Resource Recovery Alternatives for Waste Tires in North Carolina

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I. Introduction

For the past several decades there have been two dominant methods for the disposal of waste tires: stockpiling and landfilling. Approximately 234 million waste tires are generated each year in the U. S. It is estimated that 82% of these tires are landfilled, stockpiled or illegally dumped, 9% are used in energy recovery processes, 4% are exported, 2% are used in asphalt pavement and 2% are recycled into new rubber products (Robinson 1991). Tire stockpiles range from backyard storage of a few tires to massive tire piles containing thousands and sometimes millions of tires. Stockpiling has proven to be unsightly and a potential health hazard. The combination of rainwater, windblown pollen and dust trapped within discarded tires creates an environment which can increase the breeding rate of disease carrying mosquitos by a factor of 4000 (Grady 1987). Tire piles also present a significant fire hazard. Once ablaze, tire stockpiles are very difficult to extinguish, can release toxic smoke and can contaminate groundwater near a site. An April, 1990 fire in Hagersville, Ontario burned 14 million tires and leached over 158,000 gallons of oil into the surrounding soil. The danger of tire pile fires was evidenced in North Carolina on April 7, 1990 in Johnston County when 50,000 tires caught fire causing 14 emergency departments to be called before the blaze was extinguished. Though no evacuations or injuries were reported, this fire heightened North Carolina’s sensitivity to the physical and environmental dangers of tire stockpiles.

Like stockpiling, burial of tires has not been an effective waste tire management practice. When placed in a landfill with municipal solid waste, whole tires do not compact, greatly reducing landfill capacity. Whole tires frequently rise to the surface of landfills, causing damage to the cap of a closed landfill, permitting water infiltration and requiring expensive post closure landfill maintenance. Recently, landfill operators have been required to shred or slice tires before burial. To compensate for these extra costs, North Carolina landfill owners began charging tipping fees, sometimes as high as two dollars per passenger tire (Eggers 1991).

Senate Bill 111, enacted in 1989, outlaws both stockpiling and the burial of whole tires in North Carolina. At present most counties either shred and bury their tires with municipal refuse, or ship them to monofills in and out of the state. Both burial and stockpiling however, ignore the possibility that scrap tires represent a valuable resource which could be utilized rather than discarded.

The objective of this report is to critically evaluate resource recovery alternatives for waste tires in North Carolina. We focus on four alternatives which seem particularly promising and which have the potential to utilize both the scrap tires stockpiled in North
Carolina as well as those generated annually. The technologies to be discussed include the use of tires in asphalt, incineration of tires in dedicated tire to energy power plants, and burning tires as a supplemental fuel in paper mill boilers and cement kilns. The applicability of each technology to manufacturing capacity in North Carolina is evaluated. Each of these methods are technologically proven, environmentally sound and economically feasible. While the focus of this report is waste tire management in North Carolina, the technology evaluation is applicable to the entire U. S.

The rate of waste tire generation is estimated in the second section of this report and grinding technologies are discussed in section three. The use of tires in asphalt is discussed in section four followed by discussion of tire incineration for energy recovery in section five.

II. Generation and Storage of Tires in North Carolina

The tire generation rate for the State of North Carolina was estimated to be 6 million tires per year. This number was determined by averaging three separate generation estimates as described here. The first estimate is the commonly used generation rate of one tire per person per year (Kearney 1990). Based on the 1990 census, this would yield a generation rate of 6.6 million tires per year in North Carolina. This number is at the upper end of generation rate approximations. For example, Florida uses a generation rate of 0.75 tires per person per year (Ruth 1991). The second estimate is based on the number of registered vehicles in the state (5.5 million), the number of tires per automobile (4) and the estimated life span of a tire (4 years) (Estakhri 1990). This leads to an estimated generation rate of 5.5 million tires per year. This number is conservative because it neglects trucks which have more than four tires. The third estimate is based on total proceeds from the 1% scrap tire disposal fee in North Carolina. This fee generated $3,520,000 in 1990, thus 352 million dollars were spent on tires in North Carolina in 1990. Assuming an average retail price of 60 dollars per tire, a scrap tire generation rate of 5.9 million tires per year is calculated. The average of these three estimates is 6 million which will be used as the North Carolina scrap tire generation rate for this study.

In addition to tires generated annually, it is estimated that there are between nine and twelve million tires stockpiled in North Carolina (Eggers 1991). There are three large tire piles in the state, each holding about one million tires. These piles are located in Surry Co., Edgecombe Co. and Pender Co. There are also two large shredded tire monofills in North Carolina, one near Elizabeth City and one in Cabarrus County.
A typical passenger tire weighs 20 pounds of which 12 pounds are rubber, 4 pounds are steel, and 4 pounds are fiber (Estakhri 1990). Thus, North Carolinians produce 72 million pounds of potentially reusable rubber annually, as well as 24 million pounds each of steel and fiber.

III. Processes for Tire Reduction

Most of the technologies for recycling tires to be discussed here require size reduction to either chips or granules. The two methods currently used to grind tires to a required size are ambient grinding and cryogenic grinding.

Ambient grinding is performed by shredding a tire at room temperature. This process produces rubber chips that are rough and have a sponge-like surface. Shredding tires to 1” by 1” squares is relatively easy and can be performed by shredders located around the state. More advanced shredders which also dewire and defabric the tires are not as common. Capital costs for a 350,000 tire per year shredding operation of this sort can be as high as $750,000 (OMOE 1991). A tire must be ground to less than 1/16” before it can be dewired. Ambient ground dewired tire rubber is used for asphalt paving mixtures because it yields a tire chip which is rough and porous and which reacts better with asphalt than cryogenic ground tires. The shredded rubber required for all the technologies discussed in this report are most economically obtained by ambient grinding.

Cryogenic grinding involves freezing the tire with liquid nitrogen and shattering it in a hammermill. Cryogenic grinding is typically preceded by ambient grinding to reduce the tires to 1” by 1” squares. This is done to make more efficient use of the very costly liquid nitrogen. Cryogenic grinding is generally used when powdered rubber is needed for recycling into other rubber products. Capital costs for a cryogenic facility to grind 1.2 million tires per year are estimated to be between $1.5 and $2 million (OMOE 1991). In addition, use of liquid nitrogen results in high operating costs.
IV. Reuse of Tires in Asphalt Paving

Asphalt pavement is composed of aggregate held together by asphalt cement, a refined form of petroleum. There are two general methods for using rubber in asphalt mixes. In asphalt rubber, ground tire rubber is mixed with asphalt cement for use as a binder for the aggregate particles in the asphalt concrete mix. Four distinct technologies for the use of asphalt rubber are discussed in this section. The second method for using rubber in asphalt is rubber modified asphalt concrete (RUMAC). It consists of 2% to 5% ground rubber chips which replace a portion of the mineral aggregate in the asphalt concrete mix.

A. Use of Tires in Asphalt Rubber

There are four technologies by which rubber can be incorporated into asphalt including asphalt rubber crack sealants (ARCS), asphalt rubber seal coats (ARSC), asphalt rubber stress absorbing membrane interlayers (ARSAMI), and asphalt rubber concrete (ARC). All four methods are commonly called wet process mixes because they involve chemically bonding a certain percentage of rubber in hot asphalt. Each technology is discussed individually in this section. The discussion includes a description of the technology, required construction techniques with an emphasis on modifications necessary to use ground rubber, a comparison of performance relative to conventional pavement, estimates of the cost relative to conventional pavement, and an estimate of the number of tires which could be consumed if the technology were employed in North Carolina.

1. Asphalt Rubber Crack Sealants

The presence of cracks in pavement before the completion of its expected service life presents a particularly difficult problem for highway maintenance departments. While a complete overlay is not always necessary, cracks must be filled to prevent further and more serious road damage.

Crack sealing is difficult because while a crack can change its shape and volume during thermal cycles, a crack sealant can only change its shape. If a crack filler is not sufficiently elastic, then the pavement is pulled further apart. If the crack filler is too soft then it may ooze out of a crack leaving the pavement no better than before the sealant application.
Asphalt rubber crack sealant is a patented product composed of approximately 80% asphalt and 20% ground rubber. The sealant comes in solidified blocks which can be obtained from a licensed distributor (Estakhri 1990).

a. Construction Techniques and Special Considerations

A special kettle, pump and distributor wand is needed for placement of asphalt rubber crack sealant. Crack preparation consists simply of blowing out debris with an air compressor. More extensive crack preparation is generally not believed to be cost effective (Bertelson, 1981).

Asphalt rubber crack sealant should be applied in the colder months when a crack is at its widest. If an overlay is planned, the crack sealant should be placed at least six months before the resurfacing is performed to prevent the material from pushing ahead of the pavement rolling machines (Bertelson, 1981).

b. Performance

Asphalt rubber crack sealant is reported to be superior to all other sealants (Estakhri 1990). It is regarded as being very stable with no tendency to displace or weather harden (Bethune 1978). Because of its outstanding performance, asphalt rubber crack sealant is becoming the sealant of choice. This is evidenced in several western states including Texas, Arizona and Nevada, where virtually all crack sealing is done using rubberized asphalt. The extensive use in the western part of the nation is not to imply that its strong performance is limited to that part of the nation. Its wide acceptance in the West is primarily a result of the region's long history of experimenting with asphalt rubber and that ARCS patents are held by companies located in the West.

North Carolina has begun using asphalt rubber crack sealant with excellent results. The state laid 12,000 lbs of ARCS in 1990 and is in the process of expanding its use (Pace 1991).

c. Cost

The estimate of the cost differential between conventional technology and technology incorporating tire rubber is based on production costs reported in the literature and through discussions with practitioners. Throughout this report, no allowance is made for the possibility that the asphalt processor will be paid a tipping fee for accepting a tire. Thus, the cost differentials provided in this report should be considered as maximum differentials.

