Contractor's Report to the Board

Increasing the Recycled Content in New Tires

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INTEGRATED WASTE MANAGEMENT BOARD

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Table of Contents

1.0 Executive Summary

The California Integrated Waste Management Board (CIWMB) estimated that 33.5 million waste tires were generated in California in 2002, and nearly 75 percent were diverted from disposal through source reduction and recycling efforts [1]. Given the large number of waste tires generated in 2002, the 25 percent not diverted from disposal (approximately 8.4 million waste tires) could likely have a negative impact on the environment if the diversion rate stays approximately the same in subsequent years. In an effort to further reduce the number of waste tires requiring disposal, the tire industry and government agencies have considered and/or implemented several alternatives. Increasing the recycled content in new tires by adding waste tire rubber is one of the diversion alternatives being considered.

At its March 2001 meeting, the Board approved its Five-Year Plan for the Waste Tire Management Program (*Five-Year Plan for the Waste Tire Recycling Management Program: Fiscal Years 03/04—-07/08*, CIWMB publication #620-03-007).

The Five-Year Plan allocated funds to research increasing the recycled content in new tires. This report examines the potential for increasing recycled content, addressing technology and market issues, what barriers exist, and what has been done to date on this subject.

Conducting research on this recycling alternative requires an integrated approach with a complete understanding of tire design, performance, safety, and consumer expectations. Extensive literature reviews and discussions with tire manufacturers and tire recyclers were conducted to better assess the various aspects of increasing recycled content in new tires. Throughout the literature and information review process, it became apparent that preconsumer factory excess, which meets the manufacturers' quality control standards, was more often used in the production of new tires than fine crumb rubber from waste tires, particularly in critical components of the tire. The distinction between when excess recyclable material from factory processes was used and when recycled content material from waste tires was used, was often blurred. This led to confusion about the actual amount of recycled content in new tires.

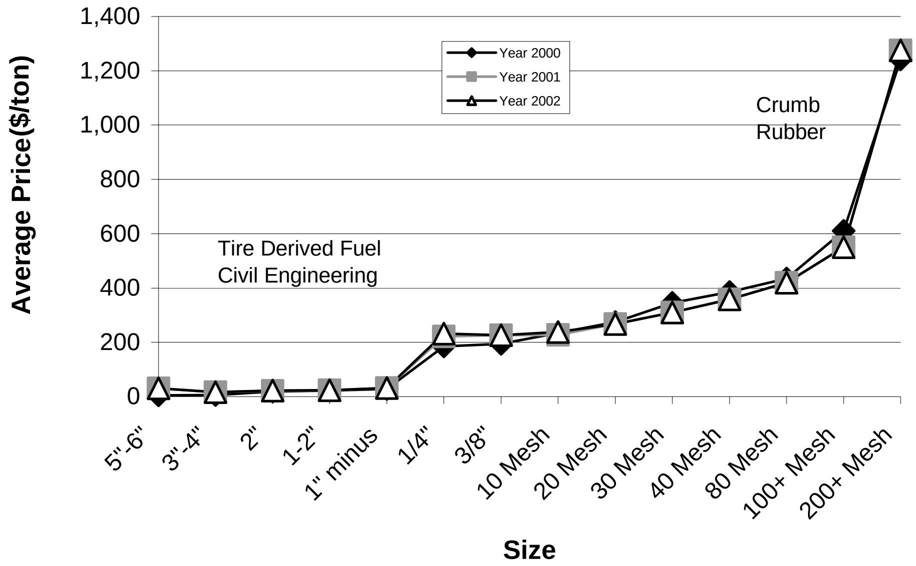
According to the Scrap Tire Management Council (STMC), [4, p. 20/13, p. 3], over the past 10 years, the recycled content in new tires has increased from 0.5 percent to 5 percent by weight. In some cases, incorporating either recycled content or factory excess of up to 10 to 15 percent in new tires was reported as technically feasible, without adversely affecting the performance characteristics of tires. Previously quoted values of 15 to 25 percent recycled content being feasible without affecting performance could not be verified at the time this report was written. Furthermore, the data indicated that once recycled content reached certain levels, the lifespan of a new tire could be adversely affected. Moreover, in a study conducted by Continental Tire North America (CTNA) for the North Carolina Division of Environment and Natural Resources (NCDENR), CTNA formulated compounds with up to 13.6 percent recycled content but concluded the tires may not be commercially viable due to reduced tread life and wet traction, as well as higher rolling resistance [58]. Finally, other factors such as economics (for example, transportation costs, energy cost, and low price of virgin rubber), availability of supplies, and crumb rubber quality limited recycled content to about 5 percent or under (by weight).

Other technological and economic barriers associated with increasing recycled content were also investigated. As part of the study, a cost-benefit analysis was conducted to examine alternative uses for recycled rubber materials based primarily on national average pricing data. The information gathered showed there were wide variations in the cost, quality, and supply of fine (80+ mesh) crumb rubber. This finding is significant, since fine crumb rubber is required for the production of new tires. In addition, the feasibility of implementing or increasing recycled content in new-tire production was analyzed. Technological as well as economic issues exist regarding processing methods, standards, and production capacity. To increase the use of recycled content rubber in new-tire production, extensive efforts would be required to standardize, improve the quality of, and streamline recycling processes.

While isolated technological advances in processing methods do exist that may help increase the recycled content of new tires, most remain at a research and developmental stage, and there is no confirmed information on their commercial feasibility. At present, the primary commercial processing methods for producing fine crumb rubber are ambient grinding and/or cryogenic grinding. Most processing plants that utilize these methods do not adhere to any common quality control procedures or standards. Nevertheless, quality control and standardization are critical to ensure a product that would meet the stringent demands for new tire production. Therefore, standardizing crumb rubber processing technologies must be an essential component of increasing recycled content in new tires. One way to accomplish this is to create a forum comprised of associations such as the Rubber Manufacturers Association (RMA), the Tire Industry Association (TIA) or its affiliate the Tire and Rubber Recycling Advisory Council (TRRAC), and the STMC to develop quality control measures and a common standard. This forum could adopt and/or expand procedures already published by the American Society for Testing and Materials (ASTM).

Finally, using waste tires in civil engineering applications, as a fuel source, in production of rubberized asphalt concrete, and in other tire-derived products are currently the most cost-effective ways to divert waste tires from disposal. The technological demands and associated costs with these applications are lower than for fine crumb rubber use in new-tire production. The primary reason relates to the need for a small size of crumb rubber for new-tire production. As the size of crumb is reduced, cleanliness becomes more crucial. At a certain point, production cost jumps significantly. As shown in Figure 1, average national prices increase as crumb size decreases. This price difference reflects more expensive infrastructure costs and increased labor skill requirements, among other factors. Unless this pricing differential is reduced or new technology is developed, current applications will remain the dominant path for waste tire diversion. Furthermore, low raw material costs, quality needs, stringent cost controls, and performance and reliability requirements provide few incentives for tire manufacturers to increase the use of recycled content in new tires. Thus, an increase of crumb rubber use in new-tire production would require technological advances, strong market incentives, or both.

Figure 1: Relative Price of Crumb Rubber, Chips, and Shreds



2.0 Introduction

The Board's Waste Tire Management Program focuses on increasing the lifespan of tires, as well as reusing and recycling waste tires and their components. The environmental impact of waste tires, as well as the economic challenges associated with managing them, has caused wide interest in the development of new technologies and recycling of waste tires. According to the Scrap Tire Management Council (STMC), the use of waste tires as ground rubber represents 11.7 percent of the total waste tires generated in the United States in 2001 (281 million waste tires). The STMC estimates that approximately 12.5 percent of this ground rubber is recycled into new tires (about 4 million passenger tire equivalents [PTE]).

Among the many uses of rubber from waste tires, the ability to use the material to manufacture new tires ranks at the top in terms of desirability. Reusing the material would effectively “close the loop” on the life cycle. Tire manufacturers have historically used varying amounts of crumb rubber from waste tires or preconsumer factory waste as recycled content for new tires. However, the primary use of recycled tire materials has been as fuel (cogeneration plants), as rubberized asphalt concrete (rubber content in asphalt roads), for surfacing (playgrounds and tracks), or for civil engineering applications (vibration and seismic dampening on roadway projects). The effort in this study was to establish the baseline data showing what percent of recycled content is being used or can potentially be incorporated into new tires based on the current state of technology, as well as to identify barriers to increasing recycled content and possible solutions.

As part of market development and technology identification, CIWMB contracted with the Nevada Automotive Test Center (NATC) to conduct research on increasing the recycled content of new tires.

3.0 Background

The background section is intended to provide a perspective on the overall growth of crumb rubber use rather than on the growth of crumb rubber use as a recycled-content product in new tires.

Tire rubber usually consists of 40 to 50 percent rubber (styrene-butadiene rubber, natural rubber, and butyl rubber), 25 to 40 percent carbon black, and 10 to15 percent low-molecular-weight additives. The exact composition depends on the type of tire and the design process of the individual tire manufacturer.

Among the many uses of rubber from waste tires, the ability to use the material to manufacture new tires ranks at the top in terms of desirability. However, the environmental impact from physical and chemical degradation of the tire composite material, along with the basic chemistry of the compounds, places limits on the processing methods that enable the use of rubber from waste tires as a recycled-content product.

Ambient grinding remains the primary processing method for technological and economic reasons. The ambient grinding process produces lesser-quality crumb rubber, which can render the increased use of recycled content in new tires unattractive compared to alternative uses such as for energy generation or for civil engineering applications. Because of the technological challenges associated with the extraction of useful components from waste tires, it is difficult to produce recycled materials that provide the same capabilities and characteristics as found in virgin materials. The failure of the recycled materials to meet stringent performance standards required for new tires creates a limit on the amount that can be used.

Energy generation remains the most easily implemented, cost-effective and practical large-scale application for waste tires. However, there is a growing trend of other smaller markets using waste tires today. Table 1 shows data for waste tire use since 1992.

Table 1: U.S. Waste Tire Market
(all figures, except for percentages, represent millions of tires)

Major Application	1992	1994	1996	1998	2001
Tire-derived fuel	57	101	115	114	115
Civil engineering	5	9	10	20	40
Ground rubber	5	4.5	12.5	15	33
Export and miscellaneous	1	24	27	28.5	30
Total Use	**68**	**138.5**	**164.5**	**177.5**	**218**
Total Generation	**252**	**253**	**265**	**270**	**281**
Use as Percent of Total Generation	**27%**	**54.7%**	**62.1%**	**67%**	**77.6%**

Source: Reference 4

By the end of 1998, the STMC estimated that markets for waste tires consumed 67 percent of the 270 million newly generated waste tires. At the end of 1998, tire-derived fuel (TDF) use was 64 percent of the waste tire market (or 42 percent of the total waste tires generated), followed by 13 percent for ground or stamped rubber products, 11 percent for civil engineering applications, 8 percent for export, and 3 percent for miscellaneous or agricultural uses [3].

By the end of 2001, STMC estimated that markets for waste tires consumed 77.6 percent of the 281 million newly generated waste tires. TDF use was 53 percent of the waste tire market, followed by 18 percent for civil engineering applications, 15 percent for ground rubber, and 14 percent for export and other miscellaneous uses [2].

By the end of 2001, 38 states had placed a ban on whole tires going to landfills, helping to create and strengthen markets for recovered tires.

According to the Scrap Tire Management Council, in 2001 approximately 50 million pounds of finely ground waste tire rubber was used in the manufacture of new tires. This is approximately 11.7 percent of the total ground rubber produced in the U.S. in 2001 (281 million tires). This implies that approximately 12.5 percent of all ground rubber from waste tires sold in 2001 was used as recycled content. The 2003 issue of *The Scrap Tire and Rubber Users Directory* also reports that 12 percent of all ground rubber was recycled into tires and other automotive parts in 2002. This report does not specify what percent of this usage is as recycled content in new tires; however, many processing plants with the capacity to produce fine crumb rubber for recycled content have either discontinued or limited the production of crumb rubber for this market for various reasons.

The Santee River crumb rubber producing facility in South Carolina is closed. Rouse Polymerics International (RPI) is focusing on markets other than recycled content in new tires. Landstar Rubber Recovery (LRR), considered also one of the largest suppliers of fine crumb rubber, has gone bankrupt. Both RPI and LRR were considered to be the two companies with the capability to supply the desired grade crumb rubber for recycled content in quantity. Prior to its bankruptcy, LRR had limited its crumb rubber processing operations for the tire production market. Other processors focus on factory waste processing. Under these circumstances, it is unclear how much of the crumb rubber used to increase recycled content is from waste tires.

Using the above estimate by STMC and assuming that all the crumb rubber is from waste tires, and further assuming 12 pounds of recovered rubber per waste tire, approximately 4 million tires were recycled into new tires. In contrast, in 1994, the total amount of ground rubber generated, including asphalt rubber and ground rubber generated for other uses, was 4.5 million tires (Table 1). While there has been a relatively substantial increase in the use of ground rubber in new tires over the past decade, more needs to be done to increase the recycling of waste tires through increased recycled content.

The State of North Carolina has made a significant effort to recruit processors to relocate to North Carolina over the past several years with no success to date. The processors were to generate crumb rubber for recycled content, and the State of North Carolina anticipated that the its grant to CTNA would result in a technology that would allow increased recycled content (up to 25 percent by weight) in new tires. After years of testing and evaluation, CTNA reported it was able to formulate compounds with up to 13.6 percent recycled content and incorporate it into new tires, but also concluded the tires may not be commercially viable due to reduced tread life and wet traction, as well as higher rolling resistance [58].

In addition, CTNA stated that tire recycling industry is not up to the task of supplying appropriate raw materials for the tire industry [58].

Challenges in regard to stable and high quality crumb rubber supply point to the economic reality that it is more cost effective to provide recycled tire material as fuel (cheaper and easier to develop the crumb rubber product and to meet emissions standards) than as material for tire production. With the recent advent of the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act (Public Law 106–414, Nov. 1, 2000) and increased public awareness of tire performance limitations and sensitivity due to nationally publicized incidents, the costs associated with anything less than “perfect” in tire performance is not acceptable to the tire manufacturer or to the consumer.

4.0 Literature Review

The environmental impact of waste tires and the economic challenges associated with managing them has caused wide interest over the past two decades in the development of new technologies to increase recycling of waste tires. As discussed in the previous sections, there are diversified uses for waste tires at the end of primary life. The focus of this review is on studies conducted to increase recycled content in new tires.

4.1 Methodology

Library, expert, and Internet searches were used in the literature review. Publications and conference presentations, trade articles and magazines, and STMC reports were used as sources. Where clarifications of reports were required, responsible authors were contacted for additional information.

At the outset of the literature search, it was immediately apparent that few published reports or ongoing research existed addressing the impact of recycled content in new tires on tire performance; including performance and reliability properties (traction, handling, cut and chip resistance, wet braking, long term thermal stability, etc.). It was determined that the focus of published research is primarily on establishing the effect of recycled content on the fundamental properties of rubber. The other primary area of published information is on the quality control standards and crumb rubber size distribution as found within the waste tire processing methods. The literature on crumb rubber processing methods addressed issues associated with the quality of crumb rubber and suitability for use as recycled content in new tires along with other factors, such as cost involved in producing crumb rubber.

4.2 Studies to Increase the Recycled Content of New Tires

Since approximately 1980, certain technological commercial successes have allowed increased recovery of rubber products. Nevertheless, the recycling of rubber into new tires has been slow to develop because of technological and economic limitations resulting from differences in chemistry and fabrication methods used to produce tires.

Rubber recovery from tires is made more difficult because pneumatic tires contain more than one rubber compound; they also include steel wire, textile cord, fiberglass, and plastic fiber. The recycling process requires separation of the steel, textile cord, and fibers from the rubber by multiple processing steps and the use of expensive equipment.

While some of the major automobile makers have set aggressive targets for recycling used vehicle components into new productions, the level of success with respect to recycled content in new tires remains limited. For example, according to Robert Pett of the Ford Motor Company, the automotive industry’s goal is to have no more than 15 percent of the vehicle parts retired from service go into landfills by 2002 [5–8]. This is to be reduced to 5 percent by 2015 [5]. It appears that these aggressive targets did not positively impact the effort of increased recycled content in new tires. Many studies focus on producing crumb rubber with consistent physical and chemical properties and a processing method that retains properties desirable for new tires. Depending on the processing methods that are employed and the quality of crumb rubber produced, it is reported that up to 15 percent recycled content is achievable with reasonable success. A few authors such as Stark and Wagner [9] have reported their progress in the production of a new synthetic rubber utilizing waste rubber since 1980. Their effort appears to be more fundamental than just to solve the waste rubber disposal problem, in that they attempted to use 100 percent recycled content to produce a new tire. Dierkes [10] reported that surface activation resulted in the doubling of material tensile strength, in comparison to untreated cured crumb.

ADVAC Elastomers, Inc. reports that it has successfully developed a proprietary product (TIRECYCLE™) which can be blended with virgin rubber and contains up to 87 percent recycled content. This information was provided by Edward Jakush of ADVAC Elastomers, Inc.[11] The level of success of ADVAC's effort with respect to commercial acceptability is not known.

At the close of the 1998 model year, the Ford Motor Company [12] reported that 1.2 million recycled tires were "rolling" on one of Ford's highest-volume vehicle lines, the Ford F-Series pickups. The 1999 Ford Windstar Limited Minivan was reported to have recycled content in its original equipment manufacturer (OEM) tires (until the model was changed, at which time the vehicle was equipped with a different brand of tire that did not have recycled content). The tires on these Ford vehicles are reported to have contained 5 percent recycled content.

Klingensmith and Baranwal [5], Zelibor et al. [13], and Myhre and MacKillop [14] provided comprehensive summaries of processes that are being investigated or being used to produce crumb rubber.

Different recycling or processing methods used to produce crumb rubber for use in new tires is summarized in the following section.

4.2.1 Processing Methods

The major process currently in use for the production of crumb rubber is either ambient temperature grinding or cryogenic grinding. The trade-off as a result of adding crumb rubber into new tires is a potential reduction in desirable physical and performance properties based on the current design of tires. Vehicle OEMs place pressure on tire manufacturers to substantially reduce the cost of tires. Tires which today cost the OEMs approximately 30 dollars each are expected to continue to drop in price over the next five years. To achieve these cost objectives, tire manufacturers must select compounds and designs that lend themselves to increased automation and reduced material weight.

This focus on reduced manufacturing costs, while retaining required performance, does not lend itself to the inclusion of recycled materials that are not necessarily as efficient and may be more costly in the short term than raw materials. This has motivated the search for cost-effective in-situ regeneration or devulcanization of waste rubber to provide superior mechanical properties [14].

The quality of the recycled components of waste tires and economic and technical feasibility, determine the use for the components (for example, TDF, recycled content of new tires, rubberized asphalt concrete). The recycled materials used in new tires must be of uniform composition, texture, and must meet exacting quality and performance criteria both as raw materials and as vulcanized material. This section of the report provides a summary of methods for producing crumb rubber [5, 13-37]. Klingensmith and Baranwal provide an informative review of these processes in their article entitled "*Recycling of Rubber: An Overview.*" As noted in that document, the major methods currently available for the production of recycled rubber are:

- Reclaiming.
- Ambient grinding.
- Cryogenic grinding.
- Wet or solution grinding.

Other methods include:

- Ultrasonic devulcanization.
- Chemical devulcanization.
- Thermal devulcanization.

4.2.1.1 Reclaiming

The reclaiming procedure consists of two steps: The waste rubber is first chopped into pieces and ground into fine particles, known as crumb rubber. In the second step, the crumb is subjected to heat in the presence of chemicals and then followed by friction milling [14]. Reclaim was widely used in tire compounding for lower cost, improving processing and fatigue resistance. However, due the need for strength and abrasion resistance requirements, reclaim is not use in radial tires [37].

For the traditional rubber "reclaim," crumb rubber is mixed with water, oil, and chemicals, and is then heated under pressure. During this process, the carbon-sulfur bonds are ruptured and the rubber becomes mostly devulcanized; it is then capable of being shaped into slabs [15]. According to Khait, tire manufacturers use these slabs as an alternative to virgin rubber for reuse in new tires or as an ingredient in other rubber products. Because reclaimed rubber has reduced elasticity, it is currently used for only about five percent of all new-tire production [15].

In the past, large quantities of whole tire tread peel, tubes, and other products were reclaimed using various reclaiming agents [6]. As much as 700 million pounds of reclaimed rubber was reported used in the U.S. in the 1950s [37].

