# Energy and CO2 savings using asphalt rubber mixes

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*ABSTRACT: The need to develop cost effective construction practices is ever more urgent and important in face of the huge efforts nations are making to reduce carbon dioxide (CO2) emissions. It is therefore incumbent upon all of us to identify ways of minimizing and accounting for CO2 emission, which some consider the cause of global warming. It is also recognized that scrap tires are one of the most difficult waste products to manage in a modern society. They are not difficult individually, but are difficult collectively. The lack of adequate disposal methods and management systems in years past has lead to wide spread, cumbersome collection of scrap tires in unmanaged or poorly managed waste tire piles. Problems associated with waste tire piles typically are: threat of fire and related environmental damage from a tire pile fire and the potential increase in vectors and pests. Secondary problems are that tire piles require substantial volume or space prior to any type of processing and are an eyesore. In this paper, a cost benefit analysis is considered for three streams (end uses). The end uses analyzed are: shredding for use in landfills as Alternate Daily Cover (ADC), shredding for use as tire derived fuel (TDF), and crumb rubber production with an end use in asphalt-rubber (A-R) (as defined in ASTM D-6114)in pavement construction, rehabilitation and maintenance. The approach identifies the energy costs in Kilo-Joules and BTUs associated with each disposal method and compares the benefits in energy recovery (if any) for each process. Finally this paper addresses the benefits of using crumb rubber in asphalt rubber pavements and the savings in CO2 emissions that result from this application.*

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*KEYWORDS: scrap tires, fuel, energy, asphalt rubber, CO2 emissions, Kyoto treaty.*

## 1. Introduction

The Kyoto Protocol and others of similar scope are having more and more far reaching effects on the world economy. Countries ratifying these agreements commit themselves to reduce their emissions of carbon dioxide (CO2) and other five greenhouse gases, or engage in expensive emissions trading if they do not fulfill the reduction targets. The Kyoto Protocol now covers more than 163 countries globally and over 55% of global greenhouse gas (GHG) emissions.

As the cost of non compliance with Kyoto is prohibitive, it is very attractive for countries and industries to invest in technologies that favor emission reduction. Alternatively, technologies saving greenhouse gas emissions grant carbon certificates that can be traded internationally at very rewarding prices. Not only governments, but private or public investors as well are eligible to negotiate those certificates. Therefore companies, or highway agencies, that may want to introduce asphalt rubber in their countries, have now a unique breakthrough opportunity, as proper asphalt rubber usage does significantly reduce CO2 emissions.

Nevertheless one could equate the alternative benefits or CO2 reductions if crumb rubber from disposed tires would be used in any other alternative application. To understand the full impact of using crumb rubber form recycle tires in asphalt rubber it is important to see the benefits of using crumb rubber in alternative competing processes as the disposal of scrap tires continues to be a major waste management issue. Scrap tires must be managed and processed in some way to prevent the build up of scrap tire piles, Figure 1.

Many methods of disposal or end uses of scrap tires have evolved over the years. The objective of this paper is to compare the energy consumption or saving of three common end uses of scrap tires and to see what CO2 benefits are derived when asphalt rubber mixes are used. Alternative three common end uses include shredding for use as Alternate Daily Cover (ADC) in landfills, shredding for use as a Tire Derived Fuel (TDF) in a combustion process and crumb rubber production with an end use in asphalt-rubber (A-R) concrete pavements.

The scope of the energy consumption examination is to discuss the potential energy use or recovery benefits of each method. It should be noted that all three methods are currently in use and serve the intended purpose of removing scrap tires from the waste stream. There are many methods of scrap tire disposal that can be used; these three were chosen to represent the range options. Which method or a mix of methods used by a governmental entity to dispose of scrap tires is a function of many factors not necessarily just the potential energy recovery benefits. Nevertheless, using energy recovery benefits is a first start in judging the overall value of each method to Society in general.

