June 1987

DOE/IR/05106--T83
DE/86-307

DISPOSAL TECHNIQUES WITH ENERGY RECOVERY FOR SCRAPPED VEHICLE TIRES

DOE/IR/05106--T83

DE89 013847

Energy Task Force
of the Urban Consortium
for Technology Initiatives

DISCLAIMER

FG02-78IR05106

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PREFACE

The Urban Consortium for Technology Initiatives was formed to pursue technological solutions to pressing urban problems. The Urban Consortium conducts its work program under the guidance of Task Forces structured according to the functions and concerns of local governments. The Energy Task Force, with a membership of municipal managers and technical professionals from eighteen Consortium jurisdictions has sponsored over 120 energy management and technology projects in thirty-four Consortium member jurisdictions since 1978.

To develop in-house energy expertise, individual projects sponsored by the Task Force are managed and conducted by staff of participating city and county governments. Projects with similar subjects are organized into *Units* of four to five projects each, with each Unit managed by a selected Task Force member. A description of the Units and projects included in the Seventh Year (1985-86) Energy Task Force program follows:

UNIT -- LOCAL GOVERNMENT OPERATIONS

Energy used for public facilities and services by the nation's local governments totals about 1.5 quadrillion BTU's per year. By focusing on applied research to improve energy use in municipal operations, the Energy Task Force helps reduce operating costs without increasing tax burdens on residents and commercial establishments. This Seventh Year Unit consisted of five projects:

- **Baltimore, Maryland** -- *The Activated Sludge Oxygen-Air Aeration Process: Improved Technology for Wastewater Treatment Efficiency*
- **Boston, Massachusetts** -- *Ground Source Heat Pumps for Commercial Application in an Urban Environment*
- **Detroit, Michigan** -- *Computer Assisted Control for a Municipal Water Distribution System: Phase II - Testing and Implementation*
- **Kansas City, Missouri** -- *Water Supply System Energy Conservation through Computer Control*
- **Phoenix, Arizona** -- *Energy Use Reduction through Wastewater Flow Equalization*

UNIT -- COMMUNITY ENERGY MANAGEMENT

Of the nation's estimated population of nearly 240 million, approximately 60 percent reside or work in urban areas. The 543 cities and counties that contain populations greater than 100,000 consume 50 quadrillion BTU's annually. Applied research by the Energy Task Force helps improve the economic vitality of this urban community by aiding energy efficiency and reducing energy costs for the community as a whole. This Year Seven unit consisted of four projects:

- **Memphis, Tennessee** -- *Technology Transfer for Energy Management in Cooperation with Regional Energy Providers*
- **New Orleans, Louisiana** -- *An Incident Prevention and Response System for Hazardous Energy Resource Materials: Phase 2*
- **New York, New York** -- *A Management Approach for Reducing Business Energy Costs: Joint City/ Utility Actions*
- **San Antonio, Texas** -- *Neighborhood Energy Efficiency and Reinvestment*

UNIT -- ALTERNATIVE AND INNOVATIVE TECHNOLOGIES

Effective use of advanced energy technology and integrated energy systems in urban areas could save from 4 to 8 quadrillion BTU's during the next two decades. Urban governments can aid the capture of these savings and improve capabilities for the use of alternative energy resources by serving as test beds for the application of new technology. This Year Seven unit consisted of four projects:

- **Albuquerque, New Mexico** -- *On-Site Municipal Fuel Cell Power Plant: A Feasibility and Applications Guide*
- **Atlanta, Georgia** -- *Atlanta District Heating and Cooling Project*
- **Denver, Colorado** -- *Disposal Techniques with Energy Recovery for Scrapped Vehicle Tires*
- **Philadelphia, Pennsylvania** -- *High Efficiency Gas Furnace Modifications for Low-Income Residents*

UNIT -- PUBLIC/PRIVATE FINANCING AND IMPLEMENTATION

City and county governments often have difficulty in carrying out otherwise sound energy efficiency or alternative energy projects due to constraints in the acquisition of initial investment capital. Many of these constraints can be overcome by providing means for private sector participation through innovative financing and financial management strategies. This Year Seven Unit consisted of five city/county projects plus a combined effort supported by USHUD to define effective strategic planning guidelines:

- **Chicago, Illinois** -- *A Neighborhood Energy Conservation Program: Phase 2*
- **Columbus, Ohio** -- *Development of a District Heating System: Organizational and Financial Strategies*
- **Hennepin County, Minnesota** -- *Technology Transfer for Residential Energy Programs in New Construction and Existing Housing* (Joint project with St. Louis)
- **St. Louis, Missouri** -- *Technology Transfer for Residential Energy Conservation in New Construction and Existing Housing* (Joint project with Hennepin County)
- **San Francisco, California** -- *A Commercial Building Energy Retrofit Program*
- **Public Technology, Inc.** -- *The Hidden Link: Energy and Economic Development -- Phase I: Strategic Planning*

Reports from each of these projects are specifically designed to aid the transfer of proven experience to staff of other local governments. Readers interested in obtaining any of these reports or further information about the Energy Task Force and the Urban Consortium should contact:

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FOREWORD

This report documents a study by the Environmental Services group of the Wastewater Management Division, Department of Public Works, City and County of Denver. Project staff included Dr. E. K. Demos who served as project director, Dr. Thomas Sladek who served as project manager and principal investigator and prepared this report, Margaret Smith who provided valuable clerical support, and Eric Howard who provided administrative assistance. Richard Cohen, P.E. was project director during the program's early stages. Technical and financial support from the Energy Task Force of the Urban Consortium for Technology Initiatives and the U. S. Department of Energy is acknowledged with appreciation. The numerous other individuals who contributed to the project are acknowledged in the Appendix.

CONTENTS

CONTENTS (Continued)

TABLES

CHAPTER 1
OVERVIEW

OBJECTIVES AND METHODOLOGY

Denver's stockpile of some 8 million old tires covers part of a Superfund site that is being evaluated by the U.S. Environmental Protection Agency (EPA). The City has been asked to move the tires, in order to facilitate the site evaluation and any future cleanup operations. Denver's objectives in the current project were (1) to find a safe, economical removal and disposal method, (2) to identify policies that could help avoid further problems, and (3) to share the findings with other cities that have problems with tires.

Achieving these objectives involved five major tasks. In Task 1: Define Resources & Recovery Options, the extent of the national scrap tire resource, and the issues associated with it, were identified. Management options were also characterized with respect to their status, potential, and limitations. In Task 2: Screening Studies, these options were assessed to identify those with potential to help Denver deal with its stockpile. In Task 3: Case Studies, the most promising options were further evaluated and were ranked based on their requirements and effects. Public policies required to support their implementation were also examined.

In Task 4: Transfer, the findings were transferred to other jurisdictions through a workshop held in Denver in February 1987. Task 5: Management & Reporting covered project management activities and the preparation of interim and final reports.

FINDINGS

The Tire Problem

Approximately 170 million tires are discarded in the United States each year. These tires are difficult to landfill because they are bulky and they may float to the surface at some unpredictable point in the future. Most incinerators cannot accommodate large quantities of whole tires because they burn more slowly than normal refuse. Because of these problems, disposal facilities that do accept tires may charge fees that are much larger than those charged for other types of waste. As a result, illegal dumping is widespread, and many large stockpiles have developed. These stockpiles are subject to extremely destructive fires. They also harbor disease vectors such as mosquitoes. Safe and cost effective disposal methods are urgently needed, both for stockpiles and for tires that will be scrapped in the future. Several states are currently regulating disposal practices by banning landfilling or using taxes to subsidize disposal or resource recovery programs. Additional policies are likely to emerge as the disposal problem becomes more serious.

The Management Options

Options include landfilling, retreading, use of whole or shredded tires in construction, shredding or chemical processing to recover materials, and energy recovery through pyrolysis or combustion. Tires can be **landfilled** safely if they are buried under large quantities of dense refuse or if they are first chopped or shredded to reduce their volume and to eliminate floating. However these handling and processing steps are expensive, and burial inhibits resource recovery. Although many old tires are suitable for **retreading,** the market for retreaded passenger tires is declining because new tires are so cheap. Tires can be used in the **construction** of breakwaters, crash barriers, and other facilities. However there are geographical, logistical, and environmental restraints and relatively few tires could be consumed. Tires can be shredded to produce **rubber chips** that can be used as soil conditioners or as bulking agents for sewage treatment, or **rubber crumbs** that can be used in asphalt rubber and new rubber goods. However the tire-derived materials would have to displace the low-cost materials currently used in these applications. These markets will remain small until tire processing costs decrease. **Chemical processing** to obtain reclaimed rubber is a traditional outlet for old tires. However many of the processes are antiquated and the industry has excess capacity.

With respect to energy recovery, **pyrolysis** is a very old but workable technology that can be economical if favorable markets are developed for the char and the liquid fuels that are recovered. Few **existing boilers** can burn whole tires. However some of the smaller power plants and steam stations can handle shredded rubber if some of the steel belts and bead wires are removed and if the boiler is equipped with adequate pollution controls. **Refuse incinerators** that can burn rubber offer an alternative to landfilling. Certain **cement kiln** technologies can be excellent markets for whole or shredded tires. However the fuel price must be low and a secure supply must be assured to encourage the operators to modify their equipment for tire burning. **Lime kilns** like those that serve the sugar industry have similar potential but are less common than cement kilns. Burning tires in **new boilers** also has potential if a large tire resource is available, if the energy product commands a high price, and if the plants can comply with environmental standards. Tire burning power plants are now being developed in California and the Northeast.

Potential Denver Solutions

Landfilling is technically feasible but expensive for Denver. At $1.09 each, whole tires are the most expensive to landfill because they occupy large volumes and are difficult to keep underground. Chopping a tire into two or more pieces reduces volume by about 50% and reduces disposal costs to $0.70. Shredding to obtain pieces smaller than 6 inches reduces volume by 80% and is most practical overall because haulage and burial costs are relatively small. The total disposal cost is $0.54 per shredded tire.

Retreading is not a practical outlet because many of the tires in the pile were put there after retreaders had found them unsuitable for further use. Retreaders can easily obtain an adequate supply of fresh carcasses from tire retailers at little or no cost.

Construction is not a practical solution because reefs and breakwaters are not needed in the Denver area, and only a few tires could be used in crash barriers and playground equipment. Some Denver tires are currently hauled to Mexico, where they are re-used or made into sandals. Although this will probably continue, the net effect on present and future scrap tires will be minimal.

Using **rubber chips** to compost sewage sludge has some promise, and using them as soil conditioners has greater potential, since many Rocky Mountain areas have highly compacted soils. Additional research is needed to determine if these applications are economical and environmentally acceptable. Scrap steel sales could help offset processing costs, although few of the stockpiled tires are steel belted and only the bead wires would be recoverable.

Asphalt rubber made with **rubber crumbs** could be cost effective in Denver's high traffic areas and on nearby mountain roads that are costly to maintain. Potential demand is very large, but the market would take years to develop. As with rubber chips, scrap steel sales would provide additional income.

Chemical processing is not a valid option for Denver. Local demand for reclaim is low and plants in other locations have excess capacity.

A **pyrolysis** plant might be economical if it could capture the stockpiled tires and most of the tires that will be discarded in the future. The liquid fuel products could be sold to nearby refineries. However the char would have to be shipped to more distant markets. Economic feasibility would be impeded by the currently low energy prices and the poor quality of the char. Airborne emissions could be a problem.

Existing combustors near Denver could consume all of the stockpiled tires plus all future discards. Shredding and transportation costs and the need to remove some of the steel from the shredded rubber could pose serious but manageable obstacles. Full implementation of this option could remove perhaps 100 tons of tires per day from the stockpile. At this rate, the stockpile would disappear in about 3 years.

The Denver area also has several **cement and lime kilns** that could burn rubber if it were offered at a favorable price. If tires provided 20% of the energy currently used to make cement, as much as 60 tons of tires per day could be drawn from the stockpile. At this rate, the pile would be depleted in about 5 years. Shredding costs could pose a formidable problem unless the kilns were modified to accept whole tires or coarse pieces. A long-term rubber supply would have to be guaranteed.

New boilers that burn only tires must be large to be economical, and they need high prices for their energy products. Denver's stockpile is too small to sustain a large facility, and the wholesale price for electric power is quite low. To be feasible, a new power plant would have to capture all future discards and to draw tires from other nearby stockpiles at little or no cost. The power would probably have to be sold in the retail market to produce sufficient revenues.

Summary Evaluation

Table 1-1 summarizes the characteristics of the possible solutions to Denver's tire stockpile problem. The parameters are defined below.

Setup Time -- the time between a decision to proceed and the commencement of tire disposal. Ratings range from zero for disposal options that could proceed without delay to -3 for options that would require long times to implement. As shown, Whole Tire Landfilling could proceed almost immediately, whereas New Boilers

Table 1-1: Summary Evaluation of the Tire Management Options for Denver

	EVALUATION CRITERIA *				
MANAGEMENT OPTION	SETUP TIME	CAPITAL COSTS	NET OPERATING COSTS	SOCIAL GAIN	NET RATING
ENERGY RECOVERY					
Existing Boilers or Lime Kilns	-2	-2	-1	3	-2
Cement Kilns	-2	-1	-1	3	-1
New Boilers	-3	-3	-1	3	-4
Pyrolysis	-3	-3	-1	3	-4
MATERIALS RECOVERY					
Rubber Chips	-2	-2	0	1	-3
Rubber Crumbs	-2	-2	-1	2	-3
LANDFILLING					
Whole Tires	-1	-1	-3	-1	-6
Chopped Tires	-2	-2	-2	0	-6
Shredded Tires	-2	-2	-1	0	-5

* See text for definitions of criteria and rating methodology.

Source: City of Denver

and Pyrolysis could need 3 years or more for design, permitting, construction, and startup. The other options would require intermediate times to acquire specialized equipment such as shredders.

Capital Costs -- initial investment to procure equipment, facilities, and financing and to cover startup costs. Ratings range from zero for options with minimal investment requirements to -3 for the most costly alternatives. As shown, New Boilers and Pyrolysis are the most expensive. Whole Tire Landfilling and the Cement Kiln market cost the least because they need relatively little equipment. Existing Boilers and Lime Kilns cost more than Cement Kilns because magnetic separators and more shredders would be required. The other options have similar ratings, largely because they would need similar types of hardware.

Net Operating Costs -- costs of operations less revenues from materials or energy sales. Ratings range from zero for options that would break even or show a modest profit without a disposal charge, to -3 for those that would require a large tire tipping fee to cover expenses. The Landfilling options have high net costs because there are no revenues to offset the burial fees. The Energy Recovery options all have positive net costs, indicating that a tire disposal fee would be needed to balance cash flows. Only for Rubber Chips are revenues expected to just about balance expenses.

Social Gain -- contribution to development of a substantial, long-term, and beneficial solution to the tire problem. Ratings range from -1 for options that would accomplish only tire disposal without otherwise benefiting society, to +3 for those that convey substantial benefits. The Landfilling options have low ratings because no resources would be recovered and landfill space would be depleted. Whole Tire landfilling is rated especially low because of the flotation problem. The Rubber Chips option has a low rating because the market would be modest and could be slow to develop. Rubber Crumbs is rated higher because the market potential is relatively large. The Energy Recovery options all have high ratings.

Summing the ratings yields the following very approximate rank ordering of the disposal options:

1. Supplemental fuel for cement kilns
2. Supplemental fuel for existing boilers and lime kilns
3. Recovery of rubber crumbs or chips
4. Construction of new boilers or pyrolysis plants
5. Landfilling shredded tires
6. Landfilling whole or chopped tires.

CONCLUSIONS

The scrap tire disposal problem is serious and widespread. However there are a number of promising management options, especially using the rubber as a supplemental fuel for existing combustors. The most cost-effective approach to dealing with Denver's tire stockpile appears to be shredding to a coarse size range, storing the shreds in a secure area, and marketing the rubber to nearby cement kilns, lime kilns, and boilers. This interim step would greatly reduce the volume of the pile, facilitate the Superfund evaluation, reduce fire and disease hazards, and simplify subsequent materials handling. Further processing to obtain rubber chips or crumbs may also be practical. However the industry and the markets would have to emerge over time. New power plants or pyrolysis facilities would be impeded by the low energy prices in Denver and the need for elaborate pollution controls. Landfilling could be considered as a last resort. Landfilling costs would be minimized if the tires are shredded.

REPORT ORGANIZATION

Chapter 2: Background Information discusses the tire disposal problem and the general options for tire management. Included are the major findings of the literature review, brief descriptions of tire processing technologies, descriptions of related work in the U.S. and abroad, examination of the incentives and impediments to the recovery of energy and materials from tires, and discussion of existing state-level policies and programs.

Chapter 3: Project Description describes the methodology used to analyze Denver's situation and presents the results and conclusions obtained. This includes evaluation of strategies to implement the more promising resource recovery options in the Denver area.

Chapter 4: Summation and Suggestions summarizes the lessons learned and identifies impediments and uncertainties that need to be addressed in any future studies. The Appendix contains additional acknowledgements, a list of references, definitions for the acronyms and units used in the text, the agenda for the tire workshop, and a brief description of a stockpile fire near Denver in June 1987.

CHAPTER 2
BACKGROUND INFORMATION

THE SCRAP TIRE PROBLEM IN THE UNITED STATES

Scrap tire management was a relatively minor problem when rubber was scarce and tires were expensive. During World War II, for example, 60% of the used tires were recycled, and most were retreaded several times before the casings were finally discarded. In the early 1950s, the U.S. rubber recycling industry produced about 350,000 tons of product, representing 22% of the total rubber consumed at that time. By 1980, however, only one tire maker had a reclaiming operation, and recyclers produced only 120,000 tons of rubber, or 3-1/2% of the U.S. rubber supply.[1] Today, the rubber industry has excess capacity and prices are low, both for tires and for the raw materials from which they are manufactured. There is a shortage of viable recycling and resource recovery options, and tires present a major waste management problem.

