United States
Environmental Protection
Agency

Solid Waste and
Emergency Response
(OS-301)

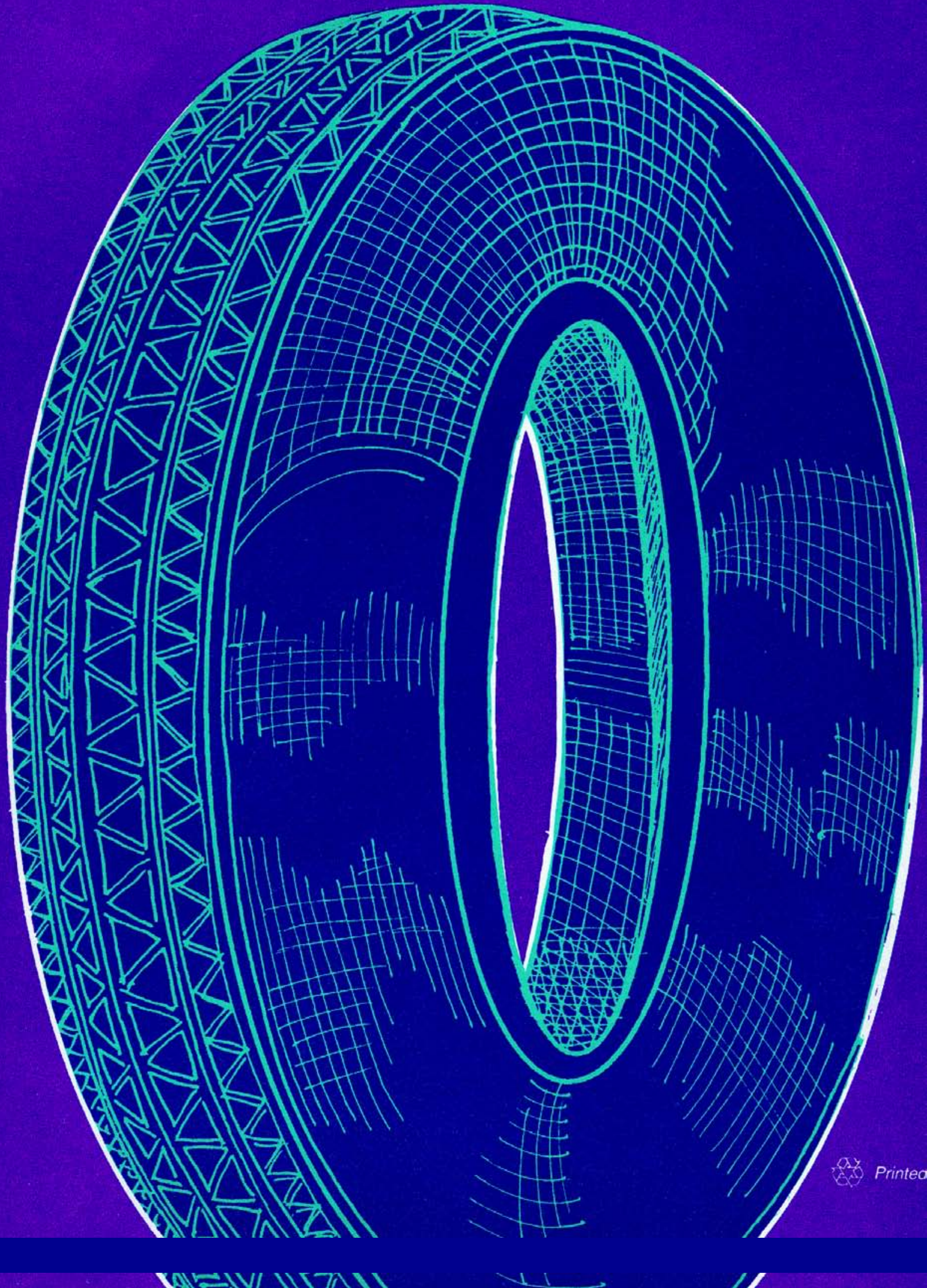
Policy, Planning
and Evaluation
(PM-221)

EPA/530-SW-90-074A

October 1991

EPA

# Markets for Scrap Tires



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# MARKETS FOR SCRAP TIRES

October 1991

**United States Environmental Protection Agency**

**Office of Solid Waste**

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Any mention of company or product names in the report does not constitute endorsement by the Environmental Protection Agency.

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# MARKETS FOR SCRAP TIRES

# EXECUTIVE SUMMARY

The management of scrap tires has become a growing problem in recent years. Scrap tires represent one of several special wastes that are difficult for municipalities to handle. Whole tires are difficult to landfill because they tend to float to the surface. Stockpiles of scrap tires are located in many communities, resulting in public health, environmental, and aesthetic problems.

This report discusses the problems associated with scrap tires and identifies existing and potential source reduction and utilization methods that may be effective in solving the tire problem. Barriers to increased utilization and options for removing the barriers are identified and evaluated.

## The Scrap Tire Problem

Over 242 million scrap tires are generated each year in the United States. In addition, about 2 billion waste tires have accumulated in stockpiles or uncontrolled tire dumps across the country. Millions more are scattered in ravines, deserts, woods, and empty lots. Scrap tires provide breeding sites for mosquitoes which can spread diseases and large tire piles often constitute fire hazards. Most tire and solid waste professionals agree that a tire problem exists.

Six facets of the tire problem are listed below:

> Tires are breeding grounds for mosquitoes. Besides the major nuisance of mosquito bites, mosquitoes can spread several serious diseases.
>
> Uncontrolled tire dumps are unsightly and are fire hazards. Fires in tire dumps have burned for months, creating acrid smoke and leaving behind a hazardous oily residue. A few tire fire locations have become Superfund sites.
>
> Tires should be utilized to minimize environmental impact and maximize conservation of natural resources. This means reuse or retreading first, followed by reuse of the rubber to make rubber products or paving, and then combustion and disposal. At present, the preferred uses do not accommodate all the tires, and disposal must be utilized to a large degree.

Waste tires have to go somewhere. They tend to migrate to the least expensive use or disposal option. As costs or difficulties of legal disposal increase, illegal dumping may increase.

Disposing of waste tires is becoming more expensive. Over the past 20 years the average tipping fees for disposing of tires have continually increased. This trend is likely to continue as landfill space becomes more scarce.

Tires take up landfill space. Whole tires are banned from many landfills or charged a higher tipping fee than other waste; even if they are carefully buried to prevent rising they are very bulky. Shredded tires take up less space, but it is space that could be saved if the tires were utilized as raw material for products or as fuel.

As described above, the continuing accumulation of waste tires has led to six concerns of varying severity. Clearly, the mosquito and fire hazard problems are the most serious of the concerns listed. Controlling them in the near term will necessitate providing adequate safeguards on existing stockpiles. Ultimately, decreasing the waste tire accumulations will involve appropriate uses of recycling, combustion, and landfilling. The current trends of reuse and source reduction indicate that the quantity of tires utilized in products is likely to remain smaller than the quantity combusted or landfilled in the future.

It is estimated that less than 7 percent of the 242 million tires discarded in 1990 were recycled into new products and about 11 percent were converted into energy. Over 77 percent, or about 188 million tires per year, were landfilled, stockpiled, or illegally dumped, and the remaining 5 percent were exported. The flow of scrap tires is shown in Figure 1.

Scrap tire legislation is increasing rapidly at the state level. In 1990, twelve states passed or finalized scrap tire laws, regulations, or amendments. As of January 1991, thirty-six now have scrap tire laws or regulations in effect, and all but 9 states regulate or have bills being proposed to regulate tires. A summary of the states' laws in effect in January 1991 are listed in Table 1. The contents of the legislations and the sources of funding are summarized in Table 2.

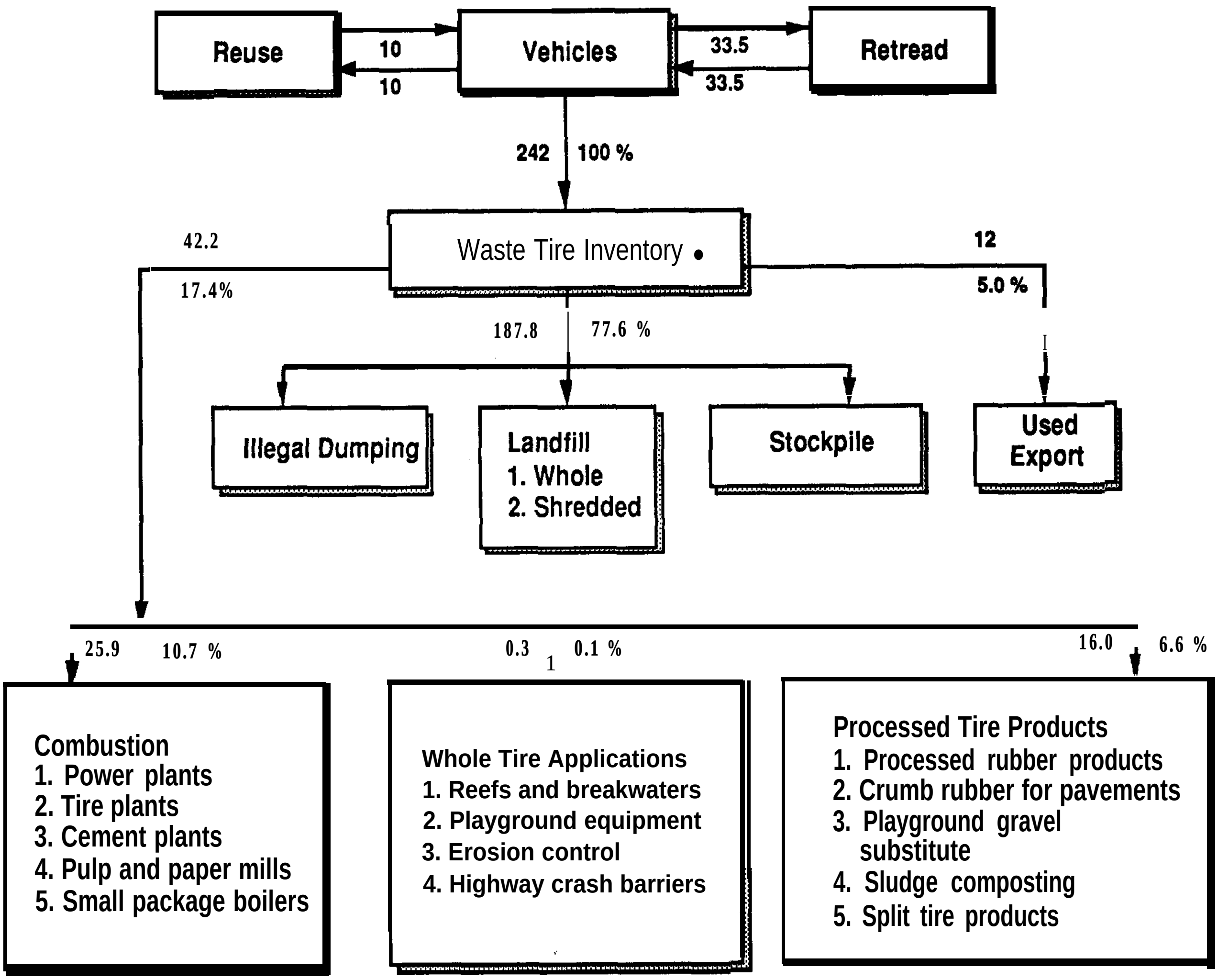


Figure 1. Flow diagram showing estimated destination of scrap tires In 1990.
(In millions of tires and percent)

•Retreads (33.5 million) and reused tires (10 million) are not counted as scrap tires.

Table 1
SCRAP TIRE LEGISLATION STATUS
January, 1991

| | Draft | Proposed | Regs | Law |
|---|---|---|---|---|
| Alabama | X | | | |
| Alaska | | | | |
| Arizona | | | | x |
| Arkansas | | X | | |
| California | | | | x |
| Colorado | | | X | |
| Connecticut | | | x | |
| Delaware | | | | |
| Florida | | | | x |
| Georgia | | | | |
| Hawaii | | | | |
| Idaho | | | | |
| Illinois | | | | x |
| Indiana | | | | x |
| Iowa | | | | X |
| Kansas | | | | X |
| Kentucky | | | | X |
| Louisiana | | | | X |
| Maine | | | | X |
| Maryland | | | | X |
| Massachusetts | | x | X | |
| Michigan | | | | x |
| Minnesota | | | | x |
| Mississippi | | x | | |
| Missouri | | | | X |
| Montana | | | | |
| Nebraska | | | | x |
| Nevada | | | | |
| New Hampshire | | | x | |
| New Jersey | | | | |
| New Mexico | | X | | |
| New York | | x | X | |
| North Carolina | | | | X |
| North Dakota | | | | |
| Ohio | | | x | |
| Oklahoma | | | | x |
| Oregon | | | | X |
| Pennsylvania | | | X | |
| Rhode Island | | | | x |
| South Carolina | | X | | |
| South Dakota | | | X | |
| Tennessee | | | X | |
| Texas | | | X | |
| Utah | | | | X |
| Vermont | | | X | |
| Virginia | | | | X |
| Washington | | | | X |
| Wisconsin | | | | X |
| West Virginia | | | X | |
| Wyoming | | | X | |

Draft - draft being written/bill in discussion
Prop - proposed/introduced in 1990 legislature
Rags - regulated under specific provision of solid waste or other laws (e.g., automotive wastes)
Law - scrap tire law passed

Source: Scrap Tire News, Vol. 5, No. 1, January 1991

## Table 2
## CONTENTS OF SCRAP TIRE LEGISLATION

| | Funding Source | Storage Rags | Processor Regs | Hauler Regs | Landfill Restrictions* | Market Incentives |
|---|---|---|---|---|---|---|
| Arizona | 2% sales tax on retail sale | | x | | x | |
| California | $0.25/tire disposal fee | X | x | | | x |
| Colorado | | x | x | | | |
| Connecticut | | x | | | | |
| Florida | $1.00/tire retail sales | x | x | x | x | R&D grants |
| Illinois | $0.50/vehicle title fee | X | X | X | | grants/loans |
| Indiana | permit feed/tire storage **sites** | X | | | x | grants |
| Iowa | | | | | x | |
| Kansas | $0.50/tire retail sales | x | x | x | x | grants |
| Kentucky | $1 .00/tire retail sales | x | | | x | |
| Louisiana | | x | | | x | |
| Maine | $1.00/tire disposal fee | x | x | draft | | grants/loans |
| Maryland | state budget appropriations | x | x | x | | |
| Michigan | $0.50 vehicle title fee | x | x | x | | grants |
| Minnesota | $4.00/vehicle title transfer | x | x | x | x | grants |
| Missouri | $0.50/tire retail sales | x | | x | x | funds/testing |
| Nebraska | $1 .00/tire retail sales | | | | | grants |
| New Hampshire | graduated vehicle regist. fee | x | | | | |
| North Carolina | 1% sales tax on new tires | x | x | x | x | funds/collection |
| Ohio | | | | | x | |
| Oklahoma | $1 .00/new tire (surcharge) | x | x | | x | grants |
| Oregon | $1.00/new tire (dspl tax) | x | x | x | x | $0.01/lb |
| Pennsylvania | | x | | | | R&D grants |
| Rhode Island | $0.50/new tire sales tax | x | x | | | |
| South Dakota | | x | x | | x | |
| Tennessee | | | | | x | |
| Texas | | x | | | x | |
| Utah | graduated tax per tire size | | | | | $20/ton |
| Vermont | | | | | x | funds/testing |
| Virginia | $0.50/new tire (dspl tax) | | | | x | |
| Washington | | x | x | x | | grants |
| Wisconsin | $2.00/tire vehicle title fee | x | x | x | x | $20/ton |

•The maiority of states have imposed regulations that require tires to be processed (cut, sliced, shredded) prior to Landfilling. Some of the states allow for storage (above ground) of shreds at landfills. OH, NC, CO are among the states considering or allowing monofils for tire shreds. Whole tires are discoraged from landfills (in almost all cases) either by law (e.g., MN) or more frequently by high disposal fees.

Source: Scrap Tire News, Vol. 5, No. 1, January 1991.

## Source Reduction Alternatives

Source reduction measures for tires include the following:

- Design of extended life tires
- Reuse of used tires
- Retreading

Great strides have been made in the last 40 years in tire manufacturing that have more than doubled the useful life of tires. Forty thousand mile tires are commonplace, and 60,000 to 80,000 mile lifetimes are often achieved. Constraints of cost, fuel consumption, and comfortable rides, make it unlikely that any major design changes will occur in the near future that will significantly increase tire life.

Frequently, when one or two tires of a set are worn, the entire set is replaced with new tires. Useful tread may remain on several of the remaining tires. These tires are often sold for second cars or farm equipment. About 10 million tires per year are currently being reused. Although the reuse of partially-worn tires cannot be expected to solve the tire problem, reuse could potentially double based on the number of good tires currently thrown away,

Retreading is the application of a new tread to a worn tire that still has a good casing. There are currently over 1,900 retreaders in the United States and Canada; however, that number is shrinking because of the decreased markets for passenger retreads. This decline is primarily due to the low price of new tires and the common misperception that retreads are unsafe. The price of inexpensive new passenger tires ($50 to $60) is often at or near the price of quality retreads. On the other hand, truck tire retreading is increasing. Truck tires are often retreaded three times before being discarded and the truck tire retreading business is increasing,

The National Tire Dealers and Retreaders Association asserts that properly-inspected retreaded tires have lifetimes and failure rates comparable to new tires, Mileage guarantees and/or warranties for retreads are often similar to or identical to new tire warranties, In 1987, about 23 million passenger and light truck tires and 14 million truck tires were retreaded, By 1990 these retread rates changed to 18.6 million and 14,9 million, respectively, It is estimated that most good truck tire casings are being retreaded due to the high cost of new truck tires, but that at least two times as many passenger and light truck tires would be suitable for retreading.

## Recycling Alternatives

Some recycling alternatives use whole tires, thus requiring no extensive processing; other alternatives require that tires be split or punched to make products; and still other alternatives involve tires that are finely ground enabling the manufacture of crumb rubber products. Some applications for each alternative are listed below

— Whole tire applications
- Artificial reefs and breakwaters
- Playground equipment
- Erosion control
- Highway crash barriers

— Split or punched tire applications
- Floor mats, belts, gaskets, shoe soles, dock bumpers, seals, muffler hangers, shims, washers, and insulators

— Shredded tire applications
- Lightweight road construction material
- Playground gravel substitutes
- Sludge composting

— Ground rubber applications
- Rubber and plastic products; for example, molded floor mats, mud guards, carpet padding, and plastic adhesives
- Rubber railroad crossings
- Additives for asphalt pavements

All of the tire recycling alternatives listed above are being used to varying degrees. However, the total usage of tires for recycling currently is estimated to be less than 7 percent of the annual generation. The markets for most of the products may be increased, but, even if increased to their fullest potential, appear to be small compared to the number of tires generated each year. Ground rubber applications hold the greatest promise. The tire recycling alternative with the greatest potential to significantly reduce the scrap tire problem of the United States is in asphalt highway construction.

There are two types of processes for using crumb rubber in pavements. One application, referred to as rubber modified asphalt concrete (RUMAC), involves replacing some of the aggregate in the asphalt mixture with ground tires. The second, called asphalt-rubber, blends/reactivates a certain percentage of the asphalt cement with ground rubber. Both systems are being evaluated by state agencies as well as the federal government.

## Tire to Energy Alternatives

Tires have a fuel value of 12,000 to 16,000 Btu per pound, slightly higher than that of coal. With existing technology, tire combustion can meet Federal and State environmental requirements. Tires may be burned whole or shredded into tire derived fuel (tdf). Whole tire combustion requires less processing expense; however, most of the plants currently burning tires for fuel do not have the capability to burn whole tires. In 1990, about 25.9 million tires (10.7 percent of total generation) were burned for energy production. Combustion facilities currently using tires as fuel include:

- Power plants
- Tire manufacturing plants
- Cement kilns
- Pulp and paper plants
- Small package steam generators

The largest scrap tires combustion system is the Oxford Energy plant in Modesto, California. It consumes about 4.9 million tires per year and generates 14 MW of power. A second Oxford Energy power plant, designed to burn about 9-10 million tires per year, is under construction in Connecticut. Commercial operation is planned for 1991.

Seven cement kilns in the United States utilize about 6 million scrap tires per year to replace conventional fuels. Cement kilns appear to be ideal for scrap tires because of their high operating temperatures (2,600 F) and good conditions for complete combustion, which minimize air pollution problems. Also, there is no residue, since the ash is incorporated into the cement product. Of the 240 cement kilns in the United States, about 50 are equipped with precalciner/preheaters, making them most suitable for tire combustion.

Many furnaces designed to burn wood chips at pulp and paper plants are suitable for burning tire-derived-fuel without major modifications. Frequently, only wire-free tdf can be used in these boilers, thus increasing the tire processing costs. An estimated 12 million tires per year are currently being consumed by the pulp and paper industry.

## Pyrolysis Alternatives

Pyrolysis of tires involves the application of heat to produce chemical changes and derive various products such as carbon black. Although several experimental pyrolysis units have been tried, none has yet demonstrated sustained commercial operation.

## Barriers to Increased Scrap Tire Utilization

Barriers to increased scrap tire utilization can be classified into two main types - economic and noneconomic.

> Economic barriers refer to the high costs or limited revenues associated with various waste tire utilization methods which make the uses unprofitable. Tire processors will not invest time or capital unless there is a sufficient rate of return to justify the efforts.
>
> Noneconomic barriers refer to a number of constraints on utilization. These include technical concerns such as lack of technical information or concerns regarding the quality of products or processes. These barriers also include the reluctance of consumers, processors, and regulators to employ new approaches or technologies for aesthetic or other reasons. They also include constraints on utilization because of health and safety, environmental issues, laws, and regulations.

The strength and persistence of these barriers are evident from the continuing buildup of tire stockpiles and dumps over the last several years.

Most of the technologies available for mitigating the nation's scrap tire problem are limited by both economic and noneconomic barriers, and it is often difficult to separate the two. For example, the use of retreaded or used automobile tires is limited by competitive new tire prices, an economic barrier, as well as consumer concerns about safety and reliability, a noneconomic barrier. Designing tires to last 100,000 miles or more would cost considerably more and also would likely result in rougher rides and more tire noise.

Making products such as reefs, playground equipment, floor mats, gaskets, etc., out of scrap whole or processed scrap tires is primarily limited by the high cost of tires compared with other raw materials. However, there are also some noneconomic barriers. Reefs made of tires, for example, are not appropriate for the rough shores of the northwest, Playground equipment made of wood or other products is often preferred for aesthetic reasons.

The two technologies with the most potential for using a major portion of scrap tires generated each year, and actually reducing the tire stockpiles, are pavements with rubber additives and combustion for energy generation.

Barriers to the increased usage of rubber in asphalt pavements are both economic and noneconomic in nature. The cost of installing roads of rubberized asphalt is greater than conventional asphalt, which is an economic barrier. On the other hand, several studies show that the total life cycle cost of rubberized asphalt is lower than conventional asphalt. This would be an economic benefit. However, decisions on paving are often made on the basis of road miles paved per year, rather than life cycle cost of the pavement.

The two forms of rubberized asphalt that have been tested the longest, asphalt-rubber and PlusRide™, are patented. The required royalty fees increase the cost of these products. Although, initially, patents may have stimulated the growth of these products, they now appear to represent an economic barrier to increased scrap tire usage by these technologies. The patent for asphalt-rubber expires in 1991. After that more companies are expected to become involved, resulting in lower costs. Non-patented rubberized asphalt roadways are also being tested.

One of the major noneconomic barriers to the use of rubber in asphalt pavements has been the lack of consensus on the results of long-term testing. Many long-term tests have been performed, but they were performed in over a dozen states, and as yet these tests have not been brought together and evaluated in a cohesive study.

Power plants to burn scrap tires involve large capital investments and annual operating expenses. However, plants located near large supplies of tires can be feasible. A key variable in determining economic feasibility for these plants is the buy-back rate granted by the utility. In areas of the country where the rate is high, such as California and the northeast, power plants are feasible. The buy-back rate is the rate the utilities pay for electricity generated from alternative fuel, and reflects the fuel and other costs avoided by the utility.

Burning tires in existing pulp and paper mills and certain types of cement kilns requires much less capital investment than the dedicated power plants mentioned above. Pulp and paper mills often burn hog-fuel (chipped wood), thus requiring very little modification for tire chips. The main economic variable is the price of the competing fuel. Tire-derived fuel must often compete with low cost coal or petroleum coke, a waste product from the petroleum refining process. If tdf is only slightly cheaper than the alternate fuel, then plant modification cannot be justified.

The main noneconomic barriers to scrap tire combustion are the time required for permitting a plant and the concerns of neighbors regarding environmental, health, and safety issues. Because of the test burns required and time delays in permitting, many cement plant and pulp and paper mill operators hesitate to change their operation for the small savings realized by burning scrap tires.

## Options for Mitigating the Scrap Tire Problem

There is now a general public awareness throughout the U.S. that a waste tire problem exists. A number of options have been identified to address the problem, many of which are currently being utilized in several states. State, local, and federal governments need to work on the waste tire problem from all possible angles, in order to arrive at a strong solution.

State governments have been very active in utilizing a variety of techniques for addressing tire problems. By the end of 1990, thirty-six states had regulated scrap tires, up from only one state in 1985. Twenty-one states had funded their state tire management programs through such means as a tax or surcharge on tires, added vehicle registration fees, or fees to transfer vehicle titles. Twenty-four states had final regulations addressing storage of tires. At least twelve states had included some type of market incentives such as rebates, grants or loans to help build markets for scrap tires.

These state laws can make a significant dent in solving the nation's tire problem. Particularly important provisions are funding sources based on taxes or fees on tires sold or on vehicles sold or transferred; mandates to clean up of tire dumps; regulations to reduce fire and mosquito hazards at tire stockpiles; and recordkeeping and tracking requirements to ensure that tires are sent only to reputable haulers, processors, or end-users who manage the tires legally. Market incentives such as the rebate systems instituted by the states of Oregon, Wisconsin, Utah, and Oklahoma, have been very successful in promoting additional recycling and the use of tires for energy recovery.

