SCRAP TIRE MANAGEMENT COUNCIL

Scrap Tire Use/Disposal Study

Final Report

A.T. Kearney

September 11, 1990

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Waste or scrap tires pose a substantial waste management challenge due both to the large number of tires coming off the road annually and to the properties built into tires to insure their safety and durability in use. The management practices applied to the majority of scrap tires generated each year, landfilling and stockpiling, have undesirable environmental and public health attributes, and waste material resources.

The Federal government, state governments, and tire manufacturing industry are concerned about the continued landfilling and stockpiling of scrap tires. The tire manufacturing industry intends to undertake a strategic program to increase the environmentally sound reuse, recycling, or disposal of scrap tires.

Purpose

The purpose of this study is to:

- o Identify methods of scrap tire disposal or reuse which are: 1) environmentally acceptable; 2) economically sound, and 3) capable of decreasing the numbers of tires going to landfills or stockpiles by 25 to 40 percent in two to five years.
- o Identify market, technical, institutional, and other barriers to the expanded use of these methods.

The results of the study are intended to help focus industry activities on furthering the development and implementation of those scrap tire use or disposal methods which have the greatest promise for significantly reducing the number of tires going to landfills or stockpiles in the near future.

Background

Estimates of scrap tire generation vary, but generally hold to the relationship that about one scrap tire is generated annually per person in the U.S. population. For purposes of this report, we have used a generation estimate of 240 million scrap tires per year.

Approximately 175 to 205 million scrap tires are added to landfills or stockpiles each year. The existing inventory of scrap tires in stockpiles is estimated to exceed 2 billion tires. Therefore, a 25 percent reduction in the amount of tires being landfilled or stockpiled corresponds to 40 to 50 million tires per year. A 40 percent reduction corresponds to 70 to 80 million tires per year. The number of scrap tires generated annually would be substantially higher if it were not for the fact that the current generation of new tires have a much longer service life than tires of ten or fifteen years ago, and the fact that the tire retreading industry extends the life of approximately 38 million tires annually by replacing the treads of previously worn or used tires.

Results

Five alternative scrap tire use or disposal methods were determined to have the potential to satisfy the evaluation criteria. These alternatives are:

- o Four alternative methods for reusing whole tires or tire-derived fuel (TDF) for energy:
  - Cement kilns
  - Pulp and paper mills
  - Utilities
  - Dedicated tire-to-energy facilities
- o Use of rubber in asphalt paving

Each of these alternatives is briefly discussed below.

Cement Kilns

Either whole tires or tire-derived fuel (TDF) can be used as supplemental fuel in cement kilns, depending on kiln size and technology. The technology is proven. At least three U.S. kilns are currently burning tires or TDF on an operating basis, with at least five additional kilns experimenting with scrap tires as fuel. Based on testing results, burning scrap tires or TDF in kilns does not adversely affect environmental performance or product quality.

Kilns currently burning TDF have volume capacities in the 0.5 - 3 million tire per year range. At an average burning rate of 1.5 million tires per year, we estimate that cement kilns could use approximately 60 million tires per year as auxiliary fuel by 1995. This assumes switchover of about 40 kilns with optimal scrap tire burning configurations, out of a total kiln population of about 240.

Principal barriers to further scrap tire use are:

- o Marginal cost advantage of TDF over typical kiln fuels (coal, petroleum coke); whole tires have a greater advantage, but can only be used in larger kilns

- Air permit modification requirements

- Reliability of tire/TDF supply (risk to recovering capital investment)

Pulp and Paper Mills

Dewired tire-derived fuel (TDF) can be used as supplemental fuel in pulp and paper mills; dewiring is required to avoid fuel feeding problems. The technology is proven. About 12 U.S. pulp and paper mills are currently burning dewired TDF on an operating basis. Burning TDF in mill boilers does not adversely affect boiler operation, but has mixed effects on environmental performance (particulate increase) which can be mitigated by limiting the percentage of TDF burned.

Pulp and paper mills currently burning TDF have volume capacities in the 0.5 - 3.5 million tire per year range. At an average burning rate of 1.5 million tires per year, we estimate that paper mills could use about 35 million tires per year as auxiliary fuel by 1995. This assumes switchover of about 25 percent of auxiliary fuel requirements to TDF.

Principal barriers to further use of TDF in this industry are:

- Marginal cost advantage of TDF over typical mill fuels (coal, purchased hog fuel); dewiring increases TDF cost

- Air permit modification requirements

- Remote location of many mills

- Reliability of TDF supply

Utilities

Either whole tires or tire-derived fuel (TDF) can be used as supplemental fuel in utility boilers, depending on boiler size and type. The burning technology is being tested in wet bottom boilers (whole tires) and cyclone boilers (dewired 1"x1" TDF) with promising results. At least three U.S. utility facilities are currently burning or planning to burn tires or TDF on an experimental basis. Early results indicate that burning scrap tires or TDF in utility boilers does not adversely affect boiler operation, with mixed impacts on environmental performance.

Utility boilers experimenting with TDF have volume capacities in the 0.5 - 3 million tire per year range. We estimate that utility boilers could use approximately 60 million tires per year as auxiliary fuel by 1995. This assumes that 25 percent of existing wet bottom boilers will switchover to scrap tires for 10 percent of their fuel requirements. The estimate does not include boilers burning 1"x1" dewired TDF, because use of this fuel requires subsidies to offset high processing costs.

Principal barriers to further scrap tire use in this industry are:

- Marginal cost advantage of scrap tires over coal; whole tire burning requires separate, expensive equipment for fuel feeding, while dewired 1"x1" TDF suitable for feeding in coal system is more expensive than coal

- Air permit modification requirements

- Unproven reliability of whole tire and TDF feed technology

- Reliability of TDF supply

- Extremely conservative/risk averse nature of utility industry.

Dedicated Tire-to-Energy Facilities

Whole tires can be used as fuel in dedicated tire-to-energy facilities. The technology has been proven in the U.S. by Oxford Energy at its operating plant in Modesto, CA, and in West Germany by Gummi Meyer. Three additional plants are planned by Oxford by 1995. The Modesto plant has had some operating difficulties due to tire handling; however, Oxford states that these problems have been corrected. Environmental operation of the plant is satisfactory.

Oxford's existing and planned facilities have volume capacities of 4.5 million to 9 million tires per year. If all four plants startup on schedule, they could use approximately 31 million tires per year as fuel by 1995.

Principal barriers to further scrap tire use in dedicated tire-to-energy facilities are:

- High capital cost of facilities. Dedicated tire-to-energy plants cost between 2 and 7 times more to construct per MW than conventional coal power plants.

- Need to site new facilities. All planned tire-to-energy facilities are new plants which may encounter local opposition, delaying or foreclosing construction.

- Environmental permitting for new facilities.

- Reliability of fuel supply.

Reuse in Asphalt

Scrap tire rubber can be used in asphalt paving as either part of the asphalt binding material or seal coat (both uses known loosely as asphalt rubber), or as aggregate (rubber modified asphalt concrete, or RUMAC). Crumb rubber is used in asphalt rubber; tire chips are used in RUMAC. Both technologies have been demonstrated commercially in small scale applications in the U.S. and in Europe. However, there are some contradictions in the data available on the ease of use and performance of both asphalt rubber (particularly when used as a binding material) and RUMAC. Both are reported to approximately double the service life of pavings, although some results conflict with these findings. There are no recognized technical standards for either material in the U.S.

Asphalt rubber seal coats use about 1,600 tires per mile of two lane road sealed. RUMAC uses between 8,000 and 12,000 tires per mile of two lane road repaved with a 3 inch lift. The potential volume capability of reuse in asphalt paving exceeds tire supply; however, on a practical basis, we estimate that use within 5 years could equal or exceed 28 million tires per year.

Principal barriers to further scrap tire use in asphalt paving applications are:

- High initial costs. Both asphalt rubber and RUMAC are approximately twice the cost of conventional asphalt.

- Marginal lifecycle economics. Service claims typically project doubling the life of conventional aphalt. However, doubling the life does not overcome the high initial costs when future costs are discounted.

- Lack of product specification by ASTM or other body.

- Concern over uniformity of scrap tire rubber.

- Scrap Polyethelene as an asphalt additive has better product enhancement characteristics and lower processing costs thus it will likely be the scrap raw material of choice.

Conclusions

Five alternative scrap tire use or disposal methods were determined to meet or nearly meet study criteria for environmental acceptability, economic viability, and volume capability. We estimate that these methods combined have the potential to reduce the number of tires being landfilled or stockpiled by about 210 million tires per year by 1995.

Each of these alternative methods face significant barriers to futher implementation. Our qualitative analysis of these barriers indicates that the alternatives' relative level of difficulty in achieving significant further use is as follows (from lowest to highest level of difficulty):

- Cement kilns
- Paper mills
- Utilities
- Dedicated tire-to-energy
- Asphalt paving.

Alternatives with the lowest barriers are most likely to achieve the potential scrap tire volumes estimated for 1995.

Several potential methods for reducing barriers which apply to one or more alternative use/disposal methods were identified. These include:

- Development of improved information/marketing of TDF and/or whole tires as fuel
- Development of additional, standardized testing and analysis results for scrap tire performance in the specific applications
- Dissemination of information which demonstrates the environmental results of air emissions tests on the use of whole tires or TDF as auxiliary fuel
- Implementation of possible incentives by the Federal or state governments (e.g., tax credits)
- Development of standardized air permit modification packages/approaches by states or nationally to expedite permit modification
- Enhancement of the reliability of tire supply.

1.0 INTRODUCTION

Waste or scrap tires pose a substantial waste management challenge due both to the large number of tires coming off the road annually (referred to as annual take-off) and to the properties built into tires to insure their safety and durability in use. The management practices applied to the majority of scrap tires generated each year, landfilling and stockpiling, have undesirable environmental and public health attributes, and waste material resources.

The Federal government, state governments, and tire manufacturing industry are concerned about the continued landfilling and stockpiling of scrap tires. Several studies have been undertaken in recent years to document the extent of landfilling and stockpiling, and their associated environmental impacts, and to explore alternative methods for reducing the number of tires being stockpiled or landfilled.

The tire industry, through the Scrap Tire Management Council, intends to undertake a strategic program to increase the environmentally sound reuse, recycling, or disposal of scrap tires. This program will focus on activities that can be undertaken to increase the environmentally acceptable use or disposal of scrap tires within a relatively short time frame (e.g., five years), in order to slow the continued buildup of tire stockpiles.

1.1 PURPOSE AND SCOPE

The purpose of this study is to:

- Identify methods of scrap tire disposal or reuse which are: 1) environmentally acceptable; 2) economically sound; and 3) capable of decreasing the numbers of tires going to landfills or stockpiles by 25 to 40 percent in two to five years.

- Identify market, technical, institutional, and other barriers to the expanded use of these methods.

The results of the study are intended to help focus industry activities on furthering the development and implementation of those scrap tire use or disposal methods which have the greatest promise for significantly reducing the number of tires going to landfills or stockpiles in the near future.

The focus of this study is limited to methods of scrap tire use or disposal which may potentially meet the three baseline criteria specified above:

- o Environmental acceptability
- o Economic feasibility
- o Volume capability within a two to five year timeframe.

As such, the study is not an exhaustive review of all potentially feasible methods of tire use or disposal which may be in the research and development stage, or which may address small markets for scrap tire products. Typically, the methods reviewed in detail here are those which have been demonstrated to be technically feasible on at least a pilot scale, either in the U.S. or in foreign countries, and which have significant volume capability.

This limitation is not intended to imply that methods currently in the research phase may not contribute to the solution of the tire disposal problem in the future. Clearly, such technologies are likely to play an important role in tire use or disposal in the long term, and deserve continued support. However, these technologies are not likely to contribute substantially to reducing the number of tires going to landfills or stockpiles within the next five years. Additionally, this focus is not intended to imply that scrap tire reuse methods addressing small markets are not an important part of the overall scrap tire reuse or disposal.

Finally, this study does not address the potential for increasing the use of reclaimed or recycled rubber from scrap tires in production of new tires.

