Asphalt-Rubber

An Anchor to Crumb Rubber Markets

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Executive Summary

The purpose of this paper is to familiarize the reader with the paving material asphalt-rubber (A-R) by providing historical perspective on its development and obstacles to its development. A-R has been a constant and stable market for crumb rubber producers in the United States most significantly within the vicinity of Arizona, California, and Florida. Agencies use A-R because of the engineering benefits it provides but also find that it contributes to the reduction of waste tires.

Additionally, an overview of tire program management in the key states of Arizona, California and Florida will be included. Government tire programs have been required to control the flow and disposal of waste tires. A fee structure has been required to remediate waste tire piles and to add value to waste tires for processors. Fees have been used to provide equipment to processors and to stimulate the production of beneficial end uses of tires. As markets develop and piles are eliminated, fees can be reduced. Regulations that focus on only one beneficial end use are typically not successful. All environmentally economical options should be included.

Stable crumb rubber markets encourage the development of new technologies that utilize the material. One emerging technology is a spray application to existing highway sound barriers that is crumb rubber based. Crumb rubber has a notable sound energy absorbing characteristic and is relatively inexpensive. This sprayed material is applied in thin layers approximately one quarter of an inch in thickness. The bonding materials experimented with to date have been synthetic stucco mud with crumb as the aggregate and a paint like polymer liquid.

Asphalt-Rubber is not the solution to the waste tire problem, but when utilized by agencies that prefer its beneficial engineering characteristics such as durability, flexibility, strength, and resistance to cracking, it contributes significantly to the reduction of waste tires.

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Key Words

Asphalt modifiers, asphalt rubber, crack resistance, crumb rubber, crumb rubber prices, emissions, life cycle cost analysis, long term cost savings, long term performance, noise barrier walls, reclaimed asphalt pavements, recyclability, scrap tire programs, sound absorption, tire recycling,

1.0 Asphalt Rubber

1.1 History

Highway engineers around the world have tried to incorporate scrap tire rubber in asphalt pavements since the 1950s. (Hanson, 1984) Some of the earliest experiments involved incorporating natural rubber with bitumen in the 1840s. (Heitzman, 1992) It was their hope to capture the flexible nature of rubber in a longer lasting paving surface. The task was difficult and early asphalt-rubber formulas provided little or no benefit, the result was a modified asphalt pavement that cost more and had a shorter service life than conventional asphalt.

It was not until the 1960s that a formulation was discovered that was successful. Charles H. MacDonald worked with the City of Phoenix after retiring from the U.S. Bureau of Public Roads (now FHWA). He first thought of asphalt-rubber while travelling across the country inspecting highway material sources for the Bureau of Roads. His mobile trailer's roof cracked and he used asphalt as a quick patching material. However, after frequent moves and long exposure to the sunlight, the asphalt would oxidize and become brittle. The roof crack "reflected" through to the surface of each successive asphalt patch. He thought he could solve the cracking problem if he incorporated rubber in his next round of patching. (Winters, 1989)

While devising methods to repair potholes on the streets of Phoenix, Arizona, MacDonald experimented with adding ground tire rubber to hot liquid asphalt. He found that after thoroughly mixing crumb rubber with asphalt and allowing it to react for periods of forty-five minutes to an hour, new material properties were obtained. This material captured beneficial engineering characteristics of both base ingredients; he called it asphalt-rubber. (Huffman, 1980) The asphalt was absorbed by the rubber particles, which swelled in size at higher temperatures allowing for greater concentrations of liquid asphalt contents in pavement mixes. He used this material to create “band-aids” for pothole repair. The patches worked so well, that the city eventually tried using asphalt-rubber as the binder for chip seals. A chip seal is a rehabilitation strategy where the hot liquid asphalt-rubber is sprayed by a distributor truck directly on the road surface and aggregate material is then spread and rolled into place.

By 1968, the Arizona Department of Transportation began numerous and diverse research and development projects involving asphalt-rubber under the direction of Gene Morris, the director of the Arizona Transportation Research Center. (Epps et al, 1980) By 1975, crumb rubber was successfully incorporated into hot mix asphalt. Based on the department of transportation’s research, agencies in other states were able to follow the progress and development of asphalt rubber. California and Texas placed chip seal test sections in the 1970s and hot mix applications in the 1980s. Florida developed an asphalt rubber binder with lower rubber contents to avoid the patents in the 1980s. In 1988, American Society for Testing and Materials (ASTM) published the definition of asphalt-rubber. ASTM D8-88 read, “…a blend of asphalt cement, reclaimed tire rubber and certain additives, in which the rubber component is least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles.”

Widespread use of the material was limited based on its experimental status and patent restrictions. However, as many as twenty-three states had placed test sections using A-R by 1990. Extensive research was completed in 1992 through the Construction Productivity Advancement Research Program sponsored by the Army Corps of Engineers and private industry (Anderton, 1992). Additionally, a pooled fund study of crumb rubber modifiers in asphalt pavements sponsored by the FHWA and several states was initiated in 1995. Although the Pooled Fund Study was not completed, a Summary of Practices in Arizona, California and Florida was published by the Transportation Research Institute of Oregon State University (Hicks et al, 1995) as well as an interim report on Construction Guidelines (Hanson, 1996). These reports have been helpful to agencies that wish to develop specifications for crumb rubber modified asphalt.