The problem has been illustrated by one casing supplier who obtains traded-in tires from dealers and either sells them or delivers them to a disposal site.[2] In a typical batch of trade-ins, 10% can be sold as used tires and 20% are high quality retreadable casings. The remaining 70% are discarded because they are unusual sizes or are too worn for retreading. In previous years, the supplier would donate his discards to a convenient field or to the waste bin of a neighborhood grocery store in the early morning hours. Now "there aren't enough dumpsters in Orlando" to handle the 700 rejects that his firm produces each day.

This experience is echoed nationwide. Approximately 200 million passenger tires and 40 million truck tires are discarded annually in the United States--an average of one per person per year. Most are recovered by auto wreckers or turned in to dealers when replacement tires are purchased. The geographical distribution is roughly the same as the population, and nearly all tires are disposed of within 200 miles of their collection point. Fewer than 30% are re-sold, retreaded, or reclaimed for other uses. The other 170 million tires enter the waste stream.

Although tires constitute only about 1% of the total solid waste generated in the United States, they present an unusually challenging disposal problem because of their size, shape, and physical and chemical properties. Tires are expensive to bury in conventional landfills because the carcasses occupy large volumes. Landfilling is also risky because carcasses trap air and landfill gases and tend to float in the soil, emerging through the surface at some unpredictable point in the future. Tires can be a useful supplemental fuel in some refuse incinerators. However many plants cannot accommodate large quantities of whole tires because they burn hotter but less quickly than normal refuse. Slicing or shredding reduces tire volume, eliminates the floating problem, and makes the rubber more suitable for incineration. However the processing equipment is expensive to buy and operate.

Because of these problems, landfilling of whole tires has been banned in several states, and some even prohibit land disposal of shredded rubber. Landfills that do accept tires may charge fees that are much larger than those charged for other types of waste. As a result, illegal tire dumping is widespread, and large stockpiles have developed in many areas. The total number of tires now in storage has been estimated at 2 billion, and many of the stockpiles are growing rapidly. A survey for the U.S. Department of Energy (DOE) in 1983 indicated that Denver's stockpile of some 8 million tires was the second largest in the country, trailing a pile of 14 million tires in California. Denver's pile has not grown since then, but the California pile now contains 38 million tires and is increasing by about 20,000 tires per day. Another stockpile northeast of Denver had about 600,000 tires in 1983. It now has 6 million, is still growing, and may soon surpass the Denver pile.

Improperly managed tire stockpiles present severe risks to the physical environment and to public health. One concern is the fire danger. Although tires do not ignite spontaneously, there is a slight potential for ignition by lightning. The risk of arson is much greater, since most of the piles are in rural areas where security is difficult and expensive to maintain. Once established, a stockpile fire is very hard to extinguish because the pile is interconnected with countless passageways that carry combustion air to the burning area.

Stockpile fires release noxious smoke and toxic gases and can contaminate soils and groundwater with organic chemicals. Water is usually ineffective unless the entire pile can be flooded. Furthermore, water flowing from the burning area can transport pollutants offsite and speed their penetration into soils and aquifers. Foam has been used successfully but it is expensive and only works if the fire is attacked during its early stages. Burial works if the tires are in pits and enough dirt can be relocated to completely smother the pile.

These lessons have been well demonstrated in a number of locations.[3,4] A fire in Waterbury, Connecticut burned for 3 weeks and consumed approximately 1 million tires, despite the state's existing guidelines to regulate storage of tires and other bulky wastes. Virginia has been particularly troubled with stockpile fires. In 1984, a fire in Winchester burned for 9 months and cost $1.3 million to contain. In 1985, a fire at a Norfolk landfill consumed approximately 5 million tires. In 1986, a fire in Walkerton burned more than 5 acres of tires. A fire in Everett, Washington burned for weeks and was very costly to contain. A 500,000 tire stockpile near Philadelphia caught fire in 1986 and burned for 21 hours before it was extinguished by 300 firefighters and 3 million gallons of water. Soot and pyrolysis oils contaminated the soils under the pile, nearby residences, and the firefighters. A expensive cleanup process has begun. Arson is suspected. In late 1986, a fire in St. Croix County, Wisconsin consumed 2 to 3 million tires despite a county ordinance prohibiting the storage or disposal of whole tires. Fire crews allowed the fire to burn itself out, rather than to use water and increase the danger of contaminated runoff. Again, arson is suspected. Serious stockpile fires have also occurred in Danville and Allenstown, New Hampshire; Pontiac and Detroit, Michigan; Humble and Port Arthur, Texas; Louisville, Kentucky; Freetown, Massachusetts; Ogden, Utah; and elsewhere.

Shredding reduces the fire hazard and makes fires easier to control, but it does not eliminate the problem. This was demonstrated near Baltimore in February 1987 when a fire occurred in a pile of shredded rubber chips obtained from tires. The fire was initially extinguished but the pile later re-ignited after the fire crews had left the site. Arson is suspected.[5]

Tire piles can also harbor disease vectors, especially mosquitoes. Rain water trapped in tire casings provides an ideal breeding environment for at least a dozen species of mosquitoes, some of which can breed 4,000 times faster in tire piles than in forests.[6] Some mosquito species can transmit serious illnesses such as yellow fever, dengue, and several forms of encephalitis. Tires are the most favorable egg-laying site for the mosquito *Aedes aegypti* which has been linked to yellow fever and dengue epidemics in the United States. Tires are also the most important means of dispersal for the Asian tiger mosquito *Aedes albopictus*. This aggressive species also transmits dengue and yellow fever and is partially resistant to the common insecticide malathion.[7] It is cold-adapted and can survive winter weather in the northern states. In Asia, the tiger mosquito extends as far north as Beijing, China, which is at the approximate latitude of Philadelphia and Denver.[8]

The tiger mosquito is believed to have entered the U.S. very recently, in truck tire casings that were imported for recapping. It is now widely dispersed and has been found in tire piles throughout the southeastern and central states and as far north as northern Ohio. A survey conducted in Harris County, Texas in 1985 found tiger mosquitoes in 56% of the 163 tire dumps that were inspected. Infestations have also been found in 10 other Texas counties, as well as in Louisiana, Mississippi, Tennessee, and Florida.[9] The Ohio Department of Health discovered that 80% of children infected with La Crosse virus lived within 80 yards of tire piles. La Crosse is a form of encephalitis that is transmitted by mosquitoes and affects only children. Another recent survey has confirmed the presence of tiger mosquitoes in northern areas of the Ohio-Mississippi Valley, an area in which La Cross encephalitis is known to be endemic.[10,11]

The danger of additional infestation is increasing because truck tire recapping is a growing industry and the importation of used casings from other countries is a common practice. In 1970, U.S. firms obtained some 200,000 recappable casings from Japan, Korea, Taiwan, and other areas where the tiger mosquito is indigenous. By 1985, imports from these areas had reached 2.8 million per year.[12] The vector may be spread to other countries when the retreaded tires are shipped abroad. Major importers of U.S. tires include Mexico, Venezuela, Saudi Arabia, and the Dominican Republic. These countries may not now have a tiger mosquito problem, but one may arise unless the vector is somehow controlled in tire piles both in the United States and in the nations that export used casings.[13-15]

THE MANAGEMENT OPTIONS

Tire manufacturing is a sophisticated technology with highly specialized raw materials and carefully controlled production methods. The principal ingredient in tires is rubber, either virgin natural rubber, or virgin synthetic rubber, or recycled rubber that is reclaimed from old tires and other wastes. Tires also contain woven rubber-impregnated sheets of polyester, nylon, rayon, or aramid fibers; belts of steel or fiberglass mesh; and hoops of steel bead wire.

The rubber that is used in tires contains various compounding ingredients to improve hardness, strength, and toughness and to increase resistance to abrasion, oil, oxygen, chemical solvents, heat, and cracking. These include:

- Sulfur which binds the rubber molecules together.

- o Softeners, plasticizers, and accelerators that expedite the manufacturing process and improve physical properties. Included are white lead, lead monoxide, zinc oxide, lime, magnesia, organic acids, oils, tars, and rosin.
- o Reinforcing agents that toughen the rubber and add strength and resistance to wear. Carbon black is the most common. Zinc oxide, silica, clays, and carbonates are also used.
- o Pigments that impart color. In tires, these include zinc oxide, titanium oxide, and zinc sulfide.

Different combinations of these chemicals are used to produce rubber with specific physical and chemical properties. Rubber for tire sidewalls, for example, contains chemicals that enhance flexibility and resistance to cracking. Rubber for tire treads has a different formula that produces high resistance to abrasion and heat.

Most tires are built by hand, in layers, on the outer surface of a cylindrical drum. First a thin rubber liner is applied. Then several layers of rubber-impregnated fabric or steel mesh are added. Then a thick layer of treadstock is applied to the middle of the cylinder, and the sidewall stock and the bead wires are added to the outer edges. The resulting cylinder is compressed in a mold to a tire-like shape. The mold is heated with steam to induce the vulcanization reaction that forms strong sulfur bonds between the rubber molecules. The tire is then cooled, inspected, and shipped to a tire dealer or vehicle manufacturer.

These materials and methods are designed to produce durable tires. Unfortunately this same durability makes disposal very difficult, since it affects the costs of preparing tires for landfilling or resource recovery and the costs of controlling the pollutants that are produced when tires are heated or burned. The disposal options, as discussed below, include specialized landfilling techniques, increased re-use or retreading, use of whole carcasses in specialized construction, physical processing to recover recyclable materials, chemical reclamation of recyclable rubber, pyrolysis to obtain liquid fuels and a carbonaceous char, and combustion in existing boilers and kilns or in new boilers designed for tire fuels. All of these options are affected in one way or another by the chemistry and ruggedness of the typical tire.

Landfilling

Landfilling whole tires is expensive because they occupy large volumes. It is also risky because tires trap air and landfill gases and tend to float in the soil. Unless the tires are carefully buried under large quantities of dense refuse, they may eventually emerge through the surface of the fill. This can be annoying while the landfill is still operating. It can be catastrophic after operations have ceased and the disposal cells have been capped as part of the closure procedure. A landfill cap ruptured by a floating tire must be repaired rapidly to prevent precipitation from reaching the refuse and increasing the rate of leachate production. These costly repairs must be repeated until all of the tires have emerged. This may take many years if a large number were buried over a long period of time.

Some landfill operators claim that whole tires can be safely buried if special procedures are followed.[16] Waste Management of Colorado, for example, buries tires at the toe of its working face, at least 25 feet from the landfill boundaries and at least 10 feet below the final contours of the completed cell. Although this may end the floating problem, it does require special handling, which is reflected in the tipping fee. In 1982, Waste Management charged $1.80 per cubic yard to accept tires, which it stockpiled in anticipation of a shredding operation to conserve landfill space. Some 10,000 tires per week were delivered to the landfill under this fee schedule. When the fee was increased to $4.60 to raise funds for the shredder, the flow of tires dropped to less than 100 per week. The rest went to other landfills, to stockpiles, and to illegal disposal sites.

Waste Management has since buried its stockpile and now charges $7 per cubic yard for tires. This translates to roughly $92 per ton or about $0.90 per tire, since one cubic yard will contain approximately 7.6 whole tires and there are about 100 tires in a ton. The fee for normal municipal refuse delivered by private haulers is $11 per ton. A similar pattern is seen in other states.[17] In California, tipping fees for tires range from $35 to $80 per ton, while typical fees for refuse are $4 to $8 per ton. Landfill fees in eastern Virginia are $75 per ton for whole tires but less than $20 for refuse. Some landfills in Vermont charge as much as $6 per tire, which is about 20 times the rate for normal refuse. A landfill in Hampton, Virginia once charged $10 per ton for both tires and refuse. When the tire fee was raised to $75, the flow of tires dropped from 1,000 to 200 per month. As happened in Colorado, tires that would have been delivered at the former fee now go to other landfills or are discarded in stockpiles or illegal dumps.

A recent survey by the National Tire Dealers & Retreaders Association found that only 58% of landfills accept whole tires. About half of the others accept sliced or shredded tires, but few have equipment in place to process tires delivered to the landfill gate.[18] Tipping fees range from zero to more than $0.50 per tire and average $0.29 per tire.

Sliced or coarsely chopped tires occupy only about half the volume and will stay buried. Shredded tires occupy one-fifth of the original tire volume and they also will not float. However slicing, chopping, and shredding are all expensive, and burying the rubber precludes or at least inhibits resource recovery. Nevertheless, shredding tires for landfilling is technically feasible and can have a large impact on the problem of newly discarded tires. Tires that are to be landfilled are routinely shredded in Atlanta, Baltimore, Key West, Buffalo, and several cities in New England. Shredding is less attractive for old stockpiles, since there is no tipping fee to offset the costs. Shredding a large stockpile is also time consuming. Mobilizing equipment and crews may take several months, and several years may be needed to process and remove the rubber.

Retreading and Re-Use

About 10 to 30% of old tires can be re-used or retreaded, and retreading firms are a traditional outlet for used tires. However the market for retreaded passenger tires is declining, partly because the mandatory 55 mi/hr speed limit has extended the life of the average tire and partly because durable radial-ply tires have become very popular. In 1970, radial tires had less than 2% of the passenger tire replacement market and less than 1% of the original equipment market. In 1986, radials accounted for 85% of replacement tires and 100% of original equipment sales. The truck tire market has responded less quickly; however radials now constitute more than 55% of replacement truck tire sales.

Radial tires last much longer than more traditional bias-ply tires. This admirable property, coupled with lower highway speeds, has reduced the demand for replacement tires and has fostered intense price competition among tire dealers. It has also forced tire manufacturers to drop the prices of their bias-ply tires--the main competitor for retreads. In 1985, the average bias-ply passenger tire cost only $13 more than a retread of the same size. This margin was insufficient to entice consumers to purchase the retreads.[19] Most retreading firms and retread dealers have experienced drastically reduced sales and many have left the business. As a result, more and more scrap tires are now sent directly to disposal, rather than to retreading companies.

Retreaders of the more expensive truck tires have been less impacted by the shrinking demand for replacement units, and the price differential between new and retreaded truck tires is still sufficient to encourage several cycles of retreading. However, truck tires are a relatively small portion of the disposal problem. The recent rise in highway speed limits may slightly increase the demand for replacement tires for both trucks and passenger vehicles. Also, the emergence of new materials and methods to produce retreaded radials may open new markets for the retreading industry. However the net impact on the scrap tire problem will be moderate at best. Even a very vigorous retreading industry would have no effect on the management of stockpiles, since most tires in these piles have already been examined, and rejected, by a casing supplier or retreader.

Construction

Using whole or cut tires in specialized construction offers a variety of opportunities. In coastal areas, whole tires can be bound together to form breakwaters and onshore revetments to protect vessels and shorelines from erosion and wave damage. Goodyear Tire Co. has tested the feasibility of these applications, plus that of banding together foam-filled tires to create floating breakwaters.[20] Tires also can be used to produce artificial reefs that foster plant and fish growth. An artificial reef is man-made or natural material placed in an aquatic environment to reproduce conditions that attract fish.[21] Such reefs are particularly effective where the bottom is soft sand that is not conducive to the attachment of algae, mussels, and other organisms that are the basis of the aquatic food chain. A reef provides a firm substrate on which these species can grow and where the fish that feed upon them can graze and hide. Japanese fisherman created artificial reefs from old boats in the 1700s. Since then, ships, car bodies, concrete rubble, wooden frames, and many other materials have been used. Tires have also been employed with considerable success in Japan, Australia, and the United States.

To build reefs, tires are ballasted with rock, or sliced or punched to release air, or bound together with wire, cable, chain, or strapping and then dumped into the water at selected locations. Within months, they provide suitable habitat for feeding and spawning fish without harmful effects on the environment. Some 2,000 tire reefs of various sizes have been installed worldwide, with at least 50 in place off Virginia, North Carolina, Florida, Maryland, and other coastal states. Maryland's reefs were developed over a 5-year period and now contain more than 500,000 tires. One of the largest reefs in the world is off Pinellas County, Florida. It contains more than 3 million tires. A more modest project in Oregon used 9,000 tires to build a reef in Tillamook Bay in 1976.[22]

There are numerous other applications.[23,24] For example, the California Department of Transportation uses whole tires to control sand drifts in desert areas, to rebuild highway shoulders in mountainous regions, to reduce erosion in drainage channels, to build retaining walls, and to anchor walls made of timber. A housing contractor in Vermont uses sliced or quartered tires as backfill around new foundations to improve drainage and avoid frost damage. Tire Playground of New Jersey has used whole tires to make equipment for more than 260 playgrounds. Each installation uses 250 to 400 truck tires. Assembly requires only drilling and bolting, and costs are said to be very low. Playtime Tires of Wisconsin converts 1,500 tires/yr into playground toys. Saf-T-Fence of New Jersey uses tires to make fences for livestock. Tire Mountain of Colorado markets used tires as feed hoppers for livestock. Tires can be used in crash barriers at bridge piers and freeway intersections. According to Goodyear Tire Co., such barriers can withstand 60 mi/hr collisions with relatively minor damage to the vehicle.[25] Tires can also be converted to furniture, planters, necklaces, teething rings for large domestic animals, scratching posts for pets, and buoys and other warning devices.

