that are naturally in the environment at concentrations greater than can be leached by water flowing through rubber (above the water table). These metals are within the vulcanized rubber polymer matrix, but can be leached from the surface by water. Multiple studies indicate that these metals do not represent an acute or chronic health or environmental hazard under conditions likely to be encountered on athletic fields based on established scientific evaluation criteria (Refs. 5 through 11).

- *Organic Chemical Emissions* – Studies indicate that a range of organic compounds may be emitted onto or from the surface of ground rubber particles. Detailed studies conducted in Europe concluded that these materials did not represent a significant hazard to players or spectators in outdoor sports arenas with synthetic sports turf (Refs 11 to 14). Maintaining a minimum air turnover rate within the normal building design range was suggested to limit exposure in indoor sports arenas. These studies were prompted by concerns raised in Europe in 2002. Athletic federations examined the data and decided that the surfaces with ground rubber were suitable for use by their athletes. The issue has been raised again in the northeastern United States and California. Additional reviews of available data have been prepared, generally reaching the same conclusions about safety and environmental concerns. A list of representative studies is provided in the reference section (Refs. 15 to 23). None of these studies indicates that the thousands of surfaces in North America or Europe have caused health problems in athletes or spectators. The State of New York issued its report in May 2009 with structured field tests, confirming the acceptability of this material and surface (Ref. 5). California and the US EPA have recently completed additional studies with similar results.

- *Lead Content* – Limited analysis identified lead within some turf filaments associated with dyes used in early fields. Manufacturers use alternatives without lead, and the levels of lead in limited historical fields has not been identified as an environmental or health risk.

It is difficult to prove a negative. However, the clear preponderance of evidence shows that crumb rubber does not represent a practical health or environmental hazard in synthetic turf installations. A general consensus would require all interested parties to read and understand the data, but the large number of additional fields being constructed each year tends to confirm their acceptability.

Playground Safety Surfaces

Sand, wood chips, and small gravel are commonly used as cushioning materials around playground equipment, but each has limitations. Wood chips deteriorate with time, causing loss of cushioning and requiring frequent addition of more wood chips. Sand and gravel are limited in their ability to absorb impact. The development of scrap tire processing technologies created products suitable for use in three alternative types of playground cushioning surfaces that have been accepted in Canada and the United States.

<u>Description</u>

The three playground cushioning alternatives involving ground rubber in different forms are: (1) loose fill, (2) pour-in-place, and (3) molded tiles. Loose fill, pictured in Exhibit 5, was the first playground safety material derived from scrap tires. It is simply ground rubber about 3/8 inch in size with virtually all of the reinforcing wire removed. Some loose fill is made from fabric-reinforced truck tires or off-road tires to be sure that no wire is present. It is spread under and around playground equipment. A 14-cm (6-inch)-thick layer generally provides protection for falls from critical heights of about 3 m (10 to 12 feet), about double the height for an equivalent thickness of traditional materials. The ground rubber loose fill is normally placed over a substrate that freely drains liquids with a wooden border to keep loose fill from spreading away from the playground area. Tires are black, but loose fill can also be colored before it is installed to improve the aesthetic appearance of the playground.

INSERT EXHIBIT 5 – LOOSE FILL PLAYGROUND INSTALLATION

Pour-in-place installations at playgrounds, shown in Exhibit 6, use a polyurethane binder to bond crumb rubber or buffings from tire retread operations into a protective surface mat 5 to 10 cm (2 to 4 inches) thick. The ground rubber and polyurethane binder are commonly mixed on site in a portable cement mixer and then trowel led into place. A surface layer of colored ethylene-propylene-diene monomer (EPDM) rubber is generally bonded to the ground rubber base to provide distinctive colored surface patterns or pictures. Pour-in-place is normally installed over a hard surface such as asphalt to provide a stable foundation. The installation should be designed and tested to provide fall protection from heights associated with the various types of equipment at the playground.

INSERT EXHIBIT 6 – PLAYGROUND POUR IN PLACE INSTALLATION

Ground rubber can also be molded into thick interlocking tiles specifically designed to provide protection from falls. The tiles, shown in Exhibit 7, are typically ⅓ to ⅔ m (1 to 2 foot) squares and 5 to 10 cm (2 to 4 inches) thick and are commonly glued to a hard sub-base such as asphalt. Each tile is designed and manufactured to provide a durable surface that meets specific cushioning specifications.

INSERT EXHIBIT 7 – PLAYGROUND INTERLOCKING TILES

Current Market Status

All three of these ground rubber products for playground cushioning have been broadly used, but no published market data define the specific quantities of ground rubber used annually for these installations. It is substantial, but not growing rapidly. Many provinces and states have encouraged use of these products through cost-sharing grants, but volumes have been limited outside of these special programs. California, Florida, Kentucky and Illinois are among the states that have aggressively promoted this application. Many Provinces have installations and encourage continuing development.

Loose fill is the least expensive to install. It has been widely used in Florida and Kentucky. The primary cost is the ground rubber itself, plus preparation of the base under the loose fill and the border around the perimeter of the area that will contain the ground rubber. Initial cost is generally more expensive than wood chips, but ground rubber does not degrade, so the annual replacement cost is lower. All loose playground cushioning products must be periodically re-leveled to maintain the desired thickness under and around equipment.

The total installed cost of pour-in-place and tiles are typically four to 10 times more than loose fill because of base preparation, the expense of binders, and labor for installation. Pour-in-place and tiles have been used extensively in California and Florida under grant programs that foster market development, but have seen limited use outside of these programs in the US.

