Contractor's Report to the Board

Designing Building Products Made With Recycled Tires

June 2004

Produced under contract by:
Chris Hammer,
The Elements Division of
BNIM Architects
Terry A. Gray, T. A. G.
Resource Recovery

ELEMENTS

INTEGRATED WASTE MANAGEMENT BOARD

Zero Waste—You Make It Happen!

STATE OF CALIFORNIA

Arnold Schwarzenegger
Governor

Terry Tamminen
Secretary, California Environmental Protection Agency

•

INTEGRATED WASTE MANAGEMENT BOARD

Linda Moulton-Patterson
Board Chair

Rosario Marin
Board Member

Rosalie Mulé
Board Member

Michael Paparian
Board Member

Cheryl Peace
Board Member

Carl Washington
Board Member

•

Mark Leary
Executive Director

For additional copies of this publication, contact:

Integrated Waste Management Board
Public Affairs Office, Publications Clearinghouse (MS–6)
1001 I Street
P.O. Box 4025
Sacramento, CA 95812-4025
www.ciwmb.ca.gov/Publications/
1-800-CA-WASTE (California only) or (916) 341-6306

Publication #433-04-008
Printed on recycled paper containing a minimum of 30 percent postconsumer fiber.

Prepared as part of contract no. IWM-2013 (total contract amount $200,000, includes other services)

The California Integrated Waste Management Board (CIWMB) does not discriminate on the basis of disability in access to its programs. CIWMB publications are available in accessible formats upon request by calling the Public Affairs Office at (916) 341-6300. Persons with hearing impairments can reach the CIWMB through the California Relay Service, 1-800-735-2929.

The energy challenge facing California is real.
Every Californian needs to take immediate action to reduce energy consumption. For a list of simple ways you can reduce demand and cut your energy costs, **Flex Your Power** and visit ***www.fypower.com/*.**

Table of Contents

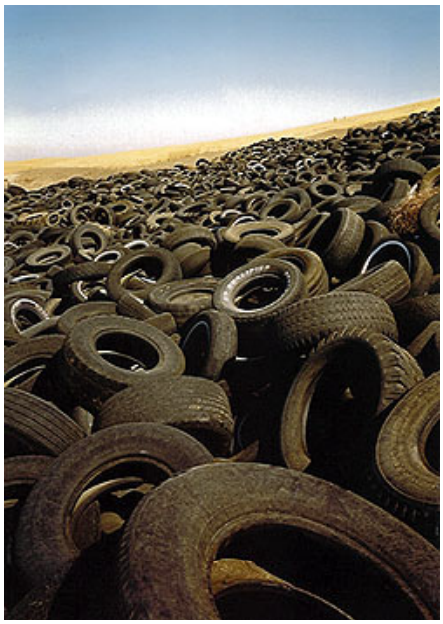
Introduction

The purpose of this paper is to provide resources for designers creating new building or landscape products made of whole tires or shredded tires. This paper provides information on the physical and technical characteristics of the raw materials designers will be working with. It also tries to alert designers to the challenges they will face in working with the unique properties of tires, tire shreds, and crumb rubber. Fortunately the tire industry and federal and state governments have been working at least 15 years to divert tires from landfills, so there are many organizations and publications dedicated to this effort. See the Tire Resources section on page 18 for a list of some additional resources.

Californians generated approximately 33.5 million waste tires in 2002, according to a report by the California Integrated Waste Management Board (CIWMB) entitled *California Waste Tire Generation, Markets and Disposal*.[1] Since the 1989 California Tire Recycling Act was enacted, the CIWMB has been working to enhance constructive utilization of this resource and reduce the detrimental impact associated with its improper disposal.[2]

About three-quarters of California's tires, or 25.1 million tires, were diverted to constructive uses in 2002, but 8.4 million tires were not.[3] These tires were shredded and disposed of in California's permitted solid waste landfills, stored at permitted sites, or otherwise illegally disposed of around the state. While the majority of tires are reused, a significant amount, one-quarter, are not. New uses must be found for the valuable raw materials embodied in whole tires and tire shreds.

Product designers have a unique role in creating a valuable product from a resource many would see as waste. Many products are made from old tires, and even more can be developed.



Source: Earthship Biotecture, Taos, N.M. Used by permission.

Market Overview

California's 25.1 million diverted tires, plus 1.5 million imported into California from neighboring states by processors, were used in the following markets:[4]

- Civil engineering, including landfill construction, and daily cover (8.9 million, or 33 percent).
- Tire-derived fuel (6.1 million, or 23 percent).
- Crumb rubber manufacturing (5.8 million, or 22 percent).
- Retreading and reuse (3.8 million, or 14 percent).
- Export (2 million, or 8 percent).

Civil engineering applications typically use large tire chunks produced by coarsely shredding waste tires at a processing facility or stockpile site. The shreds are used in numerous highway construction applications such as in a lightweight fill in highway embankments constructed over unstable soils, in abutment backfill to decrease lateral pressure on containment walls, in a

vibration dampening layer under rail tracks, and in thermal insulation under roadways to limit frost penetration. Shreds also serve as leachate drainage layers, gas transmission channels, and daily cover in modern landfills. They have also been used as an alternative septic system drain field aggregate and as a basement foundation backfill providing enhanced drainage and thermal insulation.