1.2 Politics

The asphalt-rubber story would not be complete without including the close relationship between the paving industry and government. On a regional level in California (1990), federal highway funds could not be used on asphalt rubber paving projects due to its experimental status. The late Sonny Bono, then mayor of Palm Springs and later a US Congressman, spearheaded the effort to move asphalt-rubber from an experimental status in 1991. His point was successful based on the long-standing use and construction evaluated research of asphalt-rubber by many municipal agencies and California's own Department of Transportation. This type of political activity would be necessary in each state unless the federal government would eliminate funding restrictions on experimental materials.

On the national level, the Itermodal Surface Transportation Efficiency Act (ISTEA) of 1991, Section 1038 mandated the use of rubber modified asphalt pavements in a certain portion of federally funded highway projects that would take place in 1995 and increase incrementally in subsequent years. At the time, most rubberized processes that would have been used were patented or proprietary in nature and efforts were underway to extend the oldest patents which were due to expire at that time. The asphalt paving industry was vigorously opposed to the mandate. This would have guaranteed a substantial portion of the 500 million-ton national hot mix asphalt market to a select few asphalt-rubber paving contractors. As part of the campaign against crumb rubber modified asphalt, many issues were raised about fume emissions, cost effectiveness, durability, longevity, and recyclability. Although the mandate had not taken effect, a moratorium was placed on it so that it would not take effect until those issues could be satisfactorily resolved. During the mandate moratorium, the asphalt industry was able to persuade congress to repeal Section 1038 of ISTEA ending the controversy although the issues had been resolved. It should be noted that the patents were not extended, the last expiring in 1992, and the material is now considered a part of the public domain.

During the mandate era, many scientists and engineers developed a number of different methods and formulas for using crumb rubber modifier in pavements anticipating large potential market share. As before, most were unsuccessful. Coupled with the federal mandate, these failing projects frustrated many state highway officials. The frustration was a major reason why many vowed never to try rubber modified asphalt again regardless of the benefits it may provide.

1.3 The Issues

The most common objections to using A-R are high initial costs, recyclability, hazardous emissions, and expensive equipment modifications. These issues have been adequately addressed by a large number of research projects and reports and also through long standing construction evaluation. For the sake of brevity, the most notable reports are discussed in this paper.

1. **High initial costs –** Costs are higher than conventional asphalt per unit ton until economies of scale are in place. An example, Arizona experienced relatively high costs

until the patents expired and more contractors competed for the work. Currently, the price differential between conventional and A-R hot mix is about $10.00 per ton. The falling cost trend for liquid asphalt rubber is depicted in Figure 1.

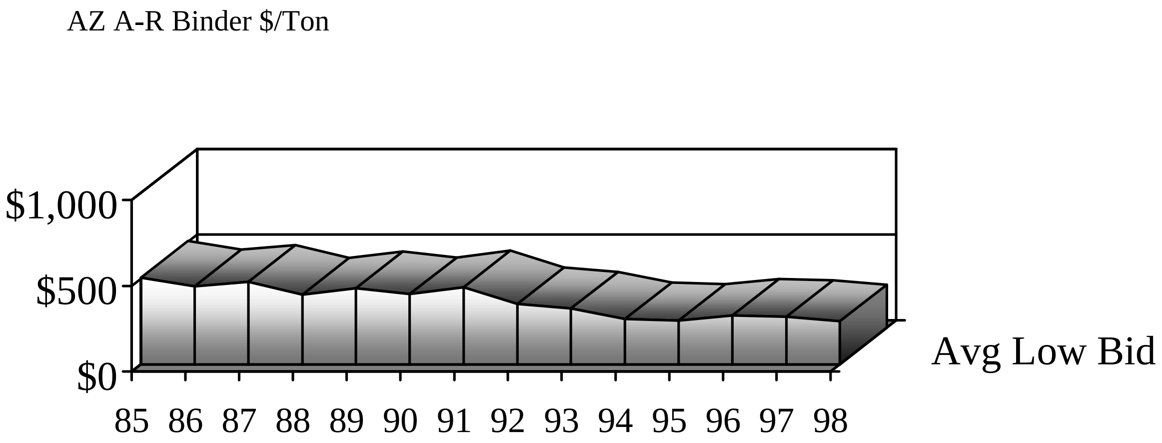

Figure 1 Asphalt Rubber Binder Prices experienced by ADOT (Way, 1999)

Initial costs are actually lower when thickness equivalency ratios are utilized. Less material can be used due to increased durability and strength in asphalt-rubber, at times the ratio is 2:1. An example of an equivalency table is provided by Caltrans in Table 1.

Table 1 California Department of Transportation Design Guide for ARHM Gap Graded.

CALTRANS Structural Equivalency Tables (Thickness in feet)

DGAC	ARHM-GG1	ARHM-GG w/SAMI
0.15	0.10[a]	----
0.20	0.10	----
0.25	0.15	0.10
0.30	0.15	0.10
0.35	0.20	0.15
0.40	0.20	0.15
0.45	0.15[b]	0.20
0.50	0.15[c]	0.20
0.55	0.20[b]	0.15[b]
0.60	0.20[c]	0.15[c]

a - The minimum allowable ARHM-GG lift thickness is 0.10'.

b - Place 0.15' of new DGAC first.

c - Place 0.20' of new DGAC first.