When environmental regulations tightened and styrene-butadiene rubber (SBR) prices lowered, the result was an almost complete elimination of reclaim in the country [5]. The use of reclaim is primarily limited to bias ply tires [7]. At present there are two reclaimers in the U.S. These are U.S. Rubber in Vicksburg, Mississippi, and TRC in Stow, Ohio. There are reclaimers in the Netherlands, Russia, Romania, India, Mexico, Korea, and several other countries [37]. Reclaims are currently used in mats, bumpers, chocks, low-performance tires, and other low-dynamic-stress rubber articles [37].

4.2.1.2 Ambient Grinding

Dry grinding at ambient temperature is the simplest grinding process. The rubber is reduced to smaller chips and then further reduced to fine size (10 to 40 mesh). The processes usually involve the following activities: coarse-crumb sizing, ultra-fine sizing, metal separation, fiber separation, bagging, and weighing [12]. The particle size and the distribution of particle sizes in crumb rubber produced by ambient grinding depends on the number of times the crumb is recycled through the mill and the type of mill used. In general, the primary mill will reduce the large pieces of waste rubber to sizes in the range of 10 to 40 mesh. This size is considered suitable for non-dynamic applications of rubber [13].

4.2.1.3 Cryogenic Grinding

In cryogenic grinding, waste rubber is first reduced into smaller chips (about ¾ inch long). After the tires are shredded into ¾-inch chips, the processor separates steel by magnetic separation and also removes the textile cord. The rubber chips are then reduced to rougher, smaller pieces by different milling devices in a series of screening and re-grinding operations to achieve the desired particle size [15]. Data reported by Klingensmith and Baranwal [5] indicate that the costs of ambient and cryogenic grinding are comparable. Klingensmith and Baranwal state that the price of liquid nitrogen, used for freezing during the cryogenic method, has come down significantly, and the ground rubber produced from this method can compete on a large scale with ambient-ground products.

The cryogenic process produces fairly smooth fracture surfaces. Little or no heat is generated in the process. This results in less degradation of the rubber. In addition, the most significant feature of this process is that almost all of the fiber or steel is separated from the rubber, resulting in a high yield of useable product with little loss of rubber.

Table 2b reveals the effect of different levels of cryogenically ground crumb rubber in a rubber compound when formulated as shown in Table 2a. Table 3 is provided as another example that demonstrates the effect of crumb rubber on the mechanical properties of a compound.

In addition, Table 4a shows ingredients for cryogenically ground butyl in the inner lining of a tire. Table 4b shows the effect of the cryogenically ground butyl in a tire inner liner with formulation as shown in Table 4a.Table 5a shows the formulation of cryogenically ground butyl in an ethylene propylene diene monomer (EPDM) compound, and Table 5b shows the effect of particle size and loading for cryogenically ground EPDM on the mechanical properties of the rubber.

Table 2a: Cryogenically Ground Rubber (20 Mesh) in an SBR 1502 Compound

Formulation Ingredient	Level
SBR*1502	100.0
Zinc oxide	5.0
Stearic acid	1.0
TMQ*	2.0
N660 carbon black	90.0
Aromatic oil	50.0
Sulfur	2.0
MBTS*	1.0
TMTD*	0.5

Source: Reference 5

* SBR: styrene-butadiene rubber
MBTS: benzothiazyl disulfide (ALTAX)
TMQ: polymerized 1,2-dihydro-2,2,4-trimethylquinoline (AGERITE RESIN D)
TMTD: tetramethylthiuram disulfied (METHYL TUADS)

Table 2b: Properties of Compound With 17, 33, and 50 Percent Crumb Addition

Properties	Control	17% Crumb	33% Crumb	50% Crumb
Mooney viscosity	40	61	91	111
Rheometer max. torque	59	57	33	34
TC90, min.*	2.5	2.4	1.8	2.0
Tensile strength (psi*)	1,470	1,150	870	560
Ultimate elongation percent	330	330	300	270

Source: Reference 5

* TC90, min.: cure time (minutes to 90 percent torque increase)
psi: pounds per square inch

Table 3: Test Results of Soft Tread Grade Compounds Containing 5 Percent by Weight of Crumb Rubber

Properties	A	B	C
Tensile strength (psi*)	2,950	2,210	2,080
Elongation percent	820	750	740
100 percent modulus (psi)	106	105	106
Hardness shore A	52	52	53
Die C tear (psi)	253	240	243

Source: Reference 15

A = control (soft tread grade compound)
B = control + 5 percent by weight of crumb rubber from tread
C = control + 5 percent by weight of crumb rubber from whole tire
* psi: pounds per square inch

Table 4a: Cryogenically Ground Butyl in the Inner Liner

Formulation Ingredient	Level
Butyl HT-1068	80.0
RSS* #1	20.0
N-650	65.0
Mineral rubber	4.0
Durez 29095	4.0
Stearic acid	2.0

Source: Reference 5
* RSS: ribbed smoked sheets; a grade of natural rubber

Table 4b: Cryogenically Ground Butyl at Various Levels

Properties	Control	5%	10%	15%
Masterbatch, phr*	188	178.6	169.2	159.8
Cryogenically ground butyl	---	9.4	18.8	26.2
Cure time, Tc90, min.*	47.5	46.3	47.0	46.5
Cure rate, lbf. in./min.*	0.59	0.58	0.55	0.56
Tensile strength (psi*)	1,410	1,350	1,290	1,280
300% modulus (psi)	1,120	1,040	1,000	950

Source: Reference 5

*phr: parts per hundred of rubber
lbf. In./min.: pound-force inch/minute
TC90, min: cure time (minutes to 90 percent torque increase)
psi: pounds per square inch

Table 5a: Cryogenically Ground Butyl in EPDM Compound

Formulation Ingredient	Level
EPDM	100.0
N-650	70.0
N-774	130.0
Paraffinic oil	130.0
Zinc oxide	5.0
Low MW PE	5.0
Stearic acid	1.0
Antioxidant	1.0
Sulfur	1.25
Sulfads	0.8
Methyl tuads	0.8
Ethyl tellurac	0.8
Altax	1.0

Source: Reference 5

Table 5b: Cryogenically Ground Butyl at 10 Percent and 20 Percent Levels

Properties	Control	40 Mesh	60 Mesh	80 Mesh	100 Mesh
Cryogenically ground rubber at 10% levels					
Tensile strength (psi*)	1,410	1,290	1,430	1,470	1,440
Ultimate elongation, %	410	330	340	400	380
300% modulus (psi)	1,180	1,220	1,230	1,230	1,220
100% modulus (psi)	535	490	530	490	480
Hardness (psi)	73	70	70	70	71
Die C tear (psi)	193	175	173	171	172
Cryogenically ground rubber at 20% levels					
Tensile strength (psi)	1,410	1,230	1,360	1,460	1,410
Ultimate elongation, %	410	320	390	390	390
300% modulus (psi)	1,180	1,220	1,300	1,200	1,160
100% modulus (psi)	535	450	500	460	460
Hardness (psi)	73	72	70	69	68
Die C tear (psi)	193	178	163	165	181

Source: Reference 5
* psi: pounds per square inch

4.2.1.4 Wet or Solution Grinding

Wet grinding involves feeding coarse ground rubber into water, followed by grinding between closely spaced wheels (similar to flour mills). The material is finely ground, and sizes ranging from 60 to 120 mesh are commonly made and used. It is reported that particle sizes as small as 500 mesh can be produced using this method [13].

Due to uniformity and cleanliness, these products are considered suitable for recycled content. However, the processing cost is prohibitive when compared to costs in using virgin compounds.

Rouse, as compiled by Khait et al. [15], reported the development of high-surface area-fine rubber powder of 80 mesh by wet grinding. These rubber powders are highly resilient and can be used in many component parts of the tire as reinforcing fillers and processing aids. It is reported that rubber powder from 80 mesh tires behaved more like a reinforcing carbon black than an inert filler, due to the enhanced surface morphology of the rubber particles. Again, the cost of processing prohibits the feasibility for use as recycled content. Therefore, processors are forced to seek other niche markets where the use of such value-added crumb rubber could be price-competitive.

4.2.1.5 Other Processing Methods

Other processing methods include chemical, thermal, and ultrasonic devulcanization [14, 23–38]. Significant research in these methods is ongoing. However, the commercial feasibility of these methods is not known. An extensive summary of waste rubber processing methods and a bibliography is presented in the rubber recycling review authored by Myhre and MacKillop [14].

Chemical devulcanization is a process in which chemicals are added to the rubber to break the chemical bonds and remove sulfur from the cross-links of the rubber compound.

Thermal devulcanization is a method in which the rubber is subjected to high temperature utilized to break the cross-links. Microwave devulcanization is considered a thermal process as well. The microwave energy causes molecular motion, thereby raising the temperature of the waste rubber and causing the cross-links to be broken. If the microwave energy can be finely controlled, sulfur-sulfur and carbon-sulfur bonds can be broken but not carbon-carbon bonds [14]. The microwave process is patented by Goodyear Tire and Rubber Company. The process was used for a number of years but has since declined due to its high cost [14].

Ultrasonic devulcanization is a process by which ultrasonic waves are utilized to break sulfur-sulfur cross-links. Significant research on the use of ultrasonic techniques to devulcanize waste tire rubber has been conducted since the early 1980s. The effect of increasing the carbon black level increases the degree of devulcanization, and the ultrasonic treatment appears to cause a partial deactivation of carbon black [14].

4.2.1.6 Testing Standards

Much of the literature that has been reviewed indicates that the finer the crumb rubber, the larger the amount that can be reused without causing the new product's properties to deteriorate. If the surface of the crumb rubber is modified, however, an even larger percentage of waste can be incorporated into the compound [5]. Material quality is widely acknowledged as one barrier to greater use of recycled rubber in new tires.

The American Society of Testing and Materials (ASTM), has published two documents that are of particular interest: ASTM D-5603-96 [39] and ASTM D-5644-96 [40]. ASTM D-5603-96 presents a method for standardized classification for recycled vulcanizate particulate rubber. ASTM D-5644-96 presents a test method for the determination of the particle size distribution of recycled vulcanizate particulate rubber products.

4.2.1.7 Summary of Tire Processing Methods

From the review of the recycling methods, it is apparent that the variability in the quality and quantity of the recycled materials is of primary concern relative to inclusion in new tires.

Processing methodologies, cost optimization, and quality control require further development and effort to standardize the process. Because of the need to properly analyze the recycled material and to determine the ability to include these materials in new tires, recent efforts have focused on co-locating the recycling effort at the tire manufacturers' plants [14].

Over the past 10 years, the amount of recycled content in new passenger and light truck tires has increased from 0.5 percent to 5.0 percent. In some cases, incorporating recycled content of up to 10 to 15 percent in new tires is reported as technically feasible, without significantly impacting the performance of tires. However, due to economic factors, stability and uniform quality of supply, and marketing factors, tire manufacturers have generally limited the recycled content to 5 percent or less.

4.2.2 Consumer Behavior That Affects the Purchase of New Tires With Increased Recycled Content

The consumer perceives the use of recycled content in new tires as an accommodation to inferior material, compared to virgin products. As a result of this perception, consumers are not willing to pay the same or higher price they would pay for tires made of fully virgin components [41]. The TREAD Act may have a negative impact on increasing the recycled content. Because of the public's tendency to react negatively when advised of recycled content, and for marketing purposes, incentive-based promotions and consumer education about environmental benefits is required.

Approximately 30 randomly chosen tire dealerships in California were contacted to assess customer awareness of recycled content in tires. Based on this limited telephone survey, it appears that tire manufacturers or dealers do not promote to the consumer the environmental benefits of using recycled content in the production of new tires. Current tire manufacturer marketing campaigns focus on safety, longevity, and performance as opposed to long-term environmental impact. Tire manufacturers regularly conduct consumer surveys to determine primary needs of the consumer. With the tire failures associated with Firestone and the Ford Explorer, long-term environmental impacts rank relatively low compared to consumer safety. The approach used in the survey of dealerships was to determine how tires are currently marketed, as tire sales are a very competitive market. If tire manufacturers could gain a significant marketing advantage through emphasis on environmental impact, greater emphasis would likely be placed on this technology. It is apparent from the dealership survey that tire dealer staff, who represent the interface between the customer and the manufacturer, do not have significant awareness of recycled –content technology or issues.

The automotive industry, on the other hand, is targeting a 25 percent increase in use of recycled content in their products and is encouraging their suppliers to provide components with recycled content. The demand created by vehicle manufacturers for component suppliers to provide products with recycled content can be an effective path through which State agencies can coordinate the promotion of recycled content in new tires.

The opinion of tire manufacturers is that the price of natural and synthetic rubber must rise significantly to warrant a more aggressive consideration of recycled content in new tires [41–43].

Currently, the market prices for virgin materials are relatively stable. However, with the significant increase in the number of vehicles manufactured for emerging markets, such as China, the availability of materials may be impacted.

4.2.3 Factors Affecting Both the Costs and Benefits of Increasing the Recycled Content in New Tires

A number of crumb rubber production technologies are available on the market. While an effort is underway to develop a sound technology that is cost-competitive, the tire industry has not yet accepted a technology for wide use in production of new tires.

There is an increasing need for waste tire rubber powder of 80 mesh and finer to create parts with smoother surfaces. Finer powders also improve the physical properties of rubber compounds and allow for faster mixing times when rubber powder is used as a partial substitute for virgin rubber. However, few techniques have been found that can produce fine tire rubber powder in a manner that meets current cost objectives [44].

To substantially increase the use of crumb rubber in new tires, several factors must be considered:

- A reliable source of crumb rubber with consistent physical characteristics such as size, shape, and surface texture. Equally significant is the consistency in the chemical composition of the ground rubber. Because of the great differences in rubber compounding between all of the tires in the waste stream, this remains a significant challenge.
- Waste tire recycling involves tire collection, transportation, and processing of waste tires, raw materials, blend treatment, and separation technology. The logistics of collecting and transporting waste tires to processing plants—or transporting processed rubber to tire manufacturing plants—in a timely manner is considered one of the cost determinants. Identifying new-tire sellers as the turning point for tires to be recycled helps close the transportation loop. Tire sellers, already familiar with tire requirements can support the grading and identification of tires, which are appropriate for recycling to new tires as opposed to tires, which are more appropriately used for fuels or other uses.
- Maintaining consistency in crumb rubbers for use in new tires has been difficult, primarily because of the many compounds used in tires.
- The processing methods must be consistent in the way the crumb rubber is produced. The same is true for the mixing of ingredients and tire building. The performance characteristics of the crumb rubber compounds must be equivalent to the virgin compounds they are replacing or be able to be integrated in a manner which does not adversely impact the overall system performance of the tire.
- Economic incentives need to be in place, particularly in the development of new technology, to produce high-quality crumb rubber. High-value products that are competitive in pricing and performance must be derived as a raw material from the waste tires.

- The low price of virgin rubber, its availability, and many years of utilizing virgin rubber materials determines the maximum cost that can be charged for crumb rubber. Significant capital investments have been made by tire manufacturers to process virgin rubber in their manufacturing plants. The processing costs are not eliminated by using recycled rubber.
- Development of new tire designs that can accommodate a higher percentage of recycled content without sacrificing tire performance or reliability.

The factors listed above need to be considered in developing a feasible approach to increasing recycled content in new tires. Most ongoing research is focused on addressing the technical feasibility at a development level and does not address the commercialization aspect of the methods and processes developed. Commercial processes are highly proprietary and therefore additional efforts with tire manufacturers and recycling companies will be required to implement effective solutions.

Ford and Michelin estimate that recycling waste tires back into new tires (with the use of recycled rubber at a rate of 10 percent) could cut the number of tires going into the landfills by approximately 33 million tires annually, or 12 percent of the approximately 281 million waste tires generated in 2001 (nationwide annual waste tire generated is assumed as approximately one tire per capita).

4.2.4 Trade-Offs and Variables Such as Cost and Performance When Tires Are Manufactured With an Increase in Recycled Content

Ambient processing of ground tire rubber usually produces crumb rubber supplies of 10 to 40 mesh and is the least expensive recycled rubber on the market. Cryogenically ground rubber is available from 40 mesh in size and finer, but at increased cost compared to ambient grinding. Klingensmith and Barnawal [5] have suggested, however, that in large-scale production, prices may be comparable. However, given the recent rise in energy prices, it is unlikely that these costs are comparable even in large-scale production.

Major manufacturers generally indicate that they have successfully been able to incorporate approximately 5 percent by weight of crumb rubber into new tires, primarily for the passenger car, van, and light-truck tires.

Adding crumb rubber to a virgin compound is reported to have the effect of lowering the physical properties by approximately 10 to 15 percent. Once the initial reduction in these properties occurs, the physical properties are largely retained at that same level [45]. Ryan [45] concluded that there is an initial reduction of in modulus upon introduction of the recycled rubber particles, but the value then remains constant. However, the increase in modulus for the treated rubber manifested poor to unacceptable levels of process ability (reduced scorching time).

Chandra and Pillai [46] concluded that in addition to the physical properties that impact the performance of tires with increased recycled content, the savings are “not significant enough” to merit the effort of introducing recycled materials into tire formulations in larger volumes.

The addition of recycled rubber to virgin rubber compounds generally lowers tensile strength and fatigue resistance, and it reduces air and moisture impermeability [13]. Air and moisture impermeability are critical safety considerations within the tire system. Air and moisture migration produce separations within the tire structure which can result in unpredicted catastrophic tire failures during operation. Tables 2a–5b illustrate the tradeoff in mechanical properties, at the rubber compound level, associated with the use of recycled content.

While tensile strength and fatigue resistance are achieved at a compound level, their economic feasibility as part of a new tire was not discussed. Reports available reveal that the research that has been conducted is primarily evaluating the performance of rubber compounds with recycled content to those with virgin ingredients, and not as a complete tire system.

Since there is no published performance data for tires with treated or untreated rubber recycled, the findings are inconclusive in identifying the most suitable approach to incorporate recycled rubber into the tire compounds. Further research beyond a paper study is required.

It is reported by many researchers that the use of crumb rubber resulted in a higher curing rate, suggesting that it may play the role of process accelerator. This indicates a potential for the use of crumb rubber as a substitute for expensive curative ingredients, such as zinc oxide.

Tread compounds for tires require acceptable properties in abrasion resistance, wet and dry frictional values, cutting and cracking growth resistance, and low hysteresis to minimize internal heat generation and rolling resistance.

Tire rolling resistance reduction is one of the factors considered in tire design that can also have a significant impact on the environment. Higher rolling resistance can produce poorer fuel economy (a 10 to 20 percent increase in some cases). The tradeoff between fuel economy and vehicle design factors, such as comfort, noise suppression, and road adhesion, will require that these factors do not dominate the importance of the rolling resistance. The thrust of research activity to reduce energy loss due to rolling resistance, can be categorized as follows [47–50]:

- Tire material properties.
- Tire construction.
- Road and tire/vehicle interaction.

In general, the addition of crumb rubber into a virgin compound increases hysteresis. Increase in hysteresis is manifested as increased internal heat generation and thereby increased rolling resistance. Therefore, the use of crumb rubber is generally limited to areas of the tire that have reduced flexure.

The internal resilience/hysteresis characteristics of typical tire rubber compounds, including the casing and materials themselves, generate heat. Due to the poor thermal conductivity of rubber, this heat causes temperatures within the structure to rise rapidly to levels that can lead to total disintegration of the tire. The failure can result in conditions such as bond failure, reduced tear strength of the tread rubber, and actual charring or melting of the casing cords.

The control of heat generation within a tire of any type is essential as maximum speed or worst-case operating conditions are approached. As discussed previously, tires with recycled content manifest higher internal heat generation compared to the virgin compounds they replace. Therefore, the use of tires with recycled content will generally be limited to the low end of the performance requirements, including reduced life span, until the recovery methods can produce recycled content comparable to the virgin ingredients.

Under Chapter 912, Statutes of 2001 (Sher, Senate Bill 1170) [51], the California Energy Commission is mandated to make recommendations on a California State Fuel-Efficient Tire Program. There is an inherent competition among the different programs sponsored by the State of California, where the coordination of efforts among the State agencies is vital for optimum outcome.

With the effort of so many companies and recycling firms trying to develop new uses for waste tires, the result has been many new and expanded uses. Therefore, if the cost-effectiveness of alternate uses for waste tires continues to be more attractive, the economic incentive to continue the research required to increase the recycled content in new tires will remain limited.