Tire-derived fuel (TDF), as its name suggests, refers to tires as a supplemental energy resource. Cement kilns combust whole tires as an alternative to save fossil fuels such as coal, oil, or natural gas. Some power plants use shredded tires as a similar replacement in full compliance with all applicable environmental regulations. Shredded tires used as TDF are typically 1–3 inches in size, with most of the bead wire removed magnetically during processing.

Crumb rubber manufacturing involves extensive processing to reduce shreds even further in size and to remove reinforcing wire and fabric contained in whole tires. Particles (1/4–3/8 inches) have been used as a cushioning material in playgrounds and equestrian rings, and slightly larger particles (3/8–1 inch) have been used as mulch (sometimes painted for aesthetic appeal) in flowerbeds. Finer particles (1/16–1/4 inch) are used as a top dressing in natural turf to enhance grass durability and in modern artificial sports fields to provide cushioning. Even smaller particles (1/80–1/4 inch) are used in molded rubber products, sealants, and rubber modified asphalt pavements. The estimated market breakdown for crumb rubber applications in 2001 is provided in the following table.

Crumb Rubber Market Share 2001[5]

Molded Products[6]	31%
Asphalt Modification	29%
Sport Surfacing	14%
Tire and Automotive Products	11%
Plastic Blends[7]	4%
Animal Bedding	4%
Surface Modifications	3%
Construction[8]	3%

Retreading, reuse, and exporting of tires is possible if the tires are not completely worn out when removed from a car. Retreading can extend the life of the main tire carcass. For instance, truck tires are generally retreaded 2–4 times before the carcass is discarded. Passenger tires are generally not retreaded in the U.S. due to the comparatively low cost of replacement tires and other technical considerations.

The breadth of applications for waste tires has expanded rapidly in the past 15 years, but existing markets may grow as more creative minds become involved in the market development process.

Tire Processing

If tires could be torn apart easily, we wouldn't want them on our cars. The combination of resilient rubber and metal alloy reinforcing wire presents a difficult challenge in tire processing. A TDF processing facility represents a multi-million dollar investment, and crumb rubber facilities have reportedly cost $4–$40 million depending on design capacity, product size, and many other factors. Every operation is maintenance-intensive because reinforcing wire rapidly dulls cutting surfaces and erodes all contact surfaces. High capital and operating costs are major components in product pricing.

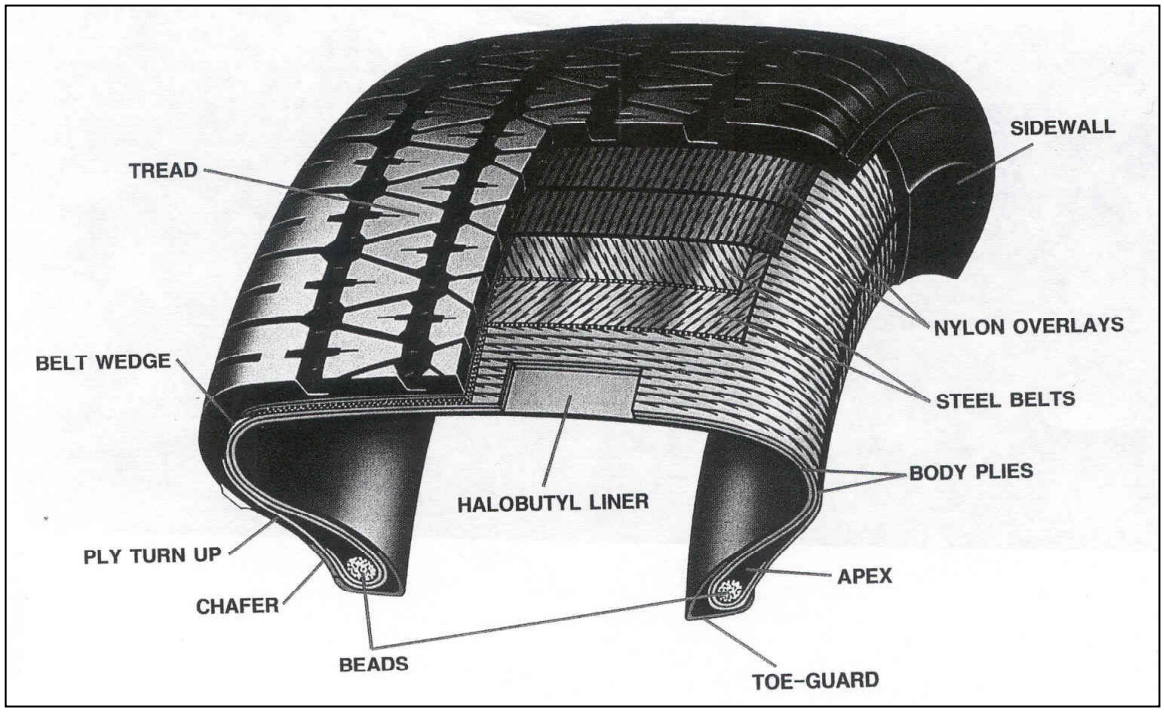
Pricing

The tables on page 4 provide general national product and pricing ranges, but local conditions can cause significant variations. The size range of actual crumb rubber products is generally more flexible than shreds. As a rule of thumb, the finer the particle size, the higher the cost due to lower productivity, lower equipment production rates, and higher maintenance expense. Higher

levels of wire and fabric removal generally command higher prices. Pricing generally increases with tight particle size specification, low volume, special packaging, coloring, or other requirements that increase processing/handling costs.