Ground Rubber Requirements

A range of ground rubber particle sizes is used in each of these playground surfaces. Manufacturing appropriate sizes for loose fill is controlled by the need to separate and remove virtually all reinforcing wire from the scrap tire to avoid puncture wounds or injury. It is normally ½ to 1¼ cm (¼ to ½ inch) in size and is sometimes produced from fabric-reinforced truck tires or off-road farm tires that do not contain fine reinforcing wire to minimize potential residual wire in the product. Heavy bead wire around the rim of a tire is removed by debeading equipment before tires are processed or by magnets after processing. The material must be free of particles smaller than 20 mesh to minimize dust generation and small particles that cling to skin and clothes like dirt. Residual fluff from reinforcing fabric in tires is sometimes left in the ground rubber; it may improve resiliency, but it may also decrease the flash point of the mixture and allow it to be ignited by vandals more readily.

Pour-in-place and tiles generally use 3/8 to 1/8 inch ground rubber. In both cases, the fabric is removed to improve the efficiency and effectiveness of the binder, and the wire must be removed to minimize scrapes and cuts. A layer of colored EPDM rubber is commonly added to the ground rubber surface to add color and enhance surface aesthetics. Light colors can decrease light absorption and lower the surface temperature in warm weather.

Application Benefits and Issues

Durability – Rubber is flexible, resilient, and durable, properties that make it a good outdoor cushioning material. Some loose-fill playgrounds have been in place for more than 10 years with minimal need to add more ground rubber to replace lost material. The longevity of pour-in-place and tile surfaces is controlled by the effectiveness of the installation, binder, foundation, and usage, but manufacturers typically project a duration of more than 5 years.

Accessibility – Accessibility of equipment by children in wheelchairs or on crutches can be an important consideration. Loose fill's excellent cushioning characteristics also make it less stable under point loads such as wheel chairs, but some products have reportedly passed tests that demonstrate accessibility. Pour-in-place and tiles have excellent accessibility, so some playgrounds use them for access pathways and around some of each equipment type to assure access. Loose fill is used in other areas to control cost.

Flammability – Tire rubber has a flash point of more than 550° Fahrenheit (higher than dry wood chips) and is not readily ignitable. Fires have occurred in loose-fill installations, but there have been no injuries or environmental damage other than the initial smoke. The CIWMB documented a detailed examination of one playground fire site and found no residual environmental damage (Ref. 26).

Public Health Benefits and Issues

Latex Sensitivity – A small percentage of people are sensitive to latex present in some types of rubber. CIWMB tested for latex sensitivity in styrene-butadiene rubber (SBR) derived from scrap tires as part of its comprehensive review of ground rubber playground surfacing. The testing showed no sensitivity using established testing procedures on SBR and EPDM ground rubber, and no documented cases were found in a literature search (Ref. 22).

Toxicity – Toxicity and environmental questions associated with ground rubber have been raised for playground applications as well as for synthetic turf, with the same general conclusions as previously discussed. CIWMB's detailed report addresses many of these concerns. It identified no issues that would preclude using the superior cushioning characteristics of ground rubber on playground safety surfaces, fully recognizing the benefits of reducing injuries through use of ground rubber. The report is titled "Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products" (Ref 22) and is available on the CIWMB web site at www.ciwmb.ca.gov.

Impact Cushioning – The primary objective of playground safety surfacing is reducing the impact of falls from equipment, and all three of these alternatives can serve this function as well as, or better than, natural materials when properly installed and maintained (Ref. 24). The U.S. Consumer Product Safety Commission has prepared a guide that provides detailed data and discussion of safety parameters for playgrounds, including surfaces. It is available on the web site at www.cpsc.gov/ as Publication 325, titled "Handbook for Public Playground Safety."

MOLDED AND EXTRUDED PRODUCTS

Molded and extruded products are one of the largest applications for crumb rubber, based on market data compiled by CATRA and the Rubber Manufacturers Association (Ref. 1). These products represent 45% percent of crumb rubber usage in Canada in 2009 and 36% in the United States in 2011. It is a diverse market in terms of products and manufacturing technology.

Description

Molded products have been made from buffing dust (rubber particles removed from a tire carcass during retreading) for many years, but the range of products and the size of the markets have expanded significantly in the past 5 to 10 years.

Many initial products were relatively small molded parts such as wheels for trash cans. There are many variations in molding technology, all using a similar basic process. A primary raw material or mixture is pretreated to allow it to flow into a mold, where the material is cured, cooled, and released from the mold to yield a solid designed shape that meets defined specifications. Pretreatment can involve heat, mixing, and additives to create a semi-viscous homogeneous raw material. Once it has been introduced into the mold, temperature, pressure, and reaction time allow the material to solidify. There are also broad variations in degree of automation, balancing capital and labor costs for a specific operating environment. This basic technology has been fully demonstrated with many polymers and rubber materials, including mixtures with ground rubber. Each component of the process requires experimentation to optimize efficiency and product quality. This technology can be labor intensive in its basic form, making products vulnerable to international competition with lower labor costs.

INSERT EXHIBIT 8 – EXAMPLES OF MOLDED PRODUCTS

Some molded products use polyurethanes, sulfur, latex, or other ingredients to bond particulate materials into a desired product, sometimes using pressure and temperature to increase density or optimize efficiency. This technology was initially used on large, low-volume products such as railroad crossing fillers and speed bumps. With improved binders and product creativity, a broad range of higher-volume products have been produced and marketed successfully. Simple welcome mats using bound ground rubber have evolved into attractively designed mats with mass market appeal, becoming a major consumer of ground rubber. Other mats gained acceptance in agricultural, recreational, and building applications. For instance, mats placed in livestock areas have been shown to increase milk production in dairy cattle and enhance weight gain in beef cattle, providing an economic driving force for this large, established market segment in North America. Canadian producers are leaders in this market.

The playground safety tile discussed in the preceding section is an example of a bound product. A newer developing market uses thin sheets of bound ground rubber as carpet cushioning and sound deadening in residential apartments and houses. This product is sometimes made by peeling a thin layer off of a large bound rubber cylinder; efficiently producing a long roll of ½ to 1 cm (¼ to ⅜ inch)-thick rubber matting that is easily transported and installed. It can also be manufactured as sized sheets.