Notes: The maximum allowable non-experimental equivalency for ARHM-GG is 2:, ARHM-GG may not prevent cold weather induced transverse cracks.
DCAG – Dense Grade Asphalt Concrete ARHM – Asphalt Rubber Hot Mix GG – Gap Graded SAMI – Stress Absorbing Membrane Interlayer

2. **Lifecycle economics –** Until a study by Hicks, Lundy, and Epps, the economic savings related to A-R were not clear. (Hicks et al, RPA 1999) Evidence of savings had been published in a variety of reports regarding reduced maintenance costs and reduced lifts, but never by using the Life Cycle Cost Analysis model adopted by the FHWA. Now it is evident that savings can be achieved when using A-R in most cases. Table 2 indicates the deterministic savings projected by using various asphalt-rubber paving strategies where appropriate compared to conventional strategies.

Table 2 – LCCA (Hicks et al, RPA 1999)

Scenario	Present Worth ($/yd)	
	Total	Savings w/ AR
Preservation - Chip Seal		
Conventional	18.39	
AR	15.87	2.52
Preservation - Thin HMA		
Conventional	20.69	
AR	17.33	3.36
Structural Overlay		
Conventional	21.97	
AR	14.63	7.34

Maintenance costs are significantly reduced when pavements resist cracking. An example of reduced maintenance cost associated with A-R compared to conventional material is provided by Figure 2.

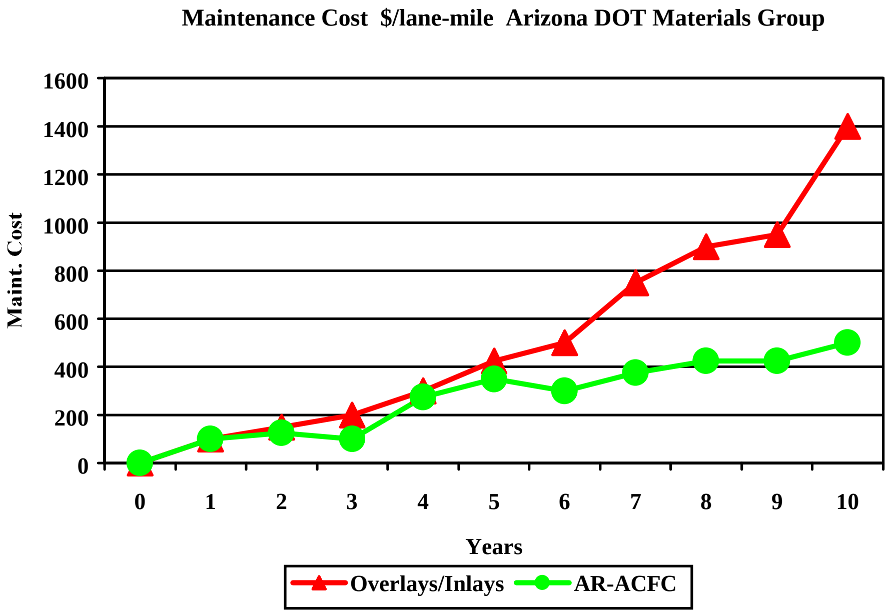

Figure 2 Maintenance Cost dollars per lane mile ADOT, Conventional overlay and inlay materials compared to Asphalt Rubber Asphalt Concrete Friction Course (Way, 1999).

Figure 3 depicts reduced cracking on an asphalt rubber overlay in a test section of Interstate 40 near Flagstaff, Arizona, USA. This test section includes a number of overlay strategies which were placed in 1990 for evaluation by the Arizona Department of Transportation. The sections have identical sub grade and base construction. The test overlay using conventional materials was placed in a thickness of four inches (10.16 cm), the test section using rubber was placed at a depth of two inches (5.08 cm). The section is located at about 7000 feet (2133 m) above sea level and experiences nearly 100 inches (2.54 m) of annual snowfall.

Figure 3 US Interstate 40 near Flagstaff, Arizona. 4” conventional asphalt (left) and 2” asphalt rubber overlays on Portland Concrete Cement placed in 1990, photo taken 1998.

3. **Recyclability –** Before 1992, A-R pavements had been performing well and the replacement/recycling of them was not necessary. During the mandate era the recyclability of asphalt rubber pavements was not validated by field experience. As some sections of asphalt rubber pavements have met their service life span, they have been successfully recycled. The Texas Transportation Institute (TTI) conducted a study in 1995 on this subject where two of the earliest crumb rubber recycling operations in the United States have transpired. (Crockford, 1995) The study concluded that “the material is recyclable and that the recycled material, if properly designed and constructed, should have acceptable long-term performance.” Additionally, the report pointed out “air quality does not seem to be any more severe a

problem than it is with conventional asphalt.” He also stated “…the effect of CRM on emissions may be relatively small in comparison to the effects of other variables.” Those variables include the fueling rate of the dryer, mix temperature, asphalt throughput rate, and asphalt binder content.