Raw Materials and Binders

Tires look like one simple black mass, but they are actually a complex mixture of various types of rubber, carbon black, inorganic materials, organic compounds, and reinforcing wire/fabric in multiple sections of a tire as shown in the diagram below.



Source: Dr. Krishna C. Baranwal, Akron Rubber Development Laboratory, *ASTM Standards & Testing of Recycle Rubber*, paper presented at Rubber Division Meeting of the American Chemical Society, San Francisco, Calif., April 29, 2003. Used by permission of author.

Crumb Rubber and Shredded Products Sizes

To turn used tires into useful products, tires are processed into shredded products or crumb rubber. These are the forms of raw material designers will be working with. A wide range of shredded tire products is currently manufactured to meet existing market requirements. Although almost any variation from theses standards could theoretically be made, utilization of existing products in the marketplace may enhance the availability and cost of material. The following table summarizes representative product sizing and pricing of shredded and crumb rubber during 2003.

Shredded Products

Product	Size	Applications	Approx. Cost Range
Coarse	5–10"	Civil Engineering (CE)	$10–$44/ton
Nominal 2"	2–3"	Tire Derived Fuel (TDF), CE	$15–$45/ton
Nominal 1"	<2"	TDF, CE	$20–$65/ton

Crumb Rubber

Product	Size	Applications	Approx. Cost Range
Particles	3/8–1/4"	Mulch, playground	$180–$300/ton
Coarse	1/5–1/10"	Sports Surfaces	$220–$360/ton
Medium	1/10–1/30"	Rubber Modified Asphalt, Molding	$220–$400/ton
Fine	1/40"	Rubber Modified Asphalt, Molding	$300–$1200/ton

Binders

Tire chips and crumb rubber can be bound together into a cohesive mass by use of binders under simple contact mixing or compression molding. Examples include use of polyurethane binders with crumb rubber to form “pour-in-place” (contact) and rubber tile (compression) cushioning surfaces in playgrounds as previously mentioned. Polyurethane, latex, and epoxy binders have been used with crumb rubber, but latex binders have historically experienced some long-term failures in running track applications.

Technical Characteristics of Whole or Processed Tires

The following is a brief discussion about some characteristics of whole and processed waste tires intended to help designers create new products from them. For most practical purposes, tires and tire products function as homogeneous mixtures, but processing can impact physical characteristics as size and shape are altered and as reinforcing wire and fabric are removed. Therefore, variations are discussed in subsequent sections where they may be important.

Density: Tires are slightly heavier than water and will sink in water unless entrapped air provides enough buoyancy to allow them to float. This generally occurs only with whole tires or fine

crumb rubber particles. However, tires and tire products are much lighter than soil or stone. The density of whole and shredded tires depends upon size, depth, and compaction as shown below:

Whole Tires (Loose)	7.5 lbs/cubic foot
Laced Passenger Tires	10 lbs/cubic foot
Stacked or Laced Truck Tires	14 lbs/cubic foot
Baled Tires	30 lbs/cubic foot
Shreds (Loose-Surface Compacted)	22–50 lbs/cubic foot
Shreds (Compacted CE Uses)	37–60 lbs/cubic foot

Density may increase even further under external pressure such as material over burden. Data on shred density as a function of pressure are provided in *D6270-98 Standard Practice for Use of Scrap Tires in Civil Engineering Applications* (*ASTM D6270-98*).[9] In general, shred density increases with decreasing shred size and with increasing overburden weight, as expected with any solid material, but the flexibility and deformability of tire chips accentuates these variations.

Durability: Tire rubber contains carbon black, antioxidants, and UV stabilizers to enhance resistance to wear, chemical decomposition, and sunlight, respectively. These characteristics are independent of particle size. Strength of whole tires is further enhanced by reinforcing wire and fabric (like nylon or polyester), but this additional strength is lost as wire and fabric are removed from smaller particles. Abrasion resistance is illustrated by the long life of tires in contact with roads. Tires and shreds are not easily damaged by blunt trauma, but they can be cut or punctured by sharp objects.

Moisture Absorption: Tires and shreds can trap water on the surface and in irregular contours, but they are relatively impervious to actual absorption. Various studies cited in *ASTM D6270-98* indicate maximum moisture absorption of 2–4 percent.

Hydraulic Conductivity: Water flows through whole and shredded tires readily, even when they are compressed in bales or under heavy overburden. Conductivity increases with larger particle size and decreases with increasing compaction. Conductivity ranges from 0.5 cm/sec (0.2 inches/sec) for compressed 10–38 mm (0.4–1.5 inches) shreds to more than 20 cm/sec (8 inches/sec) for 25–64 mm (1–2.5 inches) loose shreds, as discussed in *ASTM D6270-98*, Section X1.7.

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 wire content, compaction, moisture content, ambient temperature, and other variables. For example, thermal conductivity varies from 0.0838 Cal/meter-hour-degree C (5.6X10E-5 Btu/ft-hr-degree F) for 1mm particles in a thawed state with less than 1 percent moisture content to 0.147 Cal/meter-hour-degree C (9.8X10E-5 Btu/ft-hr-degree F) for 25 mm frozen compacted shreds with a moisture content of 5 percent. Thermal conductivity is discussed in the *ASTM, D6270-98*, Section X1.8.