4.2.5 Tire Manufacturers and Their Locations Worldwide and Manufacturers Who Have Used Recycled Content in Tires

The global distribution of tire manufacturers is included as Appendix A. The data was extracted from an article in *Rubber and Plastic News,* "Global Tire Report, 2001" [52]. The listing is divided into seven geographical regions: North America, comprising of the United States and Canada; Latin America, including Mexico, Central America, and South America; Europe, including Russia and most of the former Soviet Bloc nations; Asia, including India, Japan, the Pacific Rim, and former states of the Soviet Union located in Asia; Africa and the Middle East; and Australia and New Zealand. Within each region, tire makers are listed by country.

The major manufacturers in the U.S. indicate that they are making an ongoing effort to increase the recycled content of new tires. The general consensus in the industry is that up to 5 percent recycled content is accepted as reasonable. However, data associated with the number of tires produced with recycled content is considered proprietary. Some manufacturers indicated that they do not keep track of such data and/or do not compile it for public consumption.

NATC primarily depended on published reports and its historic contacts that have been in the industry in establishing the summary of tire manufacturers' activities with respect to recycled content. NATC approached RMA for information on recycled content practices by RMA's member tire manufacturers. NATC received a response from RMA indicating that they do not provide names of contact personnel of its members. NATC then contacted individual tire manufacturer representatives affiliated with RMA and obtained response from limited contacts.

A subsequent request that directly originated from CIWMB has resulted in the following responses. The responses obtained from these contacts indicate that the activity towards increasing the recycled content is very limited.

Letters and emails were sent to many of the major tire manufacturers in the United States. Each manufacturer was asked whether their tires contained recycled content and specified waste tires as the source of the recycled content. The following excerpts are taken from responses submitted to CIWMB:

Toyo Tires—"No, they are all new rubber tires. The only recycling we use in our tires are from parts that have not been distributed or used and are still in our factories.

However, we do have other rubber products that are not handled in this department that use recycled rubber in their construction.”

Michelin of North America, Inc. (MNA) — “MNA does use some recycled rubber in the manufacture of some of its products. This includes rubber from used tires as well as rubber that is recouped during the manufacturing process. We don’t want to give you the impression that MNA is using old tires from scrap piles in making any of its new tires. We don’t. We do however regularly recycle the inner liner rubber from some post-consumer used tires.”

Goodyear Tire and Rubber Company—“Our tires do not contain any rubber from waste tires.”

Yokohama Tires—“Yes: Various Yokohama tires sold in the state contain recycled materials. The primary material is reprocessed rubber from used rubber products. The percentage by tire varies, in some cases 1%, in others slightly higher.”

Bridgestone Firestone—“Globally, Bridgestone Corporation utilizes post consumer recycled tire material in various tire lines at varying percentages. The percentages used can vary region-to-region based on the availability and quality of supply of the recycled material. The tire type and its performance requirements also limit the potential percentage usage of recycled material.”

“Generally, the use of recycled tire material in new tires is challenged by the fact that unlike paper, metals, plastics and glass, it is not currently possible to obtain materials from tires that have properties adequately similar to the original materials used in manufacturing tires. Tire rubber materials are highly engineered, with specific qualities of hystereresis and other chemico-physical properties, designed to optimize wet and dry traction, long life, low rolling resistance, comfortable ride responsive handling and performance characteristics, at an affordable cost. Unfortunately, the products currently available from recycled tires do not provide performance-enhancing characteristics; rather they tend to degrade performance. For passenger tires, there are especially detrimental effects on tire wear life and rolling resistance (fuel consumption), therefore, the amount of post-consumer recycled material utilized must necessarily be very limited.”

Data from European countries show that the Netherlands, Sweden, and Germany have the highest used tire recovery rate (100 percent, 99 percent, and 96 percent, respectively) [6]. However, the data does not show how much of the recovery is directed to the increase of recycled content in new tires.

4.2.6 Comparison of the Use and Amount of Crumb Rubber From Waste Tires in Bias Ply Tires Versus the Use and Amount of Crumb Rubber From Waste Tires in Radial Tires

In general, the amount of crumb rubber that can be used in bias ply tires is higher than the amount that can be incorporated into radial tires. However, the volume of bias ply tires produced has shrunk to a point where no significant impact is realized as a result of incorporating crumb rubber into new bias ply tires. As a result, no data is available comparing the use and amount of crumb rubber in bias and radial tires.

The carcass and sidewall design of radial tires requires high strength and endurance properties (for example, tensile strength, shear strength, flex and abrasion and aging resistance). These requirements, to an extent, require the use of materials that have precise properties, currently only found in virgin ingredients. Thus, relative to the reduction in the manufacture of bias tires, the increased use of radial ply tires, which have measurably improved longevity and improved fuel economy, has resulted in reduced recycled content per tire.

Table 6 shows the breakdown of the ground rubber market. Since the number of bias ply tires produced has shrunk substantially, most or all of the 50 million pounds of crumb rubber used for tire manufacturing was likely recycled into radial tires.

Table 6: Ground Rubber Market Rubber Consumption by Size Range

Application	Size Range	Estimated
Rubber modified asphalt	16 – 40 Mesh	220 Million pounds
Field turf	¼ inch to 20 Mesh	50 Million pounds
Tire manufacturing	80 – 400 Mesh	50 Million pounds
Molded/extruded products	4 – 100 Mesh	50 Million pounds
Loose cover	⅜ to ¼ inch	30 Million pounds

Source: Reference 4

4.2.7 Trends and Geographical Patterns in the Use and Amounts of Crumb Rubber in Types of Tires Produced

The high physical property characteristics necessary in heavy truck compounds still dictate the use of natural rubber as the base polymer. For car tires, the adoption of wholly synthetic rubber- based compounds is cheaper and provides fundamentally high frictional values. According to the STMC [4], the shutdown of Rouse Polymer International in Vicksburg, Mississippi, and a ground rubber facility at Entire, Nebraska (both by fire), will significantly impact the ground rubber industry. Rouse Polymers International's limited operation will impact the destination for buffings, tire-manufacturing by-products, and the ultra-fine rubber market, since they were one of only two companies in the United States that can produce that class of material [4]. The other company is the Landstar Polymers facility in Chambersberg, Pennsylvania, which is also reported as non-operational at this time. States such as California, Georgia, Maryland, New York, and North Carolina have underwritten grants for the investigation of increased recycled content and/or attracting the crumb rubber producing industry. The State of New York has funded a research program to investigate recycling of postconsumer waste tires (1993) in collaboration with Dunlop Tire Company. The State of North Carolina is under contract with Continental General Tire for approximately $1.52 million to increase the recycled content in new passenger-car and light-truck tires. As part of the contract, Continental General Tire has concluded a multi-year research program on the use of recycled rubber in new tires. This research program was designed to investigate the increase of recycled content in new tires up to 25 percent.

Georgia and North Carolina appear to be in the process of developing their own ground rubber production operations. [4]. Maryland's facility, which has a capacity of processing 1.5 million tires per year, has been operational since early 2003. This facility produces 5 mesh to 40 mesh crumb rubber for non-tire applications. Additionally, one major ground rubber producing company, Recovery Technology Group (RTG), reportedly is in the process of expanding its ground rubber operations into existing facilities or restarting once-closed operations. RTG acquired the crumb rubber producing plant formerly owned by Santee River Rubber L.L.C. The Santee River plant was a crumb rubber supplier to Continental General Tire research for increasing recycled content through a grant from the State of North Carolina before bankruptcy. Blumenthal [53] reported that the state of Texas is also investigating the viability of reopening a ground rubber operation in west Texas, which failed when the Intermodial Surface Transportation Efficiency Act (ISTEA) was repealed.

There is no data available depicting the geographical patterns in the use and amount of crumb rubber in the types of tire produced.

5.0 Cost-Benefit Analysis on Increasing the Recycled Content in New Tires

5.1 Methodology

Market data identified through the literature search was used for the analysis and discussion in this section. The literature search identified that high-quality crumb rubber requirements drive the technology selected to generate crumb rubber for use as recycled content in new tires. According to the literature reviewed, the limited availability of high-quality crumb rubber and the high cost of such crumb rubber relative to virgin rubber are the barriers for using increased recycled content.

Processes at tire manufacturing plants remain unaffected due to incorporation of recycled content in new tires based on current manufacturing and design processes. Therefore, in this analysis, crumb rubber processing is considered as the effort with the most significant potential impact to increasing recycled content. In this analysis, the primary output is 80+ mesh crumb rubber or finer for use as recycled content. It is further assumed that secondary products can include reusable casings or non-reusable casings for other applications.

There were no data identified through the literature search to quantify the estimated benefits derived from environmental policy. Policy actions are generally aimed at preventing or mitigating the adverse effects of waste tires, with the market governing the path of recycling. Without quantified benefits data on which to base cost and benefits of the crumb rubber market expressed monetary ratios, certain limitations had to be overcome. To overcome these limitations, a cost-effectiveness approach was taken that distributes the price of crumb rubber as a function of the crumb rubber size. Almost all of the diverted waste tires in California are used in applications such as tire-derived fuel and civil engineering applications where fine mesh size is not required. Therefore, there is not sufficient price history to use from California to develop a price structure in this analysis. As a result, nationwide data was used.

One of the critical factors in cost-benefit analysis is the ability to define the boundary of the analysis. NATC's approach focuses on the segment of the end-of-life path of a tire, component reuse, and material recycling (Figure 2) in particular, retreading coupled with crumb rubber generation. Figure 2 depicts that the objectives of increasing the recycled content in new tires and increasing the life span serve to keep a tire material in the original application for as long as possible.

The following assumptions are made in this analysis:

1. If a reliable source of high-quality crumb rubber is available, tire manufacturers are willing to fully participate in the effort to increase the recycled content. That is, the major incentive for the tire manufacturers is availability of a reliable source and high-quality crumb rubber.
2. There is a demand for high-quality crumb rubber by tire manufacturers that will enable retreaders or processors to consider high-quality crumb rubber generation or production of buffings for further processing.
3. Crumb rubber produced from buffings is used as recycled content.

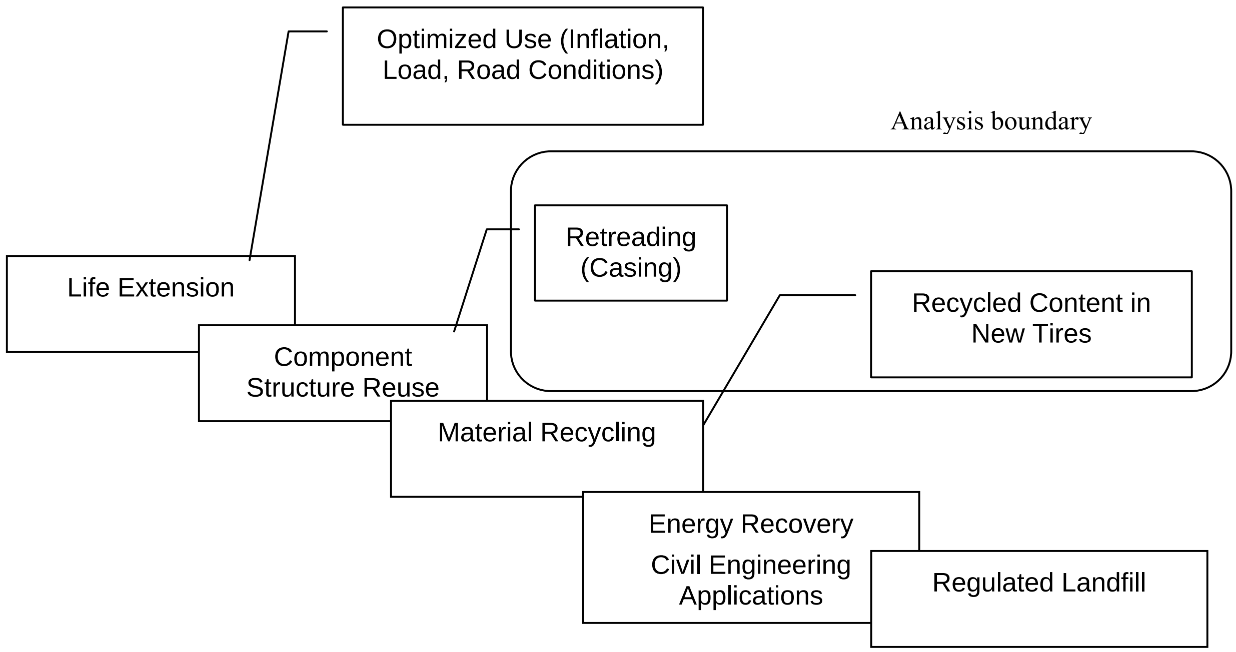
4. Removal of tread from waste tires before diverting for other uses has no significant impact on other applications.

5. Subsidies or incentives in place are uniform across the different uses of waste tires and do not bias one type of use over another.

6. Regulations relative to use of recycled tires as fuel do not change from their current status.

7. External influences such as import of crumb rubber for further processing is neglected assuming that if they occur, subsidies can be considered to maintain competitiveness of domestic processors.

Figure 2: Preferred Path to End of Life



The very characteristics that are desirable in tires—high performance and long life/durability—make their "disassembly" for recycled use difficult. The process of disassembly, whether physical or chemical, attempts to break up a product into several components or pieces, with the expectation that the pieces collectively have a net value greater than the waste product as a whole (that is before disassembly). However, unlike an assembly process, the net value added in disassembly is less. This implies that for a disassembly activity to be profitable, the labor, equipment, energy, skill, and space requirements must be relatively small or low cost.

One of the significant potential drawbacks in the success of generating crumb rubber for use to increase the recycled content in new tires, particularly for California, is the cost of transporting the crumb rubber to tire manufacturers. California has no tire manufacturing plants at present, and there are no market incentives to attract manufacturing plants into the state. One option is to ship the crumb rubber to the tire manufacturers. Some states are faced with a shortage of waste tires and are thus unable to attract investors to establish crumb rubber processing facilities. Since California has the largest population in the U.S., it has proportionally a larger number of waste tires with which to establish centralized processing centers. These centers could generate buffings or fine-mesh crumb rubber, provided other profitability requirements are met.

5.2 Technology for Increasing the Recycled Content in New Tires

Most of the technology or processes reviewed involved the crumb rubber production process. No reported changes, or modifications of equipment or process by tire manufacturers, are required for increased recycled content in new tires. This is an advantage in that tire manufacturers do not have to make a large capital investment to accommodate recycled rubber in their processes. Therefore, the technology involved focuses on the production of high-quality crumb rubber for use in new tires.

Typically, individual tire compounds are unique to each manufacturer and are integrated with the tire structure. Developing common rubber compounds will probably not represent a viable industry-wide option. As a result, tire manufacturers prefer to use their own factory waste as the recycled content in new tires. Some crumb rubber producers focus on factory waste processing. The factory wastes are source-separated at the crumb rubber processing plant. This will allow for improved quality control and long-term contracts between tire manufacturers and processing plants.

The mixing of the sidewall rubber with the tread rubber and other impurities during the whole-tire grinding process generally reduces the ability of the crumb rubber material to replace virgin materials in higher percentages, as different parts of the tire are designed for different functions. This is one limitation clearly emphasized in the literature reviewed. For example, rubber used in the sidewall is designed to withstand cyclic flexing loads. The tread compound is designed to generate good traction, reduced rolling resistance, and better handling, while retaining resistance to tear and wear due to interfacing with the road. As such, these compounds, while compatible within the tire system, have very different mechanical properties.

In addition, environmental impacts on the tire (aging due to thermal loads, exposure to ozone which produces surface cracking, tear and wear) and contaminants such as fiber and steel material can degrade the quality of crumb rubber from whole tires for use as recycled content in new tires. From a quality perspective, the relative cleanliness of the tread rubber makes it the most attractive for use in new tires.

Crumb rubber from tread can be generated without grinding the whole tire through buffing. Many processors in California are currently generating crumb rubber from buffings, which are generated during the tire recapping process.

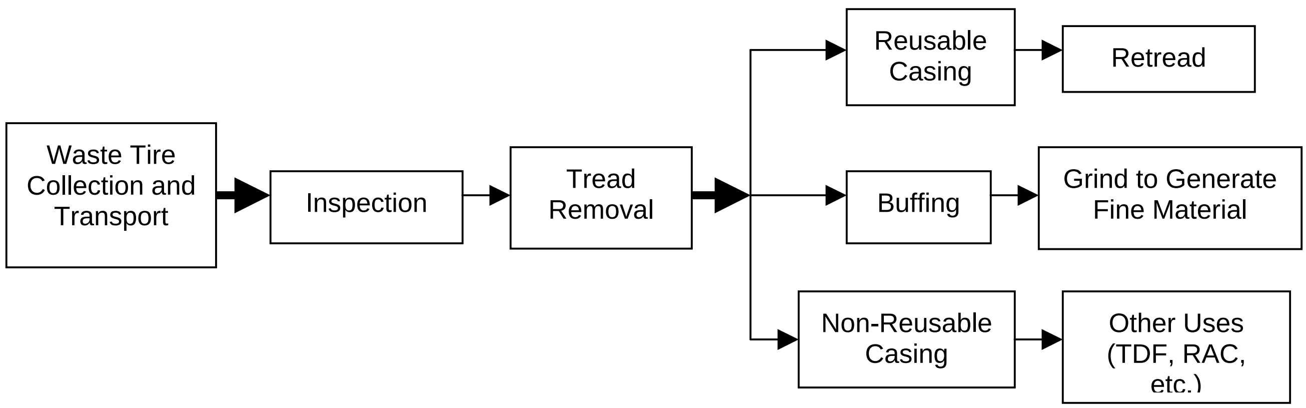
Although several processing methods have been identified as discussed in the literature section, ambient grinding and cryogenic grinding remain the commercial options currently available for generating crumb rubber for the various recycling applications.

Since California has no tire manufacturing plants at present, the market model for the production of quality crumb rubber needs to be looked at from a different perspective compared to states with tire manufacturing plants. This study proposes that the recycling of disassembled components (casings) be considered as an integral part of the effort to increase the recycled content in new tires. This is consistent with the research effort being undertaken by CIWMB to increase the life span of tires. In the case where the casing is not suitable for retreading, other alternative uses such as in rubberized asphalt concrete (RAC), tire-derived fuel, and civil engineering applications are available. Therefore, it is important to investigate the possibility of creating markets for the casings of passenger-car and light-truck tires and pursue the use of tread rubber for recycling into new tires to maintain synergy between increasing recycled content and increasing life span.

The relative cleanliness of the tread rubber, and the fact that the recycled crumb rubber is used in the tread section in new tires, makes it more attractive for the tire manufacturer to focus on the use of tread crumb rubber as the preferred recycled content. The technical barriers that exist will not impact the production of high-quality crumb rubber. Nevertheless, until such technologies become economically viable and commercially available, focusing on the recycling of crumb rubber from tread will allow for a margin of quality. This is due to less fiber and steel content, consistency, and relative simplicity of the polymer. Veredistein, a European recycling company, uses tread materials as a regular feedstock for producing crumb rubber used in new tires [54].

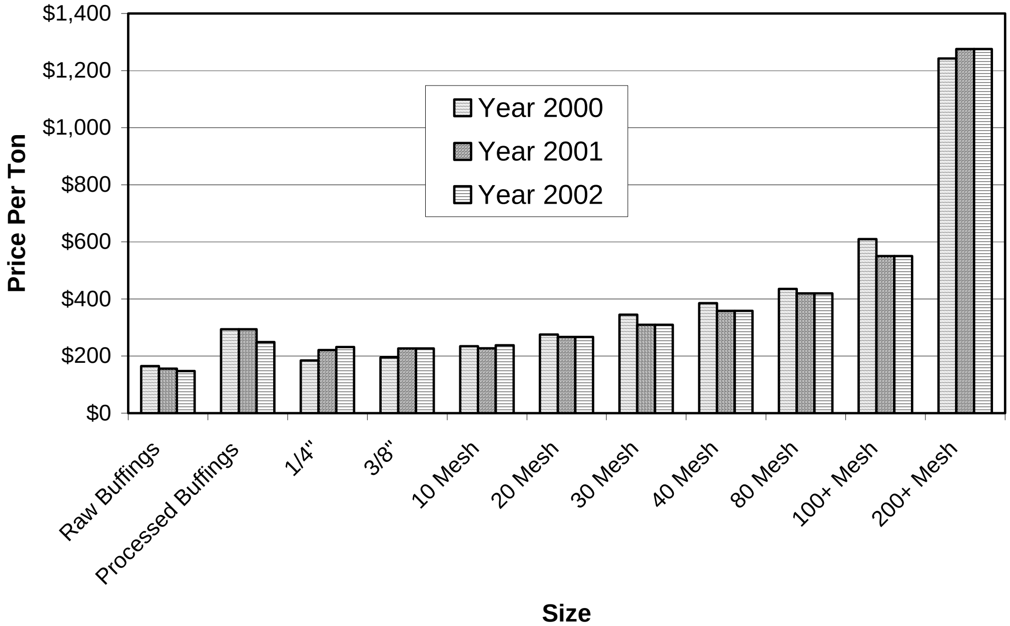
As an integral part of the life extension of a tire, the value-added fine mesh crumb rubber can be supplementary incentive for processors by maximizing the values of the products derived in the "disassembly" process of a tire (Figure 3).