The cost to purchase and lay asphalt rubber crack sealant is generally about twice that of asphalt sealant. Capital costs of $10,000 to $20,000 are required for the special equipment
needed to heat and place the rubberized crack sealant. (Ellison 1991). Nonetheless, several states, including North Carolina, consider the additional cost to be justified.

d. Potential Tire Utilization in North Carolina

The amount of conventional asphalt crack sealant placed in North Carolina could not be determined, consequently the corresponding number of tires which might be consumed in the state could not be calculated. However, based on the use of this material in other states, we estimate that less than 50,000 tires would be consumed in North Carolina, even if all crack sealing in the state utilized asphalt rubber crack sealant (Estakhri 1990). Approximately 0.2 Ib of ground rubber are used per pound of asphalt rubber crack sealant.

e. Conclusion

Though asphalt rubber crack sealing will not consume a large part of North Carolina's waste tire stream, it is a superior and well accepted product which consumes otherwise discarded tires.

2. Asphalt Rubber Seal Coats

An asphalt rubber seal coat (ARSC) is sometimes referred to as a stress absorbing membrane. A seal coat is applied to a road once it has lost its effective skid resistance and water has begun to infiltrate the structural layers. It is an inexpensive alternative to hot mix asphalt concrete overlays when structural rehabilitation is not required. A conventional seal coat or chip seal consists of a single application of asphalt sprayed by a distributor, immediately followed by a layer of aggregate which is then embedded into the asphalt by rollers. When the asphalt is mixed with 20% to 26% ground rubber, it forms a binder which is believed to be superior to conventional asphalt (Ellison 1991). The use of asphalt rubber seal coats is a patented process.

a. Construction Techniques and Special Considerations

Generally 25% ground tire rubber passing the No. 30 sieve is mixed with asphalt in a distributor tank. A conventional distributor tank can be modified so that it can blend asphalt rubber. Required modifications include an agitation device to provide continuous mixing and an electronic weighing device.

Continuous mixing is required to prevent the rubber particles from floating to the surface of the asphalt in the tank, disrupting application of a uniform mixture. Initially the specific
gravity of the rubber is between 1.14 and 1.20 while that of the heated asphalt is slightly less than 1.0. As the rubber particles are heated in the asphalt they swell to as much as twice their original size, reducing their specific gravity to below that of the heated asphalt.

An electronic weighing device is needed so that application rates can be controlled. Addition of the aforementioned agitation device prevents an inspector from checking the application rate by the conventional dipstick method.

A slightly longer mixing time, 30 to 45 minutes, is required to facilitate full reaction of the rubber in the asphalt. This longer mixing time increases cost and reduces productivity.

Conventional pneumatic tired rollers can be used to embed the aggregate. Soapy water is used in place of kerosene for roller lubrication as kerosene will react with the rubber in the binder causing it to become sticky. Once the pavement has been compacted, it should be allowed to cure for a minimum of 48 hours (Lawrence 1976).

b. Performance

The performance of asphalt rubber seal coats can be evaluated by comparing them with conventional seal coats in the areas of skid resistance, crack resistance, and effective life.

Asphalt rubber seal coats have mixed reviews in the areas of skid resistance. The primary problem is that of inappropriate proportions of aggregate and binder. Personnel inexperienced with asphalt rubber have been reported to use too much binder which causes excess bleeding on the pavement surface (Estakhri 1990). A second problem is the use of too little binder, resulting in chip loss (Schnormeier 1986). With correct placement techniques, ARSCs should provide greater Skid resistance for more years than conventional seal coats. This is because the higher viscosity of asphalt rubber leads to higher initial chip embedment and longer chip retention (Adams 1985). The skid resistance of rubberized seal coats is best when placed on roads with high traffic volumes where traffic pressure helps retain the aggregate (Ellison 1991).

Asphalt rubber seal coats have been reported to provide superior crack retardation relative to conventional seal coats (Estakhri 1990). ARSCs are especially effective in minimizing reflective cracking at the surface. Reflective cracks are those caused by increased tensile stress on the surface pavement at points where subsurface cracks exist. This often leads to the new pavement quickly exhibiting the same crack pattern as the old pavement. ARSCs tend to flex rather than crack at points of increased tensile stress. During the summer months the kneading action of the traffic tends to "heal" any cracks which do occur (Ellison 1991).
Because many pavement personnel are inexperienced with asphalt rubber seal coats, field trials using asphalt rubber seal coats have yielded mixed results. For example, a test section in Minnesota proved only equivalent performance relative to conventional chip seals but cost over twice as much (Turgeon 1989). In successful test sections, ARSCs are reported to last twice as long as conventional seal coats. ARSCs have been used extensively in Arizona where they have been reported to last eight years on interstate routes (Estakhri 1990) and ten to twelve years on intrastate routes (Schnormeier 1986) while needing little or no maintenance. Conventional chip seals typically last between six to eight years on state routes with some maintenance required (Schnormeier 1986). After five years of service in West Texas, most ARSC applications are in excellent condition (Estakhri 1990). The rubber provides an excellent waterproofing of subsurface layers and the aggregate is better retained relative to conventional binders. Another improvement is in the area of road deformation or rutting under extreme temperatures and loading. Asphalt rubber seal coats tend to rebound far better than conventional pavements, thus minimizing rutting problems (Ellison 1991). It should also be noted here that asphalt rubber chip seals have been placed on roads that were so badly cracked that conventional chip sealing would not have worked (Schnormeier 1986). Thus comparison of ARSCs with conventional chip seals is at times overly conservative and not always an accurate measurement of their cost effectiveness.

c. cost

The cost of asphalt rubber seal coats is generally two to three times that of conventional seal coats (Estakhri 1990). This is attributed to the cost of the ground tire rubber, the increased mixing times, increased attention required to insure proper construction, and the need to pay a royalty as the process is patented. However, comparing the cost of asphalt rubber seal coats to conventional seal coats is somewhat inaccurate. As discussed above, ARSCs are often placed on roads that are in such poor condition that conventional seal coating would not work. In these instances asphalt rubber seal coating has proven cost effective (Schnormeier 1986) and should be more fairly compared with the cost of complete resurfacing.
d. Potential Tire Utilization in North Carolina

surface treatment in its maintenance program in 1990. Estimates of tire consumption at various rates of usage are shown in Table 1.

<table>
<thead>
<tr>
<th>Rate of Use</th>
<th>Tires Utilized</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>21,900</td>
</tr>
<tr>
<td>25%</td>
<td>54,750</td>
</tr>
<tr>
<td>50%</td>
<td>109,500</td>
</tr>
<tr>
<td>75%</td>
<td>164,000</td>
</tr>
<tr>
<td>100%</td>
<td>219,000</td>
</tr>
</tbody>
</table>

a. The percentage of seal coats in North Carolina in which ground tires are used.

b. Calculated by multiplying the square yards of seal coats the NCDOT laid in 1990 (2.33 million) by a rate of use, the typical asphalt application rate (0.6 gal/sq. yd.), the density of hot asphalt (7.5 lbs/hot gallon), the percent of rubber mixed in the asphalt (25%), and divided by the amount of useable rubber in a tire (12 lbs).

e. Conclusion

Asphalt rubber seal coating has been in use for more than 15 years. However, it has not been widely accepted by road maintenance personnel. As shown in Table 1, potential tire utilization is not great. Even if all the seal coats placed in North Carolina used ground rubber, only 3.7% of the tires generated annually would be utilized. However, asphalt rubber seal coats do seem to have a niche in road maintenance; where seal coating is planned for heavily travelled, heavily cracked roads. Although its potential for reusing tires is not exceptional, the technology is proven, cost effective in certain instances, and provides performance capabilities superior to conventional seal coats while also serving to reduce the number of stockpiled and landfilled tires. In addition, by improving pavement durability, future maintenance and replacement can be reduced.
3. Asphalt Rubber Stress Absorbing Membrane Interlayers

An asphalt rubber stress absorbing membrane interlayer (ARSAMI) is an asphalt rubber seal coat laid over old pavement and followed by a conventional hot mix asphalt concrete overlay. The purpose of the interlayer is to dissipate tensile stresses generated at cracks in the old pavement and reduce reflective cracking in the overlay.

a. Construction Techniques and Special Considerations

The construction technique for ARSAMIs is very similar to that of asphalt rubber seal coats described in the previous section. Briefly, 25% ground tire rubber, passing the No. 30 sieve, is mixed with asphalt in a modified distributor tank equipped with electronic weighing and mechanical agitation devices. A single application of asphalt rubber is sprayed by the distributor, immediately followed by a layer of aggregate which is embedded in the asphalt rubber with pneumatic tired rollers. Finally, a conventional hot mix asphalt overlay is placed over the interlayer.

b. Performance

Asphalt rubber interlayer treatments have proven superior to conventional hot mix asphalt concrete overlays. The experiences of four states, Arizona, Texas, Washington and North Carolina are discussed here.

ARSAMIs have been in use in Arizona for more than 15 years and have been shown to successfully retard reflective cracking (Morris 1975). Three field tests were conducted in Texas in 1983 and 1984. The results from all three field trials showed that the asphalt rubber interlayer prevented reflective cracking (Estakhri 1990). Several districts in Texas have integrated ARSAMIs into their normal paving procedures (Estakhri 1990).