Vibration Insulation: The compressibility of tire shreds allows them to absorb vibrations, such as those emanating from rapid transit rail cars moving over metal rails. Preliminary unpublished

studies of this phenomenon include *Vibration Attenuation Properties of Tire Shreds*, prepared for the CIWMB in 1999; and *Vibration Attenuation Performance of Tire Shred Underlayment for Light Rail Transit Ballast and Tie Track*, prepared for the Santa Clara Valley Transportation Authority in 2001. Wilson, Ihrig, & Associates, Inc. authored both studies. The CIWMB is considering funding additional studies of methods of using shreds for earthquake vibration control around structures.

Acoustic Insulation: Tire rubber is a poor acoustic conductor and, therefore, a good insulator when used in a configuration with irregular surfaces to further diffuse sound. One application is highway sound barriers that are made from crumb rubber with various bonding agents. But durability of the bonding agent, flammability of rubber, and the higher cost of rubber—compared to existing cement barrier products—have limited crumb rubber usage for sound barriers. Use of baled tires as an acoustical barrier is limited by durability of baling wire or other containment method, as well as by aesthetics and economics.

Other Civil Engineering Design Parameters: Other critical design parameters are discussed in *ASTM D6270-98*, including resilient modulus, coefficient of lateral earth pressure, Poisson's Ratio, and sheer strength, but these charts and data do not lend themselves to brief definitions and summaries.

Temperature Tolerance: Tire rubber is capable of withstanding a full range of ambient temperature extremes without undergoing permanent property change. Some properties—like flexibility—change as a function of temperature, but this change is reversible and repeatable.

Leaching Characteristics: Tire shred leaching characteristics have been examined under a wide range of pH conditions. Under neutral pH (pH = 7) normally encountered in surface flow-through applications, iron and manganese levels increase as these metals are extracted from any exposed tire reinforcing wire. However, both metals are generally present in soils, and the increases are generally not considered to be harmful to people or the environment. The rate of dissolution of wire increases under acidic conditions (pH < 7), and zinc present within surface rubber can also be leached, but levels generally remain within acceptable parameters. Under basic conditions (pH>7), organic compounds can be leached in trace quantities.

As a result of this data, tire chips are normally used in flow-through applications above the water table to minimize long-term leaching exposure and in relatively neutral natural conditions. Extensive practical experience with such applications has confirmed the absence of any deleterious impact. Many state regulatory agencies have historically limited the use of waste tire chips to applications above the mean high water table. However, recent studies of experimental applications below the water table have shown little or no impact in downstream water quality. Leaching data is provided in Section X1.9 of ASTM D6270-98.

Energy Content: Tires are made from oil and gas. As a result, they have an energy content greater than coal, making them thermally suitable for use as a supplemental energy resource in the manufacture of cement, paper, and power. Although energy content as an application is outside the scope of this report, it accounts for almost half of the constructive use of waste tires nationally. The *ASTM D6700-01 Standard Practice for Use of Scrap Tire-Derived Fuel*,[10] may provide useful information on chemical characteristics, sampling, and size classification for mid-sized tire shreds used in many tire-derived fuel applications.

Impact Cushioning: Shredded tire products have resiliency and durability that lends itself to cushioning applications. Loose-fill crumb rubber applied below playground equipment has cushioning characteristics clearly superior to wood chips, sand, and pea gravel commonly used

for this purpose. In some cases, crumb rubber has been mixed with polyurethane binders and poured on top of an asphalt base to create a fixed "pour-in-place" cushioning surface.

Crumb rubber has also been compression-molded with polyurethane binders into large (1–3 square feet) 2–3-inch interlocking tiles that can be secured to an asphalt base as a cushioning surface. Flammability and handicap accessibility can be issues with loose fill material, but a recent study conducted by the University of Denver showed a high level of satisfaction with use of crumb rubber in this application.[11] In addition, *ASTM F1292-99 Standard Specification for Impact Attenuation of Surface Systems Under and Around Playground Equipment*[12] provides a discussion of standard practices and measurement methods for this application.

Flammability: Tire shreds have a reported flash point of 582º F, higher than some other materials used for architectural purposes such as wood, paper, foam, and fabric. The flash point is the temperature at which a material will initially ignite, and the temperature to support continuing combustion (fire point) is even higher. When crumb rubber is combined with a binder, the binder may control the flammability of the resulting product if the binder has a lower flash point. Flame propagation was slow in two known playground fires involving loose-fill crumb rubber, and no one was injured. Both fires were intentionally started by juveniles that used matches, paper, and wood to ignite the crumb rubber.

Color: Passenger tires are predominantly black, but white pigment is used to provide visible sidewall lettering. As a result, shreds and crumb rubber made from passenger tires have a mixture of black and white coloring. Truck tires do not have white pigment, so resulting products are completely black. Color can be an important performance characteristic. In addition, tire chips can be colored by mixing with some types of paint. This has been fully demonstrated in colored mulch applications where durability has been shown to depend on the paint, not the rubber substrate. In other cases, crumb rubber has been used as a comparatively inexpensive substrate and colored ethylene propylene diene monomer (EPDM) rubber has been used as the surface layer to achieve an aesthetic appearance in pour-in-place playground surface cushioning.