Many binders have been used, but polyurethanes and sulfur are the most common. Sulfur is considered more durable and suitable for ultraviolet (UV) exposure in outdoor applications. Some types of polyurethane are able to tolerate UV, and coloring can be used in these products to shield the polyurethane binder from UV exposure.

Hundreds of products have been made using bound crumb rubber, representing both small and large markets. Some products and processes are simple, while others have necessarily become more sophisticated to meet specifications or to achieve the efficiency required to compete in the marketplace. A good understanding of existing products, performance requirements, processing technology, and economics is critical to developing these applications successfully. It typically takes a committed effort over a period of time to be successful.

Long items such as hoses, weather stripping, tubes, molding, and belting are commonly made by extrusion processes. There are also many variations of this technology, but it normally involves using a screw system to mix, heat, and force a raw material through a die to produce a continuous shape. This process is sensitive to multiple parameters and requires fine mesh ground rubber (30 to 200 mesh). Any residual wire or fiber can accelerate wear or damage extrusion heads and equipment. Extrusion has the greatest applicability to blends of ground rubber with plastics or virgin rubber and is not widely used in conjunction with ground rubber. Plastic and rubber wood-substitute products are one example of an extruded product.

Ground Rubber Requirements

Crumb rubber specifications for this market segment depend on the process, product, and economics. Desired product characteristics control the particle size requirements for ground rubber used in these applications. Larger particle size reduces binder requirements and retains the characteristics of rubber, but necessarily has less bonding strength and coarser surface texture. Playground safety tiles are an example of an appropriate use of ¼-inch ground rubber. Finer particles (10 to 40 mesh) require more binder, with its associated strength, and yield a smoother surface that can approach virgin materials. Wheels and mud flaps are two examples of products that require finer particles.

Economics also play a role in rubber selection. The cost of crumb rubber generally increases with decreasing particle size, and binders are generally much more expensive than the ground rubber. As a result, products made with finer rubber and more binder generally are more expensive. Ultimately, the product must compete cost-effectively in the market to be successful.

Application Benefits and Issues

Low-Cost Raw Material – Ground rubber can be a low-cost raw material with many of the intrinsic performance properties of rubber. The creativity and technology applied to its use have increased market diversity and volumes, and this trend is expected to continue as costs of virgin raw material escalate.

Displacement Challenges – Making any new product can involve substantial investment in processing technology, equipment, optimization, product testing, distribution, and marketing. All require time and resources that are often underestimated. Incorporating ground rubber into an existing formulation can pose similar challenges, especially in process optimization and product testing.

Mixtures – Rubber generally functions as filler in mixtures with plastics. Thermoset rubber and thermoplastics do not naturally bond, resulting in significant changes in the performance characteristics of plastics when rubber is added. Impact resistance normally increases, but other critical properties such as tensile strength and elongation decrease significantly, thereby decreasing the strength of the resulting product. Broader applicability of these mixtures hinges on identification of products where impact resistance dominates other performance requirements or on development of economically viable rubber surface modification technology that will allow the materials to bond. Extensive research has been devoted to this subject with some success in reducing property deterioration, but the resulting products have rarely competed successfully with alternative virgin materials. Increasing cost of hydrocarbon-based polymers and virgin rubber may provide additional incentive to further develop this technology or for manufacturers to tolerate moderately reduced performance.

RUBBER MODIFIED ASPHALT

Rubber modified asphalt (RMA) technology was initially developed more than 30 years ago. It has been actively promoted for at least the past 20 years, and has continued to evolve. The initial patents have expired, and this technology is now commonly referred to as the Arizona Process because of its extensive use within Arizona. Variations have been developed in an effort to address perceived obstacles or improve performance. In each case, rubber is mixed with the asphalt binder, then the asphalt binder is mixed with the aggregate and spread on the roadway to form asphalt pavement. This technique is known generically as the wet process because rubber is mixed with the asphalt binder first.

INSERT EXHIBIT 9 – RMA ROADWAY, CONTRASTING TO REGULAR IF POSSIBLE

Description

The following is a brief description of the three major RMA technologies:

Arizona Process

The Arizona process involves mixing and reacting rubber with asphalt binder in specialized equipment at the paving site. Ground rubber normally represents about 20 percent of the asphalt binder mix, significantly increasing the viscosity of the binder. Greater viscosity allows a higher concentration of binder to be used in the asphalt mix, resulting in a stronger and more durable pavement. Use of rubber, more asphalt binder, and specialized on-site blending equipment increases unit cost/ton of asphalt 25 to 100 percent above traditional asphalt, depending on location, job size, and other job-specific criteria. In some cases, increased pavement strength has allowed thinner RMA overlays to demonstrate life comparable to thicker traditional asphalt, so that the installed cost of RMA is comparable.

Terminal Blending

Terminal blending involves blending rubber into the asphalt binder in a mixing tank at the asphalt supply terminal, then transporting it to the job site, thereby reducing the need for specialized equipment at the site. Rubber usage levels are specified to meet design performance characteristics for the pavement. This technology has been used for 15 years in Florida with a good performance history. Florida was the only state to specify RMA for friction course replacement on most state-maintained, high-traffic roads, including interstate highways. The technology is gradually being used more widely in other states such as California because of its lower cost.

Rubber/Polymer Blends

Styrene-butadiene-styrene (SBS) block copolymers are also used as additives in asphalt to improve performance, but proponents believe that addition of a combination of both the SBS block copolymer and rubber to the asphalt enhances the performance more than either material can when they are added separately. This technology has been broadly applied in Texas and other states by using variations of the compounds, depending on the geographic area of application. The Florida Department of Transportation (DOT) has conducted a comprehensive evaluation of several polymer/rubber technologies compared with traditional asphalt. The technology uses a low percentage of rubber to partially displace normal polymer addition levels. This technology is the newest, but it is developing a substantial experience and testing base.

