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TECHNICAL REPORT
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DISPOSAL STUDY
(TIRES AND OTHER POLYMERIC MATERIALS)

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August 1976

UNITED STATES ARMY
NATICK RESEARCH AND DEVELOPMENT COMMAND
NATICK, MASSACHUSETTS 01760

Food Sciences Laboratory

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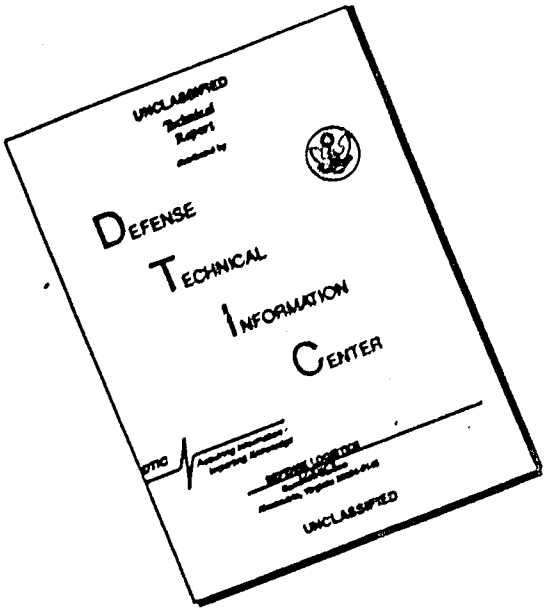

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):
The purpose of this study was to evaluate the technical and economic feasibility of various methods of tire disposal. Over thirty processes for the disposal of tires and their interrelationships were investigated. The following four promising process alternatives involving combinations of these processes were recommended for further investigation:

a. Mechanical shearing followed by incineration.
b. Landfill after mechanical shearing.

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c. Use in asphalt substances after the combined size reduction processes (mechanical shredding followed by cryogenic shredding).

d. Selling the by-products of the combined size reduction processes.

SUMMARY

The purpose of this study was to identify and evaluate the technical and economic feasibility of various methods of tire disposal including the use of a mobile scrap tire disposal unit for the Army's application. This report summarizes the results of the work done under Contract No. DAAK03-74-C-0136 with the Monsanto Research Corporation.

The quantities and approximate locations of scrap tires in the U.S. Army were identified via a questionnaire. A scrap tire disposal system was conceived; this used presently available tire disposal processes in a logical approach to arrive at several most practical process alternatives. Over thirty processes for the disposal of tires and their relationships to each other were investigated. Four process alternatives involving combinations of these processes were recommended for further investigation with respect to the local economic picture and current disposal practices at each Army installation.

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1. INTRODUCTION

The objective of this project was to study the technical and economic feasibility of various methods of tire disposal including the use of a mobile scrap tire disposal unit. This objective was met by an in-depth study involving the following factors:

a. Determination of the potential waste sources of tires and other polymeric materials---locations and quantities at Army installations.

b. Survey of literature pertinent to tire and other polymeric waste disposal.

c. Determination of technical and economic feasibility of existing disposal alternatives, and some techniques which have not been previously investigated, for disposing of tires and other polymeric materials. Emphasis was placed on the basic principle involved in operation, setup details, operation procedures, and possible problem areas. Data were obtained on equipment weights, power requirements, mobility, means of transportation, reliability, capital cost, operational cost, maintenance, amount, type, and size of material that can be processed, and the size, shape, and properties of the material after processing. Special attention was paid to cryogenic shredding.

d. Determination of potentials and possibilities for reusing or recycling discarded tires. These include the possibility of using ground tire granules in asphalt paving reinforcement, incinerating the tire material and recovering the waste heat in a useful form, destructive distillation (pyrolysis) of the tire materials, and landfilling. Cost and benefit data for these techniques were also determined.

e. Determination of the environmental impact of the various disposal techniques.

f. Determination of the likelihood of existing equipment modification to accommodate other polymeric wastes and for Army needs.

2. SYSTEM DESCRIPTION

The problems of the Army tire disposal situation are very similar in many aspects to the problems existing in the civilian sector. In each case there are a number of scrap tires generated which must be disposed of in some manner. Although the magnitudes differ greatly (2×10^8 generated annually in civilian sector compared with 2.7×10^5 in the Army), the attack on the problem is essentially the same. Both sectors must deal with the same material (tires) and have the same concerns for the quality of the environment.

The first step in meeting the objectives of this program involved organization of all information and research results, available in the literature and obtained through personal contacts, into a network which could be easily comprehended and systematically approached. The resulting network diagram, shown in Figure 1, identifies five potential processing steps for scrap tire disposal, each containing one or more tire processing option blocks. The total scrap tire disposal system consists of five major processing steps (solid waste, primary, secondary, and tertiary processing, and products); thirteen processing options, including feed material, mechanical size reduction with or without classification, combined grinding cycle (mechanical followed by cryogenic size reduction) with or without classification; and the nine processing options in secondary processing. Also, several specific processes are contained within each processing option. The diagram presented in Figure 1 provides a logical organization for presentation and discussion of tire disposal processes.

2.1 SOLID WASTE

2.1.1 Feed Material

The literature indicates that approximately 220 million scrap tires per year are generated in the civilian sector of the U.S.[1] However, no information was found in the literature on the number of scrap tires generated by the U.S. Army in the United States or by the military in general.[2] To fill this void, a questionnaire designed by MRC was distributed by the Defense Supply Agency. This questionnaire was designed to obtain information concerning scrap tire generation by the military bases. A sample of the questionnaire is included in Appendix B on page 133.

Several assumptions were made to facilitate evaluation of the questionnaire. These assumptions were:

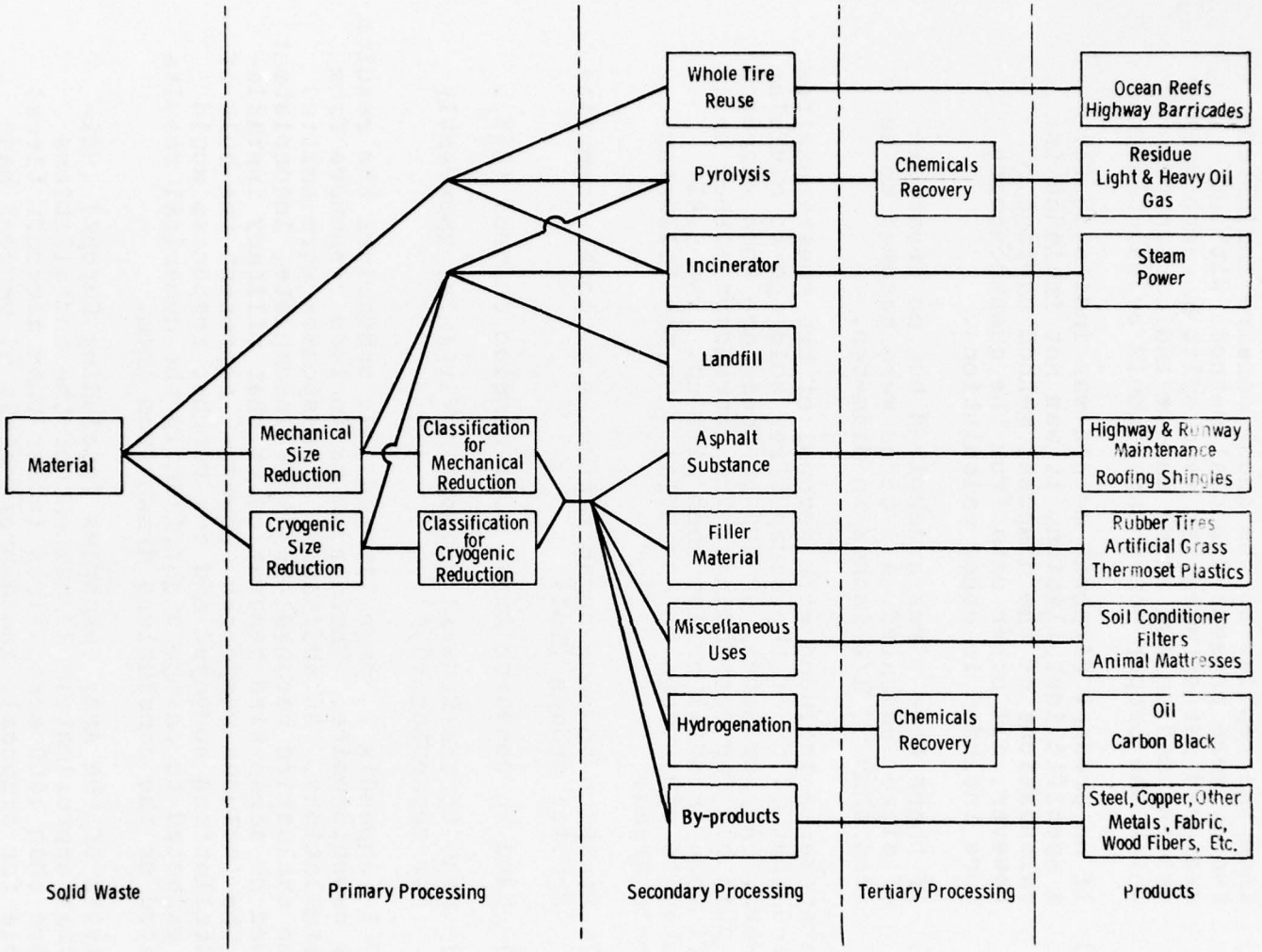


Figure 1 Network Diagram of the Scrap Tire Disposal System

1) Scrap tires other than aircraft tires weigh 25 lb.

2) Scrap aircraft tires weigh 50 lb.

3) When the replies to the questionnaire indicated two or more present disposal methods without assigned percentages, an even split by each method was assumed unless there was an indication by which the proper percentages could be calculated.

4) If no present disposal method was indicated for a specific installation, it was not included in calculations of the disposal method average. However, all other data from the questionnaire were included in other calculations.

5) If there were tires stockpiled but no breakdown of sizes indicated, all tires were assumed to be less than 53 1/2 inches in diameter.

Brief statements included with several of the questionnaires indicated that 74.6% of the scrap tires sold go to civilian retreaders. Approximately 40-50% of these are then rejected as not suitable for retreading. The retreaders either haul them off to a landfill or let them pile up. The 5.4% attributed to other uses go essentially to the following three main areas:

a) Donation to some organization, e.g. local community service groups (10%).

b) Used in research work, e.g. erosion control (35%).

c) Sent to the Federal Prison in Virginia, apparently for recapping (55%).

Table D-1 (Appendix D, page 139 and 140) summarizes the results of this questionnaire. These results include responses from 194 installations. An additional 34 responses were omitted from the evaluation because they were incomplete, inconsistent or showed no scrap tire generation at that military installation. The included responses, however, represent the bulk of the installations surveyed and any further responses would not be expected to change significantly the numerical results calculated or the conclusions drawn from them.

An analysis of the Army responses (excluding Europe) indicates that approximately 28 percent of the installations have more than 1000 scrap tires (other than aircraft tires) available for disposal, and approximately 51 percent have

over 300 tires available for disposal. When considered on a monthly generation basis, 69 percent of the responses indicated a scrap tire generation rate of less than 100 scrap tires per month for disposal and 91 percent indicated a monthly generation rate of less than 250 scrap tires. When viewed from a quantity standpoint, compared with the national problem, this amount is very small. However, the logistics of solving the problem are just as large as that confronting civilian disposal methods.

Figure 2 is a map of the 48 contiguous states indicating the concentration of scrap tires generated by Army facilities in each area as indicated by the questionnaire responses. In some cases the area indicated is in reality a point source, however, many actually include several bases close to each other with a total scrap tire generation as indicated.

An estimation of additional polymeric scrap generated by the Army at any one installation (e.g. polyfilm, retread buffings, foam packing, scrap building materials) and its composition would be difficult and lacking in accuracy since any such estimate would vary according to seasons, shipping schedules, construction, location, etc. A study done at the Red River Army Depot characterized their solid waste generation as 29% paper and cardboard, 54% wood and the remainder rubber.[3] However, this installation should not be taken as a norm, since they have a retreading facility and perform other refurbishing work.

The total quantity of buffings from retread facilities on a nationwide monthly basis can be estimated. Table D-1 (Appendix D, pages 139 and 140) indicates that the Army generates approximately 10,146 non-aircraft scrap tires per month for disposal in the U.S. excluding the 75%[4] of tires suitable for retreading. Therefore, the approximate total number of scrap tires generated per month in the U.S. by the Army would be:

$$\frac{10,146}{0.25} = 40,584 \text{ tires/month}$$

The 75% which are retreaded would then amount to 30,438 tires/month. Passenger tires produce approximately 1.5 lb of buffings per tire and truck tires produce approximately 4.0 lb of buffings per tire.[1] Assuming an even distribution of passenger and truck tires, approximately 83,700 lb of buffings per month would be generated by the Army.

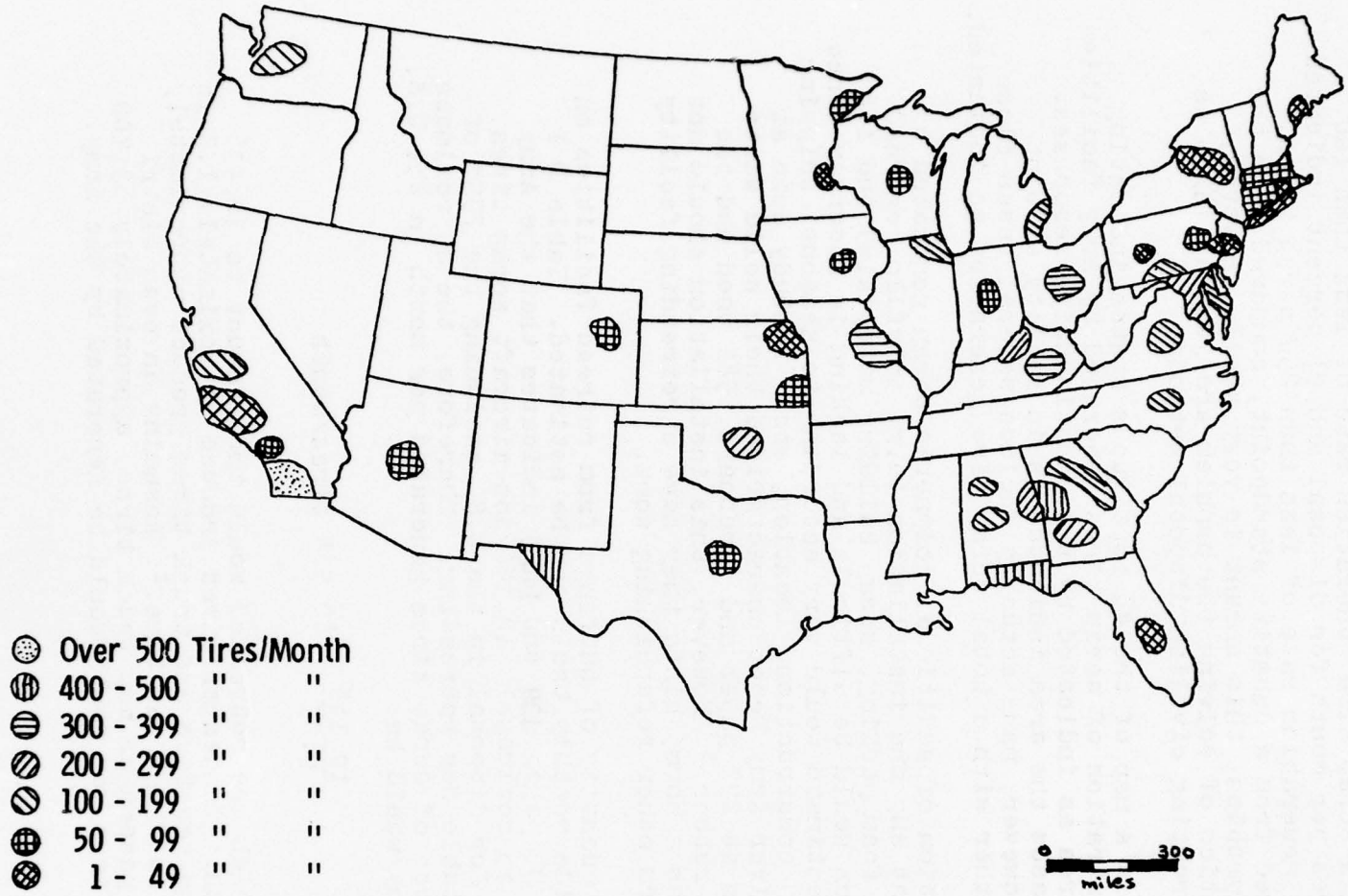


Figure 2 Monthly Scrap Tire Generation*

*This map indicates the responses received from the scrap tire questionnaire.

This number, however, is only an estimate and is not included in calculations of the size of equipment necessary to treat tire wastes. In this report it was assumed that equipment designed to handle scrap rubber tires will also be capable of handling tire buffings and all other polymeric waste. This assumption is valid in most cases. The exception would be in tire-specific size reduction apparatus which is designed to handle only tires and cannot be modified to handle other types of wastes.

2.2 PRIMARY PROCESSING

2.2.1 Mechanical Size Reduction

The operational principle behind mechanical size reduction is breaking apart the tire through extreme stress or by shearing. This method is the most common system used to reduce the size of solid waste. The number of such shredders in operation has grown from 27 in 1971 to 37 in 1974.[5] Table D-2 (Appendix D, pages 141 & 144) shows a list of shredders now in operation or for which ground has been broken in the United States.[5] All of these shredders are designed to handle municipal, commercial, or bulky wastes; however, relatively few of the shredders listed have the capabilities for handling extra tough wastes such as tires.

To more correctly assess the state-of-the-art in scrap tire mechanical size reduction another questionnaire was prepared and sent to the manufacturers of shredders, hammermills, and tire-specific slicing machines. A copy of this questionnaire is included in Appendix C. The results obtained from this questionnaire showed that while many companies manufacture mechanical size reduction apparatus, there were only twelve who responded that their equipment could possibly handle tires on a continual basis. They are the following:

COMPANY NAME/LOCATION	NUMBER OF APPLICABLE MODELS
1) Parent Manufacturing Co. Lewiston, Maine	1
2) Branick Manufacturing Fargo, North Dakota	1
3) TEB, Inc. Addison, Illinois	3
4) Barclay/Noll Associates Burlingame, California	1

COMPANY NAME/LOCATION	NUMBER OF APPLICABLE MODELS
5) Automotive-Industrial Marketing Corp. Portland, Oregon	1
6) Metropolitan Disposal Corp. Portland, Oregon	1
7) Allis-Chalmers Appleton, Wisconsin	1
8) Jeffrey Manufacturing Company Columbus, Ohio	3
9) Hammermills, Inc. Cedar Rapids, Iowa	2
10) Saturn Manufacturing Wilsonville, Oregon	1
11) Garbalizer Corporation of America Salt Lake City, Utah	3
12) Holman Industries Oakdale, California	1

The additional data regarding these units presented in subsequent sections are from private communications with representatives of each organization. A complete list of all the shredder companies contacted in our investigation is in Table D-3 (Appendix D, page 145).

2.2.1.1 Tire-Specific Size Reduction Apparatus

This equipment is specifically designed for the size reduction of tires. The tires are held by arms on the inside of the tire. The tires are then rotated against blades which cut them into pieces approximately 1/4 in. - 3 in. square. Table 1 summarizes the information obtained from companies 1, 2, 3 and 5 listed above, who manufacture this equipment.

2.2.1.2 Hammermills

The basic principle of operation of a hammermill is beating the material with steel "hammers" until the material fractures. This type of process is suitable for municipal wastes or other material which will fracture easily. However, tires are designed to withstand these kinds of forces. This makes their destruction by a hammermill very difficult.

Table 1 TIRE-SPECIFIC GRINDERS

Machine Name	Manufacturer Number	Capacity* (tires/hr)	Weight (lb)	Dimensions (ft) (width x depth x height)	Motor Voltage
Ascot Tire Cutter	1	300 p,t	1500	Not Available	110 V
Branick	2	300 p,t	1000	Not Available	220 V
Shred-Pax AZ-7	3	60 p	825	2 x 3-1/2 x	200 V 3 phase
Shred-Pax AZ-15	3	60 p,lt	1000	Not Available	200 V 3 phase
Shred-Pax AZ-20	3	300 p,t	N/A	Not Available	200 V 3 phase
Tire Gon	5	125 p,t	3000	6 x 7 x 6	220 V 3 phase

* p = passenger
lt = light truck
t = truck

Table 2 summarizes the technical data obtained from companies 7, 8 and 9 listed above. Only Allis-Chalmers claims that their machine can process tires on a continual basis. The other two companies know that their machines will take tires occasionally; however, the machines have not been tested with a continual tire feed. All economic data available for hammermills in Table 2 are presented in Section 5.1.1.2.

2.2.1.3 Shredders

Shredders are the most popular of all the size reduction equipment for application to solid waste reduction for the four following reasons:

1. The solid waste produced is homogeneous.
2. The size of output is more uniform.
3. Shredding speeds separation of the final product.
4. Shredded waste is more acceptable for landfill.

Most of the above reasons are applicable to the shredding of scrap tires as well as municipal refuse. The shredders use shearing as the method of size reduction. In each of the machines characterized in Table 3, the material is cut into strips by the machine. This operation also proves very effective on scrap rubber tires.

Table 3 is a summary of the technical data collected from companies 10, 11 and 12 listed above. Two other organizations manufacture shredders, however, sufficient data were not received to include in Table 3. Barclay/Noll Associates manufacture the Tire Gator apparatus which is capable of processing 1000 passenger and truck tires per hour. The Tire Hawg, manufactured by the Metropolitan Disposal Corporation, is capable of processing 400 passenger and truck tires per hour. The weight of this unit including the trailer is 24,000 pounds. Each of these machines requires 2 operators and produces strips of material similar to that produced by the Garbalizer unit. All economic data available for shredders listed in Table 3 is presented in Section 5.1.1.3.

2.2.2 Cryogenic Size Reduction

The basic principle of cryogenic size reduction processes is to lower the temperature of material below its brittle temperature by freezing with some cryogenic substance. These frozen materials are then crushed to facilitate separation.

Table 2 MACHINE CHARACTERISTICS OF HAMMERMILLS

Characteristic	Machine: Model KH 12/18	Model 6060	Model 6080	Model 56 WB	Model 58 WB	Model 59 WB
Manufactured by	Allis-Chalmers Appleton, Wisconsin	Hammermill Inc. Cedar Rapids, Iowa	Hammermill Inc. Cedar Rapids, Iowa	Jeffrey Mfg. Co. Columbus, Ohio	Jeffrey Mfg. Co. Columbus, Ohio	Jeffrey Mfg. Co. Columbus, Ohio
Currently used for tires	yes	occasionally	occasionally	occasionally	occasionally	occasionally
Other scrap treated	household	municipal	municipal	municipal	municipal	municipal
Capacity-tires/hr*	2,300-o	1,060-o	1,300-o	4,400-o	-	-
Pretreatment needed	none	none	none	none	none	none
Feed opening-inches	40 x 71	82 x 88	82 x 88	15 x 53-1/2	15 x 64	15 x 74-1/2
Weight - lb	28,000	-	-	35,300	45,600	51,500
Shaft orientation	horizontal	horizontal	horizontal	horizontal	horizontal	horizontal
Auxiliary equipment needed	conveyors	compression feeder & conveyors	compression feeder & conveyors	offtake conveyor	offtake conveyor	offtake conveyor
Output size	2-1/2" ave.	6"	6"	6"	6"	6"
Variability of output	1-3"	2" min.	2" min.	-	-	-
Number of men needed	1/2	2	2	2	2	2
Training period - weeks	2	2-4	2-4	2	2	2
Maintenance needed	hammers replacement	replace hammers	replace hammers	replace hammers	replace hammers	replace hammers
Maintenance period	50 hr per corner of hammer	10,000-15,000 tons hammer life	10,000-15,000 tons hammer life	?	?	?
Raw materials needed for operation	none	water	water	water	water	water
Weight of hammers	24-1/2 lb	?	?	?	?	?
Grate description	interchangable	?	?	?	?	?
No. of hammers	96	?	?	?	?	?
Motor horsepower	400	800	1000	300	-	-
Rev. per minute	1800	-	-	1200	-	-
Drive system	V-belt direct hydraulic	V-belt	V-belt	direct	direct	direct
Optional power sources	diesel	diesel	diesel	-	-	-
Portability	yes	yes	yes	?	?	?

* p = passenger
lt = light truck
t = truck
o = other refuse converted to tires/hr using 27 lb/tire

Table 3 MACHINE CHARACTERISTICS OF SHREDDERS

Characteristic	Machine				
	Model 5226	Particle-Izer	Garbalizer Model 1	Garbalizer Model 2	Garbalizer Model 3
Manufactured by	Saturn Mfg. Wilsonville, Oregon	Holman Ind. Oakdale, California	Garbalizer Corp. of America Salt Lake City Utah	Garbalizer Corp. of America Salt Lake City Utah	Garbalizer Corp. of America Salt Lake City Utah
Currently used for tires	yes	yes	yes	yes	yes
Other scrap treated	any	any	any	any	any
Capacity-tires/hr*	300 p 15 t	2,000 p 1,200 t	10,000 o	5,000 o	2,300 o
Pretreatment needed	none	none	none	none	none
Feed opening - inches	52 x 26	39 x 27	72 x 96	72 x 96	60 x 72
Weight - lb	-	16,500	200,000	100,000	60,000
Dimensions - ft (w x d x h)	6-1/2 x 3 x 1-1/2	8-1/2 x 7-1/2 x 6-1/2	12 x 43 x 12	7 x 29 x 12	7 x 24 x 12
Auxiliary equipment needed	stands, hoppers conveyors	conveyors	conveyors	conveyors	conveyors
Output size - inches	1-1/2 x 6	2 x 2	strips	strips	strips
Variability of output	up to 8" long 9" wide	2" x 2"	-	-	-
Number of men needed	2	1 operator 2 helpers	2	2	2
Training period - weeks	negligible	1	-	-	-
Maintenance needed	oil & grease sharpening	oil & grease sharpening	oil & grease sharpening	oil & grease sharpening	oil & grease sharpening
Motor horsepower or voltage	460/230 V 3 phase	440 V 100 hp	1600-3500 hp 2300 or 4160 V 3 phase	800-1750 hp 2300 or 4160 V 3 phase	600-1750 hp 2300-4160 V 3 phase
Rev. per minute	-	-	50	50	50
Drive system	-	direct	-	-	-
Optional power sources	diesel or gasoline	diesel	-	-	-
Portability	yes	yes	-	-	-

* p = passenger
lt = light truck
t = truck
o = other refuse converted to tires/hr

Cryogenic cooling must be done as quickly as possible. Even though several materials have this capability, liquid nitrogen with a boiling point of -196°C is most commonly used. The low boiling point of liquid nitrogen at atmospheric pressure permits embrittlement of many materials including metals. Its liquid state allows rapid contact with the material for efficient heat transfer.

The cryogenic method for processing scrap tires has been investigated by at least six organizations: Cryogenic Recycling International, Inc.,[6] Bellaire Hydraulics, Inc.,[7] Hazenag, U.S.A., Inc.,[8] Gateway Paint and Chemical Company,[9] U. S. Bureau of Mines,[10] and Air Products and Chemicals, Inc.[11] All of these processes use the same principles described above. Four of the major well defined processes will be described below.

2.2.2.1 Cryogenic Recycling International, Incorporated

Dr. Norman P. Braton and Dr. James A. Koutsky of Cryogenic Recycling International Inc., LaCrosse, Wisconsin, have designed a portable liquid nitrogen unit and hammermill that will process half-tires at approximately 60 tires per hour.[12] This unit is shown in Figure 3. The tires are cut in half by two large shears mounted on the back of the trailer. The crane, in the background, is equipped with a metal basket (Figure 4) in which the scrap half-tires or other materials to be processed are loaded. The loaded basket is then dipped in a liquid nitrogen bath (Figure 5) for approximately 15 seconds. After removal from the bath, the material is held in the metal basket for approximately 15 seconds to achieve better freezing characteristics. The frozen material is then dropped in a hammermill (Figure 6) where it is completely shattered in 3-5 seconds. Approximately 70% (by weight) of the tires destroyed in this manner are retained on a #16 sieve. About 25% of the material is retained on and about 5% passes through a #25 sieve.