All of these applications have potential, but there are serious geographical, logistical, and economic limitations. For example, reefs and breakwaters are confined to coastal areas and large lakes, and they can be very expensive to build. The Pinellas County reef cost roughly $1.00 to $2.00 per tire, in 1978 dollars, plus transportation expenses. A breakwater using whole tires was installed in Chicago at a cost of about $20 per tire. Expenses of this magnitude can only be justified where substantial improvements in fishing or public safety will result. One source estimates that costs and geography will limit reef and breakwater applications to no more than 500,000 tires per year.[26]

With respect to crash barriers, the highway system contains about 500,000 points that should have impact cushions. If each point were equipped with a tire crash barrier, only one year's production of scrap tires would be consumed.[27]

Logistics are particularly crucial because whole tires are very costly to transport. All of the construction applications become impractical if the end use site is more than a few hundred miles from the point where the tires are collected. According to a 1979 assessment by Argonne National Laboratory, all such uses for whole tires could be applicable on a small scale but would have negligible impact on the scrap tire problem.[28]

Physical Processing and Materials Recovery

Splitting. Tires can be processed physically in a variety of ways to recover useful materials. Most of these produce steel scrap from the bead and belt wires, in addition to recyclable rubber goods. One traditional technique is splitting and stamping, in which the bead wires and the tread are cut off, the casing is flattened, and sections are cut out with dies. The sections may be sold without further processing, or they may be laminated together to produce thicker products. One such operation is F&B Enterprises, a New England firm that converts nearly 4,000 tires/d into muffler hangers, industrial tires, rollers, lobster pots, and parts for ski lift gondolas. Other firms produce gaskets, seals, spacers, straps, floor mats, stair treads, bumpers, and many other items.[29] A lower-technology version of the industry is seen in the southwestern states, where entrepreneurs extract tires from stockpiles, cut off the sidewalls by hand, and haul the treads to Mexico where they are made into sandals.

Tire splitting is an established industry and has long been a source of many useful products, some of which attract more than $1 per pound. However entering the industry is expensive, and the processing equipment is customized and sophisticated. Little demand growth is anticipated, and the industry is expected to remain at its current level of 3 million tires/yr into the foreseeable future. Most of the tires will continue to be obtained from wreckers and dealers, since a disposal fee can be charged. Also, freshly discarded tires are generally cleaner and less weathered than those in stockpiles. Sandalmakers will be exceptional in this regard and will continue to mine the stockpiles. Both they and the larger splitting firms will be adversely affected by the rising popularity of steel belted radials.

Chips and Crumbs. Many applications exist or could be developed for rubber chips and crumbs. Chips are pieces between 1/8-inch and 3 inches in size. Crumbs are finely divided particles generally smaller than 1/8-inch. Chips can be obtained by processing tires in mechanical size reduction equipment. Crumbs can be made either mechanically or by cryogenic processing.

Mechanical size reduction equipment includes slitters, shredders, chippers, and choppers that slice or tear whole tires apart; peelers that remove the tread; abrasive buffers and grinders; and crackers that crush rubber particles between rolls and liberate some of the steel and fiber. Hammermills generally do not work well because the rubber is so resilient. An exception is the double rotor hammermill developed by SPM Group, Inc. which uses swinging hammers on parallel counter rotating shafts to beat and tear the rubber into small pieces.[30]

A slitter produces two half-tires. A chopper may produce four or more large chunks. Shredders can produce pieces smaller than 4 to 6 inches on the first pass and 2-inch or smaller particles with some screening and recycling. Crackers make even finer particles. Buffers and grinders make crumbs or dust.

Most processing plants will use a number of these machines in series to reduce a whole tire to the desired size range. In a typical reclaiming operation, for example, the beads are first removed by a cutting machine. The tires are then crushed in a cracker and sent through a magnetic separator to remove loose pieces of steel. A shredder or hogger will further grind the particles to smaller than 1 inch. Similarly, retreading firms will first slice off the tread and then use a buffer or grinder to clean the casing and reduce the treadstock to a marketable size range.

Shredders are commonly used to prepare scrap tires for resource recovery or landfilling. They are particularly useful in dealing with stockpiled tires since they are fairly compact but can quickly reduce the volume of material that must be handled. Most tire shredders have evolved from devices designed to shred other bulky wastes such as pallets, tree stumps, autos, and appliances.[31] They generally include a vertical conveyor to feed the tires, a hopper to hold the tires prior to shredding, the shredding compartment itself, another hopper to receive the shredded material, and a conveyor that moves the shreds to a storage area. The design of the shredding compartment is crucial. One simple and effective configuration uses hooked knives on two slowly moving, counter-rotating shafts to shear and tear the tires into strips.

Most shredders use a small quantity of water to lubricate the knives. Some include a rotating perforated drum called a trommel to screen out the oversize pieces, which are then recycled for additional size reduction. Others use an inclined vibrating screen for the same purpose. Capacities can range from a few hundred tires per hour for small portable units to more than 2,000 tires/hr for large stationary equipment. Power demands range from 20 to 200 horsepower. Small to medium sized shredders can be mounted on skids or trailers and equipped with portable generators to increase their operating range.

In cryogenic size reduction, whole tires or large shreds are immersed in liquid nitrogen to cool them below the glass transition temperature where the rubber becomes very brittle.[32] The rubber is then easy shattered to powder size in a hammermill or a rolling mill. Steel and fiber not become brittle and leave the mill as relatively large pieces which can easily be removed by screening. The end product is a crumbed rubber that is free of steel and fiber. The ability to create this product is a significant advantage for cryogenic processing. Its importance should increase as steel belted radials begin to dominate the scrap tire population and preparation of steel-free rubber by mechanical means becomes more difficult. Among the disadvantages are the high costs of the processing equipment and materials and the fact that cooling 1 lb of rubber consumes as much as 0.7 lb of expensive liquid nitrogen.[33]

Tires were designed never to come apart. Reducing tires to small pieces must overcome this intent by breaking the strong physical bonds between rubber and steel and the even stronger chemical bonds between the countless rubber molecules. This is difficult and expensive and requires large amounts of energy. Energy usage increases rapidly as the size of the final particle decreases. To prepare 6-inch pieces requires about 40 Btu/lb. Preparing 1-inch pieces requires 750 Btu/lb.[34] Costs also rise as size decreases. Pieces 1 to 3 inches in size cost about $20/t to make. Pieces smaller than 1/2-inch can cost more than $200/t. These costs limit the range of applications for the rubber particles, since in general they must compete with other materials that may be less expensive to prepare. Sales of the steel scrap that would be recovered during chipping and crumbing operations help offset the high processing costs. However scrap revenues depend on the availability of nearby markets such as steel mills or large recycling firms. The scrap steel market is currently soft and may remain so indefinitely.

The coarser rubber chips can be used to displace fossil fuels in boilers and furnaces, as discussed later in this chapter, and for other purposes. In one novel application, Rubber Disposal Systems of Illinois grinds tires into 3/4-inch chips and places them in layers under playground equipment to act as a cushion.[35] The use of chips as bulking agents for composting sewage sludge has fair promise and could be widespread. Some problems have been noted with respect to the leaching of heavy metals from the tire chips. Also rubber absorbs much less water than do the wood chips that are normally used. This tends to make the sludge slushy, thereby slowing the rate of biodegradation and producing handling problems. In any event, the rubber would have to compete economically with wood chips, which are quite inexpensive.[36]

The finer rubber chips can be used to make sports surfaces such as running tracks if the steel and fiber are first removed. They can also be used as soil amendments to replace peat, wood chips, and other mulches. Although this concept is still in the developmental stage, some very favorable results have been obtained and the potential appears good for areas like Colorado that have highly compacted soils.[37]

The more expensive rubber crumbs are used to replace polymer fillers in plastics manufacturing. They are also used to make offroad tires as well as floor mats, sports surfaces, footpaths, automobile belts and hoses, irrigation pipe, toys, molded products, and other light-duty goods. For example, Scientific Development of Oregon makes wheel chocks, dock bumpers, and other products by molding crumbed rubber and is developing a process to make rubber railroad ties.[38]

Blending crumbs with petroleum products to obtain rubberized roofing and paving materials is another promising application.[39] Paving materials require crumbs that are smaller than 1/4-inch, while roofing materials need particles smaller than 10 mesh (0.07 inch). Particles for both applications must be free of steel and fiber and they should have an irregular shape and a rough surface to enhance attachment to the petroleum binder. Crumbs from cryogenic processing have the appropriate size and purity, but they are smooth and round and do not adhere as well as mechanically shredded crumbs.

Several firms now market rubberized roofing compounds made by blending reclaimed rubber with asphalt and neoprene.[40-42] Rubberized paving materials, which were first developed in Phoenix in the early 1970s, have taken longer to commercialize. In a process developed by Phoenix and the Arizona Department of Highways, a mixture of about 25% by weight of crumbed rubber and 75% asphalt is heated to 375 F for 20 minutes, and a small amount of kerosene is added to temporarily reduce viscosity. This mixture can be applied to road surfaces with normal paving equipment and can replace conventional asphalt:

- o As a stress absorbing membrane (SAM) or chip seal coat applied over existing pavement to prevent fatigue cracking of the road surface;
- o As a stress absorbing membrane interlayer (SAMI) between layers of asphaltic concrete to prevent old cracks from reflecting through to the new surface;
- o As a sealant for cracks and joints.

Several firms produce and apply this asphalt rubber, as well as rubberized asphalt which is a similar material with a lower rubber content. These include Arizona Refining Co. and Crafco International Surfacing of Phoenix and Asphalt Rubber Systems Inc. of Warwick, Road Island. In addition, All Seasons Surfacing of Bellevue, Washington markets PLUSRIDE, a paving material formed by replacing some of the aggregate in asphaltic concrete with rubber chips and crumbs.

Asphalt rubber is of substantial economic interest because it can improve the properties and durability of pavement. Improved durability is particularly important in highway maintenance because both material and labor can be saved. The savings must be large, however, because asphalt rubber is considerably more expensive than conventional paving mix. There are three reasons. First, rubber crumbs sell for $350/t, while the asphalt that they replace sells for only $150-$180/t.[43] Second, an extra processing step is required to prepare the paving mix. Third, a larger volume of asphalt rubber must be used. In a typical SAM application, for example, 0.5 to 0.6 gallon of asphalt rubber is needed to replace 0.35 to 0.4 gallon of asphalt.[44]

The net effect is to make asphalt rubber about twice as expensive as conventional asphalt. To offset the higher initial cost, the rubberized pavement must last at least twice as long as conventional asphalt. Performance of this magnitude has been achieved in some, but not all, of the field tests that have been completed to date. Tests by the Arizona Department of Highways showed that highway life can be extended by a factor of five or more by using an asphalt rubber SAM. The state also developed a process in which three layers of asphalt rubber are used to restore a worn road surface. The cost is about 30% of the cost of grinding away the old pavement and replacing it with asphaltic concrete. Tests of the SAMI option showed that a road resurfaced with a 0.11-inch layer of asphalt rubber plus a 2-inch layer of asphaltic concrete lasts longer than one with a 7-inch layer of asphaltic concrete alone. Similarly favorable results have been observed in other test programs. For example, joint and crack repairs made on the New York State Thruway with asphalt rubber lasted up to three times as long as those made with conventional asphalt sealers.[45]

Arizona appears satisfied with the cost effectiveness of asphalt rubber and is expanding its paving programs. However tests in other locations such as Toronto and Saskatchewan showed an inadequate level of improvement and no further work is planned. Some experts suggest that these poor results were obtained because the condition of the existing pavement and its intended use were not adequately considered in designing the test programs. Others blame poor quality control during mixing and application for the problems that have been experienced. Some proponents claim that the test results are irrelevant because highway departments are too conservative to accept new techniques regardless of their promise.

Further study is needed to determine the best material mixes, to measure product performance, and to develop standardized blending and application methods. Additional work now underway in New Jersey, Massachusetts, Alabama, and Louisiana may yield some of this information. Results are crucial because asphalt rubber is one of the few disposal options that are suitable for both small and large scale use and that have the potential to use all of the scrap tires. An EPA report estimates that 120 million tires/yr could be used in chip seal coats and another 170 million/yr in asphaltic concrete. If these markets were fully developed, scrap tires would disappear as rapidly as they are generated. However unless the advantages of asphalt rubber are confirmed, its widespread use will depend on its costs coming in line with those of conventional asphalt. This would require substantially improved grinding processes, which would be very difficult to develop.[46]

Chemical Processing and Reclaiming

Reclaiming is the combination of physical and chemical processes by which used rubber is prepared for recycling into new rubber products. In a traditional tire reclaiming plant, tires are ground in a cracker mill--a crushing device with two corrugated rolls that rotate at different speeds. The rolls pull the tire apart and liberate the bead wire. Particles leaving the cracker are screened, and oversize pieces are recycled for more grinding. The smaller pieces pass through a second cracker with finer corrugations and are again screened and reground until they have the desired size. The fine particles are mixed with water, oil, and chemicals and heated under pressure until the bonds between the sulfur and carbon atoms are broken and the rubber decomposes to a viscous plastic mass. This material is dried, blended with special compounding ingredients, and rolled into a sheet to break up any residual particles. The reclaim is then formed into slabs or bales and shipped to manufacturers who use it as an alternative to virgin rubber to make new rubber products.

Reclaim is devulcanized rubber that contains essentially all of the chemicals used to make the various types and grades of scrap fed to the reclaiming process. Reclaim also tends to lose its elastic properties during processing and becomes less resistant to compression, stretching, and swelling. Because of these shortcomings, products made from reclaim have poorer mechanical properties than those made from virgin material. However reclaim has historically been cheap enough to encourage its widespread use. In the tire industry, reclaim's low abrasion resistance has limited its use in tire treads, although up to 80% reclaim can be used in sidewalls and casings which see much less abrasion.[47-51]

Other manufacturers use reclaim to make a variety of mild service rubber goods and asphalt products.[52] One of these is Baker Rubber, Inc. of South Bend, Indiana which makes molded rubber goods and markets reclaim for use in asphalt rubber and sports surfaces. Centrex Corp. of Findlay, Ohio makes rubberized tape for windshields and sells reclaim to a tire manufacturer. GSX Polymers, a subsidiary of Genstar Corp., operates plants in Vicksburg, Chicago, and Chandler, Arizona that convert 4 million tires/yr and 10,000 t/yr of tire buffings to crumbed rubber and reclaim. Midwest Elastomers of Wapakoneta, Ohio uses a cryogenic process to convert 100,000 tires/mo into crumbed rubber. The process was developed to service an asphalt rubber market which never materialized. Midwest Rubber Reclaiming of East St. Louis, Illinois makes reclaim for use in tires, floor mats, and other goods. Neapara Rubber of Trenton, New Jersey converts tires and scrap into several grades of reclaim for sale to non-tire manufacturers.

Together, these and other reclaiming firms consume about 10 million old tires/yr and play a very important role in solving the tire disposal problem. However the industry is much less healthy than at the end of World War II, when reclaiming was a very important activity and nearly every tire firm maintained a reclaiming operation.

Much of reclaim's decline can be related to competition from cheap petroleum. Beginning in the 1950s, synthetic rubber made from crude oil began to displace reclaim from the tire market, and polyvinyl chloride and other synthetic resins began to usurp reclaim's role in the non-tire rubber industry. Reclaim's problems were aggravated when radial tires, which use little or no reclaim, became very popular in the 1970s.[53]

In this highly competitive environment, profit margins were too small to support research on more efficient processes and superior products. As a result, modern technologies are very similar to the labor and energy intensive methods originally developed in the late 1800s. Some plants now use the same processes, and probably the same equipment, as they did in 1951. This lack of progress has gradually eroded away much of reclaim's share of the raw material market. In 1951, reclaim constituted 17.7% of the elastomers used to make tires and 30% of those used to make other rubber goods. In 1971, reclaim held a 6.4% market share in the tire industry and 8.1% in non-tire rubber articles.[54]

When crude oil prices tripled in 1974, some proponents predicted that synthetics would become so expensive that industry would be forced to use more and more reclaimed rubber, which required less energy to produce and was therefore less sensitive to oil prices. Similar forecasts came forward in 1979, when crude prices tripled again. Although rising demand was noted in both periods, it was insufficient to restore the industry to its former vigor. In 1980, reclaimers produced only 3.5% of the U.S. rubber supply. The currently low oil prices do not afford much encouragement for the industry's recovery.

Onto this darkening stage has come Rubber Research Elastomerics, which is building a plant in Babbitt, Minnesota that will convert 3 million tires/yr into chips, crumbs, and "Tirecycle"--a reclaim made by applying a polymer to the surface of ground scrap.[55-57] The developer plans to sell Tirecycle for about $500/t to a maker of rubber mats who is relocating to Babbitt. Capital for the $2.8 million project was obtained from a state loan, a state grant, a line of credit from Babbitt, and general obligation bonds issued by St. Louis County.

The state's contributions were drawn from a fund set up to deal with Minnesota's growing scrap tire problem. The county will own the plant, and Rubber Research Elastomerics will be the operator. No tipping fee will be charged at the facility, which is scheduled to open in 1987.

The developer hopes to use innovative technologies and products to succeed where its more established competitors have failed. However some industry observers have expressed concern regarding the firm's financial track record and lack of experience in tire processing, the need for an 180-fold increase in the sales of Tirecycle, reluctance on the part of the rubber industry to accept the new product, the lack of liability insurance to protect against claims arising from use of the product, and the 200-mile distance to the Twin Cities area where most of Minnesota's scrap tires are generated.[58]

The outcome of the Babbitt project is of great interest because if successful, the plant could provide a model for novel tire disposal operations in other states. As noted, however, its future is clouded by a number of uncertainties, and some industry experts are not optimistic. One points out that the supply of reclaim already far exceeds demand and that the currently soft market is not likely to improve soon. Another suggests that the industry will continue to decay unless favorable governmental policies, such as tax credits, are implanted to encourage manufacturers to use more recycled materials. Present policies, such as EPA's proposed guidelines to encourage rubber asphalt, are regarded as too vague and too riddled with loopholes.[59]

Energy Recovery

General. Table 2-1 compares the fuel properties of various kinds of tires with those of coal and municipal refuse. As shown, tire properties vary widely depending on the materials of construction. Tires with Kevlar belts have a low ash content and a heating value of nearly 17,000 Btu/lb, which is higher than the heating value of raw rubber. Bias-ply nylon or polyester tires also have high heating values and intermediate ash contents. However the heating value of a

Table 2-1: Ultimate Analysis of Tires and Other Fuels

Material	C	H	N	O	S	Moisture	Ash	Heating Value Btu/lb
	Chemical Composition, % by weight *							
Tires								
Glass Belt	75.8	6.62	0.20	4.39	1.29	-	11.7	13,974
Steel Belt	64.2	5.00	0.10	4.40	0.91	-	25.2	11,478
Nylon	78.9	6.97	0.10	5.42	1.51	-	7.2	14,908
Polyester	83.5	7.08	0.10	1.72	1.20	-	6.5	14,752
Kevlar Belt	86.5	7.35	0.10	2.11	1.49	-	2.5	16,870
Average	77.8	6.60	0.1	3.61	1.28	**	10.6	14,396
Municipal Solid Waste	25.4	3.4	0.5	20.2	0.2	25.0	24.8	4,500
Subbituminous Coal	47.9	3.4	0.6	10.8	0.5	30.4	6.4	10,245
Bituminous Coal	57.5	3.7	0.9	5.8	4.0	12.0	16.0	12,235

* Carbon, Hydrogen, Nitrogen, Oxygen, Sulfur

** Moisture not reported. Generally less than 0.5%

Sources

<u>Tire Data</u>: Energetics, Inc., "Second Year Project Analysis of Waste Tire Conversion Systems." Final Report to Argonne National Laboratory, December 1981.