1.2 BACKGROUND

Scrap tire generation, reuse, and disposal have been the subject of several studies by Federal and state agencies. It is not the purpose of this study to repeat data readily available in these sources. However, basic data on the scope of the tire disposal problem provides a useful context for considering the information presented in this report on scrap tire management alternatives. Therefore, a brief summary of relevant information on scrap tire generation and current management practices is provided below.

1.2.1 Current Tire Life

Contemporary tires have significantly longer lives than tires of 15 or 20 years ago. The development and continued improvement of the radial tire has substantially enhanced tire performance and greatly increased tire life. Advances in tire materials have also resulted in improved tire durability and extended mileage with greater safety. The tire manufacturing industry takes pride in the improvements that have been made in tires and the extent to which they contribute to vehicle performance, safety and economy.

Longer-lived tires also contribute to a reduction in the annual generation of scrap tires. As passenger tire mileage has increased to a range of 30,000 to 50,000 miles or more, it has extended tire life to 3 to 5 years of normal driving, and meant that fewer replacement tires are needed annually. While the number of vehicles in use has steadily increased over the last decade, the total volume of replacement tires, and annual scrap tire generation, has increased much more slowly.

1.2.2 Retreading

Retreading extends tire life, especially in the commercial tire market. The commercial highway tire market now seeks new tires with the capability of 500,000 miles or more of carcass life. This is accomplished through a cooperative effort of the new tire manufacturers who are striving to build tires capable of a 500,000 mile life cycle, and the retread industry, which retreads the carcass several times to permit the tire to reach this goal.

The retread industry also can retread passenger and light truck tires. Approximately 12 million passenger and light truck tires are retreaded annually.

Tire retreading makes an important contribution to the reduction in the number of tires requiring annual disposal by insuring that tires, especially medium truck tires, provide the fullest possible service life. At present, approximately 38 million tires are retreaded annually. In the medium truck market, over 50% of the annual market demand for tires is met by retreaded tires.

Of particular concern to the retread industry is the need to insure that retreadable casings get directed to the retread market. This should be an important consideration in planning scrap tire processing and disposal methods.

1.2.3 Generation

Estimates of scrap tire generation vary, but generally hold to the rough relationship that about one scrap tire is generated annually per person in the U.S. population. While there is some variation in the estimates of scrap tire generation, for purposes of this report, we have used an estimate of 240 million tires per year.

1.2.4 Management Methods

Current scrap tire management methods include landfilling, stockpiling, burning for energy recovery, reclaiming rubber for use in moldings, manufacturing fabricated products (splitting), constructing reefs and barriers, exporting, and reusing tires in asphalt paving. Estimates of the amounts or percentages of scrap tires managed by these different methods vary. However, general ranges of the percent of tires managed by these methods are as follows:

- Landfill/stockpile: 71 - 85 percent
- Energy recovery: 8 - 11 percent
- Fabricated products: 1 - 5 percent
- Reclaim rubber: 2 - 5 percent
- Asphalt rubber: 0.5 percent
- Reefs/barriers: 0.1 - 2 percent
- Tire exports: 2 - 4 percent

Thus, about 36 to 66 million scrap tires per year are currently reused to recover materials or energy. Approximately 175 to 205 million scrap tires are added to landfills or stockpiles each year. The existing inventory of scrap tires in stockpiles is estimated to exceed 2 billion tires.

1.3 METHODOLOGY

The basic methodology used to conduct this study entailed the following tasks:

- Identifying alternative scrap tire use/disposal methods. We identified potential management alternatives through review of existing studies and the technical literature, contacts with U.S. industry and government representatives, and contacts with European and Japanese industry and government representatives.

- Defining evaluation criteria. Baseline evaluation criteria were environmental acceptability, economic feasibility, and ability to reduce the volume of scrap tires going to stockpiles or landfills by 25 to 50 percent in 2 to 5 years (volume capability). These criteria were further defined as follows:

- Environmental acceptability: Extent to which the method recycled or recovered material or energy value of scrap tires; and environmental impacts of the recycling, reuse, or recovery technology.
- Economic feasibility: Extent to which the method was commercially viable without subsidies in the form of tax credits or direct government subsidies.
- Volume capability: Extent to which the potential volume of scrap tires that could be managed by the method within the specified time frame is limited by absolute size of the potential market, siting requirements, permitting requirements, or other factors.

o Defining data requirements. We defined data requirements for profiling and evaluating reuse or disposal alternatives based on the criteria defined for evaluating the alternatives. Basic data requirements included:

  - Technology description
  - Environmental, economic, and volume characteristics
  - Barriers to further development/implementation of the method
  - Information sources on the method

o Collecting data. We collected data from the literature and from representatives of industry and government, both domestic and foreign. We relied particularly heavily on contacts in order to obtain up-to-date information on the status of existing projects, economics, and barriers.

o Analyzing data. We analyzed the collected data to identify methods which met and did not meet the criteria, and for which we did not have sufficient information. We conducted supplemental data collection to fill these deficiencies, and developed a final screening of methods satisfying and not satisfying the baseline criteria.

o Preparing profiles and report. We then prepared technology profiles for each method meeting the baseline criteria covering the information elements listed above. We also prepared brief descriptions of several of the more prevalent or well studied methods which did not meet the criteria. These profiles and descriptions are compiled in this report.

The study has relied heavily on contacts with people in the various segments of the scrap tire disposal and use industry, including collectors, shredders, reclaimers, fabricators, and customers for scrap tire products such as tire-derived fuel, in order to provide current information on the use and economics of the alternative methods.

1.4 ORGANIZATION

This report is organized as follows:

- Chapter 2 - Profiles of methods which satisfied baseline criteria for environmental acceptability, economic feasibility, and volume capability. The methods profiled are:

  - Use as fuel in cement kilns
  - Use as fuel in pulp and paper mills
  - Use as fuel in utility boilers
  - Use as fuel in dedicated tire-to-energy facilities
  - Reuse in asphalt paving

- Chapter 3 - Brief descriptions of methods which did not meet the criteria. These include pyrolysis, rubber reclamation, artificial reefs, and tire splitting.

- Chapter 4 - Conclusions

- Appendix - Matrices providing in summary form information on the environmental, economic, and volume characteristics of the methods, and barriers to their implementation.

2.0 TECHNOLOGY PROFILES - ALTERNATIVES MEETING BASELINE CRITERIA

This section provides technology profiles for those alternatives for reusing scrap tires which were determined to meet study criteria. That is, the alternatives profiled in this section were determined to be environmentally acceptable, economically feasible, and capable of significantly reducing the volume of scrap tires going to landfill within a five year period.

We found five methods of scrap tire reuse which met all criteria:

- Use as fuel in cement kilns
- Use as fuel in pulp and paper mills
- Use as fuel in utility boilers
- Use as fuel in dedicated tire-to-energy facilities
- Reuse in asphalt

All of these methods share several characteristics in common, including:

- Technologies required have been proven in commercial scale applications
- Environmental impacts of substituting scrap tires for original materials used (coal, asphalt, aggregate) are negligible and controllable
- Methods have been used commercially within the U.S. in at least limited applications
- Economics of the methods are at least marginally attractive for some current applications, and within a reasonable striking distance of being commercially attractive on a larger scale
- Markets or capacity provided for scrap tires is very large in absolute terms.

The profiles provided for each method provide the following information:

- Abstract
- Technology description

- Environmental, economic, and volume characteristics
- Barriers to further implementation
- Potential methods for reducing barriers
- Information sources.

2.1 USE AS FUEL IN CEMENT KILNS

Abstract. Either whole tires or tire-derived fuel (TDF) can be used as supplemental fuel in cement kilns, depending on kiln size and technology. The technology is proven. At least two U.S. kilns are currently burning tires or TDF on an operating basis, with at least five additional kilns burning whole tires or TDF on an experimental basis. Burning scrap tires or TDF in kilns does not adversely effect environmental performance or product quality.

Kilns currently burning TDF have volume capacities in the 0.5 - 3 million tire per year range. At an average burning rate of 1.5 million tires per year, we estimate that cement kilns could use approximately 60 million tires per year as auxiliary fuel by 1995. This assumes switchover of about 40 kilns with optimal scrap tire burning configurations (kilns with preheaters/precalciners), out of a total kiln population of about 240.

Principal barriers to further scrap tire use in this industry are:

- Marginal cost advantage of TDF over typical kiln fuels (coal, petroleum coke); whole tires have a greater advantage, but can only be used in larger kilns with preheaters
- Air permit modification requirements for testing, and delays in issuing modifications
- Reliability of tire/TDF supply (risk to recovering capital investment)
- Certain kiln designs require costly feed system design modifications

2.1.1 Technology Description

Cement is manufactured by controlled heating of a mixture of finely ground calcareous material (e.g., limestone), argillaceous material (e.g, clay or shale), and siliceous material (e.g., sand) to about 1500-1600°C in a rotary kiln. These materials provide the basic elements required in cement: calcium, silicon, aluminum, and iron. The high temperatures in the kiln cause decarbonation of lime and subsequent reaction with silica to form calcium silicates. The calcium silicate "clinker" is ground with gypsum to produce cement.

Rotary kilns are long, inclined, cylindrical furnaces through which the cement ingredients move in approximately one to four hours. Due to their unusually high operating temperature and long exhaust gas residence times in the burning zone, cement kilns have the capacity to safely use a wide variety of fuels, including tires or tire-derived fuel (TDF). Whole tires or TDF are a good auxiliary fuel for coal or oil burning cement kilns because their:

- o BTU value is comparable to or higher than typical coal used in making cement
- o Nitrogen, sulfur, and ash content is lower than typical values for coal
- o Steel content provides supplemental iron for the cement.

The high operating temperature in the kiln allows for complete combustion of tires and oxidation of steel beads or belts without adversely affecting kiln operation. Therefore, steel reinforcement does not need to be removed prior to tire use as fuel. In fact, because iron is a basic ingredient in cement, and the temperature in cement kilns is high enough for complete combustion of steel to iron oxide, burning whole tires or TDF with steel content reduces raw material costs for supplemental iron for some kilns.

Cement manufacture is energy intensive, requiring about 160 kwh of energy per ton of clinker produced. Typical energy costs are about $6.00 per ton of clinker.

The form in which tires can be used as an auxiliary fuel, either whole or as tire-derived fuel, is dependent upon the configuration of the kiln. Kilns with preheaters can utilize whole tires as fuel; kilns without preheaters can only use tire-derived fuel, typically in 2 inch x 2 inch to 4 inch x 4 inch size.

In either case, kilns must be equipped with separate fuel feed systems to utilize tires. Whole tires are fed to kilns using a mechanical feed system designed for tire charging. TDF may be fed using either mechanical or pneumatic systems. Mechanical feed systems have been successful in feeding TDF to cement kilns without any problems. Three of the cement kilns using TDF on an experimental basis used pneumatic blowers to feed TDF but experienced problems with feed line plugging caused by wire. Subsequently, one of these kilns has switched over to a mechanical feed system for TDF.

Typical feed rates in the cement kilns using TDF in U.S. vary from 2-3 tons per hour, with about 10-25% of the BTU value of the fuel being provided by the tires. Average annual tire consumption at a typical facility is about 2-3 million tires.

Two cement kilns in the U.S. use TDF as an auxiliary fuel, and another five use TDF on an experimental basis with intentions to install permanent systems. Tires have been widely used in Europe and Japan as an auxiliary fuel in cement kilns for several years.