The final product of this process is well suited for classification, further processing, recycling, or disposal. The unit can process a variety of materials such as tires, transformers, wood scrap, etc. After classification, the scrap tire product material is normally reduced to essentially three piles (Figure 7). These three distinct products can then be individually recycled, or in the case of the rubber, further processed for various uses. The other materials shown are telephone transmission cable (Figure 8), copper wire from a solenoids armature (Figure 9),

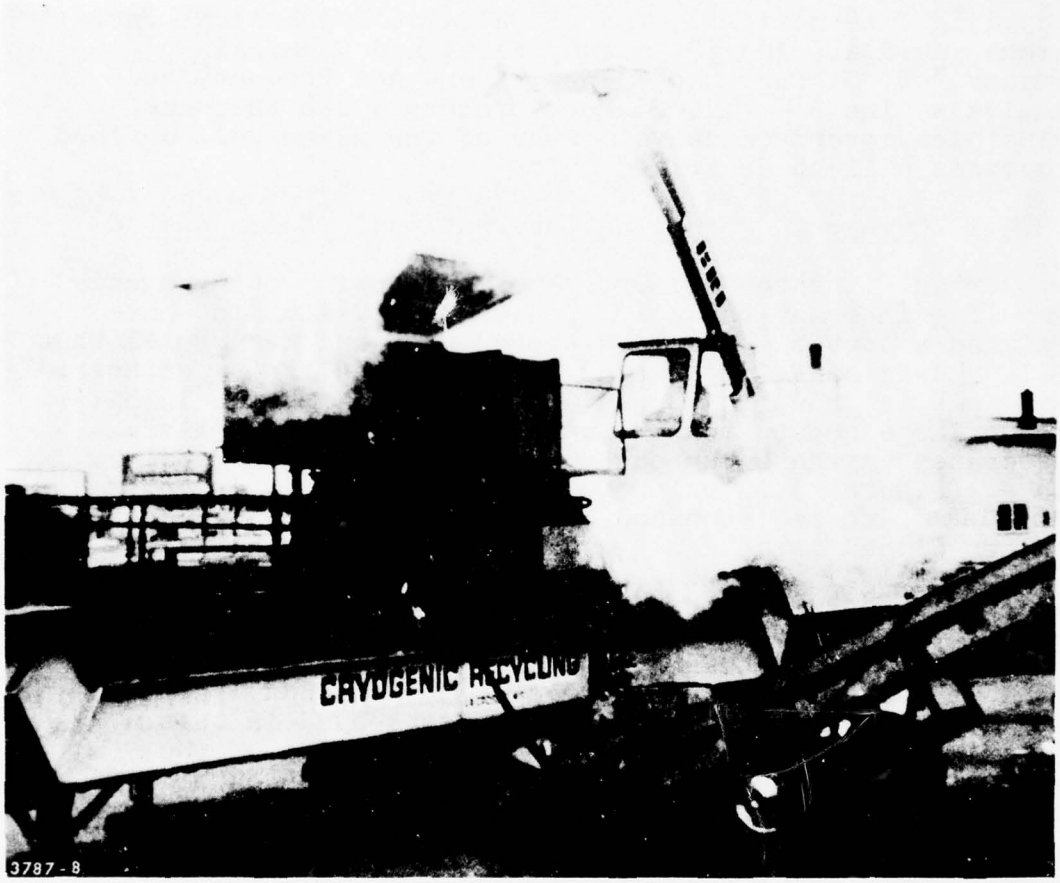


Figure 3 Cryogenic Grinding Equipment Constructed by Cryogenic Internation, Inc., LaCrosse, Wisconsin

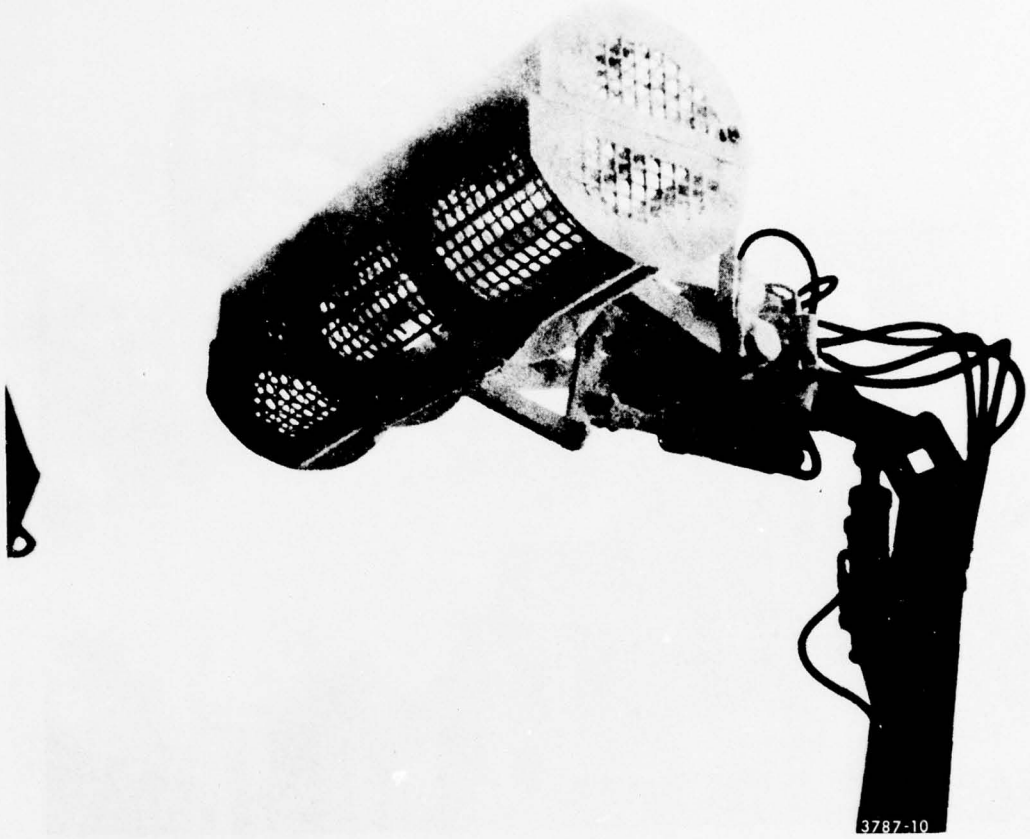


Figure 4 Metal Basket on Crane Feeder

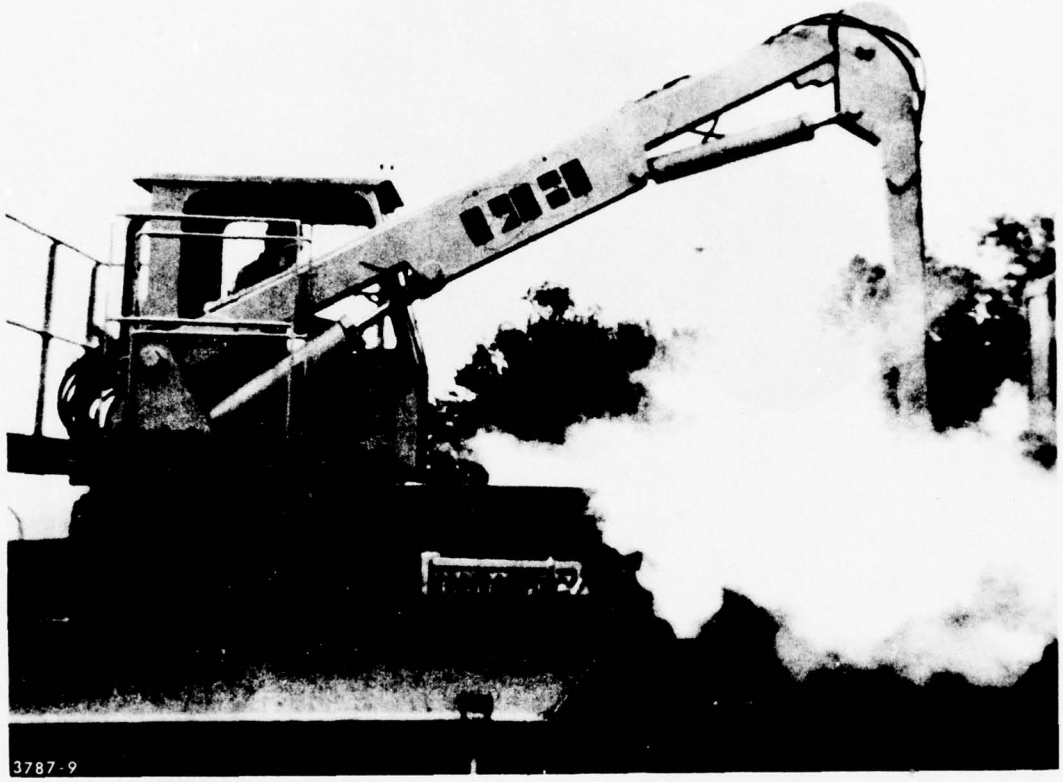


Figure 5 Crane Feeder Submersing Basket of Tires in Liquid Nitrogen Bath

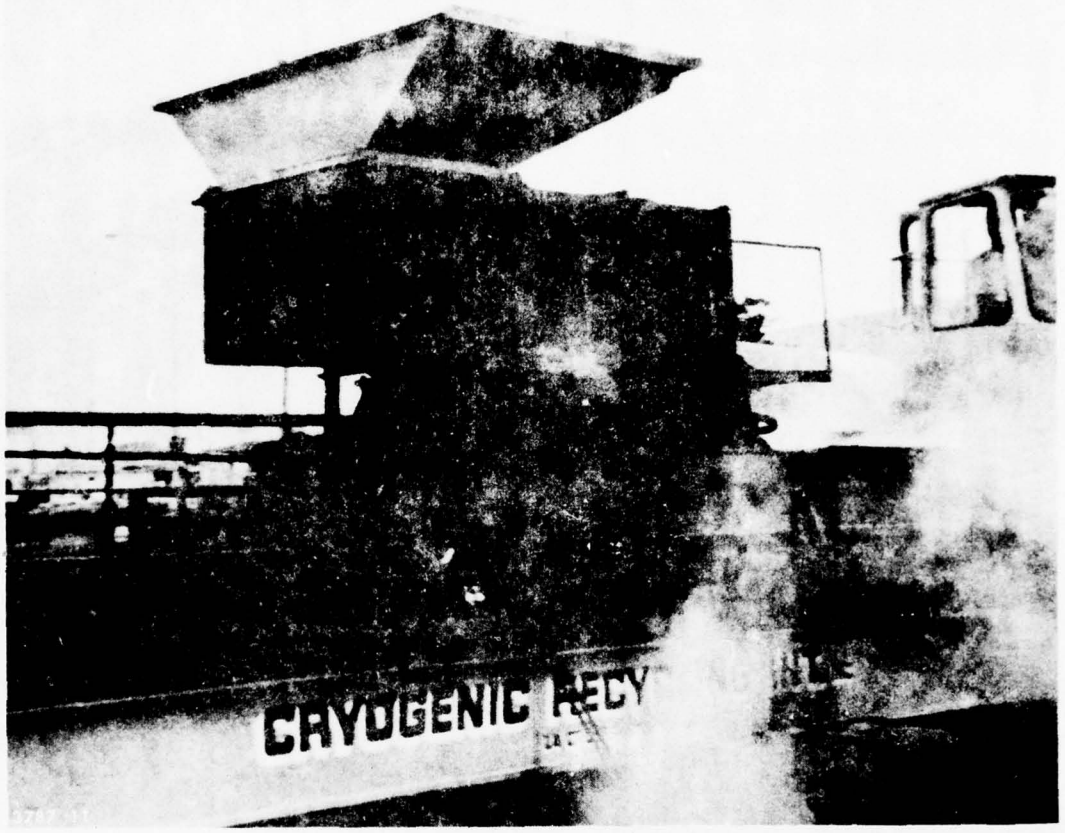
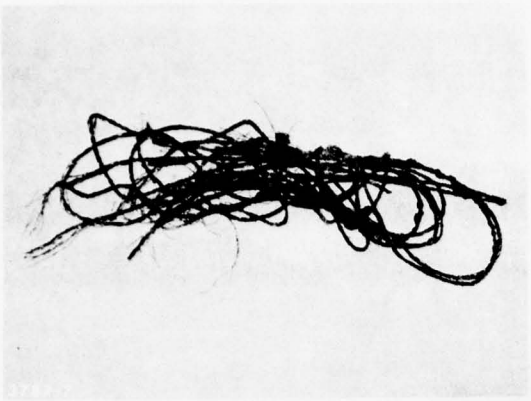


Figure 6 Hammermill and Liquid Nitrogen Bath



Steel Belt

Fiber Belt (Notice tire chunk in upper left)

Ground Rubber Tire

Figure 7 Basic Components of a Cryogenically Ground Tire

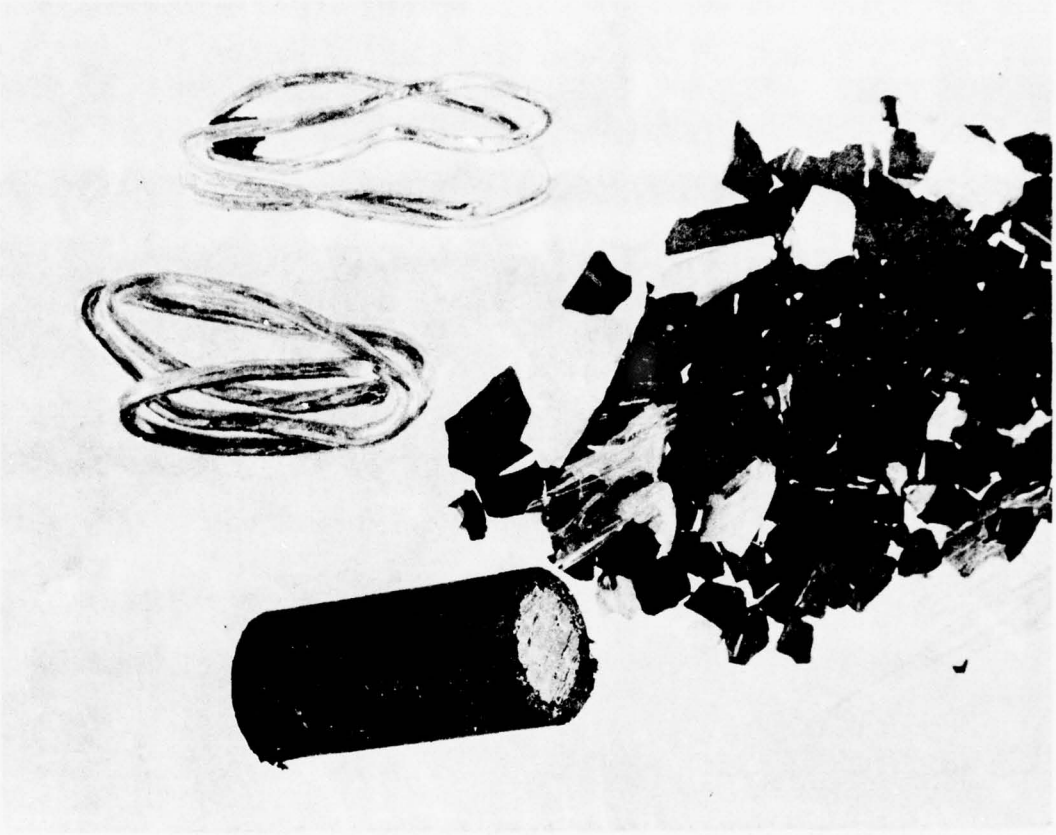


Figure 8 Telephon Transmission Cable (bottom center)
Cable from Inside After Destruction (top, left)
Casing Material After Destruction (top, right)

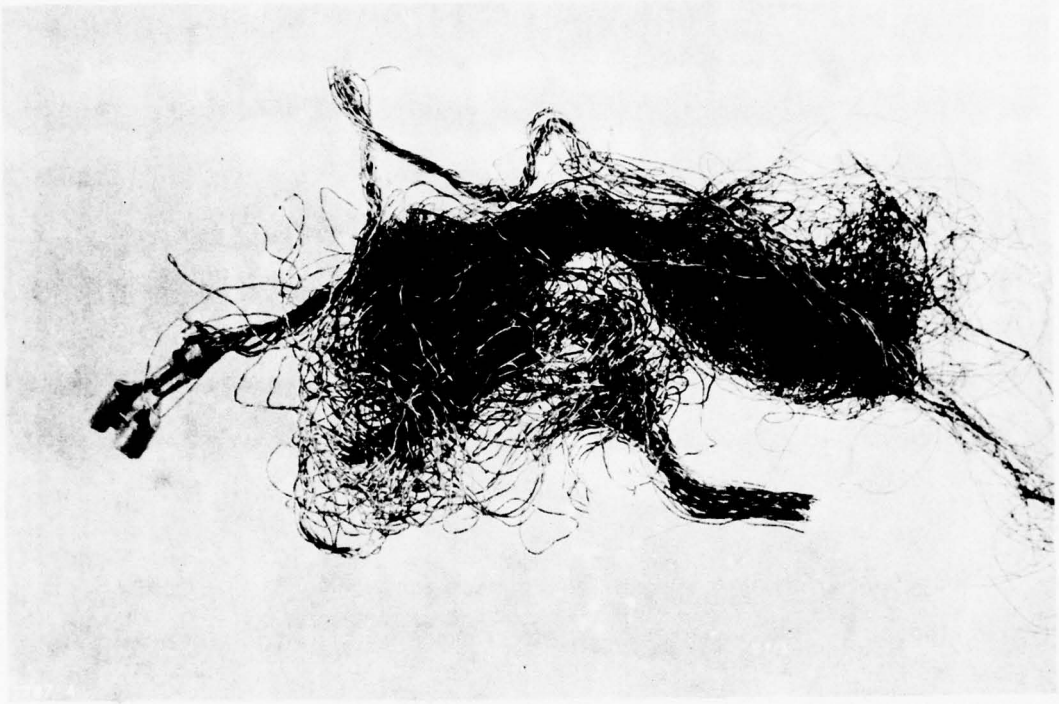


Figure 9 Copper Wire from Solenoid Armature

and lumber (Figure 10). Preliminary investigations made by the unit operators indicate that each of the products is suitable for further use since this size reduction technique does not destroy the structural characteristics of the materials processed.

2.2.2.2 Bellaire Hydraulics, Inc.

Mr. Vernon C. H. Richardson, President of Bellaire Hydraulics, Inc., is the inventor of a method and apparatus for comminuting rubber tires.[14] Two of the units similar to Figure 11 are presently being built for the Gulf Coast Waste Disposal Authority.[13] One large unit, Model S-5000, will be used in a plant located in Houston, Texas, and a portable model, P-2500, will be used to service an area within 100 miles of Houston. Each unit will be able to handle 5,000 tires per 8-hour day, recovering 45,000 lb/day of ¼-inch-plus particles, 15,000 lb/day of ¼-inch-minus fines, and 1,500 lb/day of scrap steel.[7]

This system is very similar to the Cryogenic Recycling International Inc., process. However, Richardson has expanded the cooling and size-reduction steps and processes whole tires. The tires are fed by a system of conveyors under a punch which puts a hole in the tire walls for coolant drainage. Richardson claims this reduces the loss of liquid nitrogen an undefined amount.[13] The punched tires pass through the spray chamber and are cooled from ambient conditions to about 32°F with liquid nitrogen. In the spray chamber the tires pass on a belt under spray nozzles. The tires then proceed through a liquid nitrogen bath that lowers their temperature to approximately -85°F. Initial destruction takes place by passing the tires between two crusher rollers. The material exiting these rollers is cracked rubber and the steel belt. This initial cracking is necessary to facilitate separation in the next step where a belt magnetic separator removes the wire bead and steel belt. Final destruction takes place in a hammermill after which the crushed rubber crumb passes onto an inclined screen classifier.

2.2.2.3 U.S. Bureau of Mines

A U.S. Bureau of Mines publication[10] is based upon cryogenic destruction work performed on a research scale in a batch-type operation. Plans have been made and construction is being done for a pilot scale unit.[5] This work is still in the construction and preliminary testing stages. An expected completion time has not yet been established.

Figure 10 Lumber from Cryogenic Process

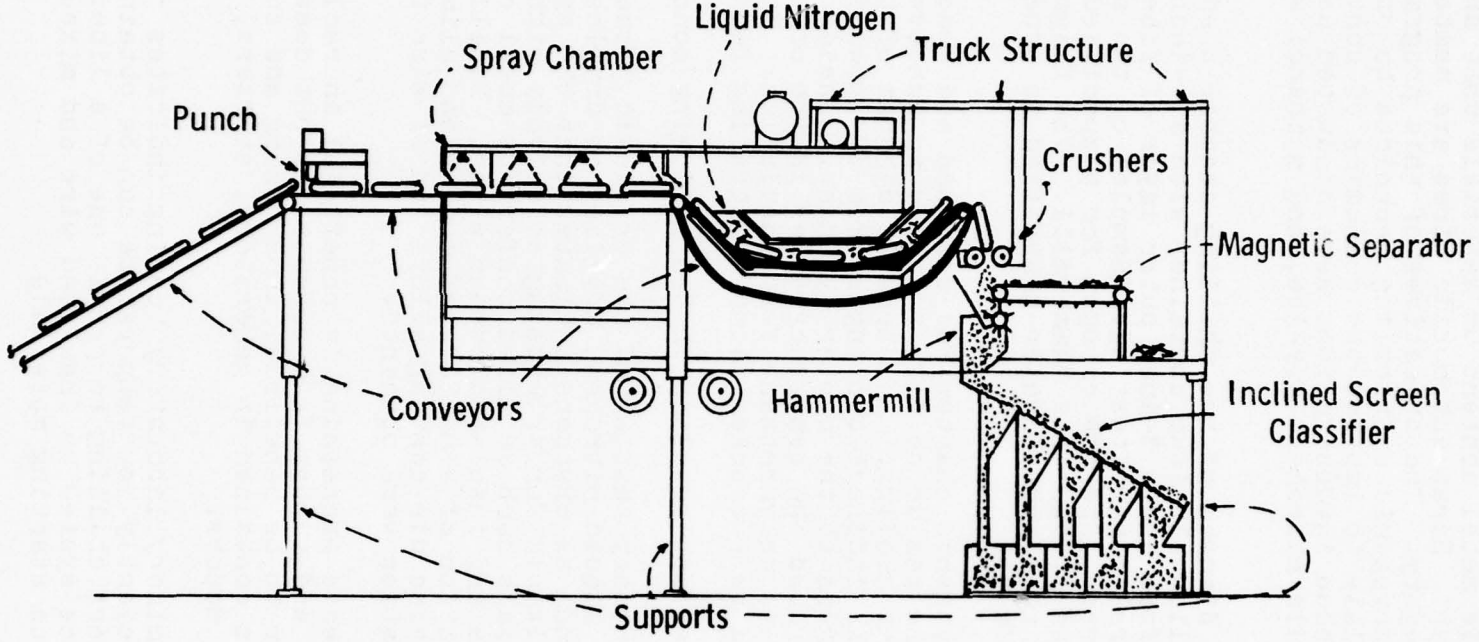


Figure 11 "Tire Eater" Cross-section Diagram[14]

Primary attention in this study was given to materials with appreciable metal content or materials that are expensive to crush. Scrap automobile tires are members of the second category. The objectives of this program were to extend the cryogenic embrittling technique to other types of materials to improve the economics of conventional processing. These investigations were conducted using three cryogens: liquid nitrogen, dry-ice, and methanol with dry-ice.

Figure 12 is a diagram of the chilling chamber used in this study. A 5-gallon aluminum container with a 4-inch inner layer of styrofoam and a 3-inch outer layer of fiberglas was used for preliminary testing. Samples of the scrap tires were lowered into the cryogen for a specified period of time and then placed in a hammermill. The fragmented materials were screened or water-classified to produce marketable products.

A prototype cryogenic chamber was designed and constructed to determine the residence time required to achieve embrittlement by indirect cooling. A schematic diagram of the prototype showing the indirect cooling system is shown in Figure 13. The feed goes to the center cylinder. Inside the annular area around the center cylinder is the cryogen. The outer cylinder is polyurethane foam insulation. The chilled material is fed to a crusher using a vibrating feeder.

These investigations resulted in the following conclusions:

1) Preliminary testing of the cryogenic procedure using liquid nitrogen, dry-ice, or dry-ice and methanol as cryogens indicates that the system is suitable for processing relatively high-value materials such as mixed nonferrous metal concentrates and insulated copper wires. Excellent separation of a mixture of copper and aliminum from zinc die-casting alloys and of wire from insulation were obtained.

2) Cryogenic processing is beneficial in reclaiming steel and rubber from scrap tires but does not appear to be beneficial in crushing and sorting metals contained in generators, starters, and small motors.

3) Preliminary laboratory testing indicates that a sufficiently low temperature can be obtained by indirect chilling to permit use of a liquid CO_2-dry-ice system on insulated wire and mixed nonferrous starting materials.

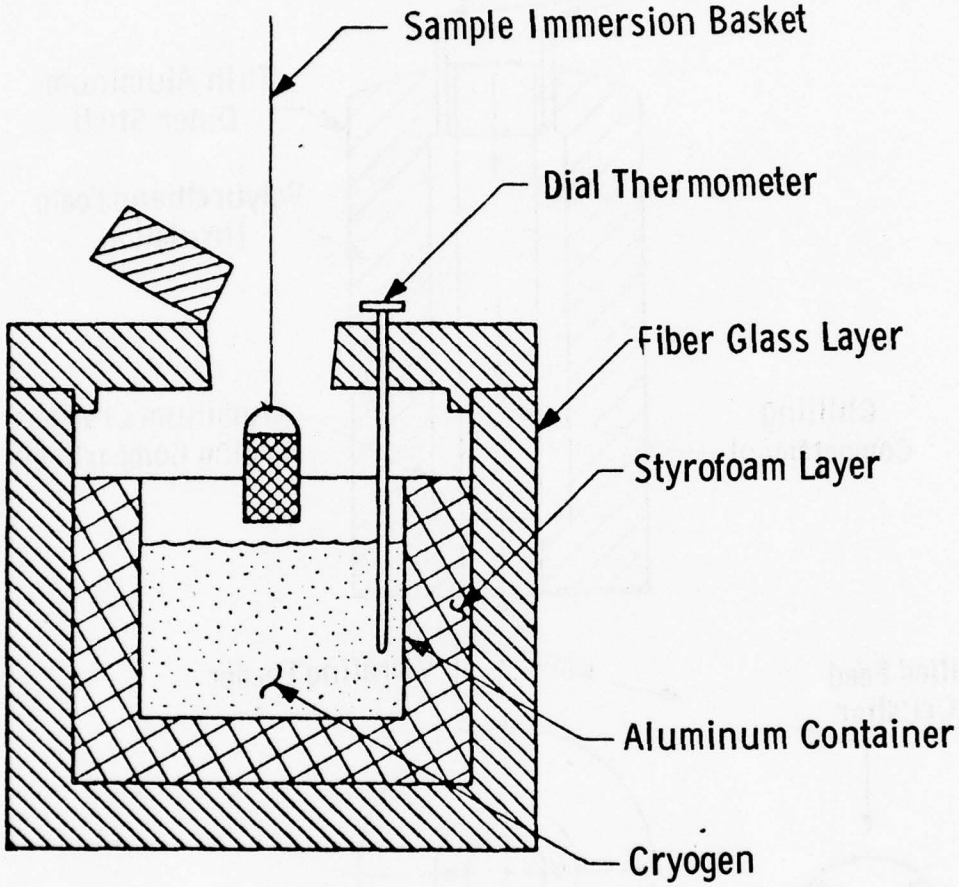


Figure 12 Chilling Chamber[6]

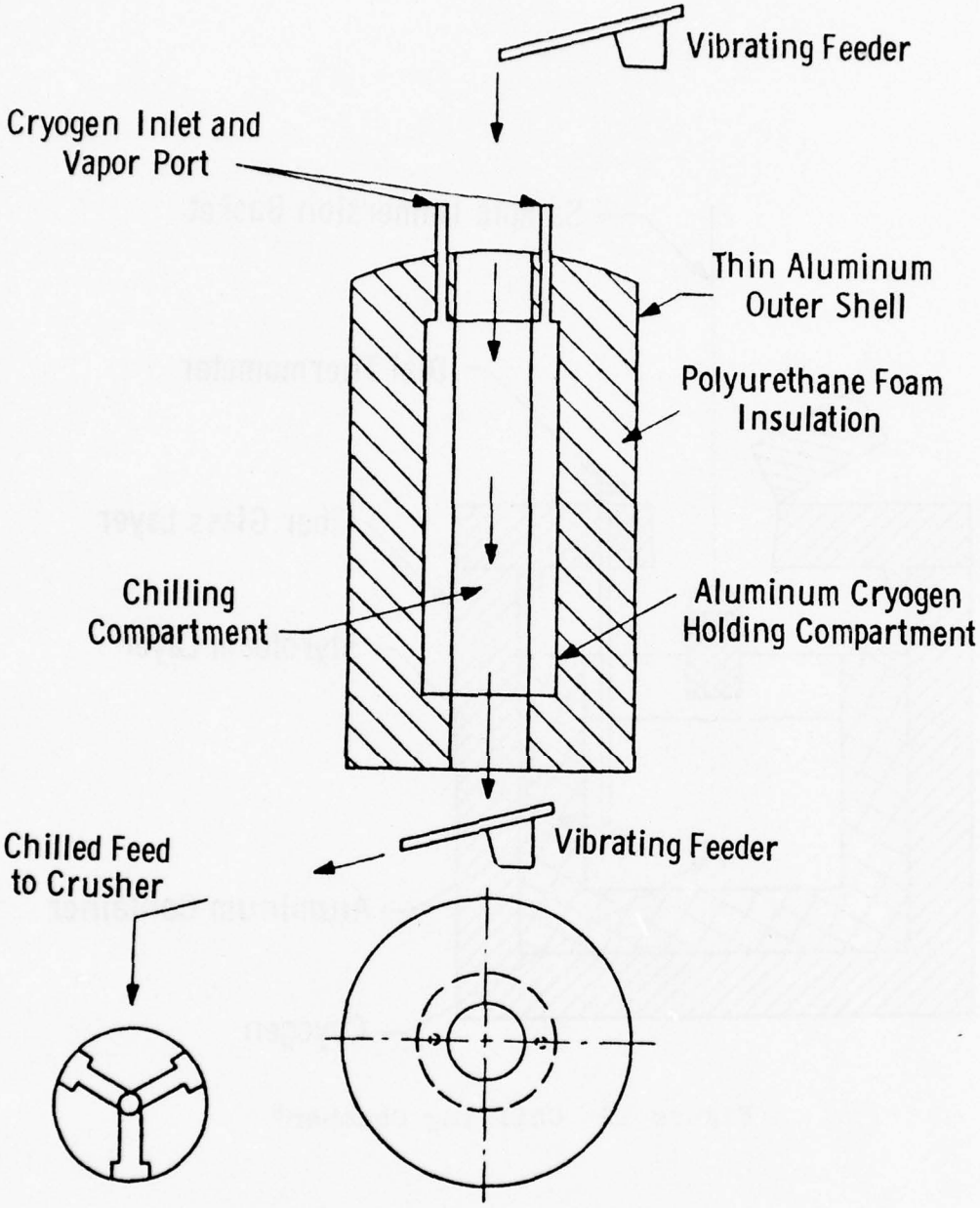


Figure 13 Prototype Cryogenic Chamber[6]

2.2.2.4 Gateway, F.M.A., Inc.

The cryogenic tire disposal process developed by the [illegible] Company is very similar to the process developed by Vernon D. L. Richardson. The differences between the processes, marketed in America by Hazemag, U.S.A., Inc. and the absorbed process previously described are the freezing chamber design and the additional grinding and separation steps.