Another recent recycle job occurred in the City of Los Angeles, California. (Youssef, 1995) The initial placement of the asphalt rubber pavement occurred in 1982. In 1994 the pavement was milled and stockpiled at a nearby asphalt plant. The asphalt rubber grindings were added to the virgin rock and oil so that the grindings composed 15% of the final mix. At another location, the grindings were put through a microwave process where nearly 100% of the output was composed of recycled asphalt rubber. This project demonstrated that asphalt rubber can be recycled using either microwave technology or conventional mix design technology. Air sampling during paving and recycling determined that employee exposure to air contaminates were well below the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PEL), and in most cases below the detection limits.

4. **Environmental concerns** - Fume emissions have been studied extensively in a number of asphalt-rubber projects since 1993 and in all cases been determined to be below the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limits. (Gunkel, 1994) Table 3 below is an excerpt from a study conducted for the Michigan Department of natural Resources in 1993 comparing conventional HMA and Asphalt-Rubber Hot Mix. In this study control mix 2 contained 100% virgin aggregates and asphalt cement with a penetration of 200-250, equivalent to an AC-2.5.

The rubber mix 1 (RBR1) also contained virgin aggregates and asphalt rubber binder manufactured using the "wet" process which was described previously.

Table 3 Continuous Emissions Measurements and Method 18 Results (Units m/m^3) Evaluation of Exhaust Gas Emissions and Worker Exposure from Asphalt Rubber Binders in Hot Mix Asphalt Mixtures. (Gunkel, 1994)

Operating Data/Conditions/ Measurements	**Control 2**	**RBR 1**
HMA Production Rate (tons per hour)	351	357
Dry Aggregate Rate (TPH)	330	333
Asphalt Cement Added (%)	5.75%	6.84%
Materials moisture content	4.17%	5.21%
Fuel Consumption (gal/hr)	655	690
Exhaust Gas Temperature (F)	311	324
Mix Temperature (F)	296	316
Sample Volume (SCF)	46.501	42.823
Sample Volume (cu. m)	1.317	1.213
Exhaust Gas Moisture (%)	27.0%	29.3%
Stack Temperature (F)	260	271
Actual Exhaust Gas Flow (ACFM)	89,540	95,450
Dry Exhaust Gas Flow (DSCFM)	47,076	47,836
Dry Exhaust Gas Flow (DSCMM)	1,333	1,355
CO2, %, Orsat Result	5.79%	6.02%
O2, %, Orsat Result	12.75%	12.10%
N2, %, Orsat Result	81.46%	81.88%
Carbon Dioxide (CO2)	6.00%	6.48%
Oxygen (O2)	12.87%	12.18%
Carbon Monoxide (CO)	430.5	259.5
Nitrogen Oxides (NOx)	139.3	124.4
Sulfur Dioxide (SO2)	74.4	76.7
Non Methane Total Hydrocarbons (NMTHC) as Carbon	225.5	183.0
Methane (CH4) as measured	27.7	10.6
Methane as Carbon	20.7	7.9
Total Hydrocarbons (THC) as Carbon	245.1	191.3
NMTHC as Carbon	225.5	183.0

The findings of this study were significant to the asphalt-rubber industry in that many of the conventional mix materials had higher, but still acceptable, emissions in certain categories than those with rubber. Very few emission studies were conducted following this report.

5. **Plant modifications –** The equipment used to blend asphalt and rubber requires little, if any, modification to a standard hot mix asphalt plant. The equipment is typically trailer mounted and is transported into the asphalt plant site as depicted in Figure 4. Dedicated mixing and reacting tanks are used which are also mobilized to the site.

Figure 4 Asphalt rubber blending unit.

Additionally, conventional paving equipment without modifications is used to place the material. The capital investment required for a fully operational asphalt rubber plant is anywhere from 500,000 to 750,000 USD. To put this into perspective, a used bulldozer (1998), can be purchased for about 800,000 USD.

1.3 The Industry Today

The traditional formulation for asphalt-rubber developed by Charles H. MacDonald is no longer controlled by patents nor is it proprietary in nature. The material is now part of the public domain. Since the expiration of the patents in 1992, more paving contractors have become involved in the industry. Initially, there were only two companies (1970s), now the number of contractors with some form of asphalt rubber blending or distributing equipment is estimated in the thirties and growing. Industry growth is dependent upon agency use of the material. It is also important to note that this technology was not developed to consume waste tires; ground tire rubber was used because it added significant engineering characteristics and qualities to asphalt pavements.

Tire rubber processed through an ambient grinding system has proven to be most effective during the blending and reacting stage in A-R binder production. The surface area of the particle is a critical factor. Rubber that is first cryogenically reduced needs to be “roughened” through a cracker mill or an equivalent piece of equipment to ensure reaction. Research has indicated that the greater surface area produced in ambient systems provides greater reactivity with liquid asphalt. In most specifications the particles must be free of metal, fabric and moisture. Common gradations for rubber particle sizes used in A-R can be found in Table 4. The percent passing range for each sieve size is listed by states with common A-R usage. The gray bar indicates an unused sieve.