ASTM Standards

A few American Standards for Testing Materials (ASTM) international standards exist for products made from waste tires. Many of these standards provide clear definitions of technology, applications, and testing methods. Examples related to waste tire products include the following:

D6270-98 Standard Practice for Use of Scrap Tires in Civil Engineering Applications [13]

This practice is intended to describe use of scrap tires, shredded scrap tires, tire chip/soil mixtures, and tire sidewalls. Civil engineering applications include lightweight embankment fill, lightweight retaining wall backfill, drainage layers, thermal insulation to limit frost penetration beneath roads, insulating backfill to limit heat loss from buildings, and replacement for soil or rock in other fill applications. Related design properties and data are provided to facilitate use of these materials.

D5603-01 Standard Classification for Rubber Compounding Materials—Recycled Vulcanizate Particulate Rubber[14]

This standard classification allows definition of critical properties for recycled vulcanizate particulate rubber, with the product derived from waste tires commonly referred to as crumb rubber. Use of these materials is important as filler in rubber compounding to decrease compound costs and/or improve performance characteristics.

D5644-01 Standard Test Method for Rubber Compounding Materials—Determination of Particle Size Distribution of Vulcanized Particulate Rubber[15]

These test methods describe improved procedures for accurately defining particle size distribution in crumb rubber, especially in fine mesh products. Quality control can be a critical parameter in successful innovative applications where crumb rubber displaces virgin raw materials that are carefully monitored for consistent quality. These procedures are gaining acceptance with quality crumb rubber producers seeking higher value markets, but they are not generally applied.

D6814-02e1 Standard Test Method for Determination of Percent Devulcanization of Crumb Rubber Based on Crosslink Density[16]

This method allows compounders to define the extent of devulcanization achieved during processing to determine proper usage of curing agents during compounding operations. Many processors have historically claimed to devulcanize crumb rubber, thereby enhancing its ability to chemically bond with other compounds and improve performance characteristics. An important side benefit of this method is to allow an evaluator to differentiate between processor claims and reality.

F1292-99 Standard Specification for Impact Attenuation of Surface Systems Under and Around Playground Equipment[17]

This clearly defines methods used to measure impact attenuation of alternative surface materials, providing a sound basis for material comparison. Playground design and safety are becoming critical factors as injury frequency, severity, and cost (medical and legal) are being recognized and publicized.

Accessibility Requirements

State regulations, Uniform Building Code, and the federal Americans with Disabilities Act all stipulate that publicly funded buildings must be accessible to individuals with disabilities. The California Building Standards Code (Title 24) provides the minimum requirements to ensure that buildings, structures, and related facilities are accessible to, and functional for, every member of the public, so as to provide equal opportunity to access public accommodations.[18]

Design Challenges

Whole and shredded tires and crumb rubber come with unique challenges as raw materials. Some of the characteristics that make tires effective on a vehicle make them challenging when they are reused for other purposes. Since the 1980s, several states have funded projects to study and create new uses and products made from tires and crumb rubber. The following technical and economic challenges represent a variety of tire and crumb rubber applications as well as modifications to crumb rubber, namely surfaced modified rubber. Some of these applications are outside the scope of the design competition (railroad crossings and tire reefs, for example) but their challenges may be applicable to building and landscape products. For a list of successful applications (building and landscape materials) of tires, see Appendix, Building and Landscape Tire-Derived Products.

Interior flooring (Indoor Air Quality Challenges)

Molded mats of all sizes and purposes are a major application for crumb rubber. One of the greatest challenges with tires is flooring products for interior applications. The State of California

tested tire-derived flooring and found that 4 of the 11 products contain chemicals—naphthalene, in particular—that compromise indoor air quality. All products emitted numerous chemicals; therefore the State does not recommend tire-derived products for classrooms and office spaces unless proper ventilation is ensured.[19] For manufacturers interested in producing tire-derived flooring, the State has created a testing methodology known as *Special Environmental Requirements Specification, Section 01350*.[20] Tires and bonding agents used in product manufacture contain a mixture of chemicals; product manufacturers should be evaluating air emissions.

Tire-Reinforced Concrete Blocks (Economic/Performance Challenges)

Baled whole tires have been used as an inner core, subsequently encased in concrete to form large building blocks. It provided a cheap initial tire disposal method, but product markets proved to be elusive. Total product cost was high, and some blocks failed due to internal pressure from bale expansion or differing thermal expansion characteristics. When combining two dissimilar materials like rubber and concrete, careful evaluation is necessary.[21]

Rubber Railroad Crossings (Performance Challenges)

Some companies have used recycled rubber tires as surface material for railroad crossings to absorb heavy traffic impacts and help protect tracks. But initial products demonstrated performance failures, resulting in lowered consumer confidence in these products. This caused decreased use of crumb rubber in future applications. Manufacturers should carefully evaluate performance of a new product before promoting its broad usage. Consumers are hesitant to give a product a second chance once it has failed in the marketplace.

Devulcanized/Surface Modified Rubber (Process Challenges)

Surface modified rubber refers to a process that enables crumb rubber particles to chemically bond with other materials in compounds, thereby becoming an integral part of the material structure rather than just a filler. In this process, the particles are chemically treated to alter the surface of the rubber particles, creating reactive functional groups on the surface. These reactive functional groups react with a broad spectrum of rubber and plastic materials. They give tenacious adhesion to polymers with which they are combined, enhancing strength and other performance properties of the compound.[22] Devulcanization is another method of restoring reactivity of crumb rubber with other virgin rubber by reactivating vulcanization reaction sites.