<u>Other Data</u>: C. R. McGowin, "Municipal Solid Waste as a Utility Fuel." Chemical Engineering Progress, March 1985.

steel belted tire is lower than that of bituminous coal and its ash content is substantially higher.

The average tire has a heating value of about 14,400 Btu/lb, which is about three times as high as refuse, 40% higher than subbituminous coal, and nearly 20% higher than a good grade of bituminous coal. Carbon is very high because of the carbon black used to make the rubber. Nitrogen is very low. Sulfur is higher than in refuse or subbituminous coal but lower than in bituminous coal. Ash is comparable to subbituminous coal, less than bituminous coal, and much less than refuse. Moisture is negligible, in contrast to levels of 12 to 30% for the other fuels.

These properties make the average tire a very attractive fuel. However the data should be used with caution, since the average properties are simply an arithmetic average of the individual tire lines. They do not reflect the relative importance of a given line within the total tire population. As noted previously, steel belted radials are the most popular new tire and they will eventually dominate the scrap tire population. At that time, scrap tires will have fuel properties that are only slightly better than those of bituminous coal.

Pyrolysis. In the beginning, pyrolysis meant a chemical change brought about by the application of heat. Its formal definition is now thermal degradation in the absence of oxygen. For tires, pyrolysis includes a range of thermal treatment processes conducted without sufficient oxygen to cause complete combustion.

Tire pyrolysis is inherently attractive because it may avoid some of the emissions problems commonly associated with tire burning. Pyrolysis can also produce storable, transportable fuel and other useful products that can be sold for relatively high prices. In most pyrolysis systems, tires are shredded and the steel and cord are separated from the rubber, which is then heated to 1,000-1,800 F in a chamber containing little or no oxygen. The reaction temperature determines the yields of fuel oil, gas, and carbon black, as well as carbon black quality. Depending on the technology and the types of tires processed, one ton of tires will yield 125 gallons of oil and

700 lb of carbon black. Low temperature technologies will produce enough combustible gas to make the process self-sustaining. Higher temperature processes will make less oil and carbon but will produce excess gas that can be sold.[60]

Pyrolysis is a very old technology, with documented experience extending back to the 1300s in the case of oil shale and coal feedstocks. Tire pyrolysis has a shorter history, but its principles are at least as well established. One recent study cited 63 pyrolysis processes, of which the seven discussed below were intended exclusively for tires.[61,62]

- o Energy Conversion Corp. of Chadds Ford, Pennsylvania has developed the Hydrocarbon Pyrolysis System in which tire chips are pyrolyzed at 1,300 F on a moving grate. The firm has proposed to build a 50 t/d plant in Derry, New Hampshire that will produce oil, carbon black, and 5 MW of electricity.
- o Enerco, Inc. has operated a 6 t/d demonstration plant in Indiana, Pennsylvania since 1983. In this batch process, tires are slit and loaded into baskets for heating in a retorting chamber. Oil is sold as heating fuel to an apartment complex. Gases are flared. About 500,000 lb of carbon black have been sold to the pigment and rubber manufacturing industries.
- o Kleenair Products, Inc. and Conrad Industries, Inc. have developed a pyrolysis plant in Chehalis, Washington, in which 24 t/d of shredded tires are pyrolyzed at 1,500 F in a tubular reactor. Oil and carbon black are sold.
- o Kutrieb Corp. of Chetek, Wisconsin, markets a tire "pyrolator" that produces oil, carbon black, gas, and steel. In 1983, a unit was installed in Perkasie, Pennsylvania but is no longer operating.
- o Nu-Tech Systems of Bensenville, Illinois operates a modular demonstration facility and claims to have three other units in place elsewhere.
- o TecSon Corp. of Janesville, Wisconsin has developed the continuous Pyro Mass Recovery System in which rubber chips or dust are converted to oil, gas, and carbon black. The fuels

can be sold or burned on-site to produce electricity. Designs for 220 lb/hr or 1 t/hr are available. The larger plant produces 1.25 MW. A 3-yr payback period is claimed. Several projects are under development but as yet there are no commercial facilities. Recycled Energy, Inc. of Blair, Nebraska is working with TecSon to develop a powerplant project that would relieve the local landfilling problems.

- Garb-Oil Corp. of Salt Lake City has proposed to build a plant in West Virginia to pyrolyze 90 t/d of shredded tires. The process was tested in the early 1980s at a demonstration facility in Edmonds, Washington which is no longer operating. Garb-Oil is also promoting the use of fluidized bed combustors to generate electricity by burning tire shreds.

Several other processes are in various stages of development. For example, Eastern Shale Research Corp. of Shelbyville, Indiana is experimenting with pyrolyzing whole tires in a pusher oven similar to those used for heat treating metal parts. Eastern Shale's process was originally developed to extract fuels from the large resources of oil shale that are found in many states.[63] Another oil shale technology--the TOSCO II retort--has also been applied to tires.[64] The lessons learned in this program provide important clues to the promise and the limitations of pyrolysis as a disposal option for scrap tires.

In the mid-1970s, Tosco Corp. and Goodyear initiated a 15 t/d pilot plant program to test the applicability of the TOSCO II retorting technology to pyrolysis of scrap tires. In this process, shredded tires are fed to a rotating drum where they contact hot ceramic balls at a temperature of 900-1,000 F. The shreds decompose into oil vapor, gases, and a solid char. The vapors and gases leave the drum and are separated in a condenser. The char and the ceramic balls leave the drum and are separated by screening. The balls are reheated and returned to the drum for another cycle of pyrolysis. The char is cooled and processed to concentrate the carbon black.

The product oil obtained from the pilot plant was a very fluid liquid with lower sulfur content, lower viscosity, and a lower pour point than conventional No. 6 fuel oil, which it could displace without further refining. Tosco was able to produce 120 to 170 gallons of this oil from each ton of tires processed, or roughly 1.2 to 1.7 gallons per tire. The gas was also of good quality and could have been upgraded to pipeline purity by reducing the levels of sulfur and carbon dioxide. However the gas was needed to fuel the pyrolysis process and it was burned as plant fuel.

The char was about 81% carbon, 2.4% sulfur, and 15% ash, plus small amounts of hydrogen, nitrogen, and chlorine. Tosco found that the organic polymers in the tire rubber decomposed to oil and gas and did not contribute appreciably to char formation. Rather the char contained the carbon black, fillers, and belting materials used to make the tires. The carbon black was recoverable in virgin form; that is, as very small particles with reinforcing properties like those of the carbon black used in the original tire formulation. By removing the ash and sulfur, the char could be upgraded to obtain a carbon black that could be marketed to the rubber industry for low to medium grade applications. Even the ash was a potentially useful source of zinc and titanium metals, since it contained about 45% zinc oxide and 13% titanium oxide.

During the test program, Tosco and Goodyear processed 800 tons of tires and produced 130,000 gallons of oil, 500,000 lb of carbon black, and 26 tons of scrap steel. Each ton of tires yielded 120-170 gal of oil worth about \$49, 575-700 lb of carbon black worth \$60, and 85-100 lb of steel worth \$2. No credit was taken for the ash. The total revenues were \$111 per ton, or about \$1.11 per tire. The keys to successful operation were efficient materials handling, careful temperature control to maximize oil yields, and production of high-quality carbon black in large quantities. Carbon black sales were especially crucial since they were the major source of revenue.

In 1978, the companies began to design a 300 t/d plant, which was the minimum commercial size for the TOSCO II technology. They estimated a capital cost of \$20 million and operating costs of \$0.88/tire. Debt service at 10% interest or depreciation of an equity investment at the same rate would increase the operating expense to \$1.06/tire, which was dangerously close to the estimated total revenue of $1.11/tire. Profitability could have been enhanced if higher prices could be obtained for either the oil or the carbon black. The value of the oil as fuel depended on the world price for conventional crude, which was beyond the control of the developers. The value of the carbon black, on the other hand, might be adjustable within certain limits.[65]

The numerous grades of carbon black are distinguished by several quality parameters including particle size and chemical purity. The highest quality, most expensive carbon black is used in tire treads because these are subject to the most severe wear. Rubber for tire casings and sidewalls uses a lower grade of carbon black that has larger particles. Sheet goods and moldings that are not subject to high levels of stress use carbon black that is much lower in quality.

Pyrolysis of whole tires produces a carbon black that is a mixture of tread grade and casing grade. At best, this product can be used to make tire casings. It is more likely to be relegated to lower-cost applications. Tosco assumed a price of $0.095/lb for its product, which is a realistic value for a medium grade carbon black. Improving the product to tread grade would increase its price to about $0.20/lb and would substantially increase revenues. This could be done, but with some difficulty. For example, slitting the treads from the casings and pyrolyzing the components separately would yield a more valuable product. However processing costs would rise as well.[66]

While this study was underway, the market for the grade of carbon black that could be recovered from old tires began to deteriorate. This was largely because the product could not be used in the increasingly popular radial tires. Tosco also found that economically sized plants could be sited only in densely populated areas, since each would consume more than 9 million tires/yr. These and other impediments led Tosco and Goodyear to defer the commercial project. It has not yet been revived.[67]

The Tosco experience teaches that although pyrolysis has the potential to convert all of the nation's scrap tires into useful products, there are technical and economic limitations. According to a 1979 study by Argonne National Laboratory, the minimum size for a pyrolysis plant is 20 t/d or about 700,000 tires/yr and a more practical minimum size is 1 million tires/yr. This tire generation rate could be achievable in urban areas but not in less densely populated regions. Building smaller plants is not necessarily a solution either since, according to Argonne, operating costs per tire processed do not vary with the capacity of the plant.[68] Innovative technologies may be able to avoid this barrier, but the processes must be well conceived, the plants must be properly engineered, and markets for the products (especially carbon black) must be carefully developed.

A more recent study by Compass Corporation supports these findings.[69] Compass found that a plant using the Eastern Shale technology could be economical without selling carbon black if a tipping fee of $0.50 could be charged for each tire processed. If the carbon black could be sold for $0.07/lb, the required tipping fee would drop to $0.25/tire, which is currently obtainable in many parts of the country. Compass concluded that pyrolysis may be economical if the costs of other tire disposal practices are high enough. Tipping fees are essential, given the presently low energy prices and the low value of carbon black from old tires. Compass also concluded that pyrolysis developers should locate only where tire disposal is a serious problem and tipping fees are high and secure. They should avoid areas that have cement kilns and stoker-fed steam or power plants that could afford to pay for scrap tires or for tire-derived fuel.

Supplemental Fuel for Existing Combustors. Tires can be burned in some existing combustion units that are designed to burn solid fuels in lump form. The principal markets are wood products plants, power plants and steam stations, and cement plants. Tires and chips can also be burned in certain refuse incinerators, although these are an alternative to landfill disposal rather than a marketplace for the fuel. As discussed below, tires are already burned in some of these facilities, although substantial untapped potential still exists.

Pulp and paper mills and other wood products plants use prodigious quantities of energy to cook their raw materials and dry their products. Most generate their own power and steam by burning wood wastes and process-derived chemicals. Because these fuels are both wet and dirty, their combustion is difficult to control and contributes to air pollution problems. Tire-derived fuel (TDF), with its much higher heating value, can be used effectively to help overcome these problems.[70]

The wood products industry has already begun to exploit this opportunity.[71] For example, Willamette Industries burns 5% rubber with wood wastes at its Albany, Oregon paper mill. Emanuel Tire in Baltimore processes about 3 million tires/yr into supplemental fuel for pulp and paper mills. Louisiana Pacific's pulp mill in Antioch, California burns 42 t/d of TDF to generate steam and electricity. Waste Recovery, Inc. shreds more than 2 million tires/yr at its Portland, Oregon facility and sells the TDF to pulp and paper mills in Oregon, Washington, Idaho, and Alaska where it is mixed with wet wood wastes and burned to generate steam. Among the clients is Louisiana Pacific's plant in Ketchikan, Alaska which burns 24 t/d of TDF that is brought in from Portland by barge. Waste Recovery's second plant in Houston will process 4 million tires/yr into fuel for paper mills and cement kilns. Tonson, Inc. of Anoka, Minnesota processes more than 2.5 million tires/yr into supplemental fuel for the Owens-Illinois facility in Tomahawk, Wisconsin. This plant consumes a total of 60 t/d of tire chips and has been burning rubber for several years. Virginia Recycling Corp. of Providence Forge, Virginia processes 500 tires/hr into 2-inch chips for sale to mills operated by Westvaco and Owens-Illinois.[72]

Although the wood products market is extremely promising, there are limitations. First, a mill must be close to a tire disposal operation to minimize transportation costs. This is not always the case, since most scrap tires are generated near cities, while mills tend to be in isolated areas with more trees than people. Second, chips should be smaller than 2 inches, and they should be free of jagged wires. Preparing such particles is expensive. Third, sulfur dioxide and particulate emissions limit the quantity of TDF that can be burned without violating air quality regulations. Finally, the TDF must be cheap enough to compete with coal or combustible wastes. This economic restraint can impose some insurmountable problems.

Many large **power plants and steam stations** burn pulverized coal in suspension-type boilers. These units cannot burn whole tires, nor can they economically burn shredded rubber because shredding tires to a fine size range is prohibitively expensive. The most appropriate boilers are rotary kilns or spreader stokers designed for lump coal or other coarse solid fuels. One such facility is a power plant operated by Centel Corp. in Canon City, Colorado about 110 miles south of Denver. The spreader stoker boiler in this plant is fueled primarily with coal, but it can handle limited quantities of combustible wastes such as wood and agricultural residues. In 1985-86, the plant also burned TDF that was purchased from Recycled Fuels of Colorado, a tire disposer in suburban Denver. The supplier hauled about 20 t/d of the 2-inch TDF to Canon City where it was sold for the same price per ton as coal. The relationship was satisfactory until Centel obtained a price break from its coal supplier. Recycled Fuels was unable to make the same concession and stopped shipping the rubber.

A number of existing **refuse incinerators** also burn waste rubber. One is the steam station in Galex, Virginia that is discussed under the Combustion in New Boilers section. This plant, and others that use rotary kiln combustors, can burn whole or shredded tires. Others that use fixed or traveling grate combustors are better supplied with TDF, since this fuel will burn more quickly and evenly than whole tires.[73] Included in this category are modular incinerators in Salem, Virginia; Dyersburg, Tennessee; and Tuscaloosa, Alabama that burn refuse and rubber to produce energy for nearby rubber plants. Another plant in Miami, Oklahoma that supplied steam to a Goodrich plant was shut down in February, 1986. Harrisburg, Pennsylvania shreds 150 tires/hr to fuel its refuse burning cogeneration plant. Akron's large incinerator burned approximately 400,000 tires over a 13 month period in a 10% mixture with municipal refuse. The plant was recently idled by an explosion but expects to resume tire burning when repairs are complete.

Current projections indicate that refuse-to-energy plants will continue to help solve the tire disposal problem. For example, General

Tire has expressed interest in buying steam from an incinerator in Mt. Vernon, Illinois which will burn about 6,000 t/yr of tires. Developers of a 4 MW powerplant project in Conway, New Hampshire intend to burn shredded tires along with refuse and wood chips. Maine Energy Recovery Corp. plans to build two incinerators in Maine that will burn tires along with processed refuse. The 22 MW plant in Biddeford, now under construction, will burn 1 million tires/yr. The 25 MW plant proposed for suburban Bangor will burn 1.2 million tires/yr.

However there are also limitations on this outlet. Logistics is less of a problem than in the wood products industry, because most incinerators are located near cities that produce both refuse and scrap tires. Steel bead wires and belting can cause operating problems in incinerators as well as in paper mills, and it is helpful to remove at least some of the wire when the tires are shredded. Sulfur dioxide and particulate emissions can also be a problem unless the boiler has adequate controls. A baghouse or a high-efficiency electrostatic precipitator is a minimum requirement, with a baghouse preferred because it can be adapted to remove sulfur as well as particulates. The major problem, however, is economic. Wood products companies prefer to pay little for tire fuels. Incinerator operators prefer to pay nothing unless they really need the supplemental fuel to satisfy an energy delivery contract. They are more likely to charge a tipping fee to accept tires or tire derived fuel.

Tires can also be burned in **cement kilns.**[74-76] Portland cement is manufactured in a three-step process. First, limestone and clays or sand containing silica are mixed and ground to a fine size range. Second, the mixture is heated to 2,700 F to calcine (decompose) the limestone and induce a reaction with silica to form cement clinker. Third, the clinker is ground together with a small amount of gypsum to form Portland cement. In a traditional flowsheet, the heating step is carried out in a single reactor--an inclined slowly-rotating cylindrical kiln which can be more than 400 ft long and 15 ft in diameter. Fuel is burned at the lower end, and the hot gases are blown up along the kiln's length. The incoming mixture of limestone and silica is first dried by the flame and then calcined, reacted, and fused to form clinker. In a more modern plant, the mixture is dried in a separate preheating vessel and further heated in a precalciner, before being charged into the main kiln. This reduces the length of the kiln and the amount of energy needed to produce the cement.