In addition to the state regulations, other ideas that have been implemented or proposed to address scrap tires, include: (1) procurement strategies; (2) research; (3) increased coordination among states; (4) education and promotion; (5) waste exchanges; (6) tradeable credits; and (7) tax incentives.

EPA's Federal procurement guidelines for retreaded tires, which became effective on November 17, 1989, are encouraging Federal agencies both to retread tires on their vehicles, and to buy retreaded tires, States may decide to develop similar guidelines to encourage retreaded tires.

There is a need to continue to perform research on methods of recycling tires, such as the use of crumb rubber in rubber products and plastics. Existing research on rubberized asphalt should be summarized, and a decision made regarding its feasibility for more widespread use, or if there are still technical or economic questions, determining exactly what additional research is needed to answer these questions, and then perform this research, States and Federal government, and environmental and transportation agencies, should coordinate research efforts so that fewer, more comprehensive research projects (particularly related to rubberized asphalt) can be performed.

Other means of exchanging information such as conferences on scrap tires, hotlines, newletters, waste exchanges, and computerized data bases, are being developed or utilized by both government and industry. Because the economics and technology of scrap tires is changing so rapidly, these sources are particularly helpful in spreading information regarding scrap tires, to government officials, entrepreneurs, environmental groups, and private citizens.

**Study Conclusions**

Each year about 242 million tires are scrapped. Current trends indicate that less than 7 percent of these tires are being recycled as products and 11 percent are being burned for energy, and 5 percent are being exported. The rest are being landfilled, stockpiled, or dumped illegally.

EPA wishes to encourage waste tire reduction and recycling, with a special emphasis on reducing the number of tires in uncontrolled stockpiles or illegal dumps. These tires are often sites of mosquito infestation, with the potential for spreading dangerous mosquito-borne diseases. Large tire dumps can also lead to fires with major releases of hazardous organic chemicals into the air, surface water, and ground water.

Recycling rubber from tires for use in asphalt pavements is a promising technology. Asphalt pavements incorporating tire rubber are claimed to have twice the lifetime of ordinary asphalt, but they can cost twice as much. Pavements with crumb rubber additives consume over one million tires per year now, and both asphalt-rubber and rubber modified asphalt concrete have considerable potential for expansion. If Federal, state, and local governments promote much broader use and demonstration of this technology, perhaps the technical issues will be resolved and usage will expand.

Using whole tires as fuel for reciprocating grate power plants appears to be economically feasible in some regions of the country, and can meet environmental permitting requirements, One such plant in Modesto, California, is currently consuming 4.9 million tires per year. Another power plant is under construction in Connecticut and is expected to consume an additional 10 million tires per year. A second 10 million tire per year plant is being planned for an area near Las Vegas, Nevada. The main barriers to such plants appear to be local resistance to incineration projects and lengthy permitting procedures.

The replacement of coal by tire-derived-fuel appears economically feasible for cement kilns. Seven such kilns are currently operating in the U. S., consuming the equivalent of about 6 million tires per year between them. There is potential for this use to expand further, particularly for those cement kilns whose feed systems are compatible with the use of TDF.

Tire-derived fuel is economically feasible for use in hog fuel boilers in the pulp and paper industry. It is estimated that the equivalent of 12 million tires is consumed annually in this way in the U.S. There is potential for this use to expand further.

Other technologies and options are promising on a smaller scale, but also are important to the overall solution. Uses of crumb rubber for such diverse products as athletic surfaces, tracks, and rubber molded products, show potential for growth. Also, increased retreading could utilize a significant number of tires. If the market justified retreading all the usable carcasses, about 20 million additional passenger and light truck tires could be retreaded each year. Current trends, however, indicate that fewer of these tires are retreaded each year.

Other uses of tires are sometimes feasible for specialized geographic conditions. Cape May County, New Jersey uses 100,000 tires per year, which is 100 percent of its scrap tires, for artificial reefs. The State of Minnesota has used about a million of its tires since 1986 for roads in swampy areas.

The markets for most other products made from tires have potential, but appear to be relatively small, These include rubber railroad crossings, artificial reefs, playground equipment, erosion control, highway crash barriers, playground gravel substitute, sludge composting, rubber farm and agricultural equipment, and rubber mats. Each of these products has the potential for using some portion of our waste tire stockpile. Collectively, they are all important parts of the solution to the tire problem.

## Chapter 1

## ASSESSMENT OF PRESENT SITUATION

### INTRODUCTION

About 242 million automotive, truck, and off-road tires are discarded in the United States each year. This is approximately equal to one waste tire per person per year. Additionally, there are 33.5 million tires that are retreaded and an estimated 10 million that are reused each year as second-hand tires. It is estimated that 7 percent of the discarded tires are currently being recycled into new products and 11 percent are converted to energy. Nearly 78 percent are being landfilled, stockpiled, or illegally dumped, with the remainder being exported.

Tires are difficult to landfill. Whole tires do not compact well, and they tend to work their way up through the soil to the top. As a result, tire stockpiles, which cost less than landfills, have sprung up all over the country. It is estimated that between 2 and 3 billion tires are stockpiled in the U.S. at present, with at least one pile containing over 30 million tires. Tire stockpiles are unsightly and are a threat to public health and safety. Not only are tire piles excellent breeding grounds for mosquitoes, but they are also fire hazards.

It is the goal of the EPA to eliminate illegal dumping altogether and to reduce the stockpiling and landfilling of discarded tires as much as possible. The report, **The Solid Waste Dilemma: An Agenda for Action,** lays out EPA's national strategy for managing municipal solid waste (MSW) (1). It sets out a three-tier hierarchy for management of municipal solid waste, with source reduction ranking first, followed by recycling, then incineration and land disposal. Interestingly enough, over the last 40 years, tires have been somewhat of a success story for source reduction. The advent of the 40,000-mile tire means that tires last longer before they wear out.

As with many other components of the waste stream, the highest priority options, source reduction and recycling, are the least utilized and landfilling is the most common practice. Potential source reduction measures for tires include the design of longer lived tires, reuse of tires removed from vehicles, and retreading. These practices all extend the useful life of tires before they are discarded. Considerable increases in tire lifetimes have been achieved in the past 20 years with the advent of the radial tire. On the other hand, partially because of the radial tires, retreading of automobile tires is decreasing each year. Radial tire side walls tend to be weaker than bias ply walls, thus the rejection rate by retreaders is higher. Radials also are more expensive to retread than bias plies. Truck tire retreading, however, is still increasing. A total of about 37 million tires were retreaded in 1987. This dropped to 33.5 million in 1990. Retreading extends the useful life of a retreadable tire from 60 to 80 percent (an automobile tire with one retread) to 300 percent (a truck tire with three retreads).

Tire recycling activities include the use of whole tires or processed tires for useful purposes. Whole tire applications include reefs and breakwaters, playground equipment, erosion control, and highway crash barriers. Processed tire products include mats and other rubber products, rubberized asphalt, playground gravel substitute, and bulking agent for sludge composting.

Scrap tire combustion is practiced in power plants, tire manufacturing plants, cement kilns, pulp and paper plants, and small package steam plants.

## GENERATION OF WASTE TIRES

It is commonly accepted in the tire industry that about one tire per person per year is discarded. Since there is no industry group or governmental agency that monitors tire disposal in the United States, the best estimates that can be made are based on tire production. The Rubber Manufacturers Association (RMA) records the number of original equipment, replacement, and export tires that are shipped each year in the United States. (See Table 3.) In 1990, a total of 264,262,000 tires were shipped. The RMA data include new tire imports, but not imported used tires. To estimate the number of tires that were discarded in the United States in 1990, the following assumptions were made:

> One tire is discarded for each replacement tire shipped, including new and used imports. (Discard is assumed to be in the same year as replacement tire production.)
>
> Original equipment tires are not discarded in the year they are produced, but rather in the year a replacement is sold.
>
> Exported tires are not discarded in the USA.
>
> Four tires are discarded for each automobile or truck when it is taken out of service.
>
> Retreads and reused tires are put back into service in the same calendar year that they were taken out. (Therefore, retreading and reuse simply have the effect of extending the tire's useful life.)

**Table 3**
**U.S. AUTO, TRUCK, AND FARM TIRE SHIPMENTS***
**(In thousands of tires)**

| **1990** | **Passenger** | **Bus/Truck** | **Farm Equipment** | **Total** |
|---|---|---|---|---|
| Original equipment | 47,199 | 6,993 | 995 | 55,187 |
| Replacement | 152,251 | 36,588 | 2,549 | 191,388 |
| Export | 14,110 | 3,283 | 294 | 17,687 |
| **Totals** | **213,560** | **46,864** | **3,838** | **264,262** |
| **1989** | | | | |
| Original equipment | 51,170 | 8,177 | 890 | 60,237 |
| Replacement | 151,156 | 35,172 | 2,664 | 188,992 |
| Export | 12,437 | 3,548 | 270 | 16,255 |
| **Totals** | **214,763** | **46,897** | **3,824** | **265,484** |
| **1988** | | | | |
| Original equipment | 54,131 | 8,801 | 753 | 63,685 |
| Replacement | 155,294 | 33,918 | 2,662 | 191,874 |
| Export | 9,365 | 3,301 | 267 | 12,933 |
| **Totals** | **218,790** | **46,020** | **3,682** | **268,492** |
| **1987** | | | | |
| Original equipment | 52,913 | 7,845 | 608 | 61,366 |
| Replacement | 151,892 | 34,514 | 2,658 | 189,064 |
| Export | 5,987 | 2,069 | 226 | 8,282 |
| **Totals** | **210,792** | **44,428** | **3,492** | **258,712** |
| **1986** | | | | |
| Original equipment | 54,392 | 6,859 | 512 | 61,763 |
| Replacement | 144,267 | 32,392 | 2,319 | 178,978 |
| Export | 4,032 | 1,302 | 170 | 5,504 |
| **Totals** | **202,691** | **40,553** | **3,001** | **246,245** |

•Includes imported new original equipment and replacement tires.

Source: Rubber Manufacturers Association (RMA) Monthly Tire Report, December 1990 and earlier years.

Although these are simplifying assumptions, they lead to a good approximation of the number of tires available for discard each year. Inaccuracies may result because sometimes when vehicles are de-licensed, they may remain in the junk yard or in a garage for a while before their tires are discarded. Also, when a tire is removed from a vehicle for retreading or reuse, a new replacement tire may take its place. For this replacement tire, there will be no corresponding discard. However, when the retreaded tire is sold again, a waste tire would be generated.

Table 4 summarizes waste tire generation based on the assumptions above. These data show that in 1990 scrap tires were generated at the rate of about 0.97 tires per person per year. Figure 2 and Table 5 show the estimated disposition of the 242 million scrap tires generated in 1990. About 16.3 million were recycled, 26 million were recovered for energy, and about 12 million were exported, leaving 188 million for landfilling, stockpiling, or illegal dumping. Figure 3 shows that in 1990 17.4 percent of the tires scrapped were recycled or burned for energy.

## ENVIRONMENTAL PROBLEMS ASSOCIATED WITH WASTE TIRE STOCKPILES

Because of the difficulty of landfilling scrap tires and the resulting high costs, stockpiles have sprung up across the country. It is estimated that between 2 and 3 billion tires are stockpiled in the U.S. at present, with at least one pile containing over 30 million tires. In addition to being unsightly, tire piles are excellent breeding grounds for mosquitoes and they are fire hazards.

### Mosquitoes

Mosquitoes have long been identified as pests and vectors of disease. It has also been known for some time that tires have the potential to serve as ideal breeding grounds for mosquitoes, especially when tires occur in large numbers in stockpiles. Because of the shape and impermeability of tires, they may hold water for long periods of time providing sites for mosquito larvae development.

Because tires can hold water, they have contributed to the introduction of non-native mosquito species when used tires are imported to the U.S. The new species are often more difficult to control and spread more disease (2).

There is evidence of tires contributing to the presence of mosquito-transmitted diseases. The main solution that has been offered is tire shredding. This guarantees that no water will be held for breeding sites. Further preventive measures could include requiring all shipped tires and all stockpiles to be fumigated. Other solutions sometimes suggested to the mosquito problem in tire stockpiles

## Table 4

### SCRAP TIRE GENERATION IN THE UNITED STATES
(In Thousands)

| | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1964 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
| Replacement Tire Shipments | | | | | | | |
| Passenger 1/ | 144,580 | 141,455 | 144,267 | 151,892 | 155,294 | 151,156 | 152,251 |
| Truck 1/ | 31,707 | 32,098 | 32,392 | 34,514 | 33,918 | 35,172 | 36,588 |
| Farm Equipment 1/ | 2,592 | 2,395 | 2,319 | 2,658 | 2,662 | 2,664 | 2,549 |
| Imported Used Tires 2/ | 1,793 | 3,233 | 2,552 | 2,925 | 1,352 | 1,466 | 1,108 |
| Total Replacement Tires | 180,672 | 179,181 | 181,530 | 191,989 | 193,226 | 190,458 | 192,496 |
| Tires from Scrapped Vehicles 3/ | | | | | | | |
| Cars | 26,700 | 30,916 | 33,768 | 32,412 | 35,016 | 37,200 4/ | 39,000 4/ |
| Trucks | 6,406 | 8,400 | 9,236 | 9,456 | 9,004 | 10,400 4/ | 11,000 4/ |
| Total Tires from Scrapped Vehicles | 33,108 | 39,316 | 43,004 | 41,866 | 44,020 | 47,600 | 50,000 |
| Total Scrap Tires in U.S. | 213,780 | 218,497 | 224,534 | 233,857 | 237,246 | 238,058 | 242,496 |
| U.S. Population (thousands) 3/ | 235,961 | 238,207 | 240,523 | 242,825 | 245,807 | 247,732 | 249,981 |
| Scrap Tires/Person/Year | 0.91 | 0.92 | 0.93 | 0.96 | 0.97 | 0.96 | 0.97 |

1/ (Includes imported new tires) National Petroleum News, Fact Book, 1986-1986. Data from the Rubber Manufacturers Association. 1986 through 1990 data from RMA Industry Monthly Tire Report, December 1989 and December 1990.
2/ U.S. Department of Commerce. “U.S. Imports for Consumption.” (FT246). 1984-1990.
3/ U.S. Department of Commerce, Statistical Abstracts, 1990 and prior years. Estimate based on 4 tires per vehicle.
4/ Estimated by Franklin Associates, by linear extrapolation.

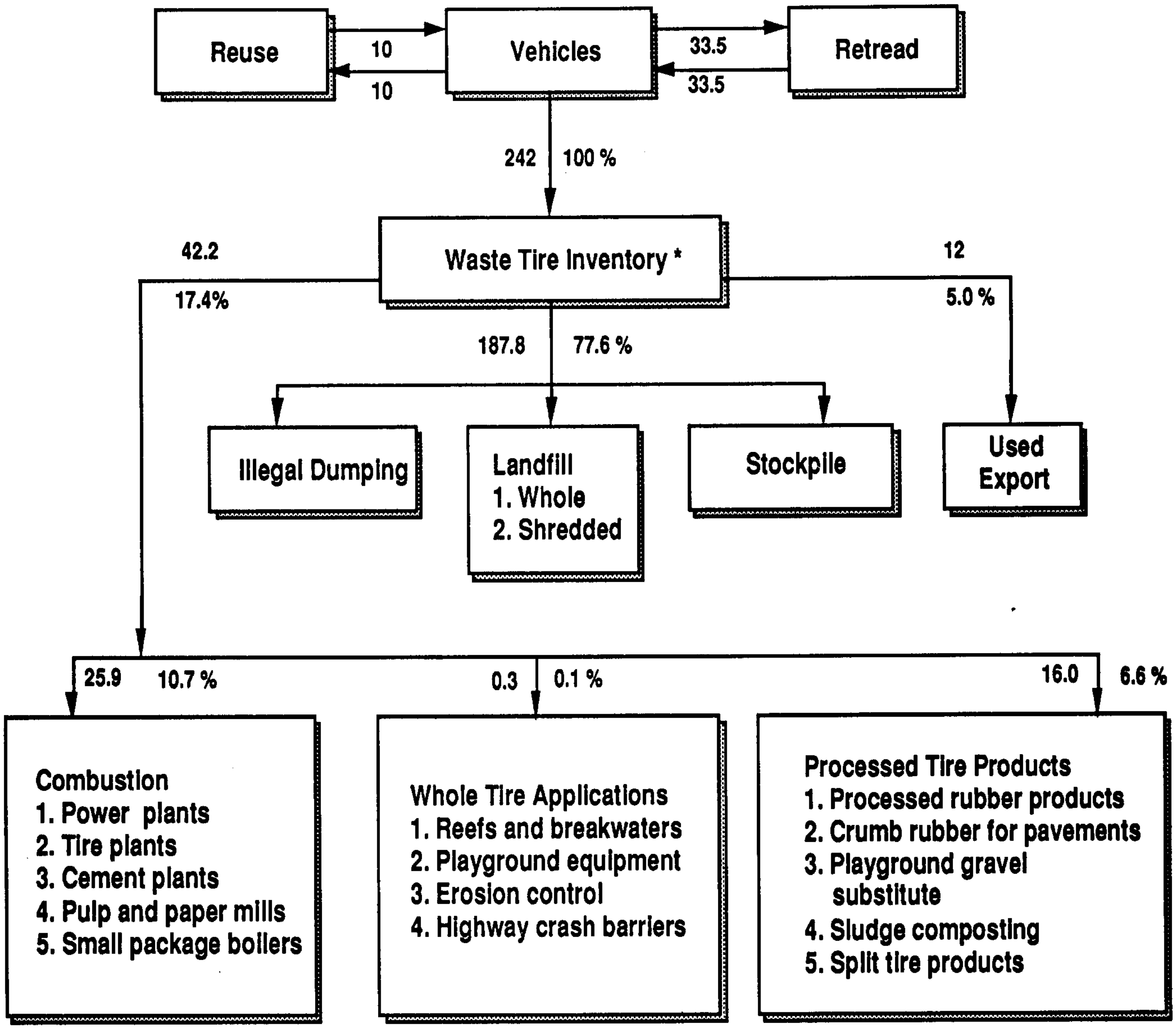


Figure 2. Flow diagram showing estimated destination of scrap tires In 1990.
(In millions of tires and percent)

* Retreads (33.5 million) and reused tires (10 million) are not counted as scrap tires.

## Table 5

### MATERIAL AND ENERGY RECOVERY FROM SCRAP TIRES

| **Method of Recovery** | **No. of Tires (in millions)** | **Percentage of 242 Million Scrap Tires** |
|---|---|---|
| Energy/Burning | 25.9 | 10.7 |
| Reclaim | 2.9 | 1.2 |
| Splitting | 2.5 | 1.0 |
| Crumb Rubber for Pavements | 2.0 | 0.8 |
| Other Crumb | 8.6 | 3.6 |
| Whole Tires | 0.3 | 0.1 |
| **Total Recovered** | 42.2 | 17.4 |
| Used Export | 12 | 5.0 |
| Landfill, Stockpile and Dumping | 188 | 77.6 |
| **Total Scrap Tires*** | 242 | 100.0 |

*Retreads (33.5 miilion) and reused tires (10 million) are not counted as scrap tires.

Source: Franklin Associates, Ltd. and Dr. Robert Hershey. Estimates based on published data and technical discussions.

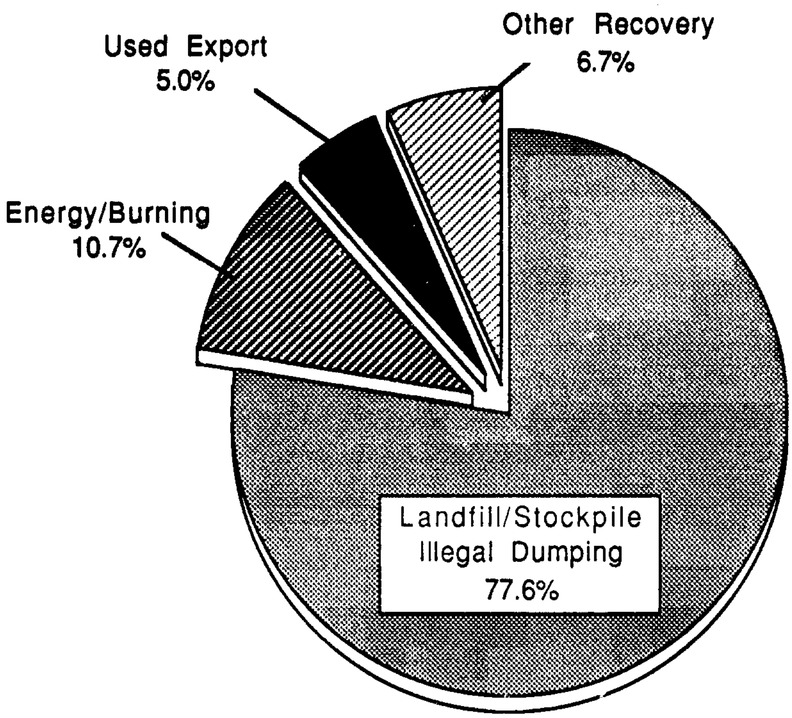


**Figure 3: Destination of Waste Tires, 1990**
**Sources: Table 5**

are to drill holes in the tires so that the water drains or to remove the tire bead and turn the carcass inside out. This has been practiced on a small scale by individuals (3).

**Fire Hazards**

For as long as it has been known that waste tires harbor mosquitoes, it has been known they pose a fire hazard. Tire fires are particularly bad because of the difficulty in extinguishing them. This is because of the 75 percent void space present in a whole waste tire, which makes it difficult to either quench the fire with water or cut off the oxygen supply. Water on tire fires often increases the production of pyrolytic oil and provides a mode of transportation to carry the oils off-site and speed up contamination of soils and water,

The potential fire hazard presented by waste tire stockpiles has been realized a number of times in the past decade. Several stockpiles have burned until their tire supplies were exhausted which, depending on weather conditions, may be a few days to more than a year. Air pollutants from tire fires include dense black smoke which impairs visibility and soils painted surfaces. Toxic gas emissions include polyaromatic hydrocarbons (PAHs), CO, $S0_2$, $N0_2$, and HC1. Following tire pile fires, oils, soot, and other materials are left on site. These tire fire by-products, besides being unsightly, may cause contamination to surface and subsurface water as well as the soils on which the tires were located. For these reasons, multimillion dollar cleanups are sometimes required to avoid further environmental problems (2).

If stockpiles for waste tires are carefully monitored, the fire hazard can be reduced. Shredded tires pose less of a threat for fires. Tire shreds behave differently than whole tires when burning and because they have less air space, they can be extinguished more easily by allowing water to smother the fire (4). Other precautions that may reduce the fire hazards of tire stockpiles are mandatory fire lanes and fire plans so that a fire can be attended to as quickly as possible (3).

Ultimately, the best solution to the problems of waste tires as fire hazards and mosquito breeding grounds is to eliminate stockpiles. At the least, the number of tires in a stockpile should be minimized, thus reducing the number of breeding sites for mosquitos and fuel for fires.

## SOURCE REDUCTION OF WASTE TIRES

There are two options for reducing the number of tires landfilled, stockpiled, and dumped. One is to increase recovery, which is discussed later in this report, and the other is to reduce the number of tires generated in the first place (source reduction). Source reduction measures that have limited potential for reducing the number of tires to be disposed include:

Design of extended life tires
Reuse of used tires
Retreading.

### Design Modifications

Great strides have been made in the last 40 years in tire manufacturing that have more than doubled the useful life of tires. Further increases in life would require higher pressure, thicker treads, or less flexible materials. Each of these methods would result in more gas consumption, higher cost, and/or rougher rides. Currently steel-belted radial passenger tires last about 40,000 miles. If these tires are properly inflated, rotated, and otherwise cared for, 60,000 to 80,000 mile lifetimes may be achieved. It is not expected that any major design changes will occur in the near future that will significantly increase tire life (5).

### Reuse

Frequently, when one or two tires of a set are worn, the entire set is replaced with new tires. Useful tread may remain on one, two, or three of the tires removed. Many tire stores and tire haulers sort out the usable tires for resale. Virtually every major city in the USA has stores that sell used tires. These tires are often sold for second cars or farm equipment.

Although the reuse of partially-worn tires cannot be expected to solve the scrap tire problem in the USA, it has been estimated that a minimum of one additional year of tire life can be achieved out of 25 percent of the tires removed from vehicles (6). Assuming this to be the case, then the reduction of the scrap tire problem by the reuse of used tires can be estimated. Suppose a set of four tires is removed after 40,000 miles. If 25 percent (one tire), on average still has a useful tread of 10,000 miles left, this is equivalent to the set of four tires lasting 42,500 miles instead of 40,000, an increase in life of 6 percent. It is not known how many good used tires are currently being reused, but based on contacts with several tire stores, it is evident that a significant portion (estimated 50 percent) of the good used tires are currently being reused. If the other 50 percent were also used, a 3 percent reduction in tire disposal could be realized.

## Retreading

The third source reduction measure which can extend the useful tire life, and therefore reduce the number of tires scrapped, is retreading. Retreading is the application of a new tread to a worn tire that still has a good casing. Retreading began in the 1910's and has always played a role in the replacement tire market. There are currently over 1,900 retreaders in the United States and Canada; however, that number is shrinking because of the decreased markets for passenger retreads. Truck tires are often retreaded three times before being discarded and the truck tire retreading business is increasing. On the other hand, passenger tire retreading is declining. This decline is primarily due to the low price of new tires and the common perception that retreads are unsafe. The price of inexpensive new passenger tires ($50 to $60) is often at or near the price of quality retreads.

The National Tire Dealers and Retreaders Association claims that properly-inspected retreaded tires have lifetimes and failure rates comparable to new tires. Mileage guarantees and/or warranties for retreads are often similar to or identical to new tire warranties.