The availability of rubber, polymer, and rubber/polymer blend technology is also playing a role in development of pavement design alternatives that can reduce road noise levels and improve the safety of highways. This is accomplished through use of open-graded friction course (OGFC) pavement using large, uniformly graded aggregate. Rainwater flows through the resulting top layer of pavement (the friction coarse) and out to the sides of the roadway, reducing hydroplaning and enhancing driver visibility by reducing water spray from the vehicle tires. The open structure also creates an acoustic surface that absorbs and deflects some sound and reduces road noise for nearby residents. Experiments are under way to determine if the noise reduction levels will allow long-term use of this pavement as an alternative to expensive and unattractive noise barriers along highways through populated areas. Arizona and California are actively using this material, and other states such as Texas are using OGFC for safety reasons on historically dangerous roads. Enhanced binders play a critical role in allowing OGFC to maintain its long-term integrity, and rubber contributes to sound reduction. Experience with rubber and/or polymer modified OGFC in cold climates is limited.

Current Market Status

RMA is the third-largest application for ground rubber in the United States, representing 18 percent of the ground rubber market or about 2 percent of the annual scrap tire generation in 2011, according to the Rubber Manufacturers Association (Ref. 1). More than 90 percent of the RMA is currently used in Arizona, Florida, Texas, California, and South Carolina. Many other states have conducted trial programs, but their use of RMA remains small. In addition, the Provinces of Alberta and Ontario have conducted thorough test programs, and others have had limited trial installations. Still, total use of crumb rubber in this application has fluctuated but not grown significantly in the past 5 to 10 years. Reduced paving and cost consciousness caused by DOT budget constraints have contributed to limited growth in the US.

Ground Rubber Requirements

Each provincial and state DOT has established its own ground rubber specifications for rubber modified asphalt, with variations for alternative applications. The Arizona process typically uses 16-30 mesh ground rubber with low limits for residual wire and fiber. Terminal blending in Florida initially used fine-mesh (minus 80 mesh) ground rubber, but found that minus 40 mesh performed well with lower cost and better availability. Polymer/rubber blends vary widely, with some technologies pre-treating the rubber to enhance its reactivity in the asphalt.

Application Benefits and Issues

Performance – Roads using the Arizona and terminal blend processes have been documented to last longer than traditional asphalt, sometimes dramatically longer, but this performance has not been universal. Poor performance has been attributed to improper installation, weather conditions, bed preparation, and aggregate grading. Florida found that RMA performed well, but that polymers out-performed terminal-blended RMA for some high-traffic applications. This finding prompted interim modification of specifications to allow use of polymers and initiated Florida's previously referenced research into polymer/rubber blends. Tests in Alberta found variations in performance, some probably attributable to the initial learning curve.

Cost – The installed cost of an equivalent thickness of RMA is generally 10 to 100 percent higher than unmodified asphalt, as previously discussed. Since DOT budgets are fixed, higher cost forces less paving and can cause short-term problems even if it has long-term benefits. Use of thinner RMA lifts can turn a cost disadvantage into an advantage where applicable and accepted.

Cost Justification – As the public becomes more aware of the safety and noise advantages of OGFC, the cost comparison should appropriately be broadened to include other avoided costs such as accidents and sound barriers. In that case, the comparison is not with traditional asphalt, but instead is with alternative OGFC mixes, and RMA is a proven material in these applications.

Ground Rubber Quality – The quality of the ground rubber is a critical performance factor in RMA. Ground rubber processors must recognize and consistently meet applicable product specifications. Failure to do so places the pavement at risk and alienates DOT and its installation contractor.

OTHER MARKETS

There are many smaller markets for ground rubber. Some are variations of the major markets discussed above, while others are unique niche products, and a few offer significant potential for growth. The following is a brief discussion of some of these products:

Horse Arena Cushioning

A variation of loose fill used as playground safety cushioning, ground rubber serves a similar function in horse arenas. It provides similar protection for horses and riders during practices and exhibitions. It also reportedly enhances footing and reduces stress on the horse's legs and joints. The material must meet defined specifications to balance sure footing with impact safety. This is a small, useful, and stable market.

INSERT EXHIBIT10 – HORSE ARENA

Animal Mats

Coarse ground rubber is used as filler in fabric mattresses that provide an alternative to the molded and bonded products discussed earlier. They are used primarily in the dairy industry to reduce leg injury, enhance comfort, and provide protection for utters of milking cows, which can increase milk production. Research has shown that rubber-filled mattresses last longer, as they do not compress as quickly and they are preferred in extreme temperatures (Ref. 26).

INSERT EXHIBIT 11 – ANIMAL MATS

Colored Mulch

Wood mulch is commonly spread around plants and flower beds to retain moisture, control weeds, and enhance beauty of the beds. However, mulch decomposes, harbors insects, and requires frequent replacement. Initial experimentation with black tire chips found that they controlled weeds much like wood chips and stayed in place, but the black color absorbed heat and had limited aesthetic appeal. Extensive experimentation led to relatively simple methods to color chips with paint that adheres and resists fading to assure warranted performance for 5 years or more.

INSERT EXHIBIT 12 – COLORED MULCH INSTALLATION

Today's colored mulch is 3/8 inch to 1 inch chips made from scrap tires with 99 percent of the reinforcing wire removed. It is manufactured in many pleasing colors to simulate wood chips or to provide coordinating and contrasting colors. It has been shown to control weeds, resist mold, retain moisture, and require infrequent addition. As added benefits, it does not harbor insects or attract neighborhood animals.