Results from two ARSAMI field trials conducted in Washington in 1978 showed no appreciable difference between the ARSAMI and the control section. The inconsistency between this result and the data from Texas and Arizona was attributed to the fact that the depths of the hot mix asphalt concrete overlay were deep enough to mask the effects of the ARSAMI (Estakhri 1990). North Carolina laid an ARSAMI test section in 1979. The performance results from the application were satisfactory. The ARSAMI provided a relatively impermeable surface to moisture intrusion and reduced reflective cracking (Strong 1983). Overall, the data indicate that ARSAMI treated roads retard cracking more completely than their control sections.
c. cost

The cost of ARSAMIs is frequently the major factor preventing their widespread use. A 1990 study by the Texas Transportation Institute estimated the annualized cost of a conventional 2-inch overlay at $3.20 per yd$^2$ compared to $4.25 per yd$^2$ for a 2-inch overlay with an ARSAMI treatment (Estakhri 1990). Based on these costs an ARSAMI treated road would have to last approximately 50 percent longer than a conventional overlay in order to be cost effective. While ARSAMIs do offer superior performance, there are no data to support a 50% increase in service life. The field trials performed in North Carolina yielded satisfactory performance results but the cost was determined to be too high and further field trials have not been attempted (Strong 1983). However, several districts in Texas feel that the life cycle cost of ARSAMIs is superior to conventional overlays in some instances and have taken steps to increase their use (Estakhri 1990).

d. Potential Tire Utilization in North Carolina

Available data on road pavement projects in North Carolina were insufficient to estimate potential consumption of tires for ARSAMIs. However, it can be assumed that the tire utilization potential is not higher than that for asphalt rubber seal coats which are projected to use no more than 3.65% of the state's annual tire generation.

e. Conclusion

Though ARSAMI treated roads have proven their ability to provide a superior road, the economic advantage is not clear. North Carolina experimented with this paving system in 1979 and found it to perform better than a control section. However, it was determined that the cost of the ARSAMI treatment was too high and further projects have not been initiated. Conversely, several districts in Texas have found the life cycle cost of ARSAMI treated roads to be cost effective. Asphalt rubber stress absorbing membrane interlayers do not have the potential to consume a significant portion of the state's annual tire generation.

4. Asphalt Rubber Concrete

Asphalt rubber concrete (ARC) is a hot mix asphalt concrete in which a mixture of asphalt cement and ground rubber is used as a binder. Use of hot mix asphalt concrete as a surface course material permits the use of 18% to 26% rubber passing the No. 20 to No. 50 sieves in the asphalt. The process is patented and has been used by the pavement industry for more than fifteen years.
A recent study by the National Center for Asphalt Technology in conjunction with field tests by the Florida Department of Transportation suggested that the state should use a non-proprietary method known as Ultrafine™. The Ultrafine™ process requires 5% rubber passing the No. 50 sieve for a dense graded surface mix and 15% passing the No. 30 sieve for an open graded surface mix (Ruth 1991). The relatively low rubber fraction was suggested until the recyclability of asphalt rubber concretes can be evaluated.

The practice of excavating old pavement, adding rejuvenating agents, and reapplying it in either the surface or structural layers, referred to as recycled asphalt pavement, is becoming increasingly popular with state transportation departments. At present, there are insufficient data on the recyclability of rubberized asphalt (Roberts 1989). However, a crumb rubber asphalt road is scheduled to be replaced in California in 1992 (Blumenthal 1991).

a. Construction Techniques and Special Considerations

A special asphalt rubber blending unit is needed to mix the asphalt and rubber. This blending equipment is typically supplied by a contractor for use at a local mix plant on a temporary basis (Murphy 1991). Heavy duty metering pumps are recommended because of the increased viscosity of asphalt rubber relative to conventional asphalt (Turgeon 1991). However, plants which use asphalt weigh buckets should operate normally with no need for larger pumps (Ruth 1991). Thus, asphalt rubber concretes can be mixed in any conventional mixing plant if the special blending equipment is available. Slightly higher heating temperatures and longer mix times are required to blend the asphalt rubber and mix in the aggregate. Hauling and placement temperatures are also slightly higher. No special equipment is needed to lay or compact asphalt rubber concrete but compaction should only be performed by steel wheeled rollers (Roberts 1989). A slightly longer time should be allowed before traffic is permitted on asphalt rubber concrete pavement relative to conventional asphalt concrete (Turgeon 1989).

b. Performance

There have been over 35 projects in 12 states in which asphalt rubber has been utilized as a binder in hot mix asphalt concretes (Estakhri 1990). Overall, asphalt rubber concretes have performed as well or better than control sections. ARC S tend to outperform conventional asphalt mixes with respect to crack resistance but seldom perform better with respect to skid resistance and roughness. Asphalt rubber concretes are also reported to be significantly
blacker because of the high carbon content in tires. This tends to reduce glare on wet pavement (Kobelt 1990).

Field trials of ARCs have yielded mixed results. Data from a 1984 field trial of ARC core samples in Minnesota indicate that asphalt rubber concrete has higher penetration and lower resilient moduli values than the control section cores. However, an onsite inspection of the road after seven years of service revealed no apparent physical difference between the rubberized section and the conventional asphalt concrete section (Turgeon 1991).

A field trial of asphalt rubber concrete in Connecticut in 1980 was performing well after 8 years of service. The ARC section is in better condition with regards to cracking; however, roughness and skid resistance values are both similar to the control section (Estakhri 1990).

Tests performed in Florida in 1990 utilizing non-proprietary percentages of ground tire rubber have not yielded conclusive results to date. However, few problems were reported during pavement construction. The Florida tests are expected to yield asphalt rubber concretes superior to the conventional sections (Ruth 1991).

c. cost

The placement cost of asphalt rubber concrete, using 18% to 26% rubber, is 50% to 100% higher than conventional hot mix asphalt concretes. This is attributed to the cost of the ground tire rubber, the increased mixing time, the limited number of licensed asphalt rubber concrete paving companies and the experimental nature of the process.

Asphalt rubber concrete using 5% and 15% rubber contents as used in Florida is reported to cost only about 10% more than conventional asphalt concrete (Ruth 1991). The reduced cost relative to the patented technique is attributed to the use of less ground rubber and the absence of a royalty payment. In addition, increased mixing times are not required due to the smaller size and percentage of rubber in the mix.

The Florida Department of Transportation receives its ground tire rubber from Rousse Industries in Vicksburg, Mississippi. Currently, an agreement is being arranged whereby Rouse Industries will accept as many of Florida's whole tires as it buys in ground tires (Murphy 1991). Rouse Industries is also in the process of developing a portable grinder capable of grinding rubber to pass the No. 50 sieve. They plan to market the use of this grinder by transporting it to a particular state and grinding tires as needed for a state's asphalt rubber projects (White 1991).
d. Potential Tire Utilization in North Carolina

The North Carolina Department of Transportation laid 3,141,000 tons of plant mix asphalt in 1990 for road resurfacing. These overlay projects typically consist of 1" to 1.5" of hot mix asphalt concrete with approximately 6.5% binder content. Potential tire consumption by the North Carolina Department of Transportation at various rates of use and two common ground tire rubber percentages are given in Table 2. The data indicate that asphalt rubber concrete could be a significant sink for waste tires in North Carolina.

<table>
<thead>
<tr>
<th>5% Ground Rate of Use(%)</th>
<th>20% Ground Tire Rubber</th>
<th>Tire Rubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>170,000</td>
<td>680,000</td>
</tr>
<tr>
<td>20</td>
<td>340,000</td>
<td>1,360,000</td>
</tr>
<tr>
<td>50</td>
<td>850,000</td>
<td>3,400,000</td>
</tr>
<tr>
<td>75</td>
<td>1,280,000</td>
<td>5,100,000</td>
</tr>
<tr>
<td>100</td>
<td>1,700,000</td>
<td>6,800,000</td>
</tr>
</tbody>
</table>

a. The percentage of pavement projects which include ground tire in the binder.
b. Use of 5% ground tire rubber in the non-proprietary process.
c. Use of 20% ground tire rubber in the proprietary process.
d. Calculated by multiplying the total amount of hot mix asphalt concrete (HMAC) used for resurfacing in North Carolina (3.141 million tons), by the rate of use, by the amount of binder in the HMAC (6.5%), and by the percent GTR, and dividing by the amount of usable rubber in the average passenger tire (12 lbs).

e. Conclusion

Asphalt rubber concrete utilizing the patented 18% to 26% method has been in use for many years. Though it generally provides a superior pavement, the 150% to 200% increase in cost is often too high for state transportation departments. This should be remedied somewhat when the patents expire in 1993 and more companies enter the asphalt rubber concrete market.

Asphalt rubber concrete field trials in Florida using non-proprietary 5% and 15% rubber have been very promising. This process most likely will provide a superior road with only a
10% cost increase over conventional asphalt concrete. It is estimated that it could utilize 25% of Florida's annual tire generation.

A very important aspect of asphalt rubber concretes is its recyclability. Studies to determine the effects of rejuvenating agents on asphalt rubber need to be performed. Until it can be shown that asphalt rubber concrete can be recycled, its widespread application may be limited.

B. Rubber Modified Asphalt Concrete

The techniques described to this point all use rubber in the asphalt. In rubber modified asphalt concrete (RUMAC), rubber is substituted for a fraction of the aggregate. RUMAC was pioneered in Sweden in the late 1960's as a way to improve asphalt pavement skid resistance and durability. RUMAC utilizes ground rubber to replace 2% to 5% of the mineral aggregate in hot mix asphalt concrete.

A process patented under the trade name PlusRide™ by Pave Tech Corporation of Seattle, Washington is the most well known and field tested RUMAC. This method uses a special aggregate gradation known as gap grading. Aggregate gradations are such that very little mineral aggregate remains between the 1/4" and No. 20 sieves. Rubber chips passing the 1/4" and retained on the No. 20 sieve are used to replace the "missing" aggregate. The PlusRide™ patent expired in 1991.