In 1987, about 23 million passenger and light truck tires and 14 million truck tires were retreaded. By 1990, the passenger and light truck retreads dropped to 18.6 million while truck retreads increased to 14.9 million (7). It is estimated that most good truck tire casings are being retreaded due to the high cost of new truck tires, but that at least twice as many passenger car and light truck tires would be suitable for retreading. While retreading will not by itself solve the nation's tire problem, growth in retreading would reduce the number of new replacement tires needed each year and, therefore, reduce the number requiring disposal. For example, if the markets could be developed so that all the passenger and light truck tires suitable for retreading were actually retreaded, then about 20 million fewer new replacement tires would be needed annually. This would reduce the number of waste tires generated per year by almost 10 percent.

## DISPOSAL OF WASTE TIRES

The removal of waste tires from the generator's property is generally performed by a tire jockey or solid waste hauler. Some hauling is done by tire users, tire dealers, or retreaders, but the majority of the over 193 million tires that go to dumps or stockpiles go by way of a hauler who is paid to remove waste tires from the dealer's property. The hauler may be held accountable for the number of tires and how they were disposed of, depending on the state. Haulers may be paid $0.35 to $5.00 per tire to dispose of the tires. If they then dispose of the tires legally, they must pay a fee at a landfill or processing facility. If they stockpile the tires or illegally dump them, the tires create serious health hazards.

### Whole Tire Disposal

There are no known whole tire disposal methods without adverse effects. Disposing of the tires above ground creates the hazards of mosquitoes and fires. The alternate disposal method is landfilling or burial, which is also not without problems. In landfills, tires require a large volume because about 75 percent of the space a tire occupies is void. This void space provides potential sites for gas collection or the harboring of rodents. Some landfill operators report that tires tend to float or rise in a landfill and come to the surface, piercing the landfill cover.

The primary advantage to whole tire disposal is that processing costs are avoided. However, landfills' bad experience with whole scrap tires has led to extremely high tipping fees or total bans on whole tires. Landfill fees for small quantities range from $2.00 per passenger tire to $5.00 per truck tire. For mass quantities, tipping fees range from $35.00 per ton to over $100 per ton for whole tires, depending on the region of the country. These fees are generally at least twice the fee for mixed municipal solid waste.

### Shredded Tire Disposal

Shredding or splitting of tires is becoming increasingly common as part of the disposal process. Shredded tires stored above ground pose less of a hazard than do whole tires. Shredding eliminates the buoyancy problem and makes tires into a material that can be easily landfilled. Shredding can reduce a tire's volume up to 75 percent. This volume reduction can also reduce transportation costs 30 to 60 percent simply because fewer trips are required and maximum hauling weights may be achieved more easily.

Haul costs depend on many factors, including truck size, distance hauled, local labor rates, etc. For semi-truck loads of 1,000 whole auto tires hauled over 100 miles, typical costs are in the 15 to 20 cents per ton-mile range. This is equivalent to 15 to 20 cents per 100 tires per mile. Shredding can reduce this cost by 30 to 60 percent.

The main disadvantage of shredding before landfilling is that an extra processing step is required, which adds costs. Shredder companies charge from $19 to $75 per ton to shred scrap tires (8). T. Y. R. E. S., Inc. of the Los Angeles area is currently shredding for $18.50 a ton. But they say these costs will soon increase significantly because of labor and liability insurance that is required by the city. They said that about 20 tons per hour need to be processed to make the shredding profitable. They have a mobile operation and must transport the machine from landfill to landfill (9). Saturn Shredders, maker of mobile shredding equipment, has broken down typical costs of a 500 to 800 tires per hour shredding operation. These are the cost per tire to the shredder company and do not include any profit or fees. The cost breakdown is outlined in Table 6. For the two processing rates, the cost per tire for coarse shredding (4- to 8-inch) ranges from 18 to 25 cents per tire, or 18 to 25 dollars per ton, assuming passenger tires at 20 pounds per tire.

Shredding costs are fairly constant nationally except for labor and fuel, which may change the total cost up or down 10 percent. When shredding costs are added to solid waste disposal fees, it reflects the cost of landfilling shredded waste tires. For comparison, several examples of tipping fees for whole waste tires in mass quantities were obtained representing the northeast, midwest, south, and west region. These values were not regional averages, but are thought to be values that are representative of the areas.

Table 7 compares the cost of landfilling whole tires and shredded tires in the United States. Shown are estimates of the money saved or lost by shredding prior to Iandfilling. In the northeast region of the United States, where landfill costs are highest, $38.00 per ton can sometimes be saved by shredding tires before landfilling them. In other areas of the country, disposal costs may increase by as much as $3.00 per ton by shredding before landfilling. These cost estimates are generalizations, and each community would need to determine if shredding before landfilling is economical. It becomes apparent through these comparisons that as landfill space is used up, shredding will become more beneficial, not only in terms of reducing hazards, but also in terms of saving money.

## State Legislation Affecting Tire Disposal

Scrap tire legislation is increasing rapidly at the state level. In 1990, twelve states passed or finalized scrap tire laws, regulations, or amendments (12). Thirty-six states now have scrap tire laws or regulations in effect, and all but 9 states regulate or have bills proposed or in draft form to regulate tires. A summary of the states' laws in effect in January 1991 is provided in Table 8. The legislations' contents are summarized in Table 9.

Several states have considered or are considering legislation that would ban all whole tires from landfills. Minnesota has already banned all tires from landfills. In some other states, landfills have such high tipping fees that whole tires are

Table 6

**ESTIMATED TIRE SHREDDING COSTS**
Mobile Shredders
(In dollars and cents per tire)

| | 800 Tires/hr(1) | 500 Tires/hr(1) |
|---|---|---|
| **CAPITAL COSTS** | | |
| Shredder | 155,000 | 155,000 |
| Shredder Stand | 48,000 | 48,000 |
| Diesel Generator | 30,000 | 30,000 |
| Infeed Conveyor | 15,200 | 15,200 |
| Discharge Conveyor | 16,800 | 16,800 |
| Total Capital Cost (2) | 265,000 | 265,000 |
| **ANNUAL COSTS** | | |
| Debt Financing (3) | 43,128 | 43,128 |
| Operating & Maintenance | | |
| Labor (3 at $1 0/hr) | 62,400 | 62,400 |
| Maintenance& Supplies | 8,100 | 5,063 |
| Cutter replacement and sharpening | 54,800 | 33,800 |
| Electricity @ 8 cents/kw-hr | 25,000 | 16,000 |
| Overhead, Administrative, insurance | 30,000 | 30,000 |
| Total O & M | 180,300 | 147,263 |
| Total Annual Cost | 223,428 | 190,390 |
| Tires Processed Per Year (25% downtime) | 1,248,000 | 780,000 |
| Shredding Cost (cents/tire) | 17.9 | 24.4 |

(1) Capacity for passenger tires.
(2) Tractor for moving from location to location not included.
(3) Financing Assumptions:
10 percent Interest
10year amortization

Source: Franklin Associates, Ltd; based on estimates supplied by Saturn Shredders.

## Table 7

### COSTS OF LANDFILLING AUTOMOTIVE WASTE TIRES IN THE UNITED STATES (In dollars per ton or cents per tire) 1/

| | Costs by Region | | | |
|---|---|---|---|---|
| | **Northeast** | **Midwest** | **South** | **West** |
| **Shredded** | | | | |
| Landfill Fee 2/ | 45 | 18 | 16 | 13 |
| Processing Cost | 25 | 25 | 25 | 25 |
| **Total** | **70** | **43** | **41** | **38** |
| **Whole** | | | | |
| Landfill Fee 3/ | 108 | 75 | 50 | 35 |
| Processing Cost | 0 | 0 | 0 | 0 |
| **Total** | **108** | **75** | **50** | **35** |
| **Savings Realized by Shredding 4/** | **38** | **32** | **9** | **-3** |

1/ Since automotive scrap tires weigh 20 pounds each on average, dollars per ton is equivalent to cents per tire.
2/ Reference 10.
3/ Reference 11.
4/ Total costs of Landfilling whole tires - total costs of Landfilling shredded tires.

effectively banned. Florida and Oregon have required that the tires be reduced in volume by methods such as slicing or shredding.

Another landfill restriction method, in addition to banning tires or requiring shredding, is to require that tires be disposed of in tire monofills, either whole or shredded. This allows precautions to be taken that will keep the tires buried. It also keeps open the potential for mining the material for some useful purpose at a later date. Specific rules for tire disposal in monofills will be drafted by Ohio in 1991, following the completion of a feasibility study that is examining the engineering properties and leaching potential of shredded tires.

## UTILIZATION ALTERNATIVES

In this section, tire utilization methods are described. These include the recycling of tires into whole tire and processed tire products. The recycling discussion is followed by a discussion of tire utilization methods that capture their energy value. These are incineration and pyrolysis.

### Applications of Whole Waste Tires

Whole waste tires can be used for artificial reefs, breakwaters, erosion control, playground equipment, and highway crash barriers.

**a) Artificial Reefs and Breakwaters.** In the late 1970s, the Goodyear Tire and Rubber Company researched a number of uses for whole tires. Among these uses were artificial reefs and breakwaters. Goodyear billed these applications as being major outlets for scrap tires. They claimed that by 1978 they had built some 2,000 reefs. In Ft. Lauderdale, Florida alone they were said to have used 3 million tires and were adding one million tires per year to that reef alone. Besides stimulating the fishing industry it was believed that tires would later be mined for their raw materials. Since that time, enthusiasm for this use has waned and scrap tire reefs are now only built in minimal numbers.

Breakwaters are barriers off shore that protect a harbor or shore from the full impact of the waves. Breakwaters using scrap tires have been tested by the U.S. Army Corps of Engineers and were found to be effective on small-scale waves. It was recognized at the outset that this application would never use a great number of scrap tires, but tires perform well in applications where floats are needed. Scrap tires for breakwaters and floats are filled with material, usually foam, which displaces 200 pounds of water and can be used to float a number of devices such as marinas and docks and serve as small breakwaters.

Topper Industries of Vancouver, Washington, has patented the concept of a material-filled floating tire. The concept employs scrap tires as a durable container for holding the flotation material together (13). Topper Industries is the only known producer of scrap tire flotation devices and that company estimates that they

## Table 8
## SCRAP TIRE LEGISLATION STATUS
## January, 1991

| | Draft | Proposed | Regs | Law |
|---|---|---|---|---|
| Alabama | X | | | |
| Alaska | | | | |
| Arizona | | | | X |
| Arkansas | | X | | |
| California | | | | X |
| Colorado | | | X | |
| Connecticut | | | X | |
| Delaware | | | | |
| Florida | | | | X |
| Georgia | | | | |
| Hawaii | | | | |
| Idaho | | | | |
| Illinois | | | | X |
| Indiana | | | | X |
| Iowa | | | | X |
| Kansas | | | | X |
| Kentucky | | | | X |
| Louisiana | | | | X |
| Maine | | | | X |
| Maryland | | | | X |
| Massachusetts | | X | X | |
| Michigan | | | | X |
| Minnesota | | | | X |
| Mississippi | | X | | |
| Missouri | | | | X |
| Montana | | | | |
| Nebraska | | | | X |
| Nevada | | | | |
| New Hampshire | | | X | |
| New Jersey | | | | |
| New Mexico | | X | | |
| New York | | X | X | |
| North Carolina | | | | X |
| North Dakota | | | | |
| Ohio | | | X | |
| Oklahoma | | | | X |
| Oregon | | | | X |
| Pennsylvania | | | X | |
| Rhode Island | | | | X |
| South Carolina | | X | | |
| South Dakota | | | X | |
| Tennessee | | | X | |
| Texas | | | X | |
| Utah | | | | X |
| Vermont | | | X | |
| Virginia | | | | X |
| Washington | | | | X |
| Wisconsin | | | | X |
| West Virginia | | | X | |
| Wyoming | | | X | |

Draft - draft being written/bill in discussion
Prop - proposed/introduced in 1990 legislature
Regs - regulated under specific provision of solid waste or other laws (e.g., automotive wastes)
Law - scrap tire law passed

Source: Scrap Tire News, Vol. 5, No. 1, January 1991

## Table 9
## CONTENTS OF SCRAP TIRE LEGISLATION

| | Funding Source | Storage Regs | Processor Regs | Hauler Regs | Landfill Restrictions* | Market Incentives |
|---|---|---|---|---|---|---|
| Arizona | 2% sales tax on retail sale | | X | | X | |
| California | $0.25/tire disposal fee | X | X | | | X |
| Colorado | | X | X | | | |
| Connecticut | | X | | | | |
| Florida | $1 .00/tire retail sales | X | X | X | X | R&D grants |
| Illinois | $0.50/vehicle title fee | x | x | x | | grants/loans |
| Indiana | permit fees/tire storage sites | x | | | X | grants |
| Iowa | | | | | x | |
| Kansas | $0.50/tire retail sales | X | X | X | X | grants |
| Kentucky | $1 .00/tire retail sales | X | | | X | |
| Louisiana | | X | | | x | |
| Maine | $1.00/tire disposal fee | X | X | draft | | grants/loans |
| Maryland | state budget appropriations | X | X | X | | |
| Michigan | $0.50 vehicle title fee | X | X | X | | grants |
| Minnesota | $4.00/vehicle title transfer | X | X | X | X | grants |
| Missouri | $0.50/tire retail sales | X | | X | X | funds/testing |
| Nebraska | $1 .00/tire retail sales | | | | | grants |
| New Hampshire | graduated vehicle regist. fee | X | | | | |
| North Carolina | 1% sales tax on new tires | X | X | X | x | funds/collection |
| Ohio | | | | | X | |
| Oklahoma | $1.00/new tire (surcharge) | X | X | | X | grants |
| Oregon | $1.00/new tire (dspl tax) | X | x | X | x | $0.01/lb |
| Pennsylvania | | X | | | | R&D grants |
| Rhode Island | $0.50/new tire sales tax | X | X | | | |
| South Dakota | | X | X | | x | |
| Tennessee | | | | | x | |
| Texas | | X | | | x | |
| Utah | graduated tax per tire size | | | | | $20/ton |
| Vermont | | | | | X | funds/testing |
| Virginia | $0.50/new tire (dspl tax) | | | | X | |
| Washington | | X | X | X | | grants |
| Wisconsin | $2.00/tire vehicle title fee | X | X | X | X | $20/ton |

• The majority of states have imposed regulations that require tires to be processed (cut, sliced, shredded) prior to landfilling. Some of the states allow for storage (above ground) of shreds at landfills. OH, NC, CO are among the states considering or allowing monofills for tire shreds. Whole tiresare discouraged from landfills (in almost all cases) either by law (e.g., MN) or more frequently by high disposal fees.

Source: Scrap Tire News, Vol. 5, No. 1, January 1991.

use 30,000 to 50,000 tires per year. These tires are included in breakwaters, marina and dock floats, buoys, and other flotation applications. Topper Industries, Inc. obtains its tires from junk dealers within a 100-mile radius of Vancouver, Washington. They then sell the floats to a market covering primarily the western half of the United States.

Costs for constructing flotation devices are determined on a dollar per pound basis. Topper Industries claims a one-half to three-fourth cost savings by using scrap tire floats over wood, wood-fill, or other alternatives. The tire floats cost approximately $0.06 to $0.08 per pound, whereas the economically closest alternative, foam-filled plastic, costs $0.10 to $0.14 per pound of flotation (14).

Breakwaters and flotation devices presently consume approximately 30,000 to 50,000 tires per year. If tire floats were to acquire the major portion of the flotation market, it may be possible to increase the current tire consumption by a factor of three to four, which would still be less than 1 percent of the annual generation of scrap tires in the United States.

Artificial reefs are constructed by splitting tires like bagels leaving about six inches attached and then stacking them in triangular fashion. Holes are drilled through this stack and about 45 pounds per tire of concrete are poured in the holes to anchor the reef. The 1,800 pound 3-foot high reefs are then hauled by barge 4 to 12 miles off the coast and dumped in 60 to 100 foot deep water. They then provide habitat for marine organisms and fish (14).

The largest operations of building artificial reefs from scrap tires are occurring in Cape May and Ocean Counties, New Jersey. These two counties consume about 120,000 tires per year in making reefs. Cape May County has a goal of using 100,000 tires per year for reefs, by combining tires with concrete and placing them in the ocean (15). This is the only disposal option for scrap tires within Ocean County. It is likely that reefs are being built in other states, particularly Florida, but quantities of tires used are small and on an irregular basis (15).

In Ocean and Cape May Counties, tires are brought in by individuals or haulers wishing to dispose of the tires. The counties may have an influx of tires when area fire departments require that storage sites be abated. Ocean County charges one dollar per tire to accept the tires, while Cape May County charges $25.25 per ton (equivalent to 25 cents per tire).

While artificial reefs do not hold the potential to solve the scrap tire problem, they do have the potential to consume more than they consume now. Currently there are an estimated 120,000 to 150,000 tires used annually in constructing reefs. The goal of Cape May and Ocean Counties is to construct reefs with about 200,000 tires annually. Currently they are doing about 60 percent of this. One estimate of national potential is between one and 1.5 million tires used yearly (16). This is much higher than current levels because only two counties are actively constructing reefs. But, it is low compared to scrap tires generated annually because artificial reefs are restricted to fairly calm sandy coastline, where reef development is needed. Much of the northwest coast has rough water and Oregon has even banned artificial reefs from their sea waters (17). Cape May and Ocean Counties do not foresee an end to their activities as long as the state fish and wildlife agency continues to provide sites to place the reefs.

Costs for constructing reefs are about $3.50 per tire. This cost is somewhat offset by charging $1 per tire in Ocean County to accept tires or $25.25 per ton to accept tires in Cape May County. This compares to the average of $45.25 per ton to landfill the tires in the northeastern United States. Since haulers in Cape May County save money by taking tires to the reef builders, tire supply is not a problem. In Ocean County, costs are minimized by using prison labor for building reefs; and a county owned barge takes the reefs to the dump site (15).

**b) Playground Equipment.** The only large producer of tire playground equipment is Tire Playground, Inc. in New Jersey. President William Weisz says that his company currently uses up to 4,500 truck tires per year, but has used up to 7,500 per year in the past. In addition to this are the small-scale local and backyard recreational uses of tires. The tire consumption cannot be easily determined, but it is thought to be small compared to the scrap tire supply. The demand for Tire Playground’s products is declining as the east coast economy improves and schools and parks select wooden playground equipment. The material cost for the tire playgrounds is one-fourth of the cost of alternative equipment (18).

Even if the market for tire playgrounds were developed completely, it would require less than a million tires per year, which is less than one-half percent of the annual generation.

**c) Erosion Control.** The California Office of Transportation Research has designed and tested several erosion control applications of scrap tires. Scrap tires were banded together and partially or completely buried on unstable slopes in tests conducted between 1982 and 1986. They found that tires used with other stabilization materials to reinforce an unstable highway shoulder or protect a channel slope remained stable and can provide economical and immediate solutions. Construction costs were reduced from 50 to 75 percent of the lowest cost alternatives such as rock, gabion (wire-mesh/stone matting), or concrete protection. Information on the applications has been distributed since 1988, but it is difficult to determine the number of times these designs have been used. John Williams of the California Transportation Laboratory believes it would be fair to say that fewer than 10,000 tires are used annually for erosion control. He says it is difficult to estimate the potential annual consumption by this method as tire designs are not always appropriate and tires for this use may not be acceptable in highly visible areas (19).

**d) Highway Crash Barriers.** The use of scrap tires as crash barriers was studied in the late 1970s by the Texas Transportation Institute. They determined that stacked tires bound by a steel cable and enclosed with fiber glass would reduce or absorb impact of automobiles traveling up to 71 miles per hour.

Since that time, no widespread use of tires in this application has occurred. State transportation departments generally prefer sand-filled crash barriers because they have excellent absorption characteristics and are easier to erect and dismantle.

**Applications of Processed Waste Tires**

Tire processing includes punching, splitting, or cutting tires into products; processing tires into crumb rubber for use in rubber or plastic products, railroad crossings, rubber reclaim, or asphalt paving; and chopping tires into small pieces or chips for use as gravel or wood chip substitutes.

Various rubber products can be manufactured using rubber from scrap tires to replace some or all of the virgin rubber or other material in the product. Tires may be either split, punched, or stamped to yield shapes suitable for fabrication, or the tires may be processed to crumb size to make new products, usually by mixing with other materials.

In this section the primary focus is on reuse of the rubber from tires. However, the fabric and steel may also be recycled.

**a) Splitting/Punching of Tires.** Splitting involves the removal of the steel bead and then using a stamp or punch to achieve the desired shape. Splitters purchase tires on the market either graded or ungraded. They are responsible for disposal of the part of the tires that are left as well as the unrecyclable tires, so they generally buy only appropriate tires. For example, steel-belted radials create problems for the splitters and are usually not wanted.

Products from the splitting of tires include floor mats, belts, gaskets, shoe soles, dock bumpers, seals, muffler hangers, shims, washers, insulators, and fishing and farming equipment. The market for this type of product is very limited; however, one Massachusetts company reports they use 2,000 tires per day to manufacture fishing equipment, such as net parts, rubber discs, rollers, chain covers, strips for traps, etc. Because this industry is so diversified and there are no published data, it is difficult to make good estimates of the nationwide usage of split rubber products. Estimates made in 1987 indicate the U.S. market for these products is about 2.5 to 3.0 million tires per year (20). In the absence of additional data, it is assumed that the markets in 1990 remained at the same level.

**b) Manufacture of Crumb Rubber from Scrap Tires.** Crumb rubber is made by either mechanical or cryogenic size reduction of tires. Because of the high cost of cryogenic size reduction (at liquid nitrogen temperatures), mechanical size reduction by chopping and grinding is used most often. Typically tires are shredded to reduce them to 3/4-inch chips. Then a magnetic separator and fiber separator remove all steel and polyester fragments. The rubber chips are then reduced to pebbles by a cracker grinder or granulator. A series of screening and regrinding operations achieves the desired crumb size, which may be 600 to 800 microns. This rubber may be used in rubber or plastic products, or processed further into reclaim rubber or asphalt products. A significant portion of the crumb rubber market demand is met by buffings and peels from retread shops.

Crumb rubber can be mixed with other materials to make new products, including plastic floor mats and adhesives. It can also be mixed with asphalt as an additive to make cement products.

**1) Crumb Rubber in Rubber and Plastic Products.** Crumb rubber may be incorporated into rubber sheet and molded products such as floor mats, vehicle mud guards, and carpet padding or into plastic products, including plastic floor mats and adhesives. Additional uses that have contributed to the expansion of this market over the last three years are rubber play surfaces, tracks and athletic surfaces, and garbage cans. In 1987 about 2.3 million tires (1 percent) were utilized in this manner. 1990 estimates have risen to 8.6 million tires per year, or 3 percent of the scrap tires generated that year.

**2) Crumb Rubber in Railroad Crossings.** OMNI Products, Inc., a subsidiary of Reidel Environmental Technologies, Inc., has a patented process for using crumb rubber to make solid rubber railroad crossings (21). The molded panels fit between the tracks and fasten to the ties. OMNI is operating in three locations: Portland, Oregon; Lancaster, Pennsylvania; and Annis, Texas. Currently only buffings from tire retreading operations are being used, but the company is testing the use of crumb rubber that still contains the fiber.

Rubberized crossings compete with crossings made of asphalt and timbers. The installed cost of the OMNI product is about 35 percent higher than timber and about 100 percent higher than asphalt. The manufacturer claims that the life cycle cost of rubberized crossings can be lower than competing materials because they expect their product to last about 10 to 20 years compared to 3 to 4 years for asphalt, depending on the traffic.

In 1990 OMNI used at least 14 million pounds of crumb rubber for railroad crossings. Another company, Park Rubber Company of Illinois, used less than 1 million pounds of crumb rubber for the same purpose. If 20 million pounds were used for rubber railroad crossings, this would be equivalent in weight to about a million scrap automotive tires. However, if only buffings are used, only about 10 percent of each tire is used, and the tire disposal problem is not solved.

There is a potential for growth of the rubber railroad crossing market. There are 185,800 public railroad crossings and at least as many private ones in the U.S. Less than 2 percent have rubber crossings. A typical railroad crossing consumes about 350 pounds of rubber per track foot.

**3) Rubber Reclaim.** For the traditional rubber "reclaim," crumb rubber is mixed with water, oil, and chemicals and heated under pressure, thus rupturing the carbon-sulfur bonds that cross-link the molecular matrix. The resulting partially devulcanized rubber maybe formed into slabs or bales and shipped to manufacturers who process and vulcanize it for use as an alternative to virgin rubber to use in tires or to make mats and other rubber products.

Reclaim rubber tends to lose its elastic properties during processing and, therefore, is no longer extensively used in tires because of the flex needed. That is, it does not become like new rubber. However, some new tires routinely contain one to 2 percent crumb rubber (5).

Because of the increased use of synthetic materials in making new tires after World War II, the reclaim industry has dramatically decreased in size. During World War II, about 60 percent of the rubber in tires was reclaimed rubber. Each of the major tire manufacturers has discontinued operating reclaim plants in the last 8 to 10 years, until now only about one to 2 percent of the raw material for tires is reclaim. There are currently only two companies that produce reclaim rubber, i.e., partially-devulcanized rubber, from whole tires for use in tires and other rubber products. These companies are Midwest Rubber Reclaiming Co. in East St. Louis, Illinois and Rouse Rubber, Inc., in Vicksburg, Mississippi (22),

In 1987, the equivalent of 3,4 million tires were consumed for reclaim rubber, By 1989 this figure had declined to 2,9 million tires (23), The reclaim industry's production capacity is estimated to be between 100 and 144 million pounds per year, (5 to 7 million tires per year), indicating a capacity of utilization of about 40 to 60 percent, due to limited market demand, The Department of Commerce is no longer updating its reclaim rubber production figures yearly, It is estimated that production remained 2,9 million tires or less in 1990,

A new reclaim producer, Rubber Research Elastomers (RRE) of Minneapolis declared bankruptcy in August, 1989 (24), RRE, under Chapter 11, is currently exploring options for restructuring its operations, Since RRE's "Tirecycle" products have generated considerable interest, the process is worth discussing,

In the Tirecycle process, first developed in 1982, finely ground scrap rubber is treated with a liquid polymer to form a reclaimed rubber product, RRE literature claims superior bonding properties and suggests use in tread rubber and other products including washers, mats, car parts, and tiedowns. The Tirecycle product is claimed to be useful with thermoplastics such as polypropylene, polyethylene, and polystyrene, as well as polyvinyl chloride, polyesters, and urethanes.