Figure 3: Component Recycling Process



The economics associated with whether to process the buffings within California is affected by the cost of energy and freight. A nationwide average of crumb rubber prices as a function of crumb rubber size is summarized below to illustrate value added by processing buffings into fine crumb rubber [55].

Figure 4: Average Price Comparisons for Different Mesh Sizes



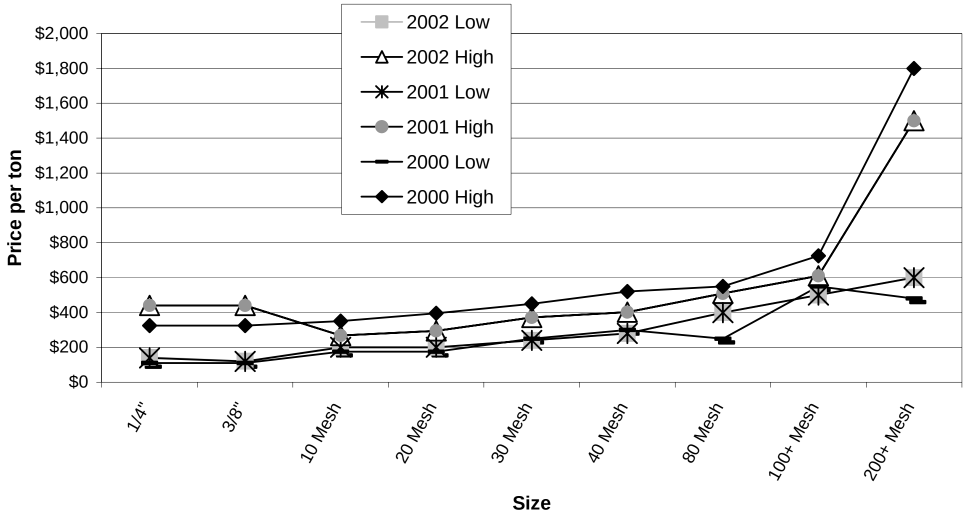
Source: Reference 55

In Figure 4, the processed buffings show prices comparable to those of mesh sizes in the 20–40 range.

Figure 5 depicts a relatively tight-banded range of prices at 10–100 mesh over the past three years. Note that the price range is tighter in 2001 and 2002 compared to year 2000. At 80-mesh size, the price is stabilized at approximately $400 per ton. By processing the buffings, the added value is that the prices are pushed to the range where prices are better stabilized.

The price ranges reflect variables such as regional conditions, raw material supply, competition, location of manufacturing facilities or end-users, State and local regulations, subsidies, credits, or other market incentives [55]. Table 7 provides a contrast of prices for tire-derived materials used for different applications.

Figure 5: Price Range Comparisons for Different Mesh Sizes



Source: Reference 55

Assuming approximately 6 pounds of tread crumb rubber can be recovered from a waste tire, about 330 tires are required to generate 1 ton of raw buffings. The average price for raw buffings in 2002 was $164.78 per ton. As shown in Table 7, the average price for 1-inch-minus shreds used as TDF for 2002 was $32.10 per ton (per 100 tires, assuming 20 pounds weight per tire). For one ton of by-product there is a ratio of 3.3:1 between the number of tires used to produce raw buffings and the number used for TDF. Thus, based on the price range given, the use of tires for fuel instead of buffings can result in $105.93 of revenue per ton of buffings.

Table 7 shows this revenue is within the range of the price of raw buffings, which is $100–$190. The advantage of buffing over whole-tire burning for fuel is twofold. The value of the by-product of the waste tires is increased. The remaining tire components, such as the casings, can be reused or further processed for other applications, including TDF. However, depending on the location of end-users and market incentives, these advantages could be reduced.

Some processors in the western region have indicated that a selling price of $180 per ton of raw buffings is required to realize a profit when removing treads from their casings without regard to whether or not the casings are reusable.

Table 7: Market Prices for Tire-Derived Materials

CRUMB RUBBER						
Size	2002	2002	2001	2001	2000	2000
	Average Price Per Ton	Range	Average Price Per Ton	Range	Average Price Per Ton	Range
1/4”	$232	$141-$440	$221	$140-$440	$185	$110-$325
3/8”	$226	$121-$440	$226	$120-$440	$195	$110-$325
10 mesh	$238	$202-$268	$227	$200-$268	$235	$175-$350
20 mesh	$267	$200-$294	$267	$200-$294	$275	$175-$395
30 mesh	$310	$240-$372	$310	$240-$372	$345	$250-$450
40 mesh	$358	$280-$402	$358	$280-$402	$385	$300-$520
80 mesh	$420	$400-$510	$420	$400-$510	$435	$250-$550
100+ mesh	$550	$500-$610	$550	$500-$610	$610	$550-$725
200+ mesh	$1,275	$600-$1,500	$1,275	$600-$1,500	-	-

BUFFINGS					
Size: Raw			Size: Processed		
Year	U. S. Average Price Per Ton	Range	Year	U. S. Average Price Per Ton	Range
2002	$164.78	$100-$190	2002	$294.30	$220-$400
2001	$155.45	$100-$190	2001	$294.30	$220-$400
2000	$147.93	$55-$245	2000	$249.40	$100-$450

TIRE-DERIVED FUEL			ENGINEERING TIRE CHIPS/SHREDS		
Size: 1" Minus			Size: 1" – 2"		
Year	U. S. Average Price Per Ton	Range	Year	U. S. Average Price Per Ton	Range
2002	$32.10	$9.50-$65	2002	$23.00	$5-$50
2001	$31.50	$9.50-$65	2001	$23.00	$5-$50
2000	$28.75	$10-$50	2000	$22.00	$4-$85

Continued on next page

Table 7, continued

TIRE-DERIVED FUEL (continued)		
Size: 2" Nominal		
Year	U. S. Average Price Per Ton	Range
2002	$22.05	$5-$35
2001	$21.00	$5-$35
2000	$18.85	$3-$55

WHOLE TIRE TIPPING FEES	
Year	U. S. Average Price Per Ton
2002	$10-$55
2001	$10-$65
2000	$35-$95

ENGINEERING TIRE CHIPS/SHREDS (continued)		
Size: 3"–4"		
Year	U. S. Average Price Per Ton	Range
2002	$17.00	$5-$35
2001	$17.00	$5-$35
2000	$5.80	$3-$20
Size: 5"–6"		
Year	U. S. Average Price Per Ton	Range
2002	$31.00	$20-$44
2001	$31.00	$20-$44
2000	$4.65	$2-$17

Source: Reference 55

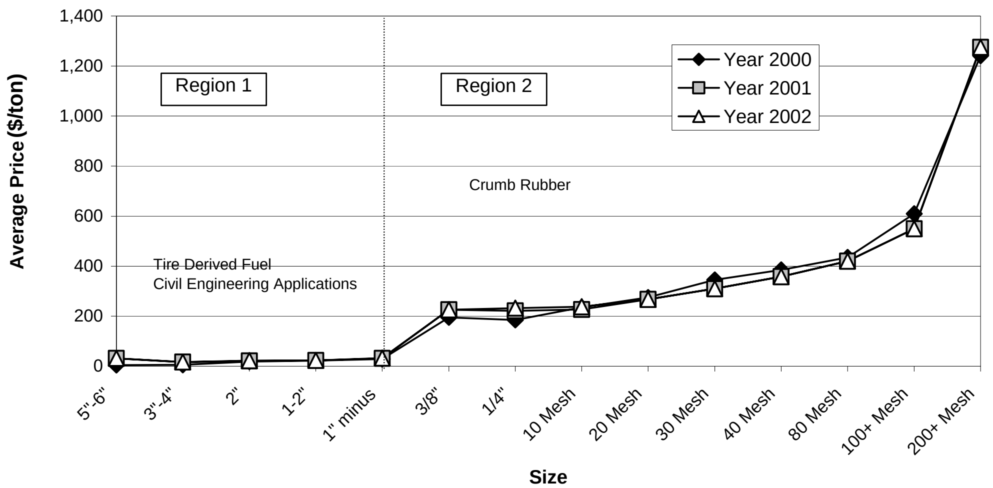
The following advantages exist for considering buffings as the source of crumb rubber for increasing the recycled content of new tires.

- Rubber will already be clean before further grinding begins.
- High density of the buffings, which means more usable material would be shipped to the manufacturer than if whole tires were shipped. On the other hand, if processing operations are co-located with the tire manufacturing plant, factors such as packaging and controlled storage requirements for size-reduced rubber as well as the ability to produce crumb rubber on site and on demand can be a more viable business model than having buffings shipped from a remote location.

The pricing data shown in the figures and table above indicate that buffings can be converted into high-value crumb rubber. The tight band in the range of cost for the 10–100 mesh crumb rubber is an indicator that the cost is relatively stabilized and the demand is sustained (Figures 3 and 4).

As illustrated in Figure 6, the jump in price between the two regions shown is directly attributed to the level of processing required to reduce the waste tire from chips and shreds to crumb rubber. For example, the increase in price from 1 inch minus shreds to crumb rubber size of ¼ inch is 7.2 times in 2002. As the sizes are reduced further and cleanliness becomes more crucial, other price jump points are reached on the market. To increase the supply of finer size crumb rubber particles, there is a need for marketing incentives and/or other monetary subsidies for companies that produce crumb rubber.

Figure 6: Relative Price of Crumb Rubber and Chips and Shreds



5.3 Technology for Producing Crumb Rubber to Meet New Specifications for Tire Manufacturers

The major commercial methods currently used to produce crumb rubber are as follows:

- Ambient grinding.
- Cryogenic grinding.
- Wet or solution grinding.

To meet the demands of the compounder or the needs of the end-user, the crumb rubber must be comparable to the virgin components that it is intended to replace in terms of material properties, quality, and cost.

The added cost of processing recycled material so as to maintain a standard comparable to that of the virgin material is considered market-prohibitive. The low price of virgin rubber sets an upper limit on the price of the crumb rubber. The added cost is not limited to a specific segment of the processing operation associated with the recycling of crumb rubber into new tires, but is distributed throughout all stages of new-tire generation from waste tires (collection of waste tires, separation, processing, packaging, and transport).

A standardized procedure to maintain consistently high-quality crumb rubber generation is required. In general, a “high quality of crumb” means low fiber content (less than 0.5 percent of total weight), low metal content (less than 0.1 percent), and high consistency [5,37]. The accepted level of maximum moisture content is about 1 percent by weight. The American Society of Testing and Materials (ASTM) has published two documents: ASTM D-5603-96 [39] and ASTM D-5644-96 [40]. ASTM D-5603-96 is a method for standardized classification for recycled vulcanizate particulate rubber. ASTM D-5644-96 is a test method for the determination of the particle size distribution of recycled vulcanizate particulate rubber products.

The use of tread rubber as the raw material for generating crumb rubber to increase the recycled content in new tires can significantly improve the quality of the crumb rubber composition. This is because the tread rubber can be free of fibers and steel.

Alternate uses of crumb rubber may be economically more feasible than producing fine mesh size crumb rubber and transporting it across the country to tire manufacturing plants. However, with proper incentives in place, the use of rubber from buffings can be a more viable intermediate step towards increasing the recycled content. Buffings from retreading processes for truck tires are currently collected and reused in the retreading process in a cost-effective manner. Buffings can be produced by existing retreading companies, thereby avoiding the significant capital investment associated with the fine-crumb-rubber production process. Purchasing modular equipment with the capabilities to meet demand fluctuations is more cost-effective than employing a single facility with a large capacity to produce crumb rubber. Moreover, the effort required to separate any fiber and steel from buffings is minimal compared to producing crumb from whole tires. As need requires, equipment and physical space can then expand in per-year increments until full capacity is reached.

Warehousing is directly related to sales. Therefore, the production capacity must be optimized, keeping warehousing cost and availability in mind.

5.4 Potential Incentives to Manufacturers, Retailers, and Customers

Under the present economic factors, no significant reduction in the cost of crumb rubber is realized in comparison to the virgin rubber. These factors include the highly competitive markets under which suppliers of waste tires operate and the economics under which tire manufacturers operate.

- **Tire Manufacturers**: The effort by tire manufacturers is primarily driven by self-imposed initiative in an attempt to assume responsibility of their product, or it is due to policies imposed by regulatory agencies or their customers. Due to implications for product reliability, no apparent incentive for tire manufacturers is present to increase the proportion of recycled content in tires. The following potential incentives could have a positive impact on increasing the number of tires with recycled content:
    - Reliable cost-competitive supply of high-quality crumb rubber.
    - Requirements imposed by vehicle manufacturers or government agencies.
- **Retailers:** There is no evidence that retailer awareness or efforts to market recycled content in new tires exist. No published reports are available which indicate participation of retailers in increasing the recycled content in new tires. None of the retailers contacted by NATC demonstrated awareness with respect to increasing recycled content in new tires. The current marketing environment demonstrates that there is significant concern on the part of the public and the federal government relative to tire safety. Concerns such as current technology associated with the inclusion of increased amounts of crumb rubber can increase the susceptibility of the tire to air and water migration. This condition can lead directly to catastrophic structural separations within the tire. Recently, such issues led to the passage of the TREAD Act. The awareness and participation of retailers is directly affected by tire manufacturers' activities with respect to increasing recycled content in new tires. Government incentives, including extending State income and sales tax exemptions,

can have a positive impact when retailers' participation is to be sought as long as minimum performance and safety requirements are met.

- **Customers:** Customer incentives can include pricing of tires that clearly presents the economic advantages in using tires with recycled content. Educating the public through different media and demonstrating the safety and performance effectiveness of tires with recycled content is necessary.

5.4.1 Economic Feasibility

The economic feasibility of producing crumb rubber for increasing recycled content depends on factors such as collection of waste tires, separation, processing, packaging, transport, and demand.

California has the highest population (over 34 million) in the United States and therefore generates the largest number of waste tires. A large-capacity facility producing high-end crumb rubber will have to import whole tires from states such as California that generate a large number of waste tires. Transporting crumb rubber from California can be more cost-effective than transporting whole tires, because crumb rubber is a concentrated high-value product as opposed to whole waste tires.

The disparity between the energy costs in California and in other tire-producing states is another factor limiting California's competition in the nationwide market. Since California currently has no tire manufacturing plants, the crumb rubber produced for use in new tires needs to be transported to other states.

The use of tires as fuel is the most economically viable means of reducing tire waste—provided the economics of the environmental and emission reduction are well integrated into the use of waste tires as fuels. This is evident in the data published by STMC and others—for example, 53 percent of total use in 2001 was as fuel. While use of tires as fuel has no strategic advantage as a long-term solution to energy problems and policies, large-scale use of waste tires for fuel will continue for the foreseeable future as a major diversion program.

Collection of economic data on waste tire processing plants is difficult due to the wide variations in the age and make of the machinery. Moreover, some of the vital data, such as cost of production, are trade secrets.

Table 8 provides a projected economic summary of a potential California market from waste tires based on an assumed tipping fee of $0.65 per tire and selling price of $0.10 per pound for tread crumb rubber. Assume six pounds of tread rubber per tire. Also, assume 30 percent of the tires are retreadable. The remaining non-retreadable casings can be supplied for use in civil engineering applications, TDF, RAC, and other applications.

The column indicated approximately 25 percent of waste tires takes into consideration a 75 percent diversion already achieved in California, as reported in a 2002 CIWMB staff report [1].

Table 8: Economic Summary of Potential California Market for Crumb Rubber Production

	100% of Waste Tires Per Year	25% of Waste Tires Per Year
Annual generation of waste tires	34,000,000	8,568,000
Pounds of tread rubber	204,000,000	51,408,000
Number of reusable casings (assume 30%)	10,200,000	2,507,400
Number of casings for further processing	23,800,000	5,997,600
Revenue from reusable casings ($2.50 per casing) from 100% of waste tires per year (Column A) or 25% of waste tires per year (Column B).	$25,500,000	$6,426,000
Revenue from tipping fees—reusable casings ($0.65/tire) from 100% of waste tires per year (Column A) or 25% of waste tires per year (Column B).	$6,630,000	$1,670,760
Revenue from tread crumb rubber ($0.10/lb) from 100% of waste tires per year (Column A) or 25% of waste tires per year (Column B).	$20,400,000	$5,140,800
Revenue	$52,530,000	$13,237,560
Freight ($0.05/ton/mile)*	$10,200,000	$2,448,000

* Cost does not include any fuel surcharges. Freight rate shown is an average of rates obtained from haulers or transporters.

Although the potential market can be significant, the two major economic barriers are the low price of virgin rubber and the market demand for crumb rubber for use in other than new tires. In the above analysis, the cost of freight is in the order of 20 percent of gross revenue. The freight cost (unless a long-term, large-volume discount negotiation with haulers is put in place) is cost-prohibitive when considering other risk factors and the sensitivity of the crumb rubber industry to price variations.

A detailed profitability analysis is required to determine the economic feasibility for the construction and operation of a new tire recycling facility to produce fine crumb rubber. Major financial elements that need to be considered are listed in Table 9.

Table 9: Financial Considerations for Profitability Analysis

CAPITAL EQUIPMENT	OPERATING COSTS AND REVENUES
Construction	Expenses
Freight	Utilities
Instrumentation	Labor
Engineering	Maintenance
Contingency	Supplies
	Insurance
CAPITAL EQUIPMENT	OPERATING COSTS AND REVENUES
	Depreciation
	Transportation
	Revenues
	Tipping Fees
	Product Sales

The economic viability is sensitive to the required capital investment, operating expenses, and projected revenues. As an example, consider a tire buffing and retreading facility processing 2,000 tires per day (500,000 tires or 3 million pounds of tread rubber per year). At a price of $165 per ton, the total projected annual revenue would be $247,500 from the sale of raw buffings. The tipping fee for the retreadable tires would be $97,500 at $0.65 per tire and $375,000 from the sale of tire casings for retread at $2.50 per tire—assuming 30 percent retreadable.

Offsetting these revenues are the expenditures associated with utilities, maintenance, labor, insurance, depreciation, freight, and taxes. For the purpose of discussion, assume the required capital investment for a facility of this size would be approximately $5 million. Assuming a uniform 10-year depreciation, this would correspond to a depreciation expense of $500,000 per year.

With a depreciation of over 50 percent of the total revenue and cost of utilities and freight factored in, operating a profitable tire tread removal facility that can produce fine mesh crumb rubber could be subject to considerable uncertainty and risk. This would be true even if a stable market demand exists for crumb rubber. The retreading operations of the business could offset some of the risk to which a facility dedicated to generating buffings only may be exposed.

In summary, the following incentives can be implemented.

- Reliable supply of high-quality crumb rubber.
- Demonstration of safety and performance effectiveness using government fleets.
- Requirements imposed by vehicle manufacturers or government agencies.
- Government incentives including extending State income and sales tax exemptions and grants that provide equipment and land.

- Large source of waste tires in relatively concentrated southern and northern regions of the state to attract processors.
- Retread/buffing represents a stable and proven technology with well-established capital investment; therefore, it should attract existing retreaders for expansion of capabilities.
- Comparative testing of tires with recycled content against like tires with virgin components for educating the consumer.
- Locate facilities where job creation will have an impact, because businesses have typically not been drawn to these regions.

6.0 Barriers to Increasing Recycled Content in New Tires

6.1 Industry Roadblocks and Technology Innovations

The literature search has demonstrated the technical feasibility of incorporating a fine crumb rubber into a tire compound without significant degradation of the performance of the tire or modification to the tire production line. There is also a clear indication that the tire manufacturers can be receptive to increased recycled content, provided quality requirements and competitive crumb rubber pricing are achieved.