A non-proprietary variation of PlusRide™ which uses smaller rubber particles to produce a denser aggregate gradation has also been developed. This method is generally credited to Dr. H. B. Takallou of the Transportation Research Institute at Oregon State University. Dr. Khosla of North Carolina State University is currently studying different rubber modified asphalt concrete mixes which follow North Carolina gradation specifications. The results should yield optimum rubber modified mix designs for North Carolina pavement types.

I. Construction Techniques and Special Considerations

The major modification required for asphalt concrete production with ground rubber in the aggregate is the need for a method of combining the rubber and aggregate in proper proportions. Continuous, dryer drum, and batch mixing plants can all be used to mix rubber modified asphalt concrete. Batch plants are generally preferred because the manual "bag count" method of introducing rubber into the aggregate offers superior quality control (Esch 1984). A conveyor elevator can be used to feed rubber into the aggregate at any of the three types of mixing plants
but properly metering the rubber feed rate is difficult (Allen 1990). It is also suggested that for PlusRide™ applications, two mineral stockpiles be kept, one with material larger than the specified gap size and the other containing material smaller than the recommended gap size (Allen 1990). A common problem arising with RUMAC is the inability of contractors to obtain sufficient fine content in the mix. This causes the pavement to have unacceptably high air void contents. Mineral filler such as fly ash, limestone dust, and Cottrel flour are recommended when achieving adequate fine percentages is a problem (Takallou 1988).

When dryer drum mixers are used, it is important that they be equipped with a heat shield due to the excessive smoke and burning of the fine rubber which can accompany RUMAC mixing (Esch 1984). Irrespective of the type of mixer used, higher mixing temperatures, longer mix times, and generally about 1% to 1.5% more binder is needed to thoroughly coat the aggregate and rubber chips with asphalt in the RUMAC process.

After mixing is complete, the mix should be maintained close to discharge temperature until placement. As with conventional asphalt pavement mixtures, this can be difficult when the mix must be hauled a long distance before placement. It is especially difficult with RUMAC because of the higher temperatures involved. The same paving equipment used for conventional hot mix asphalt concrete can be used for rubber modified asphalt concrete. However, paving machines should be equipped with full width vibratory screens to aid compaction (Takallou 1988).

Compaction of RUMAC pavements should be done with steel rollers lubricated with soapy water. Pneumatic tired rollers should never be used and the steel rollers should not stop to add water or refuel as pick up problems will occur (Allen 1990).

In summary, the major modification required to produce rubber modified asphalt concrete is a technique to properly proportion the rubber and aggregate.

2. Performance

Experiences of Plus Ride™ in four states, Alaska, Minnesota, California, and Virginia are discussed here. In several field trials in Alaska, PlusRide™ was found to offer superior stopping distance over conventional pavement, especially under icy road conditions. The average stopping distance at 25 mph on four projects in Alaska was 67 feet on the PlusRide™ pavement section and 91 feet on the conventional pavement section. These tests were performed at various subfreezing temperatures and show an overall reduction of 25% in stopping distance. It is believed that surface ice tends to crumble because the rubber particles in the pavement flex under traffic weight. The benefit of rubber particles was especially noticeable on high
speed and high traffic areas or where maintenance personnel could remove snow from the pavement. Roads with accumulated snow will not show improved skid resistance because the rubber particles will be prevented from flexing (Esch 1984).

Other states which have tried PlusRide™ have had mixed results. Of two field trials in Minnesota in 1984, performance on one test section was equivalent to the control with respect to cracking and skid resistance. A second section performed very poorly and had to be repaved within one year (Allen 1990). A trial in California produced a pavement which broke up surface ice. However, the asphalt rubber pavement did not last as long as conventional pavements (Duenno 1991). Tests in Virginia with RUMAC containing 3% rubber in 1983 provided disappointing results. The test section broke up and had to be removed after about 2 months (Hughes 1985). All three of these states attributed the problems to construction difficulties. The PlusRide™ system, as with non-proprietary RUMAC, is very unforgiving with regards to mix and construction specifications. Unless the mix and placement is tightly controlled to prevent deviations from specified guidelines, failure will result (Hughes 1985).

In general, tests have shown RUMAC to offer superior fatigue crack resistance but inferior resistance to ravelling and formation of potholes compared to conventional pavement mixtures. This is due to difficulties in obtaining low air void content in the field because sufficient mineral filler is difficult to obtain. The performance of RUMAC is very sensitive to deviations from mix and construction specifications.

There are very limited data concerning field trials of generic or unlicensed RUMAC. North Carolina has plans to place three test sections using non-proprietary variations of PlusRide™ in 1991.

3. cost

The in place cost of PlusRide™ is two to three times that of conventional asphalt. This cost increase is attributed to the cost of the rubber, the increased mixing costs relating to special aggregate gradations, the increased attention needed during mixing and construction and the limited number of proficient RUMAC paving companies. As more RUMAC field trials are laid and contractors become more confident in the product, the cost of this pavement should fall. In addition, as increased studies and field trials are performed using the generic versions of RUMAC, the price should decrease making these pavement types more attractive to state transportation departments.
4. Potential Tire Utilization in North Carolina

The North Carolina Department of Transportation (NCDOT) laid 3,141,000 tons of hot mix asphalt in its resurfacing program in 1990. Table 3 shows the quantity of waste tires the NCDOT could utilize given various rates of use of rubber modified asphalt concrete.

Table 3
Waste Tires Utilized Annually with Rubber Modified Asphalt Concrete

<table>
<thead>
<tr>
<th>Rate of Use (a)</th>
<th>Waste Tires Utilized (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>1,570,000</td>
</tr>
<tr>
<td>25%</td>
<td>3,930,000</td>
</tr>
<tr>
<td>50%</td>
<td>7,850,000</td>
</tr>
<tr>
<td>75%</td>
<td>11,780,000</td>
</tr>
<tr>
<td>100%</td>
<td>15,700,000</td>
</tr>
</tbody>
</table>

a. The percentage of asphalt pavement projects which use RUMAC.
b. Calculated by multiplying the amount of hot mix asphalt concrete (HMAC) used in North Carolina in 1990 for resurfacing (3.141 million tons) by a rate of use and by the percent of rubber in the HMAC (3%), and divided by the amount of usable rubber in a tire (12 lbs).

5. Conclusion

When constructed correctly RUMAC has been shown to be a superior pavement for icy road conditions. The cost limits its widespread use but this should decline as more field trials, especially of the generic version, are performed. RUMAC’s ability to utilize large numbers of tires is evident from Table 3. If only 25% of the overlay projects in North Carolina used RUMAC, over 50% of the states waste tires would be utilized. Installation procedures and the unique gradation requirements of RUMAC have been a major problem to date. This problem will hopefully be reduced with more construction experience.

One unanswered question is the issue of recyclability of rubber modified asphalt concretes. Very little has been done to study the recyclability of RUMAC. Currently North Carolina uses more than 20% recycled pavement in their full depth asphalt concrete projects and this percentage is expected to rise. Thus, uncertainty of the recyclability of RUMAC needs to be addressed before widespread use of this product is adopted.
C. Summary of Reuse of Tires in Asphalt Paving Mixtures

There are five methods for use of tires in asphalt; asphalt rubber crack sealing, asphalt rubber seal coating, asphalt rubber stress absorbing membrane interlayers, asphalt rubber concrete, and rubber modified asphalt concrete. Only the last two methods provide a means of reusing a significant portion of North Carolina's waste tires.

Asphalt rubber concrete involves melting ground tire chips into asphalt cement and is used as a binder for aggregate particles in the asphalt concrete mix. The only additional equipment needed to utilize ground tires in asphalt binder is a special blending unit to mix the asphalt and rubber. Asphalt rubber concretes utilizing the patented method have been tested for many years. Though it generally provides a superior pavement, the 150% to 200% increase in cost is often too high for many state transportation departments. This method could potentially utilize 11.3% of the state's waste tires. A relatively new asphalt rubber concrete technology using non-proprietary 5% and 15% rubber has been field tested in Florida with promising results. This method only costs 10% more than conventional asphalt concrete and could potentially utilize 28% of North Carolina's annual waste tire generation.

Rubber modified asphalt concrete uses 2% to 5% ground rubber chips to replace a portion of the aggregate in the asphalt concrete mix. The major modification needed to the conventional asphalt concrete process involves developing a technique to properly proportion the rubber chips and aggregate. When constructed properly, this technology has provided a superior pavement. Its price makes it somewhat restrictive for widespread use but this should decline as more field trials, especially of the generic version, are performed. The use of rubber modified asphalt concretes could potentially use 262% of North Carolina's annual scrap tire generation.

Proper installation has been a major problem to date.

One unanswered question concerning all rubberized asphalt concretes is the issue of recyclability of rubber modified asphalt concretes. Very little has been done to study the recyclability of asphalt rubber concretes or rubber modified asphalt concretes. Recycled pavement is that which has been excavated, mixed with rejuvenating agents and placed as new pavement. North Carolina uses more than 20% recycled pavement in its full depth asphalt concrete projects and this percentage is increasing.
V. Incineration of Tires for Energy Recovery

One resource recovery alternative for tires is incineration with energy recovery. Tires may be burned in either dedicated incinerators or in certain industrial boilers. The potential for burning tires in dedicated tire to energy incinerators, pulp and paper mill boilers and cement kilns is evaluated in this section.