Some issues have been raised about the use of colored mulch, as discussed below:

Flammability – Limited tests have shown that colored mulch has an ignition temperature above 550 degrees, so flammability is comparable to dry wood chips.

Temperature – Black ground rubber particles
absorb light and can heat up. Coloring decreases energy absorption and reduces the temperature increase.

Zinc Leaching – Tire rubber contains about 1.5 percent zinc as a vulcanization accelerator within the rubber polymer matrix. Water can gradually leach small amounts of zinc from the chip into the underlying soil. Traces of zinc serve as a micronutrient for many species, but excessive quantities can have a negative impact on some plants and grasses. Leaching is slow and controlled with water flowing through chips on the surface of beds, but it could be accelerated by continuous submersion in water or soil. Therefore, colored mulch should be kept on the bed surface and not mixed with soil. Coloring limits chip surface exposure to moisture and further reduces possible leaching.

Rubber mulch was initially sold in small quantities through nurseries, landscapers, and specialty shops. However, it has become an established product with increasing representation in major high-volume retailers throughout North America.

TIRE DERIVED AGGREGATE

Perspective

A broad range of civil engineering applications use substantial quantities of tire derived aggregate in Canada and the United States. It represents the third largest market in Canada (behind crumb rubber and molded products), using 68,775 tonnes or 18% of generation in 2009. In the US, it is also the third largest market (behind TDF and crumb rubber), using 18 million tires and 6% of generation in 2011.

Characteristics

Tire derived aggregate (TDA) is a term coined by Dr. Dana Humphrey, Dean of the School of Engineering at the University of Maine and a major contributor to the development of TDA applications and data. His objective was appropriate recognition of shredded tires as an engineered product made by cutting scrap tires into 25- to 300-millimeter (mm) pieces. TDA has unique properties that make it suitable for use in a wide range of geotechnical challenges, including:

Light Weight: Approximately 50 pounds per cubic foot or 0.8 macrograms per cubic meter, a fraction of the weight of traditional aggregate materials. TDA has been used as an economical light weight fill in highway embankments in 13 states and most recently in New Brunswick, Canada.

Compressibility: Produces low lateral pressures on walls (as little as one-half that of soil) and has demonstrated vibration absorption properties for use under urban rail tracks and new light rail systems.

Low thermal conductivity: TDA transmits heat or cold poorly, making it a good thermal insulator (up to eight times better than soil), and allowing it to retard frost penetration in road bases or around home foundations.

High permeability: Permeability of 1 centimeter per second allows liquids and gases to pass through TDA rapidly, making it an effective drainage medium under roadways, along highway edge drains, around house foundations, in French drains, in septic system drain fields and in landfill drainage and gas collection systems.

Good shear strength: Enhances strength and stability when placed in large applications like roadway embankments, and absorbs vibrations.

When used in appropriate applications, TDA's special properties can greatly reduce construction costs. Guidelines and construction specifications are available to help engineers take advantage of the special engineering properties of TDA. Most important of these is ASTM International Standard D6270-98 (Ref. 3), Standard Practice for Civil Engineering Applications of Scrap Tires (http://www.astm.org/Standards/D6270.htm). This document lists the typical geotechnical properties of TDA, applicable test methods, and construction guidelines.

Example Applications

TDA can be used as a substitute for conventional drainage aggregate for a wide range of applications. This material is advantageous when conventional aggregate is more expensive or is unavailable. Potential drainage applications include:

- Drainage layers within landfill leachate collection and removal systems.
- Permeable aggregate for landfill gas collection layers and trenches.
- Free draining aggregate for edge drains for roadways.
- Permeable backfill for below-grade exterior walls.
- Septic system drain fields.

In addition, TDA is used in lightweight fill applications where its low density offers significant economic advantage, such as:

Lightweight fill over unstable underlying soils, particularly in coastal and basin areas

Stabilization of landslide areas

Retaining wall backfill where TDA offers light weight, good drainage, low lateral pressure

INSERT EXHIBIT 13 - PICTURES OF TDA INSTALLATIONS AS APPROPRIATE, USING CANADIAN EXAMPLES AS MUCH AS POSSIBLE

Perspective and Issues

Economic Applicability: TDA has been economically used for a wide range of applications in Canada and the United States. The economics of using TDA depend on the local cost of TDA and competing alternative construction materials. TDA is generally cost competitive for projects that require use of lightweight fill material for embankment construction. It can offer economic advantages in applications using its thermal insulating and vibration dampening properties. TDA can also be cost-effective in drainage applications where the supply of conventional drainage aggregate is limited. TDA is not, however, a generally cost-effective substitute for conventional earth fill. Such usage is sometimes represented as a constructive use, but is more accurately just lineal landfill disposal.

Stockpile Requirements: Many civil engineering projects require large quantities of TDA for placement in a short period of time, so the material has to be stockpiled at the processor or construction site prior to use. Since TDA can be ignited, storage should follow International Fire Code and/or local Fire Marshall requirements to minimize the probability and environmental consequences of any such event. Since most construction is seasonal, storage can be for extended periods. Project delays and cancellations can further compound storage concerns. Firm project commitments prior to TDA production and proper storage design can minimize these concerns.

Leaching of metals and organic materials contained in TDA: TDA contains metals such as iron and manganese in reinforcing wire and zinc within the polymer rubber matrix. All of these metals occur naturally in soil, often at levels greater than in tires. Exposed wire can dissolve in time, gradually introducing these materials into the surrounding soil. Zinc and organics are less prone to leaching in large TDA particles because they are contained within the rubber itself and do not readily migrate to the surface under normal environmental conditions. Several studies have also shown that TDA has negligible impact on groundwater (see for example Refs). A statistical analysis of the effect of TDA on groundwater is presented in Humphrey and Swett (Ref.). Many states limit TDA applications to above the mean water table to further control leaching potential. Florida also limits septic drain field applications to residential systems to avoid extreme pH conditions that could increase leaching in some commercial systems.