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

- High costs of collection, sorting, and processing of waste tire material.
- Lack of standardized quality control procedures at processing facilities.
- Consumer perceptions of poorer quality in tires that contain recycled content.
- Cost of transporting crumb rubber to tire manufacturing plant.
- High dynamic performance requirements of tires limit amount of recycled content.
- Excess capacity in the synthetic rubber manufacturing sector has led to low prices for SBR so that the incorporation of recycled rubber is of little economic significance in the production of new tires.
- Liquid nitrogen required for cryogenic grinding can account for up to 75 percent of variable costs. The cost of liquid nitrogen depends on the cost of the electricity, which is the major cost in the production of liquid nitrogen [56]. A reduction in the liquid nitrogen consumption per unit throughput must be achieved through process improvements to reduce this dependence, which reduces costs.

The production of high-quality crumb rubber from whole tires for this application is cost-prohibitive under prevailing market conditions because of the low cost of virgin rubber. Another factor is the demand of crumb rubber by other markets that do not incur a high cost for production of crumb rubber.

Technical breakthroughs are required that can simultaneously address technological and economic barriers to producing better-quality crumb rubber and developing tire compounds and structures that better accommodate recycled rubber material without loss of performance or reliability. Technologies such as devulcanization and other thermochemical processes are at a research and development stage. These technologies have potential if they can be made commercially feasible.

The following discussion pertains to the technological and economic barriers associated with increasing the recycled content of new tires.

1. **Location of processing plants**: The location of a processing plant relative to the participating tire manufacturers affects the cost of a project. Utilities, labor, material costs, taxes, freight costs, and the site of a processing plant are all factored into the project cost. A sustained large supply of waste tires and State and local government

incentives such as extending State income and sales tax exemptions and providing grants or loans for equipment and land, also influence location selection. Availability of a reliable energy source that is cost-competitive is vital to the profitability and survival of a crumb rubber production plant. Under the present energy market conditions, all other factors being equal, processing plants in California can be at a disadvantage in competing with processors in other states or offshore.

One must carefully weigh the benefits of generating coarse crumb rubber in California and supplying it to a processor (in the proximity of a tire manufacturing plant) that would produce fine crumb rubber, against shipping the supply of fine crumb rubber directly to the tire manufacturing plant. Energy costs are higher in California ($0.12 per kilowatt hour [kWh]), compared to states such as Oklahoma ($0.08 per kWh), where many tire manufacturers exist. Because of California's higher costs, supplying buffings or coarse crumb rubber to an out-of-state processing plant may be a preferred approach.

2. **Equipment for crumb rubber processing:** Most facilities have highly unique processing systems to meet the demand of selected market segments. These plants are not sufficiently flexible to adjust to market changes.

   The use of buffings as raw materials for crumb rubber production can significantly reduce the cost associated with the shredding, regrinding, and steel and fiber separation processes. Also, maintenance on the equipment (such as frequency of blade replacement) will be reduced. Source separation of buffings also will help improve the quality of the crumb rubber, since passenger cars and truck tires can be separated at the buffing stage of the process. Source separation will allow a consistent quality of crumb rubber produced within a given class of tire sizes.

   An efficient and reliable crumb rubber plant is one that produces crumb of consistent quality, maintains flexibility of product output, and incrementally improves maintenance and operating cost efficiency and end-product yields. Modular equipment that can be flexible enough to meet demand fluctuations is more cost-effective than a single facility with a capacity for large-scale production of crumb rubber.

3. **Waste tire types and their compositions:** Variations in the mechanical properties of the rubber compounds are dependent on the proportions of material components that affect performance and durability. Some of these components are rubber, carbon black, silica, steel, fabric, zinc oxide, oil, and antioxidants. Variations due to the different design and compounding processes followed by manufacturers are also dependent on the proportions of these components. Also, environmental factors such as temperature, wear, and tear can result in the degradation of the mechanical properties of the compounds. Sorting by size and make during collection of waste tires can minimize the degree of variation.

4. **Maintenance:** One of the main cost drivers in processing waste tires for crumb rubber production is the presence of steel and fiber materials. Steel and fiber materials can accelerate the rate of wear on the blades and require frequent replacements. Alternately, if the replacement is not frequent enough, the productivity of the equipment can be limited. Moreover, the presence of steel and fiber materials lowers the processing rate and degrades quality [5]. As discussed in the previous sections, one of the advantages of using tread rubber as a raw material for crumb

rubber production is that it can be kept clean of steel and fiber material at the time of buffing.

5. **Reliable source of waste tire supply:** One of the most important factors in operating a crumb rubber facility profitably is the presence of a consistent waste tire supply. In some developed waste tire market areas, the processors cannot secure as many tires as they would like. As a result, long-term contracts with waste tire suppliers are important to assure the consistency of waste tire supply and avoid disruption of the process. Moreover, a long-term contract assures stability of tipping fees, which may otherwise be lower during high-demand periods [56, 57].

6. **Quality:** One of the crucial factors in increasing recycled content of new tires is quality. All manufacturers require a fine mesh size (80+) and the complete removal of steel and fiber to recycle crumb rubber into new tires.

   A standardized procedure for the production, packaging, and freight of crumb rubber to its use destination (tire manufacturing plants) is necessary. ASTM has introduced procedures from classification and particle size distributions (ASTM D-5603-96 [39] and ASTM D-5644-96 [40]). ASTM D-5603-96 also gives a limit of 1 percent moisture content in crumb rubber. Too much moisture can cause caking and may inhibit processing. Moisture build-up can lead to acidic conditions, resulting in slower curing rates in compounds. Therefore, recycled crumb rubber should be packaged and shipped or stored in a cool and dry space.

   The quality of the equipment used is also essential to a facility remaining cost-competitive while achieving the desired crumb rubber quality.

   Technologies such as devulcanization and other thermochemical processes are at a research and development stage. These technologies have potential if they can be made commercially feasible.

   Compounds with higher resilience characteristics that can reduce the excessive temperature rise due to hysteresis have to be developed to effectively incorporate the recycled content into new tires. These compounds must maintain the desired performance characteristics such as resistance to cutting, chipping, cracking, and abrasion.

   Better and more dependable casings must be produced where buffings are the by-products. The ability to produce more casings from waste tires will help offset market risks faced by processing plants that specialize in producing fine crumb rubber for recycled-content purposes. Moreover, an increased number of retreadable tires will allow the potential of continued and expanded retreading.

Table 10: Summary of Barriers and Recommended Solutions

Factor	Barrier	Solution
Location of processing plants	High costs of collecting, sorting, and processing waste tire material. Transportation cost of crumb rubber to tire manufacturing plant. In cryogenic grinding, the nitrogen requirement is a technological barrier.	A sustained large supply of waste tires, and State and local government incentives such as extending State income and sales tax exemptions, grants for equipment and land. Availability of a reliable energy source that is cost-competitive is vital to the profitability and survival of crumb rubber producers. Under the present energy market conditions, all other factors being equal, processing plants in California can be at a disadvantage in competing with processors in other states or offshore. If cryogenic processing is considered, the availability and freight cost of nitrogen could take precedence over proximity to a tire manufacturing plant that will use the crumb rubber produced.
Equipment for crumb rubber processing	Expensive, highly unique processing systems to meet the demand of selected market segments. These plants are not sufficiently flexible to adjust to market changes.	The use of buffings from retreads as raw materials for crumb rubber production can significantly reduce the cost associated with the shredding, regrinding, and steel and fiber separation processes.
Waste tire types and their compositions	Variation in the mechanical and thermodynamic properties of the rubber compounds.	To minimize the effects of such variations, collect and sort by size and type, potentially returning waste tires/crumb rubber materials to the same manufacturer that originally produced the tires.
Maintenance	Steel and fiber materials accelerate the rate of wear on equipment, especially blades.	Using tread rubber as a raw material for crumb rubber production.
Reliable source of waste tire supply	Lack of stable supply of crumb rubber.	Long-term contract between suppliers, processors, and tire manufacturers.
Quality	Lack of high quality crumb rubber in sufficient quantity	Use of standardized procedures such as ASTM D-5603-96 and ASTM D-5644-96.

7.0 Recommendations

Evaluation of the physical properties of rubber compounds with recycled content has been conducted through a series of standardized and customized laboratory tests. While the data is not exhaustive, Section 4.2 of this report presents a summary of representative laboratory test data.

No published "field" data are available to validate results from the laboratory tests. To verify the validity of data under consumer conditions, a comparative evaluation between tires with recycled content and conventional tires (reference tires) should be conducted. Specifically, tests need to be conducted on traction, rolling resistance, wear rate, aging, and chip-and-cut resistance. Data generated under such tests can be used for performance verification as well as for the improvement of consumer awareness. Current data indicate that there is a reduction in most tire system-related performance and durability through the use of increased recycled content. Selection of tire designs and compounds that can best utilize recycled content will be critical to ensure best value for this effort.

Developing an approach that addresses goals for increased life span, increased recycled content, and reduced rolling resistance and that also balances tradeoffs resulting from using recycled content is important.

Significant economic barriers must be overcome to establish a profitable facility processing fine crumb rubber in California. If a detailed feasibility analysis determines that such a facility can be profitable, a pilot fine crumb rubber production facility operated in collaboration with existing retreading/waste tire processing facilities can be a viable option.

Collaboration between the processing facility and a tire manufacturer or tire manufacturer associations (RMA, TIA, etc.) to improve product quality and supply is necessary to ensure the viability and sustainability of the process. California currently diverts approximately 75 percent of its waste tires for uses other than increased recycled content in new tires. The remaining 25 percent can potentially be used as a source for buffings that can be further processed and recycled into new tires. Discussion between tire manufacturers and processors should occur in order to define the scope and participation of all parties. The selection of high-quality casings and used tires for reprocessing intended for increasing recycled content can help ensure the best opportunity for returning this 25 percent to the tire manufacturing process.

Assuming 20 pounds of weight per PTE and a 5 percent rate of incorporation into new tires, approximately 50 million PTEs can be produced with recycled content. This represents approximately 25 percent of the estimated annual sale of passenger car and light-truck tires in the U.S in 2002. Thus, theoretically, by incorporating 5 percent by weight in all passenger-car and light-truck tires, an additional 150 million pounds of crumb rubber can be incorporated.

The requirements of high performance tires would not make the use of recycled content in all tires produced feasible (that is, rolling resistance and tread life would be sacrificed, which would not be desirable in high performance tires). Nonetheless, the gap between what is reported as incorporated at present and the potential projected above is an indicator that there is room for increasing recycled content at the reportedly achievable level of 5 percent for a higher number of the new tires manufactured.

With the prevailing technological level, this study proposes that a reliable source of crumb rubber produced from buffings (tread) be considered as a raw material. This can be a strategic step to continue engaging tire manufacturers in the research and feasibility of increasing the recycled content. This will allow for the synergy required between increased life span, increased recycled content, and reduced rolling resistance. The technology associated with buffings currently exists and is widely used by retreaders. This will reduce the capital investment required, as the size-reduced tread rubber is supplied to the crumb rubber producers. If the quality is acceptable to the tire manufacturers, it can also serve as a test bed to evaluate how much can be absorbed by the tire manufacturers under the present market and regulatory conditions.

The CIWMB should undertake more research to understand how recycled crumb rubber behaves in rubber compounds—for example, how it behaves when it functions as a filler or when it is cross-linked into blends with virgin materials. Resources need to be allocated for research and development work to understand the effect of increased recycled content on the dynamic properties of tires and the compounding of rubber. This can be accomplished at academic institutions, through independent organizations, or in cooperation with tire manufacturers.

Investigation should be initiated on the impact of reduced tread rubber in the waste tires for other applications, such as rubberized asphalt concrete. This would address the concern that if the tread is removed, the crumb may not be as effective for other uses. This needs to be investigated by conducting tests of RAC ingredients with tread rubber contents at various levels. Such research will address, for example, the minimum amount of tread rubber required in the use of whole-tire crumb rubber for RAC.

8.0 Future Scopes of Work

8.1 Objectives

The objectives of the scope of work are to develop an outline of future work on increasing recycled content. It is envisioned that the proposed work should address barriers the study has identified to increasing recycled content in new tires. Studies conducted recently (for example, the State of North Carolina grant to Continental General Tire) experienced a shortage of quality crumb rubber and reliable supply. A partnership between crumb rubber processors, tire manufacturers, and vehicle manufacturers should provide a solution to the quality and stable supply and demand of the crumb rubber. CIWMB plays a significant role in facilitating this process.

8.2 Scope of Work I

A team of crumb rubber processors and tire manufacturers should develop a white paper that addresses a mechanism by which recycled content in new tires can be increased. CIWMB could solicit such a white paper by creating collaboration between tire manufacturers and crumb rubber processors. The effectiveness of such cooperation between tire manufacturers and processors is evident in the processing and reuse of factory waste. The white paper would identify potential candidate teams to develop a proposal to accomplish the task of increasing recycled content in new tires. The successful parties in this selection could possibly accomplish the following:

- Develop a processing and handling method that will ensure the quality of crumb rubber from waste tire to be used as recycled content. Processors and tire manufacturers can use quality control procedures such as (ASTM D-5603-96 [39] and ASTM D-5644-96 [40]) or other internal procedures that are unique to individual tire manufacturers.
- Develop a market structure that will sustain a steady supply and demand of crumb rubber for recycled content. The proposal should clearly identify the step taken to maintain reliable supply of crumb rubber for use as recycled content.
- Determine the maximum percent of crumb rubber that can be incorporated into new tires without having any adverse effect on the performance and safety of tires. A proper experimental design to incorporate different levels of crumb rubber into new tires is one major component of the effort.

8.3 Scope of Work II

Integral to the study conducted to determine the maximum percent crumb rubber that can be incorporated into new tires is the effort needed to verify the field performance of tires with recycled content. No published "field" data are available to validate results from the laboratory tests. The following statement of work outlines tasks that need to be accomplished to conduct the field tests.

Task 1: Define the Representative Duty Cycle

To insure that the test tires are exposed to a representative user environment during the field test, a duty cycle that reflects the user environment should be defined. It is essential to establish the California's road conditions, such as degree of smoothness, percent of time wet, and amount of snow. It is also essential to establish representative driver behavior on the road as it affects the performance and durability of tires. A duty cycle that covers the representative user environment will facilitate the development of a test plan that can effectively measure the performance of the test tires in that environment.

Task 2: Develop a Test Plan

Develop a test plan to conduct performance and durability tests of tires with recycled content. The test plan should include, but not be limited to, an experimental design that includes percent levels of recycled content, multiple tire payloads, tire inflation pressures, and test surfaces over which the tires are to be used. To verify the validity of data under different road and environmental conditions, a comparative evaluation between tires with recycled content and conventional tires (reference tires) should be conducted. Specifically, tests that need to be conducted include, but are not limited to, traction, rolling resistance, braking, wear rate, aging, and chip-and-cut resistance.

Task 3: Conduct Comparative Performance Evaluation

Perform field-testing of tires with recycled content that showed no significant degradation in performance or safety in representative environments where they are anticipated to be used (for example, over wet and dry paved surfaces, snow, mud, and gravel). The deliverables under this task include a report describing the experimental design of the test; the data analysis method, and a summary of the test results along with recommendations.

8.4 Scope of Work III

Task 1: Increase Public Awareness of the Use of Recycled Content in New Tires

It is anticipated that the field test will serve two purposes. In addition to the expectation that the data will allow independent verification of the relative performance of tires with recycled content against those tires with no recycled content in the actual user environment, the data will also develop a public awareness program to promote the long-term environmental benefits to consumers.

This task, calls for the development of literature to disseminate the favorable performance test results of tires with recycled content through various media. The field test results and the environmental benefits of using tires with recycled content should be compiled in a simplified and concise format that any vehicle operator can easily understand. The contractor is required to develop brochures and other literature for publication.

CIWMB can promote to the consumer findings favorable to increasing recycled content. This effort can be part of an overall environmental impact solution that can be achieved through recycling waste tires into new tires.

9.0 Source Reference Notes

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Appendix A: Tire Manufacturers and Their Locations Worldwide

Source: 52

The listing in this appendix is broken into seven geographical regions: North America, comprising the U.S. and Canada; Latin America, including Mexico, Central and South America; Europe, including Russia and most of the former Soviet Bloc nations; Asia, including India, Japan, the Pacific Rim, and former states of the Soviet Union located in Asia; Africa, and the Middle East; and Australia and New Zealand.

Within each region, tire makers are listed by country, with names of parent companies, if any, following in parentheses.

Plant information shows: the year each unit opened, whether the plant's workers belong to a union, the number of production workers employed, types of tires made at the facility, and the facility's production capacity.

Explanation of Abbreviations

Tire Types: 1—Auto; 2—Light truck; 3—Truck/bus; 4—Agricultural; 5—Motorcycle; 6—Earthmover/OTR; 7—Industrial; 8—Aircraft; 9—Racing

Tire Construction : r—Radial, b—Bias-ply

Plant Capacities: u/d—Units per day; u/w—Units per week; u/m—Units per month; u/y—Units per year; t/d—Tons per day; t/w—Tons per week; t/m—Tons per month; t/y—Tons per year

Company/ Plant Location	Year Opened	Unionized Plant	Employees	Tire Types	Capacity
Canada					
Bridgestone/Firestone Canada Inc. (Bridgestone/Firestone Americas Holding, Inc.)					
Joliette, Quebec	1966	Yes	1,061	1, 2 (r)	15,000 u/d
Goodyear Canada Inc. (Goodyear Tire & Rubber Co.)					
Medicine Hat, Alberta	1960	Yes	350	1, 4 (r, b)	15,000 u/d
Napanee, Ontario	1990	No	650	1, 2 (r)	20,000 u/d
Valleyfield, Quebec	1964	Yes	1,500	1 (r)	26,000 u/d
Michelin North America (Canada) Inc. (Groupe Michelin)					
Bridgewater, Nova Scotia	1973	No	1,100	1, 2 (r)	11,000 u/d
Granton, Nova Scotia	1971	No	1,355	1, 2, 3 (r)	9,000 u/d
Kitchener, Ontario	1962	Yes	982	1, 2 (r)	17,000 u/d
Waterville, Nova Scotia	1982	No	982	3, 6 (r)	4,200 u/d
United States					
Bridgestone/Firestone Inc. (Bridgestone Corp.)					
Aiken County, S.C.	1998	No	788	1, 2 (r)	25,000 u/d
Akron, Ohio	1991	Yes	600	9 (r)	—
Bloomington, Ill.	1965	Yes	484	6 (r, b)	300 u/d
Des Moines, Iowa	1945	Yes	1,425	1, 3, 4, 6 (r, b)	12,100 u/d
LaVergne, Tenn.	1972	Yes	1,750	1, 2, 3 (r)	18,500 u/d
Oklahoma City, Okla.	1969	Yes	1,979	1, 2 (r)	43,500 u/d
Warren County, Tenn.	1990	Yes	974	3 (r)	7,200 u/d
Wilson, N.C.	1974	No	2.251	1, 2 (r)	41,000 u/d
Carlisle Tire & Wheel Co. (Carlisle Companies Inc.)					
Carlisle, Pa.	1917	No	735	2, 7 (b)	22,000 u/d
Continental General Tire Inc. (Continental A.G.)					