Energy conservation is an important consideration because cement manufacturing is one of the most energy-intensive of modern industrial practices. In 1984, for example, the U.S. industry produced 60 million tons of Portland cement and consumed more than 500 billion Btu of energy, the equivalent of 25 million tons of good grade coal. In 1973, oil and gas were the main fuels, and energy costs were only 31% of total manufacturing cost. By 1982, despite process improvements and substitution of lower priced fuels, energy costs had risen to nearly 38% of the total cost. Although the recent drop in energy prices has tempered the problem somewhat, the industry acknowledges its vulnerability to future surges and has continued its search for a low-cost, dependable, domestic energy supply.

Cement kilns operate at high temperatures and with long residence times, and the natural scrubbing action of the limestone can remove a variety of impurities. The kilns can therefore tolerate a wide range of fuels. Although oil and gas are the most convenient, coal is now the most common. Wastes such as rice hulls, wood shavings, coke, tires, and tire chips have also been used. The opportunity to use more tires is of great interest, because if only 10% of the energy used in cement making could be provided by tires, the scrap tire problem would disappear.

Shredded tires can be burned in preheater sections if a special feeding system is added. Whole tires can also be used in preheaters but with much more equipment modification. It is also possible, but difficult, to blow chips into the hot end of a conventional long kiln. Pollution is seldom a problem because the limestone will absorb most of the sulfur dioxide and the balance, plus the particulate matter, can be handled by existing controls. Wire is not a problem either because the steel will melt and become part of the clinker. Logistics is not a serious constraint, because most cement plants are located near large cities, where most of the scrap tires are also produced.

In Germany and Japan, whole tires have replaced 15-20% of the coal used in cement kilns. The Japanese were the first to use scrap tires, beginning in the late 1970s. Although the process was successful, few tires are now used because the cement industry has been outbid by waste-burning power plants. Germany also mounted a major effort in the late 1970s to reduce oil and gas consumption, to eliminate tire stockpiles, and to end the illegal dumping of more than 20 million tires/yr. The program has achieved its objectives and one cement firm alone now has six plants that burn tires as supplemental fuel. The cement industry in Great Britain also has a successful tire burning program.

The U.S. industry has been slower to respond. One reason is that the availability of low-cost coal has delayed the search for even cheaper alternatives. Another is that 63% of the cement is produced in the old-style long kilns, which are more difficult to feed with tires, and only 37% is made in the more tractable preheater-precalciner systems. In contrast, almost all European and Japanese plants use the more modern design. Nevertheless, some experiments have been conducted and the industry appears to have a growing interest in the tire resource. Genstar Cement's plant in Redding, California, for example, has burned tire chips continuously in a 10% mixture with coal, and Caleverias Cement of Sacramento burns 25-30 t/d of tire chips in a preheater kiln.

Further expansions appear to be limited by an economic daisy chain that may be difficult to break. On the one hand, chips are relatively easy to use and do not require extensive modifications to the cement kiln. However chips are expensive to prepare and the processor must receive a high price to cover his costs. A cement firm will be unwilling to pay this price when it can buy coal for less. Whole tires, on the other hand, are much cheaper to obtain but cannot be used without major changes to the kiln and its feed system. Such alteration can easily cost $1 million or more. A plant operator will be unwilling to make this investment without assurance of a large and stable supply of tires at very low cost.

Combustion in New Boilers. Both rotary kilns and grate furnaces can burn whole tires efficiently and cleanly. Shredded tires can be also be burned in these units or in fluidized bed boilers like those used for coal. Steam stations and power plants that burn only tires have been built in Europe and Japan. They can be practical in this country if a large tire resource is available, if the energy commands a high price, and if the plants can comply with environmental standards. Following are brief descriptions of a rotary kiln steam plant that has been installed in Virginia, a grate-type powerplant that is being built in California, a pulsed-hearth steam generator in Illinois that burns tires mixed with other fuels, and a fluidized bed combustion system that can burn shredded rubber. Other tire burning technologies are available from other firms that sell combustion equipment and systems.

Rotary Kiln. Combustion Technologies, Inc. of Troy, Michigan sells a rotary kiln combustion system that can burn whole tires.[77] In a typical system, a variable speed feeder charges whole or shredded tires into the kiln, which is an inclined cylindrical vessel that rotates about its long axis. The kiln is lined with refractory material and can operate in either starved air or oxidizing modes at temperatures up to 2,800 F. Bottom ash from the burned tires is discharged from the kiln's lower end into a pool of water in a refractory lined ash housing. A drag conveyor carries the quenched ash from the housing to a storage container prior to disposal. Combustion gases and fly ash pass from the kiln into a secondary combustion chamber where they are mixed with additional air and burned at temperatures up to 2,200 F. They then pass through a boiler, where they heat water to produce steam, and then through the pollution control system before being discharged to the atmosphere. Depending on local regulations, air quality controls can include wet or dry scrubbers and fabric filter baghouses.

Combustion Technologies' plants have ranged from 3 million to 300 million Btu/hr of heat input. However the firm recommends that tire burners be smaller than 100 million Btu/hr, since larger plants would be subject to more stringent air quality regulations. A 100 million Btu/hr facility would burn up to 12,200 passenger tires per day and would produce 63,000 lb/hr or steam or 5.5 MW of electric power.

In August 1986, Denver's project staff visited a recently completed facility in Galex, Virginia that includes a Combustion Technologies' rotary kiln. The plant was designed to burn 55 t/d of municipal refuse and to generate 20,000 lb/hr of steam for sale to an adjacent clothing mill. Tires are burned to sustain steam production when refuse is not available. We observed the burning of both refuse and whole tires. Whole tires burned completely after 15 minutes in the kiln. Steel beads and belts were discharged as balls of clean wire. The plant has a baghouse but no scrubber. However, the stack gases were clear and there was no detectable odor outside the plant building.

Grate Furnace. Oxford Energy, Inc. of New York City and Boston has licensed a grate-type combustion technology developed by Gummi Mayer, a West German retreading firm that has operated a tire burning boiler since 1971.[78] Oxford is building a tire-fueled power plant in Modesto, California that will contain two boilers, each twice as large as the West German prototype.

In a typical design, whole tires enter a refractory lined furnace on a conveyor belt and fall onto an inclined reciprocating grate which carries them through the combustion zone. Hot gases from the burning tires pass out of the furnace into a boiler, where they generate steam that is converted to electric power in a turbine generator. The gases are then cleaned in a pollution control system before being discharged to the atmosphere. In California, air quality controls include a baghouse to remove particulate matter, a wet scrubber for acid gases, and a thermal denox device to control oxides of nitrogen. Wires and bottom ash are discharged dry through a screw conveyor.[79]

Oxford has designs for plants ranging from 14 to 28 MW. The $38 million Modesto project will consume 4.5 million tires/yr and will produce 14.4 MW. About 13 MW will be sold to the local utility after satisfying in-plant power needs. Fuel will be obtained a stockpile that now contains 38 million tires and is growing by 3 million tires/yr. Oxford is also developing a 15 MW, 4.5 million tire/yr plant in Derry, New Hampshire that will cost $50 million. A 22 MW plant that will consume 7 million tires/yr has been proposed for Sterling, Connecticut. Oxford recently began shredding tires and stockpiling the rubber to ensure a fuel supply for the Sterling facility.[80]

Pulsed Hearth Furnace. Basic Environmental Engineering, Inc. of Glen Ellyn, Illinois has installed incineration equipment at two Firestone tire plants; one in Des Moines, Iowa in 1983 and one in Decatur, Illinois in 1984.[81,82] Both units are designed to burn 24 t/d of whole tires and rubber scraps with 75 t/d of paper, wood, and other solid wastes. Each incinerator produces 20-25,000 lb/hr of steam for plant use.

Batches of tires and other fuels are placed in a charging hopper which is then sealed. A hydraulic ram forces the fuel into the primary combustion chamber, which has water cooled walls and a stepped hearth. The fuel is agitated and propelled along the hearth by timed pulses of air, giving rise to the "pulsed hearth" designation. Ash is discharged through a water bath at the lower end of the hearth. Hot gases from the primary chamber pass through three additional stages of combustion before entering a firetube boiler. The boiler produces 70% of the total steam. The rest is produced in the walls of the primary chamber. Because of the staged combustion, the exhaust gases are fairly free of regulated gaseous pollutants, and the plants meet emissions standards after removing only a portion of the particulate matter.

The incinerators run continuously for periods of 7 to 17 days, depending on fuel availability. They must be shut down after 30 operating days to clean the boiler tubes. This relatively low availability is regarded as acceptable since the primary objective is to dispose of waste materials. Tires constitute only 25% by weight of the fuel, but they contribute 80% of the heating value. The ability to burn more tires is limited by the capacity of the particulate control equipment.

Fluidized Bed. When gases are blown up through a vessel containing a bed of free-flowing granular solids, they exert a drag force on the surfaces of the solid particles.[83,84] At low gas velocity, the drag force is too weak to overcome gravity and the particles do not move. At high gas velocity, the drag force raises the entire bed and sweeps it from the chamber. There is an intermediate velocity at which drag force is exactly equal to the gravitational force. When this velocity is achieved, the particles begin to vibrate and circulate in semi-stable patterns and the bed of granules begins to resemble a boiling fluid. The intense turbulence provides intimate contact between the particles and the gas. This can be exploited to induce a high rate of heat or mass transfer between the two media with a relatively low energy input.

A reaction vessel operated at or near the fluidizing gas velocity is called a fluidized bed reactor. Fluidized beds are widely used to carry out catalytic and non-catalytic chemical reactions, as well as to heat or dry solids, to separate particles of different density, to absorb or desorb gases from solids, to heat-treat ores and other materials, and to coat solid parts. If the objective is to burn the solid particles, the vessel is called a fluidized bed combustor (FBC). The particles are a solid fuel such as coal, and the fluidizing gas is air.

FBC technology has been available since about 1947, and it has been commercialized in several countries. In 1985, there were 52 manufacturers of FBC equipment worldwide, and 228 boiler plants either had FBCs in place or were scheduled to install them. China alone has 60 FBC units that burn lignite or brown coal.

FBC has taken longer to penetrate the U.S. market, although development has quickened in recent years under the sponsorship of the electric power industry. The industry's goal is to develop a coal fired steam generator that can meet sulfur dioxide emissions standards without the use of scrubbers. Research has centered both on pressurized FBCs that operate at elevated pressures and on atmospheric units that operate at ambient pressure. In both variations, the bed is a mixture of inert materials such as sand, particles of coal, and a third solid such as limestone or dolomite that can absorb the sulfur dioxide that is given off when the coal burns. Atmospheric FBCs have a lower sulfur absorbtion efficiency, but they cost less to build and are simpler to operate. This makes them more suitable for small-scale applications.

FBCs can also burn municipal refuse, agricultural wastes, peat, and other materials including shredded tires. In 1981-82, National Standard Co. of Niles, Michigan, under a cooperative agreement with DOE, tested the use of an FBC system to generate steam by burning tire chips.[85] The goal was to develop a steam generator that could be used by some of the more than 3,000 retreading companies in the United States. The larger retreaders typically operate 75 to 100 horsepower boilers to produce steam for the tire curing process. They also discard 100 to 300 tires/d. A tire burning FBC steam generator would achieve two objectives by conserving fossil fuel and eliminating a waste disposal problem.

National Standard's program consisted of tire burning tests in a lab-scale FBC followed by technical and economic analysis of a commercial scale system. Although some problems were encountered, the lab tests produced satisfactory results. Energy recoveries were high, and emissions of sulfur dioxide and nitrogen oxides were within state standards without scrubbing. A cyclone and a baghouse provided an adequate level of particulate control.

The commercial facility was designed to burn 400 lb/hr of tire shreds for 16 hr/d with an overall thermal efficiency of 70%. The FBC would produce 3,000 lb/hr of steam at 100 psig, an energy output equivalent to 75 horsepower. The capital cost for this plant would be $1 million, compared with $100,000 for a 125 horsepower package boiler fired with oil or gas. Operating costs for FBC would be $54,000/yr including credit for tire disposal savings at $0.25/tire. An oil unit would cost $131,000/yr to operate, and a gas unit would cost $108,000/yr. Although a retreader could save at least $50,000/yr in fuel and disposal costs, the additional $900,000 capital investment would not be recovered for at least 12 years. National Standard concluded that retreaders would not buy FBC systems under these circumstances, and they suspended their program.

Part of the problem stemmed from the small size of the FBC system. The utility industry had previously concluded that the smallest feasible coal-fired FBC can produce about 112 horsepower. National Standard and DOE hoped that tire disposal savings would offset the higher unit capital cost of their 75 horsepower unit. This hope was not realized under the energy prices, tire disposal costs, and interest rates that prevailed in the early 1980s.

Small-scale tire burning FBCs could become practical if interest rates stay low while both energy prices and disposal costs rise. However most of the current work involves considerably larger units. One of these is a project by Garb-Oil & Power Corp. of Salt Lake City which is developing a plant in Rialto, California that will burn 24,000 tires/d in fluidized bed boilers and generate 30 MW of electricity. Garbalizer shredders will be used to reduce the tires to 2-inch pieces. Ash will be used in concrete bricks and blocks. The project has survived a series of feasibility studies and is now immersed in California's complex air quality permitting process.[86]

Several other projects are in the conceptual stage. Shawmut Engineering Co. and National Ecology, Inc. are considering a 50 MW pressurized FBC in Baltimore that will burn 700 t/d of processed refuse and 80 to 100 truckloads per day of shredded tires.[87] Cogeneration Systems, Inc., a subsidiary of Energy Recovery Systems, Inc. of Great Neck, New York is developing a process to burn tire chips with waste wood and refuse in Riley Stoker FBCs. One potential site identified is in Madison, Maine. Finally, Ergon Fluidized Bed, Inc. is working on a number of turnkey projects to make steam from shredded tires and hazardous wastes. Sites under evaluation include New England, New York, California, the Southeast, and Alaska.[88]

Summation. Rotary kilns are well-demonstrated devices with a long history of successful application in the minerals and energy industries. Grate furnaces are also well established, since they have been used in many power plants and steam stations and are now being applied in numerous waste-to-energy facilities. Basic's unique pulsed hearth incinerators have been well demonstrated at the Firestone plants. FBC is a proven technology for coal and other fuels, but its ability to burn tires on a sustained basis has yet to be demonstrated.

Although technical feasibility seems to be indicated, an equally important question is whether a new tire burning facility can be economically viable. The answer depends on how much the plant will cost to build and operate and how much income can be obtained from disposal fees and energy sales. According to Basic, the Firestone incinerators are clear winners because while they cost only $2.6 million to install and require only one worker to operate, they save several hundred thousand dollars per year in avoided fuel and waste disposal expenses. Similarly, the Oxford plant appears to be feasible for California and New England where tipping fees and power prices are relatively high. Such a facility would be less attractive in areas like Colorado where the costs of both disposal services and energy are much lower.

Summary Evaluation of the Management Options

Table 2-2 summarizes selected characteristics of the tire management options discussed above. It is important to note that most of the options have already been implemented at some scale. For example, retreaders already recycle about 20% of the used tires, tire splitters consume about 3 million tires/yr, and chemical processors reclaim rubber from an additional 10 million carcasses. This is why only 170 million or so of the 240 million tires that are discarded each year wind up in stockpiles, illegal dumps, or other sub-optimal disposal sites. The table evaluates the potential to increase the contribution of each option and thus to further reduce the tire management problem. Following is a discussion of each parameter considered.

Status. Most of the options have been well demonstrated and can be considered proven in a technical sense. Exceptions are the soil conditioner and bulking agent applications, which are in the research stage, and asphalt rubber, which is still undergoing testing.

Outlook. Landfilling whole tires, construction, and physical processing to obtain rubber goods are generally stable applications with limited potential for expansion. Whole-tire landfilling may decline if more states ban such disposal because of the flotation problem. Landfilling chopped or shredded tires, asphalt rubber, and

Table 2-2: Summary Evaluation of the Management Options

	Status	Outlook	Potential Impact	Capital Costs	Operating Costs	Revenue	Setup Time	Environ-mental Effects	Major Restraints
LANDFILLING									
Whole	P	S	H	L	H	N	L	M	Tipping fees
Chopped	P	E	H	M	H	N	M	L	Tipping fees
Shredded	P	E	H	M	H	N	M	L	Tipping fees
RETREADING	P	D	L	M	H	H	M	N	Market
CONSTRUCTION									
Reefs	P	S	L	L	M	N	L	N	Logistics
Barriers	P	S	L	L	M	L	L	N	Market
Other	P	S	L	L	M	L	L	N	Market
PHYSICAL PROCESSING									
Rubber Goods	P	S	L	M	M	H	M	N	Market
Soil Conditioners	R	U	L	M	M	M	M	L	Market
Bulking Agents	R	U	L	M	M	M	M	L	Market
Asphalt Rubber	T	E	H	M	H	H	M	N	Costs
CHEMICAL PROCESSING	P	D	L	H	H	M	M-H	M	Market
ENERGY RECOVERY									
Pyrolysis	P	E	H	H	H	M-H	H	M	Costs
Existing Combustors	P	E	H	M	M	M-H	M	M	Market
New Boilers	P	E	H	H	H	M-H	H	M	Costs

Key

D: Declining	M: Medium	S: Stable
E: Expanding	P: Proven	T: Testing
H: High	N: None	U: Unknown
L: Low	R: Research	

Source: City of Denver

the energy recovery options are expanding. Chemical processing is likely to continue to decline unless new reclaiming technologies prove cost-effective. Retreading is also declining, although new methods and materials to produce steel-belted retreads may reverse the trend. The outlook for soil conditioners and bulking agents remains unknown pending additional research and demonstration.

Potential Impact. Landfilling, asphalt rubber, and energy recovery are the only options with high potential to further reduce the disposal problem. The others are severely limited by logistics or market problems.