Tires have several advantages over coal as a fuel. While coal yields between 11,000 and 13,500 BTU/lb., both whole tires and tire derived fuel chips yield 13,000 to 15,000 BTU/lb (OMOE 1991). For purposes of this study we will use the following BTU values; whole tires - 13,500 BTU/lb, shredded tires (larger than 2” by 2”) - 13,500 BTU/lb and dewired shredded tires (smaller than 2” by 2”) - 14,500 BTU/lb. A second advantage of tire derived fuel relative to coal is its lower sulfur and nitrogen content which results in reduced emissions of sulfur and nitrogen oxides. However, zinc and particulate emissions increase when tire derived fuel (TDF) is used.

A. Tires as Fuel in Dedicated Tire to Energy Facilities

There are currently two dedicated tire incinerators which burn tires for energy in the United States. Both plants are owned and operated by Oxford Energy of Santa Rosa, California. The plants are located in Modesto, California and Sterling, Connecticut. The Modesto plant has been in operation since 1987 and is designed to produce 14.5 MW of energy, process 4.5 million tires annually and provide electricity for nearly 15,000 homes. The Sterling plant has been operating since July, 1991 and is designed to produce 30MW, process 9 million tires annually and supply 30,000 New England homes with electricity. Oxford Energy is planning three more tire to energy facilities which, when completed, will bring Oxford's tire utilization capacity to over 50 million tires a year (Horn 1991). Two of the plants are projected to be operational by 1995.

Operation of Oxford tire incinerators as well as environmental considerations, economic characteristics and the future plans of Oxford Energy are presented here.

1. Facility Operation

Operation of an Oxford tire to energy facility can be divided into four parts: collection and separation, combustion and energy recovery, air pollution control and by-product disposal.
a. Collection and Separation

A subsidiary of Oxford Energy, Oxford Tire Recycling, provides the parent company with a tire collection and transportation network. In addition, the facility in Modesto was constructed next to a pile of nearly 40 million scrap tires; nearly 33% of which have been burned for energy since 1987 (Horn 1991). Oxford pays the owner of this pile $24 a ton or 24 cents a tire for their use (Kearney 1990). Oxford Tire Recycling currently obtains tires from local tire collectors and is paid for the service of removing them. The local tire collectors include county and private landfills, private monofills, individual tire dealers and tire brokers who collect tires to make a profit on those which can be retreaded. The fee that Oxford Tire Recycling charges for each tire is dependent on whether the tires are being delivered or collected, local tipping fees and the quality and quantity of the tires. Currently, the company actively collects tires in the Northeast and in the West. An increase in collection will proceed simultaneously with further development of the three additional tire to energy facilities (Greenstein 1991).

Collected tires are separated to identify those which can be sold to retreaders or other tire reclaimers. Reclaimers use the tires for rubberized asphalts, low grade molded or extruded rubber products such as mudflaps or mats, and as a supplemental fuel for cement kilns or paper mills. The majority of the collected tires serve to fuel Oxford's incinerators (Greenstein 1991).

b. Energy production

Whole tires are placed on a conveyor which batch feeds the combustion chamber through an air lock system. Tires are moved through the combustion chamber on a reciprocating grate which allows free air flow (Anon. 1988). The reciprocating grate is composed of thousands of moving bars which create a wave-like action to carry tires through the combustion chamber. The grate is made of an alloy to resist metal slag adherence. This would otherwise present a problem as the steel reinforcement in tires melts during combustion (Anon., 1988). The chamber accepts tires as large as 4 ft in diameter. The temperature in the combustion chamber is 2000°F to 2500°F (Sekscienski 1989). The heat produced by tire combustion is used to produce steam which powers a turbine for electricity generation. The electricity is then sold to a local electrical company.
c. Air Pollution Control

The Oxford Energy pollution control program is regarded as highly effective by both the Environmental Protection Agency (Sekscienski 1989) and the Stanislaus County, California Air Pollution Control Authority (Reeves 1991). Air pollution is controlled in three stages. The first stage removes nitrous oxides (NO,) which are a primary component of smog. Ammonia or urea (both soluble weakly basic compounds) are injected into the flue where exhaust gases are between 1300°F and 2200°F. The ammonia or urea convert up to 80% of the nitrous oxides to harmless nitrogen and water vapor. The process works best between 1700°F to 1800°F and initial problems at the Modesto plant involved proper placement of the ammonia injectors in the stack where gases were in this temperature range. During the first several years of energy production, the plant was consistently at or near their regulated nitrous oxide emission levels. Modifications to the plant including repositioning of the ammonia injectors to correct the nitrous oxide emission problem were completed in 1991.

The second stage of the pollution control system is a fabric filter baghouse which removes up to 90% of the particulate matter in the combustion gases (Sekscienski 1989). The third stage is a wet scrubber which mists the combustion gases with a lime solution. This process can achieve 95% conversion of sulfur oxides to gypsum (Anon. 1988). Actual and allowable air emissions for the Modesto plant are compared in Table 4. These data indicate that the Modesto plant is well within their permitted air emission levels and the Sterling plant is expected to perform equally well.

### Table 4
Permitted and Actual Air Emissions for the Modesto Tire Incinerator

<table>
<thead>
<tr>
<th>pollutant</th>
<th>Permitted Emissions (lbs/day)</th>
<th>Actual Emissions (lbs/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>particulate matter</td>
<td>113</td>
<td>30</td>
</tr>
<tr>
<td>nitrous oxides</td>
<td>500</td>
<td>420</td>
</tr>
<tr>
<td>sulfur oxides</td>
<td>250</td>
<td>150</td>
</tr>
<tr>
<td>carbon monoxide</td>
<td>346.3</td>
<td>1 10-320</td>
</tr>
</tbody>
</table>

a. Data represent averages for 1990.
d. By-product disposal

The major by-products from tire incineration at the Oxford facility fall into three categories; ferrous slag ash, baghouse ash and gypsum. The combustion chamber ash or bottom ash is composed primarily of ferrous slag. It is the remains of the bead wire and steel belts from radial tires. The slag falls through the reciprocating grate to the bottom of the combustion chamber where it is collected and sold to the cement industry for use as a raw material in cement. The fly ash captured by the baghouse is predominantly zinc calcine. It is sold to a metal refiner who recovers the zinc. Gypsum, the by-product of the sulfur oxide wet scrubber is sold to farmers as a soil conditioner (Valenti 1991).

By recycling the bottom ash, fly ash and gypsum, no direct landfilling of Oxford Energy by-products occurs. This recycling program is not profitable, though close to break-even (Kearney 1990).

2. Economic Characteristics

The 30MW plant in Sterling, Connecticut reportedly cost over $100 million to construct and the pay back period for this plant is estimated to be over eight years (Kearney 1990). Oxford Energy has not been profitable since 1987. The Modesto tire to energy facility posted operating losses of nearly $3.1 million in 1989 and $2.4 million in 1990. These losses are largely attributed to the high capital cost of modifications made to improve plant efficiency. Modifications included mechanical conveyors to replace the costly manual ash handling system, construction of mechanical evaporators to replace the evaporation ponds for the plant's waste water, modifications to the nitrous oxide treatment system, and the pinning together of the grate bars in the combustion chamber to improve their durability. These modifications are now complete and were incorporated into the initial construction of the Sterling plant. It should be noted that the Modesto plant posted a small operating profit during the first quarter of 1991 (Oxford Energy 1990).

A second factor leading to the economic problems of Oxford Energy is losses incurred by the company's tire collection subsidiary, Oxford Tire Recycling. The subsidiary accounted for over 40% of the parent company's losses. Oxford Tire Recycling was forced to greatly expand its collection network in preparation for the opening of its Sterling plant. However, the increased tire collection prior to the Sterling plant's opening forced the company to use very costly disposal methods. Now that the plant is fully operational these more costly disposal methods will not be necessary (Oxford Energy 1990).
3. Future Tire to Energy Facilities

The high capital costs associated with tire to energy facilities restricts the regions of the U. S. where a plant is economically feasible. The primary siting requirement is a steady, plentiful supply of tires within close proximity of the tire to energy facility. This requirement generally calls for a minimum of 10 million tires per year within a 150 mile radius of the tire to energy facility (Ruth 1991). Also, areas with a need for electricity and which have relatively high electrical rates are favorable for location of a plant. Other factors include legislation and a community's willingness to accept an incinerator. Oxford Energy will not site a plant where local legislation forbids incineration or where the population is hostile.

These strict siting requirements have led Oxford Energy to initiate development of only three additional tire to energy facilities. The first of these is the Moapa Energy Project in Nevada which was sited primarily because of the urgent need for electricity in that area and the associated high electrical rates. This plant will be constructed 50 miles northwest of Las Vegas, process over 15 million tires annually and produce 49.5 MW of power. This facility will draw its tires from across the Southwest. The Erie Energy Project in Lackawanna, New York will be a 30MW facility capable of processing over 9 million tires annually. This project was sited primarily because of the ready supply and close proximity of tires resulting from the densely populated northeast and the tax benefits offered to Oxford Energy. Both the Moapa and Erie projects are expected to be operational within 5 years (Horn 1991). Oxford Energy is also developing plans for a 30 MW facility in Michigan. This project is in the early-stages of development and a specific location for the plant has not yet been selected (Oxford Energy 1990). Currently the company has made no efforts to site tire to energy facilities in the southern, central or northwestern parts of the United States siting low population densities and inexpensive electrical rates (Horn 1991).