Table 4 Crumb Rubber Gradations for Asphalt Rubber

	#8	**#10**	**#16**	**#20**	**#30**	**#40**	**#50**	**#80**	**#100**	**#200**
Arizona	▨	**100**	**75-100**	▨	**25-100**	▨	**0-45**	▨	**0-10**	**0**
California	**100**	**95-100**	**40-80**	▨	**5-30**	▨	**0-15**	▨	▨	**0-3**
Florida	▨	▨	▨	**100**	▨	**85-100**	▨	**10-50**	**5-30**	▨

Although prices vary, a simple survey of the crumb rubber producers in the southwest provided some pricing information in Table 5. The median price trends from 1995 to 1999 for ten and twenty mesh crumb rubber are depicted in Figure 5.

Table 5 Crumb Rubber Prices Southwestern United States

Year	Price Range 10 Mesh $/lb	Price Range 20 Mesh $/lb
1995	0.13-0.138	0.16-0.175
1996	0.131-0.140	0.16-0.165
1997	0.135-0.147	0.16-0.185
1998	.0133-0.143	0.16-0.175
1999	0.143-0.153	0.16-0.175

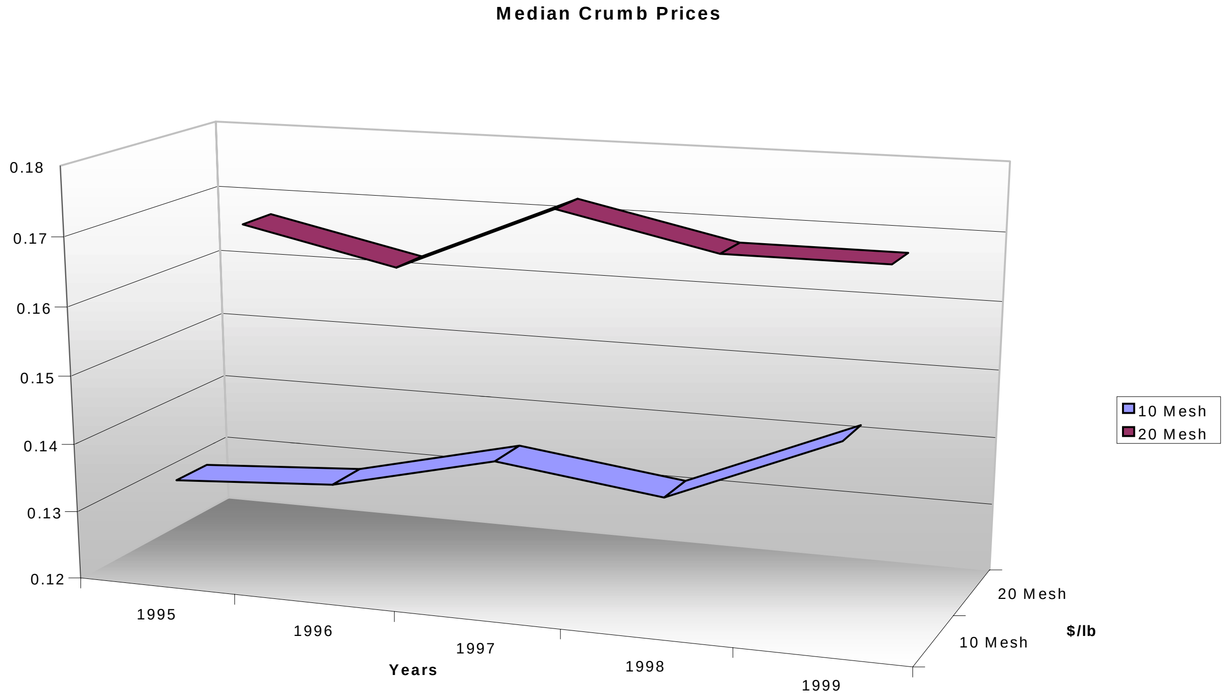

Figure 5 – Median Crumb Rubber Prices in the Southwestern United States

The use of A-R has increased significantly since 1994. DOT figures from AZ, CA, and FLA and some municipal public works departments depict a trend of growth in Figure 6. The same agencies reported 1.6 million tons placed in 1994 and 2.5 million tons placed in 1998. Total figures for the US are not currently available.