The process is designed for a capacity of 600 car tires per hour, sized 17 to 19 inches with a maximum belt width of 17½ in.[2] This plant, however, is not portable at this feed capacity. The engineers at the home office in Germany estimate that making the unit portable would reduce the capacity to 50-60 tires/hour.[16]

Figure 14 is a schematic flow diagram of the Hazemag Tire Shredding System. The tires, manually hooked in two rows on the conveyor, pass through the cold tunnel (freezer), automatically disengaging at the discharge end. The frozen tires fall into a pulverizer which separates the rubber from the carcass. The shredded material passes to the sieve hopper which achieves separation of the cord and steel belt for subsequent reuse. The large particles passing through measure up to 35 mm.

These are suitable for reuse in many applications, however, the process is designed for further grinding using Hazemag's Hovermotor mill. Ninety percent of the material exiting this mill is less than 1 mm in size and must be collected in a cyclone.

2.2.2.5 Other Processes

Gateway Paint and Chemical Company has a process which they feel will handle tire material if it is pre-treated by a chipper.[2] They do not, however, have a process which will accept whole rubber tires. The process which they have developed is not ready for scale up to a commercial unit and further development work is being conducted.

Air Products and Chemicals, Inc., have a process developed however they are keeping the exact operations proprietary. This is also probably the case with several other cryogenic processors such as Union Carbide Corporation's Linde Division.

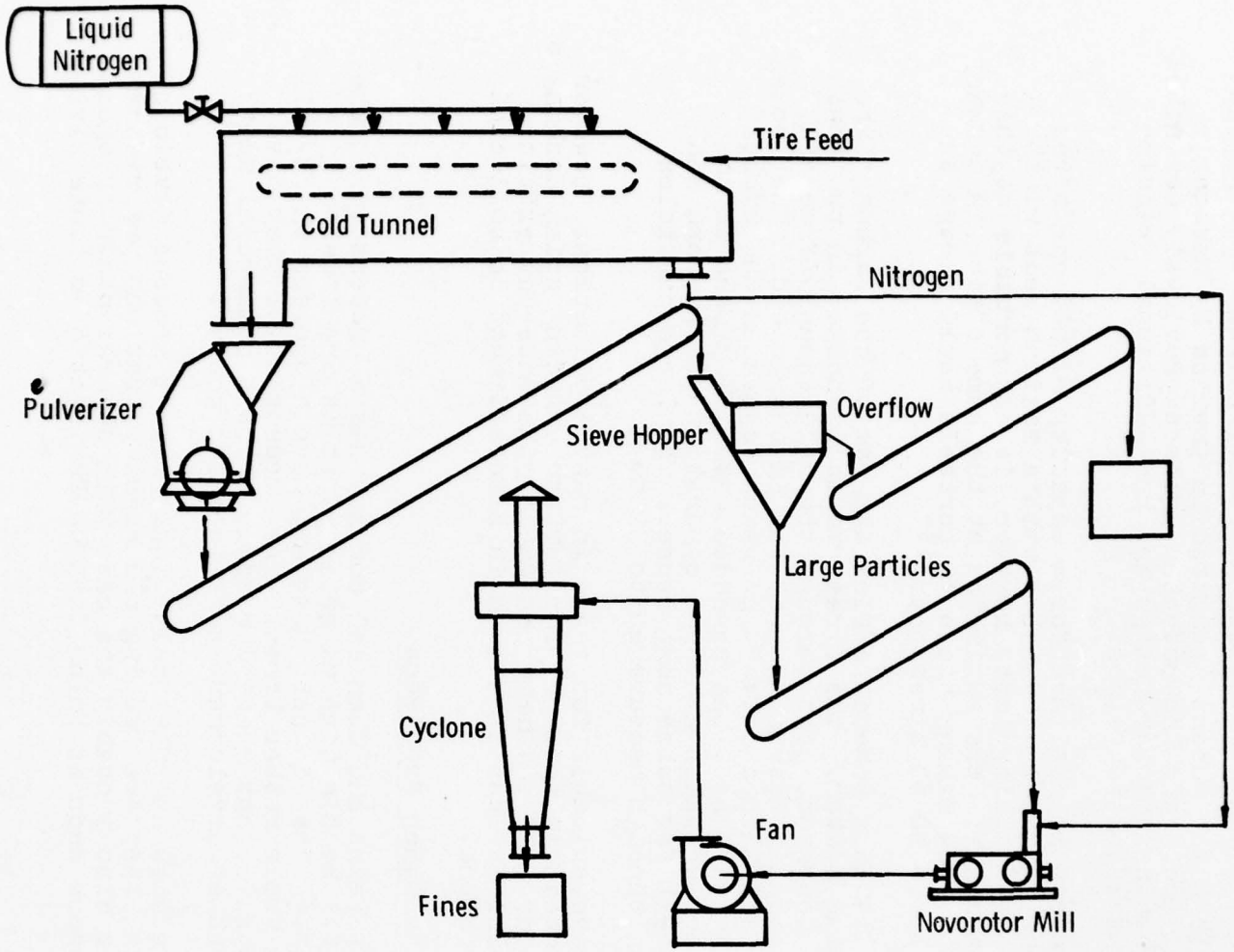


Figure 14 Hazemag, U.S.A., Inc., Cryogenic Grinding Process Schematic

2.2.3 Combined Size Reduction

In this process, the merits of both the cryogenic and mechanical size reduction options are utilized. The flow diagram in Figure 15 illustrates this process. The scrap rubber tires are pre-treated by a chipper before entering the freezing chamber. In the freezing chamber a more efficient use of the liquid nitrogen vapors is achieved due to a larger surface area-to-volume ratio. Also, after freezing, a smaller hammermill can be used, reducing capital and operating costs. This type of operation is also applicable for other feedstock. Any material which can be handled by the pretreater can be handled by this cryogenic system.

The integrated concept is currently being tested and used by Cryogenic Recycling International, Inc.[17] Figure 16 is a schematic diagram of the process which they have developed. The process was developed into stationary and portable plant designs at various capacities. Most of the portable unit in Figure 16 will fit on the straight-bed truck. The LN_2 (liquid nitrogen) freezer is mounted on a semi-trailer and is hauled separately. In small units the initial tire chipper could fit on the LN_2 freezer trailer. However, in most portable applications, the chipper and classification system, if desired, would be hauled separately.

The Gateway Paint and Chemical Company is also investigating the possibilities of using this type of system for the size reduction of scrap tires. However, they are currently only in the research stage.[9]

2.3 SECONDARY PROCESSING

As shown in Figure 1, the secondary processing step includes the majority of the processing options. These processing options shall be discussed according to the material feed type. This breakdown is consistent with Figure 1 and reinforces the logical, systematic approach to the subject of possible tire reuse options.

2.3.1 Whole Tire Feed

The three processing options considered in this category, whole tire reuse, pyrolysis and incineration, use whole tires as a feed. Pyrolysis and incineration, however, can also utilize chipped tire feed and could be included in Section 4.3.2 as well.

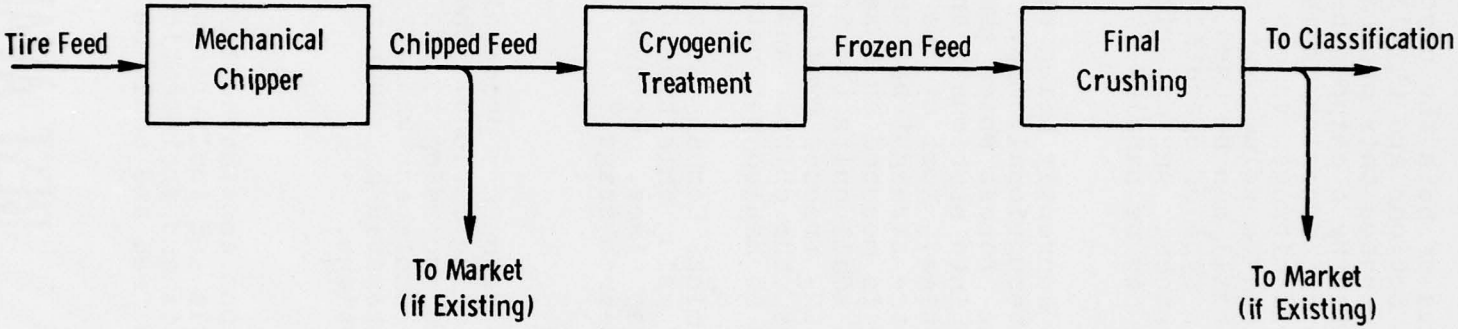


Figure 15 Combined Size Reduction Process Flow Chart

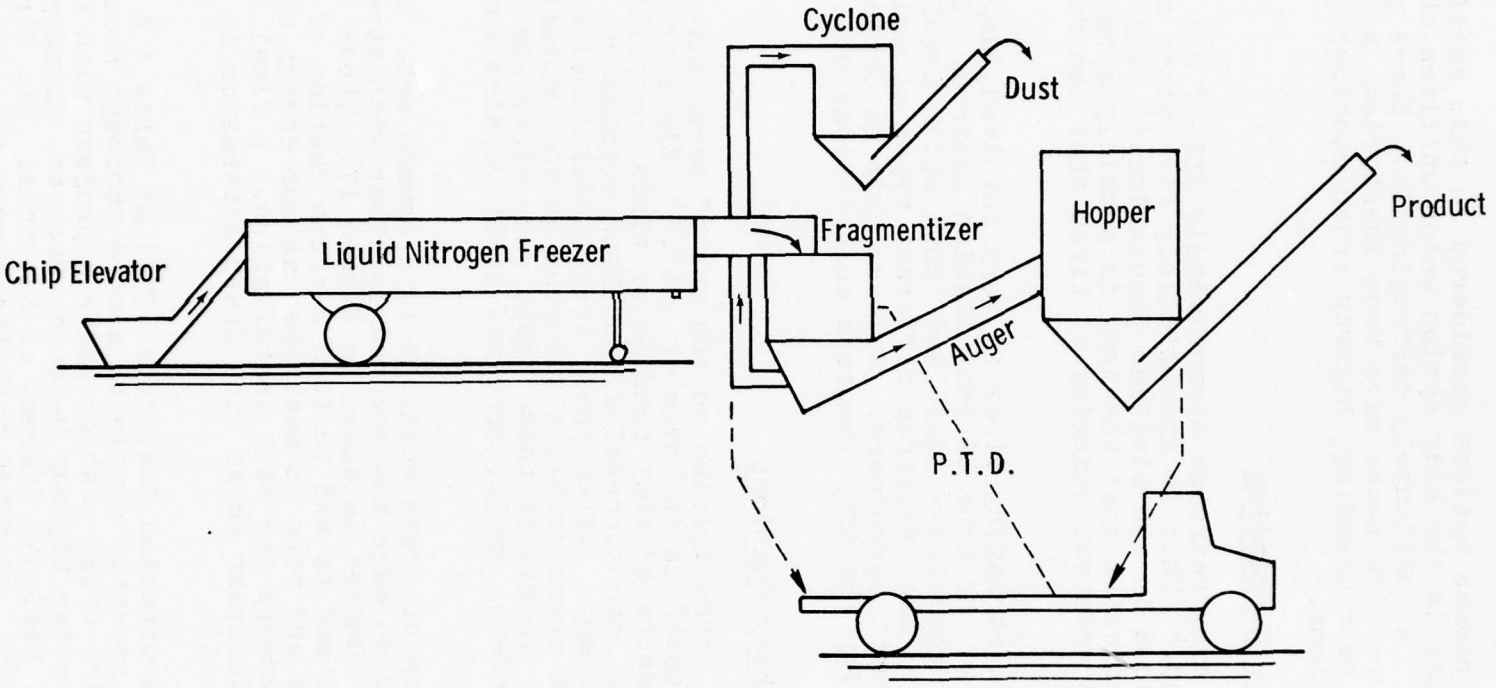


Figure 16 Cryogenic Recycling International,[13] Portable Tire Chip Spray Process

2.3.1.1 Whole Tire Reuse

Of the three process options considered in this section, whole tire reuse is the only option which utilizes the whole tire without ultimately destroying it. Three processes for whole tire reuse have been identified and evaluated: tire retreading, highway crash cushions, and ocean applications.

2.3.1.1.1 Tire Retreading

Presently the Army retreads approximately 75% of all scrap tires generated.[4] This is approximately five times the percent retreaded in the civilian population.[18] This number also indicates that the Army is possibly already retreading the greatest quantity of tires that can feasibly be done.

The process of retreading tires is very involved, depending primarily on the type of installation desired. There are two basic processes--"cold" and "hot" which involve many variables. Each requires different types of equipment and different techniques. Because this is obviously not an option for the Army, process descriptions will not be pursued.

2.3.1.1.2 Highway Cushions

Goodyear began investigation on the use of scrap tires in highway crash cushions in November 1969.[19] Since then they have demonstrated that bundles of tires, properly cabled together, can successfully cushion crashes at speeds up to 60 mph. After these tests, additional work with scrap tire crash cushions was done at the University of Cincinnati. In all of these tests only minor sheet metal work, fenders, grill, hood and light repairs were needed.

The construction of crash cushions is a common art. Scrap tires are stood on edge and secured together with steel cables to form bundles as shown in Figure 17. These bundles are then placed end to end to form a crash cushion of sufficient size and mass to meet the maximum energy absorbing requirements for each installation. A final design sketch of the Goodyear Scrap Tire Crash Attenuator is shown in Figure 18.

The Texas Transportation Institute (TTI) at Texas A & M University has recently completed a more thorough study of the scrap tire crash cushion under a project with the National Cooperative Highway Research Program, Highway Research Board, National Academy of Sciences. Dr. Hirsch, Division Head, TTI, reported that the energy dissipation

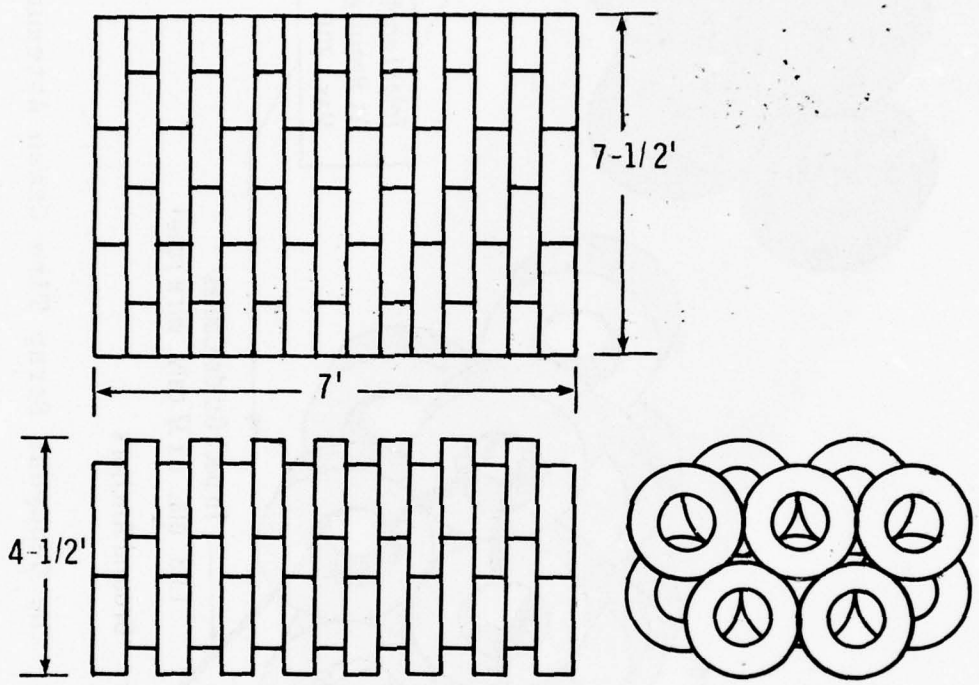


Figure 17 Single Crash Cushion Unit[19]

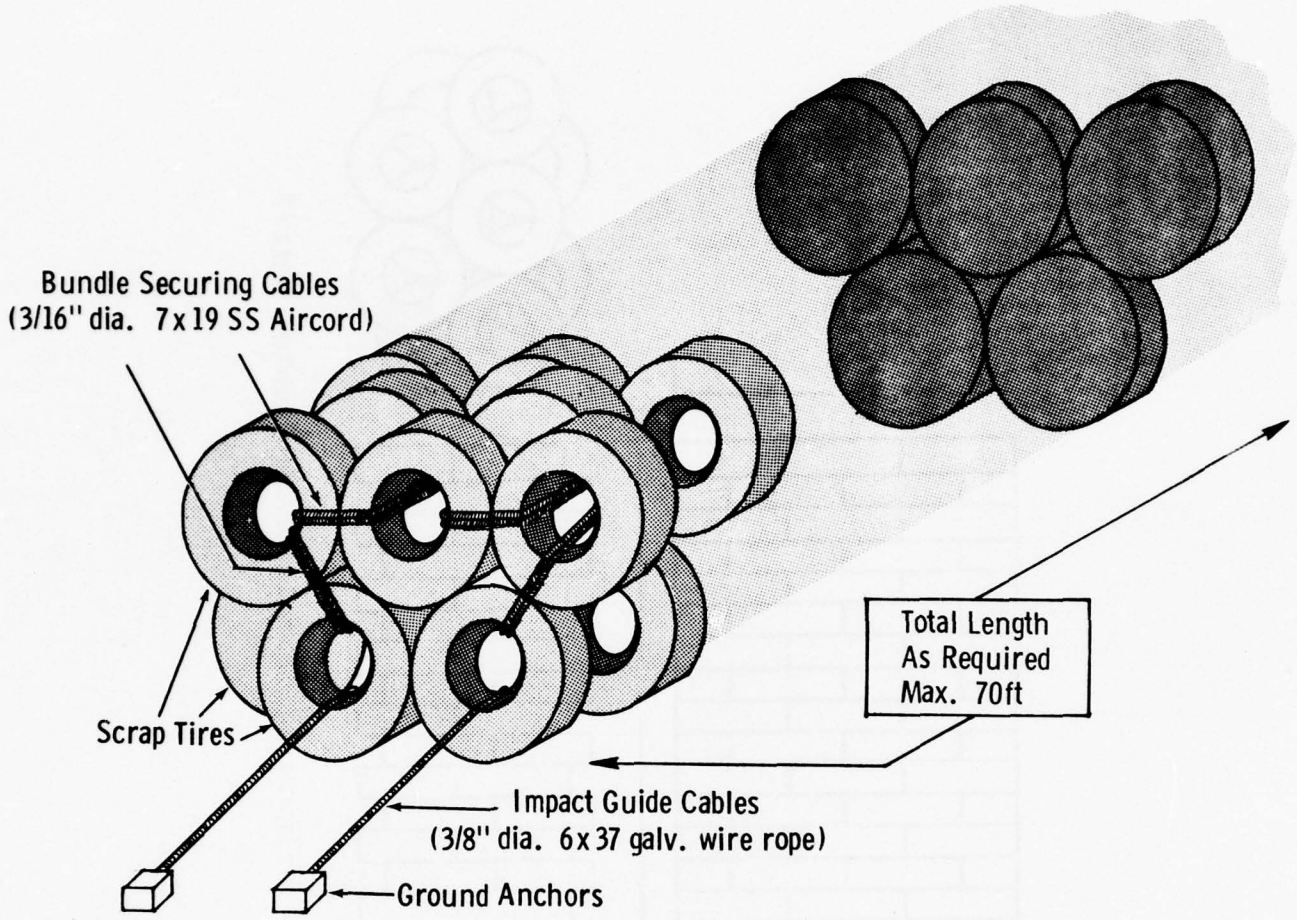


Figure 18 The Goodyear Scrap Tire Crash Attenuator[20]

characteristics of the Goodyear Tire and Rubber scrap tire cushions are excellent. All of the units tested stopped vehicles traveling at speeds greater than 60 mph with deceleration "G" loadings well below the maximum figure specified in the Federal Instructional Memorandum 40-1-71.

During the testing, several modifications were proposed, such as panels on the sides to prevent horizontal deflection. These changes were relatively minor, however, and the design presented in Figure 18 was essentially unchanged after the study.

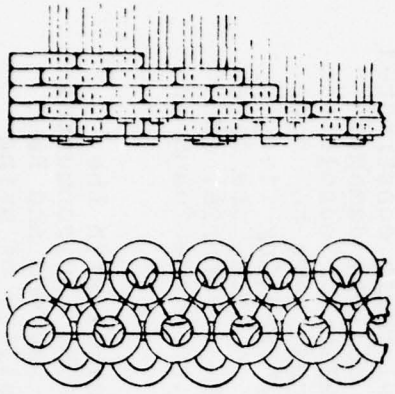
2.3.1.1.3 Ocean Applications

One of the newest developments in the use of scrap rubber tires in the ocean is as floating breakwaters. Goodyear Tire and Rubber Company has been investigating this idea with the cooperation of the University of Rhode Island. The design of these breakwaters is based on the modular building block concept. The length, width, and thickness of these modules may be varied depending on the application need. The modules are then connected together to form the needed length of breakwater.[21]

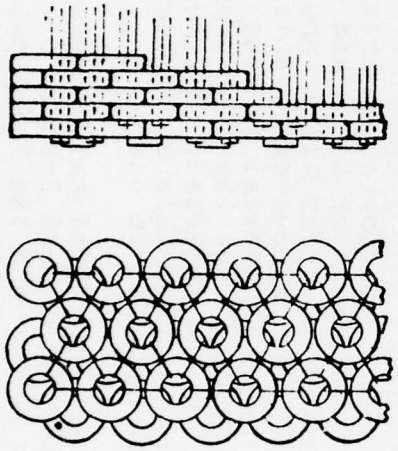
Sketches of the basic building block modules are shown in Figure 19. They are of two basic types -- bundle and mat construction. The bundle is of either double or triple thickness construction and is arranged in long strips. The mat can be of single or multiple thickness but is in a large-area, mat-type arrangement. These breakwaters could be excellent for use in the military since they are cheap, easily erected, and require low maintenance.

In 1966 testing was started on artificial reefs constructed from scrap material such as junked automobiles, damaged concrete culverts, scrap tires, and derelict or obsolete ship hulls. The objectives of this program were to determine what type of material is best for attracting fish, how these reefs affect the fish population size, the life expectancy of the material, and the cost of material and handling.[22-26] From this study scrap tires were found to be the best material to use.

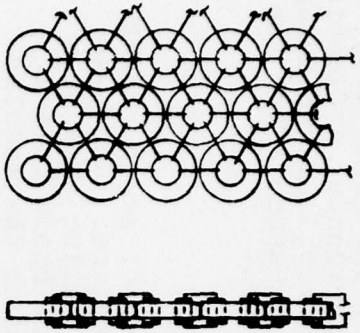
On this basis an additional program resulted with the Solid Waste Management Program of the U.S. Environmental Protection Agency and the National Tire Dealers and Retreaders Association to study the possibility of using large numbers of scrap tires to build artificial reefs in the marine environment.



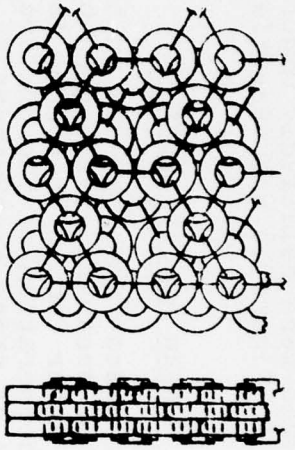
Double Tickness Bundle Construction



Triple Thickness Bundle Construction



Single Thickness Mat Banded Construction



Multiple Thickness Mat Banded Construction

Figure 19 Basic Breakwater Building Blocks[21]

As a result of this study, seven basic tire assemblies were proposed for use. These are shown in Figure 20. Each of the configurations serves a different purpose and is used in different areas of the ocean. Each unit, after being joined together, was weighted with cement to provide stability. The basic criteria for each design were potential habitat for fish, cost, degree of difficulty of assembly, and transportation.

By January 1, 1973, there were 114 approved artificial reef sites along the east coast of the United States employing about 400,000 tires in 43 of these sites.[22] Richard B. Stone estimates that over a billion tires could be used on artificial reefs in marine waters off the east coast of the United States.[22] He also estimated that the Gulf Coast could use approximately the same number and the Pacific coast could use about one-half the quantity used on the East Coast.[27]

2.3.1.2 Pyrolysis

The pyrolysis of tires and the resultant recovery of gases, light and heavy oils, and carbon black is one of the product-producing disposal processes to be examined. While not necessarily called pyrolysis, all of the processes described in this section fall generally into this category, since each produces a gas, liquid, and solid product as a result of heating. In fact, Dr. John Larsen of the Chemistry Department at the University of Tennessee's Knoxville campus specifically states that their process is catalytic decomposition and not pyrolysis.[28] It is presented in this option, however, for sake of organizational clarity, since it produces similar products as pyrolysis.