4. Conclusion

Oxford Energy has the immediate potential to consume a large part of the waste tire stream in the western, upper midwestern and northeastern parts of the country. Plants currently running and those in development could potentially utilize over 50 million tires annually. The plants have proven their environmental integrity in California. Wide scale implementation of tire to energy facilities; however, will be wholly dependent on Oxford's ability to turn a profit, something the company has had difficulty achieving. The company hopes that with the completion of its Sterling plant and modifications to its Modesto plant, profitability will increase.
B. Use of Tires as Fuel for the Pulp and Paper Industry

Pulp and paper production is an energy intensive process and most pulp and paper mills have their own boilers and turbines to meet their electrical needs. The wood scrap and bark that remain after the useable wood has been converted to pulp is often burned in pulp and paper mill boilers and is referred to as hog fuel. The American Paper Institute reports that 351 pulp and paper mills in the United States burned 393 trillion BTUs of hog fuel in 1989 (Kearney 1990). One problem with burning wood is the variability of its moisture content. The moisture content of hog fuel is typically between 40% and 55% but can be higher on rainy days or with especially wet wood (Jones 1990). Supplementary fuels such as gas, oil or coal are often used to aid the combustion of hog fuel and to stabilize boiler operations when moisture in the wood reduces boiler efficiency. The need for energy to supplement high moisture hog fuel provides an opportunity for the utilization of tires by the pulp and paper industry. Tire derived fuel (TDF) can be used to replace fossil fuels, especially coal, as a boiler stabilizer fuel. Mill boilers can typically burn between 2% and 10% TDF on a BTU basis. The use of TDF by the pulp and paper industry has gradually increased since its initial use in the mid-1970's. A 1990 report by the Scrap Tire Management Council estimates that nearly 13 million tires are used by at least 12 mills in the US. (Kearney 1990). A description of the technological, environmental, and economic characteristics of TDF as a supplementary fuel source for the pulp and paper industry is presented in this section. The potential use of TDF by paper mills in North Carolina is also discussed.

1. Technology Description

Paper mills which burn hog fuel are typically the only ones which can utilize tires. This is because hog fuel is burned in multifuel boilers which have grates in the combustion chamber. Historically grate system boilers have been easily adapted to use a variety of fuels. A brief description of conventional multifuel boiler systems and how they can be modified to incorporate TDF is presented in this section.

Bark and other wood waste is collected and placed on a conveyor which discharges into a pulverizer. The pulverizer grinds the wood waste into easily combustible chips. These chips are what is termed hog fuel. The hog fuel is placed on an elevator conveyor which discharges into a live bottom hopper. A live bottom hopper is a conical shaped storage bin which depends on mechanical agitation to discharge hog fuel at a metered rate. Various types of mechanical metered dischargers can be used to feed hog fuel to a combustion chamber stoker. The most
common is a screwfeeder. The combustion chamber stoker, typically a mechanical throwing device or an air fed blower, distributes hog fuel across the chamber grate. The grate allows free air flow for complete combustion. The heat released during combustion is used to produce steam which powers a turbine for power generation.

The only modification to this process required for utilization of TDF is an addition to the fuel feed system. A method for metering tire chips and thoroughly mixing them with the hog fuel is required. This usually involves the installation of a live bottom TDF hopper. A gravity fed hopper cannot be used because tire chips will bridge the hopper outlet. The hopper discharges onto the hog fuel conveyor at a metered rate to optimize the TDF/hog fuel mixture.

Paper mills generally purchase TDF from a local shredder. The optimum TDF particle is dewired and 2" by 1/16" (Jones 1990). Dewiring is necessary for two reasons. First, it is necessary to reduce metal contamination of the ash which otherwise would greatly complicate its disposal. Mills with landfills which do not have leachate collection and treatment systems are particularly sensitive to the high metal content of boiler ash. Secondly, dewired TDF prevents adherence of metal slag to the grate system. This would clog the grate and prevent free air flow. This would in turn limit combustion, resulting in lower boiler efficiency. There are varying degrees of dewiring required depending on a mills fuel feed, combustion grate and ash disposal system. For example, mills which have combustion grates with large gaps between the bars and a landfill with leachate collection and treatment could burn tires with a higher wire content than a mill that did not possess these characteristics. Champion Paper in Bucksport, Maine requires 95% wire removal and this appears to be typical among mills which use TDF (Harrison 1991).

2. Environmental Considerations

The two areas of environmental concern in pulp and paper mill boilers are air pollution and ash disposal. The primary air pollutants released during multifuel boiler operation are sulfur oxides, nitrous oxides, and particulate matter. Sulfur emissions are usually reduced when TDF is substituted for coal (Jones 1990). This is particularly true of coal mined in the eastern U. S. which can have double the sulfur content of TDF on a BTU basis. Coal mined in the western part of the nation generally has a slightly lower sulfur content than TDF on a BTU basis. Approximately 0.85, 1.74, and 0.70 lbs of sulfur are released from the combustion chamber for each million BTU of TDF, eastern coal, and western coal, respectively. Nitrous oxide emissions are also lower when TDF is substituted for coal. For every one million BTU of TDF
and coal burned, approximately 0.17 lbs and 1.53 lbs of nitrogen are released from the combustion chamber, respectively.

The third air pollutant of concern, particulate matter, typically increases when tires are substituted for coal. Particulate emissions are usually controlled by limiting the amount of TDF burned to less than 10% of the total fuel input on a BTU basis, and by the use of effective particulate removal systems. Mills with electrostatic precipitators are able to burn up to 10% TDF on a BTU basis and still meet air pollution control requirements (Gray 1991). Mills with other particulate removal systems, such as mechanical collectors in combination with wet scrubbers, may have to limit TDF combustion to 2.5% in order to comply with their regulated particulate emission levels (OMOE 1991).

Ash collected at the bottom of the combustion chamber (bottom ash) and by the particulate matter removal system (fly ash) is a second environmental concern of multifuel combustion. Ash which remains following combustion of hog fuel with TDF may contain as much as 1500% more zinc than if coal had been used as the stabilizer fuel (Kearney 1990). However, cadmium, chromium and lead concentrations in boiler ash are all reduced when TDF is used (Kearney 1990). Generally, before mills are allowed to burn tires they must demonstrate that they can properly dispose of high zinc ash. Zinc recovery is not economically feasible with multifuel boiler ash due to its low concentration.

3. Economic Characteristics

The capital investment needed to incorporate TDF in multifuel boilers is typically limited to the cost of TDF storage and metering equipment and the cost of environmental permit modifications. The total capital investment is estimated at between $150,000 and $350,000 (Kearney 1990).

Generally TDF is cheaper than coal on a BTU basis but this depends on several factors. The first factor is the paper mill's current fuel purchase agreements. The second factor is tipping fees available to local TDF producers which correspondingly affects the price of TDF. The last factor is the location of the paper mill and the resulting TDF transportation costs. Taking all these factors into account, the average cost to a paper mill for dewired TDF is between $1.00 and $1.70 per million BTU. The cost of coal to paper mills is generally between $1.60 and $2.00 per million BTU (Kearney 1990). Thus, there are cases where TDF would be an economically viable alternative fuel. As pressure to reduce land disposal of tires increases, the fee paid to a TDF producer for accepting tires is likely to increase, thus decreasing the cost of TDF to an end user.
4. Case Studies

Three mills which have tried burning tires or are currently burning tires for resource recovery are discussed here. Inland-Rome Incorporated of Rome, Georgia has been burning TDF for several years. They currently burn between 4% and 5% TDF on a BTU basis. The mill has a multi-clone mechanical dust collector and an electrostatic precipitator. The mill has not had trouble meeting their prescribed particulate emission level. In addition, the mill does not have sulfur scrubbers and the use of TDF has reduced sulfur emissions relative to coal (Jones 1991).

Champion International Paper in Bucksport, Maine burns approximately 8% TDF on a BTU basis. The plant is equipped with a mechanical dust collector and a wet scrubber and has had no air pollution permit problems (Harrison 1991).

Port Townsend Paper in Port Townsend, Washington attempted burning tires but was forced to cease this activity in 1989 because they were unable to remain under their regulated particulate emission levels. The problem was attributed to a faulty wet scrubber which was subsequently replaced. The mill has had continuing problems with the new scrubber and as a result particulate emissions have remained near their regulated levels. The plant is not willing to test burn TDF again until problems with the new scrubber are resolved (Gould 1991).

5. Potential Utilization of Tires as a Fuel for Paper Mills in North Carolina

In order for a pulp or paper mill to consider the use of TDF, several criteria must be considered. These include:

1. The boilers must have grates in the combustion chamber.
2. The boiler must have a particulate matter removal system which will be able to handle the increased particulate emissions that occur when TDF is substituted as the stabilizer fuel. Generally mills with electrostatic precipitators or baghouses are considered to be the best equipped to control particulate emissions.
3. Mills which are extremely far from population centers and consequently far from the source of tires will not have good access to competitively priced TDF.
4. Mills which have landfills which are not permitted for disposal of high zinc ash will not be able to use TDF without expensive landfill modifications.

One additional factor is whether a mill is being protected from current environmental pollution standards by grandfather clauses. Grandfather clauses allow variances from air
pollution regulations where such regulations were enacted after the mill was constructed. Typically a mill is given a certain length of time to meet current regulations. In order to implement a TDF utilization process, the mill would have to renegotiate its permit, thus losing its grandfather protection prematurely.

Analysis of every pulp and paper mill in North Carolina to determine its exact potential for utilizing TDF was beyond the scope of this study. However, the seven mills in North Carolina with the greatest potential for utilizing TDF are listed in Table 6. Mills are listed in descending order of likelihood. The location of these mills is illustrated in Figure 1.