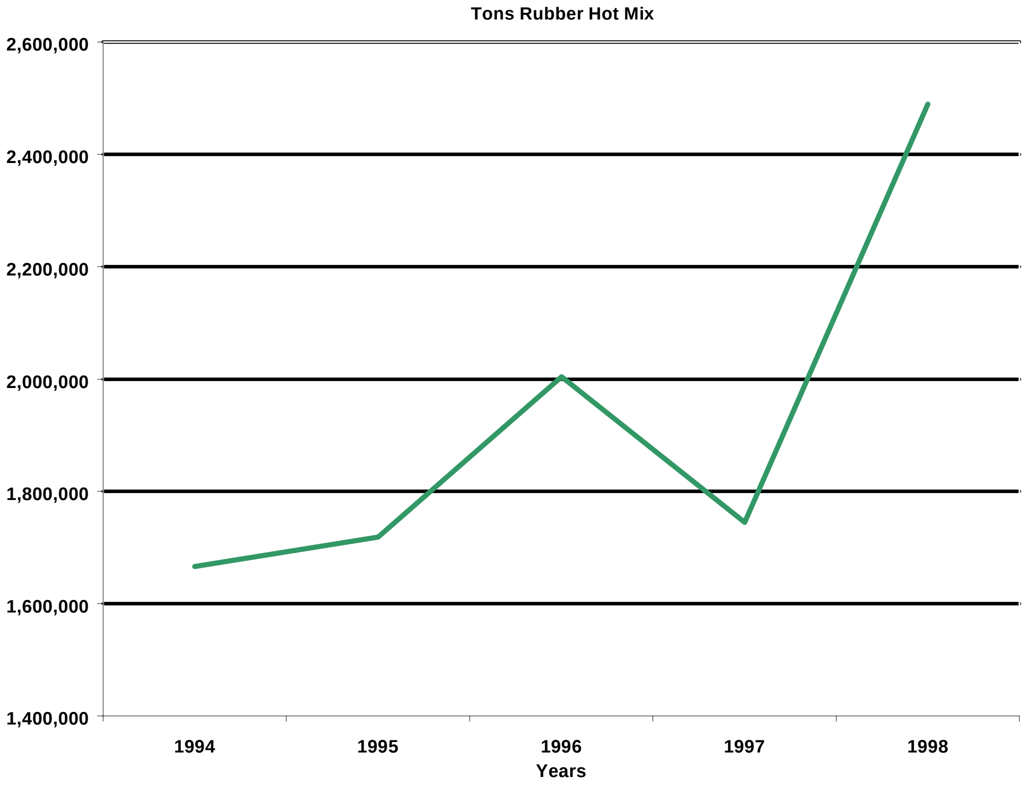

Figure 6 – Annual tonnage of Asphalt Rubber Hot Mix (Six Agencies Reporting)

Formulations for asphalt-rubber within these agencies vary. The crumb rubber content by weight of liquid asphalt cement is generally between 10 to 20% which is reacted at 149 to 204 ^{o}C (300-400 ^{o}F) for periods of 45 minutes to one hour. The most common specifications for asphalt rubber hot mix use approximately 30 pounds of rubber per ton hot mix. Estimates for crumb rubber usage in asphalt in the US have been as high as 200,000,000 million pounds for 1999 (Recycling Research Institute, The Scrap Tire and Rubber Users Directory, 1999). Surprisingly, it is difficult to ascertain the actual figures. Many agencies do not track total figures with regard to rubber used in paving applications. Based on the preceding figures, the participating agencies in this report consumed approximately 75,000,000 pounds of crumb in 1998. (30 pounds per ton)

2.0 Tire Program Management

Most states in the US initiated legislation to control the flow of waste tires in the 1990s in response to heightened environmental concerns. (Scrap Tire Management Council) For example, in 1989 only five states regulated the flow of waste tires. By 1991, thirty-five states had adopted tire legislation. By 1998, forty-eight states had implemented scrap tire legislation or regulations. Thirty-five states banned the practice of tire disposal in landfills. Fees related to tire sales or vehicle registrations were established to provide funding for pile clean up efforts and to stimulate waste tire market development to divert the flow of scrap tires from tire piles. Funding is typically made available to tire processors through grants or direct reimbursement to product output. This paper focuses on programs within Arizona, California and Florida.

2.1 Arizona

Arizona generates approximately 4 million scrap tires annually. (Arizona Department of Environmental Quality) Of these, three million are diverted to a crumbing facility near Phoenix. Approximately 2.6 million are used in paving applications and the remainder are used in molded products, gardening products, or playground safety material. See Table 6. The remaining million are collected in regions beyond the economically feasible trucking radius of the plant and are either exported to a neighboring state, or shredded and used as daily landfill cover. Although two companies are licensed to operate TDF facilities, the equipment has never been installed.

Table 6 Scrap Tire uses in Arizona, 1998 (ADEQ)

Cement Kilns/ Energy Recovery	0
Exported or Landfill cover	1 million
Reuse/retread or other recycled products	0.4 million
Crumb for paving applications	2.6 million

In 1990, the state initiated a fee on the sale of new tires. The fee, 2% or $2.00 whichever is less, is collected by tire dealers and submitted to the state tire fund quarterly. The average fee collected per tire is $1.26. The tire dealers retain 10% of the fees collected for administration and overhead. At the beginning of the program, 51.5% of the tire fund was used to build the processing plant near Phoenix, 41.5% was distributed to the counties and the remaining 5% was retained by the state for program administration. The division of funds continued through 1993 until the plant was completed. At that time, the counties were made responsible for the state tire program and received 95% of the annual tire fund fees.

Counties are required to maintain tire collection facilities which take tires from retailers at no charge. The counties then contract with processors paying a negotiated per tire fee to have them processed. The average fee paid to processors is $93 ton. All parties other than tire retailers with manifests or county residents with five or fewer tires must pay a tipping fee when disposing of tires at collection centers.

Funds are made available through the Department of Environmental Quality in the form of grants to conduct research and development of emerging technologies which utilize scrap tires.