**Figure 1** - *Scrap tires before processing.*

**2. Asphalt Rubber Performance**

The California Department of Transportation (Caltrans) conducted research between 1980 and 1992, which compared asphalt rubber concrete to conventional asphalt concrete (AC) in field evaluations. During this time cities and counties also experimented with asphalt rubber pavements. It was determined through these field evaluations that the asphalt rubber pavements could be significantly reduced in thickness and provide the same service life as thicker conventional AC pavements. This led to the development of a "Reduced Thickness Design Guide" by Caltrans in 1992 for asphalt rubber pavements (See Table 1). This was the same year that Caltrans began routine use of asphalt rubber pavements. The reduced thickness approach (up to 50%) was substantiated by research in South Africa in 1994 in field installations using the Heavy Vehicle Simulator (HVS), by the University of California, Berkeley in 1994 in the laboratory, by the University of Alaska, Fairbanks in 1995 in the laboratory, by CONSULPAV in 2000 in laboratory (Sousa, 2000) and by FHWA – ALF Turner Fairbanks center in 2004 (Sousa 2006, Qi 2006).

Asphalt rubber has been successfully used in chip seals, stress absorbing membrane interlayers (SAMI), hot mix (dense, gap and open graded), and especially in multi-layer systems. The advantages of using asphalt rubber strategies have been validated by many research efforts. Recently the cost-effectiveness of asphalt rubber strategies has been validated in a Life Cycle Cost Analysis research effort (Hicks, 2000)

In Arizona the average equivalent reduction in thickness between conventional mixes and AR mix is even grater because AR mixes are used with gradations that support higher AR binder content (see Figure 2). As it can be observed the ratio is very close to 3 in terms of equivalent thickness when AR is used over structurally sound pavements to resist reflective cracking.

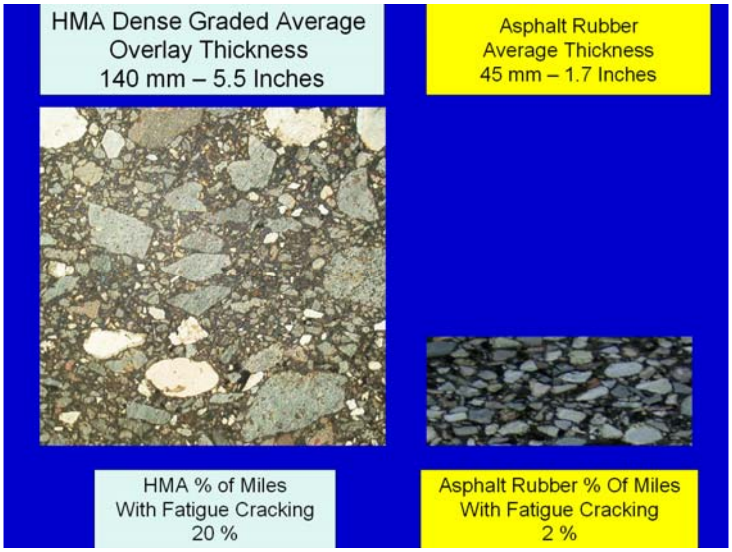


**Figure 2 –** *Comparison between equivalent thickness of AR mixes versus conventional mixes in Arizona.*

Life cycle cost analysis encouraged by the Federal Highway Administration has shown that a substantial dollar savings can be obtained over the expected life of a project when asphalt rubber paving strategies are employed (Hicks, 2000).