The RRE facility in Babbitt, Minnesota, financed by St. Louis County and the state, was envisioned to have a capacity to process three million tires per year, all of Minnesota's scrap tires. Actual production never reached over 10 percent of that value.

A study by the University of Minnesota completed May 19,1989 (25), concluded that there are adequate rubber markets for Tirecycle products, but that the Tirecycle product performance and delivery often failed to live up to customers' expectations. The study also concluded that the operation needs a large infusion of cash (over two million dollars) before reaching 60 percent of capacity and reaching breakeven conditions under an optimistic scenario. As a result of the University of Minnesota study, St. Louis County and the state decided not to continue funding the RRE Tirecycle project.

**4) Crumb Rubber Additives for Pavements.** Crumb rubber can also be combined with asphalt for use as a paving material. There are two main types of processes for doing this. Advantages claimed for both include increased durability, flexibility, and longevity, when compared with conventional asphalt pavements. One application, referred to as Rubber Modified Asphalt Concrete (RUMAC), or the dry process, involves the displacement of some of the aggregate in the asphalt mixture with the ground whole tires. For this application the tire crumbs or chips may still contain some of the reinforcing materials such as polyester, fiber glass, and steel. PlusRide™ is the commercial name by which one kind of RUMAC is marketed. The TAK system, a non-patented generic system being tested by the State of New York and others, is another form. PlusRide™ and the TAK system each have a different size distribution of the rubber aggregate in the asphalt mixture.

The second application of crumb rubber in asphalt (also a patented process) involves the blending/reactivating of a certain percentage of the asphalt cement with a ground rubber that is free of other tire constituents such as polyester, fiber glass, or steel. This application is referred to as asphalt-rubber (A-R), the Arizona process, or the wet process, While A-R typically uses only one-third of the rubber per mile of pavement that RUMAC uses (assuming equal thicknesses of material), it has been tested at more locations of the United States over a longer period of time. In the following pages, the technologies and uses of RUMAC and A-R are described. This is followed by a brief summary of research on pavements containing rubber.

**(a) Rubber Modified Asphalt Concrete.** The PlusRide™ technology typically uses 3 percent by weight (60 pounds per ton of total mix) of granulated coarse and fine rubber particles to replace some of the aggregate in the asphalt mixture (26). Wire and fabric must be removed from the tire crumb and the maximum moisture content is 2 percent. The granulated rubber is graded to specifications, and in the PlusRide™ system, the aggregate is gap graded to make room for the rubber to be uniformly dispersed throughout the paving mixture. The granulated rubber is graded to specifications as follows:

| Sieve Size | Percent Passing by Weight |
|---|---|
| 1/4 inch | 100 |
| US. No. 4 | 76-100 |
| U.S. No. 10 | 28-42 |
| U.S. No. 20 | 16-42 |

TAK, the non-patented RUMAC system being tested by the New York State Department of Transportation, uses a uniformly graded rubber crumb, and therefore does not require gap grading of the aggregate. The New York DOT is testing this system in highway strips using 1, 2, and 3 percent rubber in total asphalt mix. The results will be compared with results from PlusRide™ test strips. It is too early for any test results, since the strips were laid in the fall of 1989 (27).

The asphalt binder used in both types of RUMAC is the same as that used in conventional asphalt. Therefore, conventional equipment is used for mixing the final product. A belt conveyor is used to feed the rubber into the mixer.

The formula for PlusRide™ was invented in Sweden in the late 1960s and was patented in the United States by the PaveTech Corporation located in Seattle, Washington under the trade name PlusRide™. Marketing is done by several companies across the country,

PlusRide™ modified asphalt is currently being tested in highways, streets, bridges, and airports, PlusRide™ and TAK use all the rubber in waste tires, including the sidewall interliner and tread portions, recycling all but the steel and fabric, Chief advantages over conventional asphalt are claimed to be increased flexibility and durability, which make it attractive for rehabilitating road surfaces with severe cracking.

**(b) Asphalt-Rubber.** Asphalt-rubber was developed in the late 1960s and has been used primarily in the City of Phoenix, Arizona (28). The asphalt-rubber process involves the blending of presized granulated rubber into standard asphalt heated to over 400 degrees Fahrenheit. Blending occurs for about 45 minutes. A-R is produced by one of two procedures. In the Arizona Refinery procedure, an oil extender is added to the asphalt before heating and adding rubber, and in the McDonald procedure, kerosene is added to the hot blended mixture. Either procedure is performed just before application at the job site, as A-R cannot be stored for more than 3 days without adjustment of the mix,

The composition of A-R is highly dependent on the needs of the project. Rubber content is generally 15 to 25 percent of the binder by weight and the crumb size used ranges from fine to coarse in six different sizes. The crumb used is produced by a crumb rubber company which separates the ferrous and fabric materials from the tire and then shreds to a specific rubber particle size. Various polymers may also be added to the formula. The crack seal industry has many different mixes from which to choose.

The application process is also dependent on the type of project. Asphalt-rubber used as a seal coat is sprayed on the surface with equipment designed for asphalt-rubber's high viscosity and need for constant stirring to suspend the rubber. Hot mix projects require little special equipment as the asphalt-rubber is premixed with the aggregate and applied in the same manner as a standard overlay (29).

For the more than 20-year history of asphalt-rubber, most applications have been used for testing or experimental projects. The exception has been the wide use and success of A-R in Arizona and other southwestern states, including California and Texas. Some states that have not used A-R extensively in the past are awaiting material and application specifications to be established (30). This situation may soon be remedied as the Asphalt Rubber Producers Group (ARPG) is currently working with the American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) to establish specifications for the A-R industry (29).

Applicators with royalty agreements for A-R are located in Phoenix, Los Angeles, East Texas, Washington, and Rhode Island. These companies are able to meet the current levels of use competitively. These companies are shown in Table 10.

When A-R is applied, the applicator usually obtains crumb rubber from the shredder company that is geographically closest to the project site. Since there are a limited number of crumb rubber shredders, scrap tires may not originate from the community buying the A-R application. If, for example, a city or state buying an A-R application is located outside the 200 to 300 mile radius of the crumb producer who is providing the crumb rubber, it is likely that their own scrap tire supply is not being consumed.

The A-R process consumed 1.9 million tires in its U.S. production in 1989 (31), which is almost a 60 percent increase over 1987. In 1986,35,000 tons of A-R were placed by five U.S. applicators. In 1989,47,000 tons were used, and the ARPG predicts about 65,000 tons will be used in 1990 (31).

The longer pavement life claimed for asphalt rubber is attributed to higher viscosity and impermeability of asphalt-rubber. These properties have decreased thermal cracking, potholing, deformation, and reflective cracking in most states in which tests were performed. Studies by the Alaska Department of Transportation showed decreased stopping distances as a result of asphalt-rubber being more flexible and preventing ice formation (32).

**Table 10**

**ASPHALT-RUBBER APPLICATOR COMPANIES**

| | |
|---|---|
| International Surfacing | Phoenix, Arizona |
| Cox Paving Company | Blanco, Texas |
| Eagle Crest Construction Company | Arlington, Washington |
| Manhole Adjusting Contractors | Monterey Park, California |
| Asphalt Rubber Systems | Riverside, Rhode Island |

Source: Asphalt Rubber Producers Group

The Asphalt Rubber Producers Group (ARPG), which promotes asphalt-rubber, suggests that the doubled life of A-R pavements provides two options for departments of transportation. In one case, an inexpensive application of A-R applied to severely deteriorated pavements can extend that pavement's life. For new pavements, they suggest a long-term cost benefit by performing more than twice as long as a standard pavement even though its original cost was less than twice as much.

**(c) Research and Demonstration of RUMAC and Asphalt-Rubber.** Procurement guidelines for the use of rubber in asphalt were proposed by the U.S. EPA in 1986, but have been tabled since that time because many state highway departments felt that not enough research had been completed at that time to justify promotion of this technology nationally through procurement guidelines. Questions still remain about the life expectancy, suitability in different climates, and recyclability.

Research on RUMAC in the United States, beginning in 1981, has been conducted by a number of institutions and states, including the University of Oregon, the University of Idaho, the California, Alaska, New York, and New Jersey Departments of Transportation, and the Colorado Department of Highways. Tests are still under way, although most test results to date indicate improved durability and skid resistance and less cracking.

Because the initial cost of PlusRide™ is higher than conventional asphalt and because of the long times required for satisfactory testing, it is not being used routinely at this time. Since 1979, however, this material has been used in over 60 test applications in the United States.

Asphalt-rubber has been tested in at least 25 states over the last 2 decades. It has been used primarily as a maintenance tool to save existing distressed surfaces, and most recently as a preventive maintenance tool. It is not being used routinely in new construction.

One of the concerns regarding both RUMAC and A-R highways is their recyclability. Old asphalt is typically heated and mixed with fresh material to create new asphalt. There is concern that when the rubber modified asphalt is reheated, it may catch fire or produce noxious smoke. The industry claims that this will not occur, and that recycling of rubberized asphalt has been successfully done in Sweden. However, many state highway departments are not yet convinced.

In 1985 the New York State Department of Transportation indicated a possibility of health and environmental problems in using rubber in asphalt. They felt the presence of carbon black, carcinogens, and unhealthy fumes may cause problems in utilizing rubber in asphalt (33). Since 1985, New York has had no evidence that rubber significantly increases the health problems of asphalt (27). The California Department of Transportation, which has experience with both RUMAC and A-R, indicated they are not aware of any additional health problems due to the addition of rubber (34).

**d) Markets and Life Cycle Cost of RUMAC and Asphalt-Rubber.** Asphalt-rubber is diversifying into new markets with the construction of geomembranes for lining of evaporation tanks, hazardous waste storage sites, and ponds. A-R provides impermeable linings which restrict the movement of the substances to be contained (33). Though the A-R applicators promote these applications, they realize they are only a small supplement to the pavements market. The greatest potential for utilizing large quantities of asphalt-rubber remains in road, runway, and parking lot construction applications.

Pavement applications for asphalt-rubber include:

Crack and joint sealants
Seal coats
Interlayers
Hot mix binder in overlays.

Crack and joint sealants are applied only on cracks and joints. Seal coats include hot asphalt-rubber sprayed on the surface followed by precoated aggregate. Interlayers are the application of seal coats followed by either a standard overlay or an asphaltic-rubber overlay. Asphalt-rubber, when blended with an aggregate hot mix at about 9 to 10 percent by weight, serves as a binder in the thin overlay applied to the road surface. The hot mix binder holds the greatest potential for using large quantities of scrap rubber because of the thickness and quantity of the overlay. Fifteen to 25 percent of the binder is crumb rubber. Current investment and research projects are concentrated in this use of asphalt-rubber (29).

A general rule in comparing costs of standard asphalt and A-R or RUMAC is that the rubberized material will be between 40 and 100 percent higher than the cost of standard asphalt. The lack of an exact cost ratio between the alternatives is caused by the variability in the cost determining factors that are involved. In a California study in 1988, standard dense graded asphalt concrete controls cost approximately $3.04 per square yard, while equal thicknesses of asphalt-rubber and RUMAC applications averaged about $6.13 per square yard (36). Table 11 compares cost estimates from five areas, including New York, California, Washington, Phoenix, and Wisconsin.

Only Wisconsin has had negative results with regard to service life of asphalt-rubber. Wisconsin tried rubber mixed with recycled asphalt and got 10 times more cracking than with recycled asphalt alone. They now have 3 new A-R projects planned for 1990, using new asphalt. ARPG defends pavement life increases of two and one-half to three times greater than conventional. Standard pavements consistently last 10 to 12 years, whereas asphalt-rubber pavements last 20 or more years. The ARPG claims that if an asphalt-rubber pavement were designed to last the same length of time as a standard pavement by making the layer thinner, the costs will be the same.

The increased pavement life can be attributed to higher viscosity and impermeability of rubberized asphalt. These properties have decreased thermal cracking, potholing, deformation, and reflective cracking in most states in which tests were performed. Studies by the Alaska Department of Transportation showed decreased stopping distances as a result of rubberized asphalt being more flexible and preventing ice formation (37).

**c) Lightweight Road Construction Material.** Since 1986, the State of Minnesota has been using chipped tires as a lightweight fill material where roads cross marginal subgrade (38). In some areas of the country, this technology has potential for recycling a large number of tires. This technology was developed when the Department of Natural Resources, Division of Forestry, was interested in developing low cost means for crossing peat and other soft soils. Wood chips are often used for this purpose. Because wood chips and rubber chips are lightweight compared to gravel, settling of roadways is greatly reduced.

Rubber chips for this technology are coarse shredded to four to six inches in diameter. Steel may be left in the shredded tires. The cost of these tire chips is very competitive with wood chips.

Minnesota has used close to a million tires to date for road fill. In one 100-foot section north of the Twin Cities, where the road crosses a peat bog, 3,000 cubic yards of tire chips were used. This is equal to about 81,000 tires.

In late 1989, Minnesota tested tires for leachate and found that leaching of heavy metals, polynuclear aromatic hydrocarbons, and total petroleum hydrocarbons from tire chips could not be completely ruled out (38). Now the preferred method is to use wood chips below the water table and tire chips above the wood chips. This is expected to extend the life of the fill over using just wood chips, since wood chips degrade in the unsaturated zone.

## Table 11

### COMPARISON OF RUMAC AND ASPHALT-RUBBER COSTS WITH STANDARD ASPHALT COSTS

| Study | Ratio of Rubberized Asphalt to Standard Costs | | Predictions of Life Extension |
|---|---|---|---|
| New York Department of Transportation (1) | RUMAC | 1.50 | No data yet |
| California Department of Transportation (2) | Both | 2.0 | 3 times |
| Washington State (3) | RUMAC | 1.5 to 2.0 | No data yet |
| Phoenix (4) | A-R | 2.00 | 2 times |
| Wisconsin Department of Transportation (5) | A-R | 1.3 to 2.1 | No improvement to slightly worse |

(1) Phone conversation with Tom Van Bramer, NY State DOT, 1990.
(2) Phone conversation with Robert Doty, CA DOT, 1990.
(3) phone conversation with Dale Clark, WA DOE, 1990.
(4) phone conversation with Bob Draper, City of Phoenix, 1990.
(5) phone conversation with Clint Solberg, WI DOT, 1990.

Source: Franklin Associates, Ltd.

The Minnesota Pollution Control Agency estimates that about 20 to 30 percent of Minnesota's tires that are recycled will be used as lightweight roadway fill. At this time other states are not using this technology. Wisconsin, however, is planning to evaluate it soon.

**d) Playground Gravel Substitutes.** At least two companies make a playground gravel substitute from chipped used tires. Waste Reduction Systems in Upper Sandusky, Ohio, is marketing colorized tire chips (one-fourth to one-half inch) for use under and around playground equipment and for running tracks. The tire chips provide a better cushion than the standard materials such as asphalt, stone, and wood chips. For this use it is important that all steel is removed from the chips. By shredding to one-fourth to one-half inch, magnets can be used to remove all steel.

Dye is used to color the chips. It is reported that after one and one-half years, the dye is still on the chips.

Safety Soil of Carmichael, California produces a similar playground gravel substitute made from tires. They claim their product will not harbor sand fleas, will not splinter or deteriorate like wood, and will not get into childrens' ears or noses as will pea gravel. Safety Soil is manufactured entirely from nylon tires with the steel beads removed. Additional advantages include its ability to drain water, its cleanliness and softness, and the fact that it doesn't need replenishing. Safety Soil serves only the northern California market because shipping costs are around $400 for eight-ton loads, Shipping to southern California costs over $1,000 plus for 15.5 ton loads and is not economical for the longer distances (39). Cushion-Turf of Illinois also manufactures a similar product.

Advantages of the tire chips are that they provide a better cushion than the standard materials such as asphalt, stone, and wood chips. Their ability to drain water, stay clean, and their long life are also attributes.

Playground tire chips, when longevity is considered, can be competitive with alternate materials, Alternate materials generally range from $15 to $35 per ton. The higher initial cost of tire chips compared to other materials may discourage the use of these chips for playgrounds.

**e) Sludge Composting.** Another use for tires that have been shredded is as a bulking agent in the composting of wastewater treatment sludge, The two inch square chips are mixed with the sludge to maximize air flow through the compost pile. The chips are then removed from the compost and recycled prior to its sale or use.

Tire chips are more nearly uniform than the most commonly used alternate material, wood chips, which results in more complete and odor-free composting, The initial cost of tire chips is about three times that of wood chips. Since tire chips don't degrade, however, they can be completely recycled; whereas, about 25 to 35 percent of wood chips are lost to degradation with each batch,

Shredded tire chips were used successfully for five years as a bulking agent for sewage sludge composting in Windsor, Ontario. The Windsor facility is a 24 million gallon per day wastewater treatment plant. Sludge composting had been performed since 1978. The compost was used for landfill cover material, landspreading, greenhouse soil conditioning, and other miscellaneous uses. Tire chips were used to replace about one-third of the wood chips normally used at the Windsor facility. The tire chips were screened out and reused, so that no additional new chips were required. About 30 percent of the wood chips were lost to the compost each cycle (40).

The primary disadvantage to using tire chips for sludge composting was the initial cost of the chips. Generally, no equipment modification is required. Tire chips cost about $60 to $80 per ton; whereas wood chips are around $15 to $20 per ton. Another disadvantage is that any effect of dilution of contaminants in the sludge (particularly heavy metals such as lead and cadmium) by wood chips is lost (41). Since rubber does not decompose, none of it stays with the compost as wood chips do. Another concern that has been expressed is that zinc from the tires may somehow adversely affect the compost. It is not clear at this time whether these are valid environmental concerns.

The Windsor facility no longer composts sewage sludge, so it is not using tire chips for this purpose. This technology has been considered in Columbus, Ohio; Nashville, and several other US. communities. At this time, however, no facilities in the United States are known to use this technology on a routine basis.

**Combustion**

Tires may also be utilized for their energy value, as they have at least as high a Btu value as coal. This section describes the ways tires are being used for fuel in the United States.

In the past three years there have been major increases in the utilization of waste tires as a fuel. Applications have included power plants, tire manufacturing facilities, cement kilns, and pulp and paper production. These applications have demonstrated the capability to extract energy value from the tires in an environmentally acceptable manner, while at the same time alleviating tire disposal problems in their communities,

Waste tires make an excellent fuel since they have a fuel value slightly higher than that of coal, about 12,000 to 16,000 Btu per pound. On a national basis, they represent a potential energy source of 0.07 quadrillion Btu per year, since there are roughly 242 million tires discarded per year, each weighing about 20 pounds with 15,000 Btu per pound (42). This is equivalent to 12 million barrels of crude oil and represents about 0.09 percent of the national energy needs. As such, tires compete with other solid fuels--coal, petroleum coke, and wood wastes (hog fuel).

Burning tires whole obviates the need for expensive shredding operations. However, the burning of whole tires requires a relatively sophisticated high temperature combustion facility to keep emissions within environmental limits. It also requires equipment capable of handling the whole tires and feeding them into the combustion chamber.

Most of the plants currently burning tires for fuel do not have the capability to burn whole tires. Instead they must burn tires that have been shredded into chunks. In this form it is known as tire-derived fuel (tdf), The size of the pieces can vary from 2 inches to 6 inches, depending on the shredding operation. Typically, the rubber chunks also contain steel wire from the tire beads and steel belts. Removal of the wire involves an expensive process, which requires fine shredding and the use of powerful magnets. Wire-free tdf is considerably more expensive.

In the sections which follow, the use of tires and tdf in various combustion facilities is discussed:

Power Plants
Tire Manufacturing Plants
Cement Kilns
Pulp and Paper Plants
Small Package Steam Generators.

**a) Power Plants.** In the past three years major tire-burning power plant projects have been initiated by Oxford Energy, a company which is headquartered in Santa Rosa, California. Oxford Energy built a 14 MW power plant in Modesto, California, and they have operated it since 1987 (43). Recently, they began construction of their second plant at Sterling, Connecticut, with a 26 MW capacity (44). They have also initiated efforts for a third plant, a 26 MW unit near Las Vegas, Nevada.

Oxford Energy has pursued a strategy of developing an integrated waste tire utilization system (45), as shown schematically in Figure 4. Their philosophy is to collect and sort the waste tires, utilizing them for fuel or other applications, with no tires going to landfills. This approach includes culling out the tires in best condition, which can be sold as used tires or retreadable casings. The majority of the tires are used in a whole-tire-to-energy plant. Some tires are selected as raw material for manufacturing processes involving stamping, peeling, or buffing. Other tires are shredded for fuel for cement plants or pulp and paper plants.

**1) Modesto Power Plant.** The Modesto Energy Project of Oxford Energy is currently the world's largest tire-fueled power plant. The plant is located in Westley, California, about 90 miles east of San Francisco, It consumes approximately 4.9 million tires per year,

The Modesto plant utilizes a technology that has successfully operated at the Gummi Mayer tire facility in West Germany since 1973, The combustion system, which is shown schematically in Figure 5, operates at temperatures over 1,800 degrees Fahrenheit, There are two tire incinerators, each with an associated boiler. During combustion, the tires are supported on a reciprocating stoker grate. The grate is made of bars of high temperature metal, which can survive continued operation in the extreme heat. These high temperatures provide for complete combustion of the tires, while minimizing emissions of dioxins and furans (46). The grate configuration provides for air flow above and below, which aids combustion and helps to keep the grate cool. The grate also allows the slag and ash

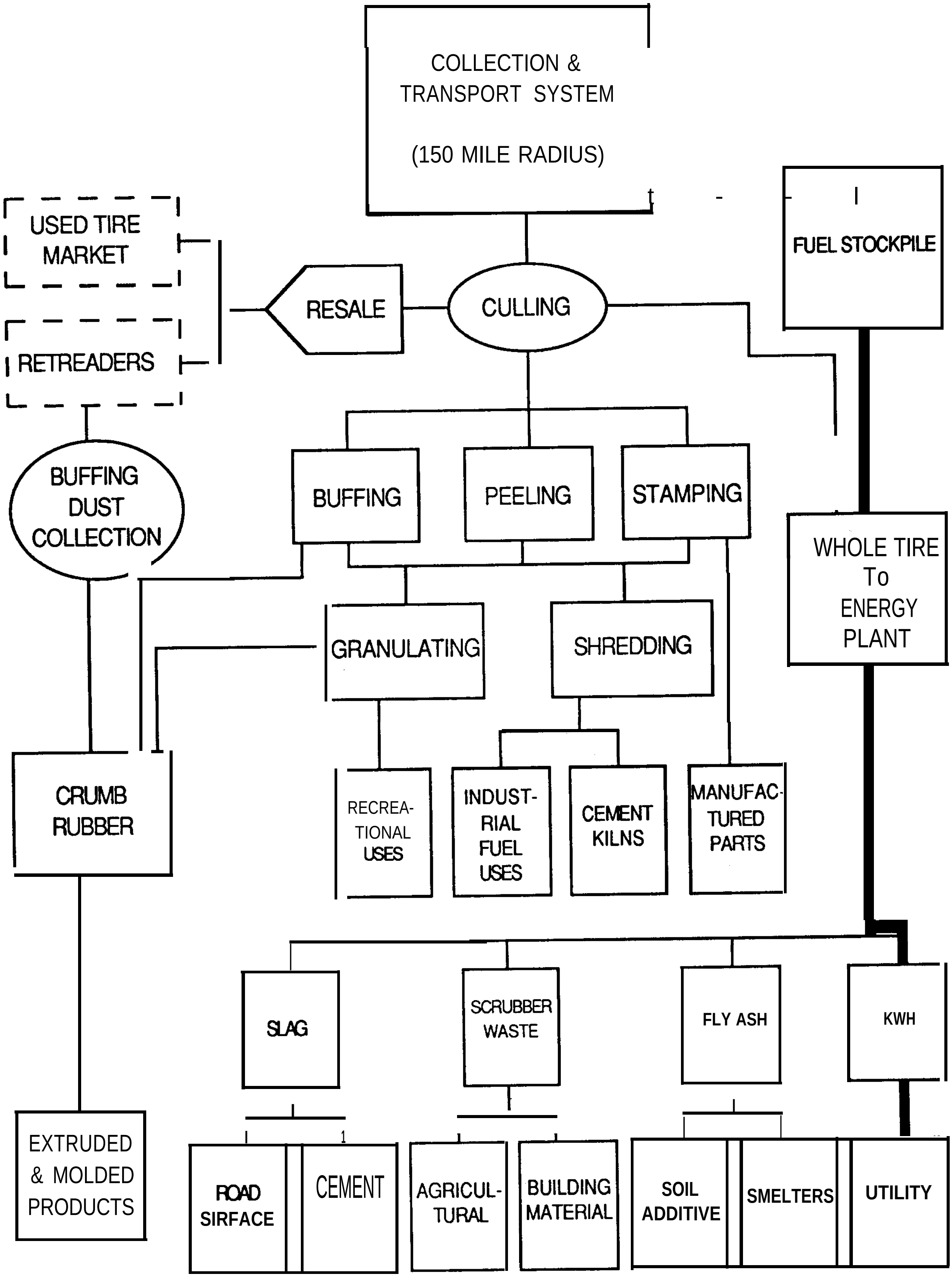


**Figure 4.** An Integrated Tire Utilization System Source: Oxford Energy Company

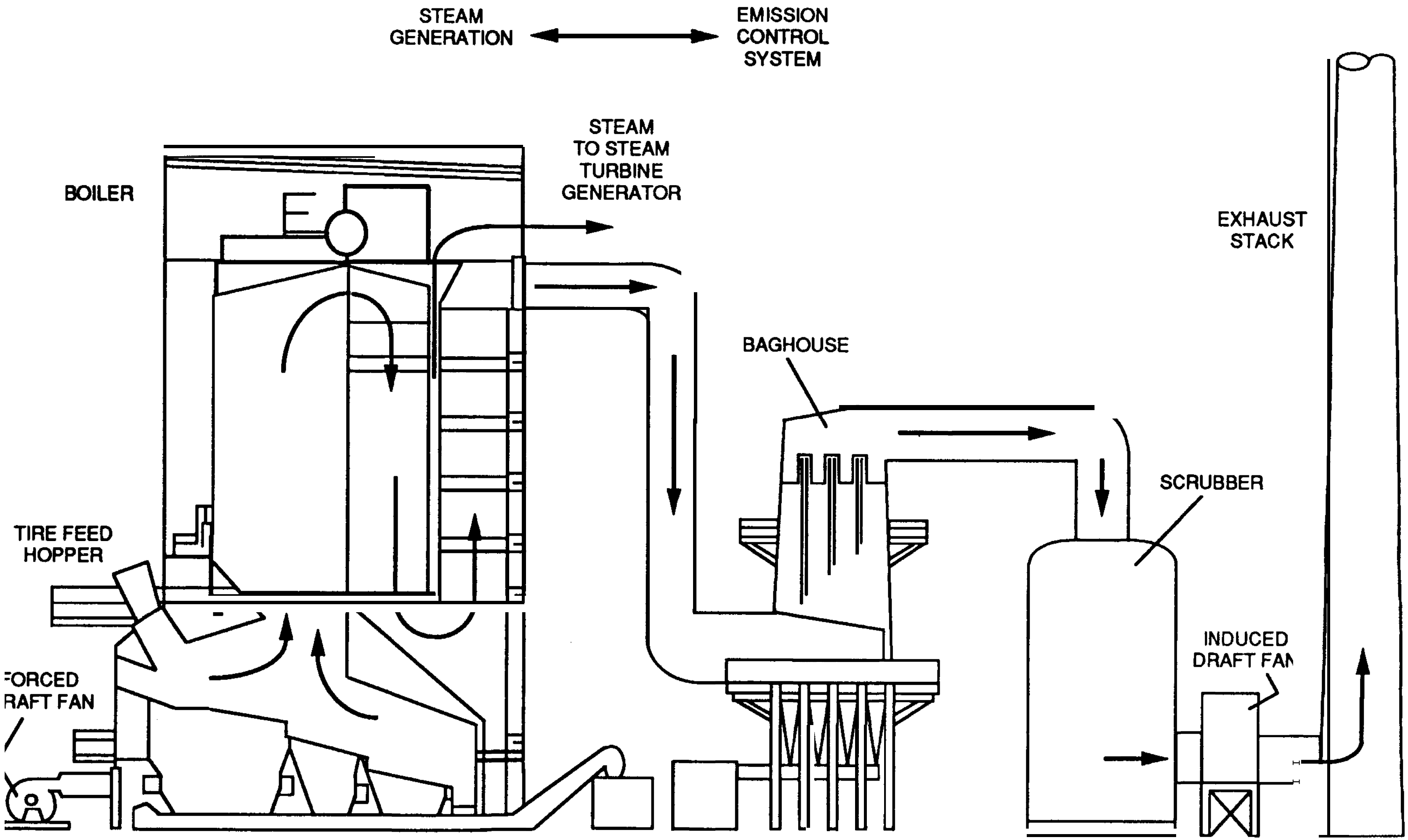


Figure 5. Schematic of a Tire Incineration Project
Source: Oxford Energy Company

to filter down to a conveyor system, which takes them to hoppers for by-product sales to off-site users.