Table 6
North Carolina Pulp and Paper Mills With the Potential to Utilize Tire Derived Fuel

<table>
<thead>
<tr>
<th>Mill, Locationa</th>
<th>Distance, City</th>
<th>Current Fuelsb</th>
<th>Particulate Controlc</th>
<th>Potential Tire Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abitibi-Price, Roaring River</td>
<td>Winston-Salem, 60 mi</td>
<td>WW,O</td>
<td>MC,WS</td>
<td>0.425</td>
</tr>
<tr>
<td>Weyerhauser, New Bern</td>
<td>Raleigh, 110 mi</td>
<td>OB</td>
<td>MC,EDS</td>
<td>0.54</td>
</tr>
<tr>
<td>Champion Paper, Roanoke Rapids</td>
<td>Raleigh, 90 mi</td>
<td>O,C,B</td>
<td>MC,WS</td>
<td>0.73</td>
</tr>
<tr>
<td>Federal Paper, Riegelwood</td>
<td>Wilmington, 25 mi</td>
<td>B,C,O,G</td>
<td>MC,WS</td>
<td>0.85</td>
</tr>
<tr>
<td>Weyerhauser, Plymouth</td>
<td>Raleigh, 125 mi</td>
<td>WW,C</td>
<td>MC,EDS</td>
<td>2.0</td>
</tr>
<tr>
<td>Champion Paper, Canton</td>
<td>Asheville, 25 mi</td>
<td>B,C,O</td>
<td>MC,WS</td>
<td>0.34</td>
</tr>
<tr>
<td>Jackson Paper, Sylva</td>
<td>Asheville, 50 mi</td>
<td>B</td>
<td>MC,WS</td>
<td>0.13</td>
</tr>
</tbody>
</table>

**Total** 5.015

b. WW: woodwaste, O: Oil, C: Coal, B: Bark, G: Gas
c. MC: mechanical dust collector, WS: wet scrubber, EDS: electrical dry scrubber
d. Expressed as millions of tires. Potential annual tire use calculated by multiplying multifuel boiler average intake in BTU/year by percentage of possible TDF use (4%), divided by BTU value of TDF (14,500 BTU/lb), and divided by the number of pounds of TDF in one tire after shredding and dewiring (16 lb).

The order of likelihood was determined by considering each plant's current fuel source, environmental pollution control systems, size, and proximity to a population center. Air
Figure 1
Pulp and Paper Mills in North Carolina with Coal/Bark Multi-Fuel Boilers
pollution permits were not considered although this could alter the order in Table 6. Abitibi-
Price is at the top of the list because they have already burned TDF in trials and have
demonstrated that they can remain within their regulated sulfur oxide, nitrous oxide and
particulate emission levels. However, trace emissions of heavy metals occurred and the plant is
currently studying ways to correct this problem.

As shown in Table 6, there is a large potential market for TDF in North Carolina. If
each one of these mills burned tires as 4% of their total fuel needs, over 5 million tires would
be utilized annually.

6. Conclusion

Burning tires as a supplementary fuel for pulp and paper mills has proven to be
economically feasible and environmentally safe. The limited capital expense required to
incorporate tires as a fuel and their competitive cost relative to coal makes them a very
attractive alternative fuel for the pulp and paper industry. There are several mills in North
Carolina which are potential candidates for TDF. One plant has already performed a test burn
with positive results. The utilization of TDF by North Carolina paper mills could consume over
80% of the state’s annual tire generation.
C. Use of Tires as a Supplemental Fuel Source for Cement Kilns

Cement production is an energy intensive process and there is potential for tires to help meet the energy needs of the cement industry. There are over 200 cement kilns in the U. S. with an estimated energy requirement of approximately 3,000 trillion BTUs a year (calculated as described in Table 7, note C). Previous experience with the use of waste tires as an alternative energy source for cement kilns has been successful. A large portion of scrap tires generated in Europe are burned for energy recovery by the cement industry. Over 37% of Germany's waste tires are incinerated by cement kilns (OMOE 1991). There are two cement kilns in the U. S. which use tires as a supplementary fuel source and another five have tried TDF on an experimental basis (Kearney 1990). A description of the cement production process, environmental and economic factors which must be considered in the use of TDF by the cement industry, and an estimate of potential tire use by regional kilns are presented in this section.

1. Technology Description

The cement production process and modifications to the process required to utilize TDF are presented here. Raw materials used for cement production are limestone, clay or shale, and iron ore or iron waste. These materials are pulverized and then mixed in either a wet or dry process. In the wet process, raw materials are ground and mixed in slurry form. In the dry process, the grinding and mixing are performed with dry raw materials. After grinding and mixing, the raw materials are discharged into the upper end of a cement kiln. Fuel is injected in the lower or downstream side of a kiln and the raw materials are exposed to a temperature of 2600°F to 3000°F for one to four hours. The heating process causes the formation of 1/2" chunks of cement referred to as clinker. Finally, the clinker is pulverized to an extremely fine powder and a small amount of gypsum is added (Kosmatka 1988).

Over the past twenty years, the cement production process has been modified by the construction of preheaters or precalciners integrated with a shorter dry kiln. These preheaters provide about 85% calcination before the feed enters the kiln. The preheaters can be divided into two sections, one section draws heat from the kiln providing about 40% calcination and a second section, a flash furnace, increases calcination to 85% (Kosmatka 1988). Preheating technology is used for a majority of cement produced in the U. S. It is installed on any new kiln and many older plants have been modified to utilize short kiln technology.

The only modifications of a cement kiln required for the use of TDF are in the fuel feed system. Kilns with preheaters can use whole tires as a supplementary fuel source. In this case, tire storage and mechanical conveying and metering equipment must be installed to transport tires from a storage bin to the preheater. Generally kilns with preheaters can use up to 20%
tire fuel on a BTU basis in the preheater (OMOE 1991). Whole tires are supplied by local brokers and the cement company may collect a tipping fee for accepting tires.

Kilns without preheaters require that tires be shredded prior to use. Such kilns can accept TDF for about 5% of their energy requirements (OMOE 1991). In this case, TDF is blown into the bottom end of the kiln as a substitute for powdered coal. Required equipment typically consists of storage bins, conveying and metering equipment and a pneumatic blower. The shredded TDF, generally 2" by 2" to 4" by 4", is bought from local shredders and stored on the plant premises. In summary, with minimal modifications to the fuel feed system, a kiln can use TDF for 5% to 25% of its energy needs.

2. Environmental Considerations

The primary pollutants produced during fuel combustion are bottom ash, fly ash, and sulfur and nitrous oxides. Cement kilns are generally equipped with baghouses which offer excellent particulate control. Fly ash recovered by the baghouse is typically remixed in the cement as a raw material. Cement kilns do not produce bottom ash as other types of incinerators, but rather non-combustibles in the fuel are incorporated into the cement. The non-combustible fraction usually contains a large amount of ferrous (iron) slag which is a raw material in cement. Thus, the iron content of TDF is advantageous. Sulfur released during the combustion of TDF or coal is incorporated into the calcining limestone to form gypsum, another raw material of cement. Thus sulfur emissions are not a concern in cement production. Finally, nitrous oxide is reduced when TDF is substituted for coal as tires have about 11% of the nitrogen content of coal on a BTU basis (OMOE 1991).

In summary, the use of tires for energy in cement kilns reduces nitrous oxide emissions and has no adverse impact on particulate and sulfur emissions.

3. Economic Considerations

The use of whole tires as a supplementary fuel source in kilns with preheaters requires the purchase of storage equipment and mechanical conveying and metering systems. These systems generally cost between $250,000 and $500,000. Capital costs for modifications to kilns which utilize TDF are between $60,000 and $100,000 (Kearney 1990). The lower capital cost associated with shredded TDF use is due to the fact that whole tire handling and storage equipment is more expensive. These cost estimates assume that shredded TDF is produced by a third party vendor.

Though the capital costs for modifications to plants without preheaters are generally less, the use of tires is generally considered more attractive to kilns with preheaters because whole tires rather than shredded TDF can be utilized. The cost of shredded TDF to a cement plant is
about $1 per million BTU. However, a plant using whole tires can charge a tipping fee, or pay only for the transportation costs associated with moving tires from collection centers to the plant. A 1990 study by the Scrap Tire Management Council estimates that for tires to be an attractive alternative fuel source for cement kilns, whole tires must be supplied at a total cost of $21 to $28/ton (or about $0.25 per tire) and TDF needs to be supplied at a price slightly less than coal which costs approximately $35 to $45/ton (Kearney 1990). Thus, kilns with local access to a large supply of tires and which can charge a tipping fee for the disposal of tires could potentially be very profitable.

Another economic advantage of using tires as a supplemental fuel source is that the steel reinforcement present in tires is completely oxidized to iron oxide during the calcining process. In that iron is a basic ingredient of cement, the use of tires as a fuel reduces raw material costs. This also applies to the gypsum which is formed when the sulfur in tire rubber reacts with limestone in the kiln.

4. Case Studies

The use of TDF in three cement kilns in the U. S. is discussed here. Calaveras Cement of Redding, California has been the pioneer in the U. S. for utilizing tires as an alternative fuel for the cement industry. The Calaveras facility is a dry-process kiln equipped with a preheater. The plant utilizes whole tires in the preheater section and blows shredded TDF into the kiln. The plant has utilized 25% TDF on a BTU basis for over 5 years. Approximately 2 million tires are used annually (Jacinta 1991). The kiln reports having no fuel costs when using tires and a 50% reduction in iron ore costs because of the iron present in the steel reinforcement in radial tires (Kearney 1990).

Arizona Portland Cement of Rillito, Arizona has four dry process kilns, including one equipped with a preheater. The kiln equipped with the preheater uses 10% TDF (2" by 2") on a BTU basis and consumes approximately three million tires a year (Bittle 1991). Arizona Portland Cement pays the city of Tuscon $20/ton or $0.75 per MM BTU for the tires to cover the city's freight and shredding costs (Kearney 1990).