Surface modified rubber has reportedly been used in the following building and landscape products:

- Carpet underlay—polyurethane foam.
- Roof sealant—polysulfide-based.
- Construction panels—phenolic-based.
- Slip-resistant coatings—acrylic, epoxy, urethane.
- Deck coatings—polyurethane-based.
- Construction Materials—rigid PVC.
- Lawn and Garden Wheels—PVC-based.

Many manufacturers have made broad claims for surface activation and devulcanization technologies and products, but most actual performance data has not supported these claims to date. None have enhanced bonding between thermoplastic polymers and thermoset crumb rubber

West Coast Rubber Recycling Makes a Profit on Old Tires

In 1999, West Coast Rubber Recycling (WCRR) was formed to simply collect tires for landfill disposal. They soon discovered a market for recycled rubber products that was more profitable and better for the environment. WCRR has since expanded to two locations, quadrupled in size, and offers 10 different recycled rubber products for sale.

Maintaining financial stability has been critical to the success of WCRR. True to its roots in recycling, the company has saved a lot of money by buying used machinery and equipment. As a small company, WCRR uses those dollars to quickly take advantage of new opportunities for recycled rubber products.

The rubber WCRR recycles is now used in residential playgrounds, horse arenas, rubber mulch, and commercial playgrounds as pour-in-place. The company also has a complete molding facility, where workers produce a variety of molded rubber products such as playground tiles, horse stall mats, speed bumps, and curbs for wholesale distribution. In addition, they ship rubber across the country for postconsumer use by other manufacturers.

All WCRR products are made from 100 percent California recycled tires, and company representatives say they enjoy making such a positive local impact. An average backyard play area will create an opportunity to divert 1,000 or more tires from landfills, and a single horse arena will allow diversion of more than 6,000 tires. The WCRR arena material offers a superior product that reduces muscle strain and injuries and controls dust and erosion, and the playground material is safe and durable.

For more information on West Coast Rubber Recycling or any of the products listed above, please contact WCRR using any of the contact information: 105 Leavesley Road, #7B, Gilroy, CA 95020, (408) 842-2401; fax (408) 842-1482; info@groundrubber.com; www.groundrubber.com/.

enough to avoid significant loss of critical properties like tensile strength. In general, minimal performance gains have not justified the increased expense associated with treatment and have not been cost-effective in major applications. The difference between technical representations and reality can sometimes be substantial.

Highway Crash Barriers (Organizational Challenges)

To absorb the impact of automobiles, tires have been stacked, bound by steel cable, and even enclosed with fiberglass. However, state transportation departments generally prefer sand-filled crash barriers because they have excellent absorption characteristics and are easier to erect and dismantle. In addition, new highway safety products require definitive testing. Engineers are naturally reluctant to change historically acceptable practices without a commanding economic or safety advantage. Recycling non-highway waste materials is not necessarily at the top of the highway department's priority list, especially in view of manpower and resource cutbacks in many states. The lesson is to realistically evaluate new product advantages and the impediments to acceptance, timing, and resources required to demonstrate performance advantages.

Tire Reefs (Unexpected Environmental Challenges)

In the 1970s in Florida, New Jersey, and North Carolina, whole tires were bound together to create artificial reefs. However, bands and even chains used to secure tires to each other and to

the ocean floor failed. This caused tires to break free and flood beaches or damage coral reefs after storms. The lesson is that tires appear to be heavy, but their density is actually only marginally heavier than water. Therefore, tires and shreds should not be used in submerged, or potentially submerged, applications where they can be displaced by turbulence. Rock and soil are much denser than tire products

Tire shred applications are much more likely to be successful if they are used for their comparative light weight. Light weight can offer an advantage as well, because a ton of tire chips occupies a much larger volume than a ton of soil or rock.

Houses (Seismic and Other Challenges)

Housing construction is a unique application for whole tires. One example is Earthship Biotexture of Taos, N.M. Builders stack tires to form walls, then pack them with earth. Finally, they install a vapor barrier and apply stucco and paint.[23] The challenges with this application are seismic, and they use too few tires compared to the number generated in the state.

Rising to the Challenge

As a raw material, whole and shredded tires and crumb rubber have beneficial attributes. These can be harnessed through creative design, processing, and marketing to reenter the economy as a beneficial money-making product. Already, many existing products use old tires (see Appendix, Building and Landscape Tire-Derived Products), but this just scratches the surface of possibilities.

Product designers and manufacturers are key to environmental problem solving. While the benefits of recycling and conserving landfill space are widely known, recycling is not cost-effective unless the materials collected can be put to good uses. This places product designers and manufacturers at the forefront of problem solving. They are finding new and better uses for society's discards—in this case old tires that are generated by the millions—while making a profit in the tradition of the best of American entrepreneurs. It's a win-win situation: opportunity abounds.

Appendix: Building and Landscape Tire-Derived Products

The following is a list of existing products made of recycled tires and sources of granulated and crumb rubber. It is not a complete list of products nor a complete listing of all manufacturers of each product. To determine if a particular product exists, designers should conduct their own research. Visit the California Integrated Waste Management Board (CIWMB) Recycled-Content Product Database for additional products and manufacturers: www.ciwmb.ca.gov/RCP/.