U.S. Facilities

- Calaveras Cement, Redding, CA:
  - Annual consumption: 2 million tires
  - 25% of BTU value of fuel is provided by tires
  - Has used TDF as supplemental fuel for 5 years

- Arizona Portland Cement:
  - Approximate annual consumption: 3 million tires
  - Uses 2" x 2" TDF at a rate of 2T/hour, expected to rise to 4T/hour
  - About 10% of BTU value of the fuel is provided by tires

- Southwest Portland Cement Co., Fairborn, OH
  - Approximate annual consumption: 1.0 million tires
  - Whole tires used
  - About 6-8% of BTU value provided by tires
  - Modified air emissions permit

- Ashgrove Cement, Durkee, Oregon
  - Has used TDF on an experimental basis for the last two years
  - Expected approximate annual consumption: 0.4 million tires
  - Completed trial burns for emissions testing for modified permit
  - Public hearings for permit scheduled for October
  - Pneumatic blower used to feed TDF
  - Use 2" relatively wire free TDF

- Ideal Cement, Seattle, WA
  - Has used TDF on an experimental basis for the last six months
  - Expected approximate annual consumption: 1.4 million tires
  - Pneumatic blower used to feed TDF
  - 20% of BTU value of fuel provided by tires

- Use 2" relatively wire free TDF

- La-Farge Cement, Texas

    - Has used TDF on an experimental basis for two years
    - Expected approximate annual consumption: 1.3 million tires
    - Completed trial burns for emissions testing; permit issuance in process
    - Modified permit will place restraint only on percentage of tires allowed to be burnt (25% of the fuel)
    - 9-10% of BTU value of fuel provided by tires
    - Auger feed system
    - Use 2" relatively wire free TDF

- Gifford Hill Cement Co., Harleyville, S.C.

    - Experimental use of whole tires
    - Test burn in May 1990
    - Expected approximate annual consumption: 1.2 to 1.5 million tires per year
    - 20% of BTU value of fuel to be provided by tires
    - Joint venture with Oxford Energy and Radian Corp.

<u>Foreign Facilities</u>

- Heidelberger Cement Plant, W. Germany:

    - Total of 50,000 MT of tires burnt per year in 6 of its cement plants
    - Tires fed whole into the kilns
    - Percent of tires in the fuel feed varies from 10-20%

- Blue Circle Dry Process Cement Works, Hope, Sheffield, England

    - Annual consumption of tires: 4,700 tons (expected to increase to about 8,000 tons)
    - Whole tires used
    - 17% of fuel substituted by tires

- Sumitomo Cement Co., Japan

- Onada Cement Co., Japan

- Chichibu Cement Co., Japan

- Osaka Cement Co., Japan

In Japan, over 69,000 tons of tires are used per year as fuel in cement kilns. Typically, tires are used whole in Japanese kilns.

2.1.2 Environmental, Economic, and Volume Characteristics

Environmental Characteristics

- TDF use reduces NO_x emissions by 10%. No changes observed in SO_2 particulates and CO (as total C) emissions.
- No waste residues produced from TDF use.
- No formation of furans from TDF use due to extremely high temperatures in the kiln.

Use of tires as fuel in cement kilns typically reduces production of nitrogen oxides and does not adversely affect other components of kiln air emissions. This is due to the relative characteristics of waste tire materials compared to typical coals used in cement manufacture.

The average sulfur content of TDF is about 1.23% by weight, as compared to 1.59% for coal. The nitrogen content of TDF is also lower than that for coal, 0.24% by weight as compared to 1.76%. The ash content of TDF is about 4.7% by weight as compared to 6.23% by weight for coal. Sulfur in the TDF becomes incorporated into the calcining lime as $CaSO_4$, which is a raw material in the manufacture of cement. All of the ash gets absorbed in the clinker, so there are no residues from the use of TDF in cement kilns. No adverse effects on the quality of cement have been observed due to the use of TDF in cement kilns.

The Bavarian State Institute for Environmental Protection (W. Germany) concluded that the best process of disposing of waste tires is to use them as a fuel in cement kilns.

Tests on kilns in the U.S. demonstrate that existing emission controls on kilns should be sufficient to enable them to use TDF as an auxiliary fuel, while meeting the emission standards as long as the percentage of TDF used is no more than 20% of the heat value of the total fuel used in the kilns.

Economic Characteristics

- Estimated break even procurement cost = $30.00 - 45.00/ton

- Typical procurement fees:
  - Calaveras Cement - $0.00/ton
  - Arizona Portland Cement - charged only freight costs by city of Tucson for TDF, and $20/ton including freight by Tucson Manufacturers, Phoenix, Arizona
  - La-Farge Cement - $1/MMBTU for TDF (compares to $1.6/MMBTU for coal and $1/MMBTU for petroleum coke)
  - Southwest Portland Cement Co. - charges tipping fee to accept tires
- Capital cost for modification of the feed system
  - Mechanical system: $250,000 - $500,000
  - Pneumatic blower system: $60,000 - $100,000
- Typical cost of coal: $1.60 - 2.00/MMBTU ($38 - $48/ton)
- Typical cost of TDF: $1.10 - $1.80/MMBTU ($30 - $50/ton)
- 50% reduction in iron ore consumption in the Calaveras Cement Plant from use of TDF.

The major deciding factor for the use of scrap tires as a fuel is the procurement cost per ton of tires paid by the facility. Scrap tires compete with standard kiln fuels, coal and petroleum coke. Typically, kilns are willing to pay for tires as fuel only at a discount to their normal fuel, to recover the costs of the tire feed system and any test burns required for permitting.

Given current coal costs, a procurement fee of as low as $0.35 per tire could make the use of tires economically unattractive to cement kilns, depending upon their relative transportation costs for coal and tires.

For large kilns with preheaters capable of burning whole tires, the economics of using tires as fuel are good for both the kilns and for scrap tire suppliers. Kilns should be willing to pay about $0.75-$1.00/MMBTU for whole tires, or $21-$28/ton, depending on whether their usual fuel is coal or petroleum coke. This price provides a fee of $0.21-$0.28/tire to the tire supplier, and allows the kiln to make a profit on its investment in tire feed equipment. Mechanical feed equipment for whole tires is typically more expensive than equipment for TDF, running about $250,000 per plant for equipment capable of moving 1.5 million tires per year.

However, for kilns which must use TDF, the economics are more marginal. For TDF to be viable as an alternative fuel to coal, its cost needs to be less than coal, approximately $35-$45/ton. This cost is nearly equivalent to the shredding and transportation cost of the tires (approximate shredding costs for 2 inch TDF is $20/ton and $25/ton for wire free TDF).

On the other hand, if the cement kilns charged a tipping fee to the tire disposers, as does Southwest Portland Cement, OH., the use of tires as an auxiliary fuel would be highly profitable.

<u>Volume Capability</u>

- Potential scrap tire use in U.S. by cement kilns: 60,000,000 tires/year

- Typical plant consumption: 1.5 - 3 million tires/year

    - Annual tire consumption at Genstar Cement Plant: 2 million tires
    - Annual tire consumption at Arizona Portland Cement Plant: 3 million tires

There are about 240 cement kilns in the United States, of which about 40-50 are equipped with preheaters/precalciners required to efficiently utilize TDF. An unknown number of these plants may be capable of burning whole tires.

About 20% of the cement kilns are located in areas where they can obtain petroleum coke at lower prices. Thus, it would be technically and economically feasible for a minimum of about 40 cement kilns to use TDF as an auxiliary fuel. If these kilns were to use TDF as an auxiliary fuel (at an average rate of 1.5 million tons TDF/year), over 20% of the scrap tires generated annually in the United States could be consumed. This estimate does not include those kilns without preheaters that could utilize TDF.

2.1.3 Barriers to Further Implementation

- Continuous supply of TDF

- Environmental permits for air emissions

- Concern over potential air toxics

- Poor information and perception in the marketplace about use of TDF as a fuel

- Maintenance of a safe tire/TDF inventory
- Marginal economics of TDF

It has been demonstrated in previous burns that air emissions from kilns are not adversely affected by the use of TDF as an auxiliary fuel. However, most states require test burns of alternative fuels for cement kilns, including scrap tires. There are costs and disruptions associated with the test burns, and delays between submitting results and receiving a permit modification to allow full scale burning.

Kiln operators are concerned over availability of a continuous supply of TDF. In order to justify the capital expense of feed system modifications, kiln operators prefer having a long-term contract for tire supply that assures a return on their investment.

Additionally, kiln operators are concerned about the potential fire hazards of maintaining a TDF inventory.

2.1.4 Potential Methods for Reducing Barriers

- Development of improved information/marketing of TDF and whole tires as fuel to the cement industry
- Dissemination of information which demonstrates the results of air emissions tests on the use of TDF as auxiliary fuel, to the cement industry, states, and public
- Implementation of possible incentives by states (e.g., tax credits) to cement kilns using TDF as fuel
- Development of standardized air permit modification package/approach by state or nationally to expedite permit modification
- Development of standard information packages for convincing states that use of tires as TDF in cement kilns is environmentally safe.
- Development of assured supplies of TDF.

2.1.5 Information Sources

The Rubber Association of Canada, Scrap Tires in Canada: Report of the Task Force for Scrap Tire Disposal, The Rubber Association of Canada, May 1989.

U.S. Department of Energy, Waste Tire Utilization, U.S. DOE, April 30, 1987.

Ohya, A. & K. Asano, Waste Tire Disposal in Japan, The Japan Automobile Tire Manufacturers Association Inc., Tokyo, Japan, October 1982.

Sikora, Mary B., Tire Recovery & Disposal: A National Problem With New Solutions, Resource Recovery Report, Washington, D.C., June 1986.

Henstock, Michael E., Technology for the Disposal & Treatment of Waste Tires in the United Kingdom, The University of Nottingham, August 1983.

Phone Conversation with Tom Brosman, Arizona Portland Cement, AZ.

Phone Conversation with Joe Jacinta, Calaveras Cement, CA.

Phone Conversation with Dave Bedle, Plant Engineer, Ashgrove Cement Co., Durkee, Oregon

Phone conversation with Al Godec Ashgrove Cement, Durkee, Oregon

Phone Conversation with Tim & Ted Stute, Southwest Portland, OH.

Phone Conversation with Kevin Edy, Plant Engineers, Ideal Cement, Seattle, WA

Phone Conversation with Michael Edmont, Plant Manager, La-Farge Cement, Texas

2.2 USE AS FUEL IN PULP AND PAPER MILLS

Abstract. Dewired tire-derived fuel (TDF) can be used as supplemental fuel in pulp and paper mills; dewiring is required to avoid fuel feeding problems. The technology is proven. About 12 U.S. pulp and paper mills are currently burning dewired TDF on an operating basis. Burning TDF in mill boilers does not adversely effect boiler operation, but has mixed effects on environmental performance (increases particulates). These effects can be mitigated by limiting the percentage of TDF burned.

Pulp and paper mills currently burning TDF have volume capacities in the 0.5 - 3.5 million tire per year range. At an average burning rate of 1.5 million tires per year, we estimate that paper mills could use about 35 million tires per year as auxiliary fuel by 1995. This assumes switchover of about 25 percent of auxiliary fuel requirements to TDF.

Principal barriers to further use of TDF in this industry are:

- Marginal cost advantage of TDF over typical mill fuels (coal, purchased hog fuel); dewiring increases TDF cost, decreasing its price advantage over coal (as compared to use in cement kilns)
- Air permit modification requirements for testing, and delays in issuing modifications
- Remote location of many mills (higher transportation costs)
- Reliability of TDF supply (risk to recovering capital investment)

2.2.1 Technology Description

The manufacturing of pulp and paper requires substantial energy which is typically supplied through on-site boilers fueled with wood waste (hog fuel). Hog fuel typically varies substantially in BTU content and moisture. Therefore, pulp and paper mills often use high heat value fuels such as coal as supplements to hog fuel to give combination fuel boilers a more stable operation.

Since the mid 1970s, tire-derived fuel (TDF) has gained industry acceptance as an alternative to coal, gas, and fuel oil. The inherent high heat value and low moisture content makes TDF an ideal supplemental fuel. The price of TDF is usually below that of competing fuels and, because hog fuel boilers normally have a stoker grate feeding system designed to burn solid wood waste, TDF can often be burned with a minimum of capital investment.

TDF is normally mixed with the hog fuel in a conveyor feeding the furnace. The principal equipment modification necessary is the installation of a metering system capable of handling the high heat value TDF. To minimize potential feeding complications (e.g., jamming) and ash contamination that may result due to steel wire from tire beads and belts, pulp and paper mills often require that TDF be wire free.

Mills that burn TDF in their boilers usually keep it below 10% of the total fuel loading on a BTU basis. Beyond this level, emission and feeding problems become more serious. Large mills can use as much as 100 tons of dewired TDF per day (about 3.5 million passenger car tire equivalents per year).