2.3.1.2.1 Tosco Process

The Oil Shale Corporation and the Goodyear Tire and Rubber Company have teamed in a program to apply TOSCO's oil shale recovery technology to the recovery of useable products from scrap rubber tires. The process used is very similar to The Oil Shale Corporation's TOSCO II process shown in Figure 21.[29]

The experimental work on this program was done at TOSCO's Rocky Flats Research Center near Golden, Colorado. Much of the data and technology obtained during the recently completed phase is still proprietary and thus unavailable to the general public.[30] However, according to Goodyear chairman Charles J. Pillirod, Jr., a full-scale plant could handle 8 million scrap tires per year. This plant would recover

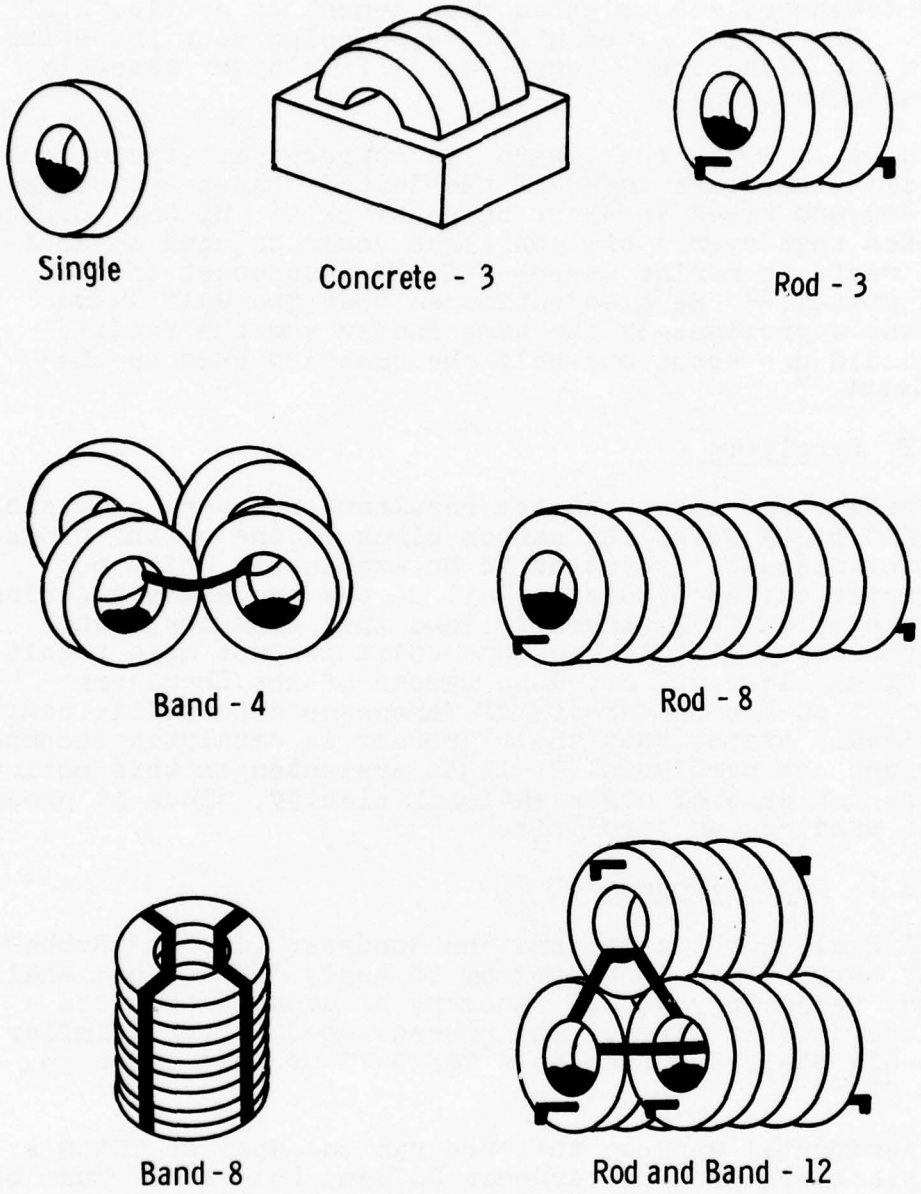


Figure 20 Basic Building Blocks for Artificial Reefs

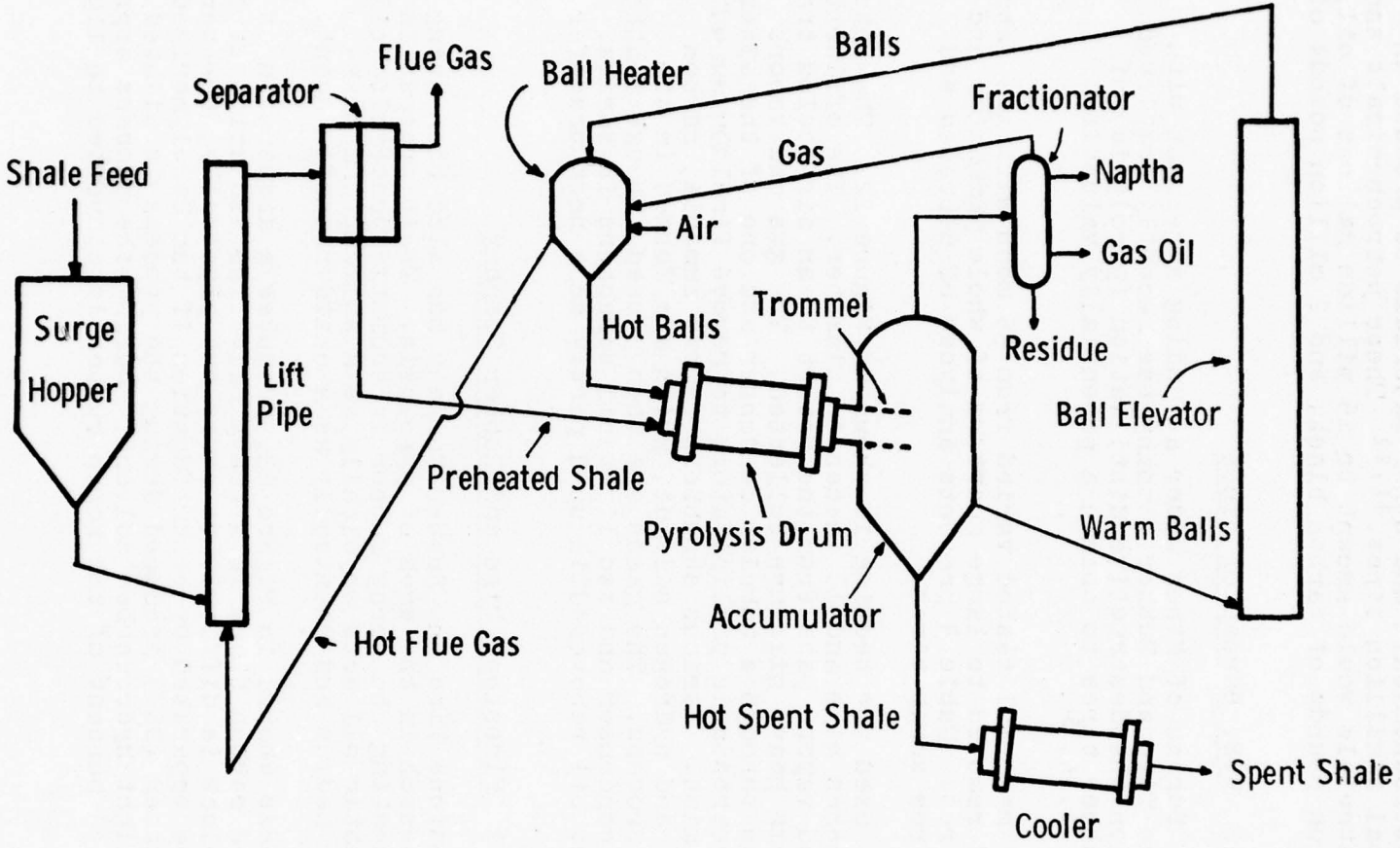


Figure 21 TOSCO II Process[30]

enough petrochemicals and other materials to produce an additional 2 million tires.[31,32] These petrochemicals and other materials would amount to 15 million gallons of oil, 73 million pounds of carbon black, and 2 million pounds of steel.[32]

2.3.1.2.2 U.S. Bureau of Mines

The U.S. Bureau of Mines under a funding agreement with Firestone Tire and Rubber Company has recently completed studies on the destructive distillation (pyrolysis) of scrap rubber tires to obtain a potentially valuable product.[33,34,35]

The feed material tested varied from 35 mesh with the fabric and bead removed to large quarters of whole passenger and truck tires. Table 4 presents analyses of debeaded and fabric-free scrap tires.

The unit used for testing is shown in Figure 22. The retort is 26 inches high and 18 inches in diameter. The effluent gases and vapors pass from the retort to an air-cooled trap where some heavy oils are collected. The gas and vapors then pass through a tubular condenser and one of the alternate electrostatic precipitators to remove final traces of the oil mist. Various scrubbers remove ammonia, carbon dioxide, and hydrogen sulfide, which are formed in the heating process. The gases are then passed through another tubular condenser and two light oil scrubbers in series. The light oil recovered is used partly as a heat transfer medium.

2.3.1.2.3 Firestone Tire and Rubber Company

The Firestone Tire and Rubber Company has also been doing some research in the area of pyrolysis. Their process involves heating the scrap rubber in aromatic processing oil.[36,37] The aromatic oil acts physically as a solvent and heat-transfer medium and chemically as a chain-transfer agent.

The process shown, in Figure 23, produces a dispersion of recovered carbon black in a heavy oil. The isolation of the carbon black is difficult to carry out physically, however, it may be separated by centrifugation if the Depolymerized Scrap Rubber (DSR) produced during the process is diluted with a light hydrocarbon solvent. During the process approximately 1-3 percent of the scrap rubber is converted to light gases.

Table 4 ANALYSES OF SCRAP TIRES[34] *

	Passenger Tires	Truck Tires
Proximate, percent:		
Moisture	0.5	0.8
Volatile matter	62.3	63.3
Fixed carbon	31.5	30.5
Ash	5.7	5.4
Ultimate, percent:		
Hydrogen	7.1	7.4
Carbon	83.2	83.2
Nitrogen	.3	.3
Oxygen	2.5	2.5
Sulfur	1.2	1.1
Ash	5.7	5.4

*Debeaded and fabric free

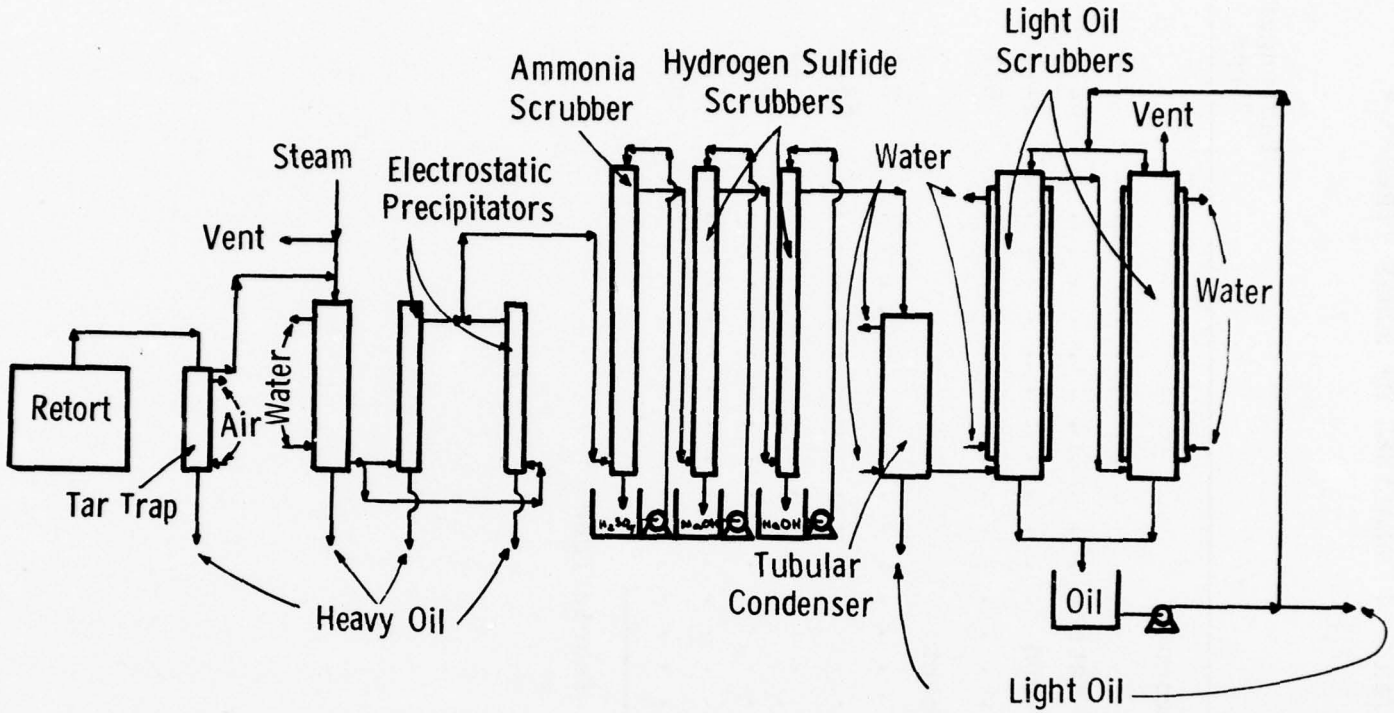


Figure 22 U.S. Bureau of Mines Pyrolysis Unit[33-35]

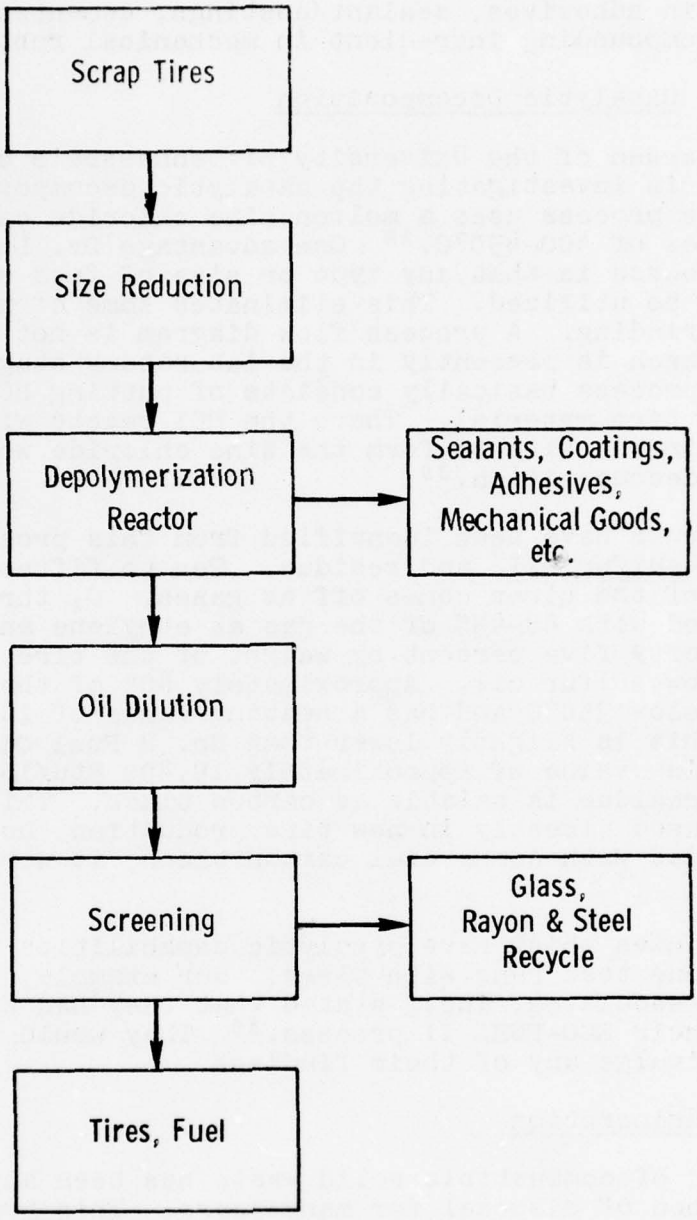


Figure 23 Simplified Flow Sheet for Depolymerized Scrap Rubber[31]

Firestone has run tests using DSR in a mixture with No. 2 Fuel Oil. The blends have a slightly lower heating value than No. 2 Fuel Oil but the flash point is constant. The DSR material can also be used in road resurfacing and potentially in adhesives, sealant/coatings, cement/concrete, and as a compounding ingredient in mechanical rubber goods.[37]

2.3.1.2.4 Catalytic Decomposition

Dr. John Larsen of the University of Tennessee's chemistry department is investigating the catalytic decomposition of tires. The process uses a molten zinc chloride catalyst at temperatures of 400-450°C.[38] One advantage Dr. Larsen sees in this process is that any type or size of feed scrap rubber can be utilized. This eliminates some of the initial costs of grinding. A process flow diagram is not available since research is presently in the laboratory stage. However, the process basically consists of putting HCl into the melted tire material. There the HCl reacts with zinc compounds in the tire to form the zinc chloride which brings about the decomposition.[38]

Three products have been identified from this process: a gas, a low-sulfur oil, and residue. Ten to fifteen percent by weight of the tires comes off as gases. C_1 through C_6 is condensed with 40-45% of the gas as ethylene and propylene. Forty to forty-five percent by weight of the tire feed comes off as a low-sulfur oil. Approximately 80% of the oil distills below 350°C and has a heating value of 18,400 Btu/lb. This is slightly lower than No. 2 Fuel Oil, which has a heating value of approximately 19,400 Btu/lb. The remaining residue is salable as carbon black. This material cannot be used directly in new tire production, however, if it is blended with commercial carbon black, it works very well.[38]

Other companies which have pyrolytic capabilities have probably done test runs with tires. For example, Combustion Equipment Associates, Inc., stated that they had tried only tires in their ECO-FUEL II process.[39] They would not, however, divulge any of their findings.

2.3.1.3 Incineration

The burning of combustible solid waste has been an established method of disposal for many years. This practice was usually done in an open or at least uncontrolled manner, thereby permitting extensive pollution, especially to the atmosphere. Burning of combustible solid waste has therefore been banned except when in compliance with rigid federal, state, or local codes.

Table 5 COMPARISON OF INCINERATORS BY DESIGN

Type	Uses	Advantages	Limitations
Solid Stationary hearth	Solids incineration	1. Low capital 2. Tight air control 3. Can be designed to include liquid incineration	1. Slow burning rates 2. Limited to batch operations 3. Requires manual ash removal 4. Does not lend itself to good air pollution control 5. Does not provide turbulence, mixing or aeration
Solid Mono hearth (rotary hearth or rotating rabble arms)	1. Used for solids incineration. The rotary hearth can incinerate essentially any liquid waste capable of being fed to a stationary liquid tar burner 2. Rotary hearth without rabble arms also used for tire destruction 3. Rotary hearths used to incinerate sludges and granular material	1. Has continuous ash 2. Capable of incinerating waste solids independently or liquids and solids in combination 3. Good maximum to minimum operating range 4. Incinerating materials will not fall through hearth 5. Can be readily incorporated with a gas scrubbing system	1. Has limited turbulence and air contact 2. Requires rabble arms or plows--thus additional maintenance 3. Susceptible to rabble arm damage 4. Partly combusted materials may flow out ash discharge
Rotary Kiln	Used for incinerating a wide variety of liquid and solid wastes	1. Capable of receiving liquids and solids independently or in combination 2. Not hampered by materials passing through a melt phase 3. Feed capability for drums and bulk containers 4. Wide flexibility in feed mechanism design 5. Provides high turbulence and air exposure of solid wastes 6. Long inventory time for slow burning refuse 7. Continuous ash discharge 8. No moving parts within the kiln 9. Can be readily incorporated with a wet gas scrubbing system	1. High capital installation for low feed rates 2. Cannot use suspended brick in kiln 3. Operating care necessary to prevent refractory damage 4. Not normally practical for very low feed rates 5. Airborne particles may be carried out of kiln before complete combustion 6. Spherical or cylindrical items may roll through kiln before complete combustion 7. Combustion air tends to channel down center of rotary kiln requiring relatively high excess air for complete combustion

The incineration of tires is now being proposed using equipment which will not only combust the material in an ecologically suitable manner but also provide for the recovery of the heat produced. The volume of sterile ash produced in scrap tire incineration is 5 per cent of the original volume.[40] The gaseous pollutants can all be removed by current removal technology.

The heat recovery from the incineration process is what makes the idea attractive. Initial investigations in this area were conducted by the Rubber and Plastics Research Association of Great Britain.[41] These studies indicate that a facility burning only tires could produce 2200 pounds of steam per hour from a feed of 560 pounds of tires per hour with a 30% heat transfer efficiency. A plant in England is currently producing 3500 pounds of steam per hour from 340 pounds of tires per hour.

Other studies report that 15 percent tires and 85 percent municipal waste could be mixed to produce 165,000 pounds per hour of steam. These plants, having the capability of burning 600 tons per day of the mixture (3 shifts) meet all applicable pollution control codes.[1]

Three basic designs have been proposed for whole tire incineration: batch, inclined rotary kiln, and rotating hearth with cyclonic gas flow. The differences in each of these designs are primarily in the method of agitation and temperature ranges for combustion. An evaluation of each of these designs is shown in Table 5.

The agitation and temperature zones are critical because of the burning characteristics of scrap rubber. As the rubber undergoes thermal degradation, the rubber and other components melt, forming a type of high temperature slag. Agitation is required to prevent this slag formation.

Ecologically sound tire incineration also involves two burning zones of differing temperatures. A primary burning zone combusts essentially all solid and liquid material. A secondary burning zone burns all gases and airborne particulates.

In addition, the following design parameters must also be considered in the design of incinerators for tire disposal: adequate air supply, residence time, environmental controls, mechanical stability, high operating factor, operational stability, environmental work area health regulations, appearance, reasonable instrumentation, capability of burning other wastes along with tires, acceptibility of whole truck or car tires, continuous operation, and high-temperature refractory lining.

2.3.1.3.1 Batch Furnace

The batch furnace can be of two designs: open pit or totally encapsulated. The open pit incinerator is essentially four refractory lined walls with a grate for ash removal on the bottom. Secondary burning is achieved by blowing over-fired air through jets mounted around the top rim of the pit and directed onto the fire. Field tests have proved this method unacceptable because of excessive noise, refractory spalling, heavy smoke, lack of operational stability, and failure to meet environmental control standards.

In both the open pit and the encapsulated batch furnaces, agitation is accomplished by "poking", manual grate shaking, and use of high-velocity burning gases and air. The secondary zone burning in the encapsulated furnace is also achieved by adding over-fired air to the gases before they exit the stack.

2.3.1.3.2 Inclined Rotary Kiln

The inclined rotary kiln is generally accepted as the best unit for the incineration of tires.[1] Agitation is achieved through the constant tumbling of the tires. This tumbling action continually exposes new surfaces to the heat, flame and air.

The two temperature zones in the inclined rotary kiln are physically distinct. The primary burning chamber is operated at an exhaust temperature of 1,400-2,000°F without auxiliary fuel, if sufficient air is present.[1] The secondary chamber is maintained at this temperature with adequate retention time to burn all of the hydrocarbons.

2.3.1.3.3 Cyclonic Rotating Hearth Furnace

Figure 24 is a cutaway view of a cyclonic rotating hearth furnace. Agitation is achieved by the hearth rotating at approximately 4-5 revolutions per hour. Tires are fed into the hearth and carried around the combustion chamber. The admission of another tire displaces the preceding partially burned carcass and thereby initiates a spiral path toward the central discharge port. A hydraulically operated ram/rake clears the hearth every cycle.

The two zone burning is carried out in the same incinerator shell. It is achieved by controlling over-fired air and the cyclonic action of the gases in the furnace. When the gases reach the top of the conical furnace outlet, the

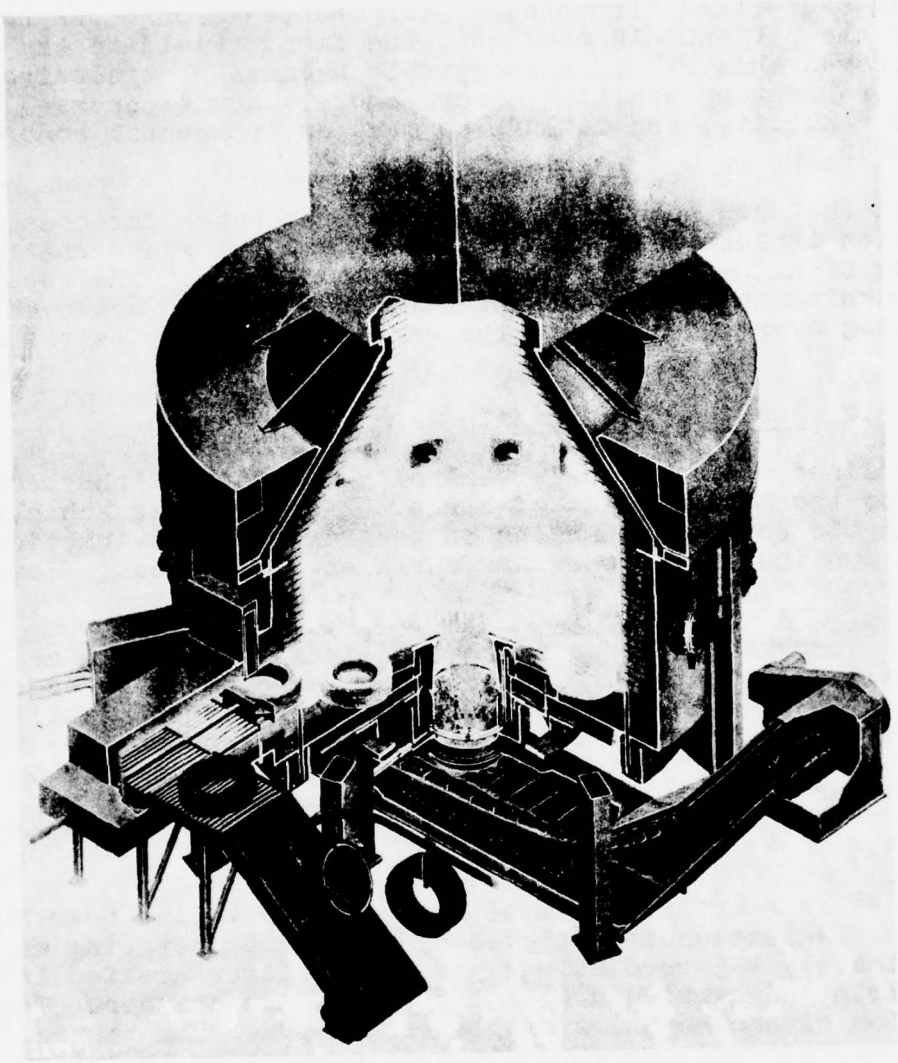


Figure 24 Cyclonic Rotating Hearth Furnace[40]

temperature is between 1700 and 3000°F, depending on the type of material being incinerated.[40] Some investigators indicate that the temperature of the exit gases when burning tires is 2000 to 2200°F.

Air for this unit, as with the other units previously described, is supplied by standard and generally available equipment. Start-up and supplementary heating is provided by four natural gas burners, each with a capacity of 5×10^6 Btu/hr.[42]

Optimum residence time in any incinerator varies with furnace temperature, oxygen level, scrap particle size, and agitation. In this furnace, residence time is approximately 1 hour.

Environmental considerations of the workers and the surroundings are a prime concern for a process such as tire incineration. This particular unit is available in a completely designed package including environmental controls (Figure 25). Estimates of the uncontrolled particulate emissions from the furnace are 0.3 gr/sdcf; the controlled emissions are less than 0.031 gr/sdcf.[40] Other environmental considerations are taken care of by careful design. Odor is eliminated by operating the system under negative pressure. A water-cooled charging zone will prevent premature ignition of tires.

Instrumentation is simply a sensing and correction process. When the temperature drops, the instrumentation responds by injecting auxiliary fuel, adding more air, increasing tire feed rate, or sounding an alarm to call the operator. A fail safe shutdown is controlled by an independent circuit.

This incinerator is lined with refractory material capable of withstanding 3500°F and reasonable thermal shock without heavy spalling or failure.