Capital Cost. Whole-tire landfilling and construction require little equipment and therefore have low capital costs. The chemical processing, pyrolysis, and new boiler options need sophisticated equipment and facilities and therefore have high capital requirements. The other options require relatively simple hardware, such as shredders, and could be implemented with a medium level of investment. Retreading lies at the upper end of the medium range.

Operating Cost. The landfilling options have high labor costs and landfill tipping fees. Retreading and chemical processing are also expensive because of labor costs and equipment maintenance and replacement charges. Pyrolysis and the new boiler option have high financing, labor, and depreciation costs. The existing combustors option has lower costs because less equipment and labor is required. Asphalt rubber requires grinding tires to a small size range, which is very expensive.

Revenue. Landfilling and reefs produce no revenues. Retreading, rubber goods, and asphalt rubber produce high revenues where a market exists for the products. Soil conditioners, bulking agents, and rubber reclaimed by chemical processing can produce only medium levels of revenue because the rubber must compete with low-cost alternate materials. The energy recovery options have medium-to-high revenues depending on the local value of the energy forms produced. New boilers could do well in areas that have high electricity costs. Existing combustors can be good markets if the rubber displaces a premium conventional fuel such as low-sulfur coal along the East Coast.

Revenues accruing to pyrolysis plants are very sensitive to the value of the char product.

Setup Time. Whole-tire landfilling and construction require minimal times to implement, whereas landfilling of chopped or shredded tires, retreading, existing combustors, and physical and chemical processing require longer times because some specialized equipment must be ordered. Pyrolysis and new boilers need the longest times to purchase equipment, build facilities, obtain financing, and gather the necessary construction and operating permits.

Environmental Effects. Retreading, construction, and the production of asphalt rubber or rubber goods should have no significant effects on the environment. Landfilling chopped or shredded tires and the use of chips as soil conditioners and bulking agents should have a low level of impact assuming that leaching of metals and organic compounds from the rubber is not a serious problem. Whole-tire landfilling could also produce leachates and is further impeded by the flotation problem. Impacts from the chemical processing and energy recovery options should be moderate if the plants are properly equipped to control airborne emissions and residues. Pyrolysis should have a relatively low level of impact because the liquid and solid products are unlikely to be burned onsite.

Synopsis. The options that appear most favorable are landfilling chopped or shredded tires and energy recovery, with marketing rubber to existing combustors somewhat favored because of its lower costs and shorter setup times. Asphalt rubber may also have a large impact if test results continue to be favorable or if the current high production costs can be reduced. Using chips as soil conditioners and bulking agents is likely to make a smaller, but nevertheless appreciable, contribution.

State and Local Programs

Several state and local governments have tire management policies in place, and many others have regulations under development. Following is a summary of these policies, based on information from Resource Recovery Report and Scrap Tire News.[89,90]

In 1982, the **California** Waste Management Board provided $150,000 grants to help Granular Systems, Inc. and Ed's Tire Disposal purchase tire shredding equipment. Granular Systems is now converting 10,000 tires/d into fuel for pulp and paper mills and a cement plant. Ed's shredder is in Texas. The state is considering two bills that discourage tire burning in areas that do not comply with national ambient air quality standards.

Connecticut regulates tire storage and processing facilities and advises landfill operators on safe methods for burying tires. The state is also considering a bill to force owners of more than 500 scrap tires to remove, cover, or shred the tires to reduce the mosquito problem. Smaller piles must be removed. The Department of Transportation has approved the use of asphalt rubber.

In **Florida,** the Palm Beach County Solid Waste Authority has a draft rule requiring tire dealers to prepare manifests for tires shipped from their premises. The intent is to reduce the illegal dumping of old tires. The state operates a plant that employs convicts to retread tires from state vehicles. The state's Department of Environmental Regulation helps local governments in their efforts to control mosquitoes by ensuring that old tires are buried.

The **Maine** Department of Environmental Protection will soon require permits for tire stockpiles, to reduce the flow of waste tires from other states. The department already regulates tire storage and landfilling.

Maryland prohibits landfilling of whole tires, and three counties shred tires at their landfills. The state has tested the use of rubber chips for sludge composting. Technical feasibility was demonstrated but economics could not be determined. Tests on asphalt rubber showed no economic advantage. The state helped Ocean City build a tire reef in the late 1970s.

Massachusetts is implementing a statewide recycling program and is considering several alternatives for scrap tires. The Department of Environmental Quality Engineering has asked citizens to help it prepare an inventory of tire stockpiles.

The **Michigan** legislature has reviewed the state's tire problem and the disposal options, and the state is considering a bill to regulate the size and location of stockpiles. A $1 surcharge on vehicle registration fees would raise funds to subsidize scrap tire processors and to help stockpile owners bring their piles into compliance. A state agency has initiated a market research study to find uses for old tires.

In 1985, **Minnesota** sponsored a comprehensive study of waste tire disposal options. The state now bans tire landfilling and regulates the collection, accumulation, and storage of tires. The Pollution Control Agency is charged to eliminate existing tire dumps. Stockpilers with more than 500 tires who do not comply with the regulations must submit cleanup plans or assign their piles to the state. A $4 surtax on vehicle registrations supports the state's cleanup projects and provides low interest loans to tire processors. The new reclaim plant in Babbitt was subsidized from this source. The state has tested asphalt rubber but has no immediate plans to use the material.

In 1986, the **Nebraska** legislature rejected a bill that would tax retailers to raise funds for recycling programs. A state task force has been formed to help develop a solid waste management and recycling plan. The state is testing asphalt rubber.

New Hampshire has state-level programs to deal with glass, paper, and other recyclables but not with tires. However the state is analyzing the literature dealing with asphalt rubber and in 1985, the state requested proposals from firms interested in developing tire recycling and disposal processes. No awards have yet been made. Several private firms have proposed to build plants that can burn tires.

In 1985, the **New Jersey** legislature rejected a bill to impose a $3 deposit on tires sold in the state. Further hearings were held in 1986, but action was postponed after discussion with tire manufacturers, dealers, and retreaders. The state's Source Separation and Recycling Act instructs the Office of Recycling to study funding mechanisms and methods for tire disposal and asks state agencies to consider asphalt rubber, which has been tested in New Jersey. The office and the Rubber Manufacturers Association have co-sponsored a study of waste tire recycling. The office also offers grants and loans to developers of waste recycling projects. The state has helped build tire reefs in the past and is now monitoring the development of pyrolysis technologies.

In 1985, Governor Cuomo of **New York** vetoed a bill directing the Department of Transportation to assess asphalt rubber. He has since directed the department to survey the research on asphalt rubber and has asked the Department of Environmental Conservation to assess the environmental aspects of current tire disposal methods. The state Department of Energy sponsored a study of tire pyrolysis that defined the market limitations. The department planned to offer support to tire recycling activities in 1986. The state is also considering a $5 deposit on new and recapped tires in order to discourage stockpiling and encourage recycling. Only tires sold in the state would be affected. These would be labeled. New York City has a project to demonstrate use of shredded tires as daily cover at the Fresh Kills landfill on Staten Island.

North Carolina has established a Used Tire and Waste Oil Committee to analyze the disposal and recycling alternatives. The state also offers tax incentives to buyers or builders of recycling or resource recovery equipment and facilities. A 1985 study for Cumberland County recommended using crumb rubber as fuel and in asphalt, an increase in tire disposal fees, and assessment of pyrolysis processes.

The **Ohio** Environmental Protection Agency is sponsoring a used tire study and has organized a task force to guide the work and assess the findings. Results are pending. TDF has been burned in waste-to-energy plants in Akron and Columbus. Tests of asphalt rubber are underway.

In **Oregon,** whole tire landfilling has been banned near Portland since the early 1970s. Portland once required permits to collect, process, or ship tires and imposed a $0.03/tire tax on new tires. This ordinance was overturned by the state legislature. The state does not restrict the landfilling of whole tires, but is considering a bill to prohibit land disposal and to offer tax incentives to purchasers of tire chips. A $1 surcharge on vehicle title transfers would fund tire cleanup projects. Regulations are being developed for stockpiles with more than 1,000 tires. The state helped build a small tire reef in 1976.

Rhode Island is developing a master plan for dealing with solid wastes including tires.

Vermont is considering a $10 deposit on each new tire to encourage orderly disposal and to support development of recycling processes. Only tires sold in the state would be affected. These would be labeled.

In 1985, after two serious stockpile fires and just before a third one, the **Virginia** legislature called for a model ordinance to deal with the public safety aspects of tire storage and recycling. No other tire-related legislation has been proposed. However the state's new air quality regulations have postponed the burning of TDF in Westvaco's paper mill until the emissions are characterized.

Washington's Used Automobile and Truck Tire Storage and Recycling Act outlaws dumping of tires on land not owned by the tire owner. It also directs the Department of Ecology to coordinate tire removal projects and to assist in the development of improved disposal and recycling projects. Activities under the act are funded by a 0.015% tax on the gross proceeds of firms that sell tires in the state. Programs include a public information campaign and support for local government projects to clean up illegal tire dumps. The state has tested asphalt rubber but no results have been released.

In 1985, the **Wisconsin** legislature rejected a bill to fund tire disposal with a $1/yr surcharge on vehicle registrations. Tests of asphalt rubber began in 1986.

Summary Evaluation of the Policy Options

Many of the regulatory programs have in common (1) banning whole tire landfilling to minimize the flotation problem, (2) regulating tire stockpiles to reduce fire hazards and propagation of disease vectors, and (3) providing a mechanism to raise funds for cleanup projects and to subsidize recycling and resource recovery. The third type of policy--the fund-raising mechanism--has proven to be the most difficult to develop.

A policy to encourage orderly disposal of a commodity should have the following characteristics:

1. It should ensure that acceptable disposal facilities are available and it should provide for their beneficial, efficient, and economical operation.
2. It should not alter existing production and marketing systems.
3. It should not attempt to modify the behavior of individual consumers.
4. It should minimize the number of organizations that inventory the discards and are responsible for their delivery to a disposal facility.
5. It should encourage competition, and it should neither favor nor impede the competitive posture of any entity or product.
6. It should have specific, achievable targets, and it should use easily measurable benchmarks to track its progress.
7. It should minimize paperwork and provide reasonable and enforceable penalties to discourage neglect, fraud, and abuse.
8. It should cover a large geographical area.

Geographical scope is crucial. Well-designed national policies should be more effective in dealing with commodities like tires that can easily cross state borders. State-level policies are less desirable and can cause problems by shifting the management burden to adjacent jurisdictions. This happened when Minnesota banned tire landfilling effective July 1, 1985. After that date, more and more tires began to appear in neighboring Wisconsin.

Timing is also crucial. Minnesota's tire management program, for example, banned landfilling and called for creation of alternate disposal facilities. However the landfill ban was imposed <u>before</u> alternatives were made available. Most waste haulers immediately began refusing to pick up tires from their residential customers. According to one observer, this made the residents "confused and angry."

There have been several attempts to develop management policies for both scrapped vehicle tires and disposable beverage containers. There is no physical similarity between a radial tire that is black, weighs 20 pounds, and lasts for 60,000 miles or 6 years whichever comes first, and a shiny aluminum can that weighs less than an ounce and has a lifespan of a few weeks. However the disposal problems associated with these ostensibly diverse materials are in many ways similar. Scrapped tires and spent containers both result from the public's desire for convenience at low cost. Both are highly visible commodities, the improper management of which can reduce the quality of life and even threaten public health and welfare. Both can be recycled or disposed of productively, but the recovery systems must be efficient to be economical. Both are generated in comparable quantities. In 1985, the beverage industry shipped about 70 billion aluminum cans weighing 1.3 million tons.[91-92] In 1985, 170 million tires, weighing about 1.7 million tons, were discarded.

Absent uniform management policies at the national level, some state governments have taken the initiative. Several have enacted deposit laws for containers in which consumers pay a deposit when they buy a filled container and receive a refund when they return the empty to a retailer or recycler. Several states have also proposed or enacted deposits and surcharges on tire sales. These actions have also been controversial and have encountered problems generally similar to those experienced in the container programs. One shortcoming of this approach is that individual citizens must change their lifestyles to accommodate recycling. Another is that retail firms must handle large quantities of discards and manage the cash flows from which refunds are paid. Substantial reporting requirements were also needed to measure progress and to avoid fraud, and it is difficult to ensure that only eligible discards are accepted for refund.

The controversy has encouraged both industries to seek more workable alternatives. One such alternative for beverage containers is the Beverage Container Recycling & Litter Reduction Act which was recently enacted in California as Assembly Bill 2020.[93] The bill avoids some of the deposit law problems by transferring the burdens from consumers and retailers to the firms that make beverages and containers and that recover the recyclable components when the containers have served their purpose. It does so by providing for a series of fees to be paid by manufacturers and distributors to organizations that collect and process containers and container materials. The program is managed by a state agency which sets the fees and imposes auditing and reporting requirements on the private participants.

The bill was a compromise that was supported by parties with widely divergent viewpoints because the alternatives were less appealing. The bill does satisfy some of the criteria stated above. If convenient disposal facilities are not created by entrepreneurs, the bill mandates their creation by beverage distributors and dealers. It does not alter existing beverage production and marketing systems, although it does complicate some of their operations. It does not require consumers to participate actively. Rather it leaves the responsibility for container collection with a much smaller number of entities--the beverage, container, and recycling companies. It affects all beverage containers regardless of their materials of construction or contents. It has specific targets and benchmarks and has the capacity to adjust if the targets are not met.

Some of the bill's provisions could be useful in legislation to encourage the orderly disposal of scrapped tires. One option is a set of state policies to ban the importation of scrap tires, require delivery of tires to licensed disposal facilities, and establish fees and a fund to provide the necessary cash flow. A surcharge could be imposed on each tire sale at the distributor level, with higher charges applied to larger tires or to those that create special disposal problems. The surcharges would be passed through to retailers and then to their customers. Distributors would deposit the surcharge proceeds in the tire management fund. Payments would be made from the fund to subsidize disposal operations. Disposers would be selected based on competitive proposals, with the winners offering an attractive balance of social benefit and low subsidy. They might include resource recovery plants or shredders to prepare the rubber for landfilling or storage.

Some states have tried to adopt this approach, with varying degrees of success.[94] The option does a number of negative aspects. First, it does not provide an incentive other than the threat of prosecution to ensure that scrap tires are delivered to an approved disposal facility. This might be handled by requiring that all tires traded in for new units be returned to the distributors, who would then be responsible for their final disposal. Each distributor would contract with a disposer for delivery of a number of tires equal to the number of tires that the distributor will sell during the same period. This process would begin to resemble a deposit law, but with a smaller number of firms afflicted, and it would be complicated and costly for the distributors. Minnesota has handled the problem in a more efficient fashion by encouraging only minimal tipping fees at the disposal facilities subsidized out of its tire management fund. It thus attempted to ensure that an approved facility was the least-cost disposal option, a necessary feature to prevent tires from moving to other states with less stringent regulations. Success was impeded when the first such facility was located 200 miles from the region that produces most of the scrap tires.

Another criticism is that the tire industry is solely responsible for collecting and transferring the surcharges. The industry advocates a free market solution with little or no government intervention.[95,96] Where market forces are not sufficient, however, the industry appears most comfortable with policies that induce other entities who derive benefit from tires to share the responsibility for their ultimate disposal. Some states have addressed this concern by imposing surcharges and taxes on motor vehicle registration fees and title transfer fees, rather than on tire sales. This policy may be more equitable because it distributes the burden to auto dealers and individual motorists, including those who happen to make or sell tires to earn a living.

CHAPTER 3
PROJECT DESCRIPTION

INTRODUCTION: THE SCRAP TIRE PROBLEM IN DENVER

Colorado's citizens discard approximately 3 million tires annually. Most of these are produced in the Denver metro area, which contains 55% of the state's population. In recent years, most of the discards have been placed in stockpiles, which in the Denver area now contain perhaps 20 million old tires. To date these piles have not been particularly troublesome because there have been no serious fires and the dry climate does not favor mosquito propagation.* There is an exception, however, that adds a unique dimension to Denver's tire management problem.

Between 1964 and 1980, portions of the City's Lowry Landfill were used for the disposal of mixed municipal and industrial wastes, including those now considered hazardous. Approximately 100 million gallons of liquid wastes were landfilled in this manner. The theory was that the refuse would absorb most of the liquids, and any that were not so stabilized would be trapped by the underlying clay soils. Beginning in 1974, scrapped tires were piled on top of the filled disposal cells. This stockpile now contains roughly 8 million tires. Most are passenger tires, although a substantial number are from large trucks and earthmovers.

Data from monitoring wells indicate that chemicals from the disposal pits are migrating into the groundwater system. In September 1984, the U.S. Environmental Protection Agency (EPA) declared that this contamination posed an imminent and substantial danger to public health. EPA listed the disposal area as a Superfund site and is now evaluating the extent of the contamination, the severity of the health

* See Appendix for an update.

threat, and the methods that could be used to mitigate further damage. The City has been asked to move the tires, in order to facilitate the site evaluation and any future cleanup operations. Denver is now trying to develop a safe, economical method to dispose of the tires and to create management policies that will help avoid tire problems in the future. The current study was initiated to determine how these goals could best be met.

OBJECTIVES, SCOPE, AND METHODOLOGY

The principal objectives were (1) to find a safe, economical method to remove and dispose of the stockpiled tires, (2) to identify management policies that could help avoid further problems, and (3) to share the findings with other jurisdictions that are struggling with tires.

Achieving the objectives involved five major tasks. In Task 1: Define Resources and Recovery Options, the technical, economic, environmental, and public health issues associated with the national tire problem were identified. Possible solutions were also characterized with respect to their status, potential, limitations, incentives, and impediments. This work included an extensive literature review, contact with other jurisdictions that have tire problems, and contact with technology developers who claim to have solutions. Also included were site visits to tire processing operations and resource recovery plants, and attendance at conferences dealing with the management of tires and other unusual solid wastes.