**Table 1 –** *Structural Equivalencies from the CALTRANS Flexible Pavement Rehabilitation Manual – June 2001*

| Structural Equivalencies Thickness (mm) | | |
|---|---|---|
| *DGAC (Dense Graded)* | ARHM-GG (Asphalt Rubber Gap Graded Mixes) | ARHM-GG on a SAMI |
| 45 | 30 | -- |
| 60 | 30 | -- |
| 75 | 45 | 30 |
| 90 | 45 | 45 |

## 3. Scope of Analysis

The technical approach taken in this paper is consistent with a study conducted by the Argonne National Laboratory in 1979 for the United States Department of Energy entitled "Discarded Tires: Energy Conservation Through Alternative Uses," (Gaines, 1979). At that time there was an energy crisis and the usefulness of tires as a fuel source was carefully examined. Also at that time waste disposal of tires was not an issue and air pollution regulations were not as strict as they are today. In light of these changes, and others such as potential global warming and the future of the Kyoto Treaty, which occurred over the past 21 years it seemed appropriate to again review this always controversial topic in some detail.

## 4. Analysis

For each of the three disposal methods a Kilo-Joule per Kilogram (kJ/kg) of rubber scorecard was created. Many of the values were derived from the Argonne Laboratory study. Other values were obtained from various industry sources for aggregate, steel, hauling (trucking) and tire shredding and grinding. Table 2 is a list of typical heat combustion values for common fuels.

**Table 2.** *Combustion Heat Kilo-Joule Per Kilogram of Fuel.*

| FUEL | kJ/kg FUEL |
|---|---|
| Coal | 25584 |
| Tire | 34888 |
| Asphalt | 34888 |
| Natural Gas | 172112 |
| Propane | 213977 |
| Gasoline | 232584 |
| Diesel | 318640 |

In this study scrap tires and asphalt have the same heat of combustion value of 34888 kJ/kg; which is slightly greater than the heat of combustion value for coal of 25585 kJ/kg. As can be seen coal, scrap rubber and asphalt are all at the low end of heat value. Presently, modern power generating plants typically use natural gas as much as possible to generate electricity and meet very demanding air pollution requirements.

## 5. Alternate Daily Cover

The first disposal method for scrap tires that is analyzed in called Alternate Daily Cover (ADC). Alternate daily cover involves the placement of rubber tire shreds generally about six inches square or larger  being placed in a landfill to cover the daily refuse pile or layer, or as a light weight civil engineering fill, Figure 3.

**Figure 3.** *Tire shreds for alternate daily cover. Tire shreds being placed as cover or fill.*

This process requires the least amount of energy of the three options. Table 3 is the heat of combustion values for ADC.

**Table 3.** *kJ/kg Utilization for Alternate Daily Cover.*

| Process | kJ/kg |
|---|---|
| **Tire Shredding** | **-93** |
| **Shred Transportation** | **-1744** |
| **Gain/Loss** | **-1837** |

ADC is composed of scrap tires that have been shredded into approximately 4-6 inch square tiles that are spread to a depth of 6 inches atop a sanitation landfill pile at the end of each day. Regional specifications can vary on the shred size and layer depth. This lightweight cover keeps loose material from blowing away. There is no net energy benefit since it takes energy to shred the tires and transport the shreds and place them. The net negative use of energy is small and under the right circumstances may be an appropriate use of shredded tires.

## 6. Tire Derived Fuel

TDF is composed of whole scrap tires or shredded tires that are introduced into a coal fired furnace to add extra heat, Figure 4.


**Figure 4.** *Tire derived fuel whole tires combusted in coal fired cement kiln.*

Table 4 is an example of the heat of combustion values for TDF.

**Table 4.** *kJ/kg Utilization for Tire Derived Fuel.*

| Process | kJ/kg |
|---|---|
| Tire Shredding | -93 |
| Shred Transportation | -1744 |
| Combustion Energy | +34888 |
| Gain/Loss | +31400 |

Tire chips can combust with fewer emissions than coal. In many locations, tire chips are used to help reduce the total emissions output. There is a net positive gain in energy of about 14,000 BTU/Lb of rubber used. This is a good use of scrap tires and presently consumes about 125 million tires in the United States (Scrap, 2000).

## 7. Asphalt Rubber

Asphalt-Rubber (A-R) is composed of crumb rubber derived from the commutation of scrap tires. Table 5 represents the heat of combustion values for crumb rubber modifier (CRM) used in A-R, Figure 5.