The hot combustion gases rise to enter the boiler, producing superheated steam. Each incinerator has its own boiler, and they both feed steam to the same turbine generator. It produces 14 MW of power, yielding 100 million kilowatt hours each year under normal operations. The power plant includes a full pollution control system, with flue gas desulfurization, thermal de-$NO_x$, and a fabric filter baghouse.

In January and March of 1988, Radian Corporation made a comprehensive series of performance measurements on the air pollution control system at Modesto (47). As shown in Table 12, the measurements included chlorinated dibenzo-p-dioxins (CDD), chlorinated dibenzofurans (CDF), polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenols (PCB), total hydrocarbons (THC), ammonia, $No_x$, sulfur trioxide, sulfur dioxide, hydrochloric acid, carbon monoxide, and particulate matter.

The measurements determined that the plant was operating within the permitted levels for all criteria pollutants. The high temperature combustion was found to be very effective in controlling the emissions of dioxins and furans, and their combined emission rate was less than one hundredth of the permitted level. The only part of the control system found to be under-performing was the thermal de-$NO_x$ system. Radian's measurements showed a three-day average of 384.3 pounds per day for $N0_2$, which was below the permitted level of 500 pounds per day, but it required the use of offsets which Oxford Energy had previously purchased. The operation of the thermal de-$NO_x$ was also found to require more ammonia than expected and ammonia emissions exceeded the limit in some of the runs. Later the cause of the under performance of the de-$NO_x$ was traced to the buildup of a white powder residue within the walls of the incinerator. This caused an increase in radiant heat transfer to the region where the de-$NO_x$ was operating, increasing the temperature and adversely affecting its performance. Oxford has installed soot blowers in the incinerator to prevent the white powder buildup. This is expected to improve the performance of the de-$NO_x$ to operate at design levels.

At the Modesto plant, all the by-products can be recycled (48). The steel slag from the incinerator, which contains the steel from the tire belts and beads, is being sold for use in cement production or road base. The zinc oxide from the baghouse can be used in zinc production or as part of a fertilizer. Currently all of the zinc oxide is being sold for zinc production. The gypsum generated by the scrubber can be used in wallboard production or as a soil conditioner. Currently all of the gypsum is being sold as a soil conditioner.

## Table 12
## SUMMARY OF MEASURED EMISSIONS AT THE CONTROL DEVICE OUTLET

| Parameter | Emissions | Factor | Units | lb/day |
|---|---|---|---|---|
| CDD | 0.515 ng/sec | 9.85E-03 | ug/MMBtu | 9.81E-08 |
| **CDF** | 1.69 ng/sec | 3.23E-02 | ug/MMBtu | 3.22E-07 |
| PAH | 61.6 Ug/sec | 1.18 | mg/MM-Btu | 1.17E-02 |
| PCB[a] | 3. **Ug/sec** | 5.74E-02 | mg/MMBtu | 5.71E-04 |
| THC[b] | 0.239 ppmv @12% $CO_2$ | 64.8 | mg/MMBtu | 0.646 |
| $NH_3$ | 63.9 ppmv@12% $CO_2$ | 0.037 | lb/lb$NH_3$ injected | 181.8 |
| **$NO_x$** | 49.54 ppmv @12% $CO_2$ | 38.6 | g/MMBtu | 384.3 |
| $SO_3$(CCS) | 4.5 ppmv @12% $CO_2$ | 5.56 | g/MMBtu | 55.4 |
| $SO_2$(M8) | 4.2 ppmv @12% $CO_2$ | 4.56 | g/MMBtu | 45.4 |
| $SO_2$(CEM) | 3.76 ppmv @12% $CO_2$ | 4.08 | g/MMBtu | 40.6 |
| HC1 | <3.5 ppmv @12% $CO_2$ | <2.24 | g/MMBtu | <22.3 |
| CO | 52.59 ppmv @12% $CO_2$ | 24.9 | g/MMBtu | 247.8 |
| PM - Front 1/2 | 0.00190 grains/dscf | 2.75 | g/MMBtu | 25.5 |
| - Back 1/2 | 0.000418 grains/dscf | 0.605 | g/MMBtu | 5.7 |
| - Total | 0.0023 grains/dxf | 3.36 | g/MMBtu | 31.2 |
| Total Metals[c] | 48.4 mg/sec | 0.92 | g/MMBtu | 9.2 |
| Particle Sizing | grains/dscf | 50% cut point | Percent Less Than 2 um | |
| | 0.423 | 0.086 Um | 79.9% | |

[a]Data obtained from Engineering-Science.
[b]Expressed as parts per million methane.
[c]Estimated based on inlet concentrations and particulate reduction.
Source Reference 47 (Oxford Energy Modesto facility).

The power generated at Modesto is sold to Pacific Gas & Electric Company. Oxford has a long-term agreement with the utility to provide electric power. In 1989, the buy-back rate was 8.3 cents per kilowatt hour,

The success of the Modesto plant showed that whole-tires-to-energy plants can be built and run profitably in the US. The characteristics of the Modesto plant which made this possible are:

Technology for burning tires economically and within environmental limits

Buy-back rate from the utility which is high enough to make the plant profitable

Supply of tires to fuel the plant and provide sufficiently high tipping fees.

Oxford Energy was able to provide all these features in siting their plant at Modesto. They located the plant at the Filbin tire pile, which is estimated to have over 35 million tires, In addition, they were able to integrate the plant into their overall tire collection and processing business and earn revenue from a continuing stream of tipping fees and collection fees to dispose of tires from tire dealers, recappers, and other sources in the area.

**2) Sterling Power Plant.** Oxford Energy has begun construction of its Exeter Energy Project in Sterling, Connecticut. The construction is being financed with $55.3 million of tax-exempt bonds issued by the Connecticut Development Authority and $42.2 million in debt instruments from Sanwa Bank and Zurn Industries (49). Zurn Industries is the construction contractor for the project. The plant will be similar in design to the Modesto facility, but will have roughly twice the capacity.

It is planned to begin commercial operation in 1991, with a buy-back rate of 6.7 cents per kilowatt-hour for the generated electricity. The buy back rate gradually increases over time, reaching 13,6 cents per kilowatt-hour in 2005. It is anticipated that in addition to whole tires, the plant will also be able to burn tdf for approximately 259% of the Btu value, This feature is important for the Sterling plant, since Oxford Energy has been collecting and shredding tires for several years in anticipation of the construction of the plant, The 26.5 MW plant will consume about 9-10 million tires per year from the continued collection and processing of tires from Connecticut and the surrounding New England area.

**3) Erie Power Plant.** In July 1989, Oxford Energy announced plans to build a 30 MW tire-to-energy facility in Lackawanna, New York (50). Oxford Energy plans that this facility, named the Erie Energy Project, be designed to burn 10 million tires per year, Under a long-term sales agreement with New York State Electric and

Gas, Oxford Energy plans to sell power at 6 cents per kilowatt-hour, beginning in 1993. Under the agreement, the rate increases gradually over time to 10 cents per kilowatt-hour in 2005. Oxford Energy has submitted applications to the City of Lackawanna and the State of New York for the necessary permits. At this time, it is not clear whether the plant will be constructed, since two other competing waste projects are also being considered for the site.

**4) Nevada Power Plant.** Late in 1989, Oxford Energy also announced plans to build a 30 MW tire-to-energy plant at Moapa, Nevada near Las Vegas. This planned facility, similar to the Sterling Power Plant, would burn tires from California and Nevada. The arid environment at the plant site is ideal for minimization of any mosquito problems associated with tire storage. Oxford Energy is proceeding with the permitting process and they have already filed for air quality permits.

In conclusion, whole-tire-to-energy power plants with a reciprocating grate system and state-of-the-art air pollution controls have proven practical, both in the US. and West Germany. With the completion of the Sterling plant, there will be the capacity in the U.S. to turn 14 million tires per year into electricity. It must be emphasized that two keys to successful operation of such plants are proximity to tire sources and adequate buy-back rates for the electricity y generated by the plants.

**b) Tire Manufacturing Plants.** Two Firestone tire plants have installed pulsating floor furnaces to dispose of scrap tires and other solid wastes (2). The two Firestone tire-burning furnaces are located in Des Moines, Iowa and Decatur, Illinois. They were built in 1983 and 1984, respectively. The furnaces were designed by Basic Environmental Engineering, Inc. of Glen Ellyn, Illinois.

Currently, only the Decatur incinerator is operating. The Des Moines incinerator was shut down in 1987 for exceeding opacity limits. The Des Moines plant produces very large agricultural tires, which are much more difficult to burn without opacity problems than the passenger tires produced at Decatur. Reopening the Des Moines incinerator would probably require the addition of a baghouse, which is not economically feasible.

Each of the two incinerators has the capacity to burn 100 tons of waste per day and produce approximately 20,000 pounds per hour of steam for use in the tire manufacturing process. Twenty-five per cent of the load to the incinerator is whole tires and rubber scraps. The remainder consists of paper, wood, and miscellaneous solid waste. The percentage of rubber does not exceed 25 percent so that the flue gas can stay within the opacity limit. Even though only one quarter of the weight of the load is tires, the tires account for 80 percent of the Btu consumed by the furnaces,

Both furnaces are fed by the same type of system, utilizing a charging hopper and a hydraulic ram, The ram pushes the solid waste into a primary combustion chamber with a stepped hearth, The walls of this chamber are water cooled. Pulses of air shake up the fuel charge and move it along through the hearth. The hot gas from the primary combustion chamber goes through three additional combustion stages before going through a fire-tube boiler, Of the 20,000 pounds per hour of steam, approximately 70 percent is produced by the fire-tube boiler and 30 percent is produced by the water-cooled walls of the primary combustion chamber.

The staged combustion system allows the operator to maintain good control of carbon monoxide and nitrogen oxide, keeping them below environmental limits. The ash from each plant is removed from the furnace bottom and sent to a water bath.

The combustion system requires cleaning of the boiler tubes after every 30 days of operation. A typical incinerator run is 7 to 17 days. This type of duty cycle is suitable for solid waste disposal at the tire plants, although it would be unacceptable for steady production of electric power,

The incinerator configuration used by Firestone at these two plants appears best suited to a tire manufacturing operation with capability to use the process steam. Each of the incinerators has the capacity to handle approximately 500,000 tires per year. No additional tire-burning incinerators using the pulsed hearth design have been built since these two plants were constructed.

**c) Cement Kilns.** Cement kilns appear to be very suitable for disposing of waste tires because these furnaces operate at very high temperatures and have long residence times. Kiln temperatures are typically around 2,600 degrees Fahrenheit. High temperatures, long residence times, and an adequate supply of oxygen assure complete burnout of organics, which minimizes the formation of dioxins and furans, a primary consideration in solid waste combustion (46). In addition, the cement production process can utilize the iron contained in the tires' steel beads and belts. The steel does not change the quality of the cement product, since large quantities of iron ore are already present as one of the main ingredients.

Figure 6 shows a schematic drawing of a rotary cement kiln. The configuration shown is typical of those used in the U. S., with no suspension preheater (51). Limestone and clay are heated together to produce the clinker, which is later ground with gypsum to produce cement. Various fuels are used in cement production, including coal, oil, natural gas, and petroleum coke, On a cost basis, tires are generally the cheapest fuel, unless petroleum coke is available locally. However, before burning tdf a cement plant operator must consider the capital equipment expenditures that may be necessary for handling and feeding the tdf. Generally the fuel change may necessitate obtaining new permits from the state or local environmental authorities.

At present there are seven cement plants utilizing scrap tires in the U. S., up from 4 plants in 1989. This contrasts with other countries, where tires have been

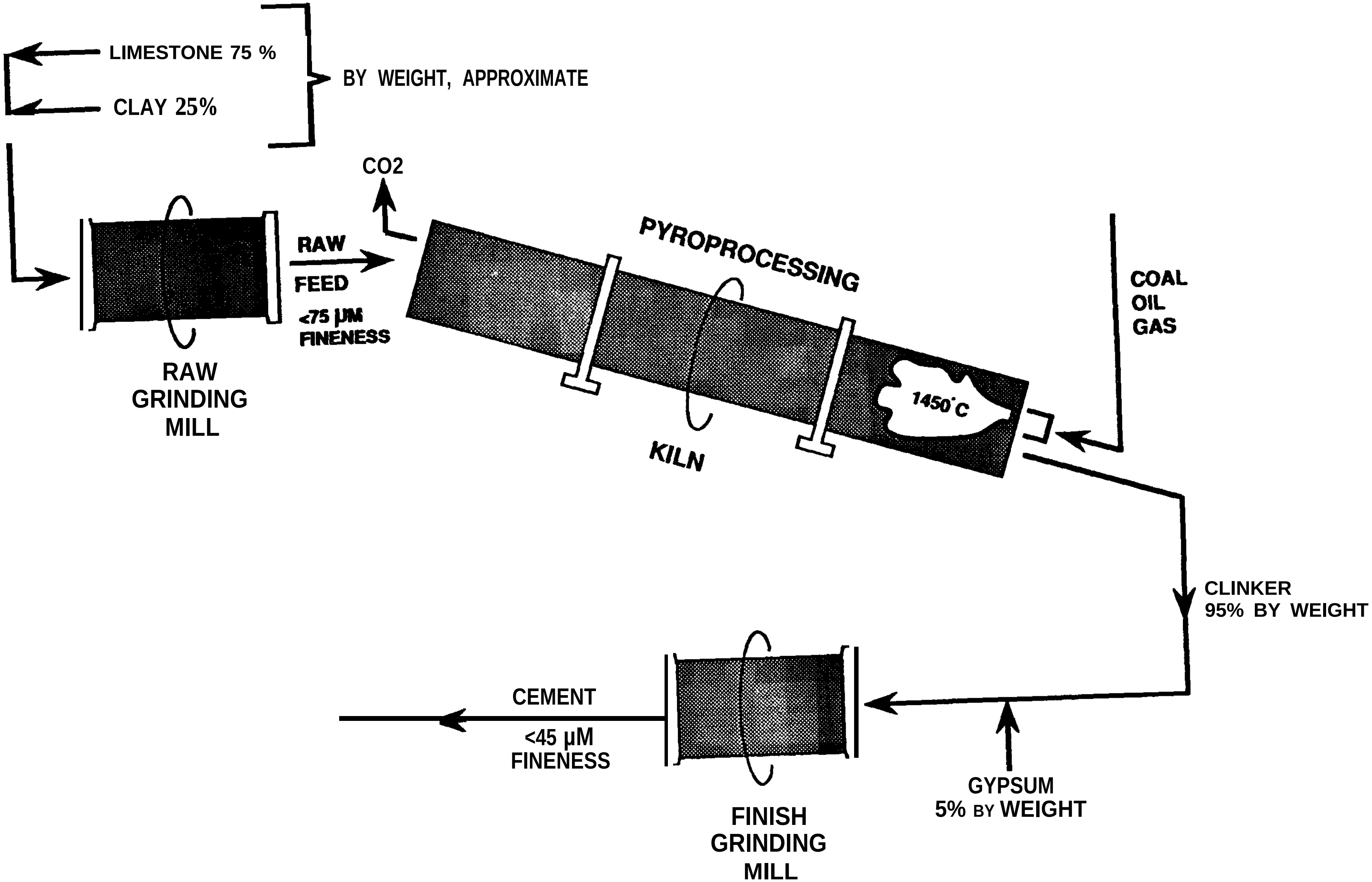


**Figure 6. Schematic of Cement Manufacturing Process**

**Source: Reference 51**

used extensively as fuel in cement plants for many years. In particular, cement plants in West Germany, Austria, France, Greece, and Japan routinely burn tires (51). The slower adoption of this means of tire disposal in the U.S. is probably due to the relative economics--fuel prices are lower here and there are still some landfills that will accept tires at fairly low tipping fees. In recent years, the slow pace of permitting the plants to burn tires as well as lack of experience with tire-derived fuel, has also retarded the U.S. implementation.

A typical example of European experience is Heidelberger Zement in West Germany. They have been burning tires in cement kilns since 1978, utilizing as much as 50,000 metric tons per year in six plants. Generally they have kept the tire percentage of the fuel below 20 percent. They have observed improvement in kiln performance and more stable operation. They have monitored air pollution levels from the kilns and observed no problems.

In the U.S. there are approximately 240 active cement kilns (52). Of these, there are 50 precalciner/preheater kilns built since 1971, which would be the kilns most likely to burn tdf. However, about 20 percent of these kilns are at locations, such as the southeast Gulf coast, where they can probably obtain petroleum coke at a lower price than tdf, and hence they would not be likely tdf buyers. The remainder could become tdf users if the economics and the environmental permitting procedures were favorable. If 40 cement plants each used the equivalent of 2 million tires per year, there could conceivably be a national usage of 80 million tires per year, or one third of the annual number of scrap tires generated.

The first three cement kilns to use tire-derived fuel were Genstar Cement in Redding, California; Arizona Portland in Rillito, Arizona; and Southwestern Portland in Fairborn, Ohio. A fourth kiln, Ash Grove, in Durkee, Oregon, burned a small amount of tire chips in 1990. Other kilns now burning tires for fuel include La Farge Cement, New Braunfels, Texas; Wholnam, Inc., Seattle, Washington, and Ideal Cement, Seattle, Washington. In addition, Tilbury Cement Ltd., Vancouver, B.C., burns some U.S. scrap tires. The experience of the first three operating plants will be described in the paragraphs that follow.

**1) Genstar Cement.** The Calaveras Cement plant of Genstar Cement Company is located in Redding, California, north of Sacramento. The kiln, which has been in operation since 1981, has a four stage preheater with a planetary cooler and an in-line calciner. In this configuration, all the gases pass through the kiln, including the excess air used to burn the precalciner fuel.

Genstar has been burning tdf at the plant for five years. They have built a feed system that introduces the tdf into the riser duct of the preheater just above the kiln feed housing (53). This allows the tdf to burn in suspension in the riser gases, providing efficient combustion. They handle the tdf using the screw feeder and elevator system shown in Figure 7. With this configuration, they find that the kiln runs smoothly and there is no difference in the cement product.

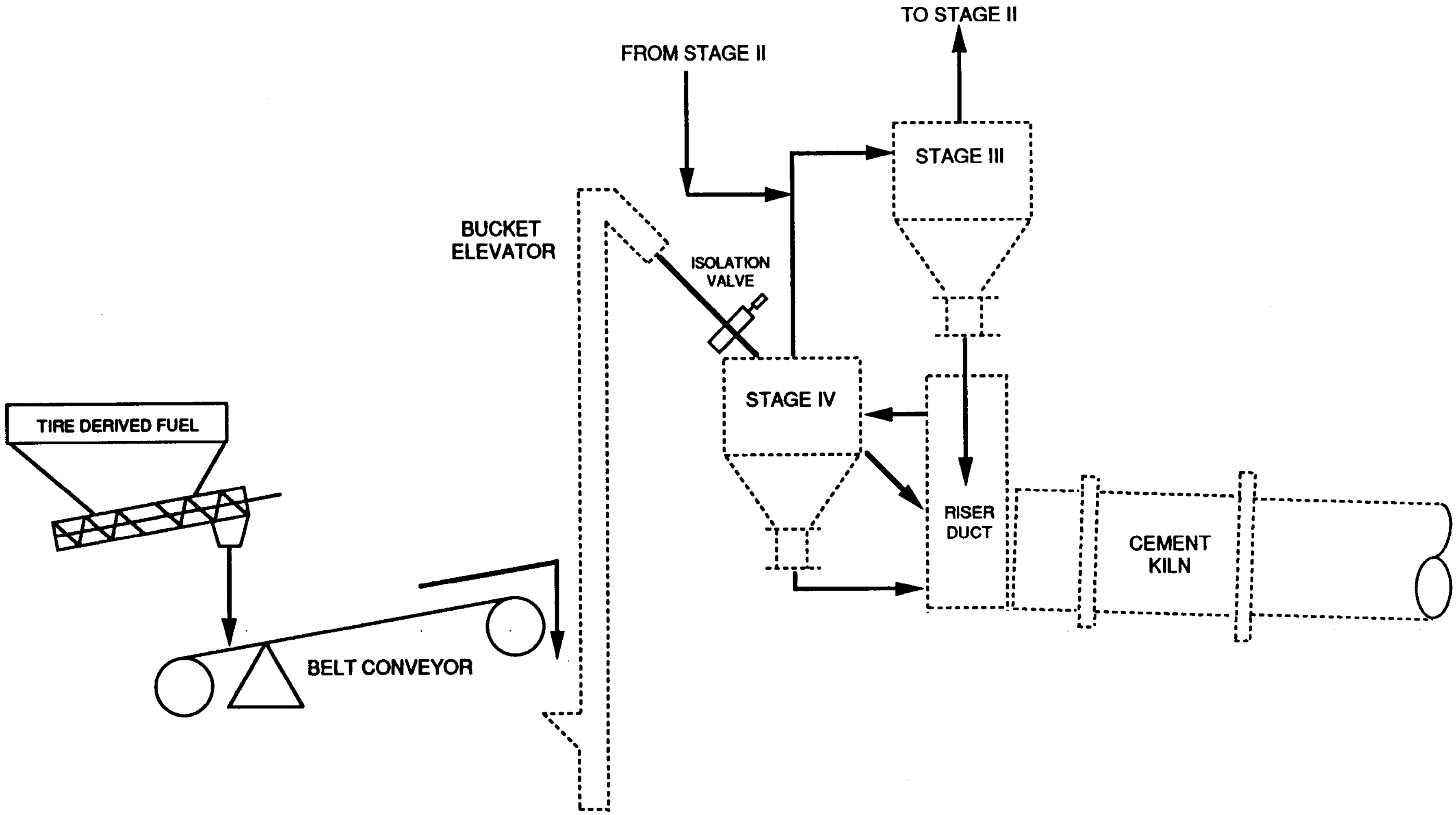


Figure 7. Tire Feed System Flow Sheet
Source: Calaveras Cement Co.

Currently, they are burning 65 tons of tdf per day at the plant. This averages about 25 percent of the Btu consumed by the plant. The remainder of the fuel is coal. With this percentage of tdf the plant meets environmental standards, emitting 95 pounds per hour of $NO_x$ and 2 pounds per hour of $SO_2$. The $SO_2$ emissions are far below the limit of 243 pounds per hour. At its current rate of tdf usage the plant burns over two million tires per year.

**2) Arizona Portland.** Arizona Portland operates a cement plant in Rillito, Arizona, near Tucson, which has been burning tdf since 1986. They have a different kiln configuration from Genstar and they use a different tdf feed system. They feed the tdf into the flash calciner at the back end of their system. Until recently, they had been using an air lock system to feed tdf into their calciner at a rate of 2 tons per hour. However, they had problems with the pneumatic feed system. Pieces of steel wire from the tdf repeatedly plugged up the elbows in the feed path. Because of these problems they decided to install a mechanical feed system instead.

With the conversion to a mechanical feed system, they expect to double their tdf feed capacity and run 4 tons per hour. This should result in a considerable fuel cost savings, because they can obtain tdf for about $1 per million Btu, whereas they would otherwise be burning more coal which costs about $2 per million Btu. With the new configuration they could obtain 10 percent of their heating value from tdf, 10 percent from natural gas, and 80 percent from coal. Both their old and new configurations utilize 2-inch by 2-inch pieces of tdf. With the new capacity Arizona Portland could increase its capacity to over 3 million scrap tires per year. In 1990, Arizona Portland utilized approximately 1 million scrap tires (54).