2.3.1.3.4 Complete Incineration Installation Concept

Figure 26 shows a complete incinerator installation including heat recovery and pollution controls. This installation can process 3,000 tires/24 hour day or about one million tires per year. At a heating value of 13,400 Btu per pound we can determine the heat available as follows:

$$\left(\frac{3000 \text{ tires}}{24 \text{ hours}}\right) \times \left(\frac{27 \text{ pounds}}{\text{tire}}\right) \times \left(\frac{13{,}400 \text{ Btu}}{\text{pound}}\right) = 4.52 \times 10^7 \text{ Btu/hr.}$$

The capacity of the boiler for this installation would be about 25,000 lb/hr of steam at 250 psi and 406°F.[42]

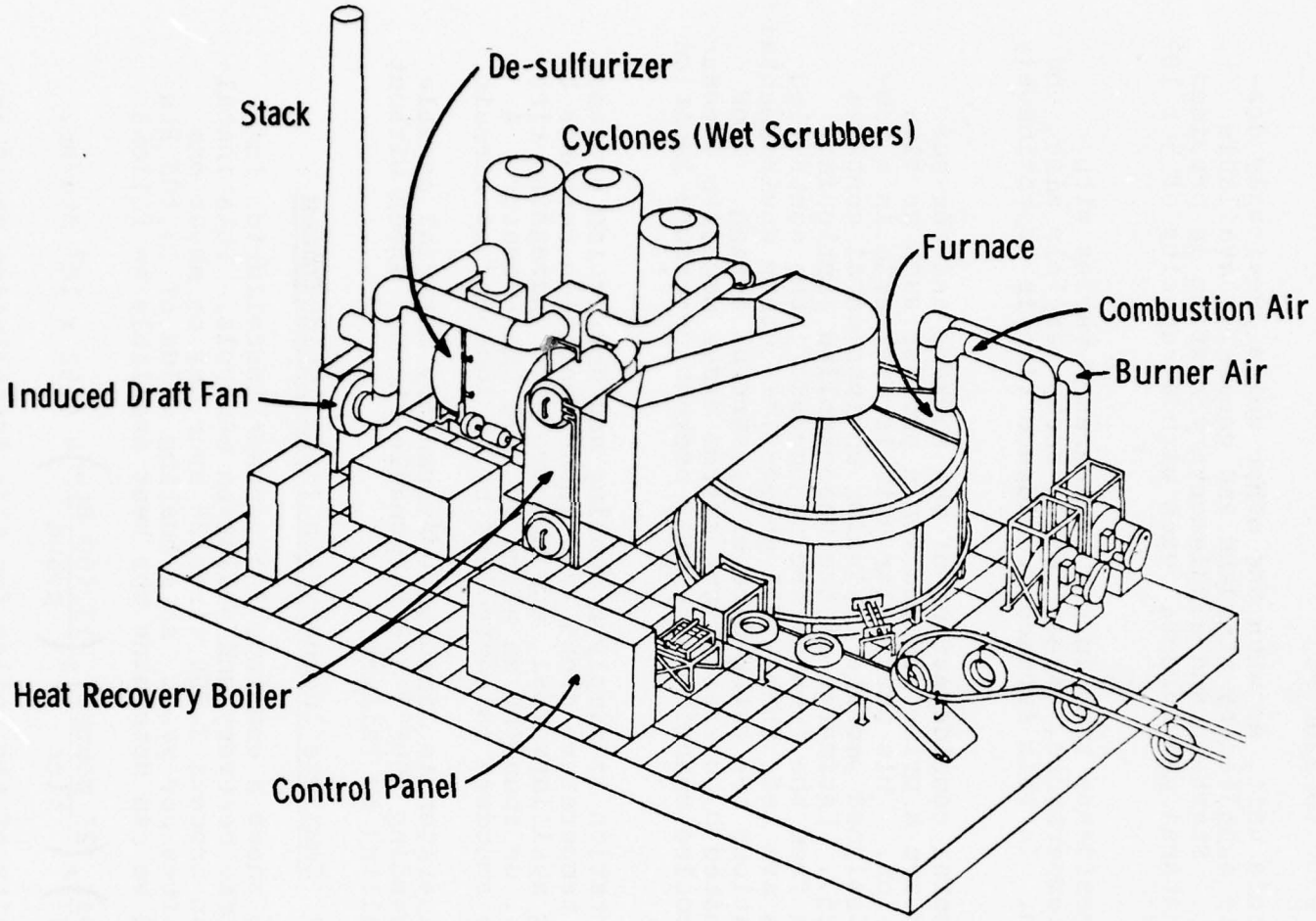


Figure 25 Typical Rotating Hearth Incinerator Installation with Heat Recovery[40]

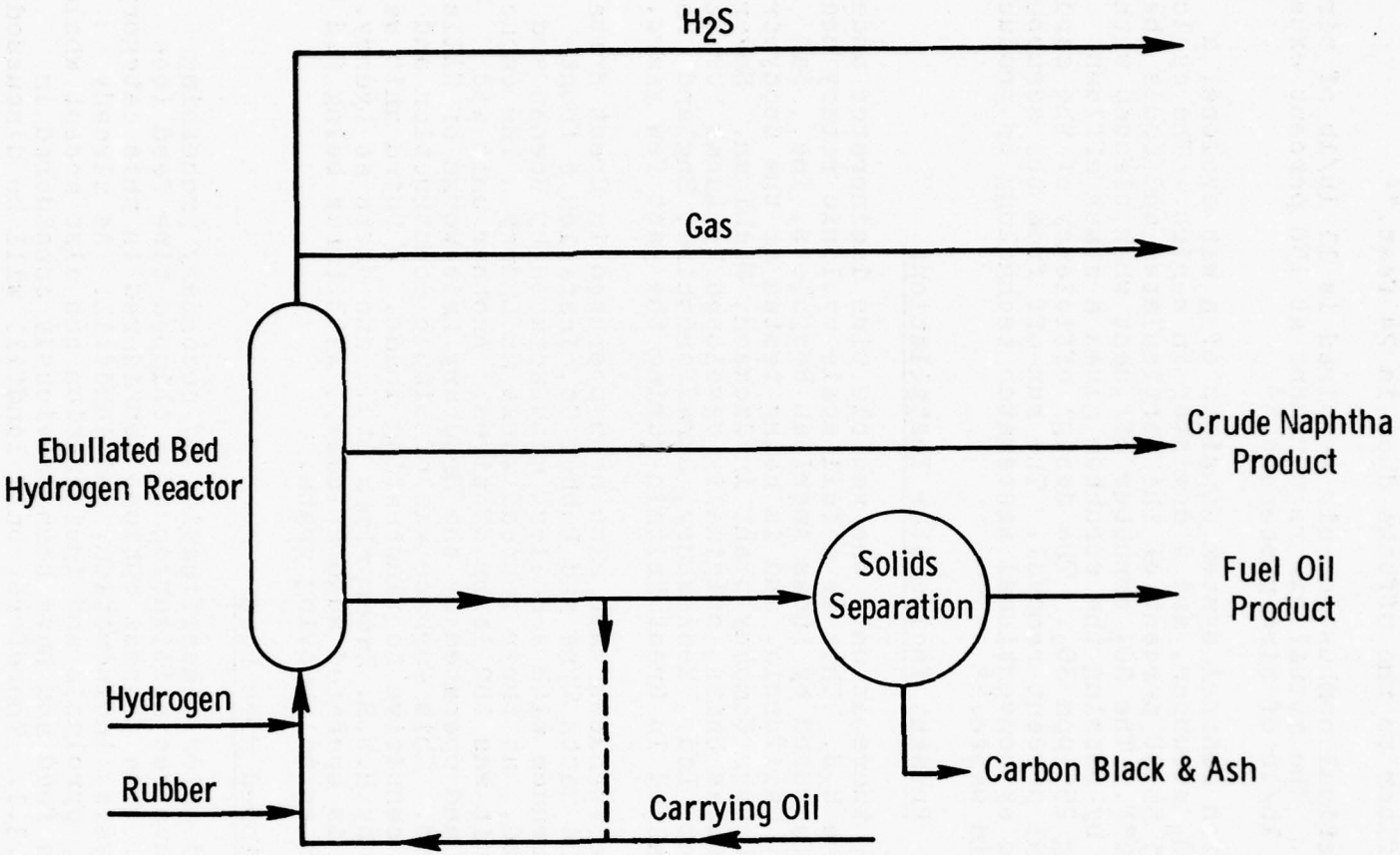


Figure 26 Conceptual H-Rubber Plant[67]

This furnace can handle tires up to 30 inches in diameter. The diameter of the hearth is 18 feet with an outside casing diameter of 20 feet. The overall height of the furnace from the floor to the offtake duct is 24 feet.[42]

The theoretical combustion air required is 11 lb/lb of tire processed. The actual air requirement at 150 percent excess air is 16 lb/lb of tire processed.[42]

The emission control system consists of a wet cyclone, a caustic SO_2 scrubber, and a demister in series. The cyclone removes 35 to 90 percent of the particulates and cools the gas to 500°F. The SO_2 scrubber effluent when blended with a portion by-passing the scrubber gives a stack effluent containing 250 ppm SO_2. The design efficiency of the scrubber is 90 to 95 percent removal. The run-off from the scrubber is treated by conventional wastewater technology to produce inert solid waste.[46]

2.3.1.3.5 Present Incinerator Installations

Currently, there is only one vehicle tire incinerator under test in the U.S. This is a full-scale cyclonic rotary hearth unit manufactured by Lucas American Recyclers, Inc., San Francisco, California, and is being tested at the Goodyear Tire and Rubber Company plant in Jackson, Michigan. Several of these Lucas Units, originally developed by Lucas Furnace Development, Ltd., Wednesbury, Straffordshire, England, have been installed in Great Britain during the past few years.[42]

Other tire furnaces have also been operated in Great Britain. In 1966 the Watts Tyre and Rubber Co. installed a front-opening furnace with a boiler, manufactured by Heenan and Froude, Ltd., at their retread works at Lydney. The capacity of this unit was 700 lb/hr of tires. Another unit was developed and operated by the Bradbury Brickworks of Hills of Swindon Ltd. This furnace was of simple construction and much less sensitive to fluctuating loads. A third unit was developed by H.W.B. Enterprises Ltd., and Watts at Lydney. This unit is operated automatically, with tires being fed by a conveyor on to a moving grate.

2.3.2 Chipped Tire Feed

The second major classification of secondary processing options involves utilization of a chipped tire feed (see Figure 1). The process options considered in this category are pyrolysis, incineration, and landfill. As already mentioned, pyrolysis and incineration can also accept whole tires as a feed and have been previously considered in section 2.3.1. Therefore, only landfill will be discussed in this section.

2.3.2.1 Landfill

One of the most obvious solutions to the scrap tire disposal problem, landfilling, is not a viable option for two reasons. First, the tires do not degrade after they are buried. Second, the scrap tires "float" to the surface after burial. This is due to the physical characteristics such as the shape and compressibility of the material[43] For these reasons the landfill of whole tires was not considered an adequate method of tire disposal.

It is clear that the scrap tires must undergo a chipping process before they can be landfilled. This can be done by any of the previously described size reduction systems (Section 2.2). However, since the only requirement for landfilling tires is to break down the tire structure, the cheapest and crudest size reduction process should be employed.

The approximate volume of land needed for landfill can be calculated by[44]

$$V = \frac{FR}{D}\left(1 - \frac{P}{100}\right) \qquad (1)$$

where V = landfill volume in cu yd/capita/year
F = factor incorporating cover material
avg. 17% for deep fills, F = 1.17
33% for shallow fills, F = 1.33
R = amount of refuse contributed in lb/capita/year
D = average density in lb/cu yd (325 for waste compacted by trucks)
P = percent reduction of refuse volume in landfill, 0-70%

This equation, designed for municipal garbage, can be adapted for use with scrap tire disposal only. For a cryogenically ground tire, the average density is 1020 lb/cu yd. If we assume that the compaction after landfill is low, e.g. <10%, then equation 1 reduces to

$$V = \left(8.82 \times 10^{-4}\right) FR \qquad (2)$$

For our applications the units for V and R would be changed to cubic yards per base per year and pounds per base per year, respectively. Assuming an F factor of 1.25, equation 2 can be further simplified to

$$V = \left(1.10 \times 10^{-3}\right) R \qquad (3)$$

Equation 3 can be used for a quick approximation of the volume needed per year per installation for cryogenically ground scrap rubber. For example, Red River Army Depot produces 30 tons of rubber per week.[3] This amounts to approximately 3.12×10^6 pounds per year. According to equation (3) the volume needed to landfill this rubber waste would be 3430 cubic yards. This number would change depending on the size reduction technique and the F factor.

2.3.3 Classified Tire Feed

The feed to the remaining five secondary processing options is a classified tire feed (see Figure 1). The classified tire feed consists of rubber which has been separated from the steel and fabric. Any of the size reduction techniques mentioned in section 2.2 and their corresponding classification systems can be employed to provide feed material. However, certain processes considered in this category have specific requirements for feed particle size which may dictate the type of size reduction equipment used.

2.3.3.1 Asphalt Substances

The use of reclaimed or shredded rubber in asphalt in various percentages is probably one of the better known applications for waste rubber. Several organizations have used the asphalt-rubber composition in various ways in different parts of the country. These tests, however, have not given consistent results and point out the need for a standardized testing procedure on a nationwide basis.

Three distinct testing or commercial programs have been conducted and will be considered separately. These tests are the laboratory investigations done by the University of Connecticut, the chip seal construction using Charles H. McDonald's formulation, and the products being offered by the U.S. Rubber Reclaiming Company, Inc.

2.3.3.1.1 University of Connecticut

These investigations considered the use of scrap rubber in pavement mixtures to improve the physical characteristics of the pavement at low temperatures (0-40°F). The objectives of this program were: 1) the modification of a satisfactory pavement mix by the addition of small amounts of reclaimed rubber crumb to investigate its effect on standard design parameters and low temperature properties of pavements, and 2) the selection of optimum blends of rubber and asphalt which would improve the overall year-round performance of highway pavements.[4,5]

These researchers found that the addition of small amounts of soft and hard rubber crumb did not diminish the performance of the pavement under any conditions. An optimal mix was established as 6 1/4% asphalt and 2% reclaimed rubber.[45] The Marshall Test results for this mix were found in compliance with current specifications. The authors feel, however, that the relatively slow Marshall Test may not be a good predictor of performance of rubber-stabilized asphalt mixes. Recognizing the great potential to increase other properties through increased rubber content, the maximum flow possible should be permitted for this type of material.[45]

Stephens and Mokrzewski also believe that the addition of a small amount of rubber will improve the overall year-round performance of a pavement, with the magnitude of the effect a function of the temperature, asphalt grade, and asphalt content.[45]

2.3.3.1.2 Seal Coat Constructions

Several papers have been published or presented concerning the asphalt-rubber surface coating process developed by Charles H. McDonald, formerly of the Highway Department, primarily in Phoenix, Arizona.[46-48] This process was developed as a seal coat to overlay pavements that exhibited severe fatigue or "alligator" cracking.

This "alligator" cracking is a result of vertical deflections of approximately 0.008 in to 0.050 in. The quantity and severity of this cracking depends on the type of pavement, the ability of the pavement to take deflections, the temperature, and the number of repetitions.[46] The solution to this problem has been difficult and expensive while the results were not always predictable.

Mr. McDonald's work utilizes a high percentage (25% by weight of asphalt-rubber compositions) of scrap rubber to increase the flexibility and elasticity of the pavement while reducing its temperature susceptibility characteristics. The undissolved particles act as units of elastic interference to the propagation of a crack once it has started.

The scrap rubber used, essentially, all passes through a No. 16 sieve and not more than 10% passes through a No. 25 sieve. The ground tire rubber is blended with hot asphalt at a temperature range of 350 to 450°F for

a period of 30 minutes. After this period of time the temperature is allowed to drop below 350°F and kerosene is added as a thinner in the amounts of 5 1/2% to 7 1/2% by volume of the asphalt-rubber composition.

The material is then spread through No. 5 nozzles on a 10 ft maximum width distributor. The application rate is between 0.47 and 0.5 gallon of binder mix per square yard followed by 37 to 39 pounds of 3/8 in nominal sized cover aggregate per square yard.

Various asphalt-rubber concentrations have been used for test patches in different parts of Arizona. The 25/75 mixture is used because of the flash danger associated with the higher temperature needed to establish a higher percentage rubber mixture, even though the higher percentage rubber compounds have better characteristics.[48]

In each case the use of rubber in seal coat construction has proven to be successful. The initial studies conducted in Phoenix have shown the process very feasible in reducing maintenance requirements.

This same type of construction has been used in the resurfacing of runways and taxiways for various Naval installations on the West Coast.[49] Successful results have also been realized from this severe use application of asphalt-rubber binder.

A very similar type of process has been developed by Battelle.[50,51] Their studies exhibited the same type of positive results realized in Phoenix. Accelerated exposures in the Weather-O-Meter showed that some test patches performed better than the controls containing no rubber.

2.3.3.1.3 U.S. Rubber Reclaiming

The U.S. Rubber Reclaiming Company, Inc., has been doing research in the area of asphalt and rubber combinations for many years. They have not only developed a seal coat as discussed above but also several other applications.[52,53]

In 1971, Galloway and LaGrone presented a new concept to alleviate reflective cracking of road base surfaces to the asphalt overlay.[54] This substance, called Strain Relieving Interlayer, is made by combining the pre-blended rubber and mineral aggregate with an asphalt emulsion. This is then applied according to standard road building procedures and must be overlaid with a surface designed for traffic use

since the Strain Relieving Interlayer is not a wearing surface. The rubber aggregate has also been shown to be an effective resilient filler material in an asphalt hot mix.[55]

Powdered reclaimed rubber can be dissolved in compatible asphalt cements by cooking at elevated temperatures to produce rubberized asphalts with improved flexibility, temperature susceptibility, resilience, adhesion and resistance to flow and brittleness.[52]

Joint and crack sealer can be produced on site in the above manner by using a conventional "tar kettle". Twenty percent by weight powdered reclaimed rubber is cooked with asphalt for 30 minutes at 400-425°F.

Several other applications of the above described compounds are chip sealing, hot mix, and friction seals. These compounds have also been tested on bridge decks for patching and waterproofing. The application is currently under field testing and no definitive results are currently available.[56]

U.S. Rubber Reclaiming has made several applications of the various rubberized asphalt substances. Several of these applications are listed below:

LOCATION	SUBSTANCE	USE
New York, New York	Ramflex/Hot mix	City streets
New York, New York	Perma-Track	Cardinal Hayes High School track
Williamstown, Mass.	Ramflex/Hot mix	City streets
New York	Joint & crack sealer	14,000 miles of state highway
North Dakota & California	Various asphalt-rubber mixes	Research with FHWA
New England Area	Perma-Track	Over 40 tracks at various universities and high schools

2.3.3.2 Filler Material

The use of ground scrap rubber as a filler material has been one of the longstanding objectives of the investigators of scrap rubber recycling alternatives. These applications include sound attenuation, rubber tires, synthetic turf and thermoset plastics.

2.3.3.2.1 Sound Attenuation

The Firestone Tire and Rubber Company has shown that ground scrap rubber in various paints and coatings can significantly reduce sound transmission of substrates coated with the mixture. This property of ground scrap rubber has not been fully investigated, but preliminary studies show that it has excellent accoustical properties.[1]

2.3.3.2.2 Rubber Tires

Ground scrap rubber can be used to a limited extent in new rubber tire production. This usage is minimal, however, due to the worsened mechanical and chemical characteristics of scrap rubber.

2.3.3.2.3 Synthetic Turf

Goodyear, Uniroyal and U.S. Rubber Reclaiming have been investigating the use of ground scrap rubber with binders or asphaltic type substances to make artificial playing surfaces.[57,58] These surfaces could be used for playgrounds, factory floors, park paths, running tracks, etc. It can be painted and is porous so that water will drain through readily. Preliminary data show that the durability exhibited by this synthetic turf is excellent.[59] Final reports are not available at this time.

2.3.3.2.4 Thermoset Plastics

The James Turner Company, Inc., has invented a process for producing a product called Leaky Pipes, an underground irrigation system. The exact process is still proprietary and not released as yet. Operating at 100% capacity, however, the inventors claim production capabilities of 48,384,000 pounds of leaky pipe per year.[60]

There are other possible uses of rubber as a filler material which have not been fully investigated. For example, rubber in concrete could be used for architectural applications. These areas of investigation are currently being pursued.[1]

2.3.3.3 Miscellaneous Uses

There are many uses for scrap tires which cannot be categorized into a large group but could provide a large market if fully developed. The uses described here do not include the trivial or already saturated markets of backyard swings, boat dock bumpers, flower planters, etc.

2.3.3.3.1 Cushions and Mulch

Ground-up tires have been used for playground areas and as a plant mulch. The material lasts much longer than conventional soft mulch and doesn't discolor or erode.[61]

Environmental Products Corp. of Cincinnati is currently producing the mulch and packaging in 40-pound Multi-film plastic bags made by U.S.I. Film Products. The mulch holds the water close to the roots of the plant controlling weed growth and protecting the roots from cold and weather damage.

2.3.3.3.2 Soil Conditioner

Drs. Walter J. Nickerson and Marcel D. Faber have invented a method of producing a soil conditioner from scrap tires.[62] In this process, ground tires (approximately 35 mesh) are used as a substrate for a yeast growth. The result is a soil conditioner which promotes retention of water when mixed with sand and passage of water when mixed with clay.[63]

2.3.3.3.3 Water Cleanup

Dr. Joseph Winkler has developed a method to absorb oil spills with a mixture of shredded rubber tires and particulate polystyrene scraps, and then to convert the resulting gelatinous conglomerate to an asphalt-like material.[57,64-66] The ground-up rubber tires and particulate polystyrene scraps are used in ratios ranging from 10:1 to 1:10 depending on the kind of oil to be cleaned up. Light oil requires more polystyrene than does heavy oil. The resulting rubberized, fiber-fortified asphaltic materials would have many applications such as in construction of roof sealants or road dressings. The volatile oil components distilled off could be condensed to useful hydrocarbons.

2.3.3.4 Hydrogenation

Hydrogenation technology was investigated by Hydrocarbon Research, Inc., under EPA contract 68-03-0050. The work done was similar to that previously developed also by Hydrocarbon Research, Inc., for processing coal and petroleum residual feedstocks.[67-73] With this technology it was found that ground rubber tires could be converted to a product of fuel gas, naphtha, gas oil, and carbon black.

A conceptual flow diagram of the process (H-rubber) is shown in Figure 26. In the process, tires are ground to a -24 mesh and combined with a slurry oil for feeding to the reactor. The slurry oils used in the research work were anthracene oil, hydrogenated anthracene oil and tetralin. In the ebullated bed reactor various operating variables were tested as listed in Table 6. No differences in the carbon blacks from catalyzed or non-catalyzed runs were noted. However, significant differences were found in the sulfur and hydrogen content of the liquid products.[67]

Table 6 OPERATING VARIABLES OF EBULLATED BED H-RUBBER UNIT

Temperature	460-850°F
Pressure	500-2,000 psig
Catalyst	Cobalt molybdate on alumina Nickel molybdate on alumina

No major operating difficulties were encountered in continuous ebullating bed, non-catalytic, operations in a 0.614-inch I.D. reactor using -24 mesh tire particles. Catalytic operation in the same pilot plant on tire tread peelings, which were essentially free of glass fibers, was also successful. However, severe operating difficulties were encountered in the same unit when operating with a catalyst bed and ground tires containing glass fibers.[67]

A design has been proposed for a 1000-ton-per-day H-rubber plant (Figure 27). Hydrogen consumed in a process of this size would be about 3 to 4 million scfd. This process would also produce about 3,000 barrels per day of hydrocarbon liquid product, 244 million pounds of carbon black per year, and 2 million scfd of refinery gas.

2.3.3.5 By-Product Sale

The sale of by-products, i.e., the steel belt, fabric, or other metal removed from the rubber in grinding, is the last alternative in the secondary processing category. Some problems associated with this alternative involve the need for the accumulation of a large quantity of steel belt before the additional labor of bundling the steel for sale would be warranted. Also, a rubber scrap market would have to exist (refer to Section 6.3.4) in close proximity so that transportation costs would be minimal.

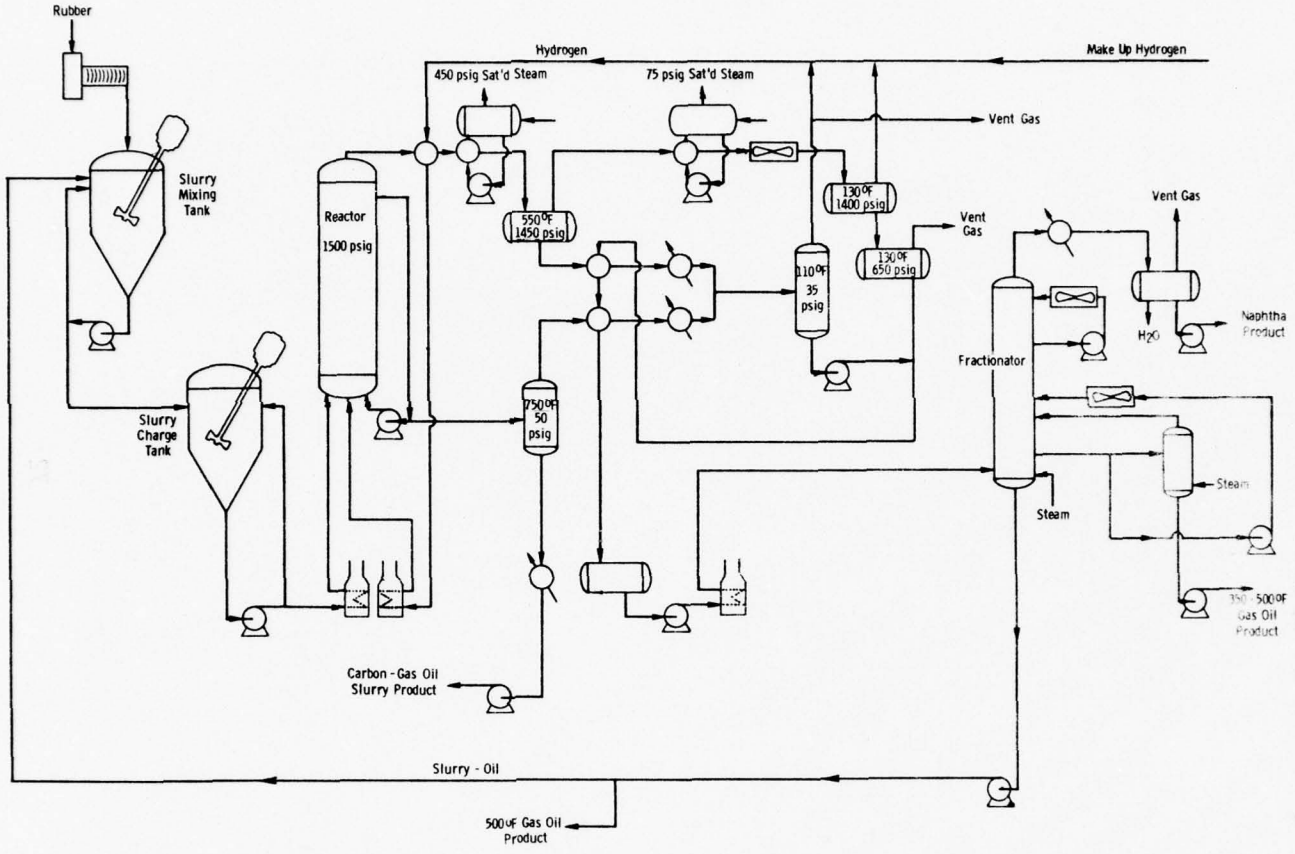


Figure 27 H-Rubber 1000 Tons per Day Plant[67]

The labor involved would be to tie up the steel in large bundles. If a very large volume of wire was to be produced, a device to mechanically compress the wire might be used to increase the bulk density of the material by decreasing the void space.

3. ENVIRONMENTAL IMPACT

As determined from the questionnaire and summarized in Table 1, there are presently approximately 320,000 scrap rubber tires at various Army installations, and this quantity is growing at the rate of 22,500 tires per month. These scrap tires are piled up awaiting sale by contract, landfilling, disposal by some other method, or no disposal at all. In their present state they may serve as breeding places for rodents and as stagnant water collection facilities for the breeding of mosquito larvae and thereby promote the spread of disease. Tires piled in a random manner are a general eyesore and take up valuable space due to large void space per tire. They are also a fire hazard.

One of the most important criteria considered in the evaluation of tire disposal systems was their effect on the environment. Each of the proposed processes identified above will remove whole tires from the environment, thus improving it in that respect. Whole tire reuse, especially in the area of ocean application, is possibly the simplest and one of the more beneficial processes. Artificial reef construction poses no negative impact on the ocean area to which the tires are transferred. The claim has been made that the use of scrap tires for artificial reefs turns areas of ocean "desert" into productive marine environments.[22] No toxic effects due to leachates from the rubber have been noticed. This apparent inertness of tires is as important asset.

Reducing the void fraction of the tire by some size reduction apparatus is another method of improving the environmental impact of scrap rubber tires. Even if the tires are then simply stored, much of the breeding potential inherent in the initial configuration is then gone, and the storage space required is reduced by at least 80%. However, the detrimental aspects of fire and unsightliness are still present.

Landfill of whole tires is unacceptable due to their tendency to float to the surface. However, once the basic annular form of the tire is broken, landfill can be a very acceptable disposal option. An investigation done by Joseph B. Hannon indicates that the inclusion of scrap tire particles in fill can prove beneficial to the mechanical characteristics of the soil.[74]

The use of scrap rubber tires in producing salable products is one of the best solutions to the tire problem from an ecological viewpoint. These alternatives not only rid the environment of the tires but also create new usable products

such as steam, chemicals or road dressings. There might be wastes produced by the processes, and it is therefore essential that in their development the problems of the environment be addressed and defined. In many cases, however, already existing technology may offer the needed solution.

4. TECHNICAL FEASIBILITY

An exhaustive technical evaluation was made of all the possible process options of the scrap tire disposal system presented in Figure 1, as well as all processes included in each processing option summarized in Section 2. This evaluation resulted in the identification of the four most technically feasible alternatives for tire disposal by the Army. The following nine criteria were selected to express the Army's requirements for each processing option:

1. Basic principle of operation
2. Set-up and/or start-up details
3. Operation procedures
4. Mobility
5. Auxiliary equipment requirements
6. Maintenance requirements
7. Feed capacity and characteristics
8. Output characteristics
9. Versatility

Section 4.1 will present evaluations of three primary processing options as presented in Section 2.2. Section 4.2 will present evaluations of the secondary processing options as identified in Figure 1, subdivided by unsuitable or suitable options. Finally, Section 4.3 will propose the four most feasible tire disposal alternatives for the Army with recommendations for further study.