Currently, there are about a dozen pulp and paper facilities in the U.S. using a total of about 11,000 tons of TDF per month (approximately 13 million passenger car tire equivalents per year).

U.S. Facilities

- Fort Howard Paper, Green Bay, Wisconsin
- Great Southern Paper, Cedar Springs, Georgia
- Inland-Rome Paper, Rome, Georgia
- Nekoosa Paper, Tomahawk, Wisconsin
- Willamette Industries, Albany, Oregon
- Jefferson Smurfit Paper, Newberg, Oregon
- Champion International, Bucksport, Maine
- Port Townsend Paper, Port Townsend, Washington

Foreign Facilities

According to industry sources, TDF is more widely accepted in the European pulp and paper industry than in the U.S. A major reason is that European mills are less likely to require TDF to be wire free and, hence, can acquire it at a significantly lower price (dewiring TDF adds from 25% to 50% to the processing cost).

2.2.2 Environmental, Economic, and Volume Characteristics

Environmental Characteristics

- o Emissions of polynuclear hydrocarbons are not significantly different when TDF is used as a supplemental fuel instead of coal or oil
- o Tests have shown particulate emissions to increase by between 38 and 93% when TDF was used a supplemental fuel in a hog fuel boiler
- o Zinc emissions have been shown to increase by as much as 1,500% in similar tests
- o Emission levels for chromium, cadmium, and lead are lower for TDF than for oil
- o SO2 and Nox emissions are reduced when TDF is substituted for coal or oil.

Burning TDF in hog fuel boilers has mixed effects on environmental performance. The major adverse impact on emissions quality is a significant increase in particulate emissions. However, SO2 and Nox emissions are reduced, as are emission levels for several heavy metals. In general, increases in the level of particulates can be kept within applicable emission limits by control of the percentage of TDF used as auxiliary fuel. The location of most paper mills in air pollution attainment areas simplifies the permitting process.

Economic Characteristics

- o Shredding costs (dewired): $0.27 - $0.37 per tire.
- o Dewired TDF cost to pulp and paper mills: $1.00 - $1.70 per MMBTU.
- o Coal prices to paper mills: $1.60 - $2.00 per MMBTU.
- o Capital investment necessary: $150,000 - $350,000.

Similar to cement kilns, the attractiveness of TDF to a pulp and paper mill is highly dependent on the cost of competing fuels in the region, tipping fees available to local shredders, and resulting prices charged by shredders for TDF. Unlike cement kilns, pulp and paper mills must use dewired TDF, which has higher processing costs (about $27-$37/ton). Therefore, the economics are somewhat more marginal for paper mills than for cement kilns.

In general, TDF suppliers try to price their product between 15% and 25% less than coal. One mill in the Southeast that burns 30 tons of dewired TDF per day and is paying $40 per ton ($1.42/MMBTU) considers TDF to be a "marginal" fuel. They plan to switch back to coal if the price of TDF goes over $45 per ton, but will make the necessary long-term capital investment to improve their feeding capability ($350,000) if they can secure a source of TDF for $25 per ton or less (note that this is less than the typical cost of dewired TDF production). A sample economic analysis from the perspective of this mill follows:

P = F + R - C -T -D

P = ? = Profit per MMBTU burned in hog fuel boiler.
F = $0.00 = No tipping fee realized by mill.
R = $0.47 = Difference of cost between TDF and local coal prices per MMBTU.
C = $0.00 = No incremental difference in processing costs.
T = $0.00 = Prices are delivered product.
D = $0.00 = No incremental difference in disposal costs.

P = $0.00 + $0.47 - $0.00 - $0.00 - $0.00
P = $0.47 per MMBTU burned.

Since the facility burns about 280,000 MMBTU of supplemental fuel per year in its hog fuel boiler, the incremental profit is about $130,000 per year. For a capital investment of $350,000, the payback period is about 2.7 years.

Volume Capability

- Total Potential Tire Use: 35 - 55 million passenger tire equivalent per year
- Typical plant consumption: 1.5 million to 3 million passenger tire equivalents per year

The American Paper Institute reports that the 603 paper mills and 351 pulp mills in the U.S. consumed approximately 393,000 billion BTU's in hog fuel boilers in 1989. If 25% of this capacity used 10% TDF on a BTU basis, the industry would consume about 35 million passenger tire equivalents per year; if 40% of capacity used 10% TDF, total consumption would be about 55 million passenger tire equivalents.

2.2.3 Barriers to Further Implementation

- Low cost of competing fuels
- Potential emission problems at higher feed rates

- Environmental permit modification requirements
- Remote location of many pulp and paper mills
- Uncertainty of long-term supply
- Conservative nature of industry.

Barriers to further utilization of TDF at pulp and paper mills are similar to those to further use in cement kilns. However, because pulp and paper mills require dewired TDF, the economics of TDF use in pulp and paper mills are less attractive. Therefore, further use is primarily impeded by the relative economics of dewired TDF production versus other fuels. The relatively marginal cost advantage of dewired TDF over competing fuels reduces pulp and paper mill incentives to invest in feed system and environmental permit modifications.

Many pulp and paper mills are located at or near raw material supplies, at substantial distances from population (and therefore tire generation) centers. Transportation costs provide an additional price disadvantage.

Other barriers include the uncertainty of long-term supplies, which increases the risks associated with mill investment in permit and feed system modifications.

2.2.4 Potential Methods for Reducing Barriers

- Development of improved information/marketing of TDF as fuel to the paper industry
- Development of lower-cost methods for dewiring TDF or offsetting dewiring costs. This would significantly lower the price and improve its advantage over competing fuels
- Development of further research on operating conditions for minimizing adverse effects of TDF on air emissions
- Dissemination of information demonstrating the results of air emissions tests and addressing the significance of increases in particulates
- Implementation of possible incentives by States (e.g., tax credits) to paper mills kilns using TDF as fuel
- Development of standardized air permit modification package/approach by state or nationally to expedite permit modification

- o Development of standard information packages for convincing state officials of the environmental safety of use of TDF in paper mills

- o Development of assured supplies of TDF.

2.2.5 Information Sources

U.S. Department of Energy, Waste Tire Utilization, U.S. DOE, April 30, 1987.

Phone Conversation with Kevin Parks, Integrated Waste Systems, Buffalo, New York, April 27, 1990.

Phone Conversation with Joseph Nicoleolo, American Paper Institute, New York, New York, April 25, 1990.

Phone Conversation with Roger Glover, Great Southern Paper Company, Cedar Springs, Georgia, April 26, 1990.

Phone Conversation with George Brown, Nekoosa Paper Company, Tomahawk, Wisconsin, April 25, 1990.

Phone Conversation with Bob Jones, Rome-Inland Paper Company, Rome, Georgia, April 26, 1990.

Phone Conversation with Tom Ryan, Boise Cascade Corporation, Deritter, Louisiana, April 24, 1990.

Phone Conversation with Norman Emanuel, Emanuel Tire, Baltimore, Maryland, April 23, 1990.

Phone Conversation with Mark Hope, Waste Recovery, Inc., Portland, Oregon, April 24, 1990.

Phone Conversation with Bob Maust, Maust Tire Recycle, Preston, Minnesota, April 25, 1990.

Port Townsend Paper Company Port Townsend Kraft Pulp Mill Source Test, Washington Department of Ecology, February 25, 1986.

Report on Diagnostic Testing at Nekoosa Packaging, Tomahawk, Wisconsin, Clean Air Engineering, November 7, 1989.

Drabek, John and Willenberg, Jay, Measurement of Polynuclear Aromatic Hydrocarbons and Metals from Burning Tire Chips for Supplementary Fuel, 1987 TAPPI Environmental Conference, Portland, Oregon, April 26-29, 1987.

Crown Zellerbach Port Angeles Thermo Mechanical Pulp Mill Source Test, Washington Department of Ecology, June 10, 1986.

Boise Cascade Wallula Kraft Pulp Mill Source Test, Washington Department of Ecology, May 20, 1986.

Hope, Mark, Summary of West Coast Experience with Emissions from Wood residue-Fired Boilers While Burning Tire-Derived Fuel (TDF) as a Supplemental Fuel, NCASL Technical Bulletin No. 465, 1985.

Phone Conversation with Paul Koziar, Director of Waste Tire Program, State of Wisconsin, Madison, Wisconsin, May 1, 1990.

Juarez, Steve, Used Tires: Health Hazard or Economic Opportunity, California State Assembly Office of Research, January, 1988.

November 1989 FOB Coal Prices, Coal Outlook, March 12, 1990.

Used Tire Recovery and Disposal in Ohio, Ohio EPA: Division of Solid Waste Management, March 1987.

2.3 USE AS FUEL IN UTILITY BOILERS

Abstract. Either whole tires or tire-derived fuel (TDF) can be used as supplemental fuel in utility boilers, depending on boiler size and technology. The burning technology is being tested in wet bottom boilers (whole tires) and cyclone boilers (dewired 1"x1" TDF) with promising results. At least three U.S. utility boiler facilities are currently burning or planning to burn tires or TDF on an experimental basis. Early results indicate that burning scrap tires or TDF in utility boilers does not adversely affect boiler operation, with mixed impacts on environmental performance (reduced NOx and SO2, increased opacity/ particulates). Further, the economics of burning whole tires in wet bottom boilers is approaching the favorable economics of cement kilns, particularly when a low tipping fee is charged, versus that of the typically higher tipping fees at landfills.

Utility boilers experimenting with TDF have volume capacities in the 0.5 - 3 million tire per year range. We estimate that utility boilers could use approximately 60 million tires per year as auxiliary fuel by 1995. This assumes that 25 percent of existing wet bottom boilers will switch over to TDF for 10 percent of their fuel requirements. These boilers can accept whole tires or regular TDF. The estimate does not include boilers burning 1"x1" dewired TDF, because use of this fuel requires subsidies to offset high processing costs.

Principal barriers to further scrap tire use in this industry are:

- Marginal cost advantage of scrap tires over coal; whole tire burning requires separate, expensive equipment for fuel feeding, while dewired 1"x1" TDF suitable for feeding in coal systems is more expensive than coal
- Air permit modification requirements for testing, and delays in issuing modifications
- Unproven reliability of whole tire and TDF feed technology
- Reliability of TDF supply (risk to recovering capital investment)
- Extremely conservative/risk averse nature of utility industry.

2.3.1. Technology Description

Utility plants designed to burn coal can, depending on boiler type and ash handling system, utilize whole tires or tire-derived fuel as supplemental fuels. Boilers designed to burn coal with low ash fusion temperatures (slagging type, or wet bottom boilers) can burn whole tires or TDF because their ash handling systems can accommodate slag formed by steel from tire beads and belts. Boilers designed to burn high ash fusion temperature coal (dry ash type) could only burn dewired TDF because their ash handling systems are designed to remove dry material.

Conventional coal feeding systems cannot be used to feed the supplemental tire fuel unless it has been very finely reduced and dewired. Typically, the size reduction required to feed tire-derived fuel in conventional feed systems is uneconomic.

There are no major power generating facilities known to be burning tires for fuel on an operating basis at the current time. However, a large midwestern utility is currently examining the possibility of burning whole tires in a wet bottom boiler. This application would require construction of a secondary fuel feed system to charge whole tires to the boiler.

In a wet bottom boiler, the furnace comprises a two-stage arrangement. In the lower part of the furnace, gas temperature is maintained high enough so that molten slag will drop onto the floor, where a pool of liquid slag is maintained and tapped into a slag tank containing water. In the upper part of the furnace, gases are cooled below the ash fusion point so that ash carried over into the convection banks is dry. This arrangement is particularly suited to the combustion of whole tires, since slag from steel in the tires can be managed by the slagged ash handling system.

Unfortunately, many wet bottom boilers are older and may not have the air pollution control equipment necessary to contain the increase in particulate emissions expected when burning tires.

Several coal-fire powered plants have been permitted to burn shredded tires (TDF). However, in all cases examined, the cost of shredding tires finely enough to work in most common furnace types has proven to be uneconomical without subsidies.