North American Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Capacity**
Bryan, Ohio	1966	Yes	275	4, 6, 7 (b)	232 u/d
Charlotte, N.C.	1967	Yes	1,308	1, 2 (r)	18,918 u/d
Mayfield, Ky.	1960	Yes	1,176	1, 2 (r, b)	18,204 u/d
Mount Vernon, Ill.	1974	No	1,157	1, 2, 3 (r)	28,053 u/d
Cooper Tire & Rubber Co.					
Albany, Ga.	1991	No	1,100	1, 2, 3 (r)	24,000 u/d
Findlay, Ohio	1919	Yes	930	1, 2 (r)	24,000 u/d
Texarkana, Ark.	1964	Yes	1,575	1, 2 (r)	40,000 u/d
Tupelo, Miss.	1984	No	1175	1 (r)	42,000 u/d
Denman Tire Corp. (Pensler Capital Corp.)					
Leavittsburg, Ohio	1919	Yes	270	1, 2, 4, 6, 7, 9 (r, b)	2,600 u/d
Goodyear Dunlop Tire Corp. (Goodyear-Sumitomo Rubber Industries Ltd. Joint Venture)					
Buffalo, N.Y.	1923	Yes	1.200	1, 2, 3, 5, 7 (r, b)	15,000 u/d
Huntsville, Ala.	1969	Yes	1,300	1, 2 (r)	27,000 u/d
Goodyear Tire & Rubber Co.					
Akron, Ohio	1983	Yes	400	9 (r, b)	2,000 u/d
Danville, Va.	1966	Yes	2,000	3, 8 (r, b)	15,000 u/d
Gadsden, Ala.	1929	Yes	1,200	1, 2 (r)	15,000 u/d
Lawton, Okla.	1978	No	2,300	1 (r)	65,000 u/d
Topeka, Kan.	1944	Yes	1,600	3, 4, 6 (r, b)	8,000 u/d
Union City, Tenn.	1968	Yes	3,900	1, 2 (r)	60,000 u/d
GTY Tire Co. (Continental Tire North America, Yokohama & Toyo Joint Venture)					
Mount Vernon, Ill.	1991	No	417	3 (r)	1,100,000 u/y
Hoosier Racing Tire Corp.					
Plymouth, Ind.	1979	No	—	9 (r, b)	—
Michelin Aircraft Tire Corp. (Groupe Michelin)					
Norwood, N.C.	1987	No	463	8 (b)	19,000 u/m
Michelin North America Inc. (Groupe Michelin)					
Ardmore, Okla.	1969	No	1,950	1, 2 (r, b)	33,000 u/d
Dothan, Ala.	1979	No	614	2 (r)	6,800 u/d

North American Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Capacity**
Fort Wayne, Ind.	1961	Yes	1,294	1, 2 (r)	24,000 u/d
Greenville, S.C.	1975	No	1,750	1 (r)	24,000 u/d
Lexington, S.C.	1981	No	1,274	1 (r)	24,000 u/d
Lexington, S.C.	1998	No	250	6 (r)	—
Opelika, Ala.	1963	Yes	1,412	1, 2 (r)	7,600,000 u/y
Spartanburg, S.C.	1978	No	1,450	3 (r)	2,200,000 u/y
Tuscaloosa, Ala.	1945	Yes	1,900	1, 2 (r)	25,000 u/d
Pirelli Tire North America (Pirelli S.p.A.)					
Rome, GA	2002	No	250	1 (r)	500,000 u/y
Specialty Tires of America Inc. (Polymer Enterprises Inc.)					
Indiana, Pa.	1915	Yes	300	2, 4, 7, 8, 9 (b)	3,300 u/d
Unicoi, Tenn.	1997	No	200	1, 2 (b)	400,000 u/y
Titan Tire Corp. (Titan International Inc.)					
Brownsville, Texas	1998	No	140	4, 6 (r, b)	6,000 u/d
Des Moines, Iowa	1943	Yes	820	2, 4, 7 (r, b)	13,000 u/d
Natchez, Miss.	1986	Plant Idled	0	2, 3, 4, 6, 7	—
Trelleborg Wheel Systems America Inc. (Trelleborg A.B.)					
Hartville, Ohio	1926	Yes	180	7 (b)	750,000 u/y
Yokohama Tire Corp. (Yokohama Rubber Co. Ltd.)					
Salem, Va.	1968	Yes	1,138	1, 2 (r)	9,000,000 u/y

Latin American Tire Production Facilities as of September 2001					
Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Argentina					
Bridgestone/Firestone Argentina S.A.I.C. (Bridgestone/Firestone Inc.)					
Buenos Aires	1931	Yes	751	1, 2, 3, 4, 6 (r, b)	7,700 u/d
FATE S.A.I.C.I.					
San Fernando, Buenos Aires	1963	Yes	1,080	1, 2, 3, 4, 6 (r, b)	12,500 u/d
Pirelli Neumaticos S.A.I.C. (Pirelli S.p.A.)					
Merlo, Buenos Aires	1968	Yes	530	1, 2, 3, 4, 5 (r, b)	6,000 u/d
Brazil					
Bridgestone/Firestone do Brasil Industria e Comercio Ltda. (Bridgestone/Firestone Inc.)					
Sao Paulo	1940	Yes	2,920	1, 2, 3, 4, 6, 7 (r, b)	28,000 u/d
Goodyear do Brasil Productos de Borracha Ltd. (Goodyear Tire & Rubber Co.)					
Americana	1971	Yes	1,900	1, 2, 3, 4, 6 (r, b)	40,000 u/d
Goodyear do Brasil Productos de Borracha Ltd. (Goodyear Tire & Rubber Co.) – Continued					
Sao Paulo	1939	Yes	1,000	2, 3, 4, 6 (b)	5,000 u/d
Industrias Joao Maggion S.A.					
Guarulhos, Sao Paulo	1972	Yes	200	1, 2, 4, 5, 7 (b)	10,000 u/d
Pirelli Pneus S.A. (Pirelli S.p.A.)					
Campinas, Sao Paulo	1953	Yes	1,250	1, 2 (r)	23,000 u/d
Feira de Santana	1976	Yes	230	1, 2, 3 (b)	1,200 u/d
Gravatai	1976	Yes	990	1, 2, 3, 4, 5, 7 (b)	180 t/d
Santo Andre, Sao Paulo	1940	Yes	1,160	2, 3, 4, 6 (r, b)	2,300 u/d
Pneumaticos Michelin Ltd. (Groupe Michelin)					
Resende	1999	No	—	1 (r)	—
Rio de Janeiro (Campo-Grande)	1981	No	2,100	3 (r)	41,700 u/m
Rinaldi S.A.—Industria de Pneumaticos					

Latin American Tire Production Facilities as of September 2001					
Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Bento Goncalves	1960	Yes	490	4, 5, 7	3,500 u/d
Chile					
Bridgestone/Firestone Chile S.A. (Bridgestone/Firestone Americas Holding, Inc.)					
Coquimbo	1975	Yes	614	1, 2, 3, 4, 6 (r, b)	2,300 u/d
Goodyear de Chile S.A.I.C. (Goodyear Tire & Rubber Co.)					
Santiago	1978	Yes	550	1, 2, 3, 9 (r, b)	8,000 u/d
Colombia					
Goodyear de Colombia S.A. (Goodyear Tire & Rubber Co.)					
Cali	1945	Yes	300	1, 3, 4, 6 (r, b)	1,500 u/d
Icollantas S.A. – Industria Colombiana de Llantas S.A. (Groupe Michelin)					
Bogota	1945	Yes	660	1, 2, 3, 4, 6 (b)	3,500 u/d
Cali	1945	Yes	403	1, 2 (r)	3,800 u/d
Costa Rica					
Firestone de Costa Rica S.A. (Bridgestone/Firestone Americas Holding, Inc.)					
San Jose	1966	No	604	1, 2 (r, b)	5,200 u/d
Cuba					
Poligom					
Emp. Nelson Fernandez, Havana	1950	—	—	1, 2, 3, 5 (r, b)	450,000 u/y total for all locations
Emp. Conrado P., Havana	1950	—	—	1, 2, 3, 5 (r, b)	
Emp. S. Moreno, Havana	1950	—	—	1, 2, 3, 5 (r, b)	
Name unknown, Havana	1950	—	—	1, 2, 3, 5 (r, b)	
Ecuador					
Compania Equatoriana del Caucho S.A. (Continental A.G.)					
Cuenca	1962	Yes	622	1, 2, 3 (b)	79 t/d
Guatemala					
Gran Industria de Neumaticos Centromericana S.A. (Goodyear Tire & Rubber Co.)					
Guatemala City	1965	Yes	1,500	1, 2, 3, 4 (r, b)	3,500 u/d

Latin American Tire Production Facilities as of September 2001					
Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Mexico					
Autopartes Internacionales de Queretaro (Groupe Michelin)					
Queretaro	1987	—	400	1, 2 (r)	6,000 u/d
Bridgestone/Firestone de Mexico, S.A. de C.V. (Bridgestone Corp.)					
Cuernavaca	1980	Yes	803	1, 2 (r)	13,000 u/d
Mexico City	1958	Yes	253	2, 3 (b)	2,200 u/d
Compania Hulera Tornel S.A. de C.V.					
Mexico City	1972	Yes	61	1, 2, 3, 4, 7 (b)	9,000 u/d
Tacuba	1946	—	200	2,3 (b)	3,500 u/d
Tultilan	1984	Yes	765	2 (r, b)	6000 u/d
General Tire Mexico (Continental A.G.)					
San Luis Potosi	1975	Yes	942	1, 2, 3, 4 (r, b)	11,241 u/d
Peru					
Compania Goodyear del Peru S.A. (Goodyear Tire & Rubber Co.)					
Lima	1945	Yes	200	1, 2, 3, 4, 7 (r, b)	3,000 u/d
Lima Caucho S.A.					
Lima	1955	Yes	142	1, 2, 3, 4 (b)	1,660 u/d
Trinidad & Tobago					
Carlisle Tire & Wheel Co. (Carlisle Companies Inc.)					
Point Fortin	1996	No	100	2, 7 (b)	5,000 u/d
Uruguay					
Fabrica Uruguaya de Neumaticos S.A. (FUNSA)					
Montevideo	1935	Yes	504	1, 2, 3, 4, 5, 6 (r, b)	2,010 u/d
Venezuela					
Bridgestone/Firestone Venezolana C.A. (Bridgestone/Firestone Americas Holding Inc.)					
Valencia	1955	Yes	1,074	1, 2, 3 (r)	8,950 u/d
C.A. Goodyear de Venezuela (Goodyear Tire & Rubber Co.)					
Valencia	1956	Yes	450	1, 2 (r, b)	10,000 u/d
Pirelli de Venezuela C.A. (Pirelli S.p.A.)					
Guacara	1950	Yes	580	1, 2, 3 (r, b)	4,000 u/d

European Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Belarus					
Belshina					
Bobruisk	1972	Yes	9,940	1, 2, 3, 4, 6, 7 (r, b)	3,000,000 u/y
Bulgaria					
Dynamic Tyre Factory					
Sofia	1929	Yes	390	1, 2, 3, 4, 6, 7 (b)	700,000 u/y
Kauchuk Co.					
Pazardjik	1931	—	—	5, 7 (b)	—
Czech Republic					
BARUM Continental S.R.O. (Continental A.G. & Barum Holding Joint Venture)					
Otrokovice	1949	No	3,700	1, 2, 3, 4, 5 (r, b)	12,500,000 u/y
Mitas A.S. (Czech Rubber Co.)					
Prague	1934	Yes	1,037	3, 4, 6, 7 (r, b)	5,000,000 t/d
Zlin	1993	Yes	1,314	1, 2, 4, 5, 7, 8 (r, b)	3,000,000 u/y
Finland					
Nokian Tyres P.L.C.					
Nokia	1904	Yes	1,000	1, 2, 4, 6, 7 (r, b)	5,000,000 u/y
France					
Bridgestone/Firestone France S.A. (Bridgestone/Firestone Europe S.A.)					
Bethune	1960	Yes	1,362	1, 2 (r)	30,000 u/d
Compagnie Generale des Establissements Michelin					
Bourges	1953	Yes	1,300	1, 2, 8 (r)	4,400 t/m
Cholet	1970	Yes	1,600	1, 2 (r)	24,000 u/d
Clermont-Ferrand, Gravanches	1988	Yes	300	1 (r)	6,725 t/m total for all locations
Clermont-Ferrand, Les Carmes	1889	Yes	14,800	3, 4, 6, 7 (r)	
Clermont-Ferrand, Cataroux	1921	Yes	8,000	1, 2, 3, 5, 6 (r)	
La Roche	1972	Yes	800	3 (r)	3,800 t/m

European Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Le Puy	1977	Yes	600	6, 7 (r)	1,835 t/m
Montceau, Mines	1970	Yes	1,440	1, 6, 7 (r)	3,000 t/m
Poitiers	1972	Yes	820	3, 7 (r)	4,200 t/m
Roanne	1974	Yes	800	1 (r)	1,625 t/m
Tours	1960	Yes	2,100	3 (r)	6,700 t/m
Continental Holding France S.A.R.L. (Continental A.G.)					
Sarreguemines	1962	Yes	1,000	1 (r)	15,050 u/d
Dunlop France S.A. (Goodyear-Sumitomo Rubber Industries Ltd. Joint Venture)					
Amiens	1958	Yes	900	1 (r)	20,000 u/d
Montlucon	1920	Yes	700	2, 3, 4, 5, 6, 7 (r, b)	8,000 u/d
Goodyear France (Pneumatiques S.A.) (Goodyear Tire & Rubber Co.)					
Amiens	1960	Yes	1,400	1, 4 (r, b)	25,000 u/d
Pneu Uniroyal Englebert S.A. (Continental A.G.)					
Clairoix	1936	Yes	1,300	1 (r)	24,000 u/d
Pneumatiques Kleber (Groupe Michelin)					
Toul	1969	—	800	1, 2 (r)	—
Troyes	1963	—	1,000	4 (r)	—
Germany					
Continental A.G.					
Hannover-Stoecken	1939	Yes	1,800	1, 2, 3, 4, 6, 7 (r, b)	16,100 u/d
Korbach	1908	Yes	1,700	1, 5, 7 (r, b)	25,000 u/d
Deutsche Goodyear GmbH (Goodyear Tire & Rubber Co.)					
Philippsburg	1967	Yes	700	1, 2 (r)	20,000 u/d
Dunlop GmbH (Goodyear & Sumitomo Rubber Industries Ltd. Joint Venture)					
Hanau	1893	Yes	1,200	1, 2, 3, 6 (r, b)	21,000 u/d
Wittlich	1971	Yes	800	1, 3 (r)	8,500 u/d
Gummiwerke Fulda GmbH (Goodyear Tire & Rubber Co.)					
Fulda	1946	Yes	1,400	1, 2 (r, b)	24,000 u/d
Metzeler Reifen GmbH (Pirelli S.p.A.)					
Breuberg, Odenwald	1957	Yes	340	5 (r, b)	5,500 u/d

European Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Michelin Reifenwerke K.G. (Groupe Michelin)					
Bad-Kreuznach	1966	Yes	2,050	1, 2 (r)	28,000 u/d
Hallstadt, Bamberg	1971	Yes	850	1 (r)	17,000 u/d
Homburg, Saar	1971	Yes	1,470	3 (r)	—
Karlsruhe	1931	Yes	1,050	3 (r)	400,000 u/y
Pirelli Reifenwerke K.G. (Pirelli S.p.A.)					
Breuberg, Odenwald	1945	Yes	2,190	1 (r)	21,000 u/d
Pneumant Reifen & Gummi Werke GmbH (Goodyear-Sumitomo Rubber Industries Ltd. Joint Venture)					
Furstenwalde	1906	Yes	550	1, 2 (r)	6,500 u/d
Riesa	1945	Yes	350	1 (r)	8,500 u/d
Reifenwerke Heidenau GmbH & Co. Produktions K.G.					
Heidenau, Saxony	1946	No	100	2, 5, 7, 9 (b)	2,000 u/d
Uniroyal Englebert Reifen GmbH (Continental A.G.)					
Aachen	1931	Yes	1,700	1 (r)	20,000 u/d
Hungary					
Taurus Rubber Co. Ltd. (Groupe Michelin)					
Budapest	1912	Yes	1,200	3 (r, b)	2,000 u/d
Nyiregyhaza	1979	Yes	1,200	4, 7 (r, b)	1,000 u/d
Italy					
Bridgestone/Firestone Italia S.p.A. (Bridgestone/Firestone Europe S.A.)					
Bari	1962	Yes	1,016	1, 2 (r)	12,300 u/d
Marangoni S.p.A.					
Anagni, Prosinone	1961	Yes	409	1, 2 (r)	8,000 u/d
Pirelli S.p.A.					
Bollate, Milan	1988	Yes	350	1 (r)	11,000 u/d
Settimo Vettura, Torino	1954	Yes	1,270	1, 2, 9 (r)	13,300 u/d
Pirelli S.p.A.					

European Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Settimo Veicoli Industrial, Torino	1961	Yes	540	3 (r)	2,300 u/d
S.A. Michelin Italiana (Groupe Michelin)					
Allessandria	1971	Yes	1,350	3 (r)	20,000 u/d
Cuneo	1963	Yes	2,650	1, 2, 8 (r)	26,000 u/d
Turin, Stura	1972	Yes	1,180	1, 5 (r)	35,000 u/d
Trelleborg Wheel Systems S.p.A. (Trelleborg A.B)					
Tivoli, Roma	1939	Yes	460	4 (r)	900 u/d
Luxembourg					
Goodyear S.A. (Goodyear Tire & Rubber Co.)					
Colmar-Berg	1951	Yes	1,300	2, 3, 6 (r)	5,000 u/d
Netherlands					
Vredestein N.V.					
Enschede	1947	Yes	1,161	1, 2, 4 (r)	17,000 u/d
Poland					
Bridgestone/Firestone Poland L.L.C. (Bridgestone Corp.)					
Poznan	2000	No	487	1 (r)	10,000 u/d
Stomil-Olsztyn S.A. (Groupe Michelin)					
Olsztyn	1968	Yes	2,300	1, 2, 3, 4, 7 (r, b)	4,000,000 u/y
TC Debica S.A. (Goodyear Tire & Rubber Co.)					
Debica	1939	Yes	3,000	1, 2, 3, 4, 7 (r, b)	35,000 u/d
Portugal					
Companhia Nacional de Borracha S.A. *(CNB/CAMAC)*					
Santo Tirso	1967	Yes	500	1, 2, 3, 4 (r, b)	3,500 u/d
Continental Mabor Industria de Pneus S.A. (Continental A.G.)					
Lousado	1946	Yes	800	1 (r)	21,000 u/d
Romania					
Continental Automotive Products S.R.L. (Continental A. G.)					
Timisoara	2000	—	1,000	1 (r)	22,000 u/d
Danubiana S.A. Tyre Co. (Tofan Grup)					
Bucharest	1962	Yes	3,091	1, 2, 3, 4, 7 (r, b)	5,700 u/d

European Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Michelin Romania (Groupe Michelin)					
Silvania	1981	Yes	1,345	3 (r)	3,000 u/d
Victoria, Prahoua	1939	Yes	3,200	1, 2 (r, b)	11,840 u/d
Olt Tyre S.A. Tyre Co.					
Caracal	1983	—	930	1	3,000 u/d
Rotras S.A. Tyre Co.					
Drobeta	1983	—	825	4, 6	156 u/d
Silvania Tyres Co. (Tofan Group)					
Zalau	1981	Yes	1,345	3 (r)	3,000 u/d
Russia					
Barnaul Tire					
Barnual	1968	—	5,100	1, 2, 3, 4, 8 (b)	2,800,000 u/y
Kirov Tyre					
Kirov	1943	Yes	4,241	1, 2, 3, 4, 5 (r, b)	4,000,000 8/y
Krasnoyarsk Tire					
Krasnoyarsk	1960	—	4,504	1, 2, 3, 4, 8 (b)	2,000,000 u/y
Matador Omskshina (Tire JV) (Matador, A. S. & OAO Omskshina Omsk Joint Venture)					
Omsk, Omsk	1996	Yes	1,850	1, 2 (r)	2,000,000 u/y
Moscow Tire Co.					
Moscow	1945	—	3,720	1, 3	2,500,000 u/y
Nizhnekamskshina					
Nizhnekamsk	1974	—	15,500	1, 3, 4 (r, b)	34,100 u/d
Omskshina					
Omsk (in Asia)	1942	—	7,600	1, 3, 4, 5 (r, b)	3,000,000 u/y
Petersburg Tire Factory					
St. Petersburg	—	—	—	1, 2, 3, 4	15,000 u/m
Uralshina (In Asia)					
Yekaterinburg	1943	—	2,650	1, 3, 5 (b)	2,000,000 u/y
Voltyre					
Volzhsky	1964	—	5,080	1, 2, 3, 4 (b)	2,800,000 u/y
Voronezhshina					

European Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Voronezh	1950	—	6,000	1, 2, 3, 4 (r, b)	2,500,000 u/y
Yaroslavl Tyre					
Yaroslavl	1932	—	8,400	1, 2, 3, 4	6,000,000 u/y
Slovak Republic					
Continental Matador S.R.O.					
Puchov	1999	—	790	3 (r)	1,500,000 u/y
Matador a.s. Puchov					
Puchov	1950	Yes	1,573	1, 2, 3, 4, 6, 7, 9 (r, b)	5,000,000 u/y
Slovenia					
Sava Tires d.o.o. (Goodyear & Sava Joint Venture)					
Kranj	1998	Yes	1,000	1, 2, 3 (r)	20,000 u/d
Spain					
Bridgestone/Firestone Hispania S.A. (Bridgestone/Firestone Europe S.A.)					
Bilbao, Pais Basque	1931	Yes	1,181	3 (r)	2,000 u/d
Burgos, Castille and Leon	1976	Yes	1,323	1, 2 (r)	21,000 u/d
Puente San Miguel, Cantabria	1965	Yes	733	1, 2, 3, 4, 7 (r)	5,000 u/d
Pirelli Pneumaticos S.A. (Pirelli S.p.A.)					
Manresa, Catalunia	1924	Yes	1,150	1, 2 (r)	17,500 u/d
S.A. para la Fabricacion en Espana (Groupe Michelin)					
Aranda de Duero	1970	Yes	—	3 (r)	7,300,000 u/y total for all locations
Lasarte	1934	Yes	3,500	1, 5 (r)	
Valladolid	1974	Yes	—	1, 4 (r)	
Vitoria	1966	Yes	4,000	1, 6 (r)	
Sweden					
Trelleborg Wheel Systems Group (Trelleborg Wheel Systems Group A. B.)					
Trelleborg	1897	Yes	280	2, 4, 6, 7 (r, b)	45,000 u/m
Ukraine					

European Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
J. S. C. Dniproshina					
Dneprotrovsk	1961	—	12,000	1, 3, 4, 5	5,000,000 u/y
C. S. C. Rosava					
Belaya Tserkov, Kiev	1972	—	6,213	1, 2, 3, 4 (r, b)	6,100,000 u/y
J. S. C. Valsa Bila Tserkva Tyre Factor No. 2 (Naftochimimpex L. L. C.)					
Belaya Tserkov	1986	—	1,430	5, 6 (r, b)	1,100,000 u/y
United Kingdom					
Cooper-Avon Tyres Ltd. (Cooper Tire & Rubber Co.)					
Melksham, England	1889	Yes	640	1, 2, 3, 4, 5, 7, 9 (r, b)	7,600 u/d
Dunlop Aircraft Tyres Ltd.					
Birmingham, England	1910	Yes	175	8 (r, b)	110,000 u/y
Dunlop Ltd. (Goodyear and Sumitomo Rubber Industries Ltd. Joint Venture)					
Birmingham, England	1916	Yes	250	650	1,500 u/d
Washington, England	1970	Yes	520	1 (r)	13,000 u/d
Goodyear Great Britain Ltd. (Goodyear Tire & Rubber Co.)					
Wolverhamp-ton, England	1927	Yes	1,200	1, 2, 3, 4 (r, b)	20,000 u/d
Michelin Tyre P.L.C. (Groupe Michelin)					
Ballymena, Northern Ireland	1969	Yes	1,150	3 (r)	950,000 u/y
Dundee, Scotland	1972	Yes	950	1 (r)	6,000 u/d
Pirelli Ltd. (Pirelli S.p.A.)					
Carlisle, England	1969	Yes	800	1 (r)	13,000 u/d
Yugoslavia					
Rekord Rubber Factory (Fabrika Gumenih Proizvoda Rekord)					
Belgrade, Serbia	1925	—	800	4, 6	1,850 u/d

European Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Zrenjanin, Serbia	1986	—	100	7 (b)	900 t/m
Ruma-Guma					
Ruma, Serbia	1964	—	1,178	4, 7	950 u/d
Tigar Rubber Products Co.					
Pirot, Serbia	1935	—	1,125	1, 2, 3, 4, 5, 7 (r, b)	11,700 u/d
Trayal Corp.					
Cicevac, Serbia	1978	Yes	690	5 (b)	12,000 u/d
Krusevac, Serbia	1961	Yes	1,052	3, 4, 6, 7 (b)	6,000 u/d
Krusevac, Serbia	1976	Yes	740	1, 2 (r)	4,500 u/d

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Burma					
Burma Tire					
Rangoon	—	—	—	—	—
Cambodia (Kampuchea)					
Kampuchea Government					
Takh Mao	—	—	—	—	3,500 u/m
China					
Anhui Grandtour Full Steel Tyre Factory					
Anhui, Hefei	1957	—	705	3 (b)	124,000 u/y
Anhui Primewell Rubber & Plastics Co. Ltd. (Grandtour Pte. Ltd. & Inoac Group Joint Venture)					
Anhui	2000	—	—	5 (r, b)	30,000 u/d
Beijing First Rubber Plant					
Beijing	1995	—	—	3, 4 (r)	—
Beijing Capital Tire Co. Ltd.					
Beijing	1970	—	2,300	1, 2, 3 (r, b)	2,000,000 u/y
Bridgestone (Shenyang) Tire Co. Ltd. (Bridgestone Corp.)					
Shenyang, Liaoning	1997	Yes	759	3 (r)	200,000 u/y
Bridgestone (Tianjin) Tire Co. Ltd. (Bridgestone Corp.)					
Tianjin	1997	No	1,132	1,2 (r)	11,000 u/d
Carlisle Tire & Wheel Co. (Carlisle Companies Inc.)					
Shenzen Buji	1994	No	500	2, 7 (b)	20,000 u/d
Chan Chun					
Chan Chun	1994	—	—	1, 2 (r)	750,000 u/y
Chaoyang Tyre					
Liaoning	1988	—	—	2, 3 (r)	150,000 u/y
Cheng Shin Rubber (Xiamen) Ind. Ltd. (Cheng Shin Rubber Industry Co. Ltd.)					
Xiamen, Fujian	1992	No	2,000	2, 3, 4, 5, 7	70,000 t/y
Cheng Shin-Toyo Tire & Rubber (China) Co. Ltd. (CST-Trading Limited)					
Kun Shan, Jian Su	1997	No	1,300	1, 2, 3 (r)	10,000 u/d
China Enterprises Ltd.					

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Hangzhou Zhongce, Hangzhou	1990	—	5,140	1, 2, 3, 4, 5, 6, 7 (r, b)	3,800,000 u/y
Yinchuan CSI, Yinchuan	1965	—	3,280	1, 2, 3, 4, 8 (r, b)	2,200,000 u/y
Chongqing Tire Factory					
Sichuan	1958	—	3,600	3, 5 (b)	—
Sichuan	1992	—	3,600	3 (r)	150,000 u/y
Dopong Feng Lion Tyre Co. Ltd. (Lion Rubber Industry Pte. Ltd.)					
Shi Yan, Wuhan/Hubei	1995	Yes	2,500	1, 2, 3 (r, b)	4,400,000 u/y
Federal Tire (Jiangxi) (JFT) (Federal Corporation)					
Nanchang, Jiangxi	1997	No	560	1, 2, 3, 4, 7 (r, b)	1,200,000 u/y
Five Stars Industrial Co. Ltd.					
Buji, Guang Dong	—	—	—	—	—
Goodyear-Dalian Tire Co. Ltd (Goodyear & Dalian Rubber General Factory Joint Venture)					
Dalian	1992	—	370	1, 2 (r)	5,000 u/d
Grandtour Tire (Anhui) Co. Ltd.					
Anhui, Hefei	1997	—	—	1, 2, 3 (r, b)	22,000 u/d
Grandtour Tire (Fujian) Co. Ltd.					
Putian, Fujian	1999	—	—	1, 2 (r, b)	15,000 u/d
Guangzhou Pearl River Rubber Tyre Ltd.					
Huadu, Guangzhou	1970	—	—	1, 2, 3, 4, 6 (b)	1,000,000 u/y
Guilin Lanyu Aircraft Tire Development Co.					
Guilin	—	—	—	8 (b)	80,000 u/y
Guilin Tire Co.					
Guilin, Guangxi	1969	—	—	1, 2, 3, 4, 6 (b)	2,600,000 u/y
Guizhou Tyre Co. Ltd.					
Guiyang, Guizhou	—	—	4,000	1, 2, 3, 4, 6 (r, b)	2,600,000 u/y
Hankook Tire Jiaxing Co. Ltd. (Hankook Tire Co. Ltd.)					

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Jiaxing City, Zhejiang	1996	No	200	1 (r)	4,200,000 u/y
Hebei Tyre Co. Ltd.					
Xingtai, Hebei	—	—	—	1, 2, 3, 4 (r, b)	1,t00,000 u/y
Henan Tyre Co Ltd.					
Jiaozhuo, Henan	—	—	2,600	1, 2, 3, 6 (b)	1,800,000 u/y
Hualin Rubber Group Co. Ltd.					
Mudanjiang, Heilongjiang	1988	Yes	7,235	1, 2, 3, 4, 7 (r, b)	2,500,000 u/y
Hwa Fong Rubber Ind. Co. Ltd.					
Shanghai, Jiangsu	1996	No	1,260	5, 7 (b)	57,000 u/d
Jiangsu Feichi Co. Ltd.					
Yancheng, Jiangsu	—		2,000	2, 5 (b)	—
Jiangsu Hankook Tire Co. Ltd. (Hankook Tire Co. Ltd. & Jiangsu Qingjiang Rubber Co. Ltd. Joint Venture)					
Huaiyin, Jiang Su	1996	Yes	1,100	1, 2, 3, 4, 7 (r, b)	2,100,000 u/y
Jinzhou Xingxing Rubber Production Co. Ltd. (Shinko Group)					
Lianoing, Jinzhou	1996	—	500	5 (b)	300,0000 u/m
Longkou Xinglong Tyre Co. Ltd.					
Longkou, Jiadong	—	—	670	2, 3, 4 (b)	500,0000 u/y
Jiangxi Rubber Plant					
Nanchang, Jiangxi	—	—	—	1, 2, 3, 4, 7 (r, b)	—
Kenda Rubber Industrial Co. Ltd.					
Kunshan, Jiansu	1994	No	850	1, 2, 3, 4, 5, 7 (r, b)	50,000 u/d
Shenzhen, Guangdoing	1990	No	2,000	2, 4, 5, 7 (b)	100,000 u/d
Kunming					
Kunming	—	—	3	—	—

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Liaoning Tyres Group Co. Ltd.					
Chaoyang, Liaoning	1952	—	7,000	1, 2, 3 (r)	2,400,000 u/y
Maanshan HaiTian Rubber Industry Ltd.					
Anhui	—		1,400	1, 5 (b)	—
Michelin Shen Yang Tire Co. (Groupe Michelin)					
Shen Yang, Liaoning	1996		500	1, 2, 3 (r)	1,000,000 u/y
Nanjing Kumho Tire Co. Ltd. (Kumho Industrial Co. Ltd. And Nanjing Investment Corp. Joint Venture)					
Xixia-Qu, Nanjing	1996	Yes	1381	1, 2, 3 (r, b)	5,000,000 u/y
Qingdao Guangming Tyres Mfg. Co. Ltd.					
Qingdao, Shandong	—	—	600	2, 3, 4 (r, b)	500,000 u/y
Qingdao Huaquing Tyre Industry Co. Ltd.					
Qingdao, Shandong	—	—	4,800	2, 3, 4 (r, b)	2,600,000 u/y
Qingdao Rubber Group Co.					
Qingdao	1940	—	6,373	1, 2, 3 (r, b)	2,000,000 u/y
Shandong	—	—	—	1, 2, 3	1,000,000 u/y
Shandong Chengshan Tire Co. Ltd.					
Rongcheng City, Shandong	1976	Yes	8,000	1, 2, 3, 4, 6, 7 (r, b)	10,000,000 u/y
Shandong Huatai Rubber Co. Ltd.					
Laiwu City, Shandong	—	—	—	2, 3, 4 (b)	—
Shandong Triangle Group Co. Ltd. (Triangle Group)					
Weihai, Shandong	1993	Yes	6,364	1, 2, 3 (b)	6,000,000 u/y
Weihai, Shandong	1993	Yes	6,200	1, 2, 3, 4, 6, 7 (r)	3,700,000 u/y
Shanghai Tyre & Rubber Co., Ltd.					
Hai Hua, Haikou	1958	—	—	3 (b)	450,000 u/y
Jiangsu, Xuzhou	1961	Yes	3,348	1, 2, 3, 4, 6, 7 (b)	1,000,000 u/y

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Ta Chung Hua, Shanghai	1928	Yes	—	2, 3, 5 (b)	2,000,000 u/y
Ta Chung Hua, Shanghai	1991	Yes	—	3 (r)	650,000 u/y
Tsen Tai, Shanghai	1927	Yes	—	1, 2, 3 (r, b)	2,000,000 u/y
Tianjin Wanda Tires Group Ltd.					
Tianjin	1988	—	—	2, 4, 5 (b)	—
Tianjin United Tire & Rubber International Co. Ltd.					
Tianjin	1987	No	940	4, 6 (b)	20,000 t/y
Weida (Wuxi) Rubber Co., Ltd.					
Wuxi	—	—	—	2, 5 (b)	7,000,000 u/y
Xiamen Rubber Factory					
Xiamen, Fujien	1970	—	3,096	2, 3, 4, 6 (b)	800,000 u/y
Xin Xing Tyre Co.					
Guangzhou	—	—	—	—	—
Yunnan Tire Co.					
Kunming	—	—	1,000	2, 3, 4, 7 (b)	2,000 u/d
Kunming, Yunnan	1997	—	—	1, 2 (r)	2,000,000 u/y
India					
Apollo Tyres Ltd.					
Baroda	1991	—	1,000	1, 2, 3	2,240 u/d
Perambra	1977	Yes	1,900	1, 2, 3, 4 (r, b)	2,310 u/d
Balkrishna Tyres					
Waluj	1988	—	—	1, 2, 4, 5	166,500 u/m
Betul Tyre Co. Ltd. (Electra Tek Corp.)					
Betul, MP	1993	No	600	1, 2, 3, 4, 8 (b)	600,000 u/y
Birla Tyres (Kesoram Industries Ltd.)					
Balasore, Orissa	1991	Yes	1,400	1, 2, 3, 4 (r, b)	143 t/d
Bridgestone ACC India Ltd. (Bridgestone Corp.)					
Kheda, Pradesh	1998	No	366	1, 2 (r)	20 t/d
CEAT Ltd.					

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Mumbai, Maharashtra	1958	—	2,038	1, 2, 3, 4, 5, 6, 7 (b)	1,000,000 u/y
Nasik, Maharashtra	1974	—	1,413	1, 2, 3, 5 (b)	2,000,000 u/y
Dewan Tyres Ltd.					
Meerut, U.P.	1993	Yes	450	3, 6, 8 (r)	3,500 u/d
Dunlop India Ltd.					
Calcutta	1936	Yes	4,007	1, 2, 3, 4, 5, 6, 8 (b)	3,250 t/m
Madras	1959	Yes	1,176	1, 2, 3, 4, 6 (r, b)	4,700 t/m
Savli, Gujaret	1997	—	—	1, 3 (r)	1,000,000 u/y
Falcon Tyres Ltd.					
Mysore	1975	—	600	1, 5	1,000,000 u/y
Goodyear India Ltd. (Goodyear Tire & Rubber Co.)					
Hariani, New Delhi	1961	Yes	850	1, 2, 3, 4 (r, b)	4,000 u/d
Govind Rubber Ltd.					
Bhiwadi/Alwar, Rajastan	1993	—	—	1,2, 5 (b)	3,000,000 u/y
Dist. Ludhiana Ponjab	—	—	—	—	—
Hindustan Tyres Pvt. Ltd.					
Ludhiana	1968	—	1,200	1, 4, 5	—
J.K. Tyre Group (J.K. Industries Ltd.)					
Banmore, Madhya Pardesh	1991	Yes	1,694	1, 2, 3, 4 (r, b)	5,3851 u/d
Kankroli, Rajasthan	1976	Yes	2,144	1, 2, 3, 4 (r, b)	3,801 u/d
Mysore, Karnataka	1980	Yes	2,221	1, 2, 3, 4, 6 (r, b)	3,400 u/d
Metro Tyres Ltd.					
Ludhiana, Punjab	1968	No	3,600	4, 5 (b)	100,000 u/d
Modi Rubber Ltd.					
Modipuran	1974	—	2,300	1, 2, 3, 4, 5 (b)	155,000 u/m

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Modipuran, U.P.	1993	—	—	1, 2, 3, 7 (r)	—
MRF Ltd.					
Arkonam, Tamil Nadu	1973	Yes	1,337	1, 2, 4, 5, 9 (r, b)	15,000 u/d
Chennai (Madras), Tamil Nadu	1962	Yes	941	2, 3, 4, 6, 7 (b)	2,400 u/d
Goa, Goa	1973	Yes	1,187	2, 3, 4 (r, b)	3,000 u/d
Kottayam, Kerala	1971	Yes	1,275	2, 3, 4 (b)	1,700 u/d
Medak, Andhra Pradesh	1991	Yes	1,271	1, 2, 3, 4, 5 (b)	15,000 u/d
Pondicherry, Pondicherry	1997	No	254	1, 2, 3 (r)	2,800 u/d
Premier Tyres Ltd. (Apollo Tyres Ltd.)					
Kalamaserry	1962	—	942	1, 2, 3, 4	100 t/d
Ramkish Tires Ltd.					
Vissakhapatnam	1993		—	1, 2, 5	1,000,000 u/y
S. Kumar					
Indore	—	—	—	5 (b)	—
South Asia Tyres Ltd. (Goodyear Tire & Rubber Co.)					
Aurangabad	1996	—	500	1, 2, 3, 6 (r)	8,000 u/d
Stallion					
Hyderabad	1976	—	—	5	40,000 u/m
Suntec Tyres Ltd.					
Trichur, Kerala	1995	—	—	2, 4 (b)	—
TVS Srichakra Ltd.					
Madurai, Tamil Nadu	1983	—	1,350	2, 4, 5, 7 (b)	4,000,000 u/y
Tyre Corp. of India Ltd.					
Kankinara	1960	—	854	1, 2, 3, 5	10,250 u/m
Wearwell Tyres & Tubes Ind. Pvt., Ltd.					
Betul, MP	1982	No	400	1, 2, 3, 4 (b)	—

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Indonesia					
P.T. Bridgestone Tire Indonesia (Bridgestone Corp.)					
Bekasi, West Jawa	1976	Yes	1,825	1, 2, 3, 4, 6, 7 (r, b)	7,900 u/d
Karawang, West Java	1999	Yes	526	1, 2 (r)	20 t/d
P.T. Elangperdana Tyre Industry					
Bogor, West Java	1997	—	670	1, 2 (r)	2,000,000 u/y
P.T. Gajah Tunggal TBK					
Tangerang, Jawa Barat	1951	Yes	6,598	1, 2, 3, 4, 5, 7 (r, b)	55,820 u/d
P.T. Goodyear Indonesia (Goodyear Tire & Rubber Co.)					
Bogor	1935	Yes	800	1, 2, 3, 4, 6 (r, b)	9,000 u/d
P.T. Industri Karet Deli					
Medang	1958	—	3,000	1, 2, 7	2,250 u/d
P.T. Sumi Rubber Indonesia (Sumitomo Rubber Industries Ltd.)					
Cikampek, Karawang	1997	Yes	630	1, 2, 3, 5 (r, b)	1,250 u/d
PT Intirub (PT Bimantara Citra Holding)					
Jakarta	1951	—	4,400	1, 2, 3	—
Jakarta	1959	—	733	1, 2, 3	800 u/d
PT Oroban Perkasa (Starsurya)					
Lemahabang, Bekasi	1995	No	760	1 (r)	8,000 u/d
Japan					
Bridgestone Corp.					
Amagi, Fukuoka	1973	Yes	747	3 (r)	9,000 u/d
Hikone, Shiga	1968	Yes	938	1 (r)	42,000 u/d
Hofu, Yamaguchi	1976	Yes	658	1, 6 (r, b)	15,000 u/d
Kurume, Fukuoka	1931	Yes	1,074	1, 2, 3, 4, 7, 8, 9 (r, b)	24,000 u/d
Nasu, Tochigi	1962	Yes	553	1, 2, 4, 5, 7 (r, b)	33,000 u/d

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Shimonoseki, Yamaguchi	1970	Yes	568	6 (r, b)	300 u/d
Tochigi, Tochigi	1971	Yes	871	1, 2, 3 (r)	22,000 u/d
Tokyo	1960	Yes	922	1, 2, 3, 4 (r, b)	32,000 u/d
Tosu, Saga	1970	Yes	725	1 (r)	26,000 u/d
Inoue Rubber Co. Ltd.					
Ikeda, Gifu	1961	Yes	100	5 (r, b)	300,000 u/m
Michelin Okamoto Tire Corp. (Groupe Michelin)					
Ohta	1964	Yes	450	1, 2 (r)	500,000 u/m
Nippon Giant Tire Co. Ltd. (Goodyear Toyo & Rubber Co. & Mitsubishi Corp. Joint Venture)					
Tatsuno	1971	Yes	246	6 (r, b)	100 u/d
Ohtsu Tire & Rubber Co. Ltd. (Sumitomo Rubber Industries Ltd.)					
Izumi-Otsu, Osaka	1944	Yes	516	1, 2, 3, 4, 7, 9 (r, b)	1,950 t/m
Miyakonojo, Miyazaki	1976	Yes	681	1, 2, 3, 9 (r)	4,800 t/m
Sumitomo Rubber Industries Ltd.					
Nagoya, Aichi	1961	Yes	981	1, 2, 3, 5, 7, 9 (r, b)	4,700 t/m
Shirakawa, Fukushima	1974	Yes	1,287	1, 2, 3 (r)	8,000 t/m
Toyo Tire & Rubber Co. Ltd.					
Kuwana, Mie	1979	Yes	747	1, 2, 3, 4, 7 (r, b)	5,000 t/m
Sendai, Miyagi	1965	Yes	860	1, 2, 3, 7, 9 (r, b)	5,300 t/m
Yokohama Rubber Co. Ltd.					
Hiratsuka, Hiratsuka City	1952	Yes	1,922	7, 8 (r, b)	2,700 t/m
Mie	1944	Yes	1,052	1, 2, 3, 4, 7 (r, b)	6,800 t/m
Mishima	1946	Yes	630	1, 2, 9 (r, b)	3,700 t/m
Onomichi	1974	Yes	198	6 (b)	1,100 t/m
Shinshiro	1964	Yes	800	1, 2 (r)	4,900 t/m
Malaysia					
DMIB Bhd. (Sime Darby Bhd. & Continental A. G. Joint Venture)					