Most of the products below are oriented to commercial or residential applications, but one or two highway-oriented products exist to illustrate a special characteristic of tire-derived products, like sound absorption. Some products don't have a manufacturer per se. The product is a generic one, so another source—instead of a manufacturer—is provided. Additionally, the companies below do not necessarily use California waste tires. Projects receiving funds from the CIMWB Tire Fund must provide certification that the project will use California waste tires.

Product Category	Manufacturers—Product name
Landscape	
Mulch	Close the Loop, LLC—Rubber Mulch www.homestead.com/prosites-closetheloop
	International Mulch Co.—Rubberific Mulch www.rubberificmulch.com
	American Rubber Technologies—Rubber Stuff Mulch www.americanrubber.com
Mulch tree rings	American Rubber Technologies—Mulch Rings www.americanrubber.com
Soil amendment	American Rubber Technologies—Rebound Soil Amendment www.americanrubber.com
Topdressing	JaiTire—Crown III www.jaitire.com
Tree ties and tree straps	Once is Not Enough—Tree Ties www.recyclestore.com
Rubberized asphalt concrete	International Surfacing Systems—Asphalt Rubber System www.asphaltrubber.com
	North West Rubber Mats, Ltd.—Surfacing www.northwestrubber.com
	GraniteRock—Rubberized Asphalt Concrete www.graniterock.com/rubberized.html

Product Category	Manufacturers—Product name
Railroad ties	TieTek—TieTek Ties www.tietek.com/index.html
Highway sound barriers	Carsonite International—Sound Barrier System www.carsonite.com
Parking curbs and speed bumps	West Coast Rubber—Parking Curbs www.groundrubber.com
	Scientific Developments—Speed Bumps www.sdirubber.com
	Enviroform Recycled Products—Speed Bumps & Wheel Stops www.enviroform.com
Sidewalks	Rubbersidewalks Inc.—Modular paving systems www.rubbersidewalks.com
Track products	Dodge-Regupol—Regupol Tracks www.regupol.com
	Marathon Athletic Surfaces—Seal-Flex www.marathonathletic.com
	Everguard Surfacing—Fast Track www.everguard.com
Playground surfacing	No Fault Sport Group—Saf Dek www.nofault.com
	RB Rubber Products—Bounce Back www.rbrubber.com
	Rainbow Turf Products—RTP Poured-in-Place www.rainbowturfproducts.com
Tennis court surfacing	Arizona State University pilot project www.azcentral.com/abgnews/articles/0515tennis15.html
Equine surfacing	Dodge-Regupol—Pavesafe www.regupol.com
Swimming pool surfacing	Rubaroc—Safetydeck www.rubaroc.com/

Product Category	Manufacturers—Product name
Planters	American Rubber Technologies—Mulch Rings www.americanrubber.com
Benches	American Rubber Technologies—Mulch Rings www.americanrubber.com
Waste shrouds	American Rubber Technologies—Mulch Rings www.americanrubber.com
Picnic tables	American Rubber Technologies—Mulch Rings www.americanrubber.com
Landscape/playground borders	Corona Wholesale Landscape Materials—Rubber Flex Curbs www.cwlm.com
	Rainbow Turf Products—RT Border Shapers www.rainbowturfproducts.com
Hoses	Mr. Drip—Moisture Master www.mrdrip.com
	Fiskars—Sprinkler Hose and Soaker Hose http://gardening.fiskars.com
	Teknor Apex—Hoses www.teknorapex.com
Building	
Concrete joint filler	J D Russell Company—REFLEX www.jdrussellco.com
Impact sound insulation	Dodge-Regupol—Regupol-QT www.regupol.com
Vibration insulation	Dodge-Regupol—Regufoam www.regupol.com
Modified bitumen roofing systems	Garland—Modified Bitumen www.garlandco.com
Roofing shingles	Carlisle—Eco Star Premium Roofing www.premiumroofs.com

Product Category	Manufacturers—Product name
Rubber lumber	New Century Northwest—Rumber Lumber www.continet.com/robbpynes/rmi
	Rumber Materials, Inc.—Rumber www.rumber.com
	American Rubber Technologies—PermaLumber www.americanrubber.com
Dock bumpers	Durable Corporation—Dock Bumpers www.durablecorp.com
	Enviroform Recycled Products—Dock Bumpers www.enviroform.com/
	GNR Technologies—Dock Bumpers www.gnrtech.com/
ADA ramp products	EMC Molding—Kid Kushion Tile & Ramp Accessories www.emcmolding.com
	Van Duerr Industries—EZ Edge Threshold Ramp www.vanduerr.com/
Carpet undercushion	Dura—Undercushion www.duracushion.com
Floor underlayment (rolls)	Gerbert—ECOunderlayments www.gerbertltd.com
Carpet	Durable Corporation—Dura Tile II www.durablecorp.com
Mats (athletic, anti-fatigue, walk-off/entry)	Ashland Rubber Mats Co., Inc.—Eco-Link ashrub@bright.net (Web address not available)
	Royal Floor Mats—Veldura and Masterpiece www.royalfloormats.com
	Dinoflex—Dinomat www.dinoflex.com

Product Category	Manufacturers—Product name
Flooring	Dinoflex—Atmosphere Recycled Rubber Flooring www.tomkt.com
	U.S. Rubber Recycling—Sure Step Tire Tile www.usrubber.com
	Marley Flexco—Flex Tuft www.flexcofloors.com
Wall & corner guards	Durable Corporation—Corner Guards www.durablecorp.com
	J.B. Mathews Company—Corner Guards www.jbmathews.com/newwebpages/loaddock/dock.html
Chair	Yemm & Hart—Data Chair www.yemmhart.com
Tables	Yemm & Hart—Drum Table www.yemmhart.com
	Modern Metalworks—Coffee Table www.modernmetalworks.com
Sources of Rubber	Granulated and Crumb Rubber Producers and Suppliers in California www.ciwmb.ca.gov/Tires/Products/CrumbRubber/Producer.htm

Tire Resources

Akron Rubber Development Laboratory <www.ardl.com/>.