The State of Wisconsin recently established a 10 year subsidy program designed to encourage the use of scrap tires as an alternative energy source. The program is being financed by a 2 dollar per tire tax on new tires sold in the state. Through the program, end users of TDF will be given a subsidy of $20 for each ton burned. In addition, the state is granting money to potential users to finance usage studies and capital investments. The state is also encouraging tire shredders to produce tire chips small enough to meet the requirements of cyclone boiler operators (1 inch square or less). Currently, 2 industrial facilities and 2 utility power facilities have shown an interest in the program. The potential TDF consumption of these four facilities is between 3.5 and 4.5 million passenger tire equivalents per year (between 70% and 90% of the scrap tires disposed of in Wisconsin each year). Facilities using older cyclone boilers (pre-1975) are the most likely to utilize the program since these units are free from the more complex permitting requirements of newer units.

In response to the program, The Wisconsin Power and Light Company has completed an initial test burn at its Rock River, Wisconsin facility. Rock River consists of two older (mid 1950s) cyclone units with a combined capacity of 150 MW. Crumb rubber was mixed with coal at levels of 5% and 10% on a BTU basis (approximately 1.5 and 3 tons per hour). According to company sources, the results of the test were technically and economically promising. Both NOX and SO2 emissions declined while opacity increased only slightly. Other plant operating parameters were normal. The facility has now applied for a grant from the state to finance a testing program designed to examine the possibility of using a larger chip size (1 inch square), explore possible ash contamination problems, and estimate the necessary capital requirements. In addition, the company is studying the possibility of integrating into the tire shredding business.

Finally, boilers using fluidized bed technology are suitable for burning a wide variety of fuels, including potentially whole tires and TDF. Fluidized bed combustion has been proven feasible in plants of 300 MW capacity or less, and is viewed as a promising technology for "clean" coal applications because it can be used to reduce SO2 and NOX emissions during the combustion process. Therefore, it may see significant use in new coal burning power plants. However, there are few, if any, fluidized bed boilers in operation at utility plants at this time. Therefore, their potential contribution to scrap tire reuse within a five year time period is negligible.

2.3.2 Environmental, Economic, and Volume Characteristics

Environmental Characteristics

- Because tires generally have less than 20% of the nitrogen content and 80% of the sulfur content of most coal, it is expected that NOX and SO2 emissions will be reduced.

- Particulate emissions can be expected to increase when TDF is substituted for coal in pulp and paper mill boilers. Because many of the facilities with wet bottom boilers are older, their current air pollution control equipment may not be able to take the additional load.

Economic Characteristics

- Coal prices to utilities: \$1.00 - \$2.00 per MMBTU.
- Tip fee earned by utility: \$0.00 - \$1.00 per tire.
- Transportation cost: \$.10 per tire.
- Capital investment: \$1,000,000
- Incremental processing costs may increase slightly due to the difficulty in handling and storing tires.

The following is a sample economic analysis for a wet bottom boiler operated by a midwestern utility with a coal cost of \$1.55/MMBTU and potential tipping fee revenue of \$0.50/tire.

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

P = ? = Incremental profit per tire burned.
F = \$0.50 = Tipping fee per tire realized by utility.
R = \$0.47 = Coal savings per tire.
C = \$0.10 = Additional processing cost per tire.
T = \$0.10 = Transportation cost per tire.
D = \$0.00 = No additional disposal cost.

P = \$0.50 + \$0.47 - \$0.10 - \$0.10 - \$0.00
P = \$0.77 per tire

Since the facility is expected to burn 1.5 million tires per year, the incremental profit will be approximately \$1.16 million. For a capital investment of \$1.0 million, the payback period is less than 1 year.

Volume Capability

- Total potential tire use: 40 - 60 million passenger tire equivalents per year.
- Tire use estimated at 1.5-3 million tires per year per facility.

There are currently about 50 active wet bottom boiler scattered around the country. Together these facilities generate approximately 2,048 MW. Assuming a total thermal efficiency of about 30%, these facilities require about 740 million MMBTUs per year in fuel input. If 25% of the wet bottom boiler generating capacity derived 10% of its energy input, the industry would consume about 62 million tire equivalents per year.

2.3.3 Barriers to Further Implementation

- Difficulty in securing a stable, long term supply of scrap tires

- Unproven technology for tire feed

- Potential effects on air pollution control equipment due to higher particulate in exhaust stream

- Age of existing wet bottom boiler units

- Conservative nature of utility industry.

In general, utilities have relatively little incentive, under current conditions, to switch a relatively small percentage of their total fuel requirement to a fuel requiring air permit modifications and new feed systems. Because utilities' business is the reliable supply of electricity, and returns on investment are regulated by state public service commissions, utilities are generally very conservative in adopting new technologies that may have low reliability or otherwise affect their ability to consistently supply electricity.

However, pressures to reduce SO2 emissions in pending Acid Rain legislation will lead coal burning utilities to look for fuel switching solutions that will reduce emissions without requiring flue gas desulfurization (FGD, or scrubbing). This should be particularly true for older plants where the capital costs for scrubbing may be prohibitive considering the remaining life of the unit, and for plants where space constraints prohibit construction of scrubber units. This in turn should lead to heightened interest by utilities in TDF as a supplement to high-priced low sulfur coal, due to its low sulfur content. However, the probable time frame for implementation of acid rain provisions (with the earliest, limited reduction requirements going into effect in 1995) indicates that these pressures are not likely to force significant use of TDF within a five year time frame.

In addition to potential incentives to increase TDF use in existing units due to acid rain standards, there may be incentives to consider TDF as a supplemental fuel in new generating units as part of "clean coal" technologies. The Department of Energy estimates that utilities will need to add

110 GW of generating capacity by the year 2000 to meet rising demand. Currently, only 37.3 GW of new capacity is on the drawing board. Requirements for new generating capacity, and for cleaner burning fuels or technology, may increase demand for fluidized bed combustion units for coal burning in the late 1990s. However, this demand is not likely to significantly affect scrap tire utilization within a five year period due to the long lead times required to design, site, and construct new power plants.

2.3.4 Potential Methods for Reducing Barriers

- Enhancement of the reliability of tire supply
- Development of additional research on operation of feed systems, effects on boiler performance, and effects on air emissions and air pollution control equipment
- Dissemination of research results on whole tire and TDF use
- Increased marketing of TDF and whole tires to utilities
- Development of standardized approach/package for air permit modification for utility boilers
- Use of Federal or state subsidies to encourage fuel utilization.

The Wisconsin subsidy program has been successful in encouraging utilities to consider using TDF. The amount of the subsidy basically covers the increased cost of tiring shredding to a 1 inch x 1 inch dewired particle size suitable for feeding into utility boilers through conventional feed systems. Thus, the subsidy, which is financed by a tax on tires, helps equalize the cost of highly processed TDF with coal.

2.3.5 Information Sources

U.S. Department of Energy, Waste Tire Utilization, U.S. DOE, April 30, 1987.

Phone Conversation with Kevin Parks, Integrated Waste Systems, Buffalo, New York, April 27, 1990.

Phone Conversation with Norman Emanuel, Emanuel Tire, Baltimore, Maryland, April 23, 1990.

Phone Conversation with Mark Hope, Waste Recovery, Inc., Portland, Oregon, April 24, 1990.

Phone Conversation with Bob Maust, Maust Tire Recycle, Preston, Minnesota, April 25, 1990.

Phone Conversation with Paul Koziar, Director of Waste Tire Program, State of Wisconsin, madison, Wisconsin, May 1, 1990.

Juarez, Steve, Used Tires: Health Hazard or Economic Opportunity, California State Assembly Office of Research., January, 1988.

November 1989 FOB Coal Prices, Coal Outlook, March 12,, 1990.

Used Tire Recovery and Disposal in Ohio, Ohio EPA: Division of Solid Waste Management, March 1987.

Phone Conversation with Bob Syring, United Power Association, Elk River, Minnesota, April 24, 1990.

Phone Conversation with Chris Bergenson, Utility Data Institute, Washington, D.C., April 26, 1990.

Phone Conversation with Mike Horvath, Ohio Edison Company, Cleveland, Ohio, April, 25, 1990.

Phone Conversation with Bob Kermes, Northern States Power, Minneapolis, Minnesota, April 26, 1990.

Phone Conversation with Chuck Linderman, Edison Electric Institute, Washington, D.C., April 23, 1990.

Phone Conversation with Jamie Platt, Electric Power Research I Institute, Palo Alto, California, April 23, 1990.

Phone Conversation with Kris McKinney, Wisconsin Power and Light, Madison, Wisconsin, May, 1990.

2.4 USE AS FUEL IN DEDICATED TIRE-TO-ENERGY FACILITIES

Abstract. Either whole tires or tire-derived fuel (TDF) can be used as fuel in dedicated tire-to-energy facilities; existing and planned facilities are designed to burn whole tires to minimize fuel costs. The technology has been proven in the U.S. by Oxford Energy at its operating plant in Modesto, CA, and in West Germany by Gummi Meyer. Three additional plants are planned by Oxford to be in existence by 1995. The Modesto plant has had some operating difficulties due to tire handling, resulting in lower than projected utilization; however, Oxford states that these problems have been corrected. Environmental operation of the plant is satisfactory, although utilization has previously been temporarily reduced due to higher than expected NOX emissions. Oxford states that these problems have also been corrected.

Oxford's existing and planned facilities have volume capacities of 4.5 million to 9 million tires per year. If all four plants startup on schedule, they could use approximately 31 million tires per year as fuel by 1995.

Principal barriers to further scrap tire use in dedicated tire-to-energy facilities are:

- High capital cost of facilities. Dedicated tire-to-energy plants cost between 2 and 7 times more to construct per MW than conventional coal power plants.

- Processing economics typically require some form of subsidy for costs to be favorable.

- Need to site new facilities. All planned tire-to-energy facilities are new plants which may encounter local opposition, delaying or foreclosing construction.

- Environmental permitting for new facilities.

- Reliability of fuel supply.

2.4.1 Technology Description

Oxford Energy of Santa Rosa, California, currently owns and operates the only power plant in the United States specifically designed to burn whole tires as its primary fuel source. The 14.5 MW facility, built adjacent to the nation's largest tire pile in Out, California (near Modesto) has been operating since 1987. The plant utilizes a technology successfully used at the Gummi Meyer tire facility in Landau, West Germany since 1973.

There are two tire incinerators at Out operating at temperatures above 2000 degrees Fahrenheit. During combustion, tires are supported on a reciprocating stoker grate. The grate configuration provides for air flow above and below the tires, which aids combustion and helps keep the grate cool. The grate also allows slag and ash to filter down to a conveyor system which takes them to hoppers for sale off-site. Tires up to 4 feet in diameter and 90 pounds can de handled. A metal detection system rejects tires with rims.

Each incinerator has its own boiler. The boilers produce 130,000 lbs/hr of 930 psig/350 degree Fahrenheit steam which combine to drive a single 15.4 MW (rated) General Electric steam turbine generator.

The plant includes a full pollution control system, with flue gas desulfurization, thermal de-NOX, and a fabric filter baghouse. The three major by-products, metallic slag, gypsum, and high zinc ash, are sold off-site.

According to company officials, as of April, 1990, the facility was producing approximately 14.5 MW of electricity, burning 600 tires/hour, and remaining on-line close to 85% of the time.

Operating problems experienced include:

- A reduction in energy recovery efficiency due to accumulated mud and water on tires from the tire pile. Company officials say this will not be a problem in future facilities since they will primarily burn tires coming directly off the road.

- During 1988, the facility was operating at only 12MW due to NOX emissions that were continuously close to the standards imposed by the State of California. The problem has since been corrected.

- Until recently, utilization rates were depressed due to various ancillary system problems.

The tire supply for the facility comes from both the adjacent tire pile and from a local tire collection service operated by Oxford. The tires collected by this service do not always go to the facility. Others are sold as used tires or retreadable castings, or shredded and sold as fuel to cement kilns and pulp and paper mills. Oxford pays the owner of the tire pile for each tire removed from the tire pile and charges a fee to collect tires in the surrounding community.