**3) Southwestern Portland.** The Southwestern Portland Cement Plant, located in Fairborn, Ohio, has been operational since 1934. Whole automobile and small truck tires have been burned at the plant on a sustained basis since June, 1989 (55).

The kiln, 220 feet long and 15 feet in diameter, is equipped with a four stage preheater similar in layout to the Genstar plant. Whole tires are fed, one at a time, into the riser duct just above the kiln feed housing through a trap door and isolation chamber. Tires are handled using a conveyor and elevator system that picks up one tire at a time.

Burning whole tires rather than tire chips saves shredding costs, but transportation costs may be higher, depending on the distance between the cement kiln and the tire supply. The feeding mechanism for whole tires is also more expensive than for chips, because a seal must be provided to prevent leaking cold air into the process with the tires.

In summary, cement kilns appear to offer an excellent market for the disposal of waste tires. At present only two plants burning tire chips and one burning whole tires have long-term operating expense, but their good results apper to offer promise for an expanded market. The two kilns burning shredded tires use tdf supplied by an Oxford Energy subsidiary instead of whole tires, which has simplified their tire fuel handling and obviated the need for extensive capital equipment. The total amount of scrap tires used by these seven plants is at least 6 million tires per year.

**d) Pulp and Paper Production.** There are many furnaces at pulp and paper plants which are configured to burn wood waste, which is also known as hog fuel. Often these furnaces can be fed tdf without major capital equipment changes. Sometimes a pulp and paper plant will choose to burn only wire-free tdf, with all the pieces of steel beads and belts removed. This type of tire fuel usually costs about 50 percent more than ordinary tdf, because of the extra processing costs involved in finer shredding and removing the steel pieces by magnetic separation. The choice of the more expensive wire-free tdf is indicated in cases where the feed system for hog fuel has a tendency to get plugged up by pieces of wire. There are also pulp and paper plants that sell their furnace ash to farmers for agricultural uses. Sometimes the farmers want the ash to be free of iron, a condition that can only be met by using wire-free tdf.

**1) Tire-Derived Fuel Supply.** At present there are probably about a dozen pulp and paper plants burning tdf, with several of them in the states of Washington, Oregon, and Wisconsin. The companies marketing over a million tires per year of tdf to the pulp and paper plants are:

Waste Recovery, Inc., Dallas, Texas
Oxford Energy, Santa Rosa, California
Maust and Sons, Inc., Preston, Minnesota
Emanuel Tire Company, Baltimore, Maryland.

It is estimated that the use of tdf in the pulp and paper industry accounted for about 12 million waste tires in 1989 (56). It is estimated that at least 12 million scrap tires were utilized for fuel by pulp and paper plants in 1990.

**2) Use of Tire-Derived Fuel.** Measurements of emissions from burning tdf with hog fuel in furnaces in the pulp and paper industry indicate levels generally similar to those measured from burning hog fuel alone, with some increase in particulate. Tests on two hog fuel furnaces run by the State of Washington Department of Ecology found that they both were capable of burning tdf as auxiliary fuel without significantly increasing the emission of polynuclear aromatic hydrocarbons (PNA) (57). They did, however, find some increase in particulate emissions--29,000 grams per hour with tdf versus 21,000 without for the first furnace and 7,000 grams per hour with versus 5,000 without for the second furnace. As expected, there was an increase in zinc emissions--22,200 grams per hour with tdf versus 1,400 without for the first furnace and 1,400 grams per hour with tdf versus

210 without for the second furnace. The levels of vanadium, nickel, lead, chromium, and cadmium were found to be much higher in burning oil than in burning tdf.

Tests were also performed on a Minnesota boiler equipped with a multicyclone and scrubber that normally burned a combination of coal, tree bark, and sludge (58). The measurements made by Pace Laboratories showed that with 15 percent tdf the particulate level rose to 0.09 pound per million Btu, compared to 0.05 pound per million Btu without tdf. The levels of $SO_2$ and NO, showed smaller increases, and polynuclear aromatic hydrocarbons were below detectable levels.

Particulate measurements on two boilers at a pulp and paper mill in Oregon showed similar results (59). The first boiler emitted 39 pounds per hour of particulate when burning hog fuel and 73 pounds per hour when 1 percent tdf was used. The other boiler showed 27 pounds per hour of particulate with 100 percent hog fuel, 46 pounds per hour with 1 percent tdf, and 57 pounds per hour with 1.5 percent tdf.

Experience in the pulp and paper industry has shown that hog fuel boilers can use tdf for up to 15 percent of their fuel value. The percentage can be adjusted to meet operational and environmental limits (42).

**e) Small Package Steam Generators,** Foreign manufacturers produce various small package steam generator units which are capable of burning tires. Eneal Alternative Energy of Milan, Italy manufactures a unit which can burn 200 tires per hour and produce 22,000 pounds per hour of process steam. However, none of the Eneal units has operated in the U.S. to date. There is currently only one small package generator operated in this country--a Japanese system operated by Les Schwab Tires, a retreader in Prineville, Oregon (42).

The Oregon installation uses a 25 tire per hour unit manufactured by Nippo in Japan and marketed in the U.S. by Tsurusaki Sealand. The unit has been in operation since 1987 with moderate success, but no US. company has yet decided to purchase another one. The draft configuration in the unit allows it to burn at 2,000 degrees Fahrenheit and produce 100 psig process steam. The unit has a Cleaver Brooks waste heat recovery boiler and a bag filter. Whole tires are automatically fed into the unit--both automobile tires and light truck tires. The State of Oregon Department of Environmental Quality has approved the operation of the unit.

To summarize the combustion alternative, various combustion installations throughout the country appear to be increasing their consumption of waste tires. The largest tire combustion facility in the world is now beginning construction--the Oxford Energy power plant at Sterling Connecticut, which will burn 9-10 million tires per year. When it is completed, it will bring the total of tires annually combusted for fuel to approximately 30 million.

## Pyrolysis

Pyrolysis of tires involves the application of heat to produce chemical changes and derive various products such as oil and carbon black. Although several experimental pyrolysis units have been tried, none has yet demonstrated sustained commercial operation. The oil produced by the process would have to compete with oil conventionally produced from crude, at its current prices. There is also the problem of marketing the char by-products, whose prices are highly dependent on quality.

The history of tire pyrolysis projects to date indicates that the problems blocking them have been technical and economic (60). These include the problems of upgrading the carbon black by-product while keeping down the operating cost of the process and the capital cost of the plant.

Recently, there has been a technical advance in char upgrading that may help to make tire pyrolysis economically feasible (61). In 1987, American Tire Reclamation (ATR) filed for a patent on a method of reclaiming carbon black from discarded tires. This method is intended to separate the char into a medium grade (Grade A) carbon black and a low grade (Grade B) char residue containing 15 percent ash. This classifier produces a carbon black with the particle size, consistency, and purity that are suitable for a semi-reinforcing filler of medium strength.

The main test for quality of a carbon black by-product is the strength it imparts to the rubber products made from it. The laboratory test involves using the carbon black sample in a recipe for styrene butadiene rubber (SBR) and then strength testing the resulting rubber samples. In such tests the samples made from ATR's by-product carbon black were not quite as strong as those made from a standard grade of carbon black known as N-774, but they were stronger than those from the N-990 grade. American Tire Reclamation calls its by-product carbon black ATR077. The strength of specimens made from ATR077 is about 2,300 psi, compared to about 3,100 for N-774. Specimens made from ATR077 are about 50% stronger than those made from ordinary carbon black derived from a tire pyrolysis char.

American Tire Reclamation has sent out samples of ATR077 for inspection and testing by more than twenty carbon black users. On the basis of the quotes obtained from potential buyers, they believe that they can sell all their potential production of ATR077 at $0.13 per pound or higher. With its acceptable strength characteristics and its competitive price, ATR077 should have a broad market in non-critical rubber parts, although not in tires. ATR077 can also be used as a carbon-black filler for blending black plastics, such as plastic pipe.

Up to now, ATR077 has been produced only in a batch process, starting with char shipped from remote pyrolysis sites. American Tire Reclamation is currently planning to build a continuous classifier plant at a downtown Detroit location. This classifier is expected to have a capacity of 2 tons of char per hour. Present plans call for the continuous classifier plant to be built in 1991 and then to run for at least six months using tire pyrolysis char shipped from remote locations. If the continuous classifier runs are successful and the ATR077 can be sold profitably, the machinery will probably be moved to a pyrolysis plant and become part of an integrated operation.

In the past several years, tire pyrolysis has not looked profitable, primarily because of the technical problems of upgrading the char. The next few years should determine whether ATR's new char classification technology can help to overcome these problems.

Up to as recently as a year ago there were no commercially operating tire pyrolysis units in the U.S. Since then, however, at least one facility, in Oregon, has commenced operation. Research and demonstration work by several entrepreneurs is described below:

**a) Baltimore Thermal** of Baltimore, Maryland indicate that they intend to build a 3.5 million tire per year pyrolysis plant, which they expect to put in operation in 1991. They plan to build the plant at a site in Maryland, which is still to be determined, and produce an oil product similar to #6 fuel oil. They are considering using the by-product separation technology developed by American Tire Reclamation for upgrading the carbon black product (description provided above).

**b) J. H. Beers, Inc.** has a small experimental tire pyrolysis unit at Wind Gap, Pennsylvania. This unit uses tire pyrolysis technology from Nu-Tech Systems of Bensenville, Illinois. Experimental runs of this unit indicated that all air pollution emissions were within allowable limits and the unit was granted an operating permit by the Pennsylvania Department of Environmental Resources. The unit emitted 102 ppm of sulfur dioxide, well below the allowable level of 500 ppm. The unit also emitted 0.002 gr/dscf of particulate, far below the limit of 0.04 gr/dscf. At this time, there are no indications of building any commercial pyrolysis plants using the Nu-Tech technology.

**c) TecSon Corporation** of Janesville, Wisconsin has developed a continuous pyrolysis system for converting rubber chips to oil, gas, and carbon black. They call their technology the “Pyro Mass Recovery System,” and they have operated a 100 tire/day pilot plant. At this time it is not clear whether their technology will be used in a commercial tire pyrolysis plant.

**d) Conrad Industries** of Chehalis, Washington has operated a one ton per hour pyrolysis unit for several years. Their 1,500 degrees Fahrenheit tubular reactor has been run with shredded tires. Their most recent runs have used other waste products as the feedstock. At present, it is not clear whether any company plans to build a commercial tire pyrolysis plant using their technology, Besides the companies listed above, who have indicated recent interest in tire pyrolysis ventures, there are also many companies who have done experimental work in tire pyrolysis in the past, Particularly noteworthy have been the efforts by Firestone and TOSCO.

**e) Firestone Tire & Rubber Company** performed a major cooperative research program with the U.S. Bureau of Mines in the early 1970s. They developed a 10 tire/day laboratory pyrolysis unit. In their studies, they determined average yields of pyrolysis products per tire as follows:

- 1 gallon oil
- 7 pounds char
- 3 pounds gas (57 scf)
- 2 pounds steel and ash,

Generally, most pyrolysis systems have produced similar yields. Thus, it is important that any successful pyrolysis plant make provisions for selling the by-products, especially the char.

**f) The Oil Shale Corporation (TOSCO)** applied their oil shale technology to tire pyrolysis in 1975. In 1975, they formed a joint venture with Goodyear and built a 15 ton per day prototype for pyrolyzing waste tires. Each ton of pyrolyzed tires yielded $49 worth of oil, $60 worth of carbon black, and $2 worth of steel (2). Apparently, this was insufficient revenue to justify the potential investment of $20 million to build a commercial-size plant. The project was discontinued.

# Chapter 2

# MARKET BARRIERS TO WASTE TIRE UTILIZATION

## INTRODUCTION

The previous chapter has discussed the current status of utilization of tires. This chapter will discuss market barriers to their utilization.

There are substantial barriers to the utilization of waste tires. These barriers can be classified into two main types - economic and noneconomic.

> Economic barriers refer to the high costs or limited revenues associated with various waste tire utilization methods which make them unprofitable. No tire processor will invest time or capital unless there is a sufficient rate of return to justify the efforts.
>
> Noneconomic barriers refer to a number of constraints on utilization. These include technical concerns such as lack of technical information or concerns regarding the quality of products or processes. These barriers also include the reluctance of consumers, processors, and regulators to employ new approaches or technologies for aesthetic or other reasons. They also include constraints on utilization because of health, safety, environmental issues, laws, and regulations.

The strength and persistence of these barriers is evident from the continuing buildup of tire stockpiles and dumps over the last several years.

Table 13 summarizes the economic and non-economic barriers that were identified for each of the tire utilization options examined in this study. An economic factor that affects all the technologies, is the low tipping fees for all solid waste, including tires at landfills. Although landfills often charge more for tires than for other solid waste, disposal costs are generally much lower than the costs for alternate means of managing scrap tires such as recycling and incineration for energy recovery.

This chapter places special emphasis on the barriers affecting the two categories of waste tire utilization that have been identified as having the greatest potential for using a considerable portion of scrap tires generated: rubberized asphalt and combustion. Both of these uses have the potential for being used in many areas of the country and to consume large numbers of scrap tires if the economic and non-economic barriers can be removed.

Table 13

**SUMMARY OF BARRIERS TO SOLVING SCRAP TIRE PROBLEM**

| Technology | Economic Barriers | Noneconomic Barriers |
|---|---|---|
| **SOURCE REDUCTION** | | |
| Design for longer life tires | Higher cost for tires<br>Higher fuel consumption | - Rougher riding tires<br>More tire noise |
| Reuse of used tires | High cost of matching, sorting and distribution | - Safety concerns<br>Consumer preference for new tires |
| Retreading | High cost of recapping<br>Competition from new tire prices (passenger)<br>(Most good truck carcasses are retreaded now) | - Consumer attitudes about safety and reliability |
| **RECYCLING** | | |
| Rubber additives for pavements | - Initial costs are about double cost of alternate materials<br>- Insufficient life-cycle cost data available<br>- Capital cost for equipment modification | Long-term testing is incomplete<br>- Conflicting test results<br>- States are waiting on other states' results<br>· Lack of information transfer among states<br>- No national specifications for rubberized asphalt<br>Patents can limit competition |

(continued)

**Table 13 (continued)**

| | | |
|---|---|---|
| Processed rubber products<br>Reclaim<br>Mats<br>Split tire products<br>Railroad crossings | - High capital requirement for reclaim plants<br>- Price competition from alternate railroad crossing materials | - Lack of market acceptance for products requiring structural integrity, particularly new tires<br>- Does not use whole tire (disposal still required)<br>- Split tire products limited to wire-free tires |
| Playground gravel substitute | - Up to 10 times more expensive than alternate materials (gravel, stone, wood chips) | - Product not as familiar to buyers as traditional playground gravel |
| Bulking agent for composting | - High cost compared to the alternative (wood chips) | - Concerns about lead and zinc from tires<br>- Lose dilution effect of heavy metals (zinc and cadmium) that is obtained with wood ChipS |
| Reefs and breakwaters | - High construction cost | - Not appropriate for all shores (e.g., northwest coast is too rough) |
| Playground equipment | - High cost compared to other materials | - Some schools and parks prefer wooden equipment for aesthetic reasons |

(continued)

**Table 13 (continued)**

| | | |
|---|---|---|
| Erosion control | High cost | |
| Highway crash barriers | - High cost | - Highway departments prefer sand-filled crash barriers<br>- More difficult to erect and dismantle than sand-filled |
| **COMBUSTION** | | |
| Power plants | - Low utility buy-back rate for electricity in many regions of Us.<br>- Capital and operating costs | - Siting problems |
| Combustion at tire plants | - High cost of air pollution control | - Concerns about the opacity of stack emissions |
| Cement kilns | - Capital costs for handling and feeding<br>- Low cost of alternate fuels (particularly in areas where petroleum coke is available)<br>- Expense and downtime in environmental permitting process | - Delays in environmental permitting procedures |

(continued)

**Table 13 (continued)**

| | | |
|---|---|---|
| Pulp and paper mills | - High cost of wire-free tdf<br>- Handling costs<br>- Low cost of alternate fuels | - Wire in tdf can plug some hog-fuel feed systems and limit ash markets<br>- Particulate emissions higher than for hog-fuel alone<br>- Use of new fuel often requires re-opening of environmental permits |
| **PYROLYSIS** | - Capital and operating costs<br>- High cost for upgrading char by-products | - Upgrading char needs to be commercially demonstrated on a sustained basis |

**source** Franklin Associates, Ltd. and Dr. Robert L. Hershey

Both technologies are commonly used in Europe, but rubberized asphalt usage in most of the United States is still in the testing stage.

In analyzing the economics of tire utilization, it is helpful to consider each situation where cost data are available in terms of the profit per tire. Entrepreneurs will launch a tire processing facility only if the potential profit per tire is high enough. The profit per tire may be computed from the equation shown below:

$$P = F + R - C - T - D$$

where

**P** is the profit per tire

**F** is the tipping fee collected per tire

**R** is the revenue received per processed tire

**C** is the processing cost per tire for operating the facility

**T** is the transportation cost to bring in tires

**D** is the disposal cost for waste products

In the sections of this chapter where data are available, the various options for processing tires into fuel are analyzed in terms of this tire profit equation.

Clearly, to motivate entrepreneurs, there must be a positive profit per tire for any feasible utilization method. If the equation yields a negative value (a loss) then the private sector will not use such a utilization method, and the tires will stay where they are. Not only must there be a profit, but it must be high enough to give a good return on the invested capital to build a plant or buy equipment. A rough method of analyzing the return is to calculate the simple payback period using the equation shown below.

$$\text{Payback Period} = \frac{\text{Capital Invested}}{\text{Annual Profit}}$$

The equation tells how many years it will take before the capital invested in the plant and equipment will be paid back. Generally, most investors will demand a payback period of three years or less before they will risk their money. In the electric power industry, which tends to have stable revenues, a payback period of seven years may be acceptable. Obviously, any venture which requires a high capital investment and yields a very low profit will have a long payback period, and the venture probably will not be financed.

In the sections which follow, the economic barriers for various waste tire utilization methods will be discussed. For those methods which seem economically feasible, the noneconomic barriers will also be examined.

## RUBBER ASPHALT PAVING SYSTEMS

Rubber for pavement use is currently experiencing a rapid growth. The Asphalt Rubber Producers Group (ARPG) claimed a 67 percent growth in 1989 over 1988, and experienced further growth in 1990. Many states have tested asphalt-rubber for roads, with about a half dozen leading the way. The PlusRide™ rubber modified asphalt concrete is not being used routinely at this time. However, because of the positive results to date, several cities and counties are having streets and roads built of this material. The TAK system, a non-proprietary type of RUMAC, is also undergoing testing.

### Economic Barriers

The economic barrier to the use of rubber in pavements is the high initial cost to the highway departments. It is difficult to obtain good data on the capital investment necessary to convert an asphalt operation to add rubber. But the consensus from the ARPG and several other sources is that the installation of rubber asphalt pavements will cost about 2 times as much as standard asphalt. Although the test results for asphalt pavements containing rubber are not yet complete, in many cases a factor of 2 or more in pavement lifetime is achieved. Therefore, if transportation departments evaluate costs over the life of the roads, the overall costs may be the same or less for rubber asphalt. The ARPG claims that rubberized asphalt roads cost less on a life-cycle basis.

The entities responsible for highways and roads are usually the state and local governments. It is difficult for them to justify doubling the highway repair investment especially if they are not quite convinced yet what the expected road life is. In addition, governmental officials may be trying to meet goals of a certain number of road miles paved per year. It may be more difficult for them to make decreased life-cycle cost their main goal.

Some state government officials have expressed concern that, because the two most proven forms of rubberized asphalt are patented, prices for this material may be higher than they would be if the material were not patented. It is estimated that the royalty adds 35 percent to the cost of asphalt-rubber and 27 percent to Plus Ride™. The patent for asphalt-rubber expires in 1991. After that time ARPG expects more companies to become involved. The TAK process is not patented, but also has not been tested as long as the patented types of rubberized asphalt.

## Noneconomic Barriers

One of the major noneconomic barriers to the use of rubber for paving in the past has been the lack of long-term test results. Some of the roads installed 15 to 20 years ago are still not worn out. Test controls are required because well designed asphalt roads may also sometimes last that long, Many of the test results are now available and more states are looking toward A-R and RUMAC. However, not many states, if any, are completely satisfied with either A-R or RUMAC to the extent that they are using either on a routine basis to build their new roads.

Some testing in Wisconsin indicated that asphalt-rubber roads may actually crack before asphalt roads. This temporarily halted activities in that state, However, after reevaluating their results and results from other states, Wisconsin has just installed 30 miles of asphalt-rubber roadway and is planning 3 new projects in 1990.

There is a need to summarize the results of asphalt-rubber and RUMAC research and establish guidelines that would help states use this process. Texas has already passed procurement guidelines,

Another potential barrier, the ability to recycle pavements containing rubber, needs to be tested. Given the similarity of the substance to conventional asphalt, however, it should be a matter of how, not whether, it can best be recycled.

Another barrier is the lack of national specifications for pavements containing rubber, Some states appear to be waiting for specifications to be written, The American Society for Testing and Materials (ASTM) has developed a standard specification (ASTM D-04.45) for asphalt-rubber to be voted on by its members in 1990-91.

When asphalt-rubber (wet process) is applied to pavements, the tires come from the neighborhood of the nearest shredding/grinding facility. Because A-R is a patented material, there are only a limited number of shredding companies that supply rubber for this process. Some state government officials have indicated concern about whether waste tires from their own state can be used, as opposed to those tires near the present shredders, which might be located in another state.

## COMBUSTION

Since tires have a Btu value comparable to the best coal, they would be expected to be an economically attractive fuel in some situations. Recent U.S. experience has shown economic feasibility for tire-to-energy power plants and for tdf used in cement kilns and pulp and paper mills. The economic barriers facing these types of tire combustion will be discussed below. Despite these economic barriers, the use of tdf has increased over the last year, and this trend is expected to continue.

### Economic Barriers

The economic barriers for combustion of tires relate primarily to the limits of the revenue received for electricity or tdf by the tire processor. The two cases--power plant and tdf--are analyzed in the sections which follow.

**a) Power Plants.** The key economic factor for a tires-to-energy power plant is the buy-back rate granted by the utility. This rate reflects the avoided cost, the cost per kilowatt-hour that the utility would incur if they built a plant themselves to generate additional power. Generally, avoided costs are highest in California and the northeast and lowest in the northwest. For Oxford Energy's Modesto power plant the rate is 8.3 cents per kilowatt-hour.

In analyzing the economics of the Modesto power plant, the tire profit equation can be used. The buy-back rate of 8.3 cents per kilowatt-hour means that each tire consumed will generate revenue of $1.84 from the sale of electricity to the utility. For tires coming from the on-site tire pile, F = O, since there is no tipping fee and T = O, because there is no transportation cost. We estimate that C = $0.50, the processing cost per tire for operations, maintenance, labor, and materials. The estimate of the net disposal cost per tire of fly ash, gypsum from the scrubber, and bottom ash (taking into account the sales of byproducts) is D = $0.08. Substituting these values into the tire profit equation yields the following results:

$$\mathbf{P = F + R - C - T - D}$$

$$= O + \$1.84 - \$0.50 - 0 - \$0.08$$

$$= \$1.26 \text{ per tire}$$

Thus the annual gross profit from the Modesto operation is $1.26 x 4.5 million tires = $5.7 million per year.

Dividing the gross profit into the $38 million capital cost of the plant yields the payback period.

$$\text{Payback Period} = \frac{\$38\text{million}}{\$5.7\text{ million}} = 6.7\text{years}$$

The payback period estimated above shows that the venture is acceptable, since investors in similar power plants generally want payback periods of 7 years or less. (The estimates in this chapter have been neither confirmed nor denied by Oxford Energy. A formal return-on-investment analysis would be necessary to be really accurate. This would include the financing structure of the venture, interest rates, depreciation, and tax considerations.)

From the tire profit equation shown above, it is apparent that the Modesto plant would be more profitable if it burned tires that brought in a tipping fee, rather than using tires from the Filbin tire pile. Newly brought tires also have a slight operational advantage since they are cleaner. Because of environmental, health, and safety concerns, however, it is important that the size of the pile be decreased. This situation has led to a compromise; Oxford Energy uses some tires from the pile and some tires from the surrounding area, for which a collection fee has been charged.

The economic feasibility of Oxford Energy's planned Sterling, Connecticut power plant can also be analyzed in a similar manner, This plant will have an initial buy-back rate of 6.7 cents per kilowatt-hour when it starts operation in 1991. The Sterling plant will cost roughly $100 million. It is estimated that the plant will consume approximately 9.5 million tires per year and will generate 26.5 MW of electricity. This means that the revenue per tire is $1.64 from the sale of electricity. Processing and disposal costs would appear to be similar to Modesto, so we would again estimate them to be C = $0.50 and D = $0.08. If the average tipping fee is $0.60 per tire and the average transportation cost is $0.05 per tire, the tire profit equation yields the following:

$$\mathbf{P} = \$0.60 + \$1.64 - \$0.50 - \$0.05 - \$0.08$$

$$= \$1.61 \text{ per tire}$$

Thus, processing 9.5 million tires per year would bring in a gross profit of $1.61 x 9.5 million = $15.3 million.

The payback period for the Exeter Energy Project at Sterling, Connecticut is

$$\text{Payback Period} = \frac{\$100\text{ million}}{\$15.3\text{ million}} = 6.5\text{ years}$$

Once again there is a payback period less than seven years for a tires-to-energy project, the kind of payback expected by utility investors.

Note that the financial feasibility depends on having a sufficient utility buy-back rate. For instance, if the buy-back rate had been $0.04 instead of $0.064 per kilowatt-hour, then the revenue per tire would have been only $0.98. This would yield a profit of only $0.95 per tire. Under this lower buy-back rate the annual gross profit would be only $9 million, and the payback period would be over 11 years. With such a long payback period the plant would have difficulty attracting investors. Therefore, the utility buy-back rate is the critical economic barrier in determining whether a plant is financially feasible.