4.1 PRIMARY PROCESSING OPTIONS

Preliminary to many of the secondary processing options is the reduction of the size and breakdown of the basic configuration of the tire. As stated in the system description (Section 2.2), this can be done in three size reduction options: mechanical, cryogenic, or combined.

4.1.1 Mechanical Size Reduction

The mechanical size reduction is a very basic operation. Each machine simply tears apart the tire in various ways. Hammermills beat the tire to pieces while the shearers cut the tire. A shearing type of action destroys the tire by a method which the tire is not built to resist. Three manufacturers offer shearing type machinery which, from currently available literature and private communications, will serve the purpose. They are the Garbalizer, manufactured by the Garbalizer Corporation of America; Model 5226, manufactured by Saturn Manufacturing, Inc.; and Holman Tire Particle-Izer, manufactured by Holman Industries, Inc.

The set-up, start-up, and operating procedures for all three of these machines are very similar and require less than two or three days for training. The major distinguishing feature is the mobility of the Saturn Model 5226 and the Holman Particle-Izer. Both of these units can be transported on a flat-bed trailer. The Garbalizer would require some disassembly for transportation.

We feel that the Holman Particle-Izer is the best mechanical size reduction unit available for treating tires. The previously mentioned features along with its large throughput (2000 tires/hr) and the output size (2 in. x 2 in. chunks) made it technically more feasible than the Saturn Model 5226. The best the Model 5226 can do is 300 tires/hr with strips ranging from 1-1/2 in x 3/4 in up to 1-1/2 in x 6-8 in.

4.1.2 Cryogenic Size Reduction

The basic principle of operation is very simple. The tires are frozen and then smashed. Set-up and start-up are not very complicated, however, the operating procedure would require some training, probably less than one week. The mobility of this unit has been established by both Bellaire Hydraulics, Inc. and Cryogenic Recycling International, Inc. However, Bellaire Hydraulics, Inc. is the only one who can send whole tires into the process. Cryogenic Recycling International, Inc., must halve the tires before processing, therein adding another piece of equipment. If a pretreatment such as this is needed a combined grinding process would be suggested instead.

There are several problems which exist in cryogenic size reduction. One of these is containment and delivery of liquid nitrogen. In a portable unit there could be an excessive use of space to hold enough liquid nitrogen for several days processing or until liquid nitrogen delivery could be made. Either one of these items, if not achieved properly, could cause shut down and delay of operation time.

A second possible problem area is in the tieup of personnel to travel with a portable unit. At least two operators, both trained in the unit operation, would be required to accompany the unit from place to place. According to the Occupational Safety and Health Act, the mechanical unit requires at least two operators. This could be implemented by only one man full-time transporting the unit and a general helper provided at each processing location.

Positive aspects of the cryogenic size reduction units are the very reusable products evolved. The product mix is easily classified using shaker screens and magnetic separa-

tors. The rubber crumb can then be sold or utilized and the fabric and metal can be sold as scrap. The size of the rubber crumb produced can be reused in filler industries, reclaim industries or for the Army's use in asphalt-rubber binders for road surfacing.

4.1.3 Combined Size Reduction

As indicated in Section 2.2.3, the combined size reduction process option is a combination of the mechanical and cryogenic size reduction units. By combining the processes, the good aspects of both are realized. A unit of this type can be completely mobile, completely stationary, or half and half. The completely mobile or complete stationary units have certain disadvantages:

1. A completely mobile unit would require at least a three-man operation, additional transportation costs due to more units to be transported, and the liquid nitrogen supply problem previously mentioned in Section 4.1.2.
2. A completely stationary unit would have a high transportation cost for the shipment of whole tires to the processing location.

The most promising size reduction unit employs a mobile mechanical shredder and a stationary cryogenic unit. With this plan there are many advantages to be realized which are not achievable with any other unit. They are the following:

1. If a group of installations had a central cryogenic unit, the mobile mechanical unit would chip the tires at the base, reducing their volume and shipping costs by approximately 80%, and then the chipped tires could be sent for processing at the cryogenic unit.
2. If an installation could landfill the chipped tires for less expense than transporting them to the central cryogenic unit, this could be done instead.
3. There would be no problem with liquid nitrogen supply since it is a permanent installation.
4. The central cryogenic unit would produce a crumb suitable for the Army's use in asphalt resurfacing or for sale to a market.
5. The entire unit can be purchased in sections. This means that a purchase of the mechanical shredder would immediately reduce the volume of tires, the purchase of cryogenic portion would be done when its feasibility is further verified.

6. The efficiency of a liquid nitrogen usage would be better since there is a higher surface area-to-volume ratio.
7. By organizing in the previously mentioned groups, the trained manpower requirements would be lower. On a continual operation basis, approximately 2-3/4 manyears per year might be required of which 1 manyear per year would be a trained operator. This would include operation of the mechanical shredder and cryogenic unit as well as the transportation of rubber chips to central unit.

4.2 SECONDARY PROCESSING OPTIONS

Several of the secondary processing options indicated in Figure 1, while technically feasible from an operational standpoint, are not feasible when reviewed with the Army's requirements. Those processing options that are not suitable are discussed in Section 4.2.1. The four secondary processing options viewed as suitable for the Army are presented in Section 4.2.2.

4.2.1 Non-Suitable Options

4.2.1.1 Whole Tire Reuse

Whole tire reuse in several cases does not offer the possibility for large volume usage. The interest of the Army in constructing breakwaters, artificial reefs, or crash cushion would be minimal. This is not a viable option even from the retreading standpoint since, as shown earlier, the Army is already at its maximum retread volume.

4.2.1.2 Pyrolysis and Hydrogenation

These two processing options would not be recommended for Army applications. Even though they are fairly well developed and substantiated and offer the possibility of a return on the investment, several negative aspects greatly outweigh the positive ones in the Army's case:

1. The operation procedures involve chemical plant-type operation. Even though the Army may have the skilled personnel to run this operation, it would seem unadvisable to use this personnel for duties involving disposal of tires.
2. Both processing options would involve extensive marketing of the products.

3. The units would not be mobile due to the extent of construction necessary for operation. This would also tie up personnel trained for plant operation.
4. Lack of centralized quantity of feed material to support continuous large operation.
5. Implementation delay in tire disposal: a minimum of 4 years should be expected before a unit of this complexity could be put into operation.

4.2.1.3 Filler Material and Miscellaneous Uses

Filler material and miscellaneous uses would not prove effective in the solution of the Army's problem for two reasons. The primary reason is that most of the processes proposed are in a limited stage of development. Even though at least two of the processes have been tried on a larger scale (leaky pipe and artificial grass), all of their operating parameters, including marketing and profit characteristics, have not been specifically defined. The second reason for not recommending this option stems from the idea proposed earlier concerning plant operation. To effectively and somewhat profitably pursue these established options many obstacles would have to be overcome, such as patent rights, manpower tieup, extensive marketing, etc.

4.2.2 Suitable Options

4.2.2.1 Incineration

Incineration is feasible only if the installation under consideration is capable of supporting it on a continuous basis. The incineration would best be done by using an inclined rotary kiln with refractory lining. The tires would be chipped and sent into the kiln along with other combustible wastes from the installation.

A specially designed rotating hearth furnace has the drawback of feed material. Unless an installation has a constant supply of tires, the efficiency of operation will be greatly lowered as a result of cool-down and refiring procedures.

4.2.2.2 Landfill

Landfill is an attractive alternative in any one of three instances: (1) when shipment to a cryogenic unit is impossible or exhorbitant, (2) when shipment to a market is

not feasible, or (3) when there is already a landfill being operated on site or near the installation.

4.2.2.3 Asphalt Substances

The use of rubber in asphalt resurfacing compounds could be very advantageous to the Army for the following reasons:

1. It would cut down on the maintenance required for roads, runways, and taxiways.
2. It could be easily implemented since resurfacing is already done.
3. It does not require any marketing capabilities since the use would be internal.
4. Equipment complexity is low.
5. Existing equipment would require little modification.

There are several disadvantages, however. They are:

1. If an outside contractor does the resurfacing work, he must be persuaded to modify his equipment to accommodate tires. If no agreeable contractor can be located, the Army would be required to do it themselves, which would involve a large expenditure of money and time.
2. The size of the rubber crumb used is critical, and it must not have steel or fabric in it. This requires a cryogenic or combined unit.
3. The behavior of and ideal mixes for asphalt-rubber binders has not been fully characterized for each climate and type of asphalt. This would indicate a certain amount of testing previous to full implementation.

4.2.2.4 By-Product Sale

There is the possibility of selling all products to markets if they are available locally. The steel and fabric produced can generally be sold to junk dealers in the area. Certain markets for the rubber crumb are developing, though none are dealing in large volumes currently.

4.3 PROPOSED PROCESSING ALTERNATIVES

A careful evaluation of the information presented in Sections 4.1 and 4.2 establishes four proposed process alternatives. These alternatives have been deemed environmentally sound

and technically feasible. However, an intensive regionalized approach evaluating the needs and supportive capabilities of each region in the United States must be conducted to establish the rank of the process alternatives according to their regional technical feasibility.

4.3.1 Incineration with Heat Recovery

This processing alternative comprises a mechanical shearer and a rotary inclined kiln with an appropriate heat recovery unit. The rotary hearth is not generally recommended since it requires whole tire feed and lacks the versatility of utilizing other plastic wastes.

This process alternative fits very nicely into the group of installation ideas mentioned previously. An incinerator could be located at the central location instead of or in addition to the central cryogenic unit. The chipped tires, after being processed by the portable mechanical chipper, would be sent to the incinerator or to the cryogenic unit depending upon the demand for their respective products.

An extensive analysis of the incinerator concept is found in reference 3. While that report considers a rather large facility, smaller units could be designed to handle whatever loads were needed.

4.3.2 Landfill

This processing alternative also fits well into the group of Army installations concept, since it involves a mobile mechanical shearer and a local landfill.

As mentioned in Section 2.3.2.1, tire substances can be landfilled if they are broken down. This may be very good for some installations that presently landfill a large percentage of their solid waste. The mobile shredder would come to the installation and shred the tires. This installation then would simply landfill the chips rather than shipping them elsewhere.

4.3.3 Asphalt Substances

This processing alternative, asphalt substances, requires the establishment of the "group of installations" concept, since one installation could not support the feed needed for this alternative to be efficient. The alternative is recommended, however, since its good aspects could result in considerable benefits to the overall Army if it were implemented in the manner proposed.

4.3.4 By-Product Sale

This processing alternative would be established in conjunction with the one mentioned in Section 4.3.3 above, or it could operate without its establishment. There is an emerging market for the rubber crumb for use in animal mattresses, battery cases, shock absorber pads, muffler and tailpipe hangers, etc. If all other alternatives fail, the rubber crumb could be sold to rubber reclaimers and the scrap steel and fabric to junk yards to recover part of the cost involved in processing. The scrap steel and fabric will be sold even if the rubber is utilized.

5. ECONOMIC ANALYSIS

In essentially every case the costs supplied by a manufacturer of size reduction systems are the actual equipment costs. The total capital investment required for the erection of a facility, however, is much more than simple equipment costs. It is the sum of installation, buildings, electrical, piping, etc., as well.[75]

Therefore, in an attempt to provide more accurate data concerning the actual investment required for the disposal of tires, certain assumptions and approximations have been made in the economic calculations. They are the following:

1. Installation costs are estimated to be 40% of the purchased equipment cost.[75]
2. Other direct costs are estimated to be 150% of the purchased equipment cost[75] and include the items listed below

Item	Percent
Piping	16
Buildings	68
Electrical	12
Yard Improvements	14
Service Facilities	40
Total	150

These direct costs will apply to only the stationary units.

3. The cost of any transportation vehicles for the portable units will be included in the purchased-equipment cost.
4. The indirect costs, including contingencies and other fees (e.g., contractor's fees), are estimated to be 20% of the total direct costs.[76]
5. The interest on the construction loan for stationary units will be 8% per year for one-half of the construction period. A standard construction period of 12 months will be assumed.[76]
6. The start-up expense will be estimated at 10% of the fixed capital investment.[76]

7. The working capital will be estimated at 11% of the fixed capital investment.[76]

8. Plant overhead costs will be estimated at 50% of the labor costs. These expenditures cover routine plant services.

9. Administrative costs will be estimated at 40% of the labor costs. These expenditures include the salaries and wages for administrators, secretaries, accountants, typists, etc., along with costs for office supplies and equipment, communications and administrative buildings.

The operating costs for the units will be calculated by the following assumptions:

1. The units will operate five days per week, eight hours per day and fifty-two weeks per year unless otherwise noted.

2. Portable units will assume a 25% operational downtime for transport and set-up. Labor charges will assume no downtime.

3. Transportation charges will be the actual fuel, oil, etc. needed to operate transport vehicles. A charge of $0.096[77] per mile for 300 miles will be used as a standard per transport and an average of 48 transports per year was assumed resulting in a cost of $1400/yr.

4. Plant overhead will be estimated to be 50% of the labor costs.[75]

5. Straight-line depreciation for the period of 10 years or 10% of the fixed capital investment per year is assumed.[78]

6. Taxes and insurance will be estimated to be 2% of the fixed capital investment.[76]

7. Administration will be 40% of the labor costs.[75]

8. The interest on the working capital will be 6% of the working capital.

9. Labor is $7.00 per manhour.

10. Electricity is $0.01/kwh.

11. Liquid nitrogen is $0.0275/lb except where referenced otherwise.

A final analysis of the scrap tire disposal system as presented in Figure 1 is in the area of economics. An analysis of each process was conducted with the economic data available. In each case an indication of the accuracy of the economic data will be indicated by a letter of the alphabet. The following is a key for the interpretation:

A - Adequate data of reasonable accuracy; accuracy estimated within ±15%
B - Partly estimated data of indeterminate accuracy; accuracy estimated up to ±25%
C - Totally estimated data of indeterminate accuracy estimated up to ±30%
D - Estimated costs based on previous economic experience; accuracy estimated over ±30%.

Section 5.1 will consider the cost of the various primary processing options. Section 5.2 will discuss the costs of the secondary processing options and Section 5.3 will indicate approximate costs for the four proposed process alternatives as identified in Section 4.3.

5.1 PRIMARY PROCESSING OPTIONS

5.1.1 Mechanical Size Reduction

To accurately assess the economics of the mechanical size reduction apparatus, a consideration of a specific piece of equipment in each category established in Section 2.2.1 is needed. In each category capital costs for every piece of equipment identified in Section 2.2.1 is presented. Operating cost approximations are presented where they were obtained from the vendor or could be estimated with a reasonable degree of accuracy. Installation costs for mechanical size reduction units are not included in the capital costs.

5.1.1.1 Tire Specific Size Reduction

The costs for these units vary depending upon the capacity and size of the unit. Listed below are the capital costs for tire-specific shredders, Table 7. These costs were obtained from private communications with the vendors.

Table 7 CAPITAL COSTS FOR TIRE-SPECIFIC SHREDDERS

Ascot Tire Cutter	$2,000-3,500	(B)
Branick	4,000	(B)
Shred-Pax AZ-7	5,000	(B)
Shred-Pax AZ-15	8,500	(B)
Shred-Pax AZ-20	19,000	(B)
Tire-Gon	30,000	(B)

The operating costs are given in the literature for the Tire-Gon shredder.[83] These costs have been calculated on a basis of 1974 economics at a rate of 1000 tires/day processed for 20 days per month or 1920 hours per year. Additional costs are presented on a proportional basis for 1560 operating hours per year (Table 8).

Table 8 OPERATING COSTS FOR TIRE-GON SHREDDER

	1920 hr/yr		1560 hr/yr	
Labor	$ 7,200/yr	(B)	$ 5,850/yr	(C)
Amortization	6,000/yr	(B)	6,000/yr	(C)
Maintenance	1,200/yr	(B)	975/yr	(C)
Power ($10/day)	2,400/yr	(B)	1,950/yr	(C)
Miscellaneous	960/yr	(B)	780/yr	(C)
Total	$17,760/yr	(B)	$15,555/yr	(C)
Unit Cost	$0.074/tire	(B)	$0.080/tire	(C)
Hourly Cost	$9.25/hr	(B)	$9.97/hr	(C)

Rough approximations of the operating costs for the remaining tire specific shredders have been made and are presented below (Table 9). They have been done on a proportional basis with costs of the Tire Gon unit.

Table 9 OPERATING COSTS FOR TIRE-SPECIFIC SHREDDERS*

Ascot Tire Cutter	$ 7,250/yr	$0.016/tire	$4.65/hr	(D)
Branick	7,850/yr	0.017/tire	5.03/hr	(D)
Shred-Pax AZ-7	9,650/yr	0.103/tire	6.19/hr	(D)
Shred-Pax AZ-15	10,000/yr	0.107/tire	6.41/hr	(D)
Shred-Pax AZ-20	11,650/yr	0.025/tire	7.47/hr	(D)
Tire-Gon	15,555/yr	0.080/tire	9.97/hr	(C)

*based on 1560 operating hours per year

5.1.1.2 Hammermills

Exact economics for the use of hammermills on tires are not readily available. This is primarily due to the small amount of work done in this area. Approximate capital costs for the Allis-Chalmers unit and the Hammermills, Inc. unit have been obtained from private communications with each company, and should serve as an indication of the cost of this type of equipment.

The Allis-Chalmers Model KA 12/18 will cost approximately $160,000. This includes all conveyors and other equipment needed for operation. Also included in this price is a trailer for mobility. Not included are the costs for a tractor and the necessary licensing.

The Hammermills, Inc., Model 6060 will cost approximately $175,000. The Model 6080 will cost approximately $200,000 (C). Feeders, conveyors and motors will cost an additional $150,000 (C). Magnetic separators could run from $10,000 to $50,000 (D) depending on the sophistication of the equipment. A complete package, therefore, would be estimated between $335,000 (D) and $373,000 (D) for a Model 6060, and between $360,000 (D) and $400,000 (D) for a Model 6080.

The operating cost for Model 6080 Hammermill is shown in Table 10. Some of the operating costs for this model have been determined by Hammermills, Inc. These costs are indicated by "B" accuracy. The remainder of the costs have been estimated and have a "D" accuracy. The Model 6080 is the most expensive of the hammermills and the estimate in Table 10 should thus indicate the upper limit of operating costs for this equipment.

5.1.1.3 Shredders

Capital costs for the shredders identified in Section 2.2.1.3 are listed below in Table 11.

Table 11 CAPITAL COSTS FOR SHREDDERS

Tire Gator	$75,000-90,000	(B)
Tire Hawg	52,500	(B)
Model 5226	35,000	(B)
Particle-Izer	250,000	(B)
Garbalizer Model 1	NA	

These costs, obtained from manufacturers' brochures, are the most recent figures available. To the best of our knowledge, the prices indicated include conveyors and related equipment.

Table 10 OPERATING COST FOR MODEL 6080 HAMMERMILL

Labor 2 men @ $7.00/hr	2080 hrs/yr (B)	29,120
Maintenance	(B)	3,700
Power (electric)	(B)	5,850
Transportation	(D)	1,400
Overhead	(D)	14,600
Depreciation	(D)	40,000
Taxes and insurance	(D)	8,100
Administration	(D)	11,600
Interest on working capital	(D)	2,600
Total operating cost	(D)	116,970/yr
Unit operating cost	(D)	0.043/tire
Hourly operating cost	(D)	56.24/hr

The operating costs for these machines depend highly on the material processed. For example, the operating costs for the Holman Particle-Izer will be calculated on the bases of 2000 passenger tires/hr and 1,200 truck tires/hr. These costs are presented in Table 12.

Table 12 OPERATING COST FOR THE HOLMAN PARTICLE-IZER

			Passenger Tires	Truck Tires
Labor 2 men @ $7.00/hr	2080 hr/yr	(D)	$29,120	$29,120
Maintenance		(D)	4,000	5,000
Power (electric)		(B)	5,300	11,400
Transportation		(D)	1,400	1,400
Overhead		(D)	14,600	14,600
Depreciation		(D)	37,000	37,000
Taxes and Insurance		(D)	7,400	7,400
Administration		(D)	11,600	11,600
Interest on working capital		(D)	2,400	2,400
Total operating cost		(D)	112,820	119,920
Unit operating cost		(D)	$0.036	$0.064
Hourly operating cost		(D)	$72.32	$76.87

Rough estimates for the other three shredders considered are presented below (Table 13).

Table 13 OPERATING COSTS FOR TIRE SHREDDERS

Tire Gator	71,420/yr	$0.275/tire	$34.34/hr	(D)
Tire Hawg	65,720/yr	0.079/tire	31.60/hr	(D)
Model 5226	63,520/yr	0.102/tire	20.54/hr	(D)
Particle-Izer	112,820/yr	0.036/tire	72.32/hr	(D)
Particle-Izer (truck tires)	119,920/yr	0.064/tire	76.87/hr	(D)

5.1.2 Cryogenic Size Reduction

The economic data presented by the three leading companies is fairly well substantiated. Each company has done some prototype work and researched the feasibility of a portable unit. The unit from Hazemag USA, Inc., has the disadvantage of being located in Germany. Using this unit in the United States would not be recommended; however, its application on the European continent is suggested for further investigation.

A summary of the cost for each process is shown in Table 14. The detailed calculation sheets are in Appendix A in Tables A-1 through A-8.

Table 14 SUMMARY OF COSTS FOR CRYOGENIC SIZE REDUCTION UNITS

Company	Style	Feed	Capital Costs-$		Annual Op. Costs-$		Unit Op. Costs		Accuracy Code
			Purchased Equipment	Total Investment	Direct	Total	$/Tire Processed	$/Operating Hour	
Hazemag USA, Inc.	Stationary Continuous	whole tires 600 tires/hr	852,200	3,704,790	321,800	762,790	0.611	366.73	B
	Portable Continuous	whole tires 50 tires/hr	165,700	336,800	57,490	128,720	1.65	82.51	C
Bellaire Hydraulics, Inc.	Stationary Continuous	whole tires 625 tires/hr	187,500	815,200	187,220	294,120	0.2286	142.37	A
	Portable Continuous	whole tires 625 tires/hr	no data available						
Cryogenic Recycling International Inc.	Portable Batch	half-tires 60 tires/hr	265,300	539,300	87,880	170,480	1.82	109.28	A

5.1.3 Combined Size Reduction

Only one company contacted gave economic data for this system concept. Cryogenic Recycling International, Inc., has now focused their work in this area. Table 15 summarizes their economic figures on three different processing styles. Tables A-9 through A-14 in Appendix A show the detailed calculations. These calculations do not include the chipper to prepare the tires for feeding into the unit. Reference is made to the Mechanical Size Reduction section (Section 5.1.2) for the various costs of mechanical shredders.

5.2 SECONDARY PROCESSING OPTIONS

Much of the economic data obtained for these options were very inaccurate or lacking in certain areas. Any assumptions which were made to calculate approximate figures are given with the calculation.

5.2.1 Whole Tire Reuse

A sample retread plant that could retread about 100 tires per day, both passenger and truck, will cost approximately $200,000 (C). Boiler capacity needed for operation of the equipment would be approximately 30 hp, while the compressor units for unit operation would need to be in the 250 psi range. This estimate includes all equipment needed; however, it does not include buildings and associated auxiliary services.[79]

The costs of construction of two proposed scrap tire crash cushions are shown in Table 16.[20] These costs assumed a zero cost for the tires. The costs involved for either of the two models are lower than the crash cushions presently approved by the FHWA.[80] This application is limited, however, until the FHWA gives its approval for their use.

The number of possible configurations for floating breakwaters are too numerous to present costs for each one. The variables encountered are number of tires, thickness, shore-to-sea dimension, and draft of the unit. The estimated cost to furnish and install:[21]

1. A single tire thickness modular breakwater which has a 30-foot shore-to-sea dimension and a 2-foot draft is $100.00 per linear foot (A).

Table 15 SUMMARY OF COSTS FOR COMBINED GRINDING CYCLE SIZE REDUCTION UNITS *

Company	Style	Feed	Capital Costs-$ Purchased Equipment	Capital Costs-$ Total Investment	Annual Op. Costs-$ Direct	Annual Op. Costs-$ Total	Unit Op. Costs $/Tire Processed	Unit Op. Costs $/Operating Hour	Accuracy Code
Cryogenic Recycling International Inc.	Portable Batch	chips 200 tires/hr	271,200	551,340	208,000	332,900	1.07	213.40	A
	Stationary Continuous	chips 286 tires/hr	280,000	1,217,200	329,700	479,200	.8063	230.38	A
	Portable Continuous	chips 286 tires/hr	285,200	579,800	255,400	342,300	.767	219.42	A

*Does not include pretreatment mechanical size reduction unit.

Table 16 SUMMARY OF APPROXIMATE COSTS OF SCRAP TIRE (60 mph, 4500 lb car) CRASH CUSHIONS

Cushion	Cost of Components-$	Modification of Existing Sites-$	Labor and Installation-$	Total Cost-$	Estimated Repair Costs for 60 mph, 4500 lb car, head-on: Cost of Components-$	Labor and Installation-$	Total Cost-$
Goodyear Crash Cushion	150	500 to 2,500	800	1,450 to 3,450	0	100	100
Modified Goodyear Crash Cushion	450	500 to 2,500	1,200	2,150 to 4,150	100	150	250

2. A double tire thickness modular breakwater which has a 30-foot shore-to-sea dimension and a 4-1/2-foot draft is $160.00 per linear foot (A).
3. A triple tire thickness modular breakwater which has a 30-foot shore-to-sea dimension and a 7-foot draft is $230.00 per linear foot (A).

Similar size mats with very little draft are less expensive, but probably less effective also. The estimated cost to furnish and install is:

1. A single tire thickness mat breakwater which has a 30-foot shore-to-sea diminsion and a 1/2-foot draft is $65.00 per linear foot (A).
2. A 5-tire thickness mat breakwater which has a 30-foot shore-to-sea dimension and a 2-foot draft is $95.00 per linear foot (A).

These costs include a zero cost for scrap tires.

The cost of building artificial reefs from tires is also highly dependent upon the configuration. Table 17 presents the costs for eight tire unit designs.[22] The major designs which build the largest reefs fall in the lower cost categories. These costs also include zero cost for the scrap tires.

5.2.2 Pyrolysis

Preliminary cost data for the TOSCO II process utilizing scrap rubber tires is available on a general basis. Exact information is still proprietary.[29] The testing was done on a 5-ton-per-day unit with a cost of approximately $30-40 per ton of tires processed (~$0.375-0.50 per tire). These costs include acquisition (purchase and collection), cracking of the tire, and the processing. The processing is estimated to be less than one-third of the overall costs, and the remaining two categories use the remaining cost. Assuming an overall cost of $40 per ton, the approximate breakdown in cost would be:

Acquisition	- $15/ton	(C)	($0.188/tire)
Shredding	- 12/ton	(C)	(0.150/tire)
Processing	- 13/ton	(C)	(0.163/tire)

Table 17 AVERAGE DOLLAR COSTS OF ARTIFICIAL TIRE REEFS FOR EIGHT UNIT DESIGNS[22]

Tire Unit	Material/ Tire*	Labor/ tire	Transportation/tire**	Total Cost	Remarks
12	0.49	0.75	2.90	4.14	Partial load of the test units accounts for high transportation costs. A full load would have reduced cost/tire about one-third.
Chain	-	-	-	-	Current cost for scrap chain is $40/ton. This amounts to a per tire cost of $0.64. We received an estimate of $1.00 per tire for labor and transportation.
Band-8	0.17	0.20	0.14	0.51	
Rod-8	0.16	0.20	0.14	0.50	
Single	0.07	0.19	0.08	0.34	
Band-4	0.07	0.25	0.10	0.42	
Rod-3	0.11	0.89	0.56	1.56	
Concrete-3	0.68	2.05	1.35	4.08	

*Figures based on a no-cost delivery of donated tires to a dockside staging area. Last two unit cost figures obtained from private and state-supported reef projects.

**Transportation for barging to a reef site. Costs figured on a charge of $700 per day for use of a two vessel. The concrete-3 estimate includes a large fraction for loading fees.

5.2.3 Incineration

According to Rigo, et al.,[3] the initial cost of an incinerator facility in 1972 was $553,200. This cost is before "contingencies and additives." The 1972 CE Plant Cost Index was 137.2 (1957-59 = 100).[81] The preliminary CE Plant Cost Index for September 1974 was 174.9. This gives a September 1974 cost for this incinerator of:

$$\$553,200 \left(\frac{174.9}{137.2}\right) = \$705,209$$

If 25% is added for "contingencies and additives" the cost of the installation becomes ~$881,500 (C).