2.2 California

California produces nearly 30 million waste tires each year. (Vitetta Group, 1999) A $0.25 waste tire fee was initiated in 1990 to provide funding for the reduction of stockpiles containing over 45 million tires in total. The tire program is administered by the California Integrated Waste Management Board (CIWMB). The fee is collected at the point of sale with 10% retained by the tire dealer for overhead. The remaining $0.225 is deposited in the state Tire Fund. Approximately $5 million is generated annually. Based on the amount collected, it appears that approximately 8 million tires escape the fee. The Tire Fund provides for permitting, enforcement and clean up activities, as well as market development programs and administrative costs. Approximately 50% of the annual waste tire flow is diverted to alternative end uses. Table 7 depicts end uses for waste tires in California according to the CIWMB.

Table 7 Scrap Tire uses in California, 1998 (CIWMB)

Cement Kilns	4.9 million
Energy Recovery	3.5 million
Reuse/retread or other recycled products	4.3 million
Crumb for paving applications	2.7 million

Due to large volume of waste tires, limited program funding, difficulties in controlling the flow (enforcement), and economic barriers to alternative end uses, many tires are land-filled or illegally stockpiled. Clean up costs of stockpiles range from $0.54 to $2.26, with a median cost of $1.27 per tire.

Recent studies indicate that the tire program is under-funded and legislation is currently being proposed to increase the tire fee and to include tires that are not currently participating in the fee such as wholesale fleet sales and truck tires.

Grants are made available through the CIWMB to private enterprise and other public agencies to purchase waste tire processing equipment and for projects which divert tires from the waste stream. The CIWMB conducts an aggressive market development program. Historically, nearly 50% of the Tire Fund has been used for activities such as biennial tire recycling conferences and regional technology centers to name a few. For a more detailed listing of market development programs contact the Board at 1-916-255-2000 or visit the web site: http://www.ciwmb.ca.gov.

2.3 Florida

The Florida tire program was established in 1988. (Florida Department of Environmental Protection) At the time an estimated 18 million tires were stockpiled around the state. Today, less than 3 million tires remain. Clean up costs range from $0.85 to $2.00 per tire.

Florida generates approximately 20 million waste tires annually. The waste tire program is funded through the Solid Waste Management Trust Fund which is funded by a $1.00 fee on the sale of each new tire. Funds are also raised by a 0.2% sales tax collection allowance and an annual sales tax registration fee. Over $17.3 million in revenue was generated in 1998. End uses of waste tires are depicted in Table 8.

Table 8 Scrap Tire Uses in Florida 1997-98 (FDEP)

Cement Kilns/Energy Recovery	9.1 million
Reuse/retread or other recycled products	6.3 million
Crumb for paving applications	3.0 million

Land filling whole tires is prohibited by law. However, shredded tires may be used as daily cover. It is assumed by the Florida Department of Environmental Protection that the “missing” 1.6 million tires in the table above were used for this purpose.

3.0 New Crumb Rubber Technology

Enterprising individuals are continuously developing new technologies to overcome the waste tire problem. Certainly, established government programs encourage growth in these industries. Some notable entries include tire chips as in septic leachate fields, soil amendment, playground safety material and noise absorption systems.

3.1 Sound Absorbing Material

Various civil engineering uses of scrap tires in highway applications have been explored extensively in the last decade. Using shreds in light fill in embankments can use large quantities of scrap tires. One use that has been only partially explored is the use of scrap tires in sound walls. Rubber has demonstrated very desirable sound absorbing characteristics.   Early technologies involved labor intensive construction of barriers using whole or parts of tires attached to or embedded within the wall structure. Later technologies developed hollow planks or boards filled with crumb. Recent work at Arizona State University's College of Civil and Environmental Engineering has explored using ground tire rubber in sound absorbing surface coatings for existing sound walls along urban highways. (Zhu, 1999) Ongoing experimentation with the sound absorptive coating has led to the use of no. 8 sieve crumb rubber mixed with liquid acrylic and alkyd polymers in a 1:1 ratio. The material has been applied with conventional spray technologies from the paint and stucco industries. Sound absorption tests are being conducted by Riverbank Acoustical Laboratories in Illinois to determine the amount of decibel reduction that can be obtained from the use of this material. Test sections will be constructed if significant noise reduction levels are obtained in lab tests.

Convergent Spray Technology ™ developed for the aerospace industry holds promise for crumb rubber based sound absorbing spray equipment. This equipment mixes the materials, both liquid polymers and dry rubber particles, at the point of dispersion (nozzle tip). This type of technology offers several advantages. The mixing occurs at the nozzle tip, so very little of the mixture is wasted and eliminates mixture storage requirements. Additionally, the equipment has a high volume application rate and provides a uniform and homogenous material.

All materials produced for use on sound walls along roadways will undergo extensive evaluation for durability criteria. The most notable are resistance to thermal and ultra-violet degradation. The design life for the material is set for twenty years. Additives such as fire retardant and color pigmentation will be tested as well.

3.2 Results

Preliminary testing results for an acrylic based crumb rubber spray are encouraging. The noise reduction coefficient measured by Riverside Acoustical Laboratories was 0.35. This coefficient is a measure of the acoustical absorption performance calculated by averaging sound absorption coefficients at 250, 500, 1000 and 2000 Hz. Sound absorption coefficients range from 0.01 for marble slate to almost 1.0 for long absorbing wedges used in anechoic rooms. Another measurement provided by the testing lab was sabins. A sabin is a measure of the sound absorption of a surface; it is the equivalent of one square foot of a perfectly absorptive surface. Table 9 provides some preliminary measurements of the crumb rubber based spray. It should be noted that the specimen area was roughly 64 square feet to give meaning to the sabin measurements. Additionally, the material was more absorptive in relation to higher frequencies which are more typical of highway traffic noise.