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Selangor, Selangor	1962	Yes	1,099	1, 2, 3, 4, 6, 7, 8 (r, b)	145 t/d
Friendship Rubber Industry M Sdn Bhd					
Batang Kali, Salangor	1993	No	75	2, 5, 7 (b)	3,000 u/d
Fung Keong Rubber Manufactory (M) Sdn. Bhd. (General Corp. Bhd.)					
Kelang, Selangor	1940	Yes	500	4, 5 (b)	27,000 u/d
Goodyear Malaysia Bhd. (Goodyear Tire & Rubber Co.)					
Selangor	1962	Yes	600	1, 2, 3, 4 (r, b)	6,800 u/d
Silverstone Tyre & Rubber Co. Sdn. Bhd. (Lion Group)					
Kamunting, Perak	1988	Yes	650	1, 2, 3 (r, b)	2,000,000 u/y
Sime Tyres International (M) Sdn. Bhd. (Sime Darby Berhad & Continental A. G. Joint Venture)					
Alor Setar, Kedah	1980	Yes	912	1, 2, 3, 5 (r, b)	100 t/d
Vredestein FKR (M) Sdn. Bhd. (Fung Keong Rubber Manufactory (m) Sdn. Bhd. & Vredestein N. V. Joint Venture)					
Kelang	1996	—	43	4, 7 (b)	800,000 u/y
Pakistan					
Atlas Tyres (Pvt.) Ltd. (Atlas Group of Industries)					
Lahore	1985	Yes	250	1, 2, 4, 5	1,000 u/d
Delta Tyre & Rubber Co.					
Islamabad	1987	—	—	1, 2, 5	—
General Tyre & Rubber Co. of Pakistan Ltd. (Continental A. G.)					
Karachi	1963	Yes	1,000	1, 2, 3, 4 (r, b)	3,250 u/d
Kings Tyre Industries					
Lahore	—	—	200	1, 2 (r, b)	2,700 u/d
Master Tyres (Pvt.) Ltd.					
Karachi	1950	Yes	250	1, 2	1,250 u/d
Mian Tyre & Rubber Co. (Pvt.) Ltd.					
Lahore	—	—	—	1, 5	—
Service Industries Ltd.					
Gujarat, Punjab	1971	Yes	700	1, 5, 7 (b)	80,000 u/m

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Philippines					
Dura Tire & Rubber					
Manila	1983	—	80	1, 2 (b)	300 u/d
Goodyear Philippines Inc. (Goodyear Tire & Rubber Co.)					
Manila, Las Pinas	1956	Yes	500	1, 2, 3 (r, b)	5,000 u/d
Yokohama Tire Philippines (Yokohama Rubber Co.)					
Clark Special Economic Zone	1996	—	400	1 (r)	5,900 u/d
South Korea					
Hankook Tire Co. Ltd.					
Daejon, Chungnam	1979	Yes	2,363	1, 2, 3 (r)	24,000,000 u/y
Kumsan, Chungnam	1997	Yes	994	1, 2, 3, 4, 6 (r)	10,000,000 u/y
Seoul	1941	Yes	800	2, 3, 4, 6, 7 (b)	1,893,286 u/y
Korea Inoue Kasei (Inoue Rubber Co.)					
Masang	1973	Yes	110	5 (b)	2,500 u/d
Kumho Industrial Co. Ltd. (Kumho Petrochemical Co. Ltd).					
Gokseong, Chollanam-Do	1989	Yes	1730	1, 3, 9 (r)	201,443 t/d
Gwangsan, Gwangju	1972	Yes	2,600	1, 2, 3, 4, 6, 7, 8 (r, b)	211,596 t/y
Nexen Tire Corp.					
Yangsan, Kyung Nam	1986	Yes	940	1, 2, 3, 4, 6, 7 (r, b)	66,000 t/y
Shing Hung Co. Ltd. (Shinko Group)					
Jinju City, Kyung Nam	1973	—	400	5, 7 (b)	250,000 u/m
Sri Lanka					
Associated Ceat Pvt. Ltd. (Ceat Ltd.)					
Kalutara	1993	Yes	160	2, 3, 4, 5 (b)	240,000 u/y
Associated Rubber Ind.					
Colombo	1959	—	—	5	—

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Bergougnan Lanka (Trelleborg A.B.)					
Colombo	1993	Yes	313	7 (b)	400,000 u/y
Ceat-Kelani Associated Holdings (Pvt) Ltd.					
Colombo	1967	—	1,470	1, 2, 3, 4	—
Taiwan					
Bridgestone Taiwan Co. Ltd. (Bridgestone Corp.)					
Hsin-Chu, Hsin-Chu	1982	Yes	320	1, 2 (r, b)	5,500 u/d
Cheng Shin Rubber Industry Co. Ltd.					
Yuanlin, Taiwan	1967	No	2,598	1, 2, 3, 4, 5, 7, 9 (r, b)	2,900,000 u/m
Federal Corp.					
Chung-Li, Taoyuan	1954	Yes	600	1, 2, 3 (r, b)	3,300,000 u/y
General Rubber Corp.					
Taipei	—	—	—	1, 2, 3 (r, b)	1,800 u/d
Goodyear Taiwan Ltd. (Goodyear Tire & Rubber Co.)					
Taipei	1972	Yes	150	1, 2, 3 (r, b)	3,000 u/d
Hwa Fong Rubber Ind. Co. Ltd.					
Yuanlin	1974	No	1,100	2, 3, 4, 5, 6, 7 (b)	35,000 u/d
Kee Liberty Tire Inc.					
Chang-Hua	1989	—	45	5, 7 (b)	3,000 u/m
Kenda Rubber Industrial Co. Ltd.					
Yuan-Lin, Yuan-Lin	1962	Yes	1,002	4, 5, 7 (b)	48,200 u/d
Yun-Lin, Tzu Tung	1985	Yes	374	2, 4, 5, 6, 7 (b)	11,000 u/d
Nankang Rubber Tire Corp. Ltd.					
Hsin Fung	1973	Yes	630	1, 2, 4, 5, 7 (r, b)	1,528 t/m
Taipei	1940	Yes	368	1, 2, 3, 4, 5, 6, 7 (r, b)	1,600 t/m
Seven Stars Rubber Co. Ltd.					
Pib-Tou, Chang-Hua	1980	—	200	5, 7 (b)	300,000 u/m

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Tech Rubber Co. Ltd.					
Fang-Yuann, Chang-Hua	1987	—	200	2, 3, 4, 5, 7 (b)	4,000,000 u/y
Union Rubber Industries Co. Ltd.					
Pushin-Hsiang, Changhua-Hsien	1959	—	200	4, 5, 7 (b)	—
Thailand					
Deestone Ltd.					
Samutsakorn, Oam-Noi	1976	No	1,138	2, 3, 5, 7 (b)	1,100 t/m
Goodyear Thailand Ltd. (Goodyear Tire & Rubber Co.)					
Bangkok	1966	Yes	660	1, 2, 3, 6, 8 (r, b)	6,500 u/d
Hwa Fong Rubber (Thailand) Co. Ltd. (Hwa Fong)					
Bangkok	1989	No	1,060	4, 5, 7 (b)	63,000 u/d
Inoue Rubber (Thailand) Co., Ltd.					
Bangkok	1970	Yes	400	5 (b)	600,000 u/m
Michelin Siam Group Co. Ltd. (Group Michelin Siam Tyre Public Co. Joint Venture)					
Cholburi, Laem Chabang	1990	Yes	846	1, 2 (r)	2,300,000 u/y
Samuthprakarn	1962	Yes	1,183	1, 2, 3, 5, 6 (r, b)	1,900,000 u/y
Saraburi, Nongkhae	1992	Yes	572	3, 8 (r, b)	626,000 u/y
Otani Tire Co. Ltd					
Nakornpathom	1989	No	600	2, 3, 4, 6 (b)	1,500 u/d
Roadstone Tyre & Rubber Co. Ltd.					
Nontabur	1986	—	130	2, 6 (b)	100,000 u/y
Siamese Rubber Co.					
Bangkok	—	—	—	5 (b)	—
Thai Bridgestone Co. Ltd. (Bridgestone Corp.)					
Nong Khae, Saraburi	1995	Yes	837	1, 2 (r)	18,000 u/d

Asian Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Rangsit, Pathumthani	1969	Yes	1,221	1, 2, 3, 4, 6, 7 (r, b)	9,700 u/d
Vee Tyre & Rubber Co. Ltd.					
Muang Smutsakorn, Smutsakorn	1995	No	800	1, 2, 3 (r, b)	500,000 u/y
Smutsakorn	—	No	800	1, 2, 3 (r, b)	500,000 u/y
Uzbekistan					
B.V. Uzbek Gummi					
Angren	—	—	—	—	—
Vietnam					
Inoue Rubber Vietnam Co. Ltd. (Inoac Corp., IRC Thailand, Fung Keong Rubber and Sao Vang Joint Venture)					
Hanoi, Vinh Phue	1998	—	200	5, 7 (b)	100,000 u/m
Kenda Rubber Industrial Co. Ltd.					
Thong Nhat, Dong Nai	1997	No	350	5, 7 (b)	11,400 u/d
Yokohama Rubber Co./Mitsubishi/Southern Rubber					
Ho Chi Minh City	1997	—	32	2, 5 (b)	1,000,000 u/y

Middle Eastern Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Capacity**
Armenia					
Armenian government					
Yerevan	1940	—	2,167	1, 3, 4	2,000,000 u/y
Azerbaijan					
Azerbaijan government					
Baku	1960	—	2,530	1, 3, 4, 5	2,000,000 u/y
Iran					
Artawheel Tyre Co.					
Ardebil	1996	Yes	1,000	1, 2, 3	26,000 t/y
Dena Tire & Rubber Manufacturing Co. Ltd.					
Shiraz	1973	—	—	1, 2, 3 (r, b)	33,000 t/y
Iran Tire Mfg. Co.					
Tehran	1963	—	—	1, 2, 3, 4 (r, b)	28,000 t/y
Iran Yasa Tire & Rubber Co.					
Yasa	—	—	—	5 (b)	10,000 t/y
Kavir Tire & Rubber Co.					
Birjand	1997	—	—	1, 2, 3 (r, b)	25,000 t/y
Kerman Tire & Rubber Co. (Public Corporation)					
Kerman, Kerman	1993	—	804	1, 2, 3, 4 (r, b)	41,000 t/y
Kian Tire Co.					
Tehran	1958	—	1,640	1, 2, 3, 4, 7 (r, b)	30,000 t/y
Pars Tire Co.					
Savah	1983	—	—	1, 2, 3 (b)	40,000 t/y
Yazd Tire Co. (National Iran Industries Organization & Bank Sepah Joint Venture)					
Yazd	1994	—	—	1, 2, 5 (b)	16,000 t/y
Iraq					
Iraq State Enterprises					
An Najafa	1991	—	—	1, 2, 3, 4	167,000 u/m
Diwaniya	1976	—	—	1, 2, 3, 5	9,000 u/m

Middle Eastern Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Capacity**
Israel					
Alliance Tire Co. (1992) Ltd.					
Hadera	1952	Yes	400	1, 2, 3, 4, 6, 7 (r, b)	55,000 t/y
Kazakhstan					
Kazakhstan Government					
Chimkent	1981	—	6,147	1, 3, 4	5,000,000 u/y
Syria					
Afamia General Tyre Co.					
Hama	—	—	—	1, 2, 3, 4, 5	2,700 u/d
Turkey					
Anlas Anadolu Lastik Sanayi Ve Ticaret A.S.					
Bolu/Duzce	1974	Yes	120	5 (b)	3,500 u/d
BRISA (Bridgestone Corp. & Sabanci Group Joint Venture)					
Izmit	1977	Yes	970	1, 2, 3, 4, 6 (r, b)	17,900 u/d
Goodyear Lastikleri Turk A.S. (Goodyear Tire & Rubber Co.)					
Adapazari	1960	Yes	800	1, 2, 3, 4, 6 (r, b)	21,000 u/d
Izmit	1963	Yes	500	2, 3, 4 (r, b)	2,000 u/d
Petlas Rubber Industry and Trade Co.					
Kirsehir	1991	Yes	658	1, 2, 3, 4, 7, 8 (b)	1,000,000 t/y
Turk Pirelli Lastikleri (Pirelli S.p.A)					
Izmit	1960	Yes	900	1, 3, 4 (r, b)	7,500 u/d

African Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Angola					
Mabor Manufactura Angolana					
Luanda	1967	—	—	1, 2, 3	700 u/d
Cameroon					
Compangnie des Industries Africaines du Caoutchouc *(C.I.A.C.)*					
Douala	—	—	—	1, 2, 5	—
Democratic Republic of Congo					
Cobra Tyre & Rubber Co. (G.A.P.)					
Kinshasa	1972	Yes	150	1, 2, 3 (r, b)	1,000 u/d
Egypt					
Alexandria Tire Co. S.A.E. (Pirelli S.p.A.)					
Alexandria	1995	Yes	700	3 (r)	550,000 u/y
Trenco (Transport Engineering Co.)					
Alexandria	1956	—	3,500	1, 2, 3, 5 (b)	1,100,000 u/y
Ethiopia					
Addis Tyre Co. (Ethiopian Govt., Yokohama & Mitsubishi Joint Venture)					
Addis Ababa, Region 14	1972	Yes	635	1, 2, 3 (b)	29 t/d
Ghana					
Bonsa Tire Company					
Bonsasa	1967	—	—	1, 2, 3, 4 (r)	1,200 u/d
Kenya					
Firestone East Africa (1996) Ltd.					
Nairobi	1971	Yes	20	1, 2, 3, 4 (r, b)	660,000 u/y
Libya					
Tajoura Tyre					
Tripoli	1984	—	800	1, 2, 3, 4	37,500 u/m
Morocco					
Goodyear Maroc S.A. (Goodyear Tire & Rubber Co.)					
Casablanca	1995	Yes	350	1, 2, 3, 4 (r, b)	3,500 u/d

African Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Mozambique					
Mabor de Mocambique (Manufactura de Borracha S.A.R.L.)					
Maputo, Maputo	1972	Yes	326	1, 2, 3, 4 (r, b)	1,024 u/d
Nigeria					
Dunlop Nigeria P.L.C. (Dunlop Tyres Int'l (Pty.) Ltd.)					
Lagos, Lagos	1962	Yes	708	1, 2, 3, 4, 6 (r, b)	12,340 t/y
Michelin (Nigeria) Ltd. (Groupe Michelin)					
Port Harcourt	1960	—	1,450	1, 2, 3 (r, b)	2,000 u/d
South Africa					
Bridgestone/Firestone South Africa (Pty.) Ltd. (Bridgestone Corp.)					
Brits	1971	Yes	770	1, 2, 3 (r)	6,000 u/d
Port Elizabeth	1936	Yes	870	1, 2, 3, 4, 6 (r, b)	5,000 u/d
Continental Tyre South Africa (Pty.) Ltd. (Continental A.G.)					
Port Elizabeth, East Cape	1949	Yes	1,650	1, 2, 3, 4, 6 (r, b)	150 t/d
Dunlop Africa Ltd.					
Durban, Kwazulu Natal	1938	Yes	743	2, 3, 4, 6, 7 (r, b)	2,100 t/m
Ladysmith, Kwazulu Natal	1972	Yes	700	1, 2 (r)	2,250 t/m
Goodyear South Africa Ltd. (Goodyear Tire & Rubber Co.)					
Uitenhage	1947	Yes	1,000	1, 2, 3, 4, 6, 7 (r, b)	15,000 u/d
Sudan					
International Tyre Mfg.					
Port Sudan	1980	—	1,500	1, 2, 3, 4, 6	1,500 u/d
Tanzania					
General Tyre East Africa Ltd. (Continental A.G.)					
Arusha	1971	Yes	270	1, 2, 3 (r, b)	1,400 u/d
Tunisia					
Societe Tunisienne des Industries du Pneumatique *(S.T.I.P.)* (Pirelli S.p.A.)					

African Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Menzel-Bourguiba, Bizerie	1967	Yes	440	1, 2, 3, 4, 6, 7 (r, b)	160,200 u/y
Msaken	1985	Yes	500	1, 2, 3 (r)	481,000 u/y
Zimbabwe					
Dunlop Zimbabwe Ltd. (Dunlop Tyres Int'l (Pty.) Ltd.)					
Bulawayo, Matabeleland	1959	No	864	1, 2, 3, 4, 6 (r, b)	8,970 t/y

Australian, New Zealand Tire Production Facilities as of September 2001					
Company/ Plant Location	**Year Opened**	**Unionized Plant**	**Employees**	**Tire Types**	**Estimated Capacity**
Australia					
Bridgestone Australia Ltd. (Bridgestone Corp.)					
Salisbury, South Australia	1965	Yes	645	1, 2, 3 (r)	9,500 u/d
South Pacific Tyres Ltd. (Goodyear Tire & Rubber Co.)					
Somerton	1961	Yes	472	1, 2 (r)	10,800 u/d
New Zealand					
Bridgestone/Firestone New Zealand Ltd. (Bridgestone Corp.)					
Christchurch	1948	Yes	270	1 (r)	4,200 u/d
South Pacific Tyres New Zealand Ltd. (Goodyear Tire & Rubber Co.)					
Wellington	1949	Yes	301	1 (r)	6,000 u/d

Appendix B: Frequently Used Abbreviations

ASTM	American Society for Testing and Materials
CTNA	Continental Tire North America
EPDM	ethylene propylene diene monomer
NATC	Nevada Automotive Test Center
RAC	rubberized asphalt concrete
RMA	Rubber Manufacturers Association
SBR	styrene-butadiene rubber
STMC	Scrap Tire Management Council
TDF	Tire-derived fuel

Appendix C: Contacts

Company	Contact	Address	Phone Number	E-Mail
ADVAC Elastomers, Inc.	Edward Jackush	P.O. Box 886 Brookfield, WI 53008	847-869-7779	www.advcrubber.com
BAS Recycling, Inc.	Murray Quance	1400 North "H" Street, San Bernardino, CA 92405	909-383-7050	cmqbas@aol.com
Bridgestone Firestone	Tim Bent	535 Marriott Drive Nashville, TN 37214	615-872-5000	
Continental Tire	Frank Papp	1800 Continental Blvd. Charlotte, NC 28273-6388	704-583-8759	
Cooper Tire and Rubber Co.	Jennifer Kinn	701 Lima Avenue Findlay, OH 45840	419-427-4793	
	Nate Kear		419-429-4403	njkear@coopertire.com
	Tom Wood, Director of Corporate Environmental Affairs		419-424-4345	tewood@coopertire.com
Goodyear Tire and Rubber Company	Dan Pyanowski	1144 East Market Street Akron, OH 44316-001	330-796-2121	dan.pyanowski@goodyear.com
Green Diamond Tire	Jeff Barlow	P.O. Box 164 Elmira, NY 14902	800-428-8696	jeff@greendiamondtire.com
Lakin Corporation	Dick Gust	2865 N. Paulina Street, Chicago, IL 60657	773-871-6360	dgust@lakincorp.com
Maryland Environmental Services	Adam Ruby	2011 Commerce Park Drive, Annapolis, MD 21401	410-242-5037, ext. 13	aruby1@earthlink.net
Michelin North America	Clarence (Red) Hermann	P.O. Box 1900 Greenville SC 29602-9001	864-422-432	

Company	Contact	Address	Phone Number	E-Mail
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* This company was contacted by the report author but is no longer in business.