Rigo also gives the annual operating cost as $159,580, including capital amortized over 20 years. This is designed to process 38,600 tons of mixed refuse per year. The operating costs would then be $4.13 per ton. A steam credit of approximately $87,000 per year could be realized bringing the operating cost down to $1.88 per ton.

It should be noted that this unit is an inclined rotary kiln designed for mixed refuse. The kiln is refractory lined and could process tires continually. The size of the unit would be smaller and the economics different with possibly a higher credit from steam if the feed was only tires.

5.2.4 Landfill

Sanitary landfill costs will also be considered with a mixture of refuse and ground rubber tires as were the incinerator costs. The initial or capital costs for a landfill vary greatly since a major portion of the initial investment is for the purchase of land and heavy equipment necessary for landfill operation.[82] For this reason, no general approximations of the capital cost may be made. The operating costs are made up of labor, equipment, expenses, cover material, administration, overhead, and other miscellaneous items. The percentage breakdown is as follows:[82]

Wages	40-50% of operating cost
Equipment Costs	30-40% " " "
Other	20% " " "

The operating cost of a small operation handling less than 50,000 tons of mixed refuse per year can range from $1.25 to approximately $5.00 per ton (Figure 28). This wide range is primarily due to the low efficiency of the small operations.

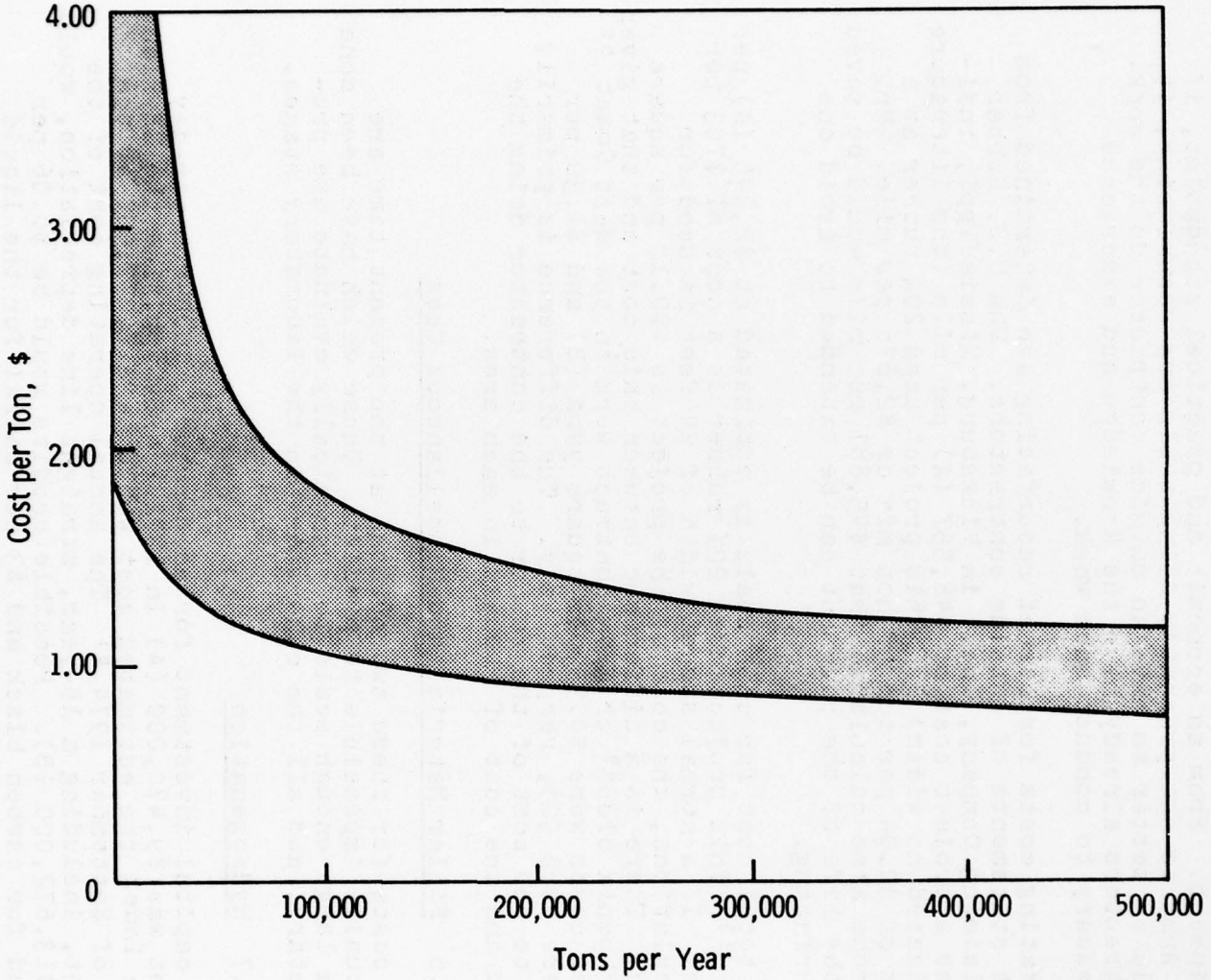


Figure 28 Cost of Landfill Operation[75]

5.2.5 Asphalt Substances

Asphalt-rubber resurfacing equipment costs approximately $52,250 (C). This cost includes the truck, distributor, distributor tank (approximately 1000 gallons), pumps, miscellaneous tools, and an air compressor and related equipment. From an economic and practical standpoint, if the Army is not presently doing their own resurfacing, it would be better to have an outside contractor do the work. Contractors already have the knowledge and experience necessary to conduct such work.

Operating costs for street resurfacing are determined from cost statements of outside contractors. The U.S. Rubber Reclaiming Company, Inc., in Vicksburg, Mississippi, indicates a project cost of $48,557 (A) per mile (the literature indicated no width).[53] This project used 20% rubber at a cost of $2.04 per ton of hot mix or $2,676 per mile. Mr. LaGrone also calculated that $45,881 per mile would be saved if the life of the pavement can be extended to avoid one resurfacing.

The total cost for chip seals is estimated at $2,495 (A) per mile.[53] This project used 20% rubber at a cost of $703 per mile. If a normal street width of 24 feet is used for calculations, the cost of the project is ~$0.18 per square yard. There is a difference between this cost and that given by Phoenix bids[49] or Navy contract work on the West Coast.[50] These costs were $0.93 per square yard (B) and $1.30 per square yard (C), respectively. The difference is primarily due to the cost of the rubber to the contractor doing the work and the cost of asphalt in each area.

5.2.6 Filler Material and Miscellaneous Uses

The costs for these two options at the present time are virtually impossible to predict. Those which have been done on a large enough scale to economically evaluate are proprietary, and all the others are in the laboratory stages.

5.2.7 Hydrogenation

The capital investment for an H-rubber, 1000-ton-per-day plant was $9,470,000 (A) in 1972.[67] By applying the CE Plant Cost Index the estimated cost would be $12,072,000 at the end of September 1974.[81] The annual operating cost of the plant, including a 15-year, straight line depreciation, would be $13,672,000 (B). Possible credits would be $0.06 per pound for carbon black and $3 per barrel for the liquid product. Table 18 summarizes the costs for the proposed plant.

Table 18 ECONOMIC SUMMARY FOR 1000 TPSD H-RUBBER PLANT

Plant Investment, $/Millions			
On-Site			8.429
Off-Site			1.041
			9.470
Working Capital			1.850
	Unit Prices	Annual $ Millions	$/Ton Rubber
Revenue			
Carbon	$0.06/lb	14.652	44.40
Naphtha	$3.00/Bbl	0.772	2.34
Gas Oil	$3.00/Bbl	2.611	7.91
Fuel Gas	$0.40/MMBTU	0.277	0.84
TOTAL REVENUE		18.312	55.49
Expenses			
Ground Rubber*	$30/Ton	9.900	30.00
Electricity	$0.008/KWH	0.167	0.51
Fuel Gas	$0.40/MMBTU	0.795	2.41
Cooling Water	$0.05/M Gal.	0.202	0.61
Boiler Feed Water	$0.10/M Gal.	0.002	0.01
Hydrogen	$0.50/MSCF	0.749	2.27
Operating & Management Payroll		0.284	0.86
Overhead (100% Payroll)		0.284	0.86
Maintenance at 4% On-Site Investment		0.337	1.02
Maintenance at 2% Off-Site Investment		0.021	0.06
Insurance & Taxes at 2% Total Investment		0.189	0.57
Interest on Working Capital at 6%		0.111	0.34
Depreciation, 15-year Straight Line		0.631	1.91
TOTAL EXPENSES		13.672	41.43
PROFIT BEFORE TAXES		4.640	14.06
PROFIT AFTER TAXES AT 48%		2.413	7.31
% RETURN ON INVESTMENT AS PROFIT		25.5	
PAYOUT, YEARS		3.92	

*Total Cost, including collection

5.2.8 By-Product Sale

Direct by-product sale is highly dependent upon local economic conditions. Presently accepted values for crumb rubber range from $0.05 to $0.10 per pound (B).[83] The steel in the tire could be worth between $15 and $20 per ton (C).[84] Other by-products produced in the other secondary processing options can be sold. For example, the residue from pyrolysis has a value only slightly under the market value for fresh carbon black.[38]

5.3 PROPOSED PROCESS ALTERNATIVES

5.3.1 Incineration with Heat Recovery

This process involves a mobile shredder and incinerator with waste heat recovery. The mobile shredder recommended for this application is the Saturn Model 5226 and the inclined rotary kiln incinerator would be similar to that indicated in Section 5.2.3 on page 91 . The capital cost for this type unit would be approximately $916,500 (C). The operating cost would be approximately $0.126 per tire (D). This number assumes that the mixed refuse feed to the incinerator is all tires (approximately 80 tires/ton). The operating cost also includes a steam credit of approximately $87,000/yr.

5.3.2 Landfill

This process involves a mobile mechanical shredder (Saturn Model 5226) as described above in Section 5.3.1 and a landfill operation. The shredder capital and operating costs would be $35,000 and $0.102/tire, respectively. The landfill costs cannot be determined on a general basis due to large local variations.

5.3.3 Asphalt Substances

This process involves a mobile shredder, a stationary cryogenic unit, and the asphalt costs. For this application the Holman Particle-Izer is suggested; however, the Saturn Model 5226 could be used. Lower throughput and higher unit operating costs will be realized with the Model 5226, but the capital expenditure will be lower. The capital and operating cost for a combined unit with the Particle-Izer is $1,467,000 and $0.842 per passenger tire or $0.084/lb of recovered rubber crumb (D). The capital and operating cost for a combined unit with the Model 5226 would be $1,252,200 and $0.908 per tire or $0.091/lb of recovered rubber crumb (D). The cost of the asphalt application would be highly variant and would depend on local conditions.

5.3.4 By-Product Sale

The costs incurred in this process alternative would be the same as indicated in Section 5.3.3 above without the asphalt costs. However, a credit of $0.05 to $0.10 per pound could possibly be realized. Using the maximum credit of $0.10 per pound and subtracting the minimum cost of $0.084 for processing, an overall credit maximum of $0.016 per pound of recovered rubber crumb would be realized.

5.4 ECONOMIC SUMMARY

Table 19 presents a brief summary of the economics that have been discussed in this section. This table should be used only for general reference. Anyone interested in the actual makeup of the economic data should consult the appropriate section in the text.

Table 19 ECONOMIC SUMMARY

Processing Option	Process	Capacity tires/hr	Capital $	Operating $/tire
Mechanical Size Reduction	Tire Specific			
	Ascot	300	3,000*	0.016
	Branick	300	4,000*	0.017
	Shred-Pax AZ-7	60	5,000*	0.103
	" " AZ-15	60	8,500*	0.107
	" " AZ-20	300	19,000*	0.025
	Tire-Gon	125	30,000*	0.074
	Hammermill	1,300	335,000* 400,000*	0.043
	Shredders			
	Tire Gator	1,000	83,000*	0.275
	Tire Hawg	400	52,500*	0.079
	Saturn 522G	300	35,000*	0.102
	Particle-Izer	2,000	250,000*	0.050
	Garbalizer	10,000		
Cryogenic Size Reduction	Hazemag-Cont.			
	Stationary	600	4.5×10^6	0.673
	Portable	50	332,300	1.65
	Bellaire-Cont.			
	Stationary	625	0.82×10^6	0.228
	Portable	625		
	Cryogenic Recycling-Batch			
	Portable	60	539,300	1.82
Combined Size Reduction (Does not include cost of mechanical size reduction unit-see above)	Cryogenic Recycling-Batch			
	Portable	200	551,340	1.07
	Continuous			
	Stationary	286	1.2×10^6	0.806
	Portable	286	579,800	0.767

Table 19 ECONOMIC SUMMARY (Continued)

Processing Option	Process	Capacity tires/hr	Capital* $	Operating $/tire
Whole Tire Reuse	Retread	12	200,000	
	Crash Cushions			
	Goodyear		2,450	
	Mod. Goodyear		3,150	
	Breakwaters		65-160/linear ft.	
	Artificial Reefs		0.34-5.63/tire	
Pyrolysis				
	Tosco	50		0.375 0.50
Incineration				
	Inclined Rotary Kiln		881,500	0.024
Landfill				0.016-0.063
Asphalt Substances	Consult Text			
Filler Material	Consult Text			
Miscellaneous Uses	Consult Text			
Hydrogenation				
	H-Rubber	1000 ton per day	12×10^6	13.7×10^6
		Possibility for Credits		
By-Products	Consult Text			

*Capital costs are totaled capital investment except where indicated by an asterisk.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

1. The actual magnitude of the scrap tire disposal problem in the Army alone is relatively small and concentrated in certain areas of the country (refer to Table D-1 pages 139 and 140 and Figure 2, page 16).

2. There is sufficient technology currently available to dispose of all the scrap tires generated by the Army. At least 30 possible tire disposal alternatives have been identified (see Figure 1, page 13). Any of these scrap tire disposal alternatives will improve the environment. However, there are only four combinations of process options which are both technically and environmentally feasible for the Army. These four alternatives are:

   a. Mechanical shearing followed by incineration

   b. Landfill after mechanical shearing

   c. Use in asphalt substances after the combined size reduction process (mechanical shredding followed by cryogenic shredding)

   d. Selling the by-products of the combined size reduction processes

3. The most important factor affecting the final choice among the four proposed disposal alternatives above is economics which is also a function of each installation's location. Results of the economic evaluations, not reflecting local economics, are summarized in Table 19, pages 102 and 103.

4. The use of scrap rubber tires in producing salable products is one of the best solutions to the tire problem from an ecological viewpoint. Such solutions not only rid the environment of the tires but also create usable products, e.g. steam, chemicals or road dressings.

5. Incineration of ground scrap rubber tires with heat recovery is a feasible tire disposal alternative if a sufficient supply of scrap tires is available. An inclined rotary kiln with refractory lining is recommended for scrap rubber tire incineration.

6. Landfill of whole tires is unacceptable due to their tendency to float and reappear on the surface, however, ground rubber scrap can be properly landfilled.

7. The most feasible method of tire size reduction and classification prior to secondary processing (excluding the whole tire, pyrolysis, incineration, and landfill options) is a combined system employing a mechanical shredder followed by a cryogenic unit to separate the steel and fabric from the rubber particles and producing completely recyclable materials. The method offers the following advantages:

   a. The mobile mechanical unit would chip the tires at the individual installations, thus reducing their volume by approximately 80%. The chipped tires could then be shipped to a central cryogenic unit for processing. Improved efficiency of liquid nitrogen usage could be realized since in using chipped tires there is a higher surface area to volume ratio.

   b. Where feasible, some of the chipped tires could be used as landfill.

   c. Since the installation of a central cryogenic unit would be permanent, a more economical and efficient cryogenic supply system could be provided.

   d. The entire size reduction unit may be purchased in sections. This means that acquisition of the mechanical shredder would immediately reduce the volume of tires; the purchase of the cryogenic portion would be done when its feasibility is further verified.

   e. The trained manpower requirements would be lower for a combined system. On a continual operation basis a combined system would require 1 man-year per year of trained operation. A mobile cryogenic unit would require at least 2 trained man-years per year.

8. Cryogenic size reduction produces reusable products. The product mix is easily classified to rubber crumb, fabric, and metal. The rubber crumb is suitable for the filler industries, reclaim industries or asphalt-rubber road dressings. The fabric and metal can be sold as scrap.

9. According to the Monsanto Research Corporation the Holman Particle-Izer appears to be the best mechanical size reduction unit available for treating tires. It is mobile and can reduce 2000 tires/hr into 2 in. square rubber chunks.

10. Hydrogenation and pyrolysis of scrap tires produce various hydrocarbons and char. However, neither of the processes are feasible for the Army because they require skilled personnel, marketing of products, permanent facilities, and a large centralized scrap tire feed. Furthermore, it would take at least 4 years before a plant of this kind could be put in operation.

11. Vehicle crash attenuators constructed of whole scrap rubber tires have excellent energy dissipation characteristics. As such, they exceed federal standards for vehicle deceleration and offer an alternative for scrap tire utilization. Whole scrap tires can be used for breakwaters and installations on coastlines which need protection from waves. However, both of these methods can use only a limited number of tires.

12. The Army is already retreading at the greatest retread rate.

13. The use of ground rubber in asphalt road resurfacing is a viable method for scrap rubber tire utilization. It offers the following advantages and disadvantages to the Army:

    a. Reduced maintenance costs for roads, runways and taxiways.

    b. Easy implementation since road resurfacing is already performed.

    c. No marketing capabilities are required.

    d. The equipment is not complex and little modification of existing equipment is required.

e. If the road resurfacing is performed by an outside contractor, he must be persuaded to modify his equipment to accommodate scrap rubber.

f. The size of the rubber crumb used is critical and must not contain steel or fabric. This requires the use of a cryogenic or combined tire size reduction unit.

g. The ideal mixes for asphalt-rubber binders have not been fully characterized for each climate and type of asphalt. This would necessitate a certain amount of testing previous to full implementation.

h. The entire Army may benefit if this alternative is designed to combine the entire wastes from a group of Army installations.

14. The Monsanto Research Corporation does not recommend the use of the Hazemag, Inc. cryogenic size reduction unit in the United States because the high transportation costs would make this unit more expensive than cryogenic units built in the United States. It is suggested that the use of this unit in Europe be investigated further.

6.2 RECOMMENDATIONS

It is recommended that:

1. The present cost for the disposal of scrap rubber tires be thoroughly analyzed and compared with the costs of the four tire disposal alternatives suggested in Sections 4.3 and 5.3.

2. These four disposal alternatives be evaluated further on a regionalized basis.

3. Each installation in the region be investigated to determine the best diposal alternative for that installation or group of installations.

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APPENDIX A

ECONOMIC CALCULATIONS FOR CRYOGENIC SIZE REDUCTION EQUIPMENT

Table A-1. TOTAL CAPITAL INVESTMENT
FOR BELLAIRE HYDRAULICS, INC., CRYOGENIC SYSTEM, STATIONARY

Capacity - 625 tires/hr

	$	Note No.
Direct Costs		
Purchased equipment cost = P.E.C. =	187,500	1
Installation costs		
I.C. = 40% of purchased equipment costs =	75,000	
Total	262,500	
Other direct costs (stationary plants only) 150% of purchased equipment costs =	281,250	
Total direct costs	543,750	
Indirect Costs		
20% of total direct costs =	108,750	
Fixed capital investment (direct costs + indirect costs) =	652,500	
Interest on construction loan 8%/yr - 6 month	25,600	
Start-up expense = 10% of F.C.I.	65,300	
Working capital = 11% of F.C.I.	71,800	
Total capital investment	815,200	

Table A-2. OPERATING COSTS FOR
BELLAIRE HYDRAULICS, INC., CRYOGENIC SYSTEM, STATIONARY

Capacity - 625 tires/hr
Operating basis - Equipment 2080 hr/yr
Labor 2080 hr/yr

	$/yr	Note No.
Direct Costs		
Materials		
Raw	-	
Operating	145,100	1
Maintenance	-	2
Labor - 2 men @ $7.00/hr	29,120	
Power and utilities (process operation only)	13,000	1
Transportation of unit (portable unit only)	-	
Total direct operating costs	187,220	
Indirect Costs		
Plant overhead = 50% of labor	14,600	
Depreciation = 10% of F.C.I.	65,300	
Taxes and insurance = 2% of F.C.I.	13,100	
Total indirect operating costs	93,000	
General		
Administration = 40% of labor	11,600	
Interest on working capital 6% of working capital	4,300	
Total general operating costs	15,900	
Total annual operating costs - $/yr	296,120	
Total unit operating costs = $/tire	0.2278	
Total hour operating costs - $/operating hr	142.37	

Table A-3 TOTAL CAPITAL INVESTMENT
FOR HAZEMAG USA, INC., CRYOGENIC UNIT, STATIONARY

Capacity - 600 tires/hr

	$	Note No.
Direct Costs		
Purchased equipment cost = P.E.C. =	852,200	3
Installation costs I.C. = 40% of purchased equipment costs	340,880*	
Total	1,193,080	
Other direct costs (stationary plants only) 150% of purchased equipment costs =	1,278,300*	
Total direct costs	2,471,380	
Indirect Costs		
20% of total direct costs =	494,280	
Fixed capital investment (direct costs + indirect costs) =	2,965,660	
Interest on construction loan 8%/yr - 6 month	116,340	
Start-up expense = 10% of F.C.I.	296,570	
Working capital = 11% of F.C.I.	326,220	
Total capital investment	3,704,790	

*The installations costs and other direct costs presented here are within ±15% of the estimates given by the manufacturers.

Hazemag USA estimated total direct cost $2,240,200
(including all the items used in our estimates)
Our estimate total direct cost $2,471,380
(based upon assumptions previously indicated)

Table A-4 OPERATING COSTS FOR
HAZEMAG USA, INC., CRYOGENIC UNIT, STATIONARY

Capacity - 600 tires/hr
Operating basis - Equipment 2080 hr/yr
Labor 2080 hr/yr

	$/yr	Note No.
Direct Costs		
Materials		
Raw	-	
Operating	224,000	4
Maintenance	15,000	5
Labor - 5 men @ $7.00/hr	72,800	
Power and utilities (process operation only)	10,000	
Transportation of unit (portable unit only)	-	
Total direct operating costs	321,800	
Indirect Costs		
Plant overhead = 50% of labor	36,400	
Depreciation = 10% of F.C.I.	296,600	
Taxes and insurance = 2% of F.C.I.	59,300	
Total indirect operating costs	392,300	
General		
Administration = 40% of labor	29,120	
Interest on working capital 6% of working capital	19,570	
Total general operating costs	48,690	
Total annual operating costs - $/yr	762,790	
Total unit operating costs - $/tire	0.611	
Total hour operating costs - $/operating hr	366.73	

Table A-5 TOTAL CAPITAL INVESTMENT
FOR HAZEMAG, USA, INC., CRYOGENIC UNIT, PORTABLE

Capacity - 50 tires/hr

	$	Note No.
Direct Costs		
Purchased equipment cost = P.E.C. =	165,700	6
Installation costs		
I.C. = 40% of purchased equipment costs	66,280	
Total	231,980	
Other direct costs (stationary plants only)		
150% of purchased equipment costs	-	
Total direct costs	231,980	
Indirect Costs		
20% of total direct costs =	46,400	
Fixed capital investment (direct costs + indirect costs) =	278,380	
Interest on construction loan 8%/yr - 6 month	-	
Start-up expense = 10% of F.C.I.	27,800	
Working capital = 11% of F.C.I.	30,620	
Total capital investment	336,800	

Table A-6 OPERATING COSTS FOR
HAZEMAG USA, INC., CRYOGENIC UNIT, PORTABLE

Capacity - 50 tires/hr
Operating basis - Equipment 1560 hr/yr (operating hours)
Labor 2080 hr/yr

	$/yr	Note No.
Direct Costs		
Materials		
Raw	-	
Operating - liquid nitrogen	14,000	7
Maintenance	1,250	7
Labor - 3 men @ $7.00/hr	40,040	8
Power and utilities (process operation only)	800	7
Transportation of unit (portable unit only)	1,400	
Total direct operating costs	57,490	
Indirect Costs		
Plant overhead = 50% of labor	20,020	
Depreciation = 10% of F.C.I.	27,800	
Taxes and insurance = 2% of F.C.I.	5,570	
Total indirect operating costs	53,390	
General		
Administration = 40% of labor	16,000	
Interest on working capital 6% of working capital	1,840	
Total general operating costs	17,840	
Total annual operating costs - $/yr	128,720	
Total unit operating costs - $/tire	1.65	
Total hour operating costs - $/operating hr	82.51	

Table A-7 TOTAL CAPITAL INVESTMENT
FOR CRI-CRYOGENIC UNIT-PORTABLE-IMMERSION-HALF TIRE-BATCH

Capacity - 60 tires/hr

	$	Note No.
Direct Costs		
Purchased equipment cost = P.E.C =	265,300	
Installation costs I.C. = 40% of purchased equipment costs	106,100	
Total	371,400	
Other direct costs (stationary plants only) 150% of purchased equipment costs	-	
Total direct costs	371,400	
Indirect Costs		
20% of total direct costs =	74,300	
Fixed capital investment (direct costs + indirect costs) =	445,700	
Interest on construction loan 8%/yr - 6 month	-	
Start-up expense = 10% of F.C.I.	44,600	
Working capital = 11% of F.C.I.	49,000	
Total capital investment	539,300	

Table A-8 OPERATING COSTS FOR
CRI-CRYOGENIC UNIT-PORTABLE-IMMERSION-HALF TIRE-BATCH

Capacity - 60 tires/hr
Operating basis - Equipment 1560 hr/yr
Labor 2080 hr/hr

	$/yr	Note No.
Direct Costs		
Materials		
Raw	-	
Operating - liquid nitrogen	51,480	10
Maintenance	300	10
Labor - 2 men @ $7.00/hr	29,100	10
Power and utilities (process operation only)	5,600	10
Transportation of unit (portable unit only)	1,400	
Total direct operating costs	87,880	
Indirect Costs		
Plant overhead = 50% of labor	14,600	
Depreciation = 10% of F.C.I.	44,600	
Taxes and insurance = 2% of F.C.I.	8,900	
Total indirect operating costs	68,100	
General		
Administration = 40% of labor	11,600	
Interest on working capital 6% of working capital	2,900	
Total general operating costs	14,500	
Total annual operating costs - $/yr	170,480	
Total unit operating costs - $/tire	1.82	
Total hour operating costs - $/operating hr	109.28	

Table A-9 TOTAL CAPITAL INVESTMENT
FOR CRI-COMBINED CYCLE-PORTABLE-IMMERSION CHIP-BATCH

Capacity - 200 tires/hr

	$	Note No.
Direct Costs		
Purchased equipment cost = P.E.C. =	271,200	9
Installation costs I.C. = 40% of purchased equipment costs	108,500	
Total	379,700	
Other direct costs (stationary plants only) 150% of purchased equipment costs	-	
Total direct costs	379,700	
Indirect Costs		
20% of total direct costs =	75,940	
Fixed capital investment (direct costs + indirect costs) =	455,640	
Interest on construction loan 8%/yr - 6 month	-	
Start-up expense = 10% of F.C.I.	45,600	
Working capital = 11% of F.C.I.	50,100	
Total capital investment	551,340	

Table A-10 OPERATING COSTS FOR
CRI-COMBINED CYCLE-PORTABLE-IMMERSION CHIP-BATCH

Capacity - 200 tires/hr
Operating basis - equipment 1560 hr/yr
Labor 2080 hr/yr

	$/yr	Note No.
Direct Cost		
Materials		
Raw	-	
Operating - liquid nitrogen	171,600	10
Maintenance	300	10
Labor - 2 men @ $7.00/hr	29,100	10
Power and utilities (process operation only)	5,600	10
Transportation of unit (portable unit only)	1,400	10
Total direct operating costs	208,000	
Indirect Cost		
Plant overhead = 50% of labor	14,600	
Depreciation = 10% of F.C.I.	45,600	
Taxes and insurance = 2% of F.C.I.	50,100	
Total indirect operating costs	110,300	
General		
Administration = 40% of labor	11,600	
Interest on working capital 6% of working capital	3,000	
Total general operating costs	14,600	
Total annual operating costs - $/yr	332,900	
Total unit operating costs - $/tire	1.07	
Total hour operating costs - $/operating hr	213.40	