**Figure 5.** *Typical asphalt rubber mix paving.*

**Table 5.** kJ/kg *Utilization for Asphalt Rubber*.

| Process | kJ/kg |
|---|---|
| **Tire Shredding** | **-93** |
| **Shred Transportation** | **-1744** |
| **Granulation** | **-3586** |
| **CRM transportation** | **-1744** |
| **Steel Recovery** | **+1900** |
| **Asphalt Saved** | **+209325 to 465168** |
| **Aggregate Saved** | **+107860** |
| **Gain/Loss** | **+310267 to +566109** |

The crumb rubber is the size of coffee grounds and is derived from either commutation by mechanical grinding, commonly called ambient grinding or from cryogenic commutation using liquid nitrogen, commonly called cryogenic grinding, Figure 6. Modern plants often employ a combination of both cryogenic and ambient technologies to obtain the most economical product. The crumb rubber is combined with liquid asphalt and then combined with aggregate materials and placed using conventional paving equipment. As this table shows there is a net positive gain in energy between 310267 and 566109 kJ/kg of rubber used.

**Figure 6.** *Crumb Rubber after grinding to a 10 mesh or finer.*

The 310267 value is consistent with the previous Argonne Laboratory finding in 1979. In 1979 the Argonne Laboratory derived their value by examining the use of an asphalt rubber chip seal and assigning its energy savings in terms of less asphalt concrete overlays would be needed over the life of the pavement. Since 1979, A-R is now commonly used as a binder in hot mixes in the states of Arizona, California, Texas and Florida.

Energy savings are now the result of using less than one half the thickness of routine paving material as reported by Arizona (Way, 2000) and California (Van, 2000). The 310267 kJ/kg energy savings refers to a two inch A-R overlay being used in place of a normal four inch asphalt pavement overlay. The 566109 kJ/kg energy savings refers to an one inch open graded A-R mix being placed on top of a concrete pavement in place of a normal five inch asphalt pavement overlay.

Other energy savings that have occurred since 1979 include aggregate savings. In many parts of the United States and Europe good quality road building aggregate is in short supply and harder to obtain. The 107860 kJ/kg energy savings refers to the mining energy and transport energy associated with using thicker pavements compared to the thinner A-R pavements. The reclaiming of steel from tires also has considerable value not recognized in 1979. In all the energy savings by using A-R is very impressive. These energy savings coupled with other A-R benefits including less cracking, less maintenance and less noise (Bollard, 1999) make this a very attractive and beneficial end use of scrap tires in a highway environment.

## 8. Summary of Energy Savings

The three processes discussed meet Society's need of preventing tire piles from accumulating and exposing the ecosystem to unnecessary risks of increased pollution and pests. However, the potential energy used or saved in tire processing should also be examined. Table 6 summarizes the energy values of the three tire processes discussed in the paper.

**Table 6.** *Comparison of Kilo-Joule Gain/Loss per kg of Rubber for the three scrap tire disposal methods*.

| Tire-Derived material | kJ (gain/loss) / kg Rubber |
|---|---|
| **Alternate Daily Cover** | **-1837** |
| **Tire Derived Fuel** | **+31399** |
| **Crumb rubber modifier in Asphalt rubber** | **+310267 to +566109** |
| | |

Besides the potential energy savings gained by using granulated tire rubber as a modifier to asphalt pavement, it should be noted that this process can substantially improve the highway assets maintained by our communities.