Auto-ignition: Deep piles of compacted tire shreds have auto-ignited during storage and use in some roadway construction. The mechanism is not fully identified but most examples have had the following common characteristics: (a) deep piles in excess of 12 feet (b) compaction by movement of heavy equipment on top of the pile (c) exposure to wet conditions (d) presence of contamination or fines within some piles (e) concentrated areas containing wire or fluff in some piles. As a result, proper storage and use of TDF avoids these common characteristics by limiting depth to 12 feet or less, avoiding compaction in storage piles, assuring water drainage from pile areas, and preventing contamination with wire, fluff, fuel or fines. Design criteria are discussed in more detail in the previously referenced ASTM Standard for Civil Engineering Applications.

Cash flow; Year round production and seasonal sales of TDA products require substantial inventory accumulation that can increase working capital requirements. Cash flow variations can impact business plans.

General Conclusion

TDA has a well developed design data base and broad proven applicability in civil engineering applications. There are established procedures for avoiding and/or controlling a limited number of potential concerns. TDA can be economically viable, especially in appropriate applications that utilize the economic advantages offered by its unique performance characteristics.

ALTERNATIVE ENERGY RESOURCE

Perspective

Scrap tires have been used as a supplemental energy resource in Japan, Europe and the United States since the 1970s, and is the largest application in most of these countries. It was the cornerstone of initial market development in many waste tire management programs, and remains an important component even as efforts have continued to develop higher value uses.

Tire-derived fuel has played an important transitional role in a number of provinces by constructively consuming large quantities from stockpile abatement activities, as well as providing an alternative while other markets are developed or experience downturns. According to CATRA, about 33,875 tonnes of Canadian waste tires were used as tire derived fuel (TDF) in 2009, representing 9% of annual generation. In contrast, about 153 million tires or 50% of annual generation were used as TDF in the US in 2011. The shear volume of scrap tires generated annually in the US forces broad market diversification to maximize constructive utilization that could not be achieved without substantial TDF markets.

Characteristics

The chemical characteristics of any energy resource affect its technical and environmental performance. Tires are a hydrocarbon-based material derived from oil and natural gas. Some inorganic materials are added to enhance vulcanization reactions or performance properties such as flexibility and ultraviolet light resistance. Tires have a heat content of 7,800 to 8,600 kcal/kg, depending on the type of tire and degree of reinforcing wire removal. By comparison, coal that may be displaced by use of tires typically contains 5,550 to 7,200 kcal/kg.

The composition of tires and coal vary depending on type and source. However, Exhibit 14 provides representative proximate and ultimate analyses of tire-derived fuel (TDF) with about 90% of the reinforcing wire removed, a northeastern bituminous coal and a western sub bituminous coal used to generate steam. Proximate analysis defines basic combustion characteristics. Ultimate analysis defines elemental composition.

EXHIBIT 14
COMPARATIVE CHEMICAL CHARACTERISTICS

CHARACTERISTIC	BITUMINOUS COAL-NORTHEASTERN US	TDF (90+% WIRE REMOVED)	SUBBITUMINOUS COAL-WESTERN US
MOISTURE (% AS RECEIVED)	10.43	0.62	24.68
HEATING VALUE (BTU/POUND, AS RECEIVED)	10,641	15,404	9,287
PROXIMATE ANALYSIS (%, DRY BASIS)			
ASH	16.16	4.81	6.37
VOLATILE CARBON	38.14	67.06	44.43
FIXED CARBON	45.70	28.13	49.20
TOTAL	100.00	100.00	100.00
ULTIMATE ANALYSIS (%, DRY BASIS)			
CARBON	65.49	83.79	70.73
HYDROGEN	4.56	7.13	4.85
NITROGEN	1.11	0.24	0.84
SULFUR	4.52	1.84	0.41
ASH	16.16	4.81	6.37
OXYGEN (by difference)	8.16	2.18	16.80
TOTAL	100.00	100.00	100.00
ULTIMATE ANALYSIS EXPRESSED AS POUNDS/MILLION BTU			
CARBON	55.13	54.05	57.36
HYDROGEN	3.84	4.60	3.93
NITROGEN	0.93	0.16	0.68
SULFUR	3.81	1.19	0.33
ASH	13.61	3.12	5.17
OXYGEN (by difference)	6.87	1.42	13.62
SUBTOTAL	84.19	64.54	81.09
MOISTURE	9.80	0.40	24.68
TOTAL	93.99	64.94	105.77

A comparison of the proximate analyses indicates that tires offer efficiency advantages versus coal. For instance, tires generally have lower moisture content than coal. Since energy required to heat and vaporize water is generally non-recoverable in the energy conversion process, lower moisture content can translate into higher combustion efficiency. Lower ash content of TDF (without wire) offers a similar advantage versus coal, and can decrease ash disposal costs. A tire's higher volatile-to-fixed carbon ratio enhances its ability to combust rapidly and completely. TDF's advantages become commanding when compared to some of the high-ash, low-BTU coal and lignite. Based on proximate analysis, tires compare favorably to coal as an energy source.

Based on ultimate analysis, tires offer some additional advantages and disadvantages. When compared to many eastern coals, TDF's lower sulfur content (especially in terms of kilograms/kilojoule) offers the potential advantage of decreasing emissions of sulfur oxide compounds referred to as SOx. However, many western coals have lower sulfur content, so SOx must be controlled within these systems to prevent an increase with TDF.