In Task 2: Screening Studies, the possible solutions were assessed to identify those with the greatest potential to help Denver deal with its tire problem in a timely and economical fashion. Particular attention was given to the availability of local markets for recovered materials and energy, and to the limits imposed by energy prices and the air pollution problem in the Denver area. Sources of information and technical assistance included regulatory agencies, tire stockpilers and processors, waste management firms, utility companies, and the suppliers and purchasers of conventional energy fuels.

In Task 3: Case Studies, the most promising management options were assessed to determine their technical and financial requirements, timing, and environmental and social effects. Options were rated based on the expected setup time, capital and operating costs, revenues from sales of energy and materials, and potential for creating a substantial, long-term, and beneficial solution to the tire problem. Public policies required to support their implementation were also examined.

In Task 4: Transfer, the findings were transferred to other jurisdictions in the Urban Consortium, principally through a workshop conducted in Denver in February 1987. Task 5: Management and Reporting covered project management activities and the preparation of interim and final reports.

FINDINGS

The findings from Task 1 were reported in Chapter 2. They are summarized below.

The National Tire Problem

Tires are difficult and expensive to bury, and many refuse incinerators cannot accommodate large quantities of whole tires. As a result, tire disposal costs are rising, illegal dumping is widespread, and large stockpiles have developed in many areas. Stockpiles are dangerous because they can harbor disease vectors and are subject to environmentally destructive fires.

The National Management Options

Landfilling. Landfilling is technically feasible and could dispose of all the scrapped tires, including those in stockpiles.

However the tires must first be sliced or shredded or carefully buried under dense refuse. The additional handling or processing is time-consuming and expensive, and burial inhibits resource recovery.

Retreading and Re-Use. The demand for retreaded passenger tires is declining. Although up to 20% of newly discarded tires may continue to be recycled, retreaders will have negligible impact on the stockpile problem.

Construction. Specialized construction could, in theory, consume several million tires per year. However logistical and economic considerations will seriously impede the full development of the option.

Physical Processing. Although **splitting** companies consume about 3 million tires/yr, little growth is anticipated and the industry may decline as steel belted scrap tires become more prevalent. Also, splitters prefer new discards to stockpiled tires that may be dirty and weathered. Using **rubber chips** as soil amendments or bulking agents may have a modest impact on the tire problem if they can displace the inexpensive materials now in use. Using the finer **rubber crumbs** in asphalt rubber is one of the few applications that could theoretically consume all of the scrap tires. Until grinding costs decrease, however, asphalt rubber may be limited to areas where road repairs are unusually expensive.

Chemical Processing. Chemical reclaiming now recycles 10 million tires per year. However the industry has been declining for 25 years, and most of the existing plants are antiquated. The potential for more modern plants is clouded by marketing uncertainties and by the surplus capacity of the existing facilities.

Energy Recovery. Rubber from the average scrap tire is a very attractive fuel compared with most coal types. However when steel-belted discards become more common, the average fuel properties will be only slightly better than a good grade of bituminous coal.

Tire **pyrolysis** is a workable approach to energy recovery, but its feasibility is sensitive to the market values of the char and the liquid fuels. Medium to high tire tipping fees are essential. Plants should not be sited near large energy users that could afford to pay for rubber fuel.

A few **existing boilers** can burn whole tires, and a much larger number can handle shredded rubber. The most appropriate boilers are rotary kilns and spreader stokers found in some of the smaller power plants and steam stations, as well as in certain refuse incinerators, pulp and paper mills, and wood processing plants. It is helpful to remove some of the wire when the tires are shredded. Emissions can be a problem unless the combustor has adequate controls.

Cement kilns with preheater or precalciner sections can be adapted to burn whole or shredded tires. The older long kilns can also burn shredded rubber, but more modification is needed and the process is more difficult to control. Wire is not a problem, and emissions can usually be accommodated by existing controls. The less-common **lime kilns**, such as those used in the sugar industry, offer a similar opportunity.

Burning tires in **new boilers** has potential if a large tire resource is available, the energy commands a high price, and environmental standards can be met. Rotary kilns, grate combustors, and pulsed hearth furnaces have been shown to burn whole tires efficiently and cleanly. Shredded tires can be also be burned in these units or in fluidized bed boilers like those used for coal.

Summary. The most attractive management options for further reducing the national scrap tire problem appear to be landfilling chopped or shredded tires, energy recovery, and asphalt rubber.

The National Policy Options

State-level tire management policies range from none to integrated programs that prohibit whole tire landfilling, regulate or prohibit stockpiles, and subsidize improved disposal practices and resource recovery plants. Some states have enacted taxes or deposits on tire sales to raise funds for disposal programs. Others have imposed surcharges on vehicle registration fees and title transfer fees. These are more acceptable to the tire industry because they distribute the responsibility for tire disposal more broadly.

Potential Denver Solutions

Following are the results from Task 2, in which the management options were screened to identify those with potential for Denver.

Landfilling is a technically feasible solution to the stockpile problem. Retreading is not a practical outlet for the stockpile because many of the tires were put there after retreaders found them unsuitable for further use. Retreaders can easily obtain an adequate supply of fresh carcasses from tire retailers at little or no cost. Construction is not a solution. There is little need for artificial reefs or breakwaters in the Denver area, although a few tires could be used in crash barriers and playground equipment.

Physical Processing has some promise. **Splitting** is not a viable option since plants in other areas already have surplus capacity and transportation costs for their products are fairly low. Also, splitters prefer clean, unweathered carcasses, which they can easily obtain from tire retailers. Some of the stockpiled tires are not clean and most are weathered. Some Denver-area tires are already being hauled to Mexico, where they are made into sandals. This will probably continue; however the net effect on the Lowry pile and on the future generation of scrap tires will be minimal. **Rubber chips** could be used to treat sewage sludge in an existing composting facility in the Denver area. Using small chips as soil amendments has greater potential, since many Rocky Mountain areas have highly compacted soils. Asphalt made with **rubber crumbs** could be cost effective in Denver's high traffic areas and on nearby mountain roads that see harsh service and are costly to maintain.

Energy Recovery has potential, but the projects would have to be carefully developed. Liquid fuels from a **pyrolysis** plant should be salable to refineries near Denver. Carbon black would have to be shipped to more distant markets. **Existing combustors** near Denver could, over time, consume all of the rubber in the stockpile plus all of the scrap tires that will be generated in the future. Potential markets include power plants, steam stations, cement plants, sugar plants, and other industrial boilers. Shredding and transportation costs, emissions controls, and the need to compete with low-cost coal are important considerations. **New boilers** dedicated to tire fuels could also be built. However Denver's stockpile is too small to sustain a large facility, and the price available for electric power is quite low.

Assessment of the Denver Solutions

As indicated above, the potential solutions to Denver's stockpile problem include landfilling, physical processing to obtain chips and crumbs, and energy recovery. Following are the findings from Task 3, in which these options were assessed in more detail.

Landfilling. Tires from the stockpile could be buried whole, chopped into large pieces, and shredded into small pieces. Costs would be incurred for collecting the carcasses from the stockpile, chopping or shredding them if desired, and hauling the rubber to a landfill. Table 3-1 contains a breakdown of the costs anticipated in each of these categories. Burial cost quotations were obtained from Waste Management of Colorado, Inc., which operates the Denver-Arapahoe Disposal Site, a sanitary landfill near the tire stockpile.[97] Collection, processing, and haulage costs were based on estimates from several firms that shred tires under contract.[98-107] "Chopped" tires are cut into two to four pieces. "Shredded" tires are cut into pieces smaller than 6 inches with a single pass through a commercial shredder. Estimates apply only to tires from cars and light trucks. Heavy equipment tires would cost much more.

As indicated, collection costs do not depend on the final condition of the rubber. However processing, haulage, and landfilling costs vary substantially. At $1.09 each, whole tires are the most expensive to bury because they occupy large volumes and are difficult to keep underground. Chopping reduces volume by about 50% and reduces disposal costs to $0.70 per tire. Shredding reduces volume by 80%, and although shredding is expensive, the option is the most practical overall because the shreds are so cheap to haul and bury. The total disposal cost is $0.54 per shredded tire.

Table 3-1: Costs of Landfilling Stockpiled Tires

Tire Condition	Unit Costs, $/tire Collect	Process	Haul	Landfill	Total
Whole	0.10	0.00	0.07	0.92	1.09
Chopped	0.10	0.24	0.03	0.33	0.70
Shredded	0.10	0.32	0.02	0.10	0.54

Source: City of Denver

Physical Processing. As noted, **rubber chips** can be used for composting sewage sludge or to condition soils. The composting option has been tested in lab and field studies in other states, although research has not yet progressed to the point where economics can be conclusively evaluated. Tire chips appear to work well, although concerns have been expressed over the release of heavy metals and the lack of water absorbtion, which makes the sludge slushy and impedes biodegradation.[108] On the other hand, tire chips can be re-used several times, an advantage not enjoyed by conventional media such as wood chips. Smaller tire chips have also produced some impressive improvements in plant growth when tested in soils laboratories.[109] Performance was at least equal to wood chips, peat, and other mulches. Tire chips have an additional advantage in that they remain intact for several years before they are finally degraded by natural biological processes. Conventional mulches last only one or two seasons.

Tire-based soil amendments may be most helpful in highly compacted clay soils like those found in the ancient alluvial basins along the Front Range of the Rockies. Potential markets include sod companies, landscaping firms, land reclamation operations, and individual homeowners. However additional research is needed to demonstrate the potential, and the chips are not ready for commercialization.[110]

Together the composting and soil conditioning markets could consume several hundred thousand old tires per year. Their potential impact on the Lowry pile would be small, although they could form the basis for a new local industry. The scrap steel co-product would provide additional revenues, although relatively few of the Lowry tires are steel belted and only the bead wires would be recoverable.

Rubber crumbs are more costly to prepare, but they have a higher market value. Crumbs could be used to make light-duty rubber products if a processing industry could be developed in the Denver area. Crumbs shipped to other areas could not compete with locally produced materials. Asphalt rubber, on the other hand, could be cost effective for repairing road surfaces in Denver's high traffic areas and in the nearby mountains. It could also be incorporated in the extensive program of new highway construction that is underway in and around Denver. Although the asphalt rubber market could take years to develop, it eventually could consume several million tires annually. As with rubber chips, scrap steel sales would provide additional income.

Energy Recovery. The liquid products from a **pyrolysis** plant could probably be sold to refineries near Denver. However the carbon black would have to be shipped to more distant markets. Economic feasibility would depend on the value of the carbon black which, as noted in Chapter 2, is inferior to virgin material and has only limited application in the tire industry. Absent a high price for the carbon, a large tire tipping fee would be needed to balance revenues and expenses. As noted previously, tire fees at Denver landfills can exceed $1 per tire. However there are stockpile operators and shredding plants that charge only 15 to 20 cents per tire. It is not clear that this revenue would be sufficient to ensure profitability.

With respect to environmental impacts, pyrolysis does tend to produce less air pollution than combustion because two of the products--oil and char--are not burned in the processing facility. However the gases normally are burned, to generate the heat that drives the pyrolysis reaction. Combustion products would have to be thoroughly cleaned to avoid aggravating Denver's air quality problem.

A modestly sized pyrolysis facility might be economical if it could capture the Lowry tires and most of the tires that will be discarded in the future. However the process would have to be thoroughly demonstrated and the plant would have to be carefully engineered and operated. It is not clear that the necessary tire tipping fee could be obtained since, as discussed below, nearby industries may be willing to accept the rubber without a fee or even to buy it as a supplemental fuel.

Like all urban regions, the Denver area has a large number of **existing combustors**, including power plants, steam stations, and industrial furnaces and boilers. Some of these might be able to burn tires or chips if they have the appropriate combustion equipment and pollution controls. The task was to learn where such plants are located and then to learn if their operators might be interested in an alternate fuel source. The approach was to work with the Colorado Department of Health, which is the state agency responsible for implementing air quality regulations under the federal Clean Air Act as amended. Other jurisdictions with the same task should be able to use similar resources. Other potential sources of information include boiler permitting and inspection agencies of state and local government, trade associations, and companies that sell engineering design services, combustion equipment, and industrial maintenance. Fuel suppliers such as coal companies could also be helpful, although they might be reluctant to provide information to a prospective competitor.

The Department's Stationary Sources branch provided a computer printout that summarized the characteristics of some 77 combustion units that are monitored regularly for compliance with the clean air regulations.[111] For each unit, the document listed location, owner, nature of the combustion equipment, type of energy produced, fuel consumed, and air quality controls in place. Units ranged from Public Service Company of Colorado's Pawnee power plant which can burn 336 t/hr of coal, to an industrial furnace that consumes about 2 lb/hr. Controls range from none to wet scrubbers.

This list was screened to isolate units that (a) burn lump coal in rotary kilns, fluidized beds, or with stoker feeders, and (b) have at least a baghouse in place. These are minimum criteria to burn shredded rubber without extensively changing the feeders or the controls. Facilities meeting these criteria are listed in Table 3-2, which also shows how much rubber would be consumed if it displaced 100%, 15%, or 20% of the coal.

The list includes two utility operations: Centel Corp. and Colorado-Ute Electric Association. Centel's plant is located in Canon City, Colorado, about 110 miles south of Denver. As described in Chapter 2, Centel has already burned shredded tires in its spreader stoker boiler. Colorado-Ute's plant is under construction in Nucla, Colorado, about 250 miles west of Denver. Shredded tires could be burned in the plant's new fluidized bed boiler or in the spreader stokers that have been idled pending completion of the new combustor.

The list also includes steam stations operated by the General Services Administration at the Denver Federal Center in nearby Lakewood, and by the U.S. Army in more distant Pueblo, Colorado. The Climax Molybdenum plant produces steam for minerals processing. The Agri-Energetics plant produces steam to process agricultural products. The beet sugar plants were idled by their previous owner, Great Western Sugar Co., but some of them have resumed production under new ownership. Facilities include two lime kilns and three process steam generators.

Full implementation of this option could remove perhaps 100 tons of tires per day from the Lowry stockpile. At this rate, the stockpile would disappear in less than 3 years. There are limitations, however. For example, although all of the facilities have baghouses to capture particulate emissions, their sulfur dioxide controls would have to be augmented unless the rubber were blended in fairly low concentrations with low-sulfur coal. Transportation costs would pose some serious obstacles for the more-distant plants. The Colorado-Ute plant is too far to be a practical outlet. The Pueblo boilers are borderline. In addition, the tires would have to be shredded to smaller than 2 inches, which is expensive, and some of the bead and belt wires would have to be removed. Sale of scrap steel would help offset the processing costs, but the income would not be substantial.

Also shown in the table are three **cement kilns** that could burn large quantities of rubber if the fuel were offered at a favorable price. One of the kilns could probably burn whole tires; the other could accommodate the coarse pieces produced by one pass through a

Table 3-2: Combustion Units In Colorado that Could Burn Shredded Rubber

FACILITY	COUNTY	PRODUCT	TONS/DAY RUBBER AT % FUEL DESIGN CAPACITY * @ 100%	@ 15%	@ 20%
Centel Corp.	Fremont	Power	199	30	40
Centel Corp.	Fremont	Power	245	37	49
Climax Moly	Grand	Steam	86	13	17
GSA	Jefferson	Steam	112	16	22
Great Western	Larimer	Steam	153	23	31
Great Western	Larimer	Lime	68	10	14
Great Western	Morgan	Steam	120	18	24
Great Western	Weld	Steam	190	29	38
Agri-Energetics	Larimer	Steam	11	2	2
U. S. Army	Pueblo	Steam	95	14	19
Colorado-Ute	Montrose	Power	912	137	182
Subtotal Boilers & Furnaces			2,191	329	438
SW Portland	Larimer	Cement	171	26	34
Ideal Basic	Larimer	Cement	329	49	66
Ideal Basic	Fremont	Cement	91	14	18
Subtotal Cement Plants			591	89	118
Total Existing Combustors			2,782	418	556

* Rubber at 15,000 Btu/lb displaces coal at 10,000 Btu/lb. Design capacity is maximum rate and is seldom achieved. 100% coal displacement unlikely because of sulfur emissions. Most applications would require several stages of shredding and possibly steel removal.

Source: City of Denver

shredder. The third, in Fremont County, has an old-style long kiln that would require much smaller tire chips.

Together the kilns consume nearly 900 t/d of coal when operated at their design capacity. This energy demand is equivalent to about 600 t/d of tire fuel. If rubber provided 20% of the energy input, as much as 120 t/d of tires could be drawn from the stockpile, and the pile would be depleted in less than 2 years. This scenario is overly optimistic, however, since technical, economic, and logistical restraints also apply here. The Fremont County plant, for example, is more than 100 miles from Denver, which could make transportation uneconomical. Although each plant is well equipped to control both particulates and sulfur, the fuel feeders would have to modified unless the tires were chipped to smaller than about 5/8-inch. The Fremont County plant would require this size range in any event. Finally, cement kilns can burn very cheap coal, and the rubber would have to be offered at a very low price to provide an economic incentive to the plant operators. A long-term supply would also have to be assured.

New boilers dedicated to tire fuels could also be built in Denver. However tire burning powerplants must be large to be economical, and they must receive high prices for the electricity they produce. Oxford Energy's California facility, for example, will consume 4.5 million tires/yr and will sell power for about $0.07 per kilowatt hour. Denver's stockpile is not large enough to sustain a facility of this size, and owners of other nearby stockpiles have less need to get rid of their tires. Furthermore, the price available for electric power in the Denver area is only $0.04 per kilowatt hour, which is considerably less than is obtainable in the locations where Oxford is building its power plants.

Smaller tire-burning plants like the one in Galex, Virginia could get by with fewer tires. However they would have higher capital and operating costs per tire processed, and they would also be afflicted by the low energy prices. Both large and small plants would have to charge high tire tipping fees to balance their cash flows. While Denver might consider a high fee to relieve the stockpile problem, other tire owners would be less interested, particularly if a cement plant or other fuel user were willing to pay for the tires. A reliable fuel source would therefore be difficult to ensure. This would be a major impediment to obtaining project financing.

Summary Evaluation

Table 3-3 summarizes the characteristics of the possible solutions to Denver's tire stockpile problem. The parameters are defined below.