## 9. Summary of CO2 Savings

Based on the IEA spreadsheet model (IEA/SMP, 2004) IEA/SMP Transport Model it was derived that about 156.425 lbs CO2 emissions per one million BTUS of energy produced by Diesel fuel. Given that the vast majority of BTU saves when AR products are used comes from diesel burning equipment it is a reasonable assumption to use the CO2 savings corresponding to this combustible. Table 7 shows that total savings in CO2 if AR is used as a GAP Grade mix which reaches 154 tons per lane mile. However is AR-OPEN is used over concrete pavements replacing 3 inches of conventional mix the CO2 savings reach 343 tons per lane mile.

| | Use of 2 in of AR-GAP instead of 4 in of Conventional (CALTRANS) |
|---|---|
| BTU/lb crumb rubber | 91286 |
| lbs of crumb rubber/mile | 23793 |
| BTU/mile | 2171925961 |
| Lbs CO2/ Million BTU (Diesel) | 156.425 |
| Ton CO2 saved lane/mile | **154** |
| | |
| | **Use of 1 in of AR-OPEN instead of 3 in of Conventional (ARIZONA)** |
| BTU/lb crumb rubber | 203000 |
| lbs of crumb rubber/mile | 23793 |
| BTU/mile | 4829885964 |
| Lbs CO2/ Million BTU (Diesel) | 156.425 |
| Ton CO2 saved lane/mile | **343** |

**Table 7.** - CO2 savings per lane/mile using AR strategies in California and in Arizona when GAP Grade AR mixes and AR-OPEN graded mixes are respectively used instead of the conventional mixes they replace.

## 10. Discussion

The above academic exercise demonstrates the wide range of energy usefulness that scrap tires have to offer society in general but what about the practical side of the issue? These values are converted to metric units of kg/lane-km of energy and CO2 savings as shown in Table 8. Additional information on the subject energy savings and reduction of CO2 emissions can be found at the following website links, (World, 2007), (Nat, 2007), (NCAR, 2007) and (Audubon, 2007). Such savings are real and can also be coupled to reductions of other environmental concerns as demonstrated in Arizona.

| | Energy Savings kJ/lane-km | Saved Metric Tons of CO2 per lane-km |
|---|---|---|
| AR Gap Graded | 1375962879 | 100.4 |
| AR Open Graded | 3059839016 | 223.3 |

**Table 8. –** Metric energy and CO2 savings kJ/km using AR strategies in California and in Arizona when GAP Grade AR mixes and AR-OPEN graded mixes are respectively used instead of the conventional mixes they replace.

Such environmental concerns revolving around emissions can best be described by with experiences in the State of Arizona. These experiences are of value in discussing the pros and cons of uses of the methods previously discussed as well as energy savings and reductions of CO2 emissions. In the mid 1970's tires were combusted in copper smelters in Arizona. As air pollution laws changed Copper smelters found it more difficult to operate in Arizona and thus by the mid 1980's all copper smelters were shut down in Arizona. Copper from Arizona mines is now smelted in Mexico. In the mid 1980's cement plants burned tires. Due to environmental concerns the cement plants decided to end the burning of tires even though such burning can be legally permitted. Thus by 1990 no tires were being burned in Arizona. Coincidentally the Arizona Department of Transportation (ADOT) along with cities and counties in the state began to routinely use asphalt rubber as an engineered binder in pavements in 1988. Since that time ADOT alone has used over 20 million tires in pavements. There was and is no special program to reuse tires in pavements in Arizona, however the State law does encourage recycling of tires as the highest priority. Approximately 70 percent of the scrap tires in Arizona now go into pavements, with the remainder going into various commercial products. Now asphalt rubber is extensive used over concrete pavement to reduce noise and provide an improved and safer ride.

## 11. Conclusion

With the ever increasing need to reduce CO2 emissions society must look at all and possible ways to achieve that goal. This paper demonstrates how using scrap tires and incorporating them into asphalt rubber mixes and pavements leads to huge savings in CO2 emissions and energy in general. If design criteria is employed as implemented in California and Arizona Departments of Transportation the CO2 savings per lane/mile can vary from 154 to 343 tons per lane mile. These are huge numbers specially if considering the extensive road networks that today exist in the World and are in need of maintenance and the new roads that have yet to be built.

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