American Chemical Society, Rubber Division <www.rubber.org/>.

California Integrated Waste Management Board <www.ciwmb.ca.gov/Tires>.

Clean Washington Center <www.cwc.org/>.

Rubber and Plastic News <www.rubbernews.com/>.

Rubber Manufacturers Association <www.rma.org/>.

Rubber World <www.rubberworld.com/>.

Resource Recycling <www.resource-recycling.com/>.

Scrap Tire and Rubber Users Directory 2003, Recycling Research Institute, Leesburg, Va., 2003.

Scrap Tire News <www.scraptirenews.com/>.

U.S. Environmental Protection Agency, "Markets for Scrap Tires," October 1991, EPA 530/SW-90/074a <www.epa.gov/>.

1997 RAC [Rubberized Asphalt Concrete] and Crumb Rubber Products Workshop: Program Proceedings, California Integrated Waste Management Board, May 23, 1997, Monterey, Calif., and May 30, 1997, Anaheim, Calif. Available in the Cal/EPA Library or through the Board's Waste Tire Diversion Section of the Special Waste Division <www.ciwmb.ca.gov/Tires/Pubs.htm>.

Endnotes

[1] *California Waste Tire Generation, Markets and Disposal: 2002 Staff Report*, Publication #620-03-015, California Integrated Waste Management Board, Sacramento, Calif., 2003, p. 2.

[2] Robert W. Wassmer, "Changing Tires," *Resource Recycling*, September 2002, p.21.

[3] *California Waste Tire Generation 2002 Staff Report*, p. 7.

[4] Ibid, p. 5.

[5] Nongnard Sunthonpagasit and Michael R. Duffey, "Sizing Up the Crumb Rubber Market," *Resource Recycling*, April 2003, p. 12.

[6] Kurt Reschner, "A Summary of Prevalent Scrap Tire Recycling Methods," *Scrap Tire Recycling*, April 22, 2003 <http://home.snafu.de/kurtr/str/en_prod.html>. Molded products include high-volume, low-tech products, such as livestock mats, railroad crossings, removable speed bumps, and athletic mats.

[7] Ibid. Plastic and rubber blends include high-volume products like pallets, railroad ties, and acoustic insulation for cars.

[8] *Scrap Tire News Online*, 1999 <www.scraptirenews.com/areas/crumb/market.html>. Construction products include roofing products, building materials, insulation, and soundproofing.

[9] American Society for Testing and Materials, *D6270-98 Standard Practice for Use of Scrap Tires in Civil Engineering Applications*, ASTM International, 1998 <www.astm.org/>.

[10] American Society for Testing and Materials, *D6700-01 Standard Practice for Use of Scrap Tire-Derived Fuel*, ASTM International, 1998 <www.astm.org/>.

[11]Robert C. Amme et al., "Scrap Tires in Full Swing," *Resource Recycling*, March 2003, p. 32.

[12] American Society for Testing and Materials, *F1292-99 Standard Specification for Impact Attenuation of Surface Systems Under and Around Playground Equipment*, ASTM International, 1998 <www.astm.org/>.

[13] American Society for Testing and Materials, *D6270-98 Standard Practice for Use of Scrap Tires in Civil Engineering Applications*, ASTM International, 1998 <www.astm.org/> (search by D6270).

[14] American Society for Testing and Materials, *D5603-01 Standard Classification for Rubber Compounding Materials—Recycled Vulcanizate Particulate Rubber*, ASTM International, 1998 <www.astm.org/> (search by D5603).

[15] American Society for Testing and Materials, *D5644-01 Standard Test Method for Rubber Compounding Materials—Determination of Particle Size Distribution of Vulcanized Particulate Rubber, ASTM International*, 1998 <www.astm.org/> (search by D5644).

[16] American Society for Testing and Materials, *D6814-02e1 Standard Test Method for Determination of Percent Devulcanization of Crumb Rubber Based on Crosslink Density*, ASTM International, 1998 <www.astm.org/> (search by D6814).

[17] American Society for Testing and Materials, *F1292-99 Standard Specification for Impact Attenuation of Surface Systems Under and Around Playground Equipment*, ASTM International, 1998, <www.astm.org/> (search by F1292).

[18] California Division of the State Architect, April 2004 <www.dsa.dgs.ca.gov/UniversalDesign/>.

[19] Building Material Emissions Testing, California Department of Health Services, November, 2003 <www.ciwmb.ca.gov/GreenBuilding/Specs/Section01350/METStudy.htm>.

[20] Special Environmental Requirements Specification, California Integrated Waste Management Board <www.ciwmb.ca.gov/GreenBuilding/Specs/Section01350/>.

[21]Enviro-block <www.eagle-internationalllc.com/enviro-block/enviro.html>.

[22] Engineered Particle Systems <www.vistamer.com/>.

[23] Earthship Biotecture <www.earthship.org/>.