Oxford Energy currently has three additional whole tire to energy facilities in various stages of development. A 30MW facility designed to consume 9 million tires/year is under construction in

Sterling, Connecticut. Two additional 30MW facilities located in Lackawanna, New York and Moapa, Nevada are in preliminary or development stages. The following is a summary of those facilities in the U.S. and overseas:

U.S. Facilities

- Oxford Energy, Out, CA: 4.5 million tires/year
- Oxford Energy, Sterling, CT (under construction): 9 million tires/year
- Oxford Energy, Lackawana, NY (planned): 9 million tires/year.
- Oxford Energy, Moapa, NV (planned): 9 million tires/year.

Foreign Facilities

- Gummi Meyer, Landau, West Germany (two units): 3 million tires/year

2.4.2 Environmental, Economic, and Volume Characteristics

Environmental Characteristics

- High temperatures provide for complete combustion of tires while minimizing the emissions of dioxins and furans.
- For each tire consumed, the facility generates approximately 3.5 pounds of metallic slag, 1.1 pounds of gypsum, and 0.6 pounds of high zinc (45%) ash. Each of these byproducts has been successfully marketed off site.
- Facility was designed to use approximately 25 gallons of process water for each tire consumed. All waste water is either evaporated or treated to meet California standards.
- Tires have a lower sulfur and nitrogen content than typical coal used in power plants. However, concentrations of zinc and chromium tend to be much higher.

Economic Characteristics

- Capital costs for new whole tire to energy power facilities are expected to exceed \$3.5 million per MW (\$11 per annual tire of capacity). The cost for a new coal-fired facility is usually in the range of \$0.5 million to \$2.0 million per MW.

- o Power generated at the Out facility is sold to Pacific Gas and Electric under a long-term contract. Currently, the buy back-rate is \$.083 per kilowatt hour. This is equivalent to approximately \$1.84 per tire consumed.

- o Oxford Energy currently pays Ed Philbin, the owner of the tire pile, a fee for each tire (fee is paid on a per pound basis) removed from the pile. In the third year of operation, this fee was \$21 per ton (\$0.21 per tire). The fee will increase to \$24 per ton by the end of the sixth year.

- o In 1989, Oxford Energy was charging \$4 per truck tire for picking up at landfills in the Out area

The following is a sample economic analysis for the Oxford facility under construction in Sterling, Connecticut:

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

P = ?
F = \$0.50 = Estimate of tipping fee per tire.
R = \$1.41 = Revenue generated for each tire burned (\$0.067/kwh)
C = \$0.50 = Estimated processing cost per tire.
T = \$0.10 = Transportation cost for each tire delivered to plant.
D = \$0.00 = Disposal costs per tire (facility is close to break even on byproduct sales).

P = \$0.50 + \$1.41 - \$0.50 - \$0.10 - \$0.00
P = \$1.31 per tire burned

Since the facility is designed to consume about 9.5 million tires per year and capital costs are estimated at \$100,000,000, the projected payback period is approximately 8.1 years. Some analysts have estimated the plant cost to be greater than \$120,000,000, in which case the payback period increases to almost 10 years.

Because of the extremely high capital requirements, whole tire to energy facilities will only be practical in those parts of the country with high electric rates and tipping fees.

Volume Capability

- o Total potential tire use: 20 - 30 million automobile equivalents per year by 1995 if planned Oxford facilities are constructed on time.

The DOE estimates that utilities will need to add 110 GW of electric generating capacity by the year 2000, but only 37.3 GW are now on the drawing boards. Since the Oxford facility can generate 1 MW for every 300,000 of annual tire consumption capacity, the annual U.S. dumping/stockpiling/landfilling of 250 million automobile tire equivalents could be used to supply the fuel needs of .830 GW of generating capacity or a little more than 1% of the capacity that the DOE estimates will be needed. However, the long lead times required to bring one of these facilities on line make it highly unlikely that any plant other than those being proposed by Oxford will be on line before 1995.

2.4.3 Barriers to Further Implementation

- o High capital costs for facility construction
- o Low cost of alternative fuels such as coal, fuel oil, and gas
- o Stringent environmental permitting requirements
- o Public opposition to siting new power facilities
- o Difficulty in securing a stable, long-term tire supply.

2.4.4 Potential Methods for Reducing Barriers

- o Development of integrated tire collection and disposal systems (Oxford Energy has been successful at this) by plant owners.
- o Federal or state subsidies/tax credits to offset high capital expense.

2.4.5 Information Sources

U.S. Department of Energy, Waste Tire Utilization, U.S. DOE, April 30, 1987.

Phone Conversation with Kirby Hammond, The Oxford Energy Company, Santa Rosa, California.

The Oxford Energy Company 1988 Annual Report, Oxford Energy Company, Spring 1989.

Phone Conversation with Bob Mooney, Manager of Engineering, Fichtner USA, Atlanta, Georgia.

World's Largest Tire-Fueled Power Plant: It's Components -- It's Impact, Oxford Energy Company Report.

The Exeter Energy Project - A Project of the Oxford Energy Company, Oxford Energy Company Information Brochure.

Phone Conversation with Chris Bergenson, Utility Data Institute, Washington, D.C., April 26,1990.

GE Completes Construction of Nations Largest Whole-Tire-to-Energy Power Plant, General Electric Company Press Report, November 10, 1987.

Oxford meets Performance Goals Firing Whole Tires, Power, October, 1988.

The Erie Energy Project - A Project of the Oxford Energy Company, Oxford Energy Company Brochure.

Vogel, Mike, Lackawanna is chosen for Energy Plant, The Buffalo News, July 13, 1989.

Project Description, Electrical Generation Plant, Oxford Energy Company, December, 1986.

Oxford Energy's Tire-Fueled Power Plant Receives Operating Permit in California, Oxford Energy Company Press Release, March 10, 1988.

2.5 REUSE IN ASPHALT PAVING

Abstract. Scrap tire rubber can be used in asphalt paving either as part of the asphalt binding material or seal coat (both uses known loosely as asphalt rubber), or as aggregate (rubber modified asphalt concrete, or RUMAC). Crumb rubber is used in asphalt rubber; tire chips are used in RUMAC. Both technologies have been demonstrated commercially in small scale applications in the U.S. and in Europe. However, there are some contradictions in the data available on the ease of use and performance of both asphalt rubber (particularly when used as a binding material) and RUMAC. Both are reported to approximately double the service life of pavings, although some results conflict with these findings. There are no recognized technical standards for either material in the U.S.

Asphalt rubber seal coats use about 1,600 tires per mile of two lane road sealed. RUMAC uses between 8,000 and 12,000 tires per mile of two lane road repaved with a 3 inch lift. The potential volume capability of reuse in asphalt paving exceeds the scrap tire supply; however, on a practical basis, we estimate that use within 5 years could equal or exceed 28 million tires per year.

Principal barriers to further scrap tire use in asphalt paving applications are:

- High initial costs. Both asphalt rubber and RUMAC cost approximately twice the cost of conventional asphalt.

- Marginal lifecycle economics. Service claims typically project doubling the life of conventional asphalt. However, doubling the life does not overcome the high initial costs when future costs are discounted.

- Lack of product specification by ASTM or other body.

- Concern over uniformity of scrap tire rubber.

2.5.1 Technology Description

Tires can be utilized in asphalt paving in two ways: Asphalt-rubber, which is typically used as a sealant or as a relatively thin inter-layer between two paving layers; and in rubber modified asphalt concrete (RUMAC), in which tire rubber chips replace part of the aggregate in the paving mix, which is then applied in the same manner as conventional asphalt.

Asphalt-rubber is an asphalt cement that is produced by heating asphalt to about 400°F and adding presized crumb rubber while blending constantly for about 45 minutes. Typically, the crumb rubber added is in the range of 15 to 25 percent of the total asphalt-rubber cement. Asphalt-rubber must be made immediately prior to use, because the material cannot be stored due to difficulties in maintaining rubber in suspension. Asphalt-rubber mixing plants require little special equipment, as the asphalt-rubber is pre-mixed with the asphalt aggregate and is applied in the same manner as the standard asphalt cement.

To make asphalt-rubber, tires must be ground to a maximum size of 16-25 mesh. If the scrap rubber is not ground finely enough, and the digestion (mixing/heating) conditions (temperature and time) are not severe enough, the resulting asphalt-rubber cement is weakened and aggregate can break loose. Steel reinforcement and fabric must be removed from the scrap rubber for it to be used in asphalt-rubber.

Asphalt-rubber is used for:

- Pavement seal coats
- Stress-absorbent pavement interlayers
- Binders for surface courses
- Subgrade seals
- Lake/lagoon liners
- Roofing
- Crack/joint sealing

Addition of scrap crumb rubber to asphalt cement is reported to increase the ductility of the wearing surface, improve crack resistance, and reduce cold weather brittleness and hot weather bleeding.

Rubber modified asphalt concrete (RUMAC) is asphalt pavement in which some of the aggregate in the asphalt mixture is displaced by ground or chipped tires. This method was invented in Sweden and is patented in the U.S. under the name Plus Ride by Pave Tech Corporation of Seattle, WA. Plus Ride uses all the rubber in the used tires, including sidewalls, centerliner and tread portions, recycling all but the steel and fabric. Plus Ride modified asphalt is a combination of asphalt cement, aggregate and ground rubber from scrap tires. It has been used in highways, streets, bridges and airports. Its advantages are increased flexibility and durability.

Both the Nordic Construction Co., Stockholm, Sweden, and the Swedish Road and Traffic Research Institute stated that the performance of RUMAC is highly dependent on proper compaction of the pavement. The pavement has to be carefully laid, and extra care has to be taken in its compaction to prevent it from disintegrating.

U.S. Facilities/Use

- o Pave Tech Corporation, Seattle, WA, has patented rubber modified asphalt concrete under the name Plus Ride. It has been successfully used in highways, streets, bridges and airports. The patent expires in 1991.
- o International Surfacing, Phoenix, AZ
- o Cox Paving Co., Blanco, TX
- o Eagle Crest Construction Co., Arlington, WA
- o Manhole Adjusting Contractors, Monterey Park, CA
- o Asphalt Rubber Systems, Riverside, RI.

Rubberized seal coats have been extensively tested in Phoenix, Arizona, where street resurfacing with rubberized seal coats began in 1966. Asphalt-rubber has been successfully used in Arizona, the southwestern U.S., California, and Texas.

Foreign Facilities/Use

- o Nordic Construction Co., Stockholm, Sweden

The Plus Ride process has been successfully used in limited applications for highway construction in Sweden for more than 20 years. The process was originally developed in Sweden. RUMAC has been used in repaving about 10 kms/year of roads in Sweden, with the primary application being bridge paving.

RUMAC pavement strips laid in Sweden have been short in length and, as a result, have not been evaluated for long-term performance. The longest single strip, a stretch 14 km long and 13 m wide, was laid in 1989 and is being evaluated for long-term performance.

In the next 5 years only about 100 kms of RUMAC pavement is expected to be laid by the Nordic Construction Co. The Swedish Road and Traffic Research Institute confirmed superior performance such as good friction and abrasion and de-icing effect of RUMAC pavement.

2.5.2 Environmental, Economic, and Volume Characteristics

Environmental Characteristics

- o Some concern over constituents leaching from tire chips in road beds where bed is below the water table
- o No other significant environmental concerns.

Leach tests on tire chips used in roadbed materials show somewhat equivocal results for constituent leaching. However, leaching is only a potential concern where the road bed is immersed in ground water, which occurs only in relatively limited situations. Therefore, this environmental concern can be easily addressed through limitations on use.

Economic Characteristics

- o Initial cost of rubber-modified asphalt concrete (Plus Ride) in the U.S. is about twice that of conventional asphalt.
- o Cost of asphalt-rubber is about 40-100% higher than the cost of standard asphalt.
- o Cost of dense-graded asphalt concrete was approximately $3.04/sq. yard, compared to $6.13/sq. yard (thickness not specified) for asphalt rubber in 1988 in California.
- o Service life of asphalt-rubber pavements is expected to be 20 years or more, compared to 10-12 years for asphalt pavements.
- o Initial cost of RUMAC given to be 1.5 times that of conventional asphalt by Nordic Construction Co., Sweden and Swedish Road and Traffic Research Institute.
- o Cost of RUMAC in Sweden given to be $2.5/sq.m/cm thickness.
- o Service life of rubber-modified-asphalt concrete is about twice that of conventional asphalt concrete.