Table A-11 TOTAL CAPITAL INVESTMENT
FOR CRI - COMBINED CYCLE - STATIONARY

Capacity - 286 tires/hr

	$	Note No.
Direct Costs		
Purchased equipment cost = P.E.C. =	280,000	9
Installation costs I.C. = 40% of purchased equipment costs	112,000	
Total	392,000	
Other direct costs (stationary plants only) 150% of purchased equipment costs	420,000	
Total direct costs	812,000	
Indirect Costs		
20% of total direct costs =	162,400	
Fixed capital investment (direct costs + indirect costs) =	974,400	
Interest on construction loan 8%/yr - 6 month	38,200	
Start-up expense = 10% of F.C.I.	97,400	
Working capital = 11% of F.C.I.	107,200	
Total capital investment	1,217,200	

Table A-12 OPERATING COSTS FOR
CRI - COMBINED CYCLE - STATIONARY

Capacity - 286 tires/hr
Operating basis - Equipment 2080 hr/yr
Labor 2080 hr/hr

	$/yr	Note No.
Direct Costs		
Materials		
Raw	-	
Operating - liquid nitrogen	292,900	10
Maintenance	400	10
Labor - 2 men @ $7.00/hr	29,100	11
Power and utilities (process operation only)	7,300	10
Transportation of unit (portable unit only)	-	
Total direct operating costs	329,700	
Indirect Costs		
Plant overhead = 50% of labor	14,600	
Depreciation = 10% of F.C.I.	97,400	
Taxes and insurance = 2% of F.C.I.	19,500	
Total indirect operating costs	131,500	
General		
Administration = 40% of labor	11,600	
Interest on working capital 6% of working capital	6,400	
Total general operating costs	18,000	
Total annual operating costs - $/yr	479,200	
Total unit operating costs - $/tire	0.8055	
Total hour operating costs - $/operating hr	230.38	

Table A-13 TOTAL CAPITAL INVESTMENT
FOR CRI - COMBINED CYCLE - PORTABLE SPRAY

Capacity - 280 tires/hr

	$	Note No.
Direct Costs		
Purchased equipment cost = P.E.C. =	285,200	9
Installation costs I.C. = 40% of purchased equipment costs	114,100	
Total	399,300	
Other direct costs (stationary plants only) 150% of purchased equipment costs	-	
Total direct costs	399,300	
Indirect Costs		
20% of total direct costs =	79,900	
Fixed capital investment (direct costs + indirect costs) =	479,200	
Interest on construction loan 8%/yr - 6 month	-	
Start-up expense = 10% of F.C.I.	47,900	
Working capital = 11% of F.C.I.	52,700	
Total capital investment	579,800	

Table A-14 OPERATING COSTS FOR
CRI - COMBINED CYCLE - PORTABLE SPRAY

Capacity - 286 tires/hr
Operating basis - Equipment 1560 hr/hr
Labor 2080 hr/yr

	$/yr	Note No.
Direct Costs		
Materials		
Raw	-	
Operating - liquid nitrogen	219,600	10
Maintenance	250	10
Labor - 2 men @ $7.00/hr	29,100	10
Power and utilities (process operation only)	5,050	10
Transportation of unit (portable unit only)	1,400	10
Total direct operating costs	255,400	
Indirect Costs		
Plant overhead = 50% of labor	14,600	
Depreciation = 10% of F.C.I.	47,900	
Taxes and insurance = 2% of F.C.I.	9.600	
Total indirect operating costs	72,100	
General		
Administration = 40% of labor	11,600	
Interest on working capital 6% of working capital	3,200	
Total general operating costs	14,800	
Total annual operating costs - $/yr	342,300	
Total unit operating costs - $/tire	0.7672	
Total hour operating costs - $/operating hr	219.42	

NOTES FOR ECONOMIC CALCULATIONS

1. Private communication with Vernon C. H. Richardson, Belaire Hydraulics, Inc., Belaire, Texas, November 1974.

2. No extraordinary maintenance needed. Basic lubrication is all that is necessary

3. Private communication with J. J. McGlone, Hazemag USA, Inc., Uniontown, Pennsylvania, August 1974. This cost is derived from the Deutschmark cost given in their literature. A conversion of 0.65 x DM's was suggested to give U.S. costs in dollars including freight, duty, handling, etc. To approximate the dollar cost in Germany, multiply the costs given in the table by 0.615.[8] To convert Deutschmarks to dollars not including freight, etc., multiply by $0.40.[8]

4. Assume a nitrogen plant is located within 50 miles of the cryogenic shredding plant.

$$\left(\frac{2200 \text{ liter } N_2}{\text{hr}}\right) \times \left(\frac{2080 \text{ hr}}{\text{yr}}\right) \times \left(\frac{0.03532 \text{ ft}^3}{\text{liter}}\right) \times \left(\frac{50.4 \text{ lb}}{\text{ft}^3}\right) \times \left(\frac{\$0.0275}{\text{lb}}\right) = \$224,000$$

5. See note 3 above which gives references for figures

$$\left(\frac{30 \text{ DM}}{1000 \text{ tires}}\right) \times \left(\frac{\$0.40}{\text{DM}}\right) \times \left(\frac{600 \text{ tires}}{\text{hr}}\right) \times \left(\frac{2080 \text{ hr}}{\text{yr}}\right) = \$14,976$$

6. Total equipment cost includes unit cost determined by six-tenths rule using exponent of 0.7 and trailer cost; from private communication with J. W. Jacobs, Hogan Transportation Equipment, Inc., Dayton, Ohio, July 1974.

Unit cost	$149,700
2 - low boy trailers	16,000
	$165,700

7. Scaled down quantities for portable unit. Assume linear relationship and multiply stationary unit by $\frac{50}{600} = 0.083$.

8. The labor charges for this unit include two operators traveling with the unit charging 2080 hours per year and one man supplied at the point of operation charging 1560 hours per year.

9. Purchased equipment costs were obtained from R. Kisielewski, Cryogenics Recycling International, Inc., LaCrosse, Wisconsin. The costs indicated include all equipment for operation and transport (in the case of the portable unit) except the tractor for pulling the freezing tunnel trailer and the initial chipper.

	Stationary (Spray)	Portable (Spray)	Portable (Immersion) Chip	Portable (Immersion) Half-Tire
Cryogenic unit	$238,000	$243,200	$225,000	$225,000
*Classification System	30,000	30,000	30,000	30,000
*Liquid Nitrogen Storage Vessel (operating time)	12,000 (40 hr)	12,000 (40 hr)	16,200 (24 hr)	10,300 (40 hr)
Total	280,000	285,200	271,200	265,300

*Costs only approximated

10. Private communication with R. Kisielewski (see Note 9 above).

11. One operator and one general laborer designated by manufacturer. For Army personnel 2 equally trained operators were assumed.

APPENDIX B

SCRAP TIRE QUESTIONNAIRE

SCRAP TIRE
QUESTIONNAIRE

The purpose of this study is to evaluate the extent of the tire disposal problem at U.S. military installations. The study is not intended to include tires that are new or that can be retreaded or reused, only scrap tires should be considered. Please make your best estimate in case you do not have accurate information (some information is better than none).

1. Name of this location _____

2. What is the present means of disposal of scrap tires at this location:
(Check method. If more than one method, give approximate percentages of each method)

_____ Landfill
_____ Burn
_____ Sell to other party
_____ Pile up and save
_____ Other (describe) _____
_____ None

3. How many scrap tires, other than aircraft tires, are presently stockpiled? _____

4. Of the total number mentioned in question 2 above, how many are in each size range? (number or percent of total - please indicate)

Diameter less than 53½" _____
Diameter between 53½" and 64" _____
Diameter between 64" and 74½" _____
Diameter larger than 74½" _____

5. What percentage of the total mentioned in question 2 above are steel belted tires? _____

6. How many scrap aircraft tires are presently stockpiled?
_____

7. How many scrap tires, other than aircraft tires, are added to the stockpile each month? _____

Scrap Tire Questionnaire

8. Of the total number mentioned in question 6 above, how many are in each size range? (number or percent please indicate)

   Diameter less than 53½" _____
   Diameter between 53½" and 64" _____
   Diameter between 64" and 74½" _____
   Diameter larger than 74½" _____

9. What percentage of the total mentioned in question 6 above are steel belted tires? _____

10. How many scrap aircraft tires are added to the stockpile each month? _____

11. Assuming that a mobile tire disposal unit is designed, what type of access would be most practical at your location? (trailer weight loaded 55,000 lb, length 39.5 ft, width 7.5 ft)

    Railroad spur _____
    Highway system _____
    Other (explain) _____

Questionnaire Answered by: _____

Title: _____

APPENDIX C

SHREDDING EQUIPMENT VENDORS QUESTIONNAIRE

QUESTIONNAIRE

DISPOSAL OF SCRAP TIRES

1. Are tires used regularly and what types of other materials can be processed in your shredding equipment?

2. What size reduction technique is utilized in your shredder (hammermill, grinder, etc)?

3. How does the shredder power requirement vary with throughput, 1, 5, 10 tons of tires per hour?
   With product size (e.g. 3", 1", 1/4")?

4. What types of power sources can be used for this unit (diesel, electricity)?

5. What auxiliary equipment is supplied with the shredder and what is its power requirement?

6. What are the manpower requirements for this shredder and the auxiliary equipment?

7. What type and how much training must an operator have before using this equipment?

8. How is the shredder feed material handled or pretreated?

9. What are the limits on feed material size?

10. What is the product from the shredder and what are its characteristics? (e.g. size)
    Can the product characteristics (e.g. size) be controlled and how?

11. What type of maintenance does your unit require (blade life, etc)?

12. How versatile would the unit be for handling other materials - lumber, polyethylene film, plastic furniture, tank track pads, copper or steel wire, etc?

13. Are any raw materials required to operate this equipment?

14. What type of additional equipment is necessary to handle processed material (packaging, bailing, incineration, etc)?

15. Is your unit portable and can it be mounted on a 40' trailer or railroad flat-car?

16. What types of problems do you foresee in applying your shredder to the disposal of tires? Include the R&D efforts required, if any, which would be necessary before using your equipment on discarded tires.

17. What is the cost of the shredder unit to process 1, 5, 10 tons of tires/hour? (Assume 90% of tires processed are mounted on rims).

18. What is the cost of the necessary auxiliary equipment to handle the same throughput?

APPENDIX D

TABULATED SURVEY RESULTS

Table D-1 SCRAP TIRE DISPOSAL QUESTIONNAIRE RESULTS

	ARMY				AIR FORCE				MARINES				NAVAL & COAST GUARD			
	U.S.	Europe	Asia	Other	U.S.	Europe	Asia	Other	U.S.	Europe	Asia	Other	U.S.	Europe	Asia	Other
Present Disposal Methods - Avg.%																
Landfill	16.57	0	0	1.67	3.54	0	0	-	18.67	-	-	-	4.0	-	-	-
Burning	0	0	0	0	0	0	0	-	0	-	-	-	0	-	-	-
Selling	70.23	25.00	98.75	53.33	77.95	100.0	100.0	-	81.33	-	-	-	70.5	-	-	-
Stockpile	0.63	66.67	0	45.0	6.48	0	0	-	0	-	-	-	0	-	-	-
Other	12.57	1.0	1.25	0	5.03	0	0	-	0	-	-	-	25.5	-	-	-
None	0	7.33	0	0	0	0	0	-	0	-	-	-	0	-	-	-
TOTAL	100.00	100.00	100.00	100.00	100.00	100.0	100.0	-	100.00	-	-	-	100.0	-	-	-
Tires for Disposal - No. other than Aircraft	124,012	160,920	11,892	3,965	21,540	530	473	-	7,122	-	-	-	4,800	-	-	-
Aircraft	13,297	920	4,346	279	22,844	552	61	-	7,990	-	-	-	1,634	-	-	-
Size of Tires for Disposal - No. other than Aircraft																
x<53½"	110,880	101,944	9,269	3,934	19,019	338	409	-	7,100	-	-	-	4,403	-	-	-
53½"<x<64"	7,841	36,360	385	16	684	162	32	-	7	-	-	-	112	-	-	-
64"<x<74½"	4,089	16,880	2,202	11	646	30	16	-	13	-	-	-	146	-	-	-
74½"<x	1,202	5,736	36	4	1,191	0	16	-	2	-	-	-	139	-	-	-
Aircraft																
x<53½	11,256	845	4,081	270	18,852	552	47	-	7,990	-	-	-	1,487	-	-	-
53½"<x<64"	1,516	[illegible]	265	9	3,393	0	14	-	0	-	-	-	105	-	-	-
64"<x<74½"	319	[illegible]	0	[illegible]	286	0	0	-	0	-	-	-	32	-	-	-
74½"<x	206	[illegible]	0	0	313	0	0	-	0	-	-	-	10	-	-	-
Percent Steel Belted-% other than Aircraft	0.44	[illegible]	0.83	[illegible]	0.43	[illegible]	0	-	0.17	-	-	-	5.5	-	-	-
Aircraft	2.70	[illegible]	0.35	[illegible]	0.45	[illegible]	0	-	0.17	-	-	-	2.8	-	-	-
Rate of Increase - Tires/Mo. other than Aircraft	10,146	5,48[illegible]	2,[illegible]	[illegible]	3,369	400	960	-	467	-	-	-	1,351	-	-	-
Aircraft	2,276	[illegible]	[illegible]	[illegible]	1,840	80	200	-	800	-	-	-	484	-	-	-

Table D-1 SCRAP TIRE DISPOSAL QUESTIONNAIRE RESULTS (Continued)

SUMMARIES & TOTALS

	U.S.	Europe	Asia	Other	Army	Air Force	Marines	Naval & Coast Guard	General Totals Percent Number (tons)
Present Disposal Methods - Avg. %									
Landfill	12.50	0	0	1.67	4.56	3.51	18.67	4.0	5.61±6.6
Burning	0	0	0	0	0	0	0	0	0
Selling	75.0	62.50	99.38	53.33	61.83	92.65	81.33	70.5	74.6±15.9
Stockpile	1.67	33.34	0	45.0	28.08	2.16	0	0	13.8±18.6
Other	10.83	0.5	0.62	0	3.70	1.68	0	25.5	5.4±8.9
None	0	3.66	0	0	1.83	0	0	0	0.69±1.36
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Tires for Disposal - No. other than Aircraft	157,474	161,450	12,365	3,965	300,789	22,543	7,122	4,800	335,254 (4190)
Aircraft	45,765	1,472	4,407	279	18,842	33,457	7,990	1,634	51,923 (1,298)
Size of Tires for Disposal - No. other than Aircraft									
x<53½"	141,402	102,282	9,678	3,934	226,027	19,766	7,100	4,403	257,296 (3,216)
53½"<x<64"	8,644	36,522	417	16	44,602	878	7	112	45,599 (570)
64"<x<74½"	4,894	16,910	2,218	11	23,182	692	13	146	24,033 (300)
74½"<x	2,534	5,736	52	4	6,978	1,207	2	139	8,326 (104)
Aircraft									
x<53½"	39,585	1,397	4,128	270	16,452	19,451	7,990	1,487	45,380 (1,134)
53½"<x<64"	5,014	25	279	9	1,815	3,407	0	105	5,327 (133)
64"<x<74½"	637	25	0	0	344	286	0	32	662 (17)
74½"<x	529	25	0	0	231	313	0	10	554 (14)
Percent Steel Belted - % other than Aircraft	1.64	3.64	0.42	0	2.14	0.14	0.17	5.5	1.71±1.99
Aircraft	1.55	33.34	0.17	0	17.45	0.15	0.17	2.8	6.95±12.19
Rate of Increase - Tires/mo. other than Aircraft	15,333	6,889	3,650	642	19,967	4,729	467	1,351	26,514 (331)
Aircraft	5,400	117	320	39	2,472	2,120	800	484	5,876 (147)

Table D-2 SHREDDER CENSUS

Location	Start up date	Type of shredder	Type of waste shredded	Rated capacity	Disposition of waste
			ALABAMA		
Decatur	November 1969	Horizontal	Industrial	40 T.P.H.	Separation & Recycling
Mobile	1965			35-40 T.P.H.	
			CALIFORNIA		
Los Gatos	1969	Horizontal Shaft, 3 Units Primary Secondary Tertiary	Municipal, both Packer Truck & Bulky Waste	30 T.P.H. for Whole System	Recycling and Some Incineration
Menlo Park	March, 1973	Vertical	Municipal Packer Packer Truck	3 T.P.H.	Power Generation
Mountainview	June, 1974	One Vertical	Municipal & Commercial	15 Tons/Hr.	Landfill
San Diego	1970	Horizontal	Municipal	40 T.P.H.	Bale & Landfill
Mobile Shredders U.S. Air Force	October, 1974	Vertical	Commercial & Industrial	4 to 12 Tons per hr.	Landfill
			COLORADO		
Alamosa	June, 1972	One Vertical	Municipal	15 Tons/Hr.	Landfill
Chaffee County	June, 1974	One Vertical	Municipal & Commercial	15 Tons/Hr.	Landfill
Pueblo	December, 1974	Two Vertical	Municipal & Commercial	40 Tons/Hr.	Landfill with ferrous separation
			CONNECTICUT		
Ansonia	May, 1974	Horizontal	Over-Sized Bulky Waste	30 T.P.H.	Resource Recovery & Incineration
Milford	April, 1972	Vertical	Municipal, Commercial, Over Sized Bulky Waste White Goods	50 T.P.H.	Landfill
New Britain	August, 1975	Horizontal	Municipal & Over-Sized Bulky Waste	50 T.P.H.	Landfill
City of New London	July, 1972	Horizontal	Municipal	80 T.P.H.	Landfill
			DELAWARE		
New Castle	1972	Horizontal	Municipal Household Collections	100 T.P.H. (50 Tons per line)	Landfill
			FLORIDA		
Ft. Lauderdale	1973	Horizontal	Municipal	400 Yd/Hr.	Incineration/Landfill
Tampa	June 13, 1967	Horizontal	Municipal Over-Sized Wood	6 to 8 T.P.H.	Incineration
Pompano Beach	October, 1972	One Vertical	Municipal & Commercial	15 Tons/Hr.	Landfill with paper & ferrous recovery
			GEORGIA		
Atlanta	February, 1975	Horizontal	Municipal & Over-Sized Bulky Waste	75 T.P.H.	Bale-Rail Haul Landfill
DeKalb County	April, 1973	Vertical	Municipal, Commercial, Over-Sized Bulky Waste White Goods	50 T.P.H.	Landfill
DeKalb County	January 3, 1963	Horizontal	Municipal Over-Sized Wood	6 to 8 T.P.H.	Incineration
DeKalb County (Atlanta)	June, 1973	Three Vertical	Municipal	45 Tons/Hr.	Landfill
			ILLINOIS		
Chicago	June, 1975	Vertical	Secondary Grind	60 T.P.H.	Energy Recovery
Chicago	1971	Horizontal	Municipal Collection for incineration, including bulky waste	30 T.P.H. (Expected)	Landfill

Table D-2 SHREDDER CENSUS (Continued)

Location	Start up date	Type of shredder	Type of waste shredded	Rated Capacity	Disposition of waste
Chicago	June, 1970	Horizontal	Municipal	80 T.P.H.	Landfill
Chicago	October, 1975	Horizontal	Municipal & Over-Sized Bulky Waste	75 T.P.H.	BTU Recovery
			INDIANA		
Indianapolis	1971 August, 1971	Horizontal Horizontal	Municipal Municipal Over-Sized Wood	200 Cu. Yd/Hr. 25 to 35 T.P.H.	Landfill Incineration
Ft. Wayne	February, 1971	Horizontal	Municipal Over-Sized Wood	35 to 50 T.P.H.	Incineration
			IOWA		
Ames	To Be Delivered August, 1974	(2) Horizontal	Municipal Over-Sized Wood	50 T.P.H. Each	Incineration
Pleasant Hill	1973	Horizontal, Single Direction	Municipal	20 T.P.H.	Composting
			KENTUCKY		
Louisville	July, 1969	Horizontal	Industrial	40 T.P.H.	Resource Recovery & Landfill
Louisville	April, 1962	Horizontal	Over-Sized Bulky Waste	20 T.P.H.	Incineration
Louisville	February, 1968	Horizontal	Industrial	32 T.P.H.	Landfill
			MAINE		
Romford	October, 1972	Horizontal	Industrial	40 T.P.H.	BTU Recovery
			MARYLAND		
Baltimore	1974	2 Horizontal	Municipal, Industrial Over-Size Bulky	50 T.P.H. each	Pyrolysis
			MASSACHUSETTS		
Holliston	January, 1974	Horizontal	Industrial	40 T.P.H.	Resource Recovery
Marlboro	November, 1973	Horizontal	Municipal	30 T.P.H.	Incineration
			MICHIGAN		
Dearborn	August, 1970	Horizontal	Industrial	40 T.P.H.	Resource Recovery & Landfill
Detroit	June, 1967	Horizontal	Industrial	20 T.P.H.	Landfill
			MISSOURI		
St. Louis	1971	Horizontal	Municipal	75 T.P.H. (Expected)	Power-Generation
	June, 1969	Horizontal	Over-Sized Bulky Waste	30 T.P.H.	Incineration
Mobile Shredders U.S. Air Force	October, 1974	Vertical	Commercial & Industrial	4 to 12 tons per hr.	Landfill
			MONTANA		
Great Falls	August, 1973	Two Vertical	Municipal & Commercial	35 Tons/Hr.	Landfill with ferrous separation
			NEBRASKA		
Mobile Shredders U.S. Air Force	October, 1974	Vertical	Commercial & Industrial	4 to 12 tons per hr.	Landfill
			NEW JERSEY		
Monmouth Co.	November, 1974	Vertical	Municipal, Commercial, Over-Sized Bulky Waste White Goods	50 T.P.H.	Landfill
			NEW YORK		
Buffalo	1970	Horizontal	Municipal	240 Cu Yd/Hr.	Incineration
Berlin	August, 1972	Horizontal	Industrial	10 T.P.H.	Power Generation
Elmira	1973	2 Horizontal	Municipal, Industrial Over-Size Bulky	40 T.P.H. Each	Landfill
New York City	1973	Horizontal	Institutional Waste	7 T.P.H.	Incineration

Table D-2 SHREDDER CENSUS (Continued)

Location	Start up date	Type of shredder	Type of waste shredded	Rated capacity	Disposition of waste
New York City	1969	Horizontal 4 Units 2 Primary 2 Secondary	Municipal Waste Packer Truck	20 T.P.H. Per Line 40 T.P.H. For System	Composting
Onondaga Cty.	(1) November, 1973 (1) July, 1974 (1) September, 1974	Vertical	Municipal Commercial, Over-Sized Bulky Waste, White Goods	50 T.P.H.	Landfill
Rochester	April, 1968	Horizontal	Industrial	32 T.P.H.	Separation-Recycling
		NORTH CAROLINA			
Guilford County	January, 1974	Vertical	Municipal, Commercial, Over-Sized Bulky Waste, White Goods	50 T.P.H.	Landfill
		NORTH DAKOTA			
Mobile Shredders U.S. Air Force	October, 1974	Vertical	Commercial & Industrial	4 to 12 tons per hr.	Landfill
		OHIO			
Columbus	1974	3 Horizontal	Municipal, Industrial Over-Size Bulky	60 T.P.H.	Landfill
Dayton	1969	Horizontal Single Direction	Lumber Bulky Wood	10 T.P.H.	Incineration
Newark	1969	Horizontal Single Direction	Industrial	10 T.P.H.	Landfill
Willoughby	August, 1973	Vertical	Municipal Packer Truck	25 T.P.H.	Landfill
		OREGON			
Portland	1973	Horizontal Single Direction	Municipal	20 T.P.H.	Landfill
		PENNSYLVANIA			
Altoona	March, 1966	Horizontal	Municipal	15 T.P.H.	Composting
Harrisburg	December, 1970	Horizontal	Municipal	80 T.P.H.	Incineration
LeHigh County	September, 1974	Two Vertical	Municipal & Commercial	40 Tons/Hr.	Landfill
		RHODE ISLAND			
Providence	August, 1972	Vertical	Municipal & Industrial Waste	50 T.P.H.	Landfill
		SOUTH CAROLINA			
Charleston	June, 1974	Three Vertical	Municipal, Industrial White Goods, Over-Sized Bulky Wastes	80 Tons/Hr.	Landfill
Georgetown Cty.	April, 1974	One Vertical	Municipal & Commercial	20 Tons/Hr.	Landfill
Williamsburg Cty.	September, 1973	One Vertical	Municipal & Commercial	20 Tons/Hr.	Landfill
		TEXAS			
Galveston	September, 1973	Vertical	Municipal & Industrial Waste	25 T.P.H.	Landfill
Houston	1965	Horizontal	Municipal	40 T.P.H.	Resource Recovery
Odessa	June, 1974	Horizontal	Residential & Commercial	50 T.P.H.	
Mobile Shredders U.S. Air Force	October, 1974	Vertical	Commercial & Industrial	4 to 12 tons per hr.	Landfill
		VIRGINIA			
Norfolk	1974	2 Horizontal	Municipal (20 foot pilings)	30 T.P.H.	Incineration
Roanoke	July, 1968	Horizontal	Industrial	40 T.P.H.	Landfill
Richmond	June, 1974	One Vertical	Commercial & Industrial	20 Tons/Hr.	Landfill with ferrous separation

Table D-2 SHREDDER CENSUS (Continued)

Location	Start up date	Type of shredder	Type of waste shredded	Rated capacity	Disposition of waste
			VERMONT		
Hancock	October, 1971	Horizontal	Industrial	25 T.P.H.	BTU Recovery
			WASHINGTON		
Cowlitz County	Early, 1975	Horizontal	Municipal	50 T.P.H.	Power Generation
Longview	1971	Horizontal	Municipal & Pulp & Paper Mill Waste	50 T.P.H.	In Plant Incineration
Longview	1970	Horizontal Single Direction	Industrial Polyethelene	20 T.P.H.	Incineration
State of Wash.	1971	Horizontal	Wood Scrap	3 T.P.H.	Incineration
Tacoma	1971	Horizontal	Over-Sized Bulky Waste	40 T.P.H.	Landfill
			WISCONSIN		
Appleton	June, 1974	Horizontal	Municipal	50 T.P.H.	Recycling
Racine	May, 1958	Horizontal	Municipal	24 T.P.H.	Landfill
Madison	1967	One Horizontal One Vertical	Municipal	25 Tons/Hr.	Landfill with ferrous separation
			JAMAICA		
Kingston	1962	2 Shredders	Municipal Refuse	20 T.P.A.	Composting
			CANADA		
Edmonton, Alberta	September 1970	Vertical	Municipal Packer Truck	25 T.P.H.	Landfill
Vancouver, B.C.	July, 1971	Vertical	Municipal & Industrial Waste	50 T.P.H.	Landfill
Windsor, Ontario	July, 1965	Horizontal	Over Sized	40 T.P.H.	Landfill

Table D-3 SHREDDER MANUFACTURERS CONTACTED

1) Allis-Chalmers
Appleton, Wisconsin

2) American Pulverizer
St. Louis, Missouri

3) Automotive-Industrial
Marketing Corp.
Portland, Oregon

4) Barclay/Noll Associates
Burlingame, California

5) Branick Manufacturing
Fargo, North Dakota

6) Carborundum Company/
Pangborn Division
Hagerstown, Maryland

7) Garbalizer Corporation
of America
Salt Lake City, Utah

8) Gruendler Crusher
& Pulverizer
St. Louis, Missouri

9) Hammermills, Inc.
Cedar Rapids, Iowa

10) The Heil Company
Milwaukee, Wisconsin

11) Holman Industries
Oakdale, California

12) Jeffrey Manufacturing Co.
Columbus, Ohio

13) Metropolitan Disposal Corp.
Portland, Oregon

14) Newell Manufacturing
San Antonio, Texas

15) Parent Manufacturing Co.
Lewiston, Maine

16) Pennsylvania Crusher Corp.
Brommall, Pennsylvania

17) Saturn Manufacturing
Wilsonville, Oregon

18) TEB, Inc. (Quinn Brothers -
Philadelphia, Pennsylvania)
Addison, Illinois

19) Williams Patent Crusher
and Pulverizer Company
St. Louis, Missouri

Table E METRIC CONVERSION TABLE

English	Metric	Multiplier
inches	meter (m)	2.54×10^{-2}
feet	meter (m)	3.084×10^{-1}
foot^2	meter^2(m)^2	9.29×10^{-2}
foot^3	meter^3(m)^3	2.83×10^{-2}
yard	meter (m)	9.144×10^{-1}
yard^2	meter^2(m)^2	8.36×10^{-1}
yard^3	meter^3(m)^3	7.65×10^{-1}
miles	kilometer (km)	1.61
pounds	kilogram (kg)	4.536×10^{-1}
tons	metric tons (mt)	0.9072
^oF	^oC	5/9 (F-32)
quarts	liters (1)	1.06
gallons	liters (1)	3.79
barrels	liters (1)	1.59×10^2
psi	pascal (Pa)	6.89×10^3
Btu/pound	Joule per kilogram (J/kg)	2.33×10^3