A cement kiln in South Carolina, Gifford-Hill of Harleyville, test burned tires in May, 1990. The facility had planned to continue use of TDF in a joint venture with Oxford Tire Recycling and Radian Corporation. However, the kiln was recently sold and the fate of this project as of the summer of 1991 is uncertain (Greenstein, 1991).
5. Potential Utilization of Tires by Regional Cement Kilns

There are no cement kilns in North Carolina so the state will have to look to kilns elsewhere in the Southeast to dispose of its waste tires. There are seven kilns within a reasonable distance of North Carolina population centers. A map of all the cement kilns in the Southeast is presented in Figure 2. Though the exact potential of each kiln to utilize tires as a supplemental fuel source was beyond the scope of this study, an estimate of the potential tire use of the seven closest kilns was performed. These data are presented in Table 7.

Table 7
Potential Tire Utilization by Cement Kilns Bordering North Carolina

<table>
<thead>
<tr>
<th>Company, Location</th>
<th>Kiln City, Distance</th>
<th>Type</th>
<th>Capacity (10^6 tons/yr)</th>
<th>Potential Tire Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santee, Holly Hill, SC</td>
<td>Charlotte, 150 mi</td>
<td>Wet</td>
<td>1.053</td>
<td>0.88</td>
</tr>
<tr>
<td>Giant, Harleyville, SC</td>
<td>Charlotte, 150 mi</td>
<td>Wet</td>
<td>0.813</td>
<td>0.68</td>
</tr>
<tr>
<td>Blue Circle, Harleyville, SC</td>
<td>Charlotte, 150 mi</td>
<td>Dry (pc)</td>
<td>0.645</td>
<td>1.64</td>
</tr>
<tr>
<td>Blue Circle, Atlanta, GA</td>
<td>Charlotte, 250 mi</td>
<td>Dry</td>
<td>0.612</td>
<td>0.39</td>
</tr>
<tr>
<td>Southwestern, Knoxville, TN</td>
<td>Asheville, 125 mi</td>
<td>Dry (pc)</td>
<td>0.6</td>
<td>1.53</td>
</tr>
<tr>
<td>Signal Mt., Chattanooga, TN</td>
<td>Asheville, 200 mi</td>
<td>Wet</td>
<td>0.45</td>
<td>0.38</td>
</tr>
<tr>
<td>Tarmac-Lonestar, Cloverdale, VA</td>
<td>Win.-Sal., 100 mi</td>
<td>Dry (pc)</td>
<td>1.1</td>
<td>1.73</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>7.23</strong></td>
<td></td>
</tr>
</tbody>
</table>

a. Kiln location, type and capacity as reported by the Portland Cement Association (1990).
b. Type of kiln, either wet process or dry process; (pc) - kiln has a precalciner.
c. Annual clinker production.
d. Expressed as millions of tires. Potential tire use calculated as follows:
   (1) dry process: assume 3.44 MMBTU/ton product, 5% utilization of tires on a BTU basis, 13,500 BTU/lb-tires and 20lb/tire
   (2) dry process with precalciner: assume 3.44 MMBTU/ton product, 20% utilization of tires on a BTU basis, 13,500 BTU/lb-tires and 20lb/tire
   (3) wet process: assume 45 MMBTU/ton product, 5% utilization of tires on a BTU basis, 13,500 BTU/lb-tires and 20lb/tire
e. One of Tarmac-Lonestar’s kilns (capacity 540,000 tons/year) has a preheater.
Figure 2
Portland Cement Plants in the Southeast

Annual Gray Cement Capacity
- <500,000 tons
- 500,000-900,000 tons
- >900,000 tons
The data in Table 7 indicate that there is significant potential to utilize North Carolina's waste tires by regional cement kilns. Of course, there may be regulatory or political factors which will restrict implementation of this alternative for utilization of waste tires produced in North Carolina. Nevertheless, cement kilns in the southeast represent a viable alternative for resource recovery of tires produced in close proximity to each kiln.

6. Conclusion

Incineration of tires for energy recovery by the cement industry has proven to be an economically viable and environmentally sound method for disposing of this particularly troublesome component of the solid waste stream. The environmental record on tire incineration in cement kilns is excellent as most of the pollutants become incorporated as raw materials in the cement production process. The limited capital required and the opportunity to obtain an inexpensive fuel source has made the economics of this resource recovery alternative attractive. There are several cement kilns in the southeast with the potential to utilize tires generated both in North Carolina and in each kiln's home state.
VI. Summary and Conclusion

The U. S. disposes of an estimated 175-205 million tires in landfills and stockpiles each year. North Carolina's portion of this sum is estimated to be six million tires. This study investigated four of the most promising resource recovery alternatives for waste tires: reuse in asphalt pavement, use as fuel in dedicated tire to energy facilities, and use as supplemental fuel in pulp and paper mill boilers and cement kilns.

There are five methods for reusing waste tires in asphalt pavement. The number of tires which could be consumed using each technology is reported based on road pavement activity in North Carolina. The first method for reusing waste tires in asphalt paving mixtures is as asphalt rubber crack sealants which are a mixture of approximately 20% rubber and 80% asphalt. Though potential tire utilization is less than 50,000 per year, this technology is superior to all other sealants and cost effective. The second method for use of rubber in asphalt is a patented process for an asphalt rubber seal coat which uses 20% to 26% rubber mixed with asphalt as the binder for a seal. The incorporation of tire rubber in seal coats would consume approximately 220,000 tires annually. This technology has had extensive testing with good results. The third method for use of rubber in asphalt is an asphalt rubber stress absorbing membrane interlayer. This is an asphalt rubber seal coat immediately followed by a full pavement overlay. The results of projects using interlayers have been good but the cost can be excessive and potential utilization in North Carolina is small relative to generation rates.

The fourth method for use of rubber in asphalt is asphalt rubber concrete which is a mixture of melted rubber in asphalt. There are two methods for use of rubber in hot mix asphalt; (1) a proprietary method which uses 18% to 26% rubber by weight of binder and (2) a non-proprietary method in which 5% to 15% rubber by weight of binder is used. The proprietary method has proven its ability to provide a superior road surface but can cost twice as much as conventional asphalt concrete projects. The non-proprietary method has not been fully field tested but preliminary data suggest that performance results will be superior to conventional asphalt concrete with a cost increase of only 10%. If all pavement projects in North Carolina utilized tire rubber, the number of tires that the proprietary and non-proprietary methods could utilize annually are approximately 6.8 million and 1.7 million, respectively.

The fifth method evaluated for the use of rubber in pavement is rubber modified asphalt concrete. Here, rubber chips are used to replace 2% to 5% of the mineral aggregate in hot mix asphalt concretes. As with asphalt rubber concrete, there is a proprietary and a non-proprietary version of this technology. The difference between the two concerns the size of the rubber rather than the amount. Both methods are believed to offer superior road surfaces.
However, problems with proper construction have led to many failures. Another drawback to rubber modified asphalt is that it generally costs two to three times more than conventional asphalt pavements. This technology could potentially utilize the most tires of all the asphalt technologies, 15.8 million per year annually. However, the aforementioned drawbacks suggest that large scale implementation is in the future.

The use of tires as an alternative fuel source has excellent potential for using a large number of tires. Tires have several advantages over eastern coal including a higher BTU value, and lower sulfur and nitrogen concentrations. The use of tires in dedicated tire to energy plants has proven to be a technologically sound and environmentally safe method of resource recovery. Oxford Energy of Santa Rosa, California owns and operates two dedicated tire to energy facilities with a total capacity of 13.5 million tires per year. They have plans for development of at least three more facilities which will bring their total tire consumption capacity to over 50 million tires annually within 5 years. However, Oxford Energy does not have plans to construct a tire incinerator in the Southeast. In addition, the company's failure to show a profit to date casts some doubt on their ability to be a major consumer of used tires.

Utilizing tires to supplement the energy needs of pulp and paper mills has proven to be an economical and environmentally feasible method of reusing waste tires. Shredded and dewired tires are used to supplement coal in twelve pulp and paper mill boilers in the U.S. Relative to coal, tires have a higher BTU value, less sulfur and nitrogen, and often cost less, making them an attractive alternative fuel. The percentage of tires utilized in pulp and paper mill boilers is generally kept below 10% so to not exceed particulate emissions regulations. The tire utilization potential of seven of the most likely candidate mills in North Carolina is approximately five million tires per year.

The use of shredded and whole tires to supplement the fuel needs of the cement industry is practised extensively in Europe as well as at two kilns in the U.S. Most of the waste products from tire combustion are incorporated into the cement product. In addition, the low capital investment required and the potential for some kilns to charge tipping fees for burning tires leads to favorable economics. There are no cement kilns in North Carolina. However, there are several within a reasonable distance of North Carolina population centers. The potential tire utilization by these kilns is approximately 7.23 million tires per year.
VII. References


Duenno, E., California Dept. of Transportation, personal communication, July 1991.


Morris, G. R., Asphalt-Rubber Membranes Development, Use, Potential, Highways Division Research Section, Arizona Department of Transportation, Presented at the 1975 Conference of the Rubber Reclaimers Association, Cleveland, Ohio.

Murphy, K., Florida Dept. of Transportation, personal communication, July, 1991.


Pace, F., North Carolina Dept. of Transportation, personal communication, June, 1991.


Reeves, G., Stanislaus County Air Pollution Control, personal communication, July, 1991.


Turgeon, C. M., The Use of Asphalt Rubber Products in Minnesota, Minnesota Department of Transportation, 1989.