Asphalt-rubber and RUMAC are both approximately twice the initial cost of the standard asphalt or aggregate they replace. Performance information on both asphalt rubber and RUMAC indicate that they both extend service life of pavements significantly, when properly mixed and applied, between 80 and 100 percent. These data would tend to indicate that, on a lifecycle basis, asphalt-rubber and RUMAC are cost competitive to standard asphalt and aggregate, but are somewhat more expensive due to the higher initial costs of these materials and discounting of future costs associated with more frequent repaving of standard asphalt pavings.

The higher initial costs of using rubber as an additive can be attributed to the cost of processing tire rubber, blending and mixing rubber with asphalt, added energy consumption and plant maintenance, and some modifications, such as need for more powerful pumps due to the higher viscosity of asphalt-rubber/asphalt-rubber-concrete.

Volume Capability

- o 225 million tires/year, if 10% of the aggregate used annually in asphalt were replaced by rubber from tires.
- o 28 million tires/year if an asphalt-rubber seal coat is used on only approximately 1% of the two-lane highways (approximately 17,500 miles) replaced every year.
- o 8,000-12,000 tires/mile for a two-lane highway overlaid with 3 inches of rubber-modified asphalt concrete.
- o 1,600 tires/mile for a two-lane highway for an asphalt-rubber seal coat.

There are about 3.5 million miles of paved road surfaces in the U.S., a fraction of which are repaired or replaced every year. Total asphalt concrete laid each year in the U.S. is about 450 million tons. Rubber-modified asphalt concrete (RUMAC) uses about 60 lbs. of rubber/ton of mix, resulting in recycling of five tires per ton of rubber modified asphalt concrete, as each tire yields about 12 lbs. of rubber. Thus, about 12,000 tires can be recycled per mile on a two-lane highway overlaid with 3 inches of RUMAC pavement. Thus, RUMAC has the potential to use up all the scrap tires produced in the U.S. every year even if only 1/8 of the asphalt concrete laid each year were to be replaced by RUMAC. Rubber-asphalt seals have the potential to use up about one-quarter of the nation's supply of scrap rubber every year.

2.5.3 Barriers to Further Implementation

- o Use of worn tires as asphalt-rubber additives is not accepted due to the uncertainty about durability, performance and initial cost.
- o Scrap polyethylene addition to asphalt provides an improvement of 20% and enhances both crack resistance at low temperatures and creep resistance at higher

temperatures. Polyethylene will likely be the scrap raw material of choice, as it offers greater performance improvement.

- High initial cost.
- Product specifications not laid out by ASTM.
- Lack of information on relative benefits and costs.
- Concern over availability of uniform-quality rubber from tires.
- Reluctance of highway administrators to take risks in using innovative material.
- Steel and fabric have to be separated from the tire, thus about 60-75% of tire is not used, and processing costs are high.

It is necessary to prove the effectiveness of rubber/asphalt as an aggregate binder, as distinguished from the present membrane usage.

2.5.4 Potential Methods for Reducing Barriers

- Following up and documenting the performance, cost/benefits from the use of rubber-asphalt seal coats and rubber-modified asphalt concrete where used, as compared to asphalt.
- Standardization of asphalt-rubber additive product specifications by ASTM.

The industry is wary of using rubber-asphalt additives in laying pavement, due to lack of information on the performance, relative benefits and costs and also the lack of ASTM specifications for such products. Use of asphalt-rubber seals and RUMAC has usually not been followed by cost-benefit economic evaluations and technical evaluations. Collection and dissemination of such information will go a long way in evaluating the possibility of RUMAC and asphalt-rubber seals as a large-volume consumers of scrap tires.

2.5.5 Information Sources

Waste Tires in New York State: Alternatives to Disposal, Conference Proceedings, New York State Department of Environmental Conservation and New York State Department of Transportation.

U.S. Department of Energy, Waste Tire Utilization, U.S. DOE, April 30, 1987.

Sikora, Mary B., Tire Recovery & Disposal: A National Problem With New Solutions, Resource Recovery Report, Washington, D.C., June 1986.

Phone Conversation with Perolos Olhsson, Research Engineer, Materials Section, Swedish Road & Traffic Research

Phone Conversation with Neils Ulmgrem, Head of Research labs, Nordic Construction C., Stockholm, Sweden

Phone Conversation with Mike Harrington, Pave Tech, Seattle, WA.

3.0 TECHNOLOGY BRIEFS - OTHER TECHNOLOGIES NOT MEETING STUDY CRITERIA

This section discusses technologies which were reviewed and found to not meet study criteria for environmental acceptability, economic feasibility, or volume capability. These technologies include pyrolysis, rubber reclaim, tire splitting, and artificial reefs.

Pyrolysis is fully profiled in this section because it is a proven technology which could theoretically be used to recycle a large volume of scrap tires, but which is economically infeasible due to both very high capital and operating costs and low revenues from sale of pyrolysis products. Large-scale commercialization of pyrolysis is technically feasible, but only with very high subsidies, as are provided in Europe.

The other technologies discussed are addressed in a brief form. These technologies are constrained by the absolute size of the market for the products produced (e.g., reclaimed rubber, tire splitting) and/or their economics (e.g., artificial reefs). While not capable of consuming large volumes of tires, they can make a contribution to sound tire disposal.

3.1 PYROLYSIS

3.1.1 Technology Description

Pyrolysis is the process of breaking organic chemical bonds by heating. It is also known as destructive distillation. Pyrolysis in the strictest sense is combustion in the absence of oxygen.

Pyrolysis has been used to break down tires into some of its constituents. Char, gas, oil and steel are the products. The quantity produced of each is a function of the process used and temperature. Gas generation increases with increasing temperature; oil generation decreases with increasing temperature; char generation is dependent on process type rather than temperature. Pyrolysis temperatures vary between 500° and 1100F.

Tire pyrolysis can be oxidative or reductive. In the oxidative process oxygen or steam is injected and combustion of a portion of tire material takes place under substoichiometric conditions.

The majority of pyrolysis processes are reductive. In reductive pyrolysis hydrogen gas is added to produce a reducing atmosphere and to hydrogenize the tires. This results in the production of hydrogen sulfide gas and a reduction in the sulfur content of oil, char and gas.

Typical product yields per tire are:

- 1 gal oil
- 7 lbs char
- 3 lbs gas (57 scf)
- 2 lbs steel and ash

Yields per ton of tires are:

- Oil (gal): 82 - 171
- Char (lb): 500 - 800
- Steel (lb): 38 - 380

In the oxidative process the relative yield of gas is higher, but the heating value of gas is lower than that of the gas produced in the reductive process. Gases from reductive processes have a high heating value, sometimes double that of natural gas. Gases typically contain paraffins and olefins with carbon number up to 5. In oxidative processes gas also contains CO, CO_2, H_2 and N_2 (if air is used). A portion of the gas is burned to heat the reactor.

All of the pyrolytic oil fractions or separate liquid fractions can be collected. Three boiling fractions are usually distilled from the oil:

- o Naphtha
- o Fuel Oil
- o Extender Oil

The liquid fraction contains most of the hydrocarbons with a carbon number of 6 or higher. This liquid fraction consists almost entirely of HCs, with about 26% by weight being either benzene or toluene. Heating value of oil is about 17,000 -18,000 BTU/lb and is comparable to No. 6 fuel oil.

Typical particle size of char is usually too large to qualify as a high quality carbon black.

U.S. Facilities

Only one commercial pyrolysis unit is operating in the country. Several experimental pyrolysis units have been tried though none have demonstrated sustained commercial operation.

- o Conrad Industries, Centralia, WA
  - 24 ton/d shredded tires commercial unit in operation for four years
  - No further information provided by the industry
- o J.M. Beers, Inc., Wind Gap, PA
  - A small experimental pyrolysis plant
  - Operating permit granted by Pennsylvania Department of Environmental Resources
  - Meets air emissions standards

Foreign facilities

- o Deutsche Reifen und Kuiststoff - Pyrolyse GmbH (DRP), West Germany

- Consumption of tires:	7,716 tons/year
- Estimated capital cost:	$ 6.5 - 8.5 million
- Estimated revenue:	$ 0.49/gal - oil
	$ 0.045/lb - char
	$19.32/ton - scrap
- Tire acquisition cost:	$ 0.09/tire

- o Kobe Steel and Sumitomo Cement, Ako-city Japan
  - Consumption of tires: 7,700 tons/year
  - Pyrolysis temperature: 600°C, indirectly heated rotary kiln
  - Estimated cost: $4.5 million (in 1979)
  - Estimated revenue: $1.62 million
  - Production: Carbon black - 2400 ton/yr
Heavy oil - 2800 ton/yr
Scrap wire - 350 ton/yr

- o Omahama Smelting & Refining Co., Japan
  - Consumption of tires - 10,000 tons/year (planned to increase to 30,000 tons/year)
  - Pyrolysis temperature 750°F
  - Production:
Oil - 21% - 14,200 BTU/lb
Gas - 51% - 225-340 BTU/scf
Char - 13% - 12,250 BTU/lb

Pyrolysis plants are in use in W. Germany, Japan and England. All these full-scale plants are subsidized by the government in the form of both direct subsidies and low percentage interest loans.

3.1.2 Environmental, Economic and Volume Characteristics

Environmental Characteristics

- o Energy recovery is about 75-82% based on the heat of combustion of tire rubber
- o Vapors released during pyrolysis are cooled in a quench tower.

Economic characteristics

- o Break even rate:
  - Tire tipping rate: $3.00/tire (industrial sources)
  - Oil price: $0.60 - 0.99/gal
  - Char price: $0.06 - 0.08/lb
  - Current No. 6 oil price: $0.50/gal
  - Current char price: $0.02/lb
- o Separated grade A carbon black from pyrolysis can be sold approximately for $0.13/lb.

- o Probable price of oil (as equated to No. 6 oil) about \$0.50/gal or \$21.00/barrel (fob price for barge/tank car, New York).

- o Highest value for pyrolysis oil is as petrochemical intermediate.

- o Possible uses of liquid fraction (in the order of importance):

  - Gasoline octane extender, due to the high benzene and toluene content of the oil
  - Gasoline blending stock
  - Boiler fuel
  - Extender oil for tire rubber

- o Carbon black is low grade and can only be used for molded goods, conveyor belting, shoe soles, etc.

- o Capital costs and lack of economic viability of feedstock tires can be prohibitively expensive.

The quality of the carbon black obtained from the char is variable and, at best, of SRF grade after treatment. SRF is a carcass grade carbon black and is not used in tread rubber in tires. As a result of its poor quality, its use and marketability is limited. The oil obtained from pyrolysis is, at best, comparable to No. 6 oil, and cannot be marketed as a pipeline oil due to its low quality.

The pyrolysis technology is not demonstrated to be economically feasible at present due to high capital costs, large variability in quality and quantity of products, and uncertain demand for products. Pyrolysis has been viable in W. Germany, Japan and England only because of the high subsidies paid by government.

Volume capability

Only one commercial facility exists at present in the U.S., though several have been in the planning stages for many years. The volume capability of pyrolysis is negligible.

3.1.3 Barriers to Further Implementation

- o Pyrolytic processes found to be inefficient with low energy recovery.

- o Tire feed preparation such as shredding, grinding, etc. is required.

- o Variability in quality of products from different operations.
- o Oil and char not of sufficient quality for substitution of heating oil and carbon black.
- o Gas has a high heating value but can't be marketed as a pipeline gas because of excessive CO content.

Lack of widespread use of pyrolysis is due to major economic barriers relating to product marketability, product quality and prices. In one study over 31 facilities using pyrolysis were identified. Nearly all of the facilities have been abandoned for economic reasons. Even though pyrolysis is an established technology, it has not been proven to be financially viable.

3.1.4 References

U.S. Department Of Energy, Scrap Tires: A Resource & Technology Evaluation of Tire Pyrolysis & Other Selected Alternate Technologies, U.S. DOE, November 1983.

Phone Conversation with Lester Bergey, Bergey Inc., Franconia, PA.