**b) Tire-Derived Fuel.** In analyzing the economic feasibility of a tire-derived fuel venture, the main economic barrier is the price of the competing fuel. For instance, the cement plants in Texas and Louisiana are often able to obtain petroleum coke locally, a waste product from the petroleum refining process. Petroleum coke is a cheaper fuel than tires; therefore, tdf cannot capture this local market. Similarly, tdf must often compete with coal as the fuel for cement plants. If tdf is only slightly cheaper, it is hard to justify any capital costs for new equipment that might be necessary to burn tdf. Obviously tdf becomes more attractive if energy prices rise.

The tire profit equation can be used to analyze the profit situation for an entrepreneur considering building a $1 million facility to shred 1 million tires per year and produce tdf. If he can sell the tdf for $20 per ton, then by the rule of thumb of 100 tires per ton **R** = $0.20. Assume that he operates in an area where tire disposal is difficult and he can collect a tipping fee of $0.70 per tire. For maintaining a steady flow of tires he may occasionally have to truck them in, with an average transportation cost of **T** = $0.05. For the projected shredding operation the processing cost is **C** = $0.40. If the entrepreneur is selling tdf to cement kilns, he can leave the wire in the tdf from the steel belts and beads and **D** = O. Substituting these values in the tire profit equation yields:

$$\mathbf{P} = \$0.70 + \$0.20 - \$0.40 - \$0.05 - 0$$

$$= \$0.45$$

With a profit per tire of $0.45, his gross annual profit is $0.45 x 1 million tires = $450,000. Then the payback period on the $1 million facility is

$$\text{Payback Period} = \frac{\$1{,}000{,}000}{\$450{,}000} = 2.2 \text{ years}$$

This payback period is fairly attractive for a commercial facility, since it is less than three years. However, it is dependent on a relatively high tipping fee and a continuing demand for tdf at $20 per ton. If either of these decreased significantly, the venture would not be financially feasible.

The tire profit equation can also be used to look at the economic feasibility of burning tdf from the point of view of a cement kiln operator. For the cement plant there is no incremental operating cost in labor for feeding the kiln with tdf instead of coal. There is no disposal cost since the steel wire in the tdf becomes iron oxide, which is incorporated into the cement product. If the tdf is trucked to his plant by the tdf processor, then four terms of the equation can be set equal to zero: **F** =0, **C** = O, **T** = O, and **D** = O. Thus, for the cement kiln operator, the profit per tire he receives equals the revenue, which in this case is a fuel cost savings. If coal costs $50 per ton and he can get the same Btu value with $20 per ton tdf, then his savings is $30 per ton for using tdf. With the rule of thumb of 100 tires to the ton, R = $0.30.

The tire profit equation becomes

$$\mathbf{P} = 0 + \$0.30 + 0 + 0 + 0$$

$$= \$0.30$$

If the cement operator burns 65 tons of tdf per day, he will burn the equivalent of about 2.4 million tires per year. His annual fuel cost savings from burning tdf is $0.30 x 2.4 million = $700,000. If he has to make capital investments of $1.5 million to setup the feed system for tdf, then the payback period is

$$\text{Payback Period} = \frac{\$1{,}500{,}000}{\$700{,}000} = 2.1 \text{ years}$$

Since this is less than three years, this looks like a fairly attractive investment for the cement plant operator.

Note that if he could obtain coal for $35 per ton instead of $50 per ton, his profit per tire consumed would drop to only $0.15 per tire and his resulting payback period would be over 4 years. Then making the equipment investment to use tdf would not be economically attractive. This shows the importance of competing fuel prices in determining the economic feasibility of using tdf.

Burning tdf is often economically attractive for pulp and paper mills. Since their boilers are generally equipped to burn hog fuel, very little equipment modification is necessary to burn tdf. Often the competing fuel for the boiler is hog fuel, which is sometimes more expensive than tdf on a dollars per million Btu basis. For instance, at $30 per ton for wire-free tdf, the equivalent cost per tire consumed is about $0.30. The cost for the same fuel value of hog fuel can be as high as $0.45, when hog fuel is in short supply. If the costs of handling, transportation, and ash disposal are the same for tdf as for hog fuel, then for the pulp and paper boiler operator, the profit equals the fuel cost savings.

**P** = $0.15

If the pulp and paper mill consumes 500,000 tires per year as tdf, then the annual fuel cost saving over hog fuel is $0.15x 500,000 = $75,000.

If $150,000 in equipment changes are necessary to handle the tdf, the payback period is:

$$\text{Payback Period} = \frac{\$150{,}000}{\$75{,}000} = 2 \text{ years}$$

As shown above, a pulp and paper plant can often burn tdf economically. The annual cost savings can justify minor modifications to the equipment to handle tdf.

As discussed above, there are currently operating facilities where the combustion of tires and tdf has proven to be profitable. The economic feasibility of tires-to-energy plants depends on the buy-back rate for the electricity. For tdf consumed at cement kilns or pulp and paper mills, the economic feasibility depends on cost savings over competing fuels. Only a substantial annual cost savings justifies modifying a plant to handle tdf. The next section discusses the noneconomic barriers that must be considered once it has been determined that tire combustion is economically feasible.

**Noneconomic Barriers**

Noneconomic barriers to scrap tire combustion include problems in siting new facilities and environmental concerns, These two types of noneconomic barriers are related since objections to siting are usually due to perceived environmental problems. These noneconomic barriers are discussed below for power plants and tire derived fuel usage.

**a) Power Plants.** Tire-to-energy power plants are large facilities which cost from $30 million to $100 million. They cover a substantial land area and therefore create considerable public attention. Inevitably, for a potential facility of this size, there are some neighbors who believe the new plant will affect them adversely. This is the not-in-my-back-yard (NIMBY) syndrome, which is a barrier for siting many solid waste facilities.

In attempting to allay the neighbors' fears, Oxford Energy has designed their plant with more extensive pollution controls than the California regulations would dictate. They have a scrubber, a thermal de-$NO_x$ unit, and a baghouse for reducing $SO_x$, $NO_x$, and particulate. The high temperature reciprocating grate technology minimizes the formation of dioxins during combustion. A consultant's study of air pollution tests showed the plant to be operating within its permitted limits. The plant also has continuous emission monitoring (47).

The configuration chosen for the plant produces salable by-products, rather than waste products, The flyash from the plant is sold to a zinc smelter. The gypsum produced by the scrubber has been labeled by the state of California as appropriate for agricultural uses, It is sold as a soil conditioner. The steel slag from the plant is sold to a cement kiln for use in cement production.

Oxford Energy's strategy for protecting the tire pile from potential fire hazards includes providing continuous 24-hour surveillance with lighting at night. Guards in watch towers are equipped with infrared telescopes, The entire facility is surrounded by an 8-ft chain link fence, Fire hydrants are provided at strategic locations, connected to emergency water supplies.

In addition to all the investments in environmental control and safety equipment, Oxford Energy also spent considerable effort to inform the public about the plant. They led tours of the plant site and made presentations at public meetings. They also paid for trips to Germany by two Modesto community representatives to tour the Gummi Mayer tire incinerator that had already been operating for over 14 years using the same technology, Oxford Energy's efforts were successful in convincing the plant's neighbors and the permits were granted,

However, the NIMBY syndrome cannot always be overcome by the methods described above. Oxford Energy was not successful in launching a plant in the State of New Hampshire. The air quality and waste management permits were granted by the State, but a long court battle with the neighbors followed, After another year and considerable expenditure, Oxford Energy concluded that they would not be allowed to build,

The main noneconomic barriers to a tires-to-energy plant are the time required for permitting a plant, and the concerns of neighbors regarding environmental, health, and safety issues.

**b) Tire-Derived Fuel.** The use of tdf in cement kilns and pulp and paper mills faces considerable noneconomic barriers. This typically occurs when a plant is first considering switching to tdf. At this point new permits are generally required. This generally requires test burns with air pollution measurements, leading to expenditures and additional time for testing. Many plant operators would rather not bother with the disruption and delay, which erodes the projected fuel cost savings. Thus the producer of tdf may have considerable difficulty convincing a plant manager to burn the fuel.

There is a similar situation with pulp and paper mills attempting to burn tdf. Generally, state and local officials have required test burns to ensure that emissions are within regulatory limits. Since tdf burned in pulp and paper mills tends to increase the particulate emissions somewhat, the permits sometimes restrict the percentage of tdf that maybe burned.

Sometimes the stringent procedures required in permitting tdf burning can have the effect of controlling one pollutant while increasing another. They reduce any possibilities of increasing air pollution, but at the same time, they force the remaining tires (after source reduction and recycling have taken place) into the waste disposal stream.

**PYROLYSIS**

At this time, there has been very limited commercial operation of pyrolysis plants in the United States. The primary barriers are economic and technical. In particular, there has yet to be a commercial demonstration of a process to economically upgrade the carbon black to a high-quality profitable by-product. Until such sustained commercial operation occurs, any potential non-economic barriers constitute a moot point.

## Chapter 3

## OPTIONS FOR MITIGATING THE WASTE TIRE PROBLEM

### INTRODUTION

There is now a general public awareness throughout the U.S. that a waste tire problem exists. However, there is still controversy about the best solution to the problem and how we get there from here. This chapter provides options to address the problem. Several of them may need to be utilized to solve the tire problem.

Over 2 billion waste tires have accumulated in the United States. Some are in carefully controlled tire stockpiles. Many more are in uncontrolled tire dumps. Millions more are scattered at random in ravines, deserts, woods, and empty lots across the country. Each year 242 million more scrap tires are generated. Some of the waste tires are infested with mosquitoes capable of spreading diseases. Large tire piles often constitute a fire hazard. Most tire and solid waste professionals agree that a tire problem exists.

Six facets of the tire problem are listed below:

> Tires are breeding grounds for mosquitoes. Besides the major nuisance of mosquito bites, mosquitoes can spread several serious diseases.
>
> Uncontrolled tire dumps are a fire hazard. Fires in tire dumps have burned for months, creating acrid smoke and leaving behind a hazardous oily residue. A few tire fire locations have become Superfund sites.
>
> Tires should be utilized at their highest value. This means reuse or retreading first, followed by reuse of the rubber to make rubber products or paving and then combustion and disposal. At present, the preferred uses do not accommodate all the tires, and disposal must be utilized to a large degree.
>
> Scrap tires have to go somewhere. They tend to migrate to the least expensive use or disposal option, and as costs increase, illegal dumping increases.
>
> Disposing of waste tires is becoming more expensive. Over the past 20 years the average tipping fees for disposing of tires have continually

increased. This trend is likely to continue as landfill space becomes more scarce.

Tires take up landfill space. Whole tires are banned from many landfills or charged a higher tipping fee than other waste; even if they are carefully buried to prevent rising they are very bulky. Shredded tires take up less space, but it is space that could be saved if the tires were utilized as raw material for products or as fuel.

As listed above, the continuing accumulation of waste tires has led to six concerns of varying severity. Clearly, the mosquito and fire hazard problems are the most serious of the problems listed. Controlling them in the near term will necessitate providing adequate safeguards on presently existing stockpiles. Ultimately, decreasing the waste tire accumulations will involve appropriate uses of recycling, combustion, and landfilling. The current trends indicate that the quantity of tires utilized in products is likely to remain smaller than the quantity combusted or landfilled in the future.

An integrated solution is needed to the waste tire problem. Both government and industry need to work together to develop markets for scrap tires and to ensure proper disposal of those tires that are not recycled and are not incinerated for their energy value. In the next two sections of this chapter, options for mitigating the scrap tire problem are discussed.

In the first section, the regulatory approaches taken by states are described. Minnesota, in 1985, was the first state to regulate scrap tires (61). Four years later, only ten percent of the states had passed scrap tire regulations. By January 1991, 36 states had regulated scrap tires (12). This section describes the types of provisions included in the state scrap tire regulations, and presents advantages and disadvantages of these options, where relevant.

The second section presents other regulatory and non-regulatory options. Some of these have already been instituted at the Federal or State level, and others are in the form of proposals.

## REGULATORY OPTIONS--BASED ON EXISTING STATE PROGRAMS

As reported in Chapter 1,23 states have responded to the scrap tire problem by issuing laws that specifically address this problem. An additional 13 states have regulated tires under provisions of other laws, for instance solid waste laws. As of January 1991, an additional 7 more were in the process of drafting or proposing scrap tire laws or regulations (12).

As described below, state scrap tire laws may include (1) funding sources; (2) mandates to clean up tire dumps; (3) scrap tire management procedures including stockpile, processor, and hauler regulations; (4) market development incentives; and (5) regulations regarding landfilling of tires.

## Funding Sources

Most of the states with scrap tire laws obtain funding through taxes or fees on vehicle registrations or on the tires themselves. The means of funding state scrap tire management programs are described below.

**a) Taxes or Fees on Vehicle Titles or Registration.** Five states have taxes or fees on vehicle titles. These range from $0.50 to $2.00. In addition the state of Minnesota has a $4.00 title transfer tax on motor vehicles. Advantages are that these fees are collected by the government, therefore do not add to the administrative burden experienced by tire dealers. A disadvantage is that they do not directly tax tires. In addition, in times of recession, revenue decreases. Another disadvantage is that this type of law can be difficult for some states to pass because of state constitutional issues.

**b) Taxes or Fees on the Sales of New Tires or the Disposal of Old Tires.** Twelve states have taxes on the sales of new tires, and two states have fees on the disposal of waste tires. Taxes on the sale of new tires range from 1-2%, and fees range from $0.50 to $1.00 per tire. Disposal fees on tires range from $0.25 to $1.00 per tire. Advantages of these types of taxes or fees are that they are assessed directly on tires. A disadvantage is that they are often collected by the tire dealer or tire disposer/processor, so there are administrative costs incurred by these intermediaries, before the money is collected by the state government. Some states arrange for tire dealers to retain a designated percentage of the taxes or fees, to defray their administrative costs.

**c) Fees on the Permitting of Tire Processing or Disposal Facilities, and the Use of State Budget Appropriations.** One state has chosen permit fees on tire storage sites as a means of creating a fund for managing scrap tires. Another state appropriates money for scrap tire management out of its general fund (12). Disadvantages are, however, that funds are dependent on the number of tire-related permits being granted in the state, or the yearly budgetary process. Taxes or fees on vehicles or tires may provide more stable means of funding.

## Identify and Clean Up Tire Dumps

Most of the state laws set aside a certain portion of the funds for cleaning up major abandoned tire dumps. As a first step, some states develop an inventory of the tire dumps in the state. They may then rank them in priority order for clean-up. Criteria such as the size of the dumps, and proximity to highly populated areas or to critical natural resources may be used in determining which dumps are cleaned up first. Other actions commonly taken are putting fire protection measures in place, such as installing fire lanes. As the dumps are cleaned up, the tires may be recycled, utilized for energy recovery, or disposed of in a landfill.

Figures from the state of Minnesota show that tire dumps in that state have cost an average of $81,250 per site to clean up, or 65 cents per tire, The most expensive dump cost $300,000 to clean up, and the least expensive one cost $3,000. From 1988 to August 1990, the state of Minnesota spent 17 million dollars on clean-up programs to remove and process waste tires (63). These expenditures have resulted in an estimated 64% of tire dumps (26 sites) either undergoing clean-up or having completed clean-up. (62). It is clear from these figures that the clean-up of tire dumps is expensive. It is, however, less expensive than the costs of fighting tire fires and associated environmental reparations, which Minnesota estimates could cost more than $2 per tire (63).

**Methods for Managing Current Tire Disposal**

Most states have developed regulations to manage tire stockpiles and processing operations. A number of states have also addressed tire haulers in their regulations (12). These regulations are described below.

**a) Stockpile Regulations.** Twenty-four states have regulated tire stockpiles (12). Generally, state, or in a few cases local, regulations limit the size of stockpiles; limit the length of tire storage; require fire lanes; require the stockpiles to be fenced in; and may also require permits for stockpiles over a given size. In addition, some States such as Minnesota require owners of stockpiles to establish financial responsibility. They must prove they have the funds to completely remove and dispose of the tires, should the need arise.

**b) Processor Regulations.** Seventeen states have some type of regulations on processors (12). States may require processors to obtain permits or merely to register. Generally, these regulations limit stockpile size, and establish tire management practices. Processors may also be required to keep records on the source of tires they receive and the final end-user. Some States have less stringent rules for smaller tire piles. For instance, the State of Minnesota regulates tire processors storing 500 or fewer waste tires at a given time, using a permit-by-rule arrangement. Mobile equipment operators need only notify the State of when and where they will be operating their equipment (64).

Advantages of these regulations are better control of processing operations, and disadvantages are the administrative costs to government and industry of these programs.

**c) Hauler Regulations.** Eleven States have passed regulations on tire haulers (12). These may include provisions such as a state-supplied identification number, and a requirement that only haulers with these ID numbers may take tires. Some states require that tire dealers, processors, and haulers all keep records of their shipments of scrap tires. Generally these records include a contact person, the name and address of the company receiving the tires, and the quantity of tires. This aids in both preventing illegal activity, and aids investigations once any laws have been disobeyed. Again, the balance is between the administative effort and cost by government and industry to maintain permitting and recordkeeping programs, weighed against the benefits they provide in encouraging and enforcing good tire management.

**Market Development Incentives**

At least twelve states have developed laws incorporating market development incentives for scrap tires. These fall into three categories: (1) rebates to tire recyclers and users of tires for fuel, (2) grants and loans to encourage businesses to recycle tires or use them for fuel, and (3) funds for testing innovative uses of scrap tires. Below, information is provided on the states that have instituted such programs, how the programs work, results, and advantages and disadvantages.

**a) Rebates for Tire Recycling and Energy Uses.** Oregon, in 1987, was the first state to establish a rebate program. Implementation began the following year (62). Wisconsin and Oklahoma have since passed similar legislation (12). Some of the money collected by the states for their scrap tire management programs is returned to entrepreneurs who are recycling tires or using them for energy recovery. At a minimum, reimbursement is made available at the rate of 1 cent per pound of tire used. This is equivalent to $20 per ton. Below, information on the administration of these programs, their results, and their advantages and disadvantages, is provided.

In all three programs, a portion of the money collected by the state is redistributed to users of tires. In Oregon and Wisconsin the state performs this role, and in Utah the funds are distributed through the local Boards of Health.

Each state has somewhat different rules on who is eligible for reimbursement. The Oregon program provides rebates to end-users of tires, specifically recyclers and those utilizing tires as fuel. Certain uses of tires, such as retreading, and the use of rubber buffings from re-treads are not eligibIe for funding. Artificial reefs made from tires are eligible in protected coastal areas such as estuaries and bays, but not in the ocean. Some uses such as paving projects using crumb rubber from tires, are reimbursed at higher rates. This is because the state would like to encourage recycling, and because the rebate must be higher to offset the difference in cost to make the product using rubber compared to the competing conventional product.

The Wisconsin program provides rebates to end-users of scrap tire materials but not to processors. Processors may, however, benefit indirectly if the end-users can now afford to pay them more for the processed tire material. Like the Oregon program, rebates can be provided to out-of-state end-users that are using Wisconsin tires.

The Utah program provides rebates to end-users of tires, to tire processors, and to certain Utah haulers who are taking tires out of state for recycling or for energy recovery. Utah's legislation includes a sunset clause that ends the rebate program after five years (66).

An advantage of these rebate programs is that state governments can use them to directly encourage forms of tire recycling and disposal that they believe are most beneficial in helping to manage tires entering the waste stream and in cleaning up tire piles. Representatives from both Oregon and Wisconsin state governments report that the rebate systems have been very successful in encouraging additional companies to start using scrap tires, especially for use as fuel. They believe the rebates have made a strong contribution to the success of their scrap tire management programs (65, 66). It is too early for evaluations of Utah's program because the legislation was passed in 1990.

Some argue that a disadvantage of these programs is that many of the companies receiving the rebates would be using the tires regardless of any rebates. In addition, in states in which processors are not eligible for rebates, some processors have asserted that they should be allowed to receive rebates. The Wisconsin system, in which out-of-state end-users can receive rebates for Wisconsin tires, have caused some difficulties for nearby states. Some of the processors in nearby states prefer to utilize Wisconsin tires rather than tires from their own state.

Another disadvantage is that at the outset, these programs can be controversial. After such legislation has passed, it takes some time to build up funds for rebates, meanwhile entrepreneurs may be stockpiling tires so that they can take advantage of the rebates once they start flowing. In addition, consumers may criticize a system in which recyclers and waste-to-energy companies are receiving rebates, while the consumers are paying $1 to $3 to accept their scrap tires (66). Experience with Oregon's and Wisconsin's programs, however, show that these may be short-term disadvantages.

**b) Grants and Loans by State Governments.** At least twelve states have programs in which grants or loans are available to tire entrepreneurs and to others who would like to perform research or investigations into uses for tires, or who would like to start or expand businesses that utilize scrap tires. These programs may be specifically for scrap tires, or maybe part of larger recycling or solid waste management programs. As of May 1990, Minnesota, Illinois, New York, and Michigan had both grant and loan programs. In addition, Pennsylvania and New Jersey have a loan program, and Wisconsin has a grant program (67).

Provisions of these programs vary widely from state to state. Michigan's program can provide loans for market development research in recycling, as well as for product marketing of recycled materials. New Jersey also has financing available to recyclers. Higher loan limits are available for recycled plastic and tires than for other recycled materials (67).

Several states provide grants for feasibility studies to investigate recycling processes and methods, or for feasibility studies regarding new businesses. Grants range from 50 percent to 100 percent of the cost of these projects or studies (66).

As with any grant or loan program, advantages are that the government is helping businesses or other entities develop better ways to utilize tires and increase the number of tires that are recycled or utilized for their energy value. Disadvantages occur when grants or loans are provided to enterprises that could have succeeded without the extra help, or to enterprises that falter when the extra help is no longer available. The cost of administering grant and loan programs is also a disadvantage.

**c) Funds for Testing Innovative Uses of Scrap Tires.** Several states have set aside funds for research and development of innovative uses for scrap tires. A number of states, including Minnesota, Florida, New York, and Oregon, have been testing rubberized asphalt. Several states have been evaluating air emissions from the incineration of tire-derived fuel in facilities such as cement kilns, pulp and paper plants, and power plants for electricity generation.

### Regulations Regarding the Landfilling of Tires

Many states have passed laws regulating the landfilling of tires. Some states require that tires be split (Florida requires at least eight pieces) and other states require that tires be shredded before landfilling. The State of Ohio is considering tire monofills and monocells for shredded tires. As a practical matter, whole tires often are charged high fees at landfills, because operators find them difficult to handle. Therefore, even in states where landfilling of whole tires is allowed, the practice has been decreasing.

Advantages of regulations on landfilling tires are that they can make tire material easier to handle at landfills. These regulations also may discourage landfilling. This could spur the state and industry to develop and improve means of using waste tires, such as retreading, recycling, and tires-to-energy alternatives. However, if these alternate means do not become available soon enough, this may result in illegal dumping, or an increase in the export of tires to other states. It is, therefore, important not to restrict tire management options prematurely before there is adequate source reduction and utilization capacity.

## OTHER REGULATORY AND NON-REGULATORY OPTIONS

Following are additional regulatory and non-regulatory options which have been suggested to help mitigate the scrap tire problem. Some of these have been implemented and others are merely ideas under consideration by some tire or solid waste management experts from government or industry. The following topics are discussed below: (1) procurement strategies; (2) research; (3) grants and loans; (4) additional coordination among states; (5) education and promotion; (6) waste exchanges; (7) tradeable credits; and (8) tax incentives.

**Procurement Strategies**

The Resource, Conservation, and Recovery Act of 1976 (RCRA) mandated that EPA prepare guidelines for the purchase of retreaded tires for federal agencies and for agencies using Federal funds to procure supplies. The final rule was issued November 17, 1988 and became effective November 17, 1989. Since then the U.S. General Services Administration (GSA) has developed specifications for retreaded tires and has developed protocols for testing tires. Of 365 contract awards for supplying tires to the Federal government, 70 went to retread tire manufacturers.

On February 20, 1986, EPA proposed procurement guidelines for scrap rubber usage in asphalt; however, they were not made final because many state highway departments believed that not enough research had been completed at that point to justify promotion of this technology nationally through procurement guidelines.

Procurement guidelines for materials such as rubberized asphalt, products made from reprocessed rubber, and rubber railroad crossings are all potential means of helping to encourage these uses of scrap tires.

**Research**

Both the Federal government and states have sponsored research. Funding levels for Federal research on the waste tire problem have fluctuated widely over the past two decades. The Department of Energy (DOE) has also researched recycling of tires, incineration and pyrolysis. Pyrolysis in particular, received significant research funding in the 1970's, but the economics as yet have not been favorable for this technology to be commercially established in the United States.

Both the Federal Highway Administration, and in the 1970s, the EPA, have funded research on the use of rubber in pavements. Many states' highway departments have also funded research. A five-year research project, the Strategic Highway Research Program, is addressing the use of additives such as rubber from tires, in asphalt. This is a joint effort by the National Research Council, the Federal Highway Administration, and the American Association of State Highway and Transportation Officials.

Areas which appear ripe for further research include: (1) research on the use of crumb rubber in plastic and rubber products, (2) research on environmental emissions from tire incineration, and (3) research on rubberized asphalt.

Presently DOE is funding Air Products & Chemical Company for the development of a fluorine surface treatment of tire rubber (crumb rubber) to modify its adhesion properties. This modified rubber could be used in making polymers such as polyurethane and epoxies. The tire rubber might also be used in certain plastics such as polystyrene and PVC, and in rubber products (68).

EPA is currently collecting existing environmental emissions data from facilities incinerating tires for energy purposes. This information can be compared to data on emissions from these same facilities when using conventional fuels such as coal and hog fuel, Several states and industrial facilities have been conducting test burns of tire-derived fuel, to gather this environmental data.

Research on the use of crumb rubber in asphalt paving needs to be intensified and brought to a conclusion. Research on newer forms of rubber and asphalt mixtures, some without patent protection (thus available at lower cost), needs to be continued. Research on how asphalt-rubber and rubber modified asphalt concrete can best be recycled should be performed.