Setup Time -- the time between a decision to proceed and the commencement of tire disposal. Ratings range from zero for disposal options that could proceed without delay to -3 for options that would require long times to implement. As shown, Whole Tire Landfilling could proceed almost immediately, whereas New Boilers and Pyrolysis could need 3 years or more for design, permitting, construction, and startup. The other options would require intermediate times to acquire specialized equipment such as shredders.

Capital Costs -- initial investment to procure equipment, facilities, and financing and to cover startup costs. Ratings range from zero for options with minimal investment requirements to -3 for the most costly facilities. As shown, New Boilers and Pyrolysis are the most expensive. Whole Tire Landfilling and the Cement Kiln market cost the least because they need relatively little equipment. Existing Boilers and Lime Kilns cost more than Cement Kilns because magnetic separators and more shredders would be required. The other options have similar ratings, largely because they would need similar types of hardware.

Net Operating Costs -- costs of operations less revenues from materials or energy sales. Ratings range from zero for options that would break even or show a modest profit without a disposal charge, to -3 for those that would require a large tire tipping fee to cover expenses. The Landfilling options have high net costs because there are no revenues to offset the burial fees. The Energy Recovery options all have positive net costs, indicating that a tire disposal fee would be needed to balance

Table 3-3: Summary Evaluation of the Tire Management Options for Denver

MANAGEMENT OPTION	SETUP TIME	CAPITAL COSTS	NET OPERATING COSTS	SOCIAL GAIN	NET RATING
	EVALUATION CRITERIA *				
ENERGY RECOVERY					
Existing Boilers or Lime Kilns	-2	-2	-1	3	-2
Cement Kilns	-2	-1	-1	3	-1
New Boilers	-3	-3	-1	3	-4
Pyrolysis	-3	-3	-1	3	-4
MATERIALS RECOVERY					
Rubber Chips	-2	-2	0	1	-3
Rubber Crumbs	-2	-2	-1	2	-3
LANDFILLING					
Whole Tires	-1	-1	-3	-1	-6
Chopped Tires	-2	-2	-2	0	-6
Shredded Tires	-2	-2	-1	0	-5

* See text for definitions of criteria and rating methodology.

Source: City of Denver

cash flows. Only for Rubber Chips are revenues expected to just about balance expenses.

Social Gain -- contribution to development of a substantial, long-term, environmentally acceptable, and otherwise beneficial solution to the tire problem. Ratings range from -1 for options that would accomplish only tire disposal without otherwise benefiting society, to +3 for those that convey substantial benefits. The Landfilling options have low ratings because no resources would be recovered and landfill space would be depleted. Whole Tire landfilling is rated especially low because of the flotation problem. The Rubber Chips option has a low rating because the market would be modest and could be slow to develop. Rubber Crumbs is rated higher because the market potential is relatively large. The Energy Recovery options all have high ratings, under the assumption that the plants would use advanced pollution controls to comply with the Denver area's stringent environmental regulations.

The final column displays the algebraic sums of the ratings for these four parameters. It is dangerous to attach much significance to these sums. To do so would imply that the parameters all have equal importance, which they do not. Setting these concerns aside yields the following very approximate rank ordering of the disposal options:

1. Supplemental fuel for cement kilns
2. Supplemental fuel for existing boilers and lime kilns
3. Recovery of rubber crumbs or chips
4. Construction of new boilers or pyrolysis plants
5. Landfilling shredded tires
6. Landfilling whole or chopped tires.

Other Considerations

First is the sense of urgency surrounding removal of the Lowry pile. The resource recovery markets will take time to develop, and several additional years will be required to deplete the pile. During this interval, site characterization studies and cleanup operations will be substantially impeded. This problem could be minimized by shredding the tires to a coarse size range and placing the shreds in a secure impoundment on the Lowry site but away from the Superfund area. This interim program could be accomplished within 18 to 36 months with careful planning.

Second is the fire hazard associated with the current stockpile. Although the area is patrolled, there is danger of arson or even ignition by lightning. Once ignited, the pile would be very difficult to extinguish and would produce serious environmental damage, both by emission of smoke and toxic gases and by contamination of soil and groundwater with pyrolysis products. This hazard would be reduced by the initial shredding step outlined above, which provides added incentive for its early implementation.

Third is the need to avoid problems with the chemicals found around the stockpile. Most of the tires are clean. However the bottom layer has been pressed into the soil, which near the disposal site contains chemicals that have percolated from the pits. In addition, a few tires were once wetted by a sprayback system used to prevent overflow of a surface water impoundment. Contamination should not now be serious, since chemical concentrations were originally small and the tires have been exposed to intense sunlight for several years. This premise should be verified before the tires are handled, processed, or sent offsite for burial or resource recovery. Contaminated soils also should be characterized and appropriate measures taken to protect workers from any hazardous liquids and vapors.

Fourth is the City's need to choose the extent of its future involvement in the scrap tire problem. There are three options:

1. The City can hire a firm to remove the tires and be responsible for their final disposal. The City's involvement would end when the contact was completed.
2. The City can shred the tires, stockpile the shreds, and arrange for their delivery to resource recovery facilities. This work could be performed by City personnel or by contractors. The City's involvement would end when the interim stockpile was depleted.

3. The City can work with other jurisdictions to develop effective and equitable state-wide programs to deal with existing tire stockpiles and with the tires that will be discarded in the future. The City's involvement with tires would continue indefinitely.

CONCLUSIONS

The scrap tire disposal problem is serious and widespread. However there are a number of promising management options, especially using the rubber as supplemental fuel for existing boilers and cement plants. The most cost-effective approach to dealing with Denver's tire stockpile appears to be shredding to a coarse size range, storing the shreds in a secure area, and marketing the rubber to nearby cement kilns and boilers. This interim step would greatly reduce the volume of the pile, end interference with the Superfund evaluation, eliminate fire and disease hazards, and simplify subsequent materials handling. Further processing to obtain rubber chips or crumbs may also be practical. However the industry and the markets would have to emerge over time. Construction of new powerplants or pyrolysis facilities could be advantageous under special circumstances. However the feasibility of these operations is not apparent, given the low energy prices in Denver and the need for elaborate pollution controls. Land disposal could be considered as a last resort. Landfilling costs would be minimized if the tires are shredded. Any displacement of the tires should be preceded by an analytical program to isolate any that are contaminated and to develop practices to protect the workers. The City also needs to consider whether it should minimize or expand its future involvement in scrap tire management.

CHAPTER 4
SUMMATION AND SUGGESTIONS

FINDINGS

The 170 million tires that are scrapped in the United States each year pose a serious management problem to many state and local governments. However there are a variety of management options available, including landfilling, physical or chemical processing, and energy recovery. Most of these have been proven in a technical sense, and further development is being pursued on several fronts. Unfortunately most of the options are impeded by marketing uncertainties, high costs, and environmental considerations. State-level policies, including possibly subsidy programs, may be required to ensure the implementation of acceptable tire disposal practices. Several states already have scrap tire policies in place, and many others are developing them.

Denver's problem is unusually complex because its large stockpile must be removed to expedite a Superfund project. This will be costly, but it appears to be achievable by coarsely shredding the tires and piling the shreds in an adjacent area for use as feed material in existing combustors and future resource recovery plants. Tire removal should be preceded by an analytical program to identify any tires that are contaminated with chemicals from the old waste disposal site.

SUCCESSES

The scrap tire problem was reviewed on both a national and local level. The disposal and resource recovery options were assessed to the extent possible within the project scope and schedule. Management policies implemented by various state and local governments were examined. Alternatives available to deal with Denver's stockpile were reviewed, and a management program was suggested. Findings were conveyed to other interested parties through a scrap tire workshop.

The workshop, which was held in Denver on February 12, 1987, was attended by more than 100 participants. A copy of the agenda is included in the Appendix. Topics of discussion included the tire management problem in Denver and nationwide, opportunities to recover energy and materials from tires, environmental and public health issues associated with tire management programs, and analysis of the legislative options. Denver's project personnel benefited by becoming more familiar with tire problems in other areas and with the processes and technologies that might offer at least partial solutions. The contacts established during the workshop should be very helpful when the City proceeds to remove the tire pile at Lowry Landfill.

PROBLEMS

No major problems were encountered.

SUGGESTIONS

Local governments should work with surrounding jurisdictions to develop uniform tire management policies. Well designed state-level or even multi-state policies should be more effective in dealing with the tire problem in an equitable manner. In encouraging resource recovery from tires, governments should first look for existing combustion facilities that might purchase tires or tire-derived rubber to replace or supplement conventional fuels. State agencies that regulate industrial air pollution should be excellent source of information on such facilities.

APPENDIX

ACKNOWLEDGEMENTS

Contributions of the following individuals and organizations are gratefully acknowledged:

- Willis Green: Centel Electric of Colorado
- Richard Rader: Citizens Intelligence Network
- Robert Graham: C&H Combustion, Inc.
- Bruce Battaglia: Columbus McKinnon Corp.
- Orville Stoddard & Nadine Quigley: Colorado Dept. of Health
- Charles Bisel & A. B. Simpson: Combined Technology Corp.
- Paul Petzrick: Compass Corporation
- Rodolphe de Laboulaye & Jean-Louis Juillard: DITT, Inc.
- Victor Carr: Eastern Shale Research Corp.
- Paul Ashford & Jim Butler: The Ecocure Network, Inc.
- Juliane Dodds: EG&G Idaho, Inc.
- Richard Hooper: Electric Power Research Institute
- Michael Martinez: City of Galex, Virginia
- John Brewer: Garb-Oil & Power Corp.
- Ernest Karger: Gates Rubber Co.
- Tom Dibernardo: General Services Administration
- Robert Miller: Hennepin County, Minnesota
- Paul Thompson: Hydro-Sonic Systems, Inc.
- Harry Javernick & Scott Marsh: Ideal Basic Industries
- Dr. Mark Atwood: J&A Associates, Inc.
- Joseph Krehbiel: Microdine, Inc.
- Robert Scheck & Dr. Robert White: Morrison-Knudsen Engineers
- Bill Fritz & Jerry Jackson: Multiple Energy Corp.
- Donald Wilson: National Tire Dealers & Retreaders Assoc.
- Dr. Michael Carroll: City of New Orleans
- Arch Ford, Gordon Marker, & Phillip Rettger: Oxford Energy, Inc.
- Jim King & Dr. Nugent Myrick: Process Design, Inc.
- David & Linda Hedges: Recycled Tire Consultants
- Jeffrey Davis & Francis Kent: Oxford Recycled Aggregates, Inc.
- Harold Dunkin: Rock River, Wyoming
- Frank Ryan: Rubber Manufacturer's Association
- Damon Dedo: Saturn Shredders Division of MAC Corporation
- Wayne Coppel: Shredding Systems, Inc.
- Robert Malmgren: Land Systems International
- Roy Cook: Southwestern Portland Cement Co.
- Curtis Cobb & Konrad Ruckstuhl: SPM Group, Inc.
- Leslie Marzahl & Don Gaines: TecSon Corporation
- Leonard Butler & Arend Lenderink: Waste Management, Inc.
- Michael Rouse: Waste Recovery, Inc.
- Gary Maggi: The Western Sugar Co.

Support from the following members of Denver's city government is also acknowledged with appreciation:

- Federico Pena, Mayor
- John S. Mrozek, Deputy Mayor
- Dr. Howard McCann, Executive Deputy Manager of Public Works
- George C. Rupert, Deputy Manager of Public Works
- Martin E. Flahive, Urban Consortium Representative

- o Councilman Robert Crider
- o Councilman William A. Scheitler
- o Councilman Ted J. Hackworth
- o Councilman Sam Sandos
- o Councilwoman Stephanie A. Foote
- o Councilman Paul L. Swalm
- o Councilman John J. Silchia
- o Councilwoman Nieves Perez McIntire
- o Councilman Hiawatha Davis, Jr.
- o Councilman Salvadore Carpio
- o Councilwoman Cathy Donohue
- o Councilman William R. Roberts
- o Councilwoman Cathy Reynolds

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ACRONYMS

Btu	British thermal unit
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FBC	Fluidized bed combustor
MW	Megawatt (One million watts)
psig	Pounds/square inch, guage
SAM	Stress absorbing membrane
SAMI	Stress absorbing membrane interlayer
TDF	Tire derived fuel

UNITS

Btu	British thermal unit	MW	Megawatt
Btu/hr	Btu per hour	psig	Pounds/square inch, guage
Btu/lb	Btu per pound	tires/d	Tires per day
$/lb	Dollars per pound	tires/hr	Tires per hour
$/tire	Dollars per tire	tires/mo	Tires per month
$/ton	Dollars per ton	tires/yr	Tires per year
$/yr	Dollars per year	t/d	Tons per day
F	Degrees Fahrenheit	t/hr	Tons per hour
ft	Feet of length	t/mo	Tons per month
in	Inches of length	t/yr	Tons per year
lb/d	Pounds per day		
lb/hr	Pounds per hour		

WORKSHOP AGENDA

DISPOSAL TECHNIQUES WITH ENERGY RECOVERY FOR SCRAPPED VEHICLE TIRES

Sponsored by:
U. S. Department of Energy
Urban Consortium Energy Task Force
City & County of Denver

Denver, Colorado February 12, 1987

8:00 - 12:00 TIRE PROBLEMS & TECHNOLOGIES

THE TIRE MANAGEMENT SITUATION IN DENVER

Opening Remarks
E. K. Demos, Director, Environmental Services, City & County of Denver
George Rupert, Deputy Manager of Public Works, City & County of Denver

Denver's Tire Management Problem
E. K. Demos, Director, Environmental Services, City & County of Denver

Assessment of the Tire Disposal Options
Thomas Sladek, Project Manager, City & County of Denver

RESOURCE RECOVERY OPPORTUNITIES FOR SCRAPPED TIRES

Applications for Tire Derived Fuels
Michael Rouse, President, Waste Recovery Inc.

Tires as Supplemental Fuel for Cement Kilns
Julianne Dodds, Project Manager, EG&G Idaho Inc.

The Oxford Energy Tire Combustion Process
Gordon Marker, Executive Vice President, Oxford Energy Inc.

The C&H Combustion Technology
Robert Graham, President, C&H Combustion Inc.

Pyrolysis Processes for Scrap Tires
Paul Petzrick, Vice President, Compass Corporation

Uses for Tire-Derived Materials
Curtis Cobb, Executive Vice President, SPM Group Inc.

12:00 - 1:00 LUNCHEON & DISCUSSION
John Mrozek, Manager of Public Works, City & County of Denver

1:00 - 5:00 ISSUES & POLICIES

ENVIRONMENTAL & PUBLIC HEALTH ISSUES

Air Quality Control in New Tire Burning Facilities
O. L. Holland, Operations Manager, Hydro-Sonic Systems Inc.

Control Adaptations for Existing Combustion Facilities
Robert Scheck, Process Design Manager, Morrison-Knudsen Engineers

Advanced Air Pollution Control Methods
Richard Hooper, Project Manager, Electric Power Research Institute

Public Health Considerations in Scrap Tire Management
Michael Carroll, Ass't Administrator, New Orleans Mosquito Control Board

PERSPECTIVES ON THE LEGISLATIVE OPTIONS

State & Local Government
Robert Miller, Supervising Planner, City of Minneapolis

Tire Manufacturers
Frank Ryan, Vice President, Rubber Manufacturers Association

Tire Dealers & Retreaders
Donald Wilson, Director of Governmental Relations, National Tire Dealers & Retreaders Association

The Waste Management Industry
Leonard Butler, Head Engineer, Waste Management of Colorado Inc.

6:00 RECEPTION
7:00 DINNER & DISCUSSION

UPDATE ON THE TIRE PROBLEM IN THE DENVER AREA

Tire Mountain, Inc. is a tire stockpile located 30 miles northeast of Denver near the town of Hudson in rural Weld County. Until recently, the site contained approximately 6 million tires, piled up to 25 feet high in seven rectangular sections divided by narrow access roads. At about 10:00 PM on Tuesday, June 8, 1987, lightning struck near the center of one of the sections. By the time firefighters arrived at 11:30 PM, flames had spread over most of the section. The fire subsequently spanned an access road and ignited a second section. Fire crews were able to confine the blaze to those two sections by widening the surrounding access roads, building dirt berms all around the burning area, and using water to cool the nearby tires.

A thick column of smoke rose 4,000 feet into the air and was visible from south Denver more than 50 miles away. Nearby residents were alerted to the health risk and were advised to leave the area if they experienced respiratory distress. Water from firehoses was totally ineffective, as were several bombing runs by a U.S. Forest Service plane which dropped a slurry used to combat forest fires. Use of water was discontinued after health officials expressed concern that cooling the fire would increase production of harmful organic vapors and soot.

The fire was finally controlled by scraping dirt from nearby fields and pushing it into the edges of the burning area with bulldozers. It was declared out at 2:00 PM on Saturday, after 45,000 cubic yards of Colorado topsoil had been relocated. Monitoring will continue for several weeks to ensure the early detection of any re-ignition.

More than 150 volunteers from 9 local fire departments were involved in fighting the blaze, which was observed by a similar number of news media representatives plus personnel from the state and local health departments and the U.S. Environmental Protection Agency. Nearly 3 million tires burned. The costs of fire control and the economic loss to the stockpile owner have yet to be determined, as have the long-term environmental effects. Aside from the relatively brief episode of extreme air pollution, the impacts may not be serious since groundwater resources are protected by 20 feet of clay and 500 feet of relatively impermeable soils. The fire has focused additional public attention on the tire stockpile at Lowry Landfill.

REPORT AND INFORMATION SOURCES

Additional copies of this report, "Disposal Techniques with Energy Recovery for Scrapped Vehicle Tires," are available from:

Publications and Distribution
Public Technology, Inc.
1301 Pennsylvania Avenue, N.W.
Washington, DC 20004

For additional information on the process and the results of the work described in this report or for information on the overall energy management programs in Denver, Colorado, please contact:

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Order No. DG/86-307
07/87-100