Future tests should provide greater sound absorptive figures. The first sample was relatively dense due to higher percentages of polymers in the mix. The next sample to be tested will be from the nozzle mixed equipment which allows for lower percentages of liquid polymers in the mix. Tests should be available on the web-site: www.rubberpavements.org by December 1999.

Table 9 Riverside Acoustical Laboratories test results of crumb rubber sound spray. (Zhu, 1999)

1/3 Octave Center Freq. (Hz)	Absorption Coefficient	Absorption in Sabins
100	0.05	3.46
125	0.06	3.53
160	0.05	3.22
200	0.04	2.47
250	0.10	6.11
315	0.13	8.14
400	0.17	10.54
500	0.28	18.12
630	0.36	23.21
800	0.43	27.12
1000	0.48	30.34
1250	0.49	31.00
1600	0.53	33.86
2000	0.54	34.26
2500	0.54	34.31
3150	0.53	34.04
4000	0.55	34.88
5000	0.56	35.65

4.0 Waste Tire Solutions

4.1 Early technologies

Many of the early technologies were developed specifically with intent to solve the waste tire problem. Sustainable markets did not exist and government involvement was required to assist in market development, to provide capital investment or equipment, or secure markets to reduce new market entry risks. Unfortunately, this tactic was not very successful because it usually required focusing on only one end use of tires while ignoring the others due to limited funds. Competition among the waste tire industries involved often created a position of stalemate so that in the end limited progress was accomplished to reduce the waste tire problem. Risk levels were extremely high when markets were not guaranteed for a dedicated and exclusive end use. This caused likely entries into the waste tire market to hesitate in committing large capital investments in plants and equipment which could process tires as fuel or reduce them to crumb.

However, in cases where certain technologies have been exclusively guaranteed, the waste tire problem either continued to grow beyond facility capacity or the economics of moving waste tires to a specific site had proven to cost more than was sustainable. Public opposition to technologies requiring combustion has also slowed growth in the United States out of fear of contributions to global warming or hazardous emissions. Although these fears seem unfounded, it has definitely caused a down turn expanding TDF markets further.

Pyrolisis technologies offered hope to waste tire program managers in the US during the 1980s and early 1990s. The process involves submitting tires to intense temperatures in a vacuum. The tire decomposes into its base elements, steel, petrochemicals and carbon black. The costs associated with plant construction and lack of sustainable markets for the pyrolitic products have severely limited the growth of this industry. Additionally, failed attempts in establishing this technology have been notorious for abandoning millions of tires at sites throughout the US. This industry, unfortunately, has not had a successful track record.

Mono-filling of tires in landfills or burying tires only at other dedicated sites has been used occasionally to prevent the build up of waste tire stockpiles. This practice could be considered to store tires for future economical or profitable uses but is not currently well controlled. The most significant problem is that the tires or shreds are not protected from soil contamination. Future users will have to first clean tire material unless the developed technology can utilize soiled tires. The mining costs associated with tire recovery could be prohibitive and new waste tires will remain the most economical source of recycled tire rubber.

4.2 Environmentally Economic Solutions

New approaches to solving the waste tire problem should integrate sustainable technologies that provide continuous benefit to the public. Combustion technologies are effective in the disposal of large quantities of waste tires and should be used where feasible and acceptable to the public. However, the combustion of tires does not provide a continuous public benefit and results in a net energy loss when all is considered. Although approximately 15,000 BTUs are recaptured when a tire is combusted, 30,000 BTUs were expended to create each tire. In contrast, the United States Department of Energy has estimated that over 90,000 BTUs can be saved by utilizing asphalt-rubber through reduced materials usage and its long lasting performance (Gaines and Wolsky, 1979). However, the TDF technologies will continue to play an important role in the reduction in waste tire stockpiles. Most importantly, solutions to the waste tire problem must be sought and a stand-off avoided.

5.0 Conclusions

Crumb rubber can not be considered a waste material. It is a valuable commodity with ongoing expansion and growth in diversified markets. Its use in asphalt is not making a highway into a linear landfill. Crumb rubber has proven to be one of the only additives to hot mix asphalt derived from a waste material that has a beneficial impact and actually improves performance. Some conclusions from studying this market may include:

1. Crumb rubber production is an environmentally economical sound method of waste tire reduction,
2. Asphalt Rubber has proven long term performance, cost effectiveness, and sustainable market growth, and
3. Asphalt Rubber paving programs are key components to acceptable and successful waste tire management programs.

All options must be considered to reduce the build up of waste tires. It is far better to remove tires from the waste stream, regardless of disposal method, than to allow the continuation of uncontrollable and disastrous waste tire stockpile fires through out the world. Without question, the emissions from equipment and facilities that process waste tires will always be lower than the emissions from a waste tire fire burning out of control in the open demonstrated by Figure 7.

Figure 7 – Filbin/Oxford tire fire, California, USA. Photo courtesy Sacramento Bee September 1999. Six to Eight million tires in flames.

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7.0 References

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