## Additional Coordination Among States and Localities

States and communities can work together to address tire problems. They can pool resources so that studies of the use of rubber in pavements, and studies of other uses of rubber from tires, could be performed on a larger scale leading to more useful results.

Tires tend to migrate to the least expensive use or disposal option. Neighboring jurisdictions can work together in planning their policies so that there are consistent economic incentives to send the tires to a location where they can be utilized, such as to a tire product facilit y, a tire-to-energy power plant, or a tdf production facility. This can help ensure the success of the facility. For instance, if one town has a tires-to-energy power plant, it may be counterproductive for a nearby city to set up a municipally subsidized landfill with a shredder that will accept tires at a lower tipping fee. In this case, most of the tires would gravitate toward the lower tipping fee and be landfilled, rather than go to the power plant to be utilized.

## Education and Promotion

Education and promotion is an important component of any program to alleviate the problems of waste tires. Audiences that may need to be informed about one facet or another of the scrap tire problem include individual citizens, environmental groups, tire dealers, corporations, those who are or would like to be involved in businesses related to scrap tires, potential users of scrap tire material, and representatives of local, state and Federal government.

It is particularly difficult to control the dumping of tires in sparsely populated areas, and special efforts may be needed to recognize the problems before they get out of hand. Waste tire dumps may be started on abandoned land and may accumulate thousands of tires before authorities become aware and are able to take action. Informed citizens and local police may be particularly helpful in spotting nascent illegal tire dumps.

Citizens can be educated regarding source reduction alternatives such as caring properly for tires and using retread tires. Both governments and companies operating fleets of vehicles can be encouraged similarly. Federal procurement guidelines for retreaded tires, described above, address this issue.

Tire dealers need ready access to information on reputable or licensed haulers, recyclers, or disposers of waste tires. They also need information on companies that sell used tires and that retread tires. Information on the location of large tire piles is helpful to entrepreneurs seeking to process these tires for eventual recycling or energy recovery.

Suppliers of scrap tire-derived products often need to educate themselves on the requirements of potential users of their products. For example, facilities that can use tire-derived fuel may need this fuel supplied with uniform, consistent quality. Producers and users of tdf need to work together to classify this material based on factors such as size of chips and quality of the cut. (i.e., Are there wires protruding from the rubber chips or is it clean-cut?) This information will help potential users be assured of quality supplies that will not damage equipment. This information in turn, aids in developing and expanding markets for tire-derived material.

Information on all potential uses of tires for recycled products and for fuel should be widely distributed. Dissemination of available data regarding environmental controls and emissions is also helpful in ensuring that industrial users of scrap tires implement environmentally sound practices.

Education and promotion may take several forms. Newsletters, fact sheets, hotlines and conferences on scrap tires can provide the most current formation on such topics as regulatory developments or new processes for utilizing tires. Computerized data bases, and clearinghouses, whether operated by government or by trade groups, are also helpful. These means of communicating are particularly important for scrap tires, as this field, like much of recycling, is changing quickly. Reports and studies can provide either broad overviews or more in-depth coverage of specific tire-related topics.

**Waste Exchanges**

Another means to aid recycling of tires and the utilization of tires as fuel is to expand the use of existing solid waste exchanges to include tires. Classified advertisements in magazines and newsletters can help those who have sources of tires to find users of tires. Appendix C provides a partial list of newsletters and magazines that may contain advertisements helpful to entrepreneurs dealing with scrap tires.

**Tradeable Credits**

Congress has been considering numerous pieces of legislation that pertain to the management of municipal solid waste. Some of these focus particularly on scrap tires. One innovative approach under discussion is a credit system. Manufacturers would only be allowed to produce a new tire if a given number of tires were recycled, processed, and/or burned for energy recovery.

Credits would be allocated as follows. One quarter credit could be granted for shredding one tire, or for burning a shredded tire. One-half credit could be granted for burning a whole tire. Three-fourths credit could be granted for reusing or recycling a shredded tire. Finally, one credit could be granted for reusing or recycling one whole tire (69). The Federal government would work with state governments to administer this program.

**Tax Incentives**

Tax incentives were utilized as part of the financing package to build the Modesto tires-to-energy power plant. Tax-free municipal bonds were issued to borrow money from investors to build the plant. Utilizing tax-free municipal bonds allowed borrowing the money at a lower interest rate.

Entrepreneurs are clearly responsive to tax incentives in building a major waste tire processing facility such as this one. If a state or local government deemed it especially desirable to site such a facility they could enact legislation to award appropriate tax breaks.

The utility buy-back rates paid to tires-to-energy facilities have an effect similar to tax incentives. The difference is that the money ultimately comes from the utility customers rather than the tax payers. No state has yet attempted to use state funding to subsidize tires-to-energy plants.

# Chapter 4

## CONCLUSIONS

Each year over 240 million tires are scrapped. Current trends indicate that about 6 percent of these tires are being recycled as products and 11 percent used as fuel. About 5 percent are exported. The rest are being landfilled, stockpiled, or dumped illegally.

The primary concern is to reduce the number of tires in uncontrolled stockpiles or illegal dumps. These tires are often sites of mosquito infestation, with the potential for spreading dangerous mosquito-borne diseases. Large tire dumps can also lead to fires with major releases of air pollution and hazardous organic chemicals into surface and groundwater.

Recycling rubber from tires for use in asphalt pavements is a promising technology. Asphalt pavements with rubber added are claimed to have twice the lifetime of ordinary asphalt, but they can cost twice as much. Pavements with crumb rubber additives consume over one million tires per year now, and both asphalt-rubber and rubber modified asphalt concrete have considerable potential for expansion. If Federal, state, and local governments promote much broader demonstration and use of this technology, perhaps the technical issues will be resolved and usage will expand.

Using whole tires as fuel for reciprocating grate power plants appears to be economically feasible in some situations and can meet environmental permitting requirements. One such plant in Modesto, California, is currently consuming 4.9 million tires per year. Another power plant is under construction in Connecticut and is expected to consume an additional 10 million tires per year. A second 10 million tire per year plant is being considered for an area near Las Vegas, Nevada. The main barriers to such plants appear to be local resistance to incineration projects and lengthy permitting procedures.

The replacement of coal by tire-derived-fuel appears economically feasible for cement kilns. Seven such kilns are currently operating in the U. S., consuming the equivalent of about 6 million tires per year between them. There is potential for this use to expand further, particularly for those cement kilns whose feed systems are compatible with the use of TDF.

Tire-derived fuel is economically feasible for use in hog fuel boilers in the pulp and paper industry. It is estimated that the equivalent of 12 million tires is consumed annually in this way in the U.S. There is potential for this use to expand further.

Other technologies and options are promising on a smaller scale, but also are important to the overall solution. Uses of crumb rubber for such diverse products as athletic surfaces, tracks, and garbage cans show potential for growth. Also, increased retreading could utilize about 20 million additional passenger and light truck tires each year, thus delaying their disposal. Current trends, however, indicate fewer of these tires are retreaded each year.

Other uses of tires can be important in certain geographic areas. Each year, Cape May County, New Jersey uses about 100,000 tires, which is 100 percent of its scrap tires, for artificial reefs. The State of Minnesota has used about a million of its scrap tires since 1986 for roads in swampy areas.

The markets for most other products made from tires have potential, but appear to be relatively small. These include rubber railroad crossings, artificial reefs, playground equipment, erosion control, highway crash barriers, playground gravel substitute, sludge composting, rubber parts for agricultural and fishing equipment, and rubber mats. Each of these products has the potential for using some portion of our waste tire stockpile. Collectively, they are all important parts of the solution to the tire problem.

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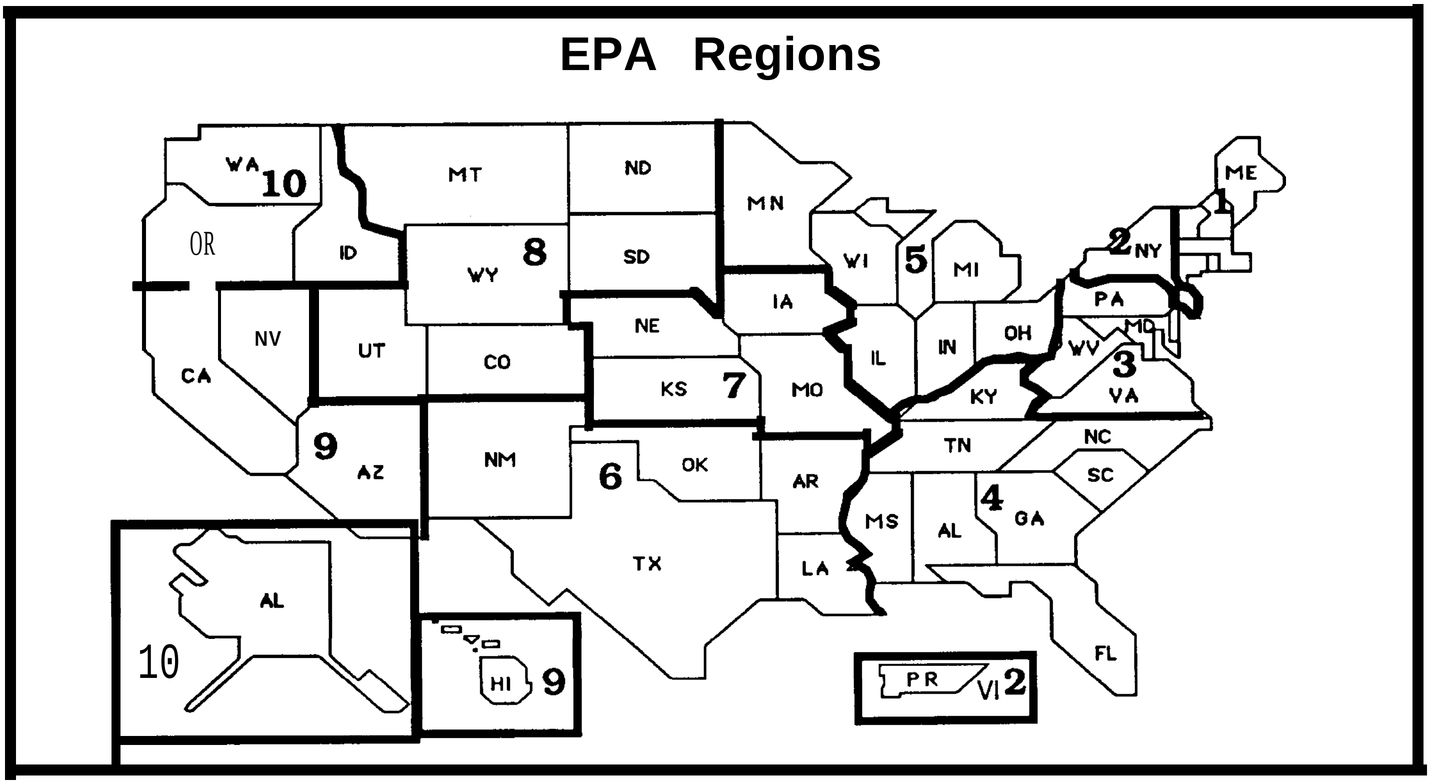
# APPENDICES

## Appendix A

### EPA REGIONAL OFFICES




**Region 1**

U.S. EPA - Region 1
J.F.K. Federal Building
Boston, Massachusetts 02203
Telephone: 617-565-3715

**Region 2**

U.S. EPA - Region 2
26 Federal Plaza
New York, New York 10278
Telephone: 212-264-2657

**Region 3**

U.S. EPA - Region 3
841 Chestnut Street
Philadelphia, Pennsylvania 19107
Telephone: 215-597-9800

**Region 4**

U.S. EPA - Region 4
345 Courtland Street, NE
Atlanta, Georgia 30365
Telephone: 404-347-4727

**Region 5**

U.S. EPA - Region 5
230 South Dearborn Street
Chicago, Illinois 60604
Telephone: 312-353-2000

**Region 6**

U.S. EPA - Region 6
First Interstate Bank Tower
1445 Ross Avenue
Dallas, Texas 75270-2733
Telephone: 214-655-6444

**Region 7**

U.S. EPA - Region 7
726 Minnesota Avenue
Kansas City, Kansas 66101
Telephone: 913-551-7000

**Region 8**

U.S. EPA - Region 8
Denver Place (81 lWM-RI)
999 18th Street, Suite 500
Denver, Colorado 80202-2405
Telephone: 303-293-1603

**Region 9**

U.S. EPA - Region 9
1235 Mission Street
San Francisco, California 94105
Telephone: 415-556-6322

**Region 10**

U.S. EPA - Region 10
1200 Sixth Avenue
Seattle, Washington 98101
Telephone: 206-442-1200

## Appendix B

## STATE CONTACTS FOR WASTE TIRE PROGRAMS

### ALABAMA

Jack Honeycut
Alabama Department of Environmental Management
Solid Waste Section
1751 Congressman W.L. Dickinson Drive
Montgomery, Alabama 36130
Telephone: 205-271-7761

### ALASKA

Glen Miller
Alaska Department of Environmental Conservation
P.o. Box O
Juneau, Alaska 99811-1800
Telephone: 907-465-2671

### ARIZONA

Barry Abbott
Arizona Department of Environmental Quality
Office of Solid Waste Programs
2005 North Central
Phoenix, Arizona 85004
Telephone: 602-257-2176

### ARKANSAS

Tom Boston
Arkansas Department of Pollution Control and Ecology
Solid Waste Division
P.O. BOX 9583
Little Rock, Arkansas 72209
Telephone: 501-570-2858

### CALIFORNIA

Bob Boughton
California Waste Management Board
1020 Ninth Street, Suite 300
Sacramento, California 95814
Telephone: 916-322-2674

## COLORADO

Pamela Harley
Colorado Department of Health
Hazardous Materials and Waste Management Division
4210 East 11th Avenue
Denver, Colorado 80220
Telephone: 303-331-4875

## CONNECTICUT

David Nash
Connecticut Department of Environmental Protection
Solid Waste Management Division
165 Capital Avenue
Hartford, Connecticut 06106
Telephone 203-566-5847

## DELAWARE

Richard Folmsbee
Delaware Department of Natural Resources and
Environmental Control
Division of Air and Waste Management
P.O. Box 1401
Dover, Delaware 19903
Telephone: 302-739-3820

## DISTRICT OF COLUMBIA

Joe O'Donnel
Recycling Department
2750 South Capitol St., SW
Washington, DC 20032
Telephone: 202-767-8512

## FLORIDA

Bill Parker
Department of Environmental Regulation
Office of Solid Waste - Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, Florida 32399-2400
Telephone: 904-922-6104

**GEORGIA**

Charles Evans
Georgia Department of Natural Resources
Industrial and Hazardous Waste Management Program
3420 Norman Berry Drive -7th Floor
Hapeville, Georgia 30354
Telephone: 404-656-2836

**HAWAII**

Al Durg
Department of Health and Environmental Quality
Solid and Hazardous Waste
5 Waterfront Plaza - Suite 250
Honolulu, Hawaii 96813
Telephone: 808-543-8243

**IDAHO**

Jerome Jankowski
Department of Health and Welfare
Division of Environmental Quality
Hazardous Materials Bureau
1410 North Hilton
Boise, Idaho 83706
Telephone: 208-334-5879

**ILLINOIS**
Chris Burger
Dept. of Environment and Natural Resources
325 West Adams - Room 300
Springfield, Illinois 62704-1892
Telephone: 217-524-5454

**INDIANA**

Timothy Holtz
Department of Environmental Management
Solid and Hazardous Waste Management
105 South Meridian Street
Indianapolis, Indiana 46225
Telephone: 317-232-7155

**IOWA**

Teresa Hay
Iowa Department of Natural Resources
Waste Management Authority
900 East Grand Avenue
Henry A. Wallace Building
Des Moines, Iowa 50319-0034
Telephone: 515-281-8941

**KANSAS**

Ashok Sunderraj
Kansas Department of Health and Environment
Bureau of Waste Management
Forbes Field
Topeka, Kansas 66620
Telephone: 913-296-1595

**KENTUCKY**

Charles Peters
Department of Environmental Protection
Division of Waste Management
18 Reilly Road
Frankfort, Kentucky 40601
Telephone: 502-564-6716

Randy Johann
Kentuckian Regional Planning and Development
11520 Commonwealth Drive
Louisville, Kentucky 40299
Telephone: 502-266-6084

**LOUISIANA**

Butch Stegall
Louisiana Department of Environmental Quality
Office of Solid and Hazardous Waste
P.O. Box 44066
Baton Rouge, Louisiana 70804-4066
Telephone: 504-342-9445

**MAINE**

General: Cliff Eliason; Enforcement: Terry McGovern
Department of Environmental Protection
Bureau of Solid Waste and Management
State House, Station 17
Augusta, Maine 04333
Telephone: 207-582-8740

Jody Harris
Recycling: Maine Waste Management Agency
Office of Waste Recycling & Reduction
State House Station No. 154
Augusta, Maine 04333
Telephone: 207-289-5300

**MARYLAND**

Muhamud Masood
Department of the Environment
Hazardous and Solid Waste Management Administration
2500 Broening Highway, Building 40
Baltimore, Maryland 21224
Telephone: 301-631-3315

**MASSACHUSETTS**

Jim Roberts
Department of Environmental Quality
Division of Solid Waste
1 Winter Street, 4th Floor
Boston, Massachusetts 02108
Telephone: 617-292-5964

**MICHIGAN**

Kyle Cruse
Department of Natural Resources
Resource Recovery Section
P.O. Box 30241
Lansing, Michigan 48909
Telephone: 517-373-4738

**MINNESOTA**

Tom Newman
Pollution Control Specialist
Minnesota Pollution Control Agency
Waste Tire Management Unit
520 Lafayette Road
St. Paul, Minnesota 55155
Telephone: 612-296-7170

**MISSISSIPPI**

Bill Lee
Department of Environmental Quality
Office of Pollution Control
Division of Solid Waste Management
P.O. Box 10385
Jackson, Mississippi 39209
Telephone: 601-961-5171

**MISSOURI**

Jim Hull
Department of Natural Resources
Waste Management Program
P.O. Box 176
Jefferson City, Missouri 65102
Telephone: 314751-3176

**MONTANA**

Tony Grover
Department of Health and Environmental Sciences
Solid and Hazardous Waste Bureau
Room B-201, Cogswell Building
Helena, Montana 59620
Telephone: 406-444-2821

**NEBRASKA**

Dannie Dearing
Department of Environmental Control
Land Quality Division
P.O. Box 98922
Lincoln, Nebraska 68509-8922
Telephone: 402-471-4210

**NEVADA**

John West
Division of Environmental Protection
Bureau of Waste Management
123 West Nye Lane - Capitol Complex
Carson City, Nevada 89710
Telephone: 702-687-5872

**NEW HAMPSHIRE**

William Evans
New Hampshire Department of Environmental Services
Waste Management Division
6 Hazen Drive
Concord, New Hampshire 03301
Telephone: 603-271-3713

**NEW JERSEY**

Joe Carpenter
Recycling Division
Department of Environmental Protection
Division of Solid Waste Management
850 Bear Tavern Road, CN 414
Trenton, New Jersey 08625-0414
Telephone: 609-530-4001

**NEW MEXICO**

Marilyn G. Brown
Health and Environmental Department
Solid and Hazardous Waste Management Program
1190 St. Francis Drive
Santa Fe, New Mexico 87503
Telephone: 505-827-2892

**NEW YORK**

Ben Pierson
Division of Solid Waste
Department of Environmental Conservation
50 Wolf Road
Albany, New York 12233
Telephone: 518-457-7337

**NORTH CAROLINA**

Jim Coffey, Dee Eggers (technical assistance)
Department of Environment, Health, and Natural Resources
Solid Waste Management Division, Solid Waste Section
P.O. BOX 27687
Raleigh, North Carolina 27611-7687
Telephone: 919-733-0692

## NORTH DAKOTA

Steve Tillotson
State Department of Health
Division of Waste Management & Special Studies
P.O. Box 5520
Bismarck, North Dakota 58502-5520
Telephone: 701-224-2366

## OHIO

Natalie Farber
Ohio Environmental Protection Agency
Division of Solid &Hazardous Waste Management
1800 Watermark Drive
Columbus, Ohio 43266-0149
Telephone: 614-644-2917

## OKLAHOMA

Kelly Dixon
Oklahoma State Department of Health
Waste Management Service
P.O. Box 53551
Oklahoma City, Oklahoma 73152
Telephone: 405-271-7159

## OREGON

Deanna Mueller-Crispin
Department of Environmental Quality
Hazardous & Solid Waste Division
811 SW Sixth
Portland, Oregon 97204
Telephone: 503-229-5808

## PENNSYLVANIA

Jay Ort
Department of Environmental Resources
Bureau of Waste Management
P.O. Box 2063, Fulton Building
Harrisburg, Pennsylvania 17105-2063
Telephone: 717-787-1749

## RHODE ISLAND

Victor Bell
Office of Environmental Coordination
83 Park Street
Providence, Rhode Island 02903
Telephone: 401-277-3434

Adam Marks
Central Landfill
65 Shun Pike
Johnson, Rhode Island 02919
Telephone: 401-942-1430

## SOUTH CAROLINA

John Ohlandt
Charleston County Health Department
334 Calhoun Street
Charleston, South Carolina 29401
Telephone: 803-724-5970

## SOUTH DAKOTA

Terry Keller
Department of Water and Natural Resources
Office of Solid Waste
Room 222, Foss Building
523 East Capital
Pierre, South Dakota 57501
Telephone: 605-773-3153

## TENNESSEE

Frank Victory
Department of Health and Environment
Division of Solid Waste Management
Customs House, 4th Floor
701 Broadway
Nashville, Tennessee 37247-3530
Telephone: 615-741-3424

## TEXAS

L.D. Hancock
Department of Health
Permits & Registration Division
Division of Solid Waste Management
1100 West 49th Street
Austin, Texas 78756-3199
Telephone: 512-458-7271

Donald O'Connor
Texas State Department of Highways and
Public Transportation
Materials and Testing Division
125 East 11th Street
Austin, Texas 78701
Telephone 512-465-7352

**UTAH**

Dorothy Adams
Salt Lake City County Health Department
Sanitation & Safety Bureau
610 South 200 East
Salt Lake City, Utah 84111
Telephone: 801-534-4526

**VERMONT**

Eldon Morrison
Agency of Natural Resources
Department of Environmental Conservation
Waste Management Division
103 South Main Street, Laundry Building
Waterbury, Vermont 05676
Telephone: 802-244-7831

**VIRGINIA**

R. Allan Lassiter, Jr.
Division of Recycling & Litter Control
Department of Waste Management
101 North 14th Street
James Monroe Building, 11th Floor
Richmond, Virginia 23219
Telephone: 804-786-8679

**WASHINGTON**

Dale Clark
Department of Ecology
Solid and Hazardous Waste Management Program
Mail Stop PV-11
Olympia, Washington 98504-8711
Telephone: 206-459-6258

**WEST VIRGINIA**

Paul Benedun
Department of Natural Resources
Division of Waste Management
1456 Hansford Street
Charleston, West Virginia 25301
Telephone: 304-348-6350

**WISCONSIN**

Paul Koziar
Department of Natural Resources
Bureau of Solid & Hazardous Waste Management
101 South Webster Street
Madison, Wisconsin 53707
Telephone: 608-267-9388

**WYOMING**

Timothy Link
Department of Environmental Quality
Solid Waste Management Program
122 West 25th Street
Herschler Building, 4th Floor
Cheyenne, Wyoming 82002
Telephone: 307-777-7752

# Appendix C

## ADDITIONAL SOURCES OF INFORMATION ON SCRAP TIRES

### Newsletters and Magazines

Crain Communications, Inc.
**Rubber and Plastic News**
1725 Merriman Road, Suite 300
Akron, Ohio 44313
Telephone 216-836-9180

Crain Communications, Inc.
**Tire Business**
1725 Merriman Road, Suite 300
Akron, Ohio 44313
Telephone: 216-836-9180

National Solid Wastes Management Association
**Recycling Times**
1730 Rhode Island Avenue, NW - Suite 1000
Washington, DC 20036
Telephone 202-861-0708

National Solid Wastes Management Association
**Waste Age**
1730 Rhode Island Avenue, NW - Suite 1000
Washington, DC 20036
Telephone: 202-861-0708

National Tire Dealers & Retreaders Association, Inc.
**Dealer News**
Suite 400, 1250 "I" Street, N.W.
Washington, D.C. 20005-3989
Telephone: 202-789-2300, 800-87N-TDRA

Old House Journal Corp.
**Garbage**
435 Ninth Street
Brooklyn, New York 11315
Telephone: 718-788-1700

Recycling Research Institute
**Scrap Tire News**
133 Mountain Road
Suffield, Connecticut 06078
Telephone: 203-668-5422

Resource Recycling, Inc.
**Resource Recycling**
1218 NW 21st Street
Portland, Oregon 97210
Telephone: 503-227-1319

**Trade Associations**

American Retreaders' Association, Inc.
P.O. Box 17203
Louisville, Kentucky 40217
Telephone: 502-367-9133

Asphalt Rubber Producer's Group
3336 North 32nd St. - Suite 106
Phoenix, Arizona 85018
Telephone 602-955-1141

National Asphalt Paving Association
5100 Forbes Boulevard
Lanham, Maryland 20706-4413

National Tire Dealers and Retreader's Association
1250 I Street, NW
Washington, DC 20005
Telephone: 202-789-2300

Rubber Manufacturer's Association
1400 K Street, NW
Washington, DC 20005
Telephone 202-682-4800

Scrap Tire Management Council
1400 K Street, NW
Washington, DC 20005
Telephone: 202-408-7783

Tire Retread Information Bureau
P.o. Box 374
Pebble Beach, California 93953
Telephone 408-625-3247

**United States Government**

Federal Highway Administration
400 7th Street, SW
Washington, DC 20590
Telephone: 202-366-0660

RCRA Information Center
Office of Solid Waste (0S-305)
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

RCRA/Superfund Hotline
Telephone: 800-424-9346

Small Business Administration
1441 L St., NW
Washington, DC 20416
Telephone 202-653-6567

U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585
Telephone 202-586-5000