Combustion systems burn less of a high-energy fuel to obtain the same amount of energy, so expressing the ultimate analysis as pounds per unit of energy (kilojoule) identifies some other important environmental factors. Combustion of TDF generates less carbon per kilojoule than either coal cited in Exhibit 3. Since carbon converts to the greenhouse gas carbon dioxide during combustion, TDF reduces emissions of carbon dioxide compared with these coals. TDF also has higher hydrogen content. When hydrogen combines with oxygen during combustion, it releases energy and forms water (H_2O) with no greenhouse gas. Therefore, TDF's lower carbon and higher hydrogen content on an energy basis results in lower greenhouse gas generation. In addition, TDF's lower nitrogen content can marginally decrease emissions of nitrogen oxide compounds called NOx.

Tires generally contain metal concentrations comparable to, or lower than, coal with one notable exception. Zinc is added to tires as part of the rubber vulcanization process at levels approaching 1.0 - 1.5% by weight. Therefore, zinc levels in tires are much higher than coal. Applications using tires as an energy resource must be able to control zinc emissions to avoid a negative environmental impact. Common air pollution control equipment such as electrostatic precipitators and baghouses effectively control zinc oxide emissions from TDF combustion.

From a chemical standpoint, tires offer both environmental advantages and disadvantages versus coal. Therefore, tires can provide a valuable and environmentally-friendly energy resource when used in applications that draw on their advantages and properly control their disadvantages.

Applicability

Whole or shredded tires can be used as an energy resource. Examples of facilities that have demonstrated their ability to use TDF in compliance with all applicable regulations include the following:

Cement Manufacturing Kilns - Cement manufacturing consumes massive amounts of energy to heat a complex mixture of raw materials to over 1400 degrees Centigrade. Whole or shredded tires can be injected into the cement process at several points to increase energy efficiency and decrease NOx generation. Tires have been used successfully in all major variations of cement manufacturing processes. Reinforcing wire in tires provides a raw material required in cement, thereby reducing iron purchases by the cement company.

Some Power Generation Plants – TDF has demonstrated its environmental and technical performance in fluidized bed, cyclone and some stoker-fired power boilers, generally displacing coal usage. These boilers have combustion conditions conducive to complete combustion of economically-produced TDF particle sizes.

Some Paper Mills - Paper mills often combust bark, sawdust and other wood wastes to generate steam and power required for paper production. Wood absorbs moisture during rainy periods and can be difficult to combust fully. The high energy content of TDF serves as an octane booster to enhance boiler performance and complete combustion. TDF generally displaces supplemental fossil fuel usage, often oil, coal or natural gas.

All suitable facilities have the following characteristics:

Solid Fuel – Tires can be used whole in some applications like cement kilns. Others require tires to be shredded into smaller chips called tire-derived fuel (TDF), with reinforcing bead and cord wire removed if necessary. Regardless of particle size, tires remain a solid fuel, so applicable systems must be able to receive and combust solid fuel to be a candidate for TDF use. However, the energy from TDF can replace higher-cost oil and gas in some cases where oil, gas, and solid fuels are co-fired in the same furnace.

Complete Combustion – Appropriate applications must have a combination of air/fuel residence time, combustion temperature profile and air turbulence to assure complete combustion.

Emissions Control – Appropriate facilities must have emissions systems capable of controlling any changes in SOx and particulate within environmentally sound permit limits.

Perceptions and Issues

Evaluation of TDF for specific applications involves consideration of the following technical, environmental, economic, perception and policy issues:

Technical Issues – Many technical issues must be evaluated to assess the suitability of using TDF in specific applications, including fuel handling, combustion conditions, ash handling/disposal and emissions control capabilities. In general, most cement manufacturing facilities, some specific types of power plants (most circulating fluidized bed boilers, some cyclone-fired power boilers) and some wood burning stoker-fired boilers in paper mills are worthy of consideration.

Operational Consistency – Operational consistency is a critical parameter in controlled combustion, so TDF is normally metered into the combustion unit by a suitably designed and demonstrated metering unit. The unit is electronically tied to the boiler control room and boiler controls to assure proper operation.

Environmental Factors – In appropriate applications, many emissions parameters are monitored and tested. Some decrease or increase marginally with TDF usage, but the overall impact is not significant and remains within established permit limits. This performance has been demonstrated by over 20 years of usage involving over 100 facilities in the US and Canada. Any new applications must be confirmed by performance testing and continuous monitoring of major environmental parameters. TDF should only be used in facilities capable of maintaining environmental performance in compliance with all applicable regulations and permits. As previously discussed, TDF can actually result in reduced green house gas generation versus displaced coal.

Economic Considerations – TDF substitution for traditional fossil fuels generally results in significant savings, enhancing the economic viability of some facilities in today's globally competitive market and contributing to job preservation at these facilities.

Public Perception – Tire stockpile fires generate massive amounts of dense black smoke and noxious fumes from incomplete combustion due to oxygen starvation at the surface of the fire. This uncontrolled combustion is totally different from carefully controlled combustion in industrial applications. Industrial applications are designed, controlled and monitored to achieve complete combustion and controlled emissions. In the absence of technical understanding, some people maintain the perception that TDF use will result in black smoke and dangerous emissions.

Policy - Many provinces have defined policies prohibiting combustion of waste materials, including tires. This policy forces wastes into higher value markets and sometimes into even lower value markets than energy utilization. Some provinces have chosen to evaluate potential markets based on program needs, allowing TDF to absorb stockpile abatement tires or incremental generation while higher value markets are developed. It avoids low value uses like daily cover and soil substitution where TDA offers no technical advantage.

High Value Market Transition - One driving force behind a policy prohibiting TDF combustion is the perception that other markets will not be developed if TDF is allowed. However, economics dictate that scrap tires flow from TDF and civil engineering markets as higher value markets are developed. Higher revenue draws tires to higher value products naturally. This has been proven repeatedly in practice.

Pyrolysis

Pyrolysis is, by definition, thermal decomposition of organic compounds in an oxygen-limited environment. Promoters have called their pyrolysis processes thermal distillation, destructive distillation and many other names to avoid identification with pyrolysis.