Phone Conversation with Bob Conrad, Conrad Industries, Seattle, WA.

Phone Conversation with John Kreishner, Kutreib Corp., WI.

Hitachi Zosen Corporation, Outline: Present State of Disposal & Recycling of Waste Tires in Japan, Hitachi Zosen Corporation, Osaka, Japan, April 1982.

The Rubber Association of Canada, Scrap Tires in Canada: Report of the Task Force for Scrap Tire Disposal, The Rubber Association of Canada, May 1989.

U.S. Department of Energy, Waste Tire Utilization, U.S. DOE, April 30, 1987.

Ohya, A. & K. Asano, Waste Tire Disposal in Japan, The Japan Automobile Tire Manufacturers Association Inc., Tokyo, Japan, October 1982.

Sikora, Mary B., Tire Recovery & Disposal: A National Problem With New Solutions, Resource Recovery Report, Washington, D.C., June 1986.

Henstock, Michael E., Technology for the Disposal & Treatment of Waste Tires in the United Kingdom, The University of Nottingham, August 1983.

Hitachi Zosen Corporation, Fuel Gas Production System by Pyrolysing Waste Tires, Hitachi Zosen Corporation, Osaka, Japan, August 1985.

3.2 OTHER TECHNOLOGIES

3.2.1 Rubber Recovery

Rubber can be reclaimed by shredding, grinding, pulverization, and treatment with chemicals and plasticizers under pressure and heat (partial de-vulcanization). During vulcanization, strong carbon-sulfur chemical bonds are created, replacing some of the double chemical bonds present in the original monomer. As a result, vulcanized rubber loses much of its thermoplastic characteristics and becomes stable over a wide range of temperatures encountered during driving conditions.

No technology at present allows complete de-vulcanization of rubber (breaking of the carbon-sulfur bond). Without de-vulcanization, use of reclaimed rubber is dependent on physical bonding, as opposed to chemical and physical chemical bonding.

Rubber reclaimed by grinding is known as crumb rubber. Grinding can be ambient or cryogenic. Steel and fabric are separated from crumb by magnetic and gravity separators.

Ambient grinding (at room temperature) produces rubber particles with rough exterior surface, about 1 mm in size, suitable only for physical bonding. Such rubber is used in products with low stress requirements.

Cryogenic grinding is performed at a temperature below the glass transition temperature. This is usually accomplished by application of liquid nitrogen. Cryogenic grinding produces a shred-lie particle about 0.3mm in size, and is more expensive than ambient grinding due to the use of liquid nitrogen.

Crumb rubber may be used in rubber mats and anti-fatigue mats for workers who spend much of their time standing in one place. Other uses are in athletic surfaces, carpet underlay, parking curbs, railroad crossing beds and as asphalt additives.

Crumb rubber has been used extensively in Japan in railway mats to suppress vibrations and noise pollution. These pads are laid between the concrete and the ballast. About 70,000 tons of crumb rubber was used to lay a stretch of 131 kms of padded railroad tracks from 1975-1981. One of the largest commercial crumb rubber plants, Tire Recycle Center, Osaka, Japan, has a capacity of 7,000 tons/year.

Rubber can also be reclaimed by depolymerization and heating (partial de-vulcanization). This requires more processing than that required for producing crumb rubber. A small fraction of the reclaimed rubber may be used in tires, especially in the carcass and sidewall compounds. It can also be used in inks for copiers, sheeted rubber, and reclaimed butyl.

In the United States, approximately 3.4 million tires were used for reclaiming rubber in 1987, though the number of tires used for rubber reclamation has been decreasing. Of these, an estimated 1 million tires are used annually for crumb rubber products. The volume of tires used for reclaiming rubber has been decreasing due to:

- Low incentive to reclaim rubber because of the availability of cheap synthetic rubber from petroleum
- Lower quality of the reclaimed rubber because of the loss of some of its elastic properties during processing.

Reidel Omni Products, Portland, Oregon, produces rubber railroad crossings using tire buffings. These tire buffings are procured from the retreading industry, where they are produced as by-product or waste during the retreading operation. About 350 lbs. of buffings are used per track foot of the rubber railroad crossings. About 50,000 track feet of rubber railroad crossings were laid by Reidel in 1989. This represents about 10,000 tons of tire rubber buffings used in 1989. Such use does not increase capacity of the tire disposal capabilities as the tire buffings used are a byproduct of the tire retreading industry. The service life of the rubber railroad crossing is projected to be about 15 years, as compared to about 4 years for an asphalt railroad crossings. The major clients for the rubber railroad crossings are private railroads, with municipalities and cities being small-scale consumers.

3.2.2 Tire Splitting

Tire splitting involves direct reuse of rubber strips obtained from tires in the manufacture of other rubber products. Fabric reinforced rubber strips are obtained from tires by removing the bead and cutting away the tread from the tire. These strips are die-cast into different products such as dock bumpers, floor mats, conveyor belts, seals, gaskets, etc. Such use of tires represents a high value use, as only minimal processing of the tire is required. The consumption of scrap tires by the splitting industry is minimal due to the low demand for its products.

3.2.3 Artificial Reefs

Scrap tires are ballasted and sunk off-shore. The tires form artificial reefs that provide habitat to fish. No positive effects on the fishery industry due to use of artificial reefs have been observed due to the very small number of tires used for this purpose. Scrap tires have been used as artificial reefs in Florida and New Jersey, though they are being used only in minimal numbers at the present.

Scrap tires have also been used as breakwater barriers to protect shorelines from sea waves.

Such use of scrap tires is expensive, with very minimal volume capabilities.

3.2.4 References

U.S. Department of Energy, Waste Tire Utilization, U.S. DOE, April 30, 1987

Sikora, Mary B., Tire Recovery and Disposal: A National Problem with New Solutions, Resource Recovery Report, Washington, D.C., June 1986

Ohya, A. and K. Asano, Waste Tire Disposal in Japan, The Japan Automobile Tire Manufacturers Association, Inc., Tokyo, Japan, October 1982

Phone Conversation with Don Wilson, National tire Retreaders and Dealers Association

Phone Conversation with Brian Holland, Vice President Operations, Riedel Omni Products, Portland, Oregon

U.S. EPA, An Economic Evaluation of Technical Systems for Scrap Tire Recycling, U.S. EPA, Cincinnati, Ohio, December 1975

Henstock, Michael E., Technology for the Disposal and Treatment of Waste Tires in the United Kingdom, The University of Nottingham, August 1983

4.0 CONCLUSIONS

Five alternative scrap tire use or disposal methods were determined to meet or nearly meet study criteria for environmental acceptability, economic viability, and volume capability. We estimate that these methods combined have the potential to reduce the number of tires being landfilled or stockpiled by about 210,000,000 tires per year by 1995.

Each of these alternative methods faces significant barriers to further implementation. These barriers include:

- Marginal cost advantage over other fuels (coal, petroleum coke)
- Unproven reliability of whole tire and TDF feed technology
- Air permit modification requirements
- Reliability of tire/TDF supply (risk to recovering capital investment)
- Conservative/risk averse nature of user industries
- High capital or initial costs
- Local opposition, particularly where method involves new facilities.

Our qualitative analysis of these barriers indicates that the alternatives' relative level of difficulty in achieving significant further use is as follows (from lowest to highest level of difficulty). The estimated potential scrap tire volume that could be utilized by each method by 1995 is also provided:

- Cement kilns (least difficult) - 60 million
- Paper mills - 35 million
- Utilities - 60 million
- Dedicated tire-to-energy - 27 million
- Asphalt paving - 28 million.

Alternatives with the lowest barriers are most likely to achieve the potential scrap tire volumes estimated for 1995.

Several potential methods for reducing barriers which apply to one or more alternative use/disposal methods were identified. These include:

- Development of improved information/marketing of TDF and/or whole tires as fuel
- Development of additional, standardized testing and analysis results for scrap tire performance in the specific applications
- Dissemination of information which demonstrates the environmental results of air emissions tests on the use of whole tires or TDF as auxiliary fuel
- Implementation of possible incentives by the Federal or state governments (e.g., tax credits)
- Development of standardized air permit modification packages/approaches by states or nationally to expedite permit modification
- Enhancement of the reliability of tire supply.

APPENDIX -

MATRICES SUMMARIZING TECHNOLOGY CHARACTERISTICS AND BARRIERS

TECHNOLOGIES MEETING BASELINE CRITERIA

TECHNOLOGY	ENVIRONMENTAL	ECONOMICS	VOLUME CAPABILITY	BARRIERS
Cement Kilns	No_x emissions reduced SO_2, particulate emissions not affected No waste residues No extra emission controls required	Break even procurement cost/tire = $0.00 Cost/million BTU - Coal - $1.60 TDF - $1.00 Cost of mechanical feed equipment $250,000-$500,000	Potential volume capacity = 130 million tires if only 50 kilns used tires as auxiliary fuel	Test burns/review of air emission permits Continuous supply of TDF Poor perception in marketplace of TDF as a fuel
Pulp & Paper Mills	SO_2, NO_x emissions reduced Zinc and particulate emissions not affected when using wire free TDF, else increase dramatically Chromium emissions increase	Cost/million BTU Coal - $1.60-$2.00 Wire free TDF - $1.00-$1.70 Capital investment $150,000-$350,000	45-50 million tire equivalents by 1995 if 25% of mills used TDF	Environmental permitting Cost of competing fuels Industry inertia to use alternative fuels
Utilities	No information available, as no utilities use tires SO_2 and NO_x emissions expected to decrease Particulate emissions expected to increase	Revenue saved per tire burnt = $0.77 Expected capital investment - $1 million Expected pay back period - 1 year (for a facility using 1.5 million tires/year)	None at present 50-70 million tires per year if 25% of generative capacity of utilities equipped with wet bottom boilers used tires as 10% fuel	Unproven technology Continous supply of tires Potentially high particulate emissions

TECHNOLOGIES MEETING BASELINE CRITERIA

TECHNOLOGY	ENVIRONMENTAL	ECONOMICS	VOLUME CAPABILITY	BARRIERS
Dedicated Tire to Energy Facilities	Complete combustion of tires Minimization of dioxin and furan formation	Capital costs per MW: whole tire facility - \$3.5 million coal fired facility - \$0.5-2.0 million Long payback period of 8-10 years	20-30 million tire equivalents per year by 1995	Extremely high capital investment Continuous supply of tires Long permitting process
Rubber in Asphalt	No adverse effect on environment Only 40-60% of the tire used; steel and fabric has to be removed Improved pavement performance	Initial cost of rubber modified asphalt concrete (RUMAC) twice that of asphalt concrete Cost of asphalt rubber 1.4-2 times that of asphalt Little or no capital investment	65 million tires per year if asphalt rubber used on 1% of two lane highways Eight times the annual supply of tires if RUMAC used for paving all roads resurfaced each year	No ASTM product specifications Uncertain durability and performance of pavement

OTHER TECHNOLOGIES

TECHNOLOGY	ENVIRONMENTAL	ECONOMICS	VOLUME CAPABILITY	BARRIERS
Pyrolysis	Only 75-82% energy recovery No major emission problems	Break even tipping rate: $3.00/tire Low fuel oil and char price Gas not saleable High capital costs	Negligible Only one commercial facility using TDF as partial feed	Inefficient energy recovery Variability in product quality Very low market potential for products Economically not feasible
Rubber Recovery	Only part of tire processed - steel and fabric have to be removed No environmental problems	Large capital outlay Small scale of market	Low - about 3.4 million tires annually	High capital outlays No ASTM product specifications
Splitting Industry	No environmental effects or concerns Waste rubber used as raw material	Low capital costs Expensive products	Minimal	Low demand for products Cheaper alternative products
Artificial Reefs	No major environmental effects or concerns	Expensive disposal technique	Minimal Use reducing with time	Cheaper alternative methods to build reefs Expensive tire disposal technology
Playground Gravel Substitute	No major environmental effects or concerns	Cost per ton: Treated tire chips - $300/ton alternative material - $15-35/ton	Negligible to none	High cost of product No existing market for product

Scrap Tire Management Council

REDUCE RE-USE RECYCLE RECOVER

1400 K Street, N.W. • Washington, D.C. 20005