Pyrolysis of waste tires typically generates gas, oil, and char products. The quantity and quality of each product depend upon many process variables including temperature, pressure and residence time. Twenty to thirty-five percent of a tire's energy content is typically converted into a combustible gas that is used to fuel the pyrolysis process or is combusted in a flare prior to release. Thirty-five to fifty percent of the output from the process is transformed into an oil product that varies in quality from saleable fuel oil to lower-value oil blend stock. The residual solid product referred to as char) constitutes 25-40 percent and contains a mixture of the following materials:

(1) multiple types of carbon black used in various sections of a tire for strength, wear or other critical performance properties;
(2) titanium dioxide from white sidewalls and lettering;
(3) zinc dispersed uniformly within tires as a vulcanization accelerator;
(4) steel from bead and radial reinforcement wire
(5) other inorganic chemicals.

Historical Experience

Pyrolysis is not a new process. It was developed in Europe over 60 years ago to transform coal into gas for street lamps. Over the past twenty-five years, many processes, equipment and operating variations have been applied to scrap tires. A U.S. Department of Energy publication entitled "Scrap Tires: A Resource and Technology Evaluation of Tire Pyrolysis and Other Selected Alternate Technologies" identified 31 pyrolysis projects in 1991 utilizing fluidized beds, traveling grate chambers, rotary kilns, retorts, molten salt and hot oil baths, plasma arc units and microwave chambers as reactors. Various operating conditions have been extensively explored to optimize production and quality of product streams. In spite of this extensive developmental effort, no commercial-scale pyrolysis systems currently operate continuously in North America.

Extensive technical and economic resources (an estimated $250 million) have been invested in projects developed by major companies such as Goodyear/Tosco (The Oil Shale Co.), Firestone, Occidental, Uniroyal, Nippon and Foster-Wheeler. In addition, many pilot or "demonstration" projects have been developed by smaller companies and entrepreneurs. One major project developed by Foster-Wheeler in England (called Tyrolysis) failed technically and economically after expenditures exceeding $30 million.

Major reasons for failure of pyrolysis projects have included the following:

(1) Operating Problems: Utilizing complex equipment at high temperatures with an abrasive feedstock such as scrap tires is generally maintenance-intensive. Downtime and maintenance expenses have often been under-estimated in projections of total project costs.

(2) Safety: Operating in an oxygen-limited, high-temperature environment creates the possibility of fires or explosions if air enters the system accidentally. Such accidents have destroyed or damaged numerous pyrolysis facilities, including complete destruction of the $6 million Intenco operation in Texas.

(3) Feed Availability and Processing: The size required for economic feasibility can require more tires than are available within an economical delivery area at projected net tipping fees. In addition, capital and operating costs associated with shredding or feed preparation have often been under-estimated.

(4) Product Quality: It is difficult to optimize quality and yields of three inter-related product streams (gas, oil, and char) since conditions favoring one often have a negative impact on another. Due to the mixture of carbon blacks and other constituents, the char has historically only been suitable for low value applications with limited market volumes, even when the char is further processed to control size uniformity and iron content.

(5) Environmental Impact: Tires contain about 1.8 percent sulfur and 1.2 - 1.5 percent zinc, by weight. These inorganic materials are not destroyed or decomposed thermally, so they remain in one or more of

the pyrolysis products as dictated by an elemental mass balance for specific operating conditions. In addition, partially decomposed hydrocarbons may not be fully removed from the exhaust gas stream by condensation or combustion. As a result, pyrolysis systems must have air pollution control systems to prevent discharges to the environment. Pyrolysis promoters often claim that their process has no emissions because all materials are captured as products. However, the gas product is generally combusted to fuel the process or flared on-site because it cannot be transferred in normal gas transmission lines. In either case, combustion creates emissions that require controls to comply with clean air standards in the U.S... In addition, the char product may require disposal as a hazardous waste if it is not marketable. These practically realities should be reflected in capital and operating cost projections, but rarely are.

(6) Economics: The economic feasibility of pyrolysis is dependent upon many operating factors such as system reliability, capital and labor costs, process, feedstock preparation expense, environmental control requirements and product revenue. Past operations have not been economically sustainable at reasonable tipping fees because they have not been able to develop high-value (greater than 1.5 pesos or $0.15 per pound) markets for all of the char generated. The materials recovery appeal and economic viability of this process is totally dependent upon high-value application of the carbon black content of the char stream. Unless this objective is accomplished, pyrolysis simply becomes a capital-intensive process for conversion of a solid fuel into a low-grade liquid fuel, while wasting up to 70% of its initial energy content.

Current Practice

There are many companies promoting pyrolysis systems within North America. None of these technologies have been practiced on a commercial scale for an adequate period of time to fully demonstrate long-term operating economics and char marketability. Most of these companies, like the many failures before them, claim technical improvements that overcome historical failures.

Some proponents identify multiple processing steps intended to improve particle size uniformity of the char product. However, the pyrolytic char does not retain the structural reinforcing properties of virgin carbon blacks used in tires and other performance applications. Size reduction and particle size classification will not restore these critical properties. High metals content and residual organics from decomposition of rubber polymers further limit potential markets for the char product. Historical experience dictates that actual markets should be specifically defined and supported by verifiable contractual commitments prior to any future investment in "commercial" pyrolysis technologies.

SUMMARY

Scrap tires have achieved a high rate of constructive utilization due to a broad range of applications that utilize the physical and chemical characteristics of tires. Development of new products and applications can raise questions, and these questions have been explored extensively to assure protection of health and the environment. All Canadian Provinces have instituted comprehensive scrap tire management programs to assist in developing and understanding constructive applications for the valuable resource represented by scrap tires. Canada has been a North American leader in developing high value applications.

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