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Review of Available Data on Lifecycle Impacts of Tire Diversion, Calculation of Multipliers for Sequences of Diversion Options, & Proposed Tire Management Hierarchy

by
Jeffrey Morris*

The following report exhibits and explains available empirical data on the lifecycle impacts of the major management options that are currently used to handle vehicle tires once they have reached the end of their life on a vehicle. The report also provides *benefits multipliers* for sequences of certain management options. These multipliers account for the benefits of additional cycles of diversion that are potentially available when a used tire is managed by an option that does not result in destruction of the tire rubber. Finally, the report develops a proposed tire management hierarchy based on the reviewed lifecycle impacts data.

Significant Studies on Lifecycle Impacts of Scrap Tire Management Options

Several rather detailed studies on the lifecycle impacts of a number of tire waste reduction, reuse, recycling, recovery and disposal options are available. The most comprehensive of these reports are based on European experience:

- Pieter van Beukering, *et al*, *Waste Management and Recycling of Tyres in Europe*, Institute for Environmental Studies, Amsterdam, The Netherlands, Report number R98/13, December 1998.
- Pieter van Beukering and Marco A. Janssen, "A Dynamic Integrated Analysis of Truck Tires in Western Europe," *Journal of Industrial Ecology*, Vol. 4, No. 2, 2001.
- U.K. Environment Agency, *Tires in the Environment*, U.K. Government, London, 1998.

According to one of these studies, a full lifecycle analysis of tire use tentatively indicates, "95% of the overall environmental impact during the life of a tire occurs during the use of the tire, due to the impact of tires on automotive fuel efficiency. Better maintenance of tire pressure and use of eco-tires produce greater environmental and economics benefits than more-durable and/or less-expensive (Asian) tires."[1]

Despite this finding, state and local governments have rather limited options for influencing greater use of eco-tires that improve gas mileage or for assuring that vehicle drivers maintain tire pressures closer to the maximum pressures allowed. At the same time, local governmental agencies are faced with the problem of managing tires at the end of their useful life on vehicles.

It is in this context that this brief report presents and interprets available data comparing the lifecycle impacts of used tire management options. Table 1, First Cycle Energy Savings and Pollution Reduction from Tire Reuse, Recycling and Recovery Options vs. Landfilling, summarizes energy savings and pollution reductions (or increases, shown as negative reductions[2]) associated with the *first cycle* of reuse, recycling or recovery as compared with landfill disposal.

When a used tire is landfilled the energy and material resources embodied in that used tire are lost to society and must be replaced with newly extracted resources. For example, if a used tire is thrown away prior to the end of its useful life, then the resources that are lost include that pro-

* Jeffrey Morris is a University of California-Berkeley Ph.D. economist at Sound Resource Management in Bellingham, WA. Preparation of this paper was supported in part by Metro in Portland, OR and Seattle Public Utilities (SPU) in Seattle, WA. The author is grateful for the thoughtful comments and suggestions on this report by Metro and SPU staff. Analyses and conclusions in this paper remain the responsibility of the author.

[1] Van Beukering and Janssen (2001), p. 93.

[2] The user of the data in Table 1 needs to be aware that for some management options and some categories of pollutants there are negative numbers in the table to indicate an increase in emissions. For example, energy recovery in a cement kiln results in increased emissions of nitrogen oxides and hydrocarbons, even after taking into account savings of virgin energy resources and reductions in emissions of pollutants associated with use of those virgin energy resources.

portion of the resources required to make a new tire of similar quality and size that is equal to the proportion of the tire's remaining useful mileage. When that used tire is reused on another vehicle until the end of the tire's useful life instead of being thrown away after the tire is removed from the vehicle on which it was first mounted as a new tire, then society avoids extracting that proportion of materials and energy required for a new tire.

Or, as a second example, if a used tire has outlived its ability to safely serve as a vehicle tire, then it might be recycled into, say, a new tire, a rubber mat, rubber modified asphalt (RMA) for use in road surfacing, chips for use in roadbed construction, or substituted for some other energy source in a cement kiln or industrial boiler. In each of these applications the use rather than landfilling of the scrap tire will have avoided extraction of raw materials and/or energy resources that otherwise would have been required to make the tire or mat or road surface or road fill, or used to produce energy.

These avoided extractions of virgin materials and energy resources result in reduced energy requirements and lower emissions of pollutants. For example, although grinding scrap tires into crumb rubber requires an expenditure of energy, Table 1 shows first cycle energy savings of 10,100 btus for each pound of scrap tire material that is substituted for virgin rubber and steel in manufacturing products such as mats and concrete reinforcing bar. This savings occurs because the energy required to shred, grind and separate scrap tires into recyclable crumb rubber and steel (from the tire's steel bead, as well as the steel belts in most tires) is much less than the energy that is saved by not needing to extract virgin resources to make products from rubber and steel. Instead of using virgin resources, those products are produced from the crumb rubber and steel recovered from scrap tires.

Interpreting & Using the Data in Table 1

Some care is required in interpreting the figures shown in Table 1, and the footnotes below the table need to be read carefully. For example, a cursory glance at the figures on energy savings appears to suggest that retreading is more beneficial than reuse of a used tire that still has useable tread on it. However, the 9,100 btus per pound shown for reuse is for a tire that has 25% of its life remaining. Reuse of that tire until the tread is worn out saves 25% of the 36,500 btus per pound required to extract virgin resources and manufacture a new tire, which would be necessary if the tire were thrown into a landfill. In addition, that same tire might still be retreadable after it is reused. In that case an additional 23,500 btus of energy savings would accrue to that same used tire, resulting in an overall energy savings of 32,600 (= 9,100 + 23,500) versus landfilling the tire prior to the end of its initial useful life.

Consider also that the data shown in Table 1 for reuse and recycling options are for just one reuse or recycle cycle. Some options such as the use of bales of used tires in roadbeds may result in avoidance of several applications of virgin materials. Further, the cycles of recycling that follow the first cycle also save energy and reduce pollution. Both avoidance of multiple applications of virgin materials and multiple cycles of recycling increase energy savings and emissions reductions by some multiple of the first cycle energy savings and pollution reductions estimates shown in Table 1.

These considerations suggest that one needs to take account of future material recovery possibilities that might follow a current recovery or disposal option. In the case of energy recovery the used tire is physically destroyed through incineration to recover its btu content. After incineration there will be no tire rubber remaining for future use, although there may be useful scrap steel to recover. In the case of landfill disposal there may exist the possibility of future mining of the landfill to exhume the tire for material or energy recovery. However, this possibility is sufficiently problematic that it is excluded from the analysis herein. It is for the reuse and material recycling options that one needs to be most careful to take into account the benefits from a potentially very long sequence of uses of the used tire's rubber and steel.

Calculation of a Benefits Multiplier for Closed-Loop Tire Rubber Recycling

Consider the situation of closed-loop recycling of scrap tire rubber into new tires. Suppose that R is the recycling rate for scrap tires for use in new tires and Y is the proportion of a scrap tire that can be transformed into rubber that substitutes for virgin natural and synthetic rubbers in manufacturing a new tire.

Then, letting r (= R*Y) be that proportion of a scrap tire's rubber that is recycled back into new tires in some period, and suppose for ease of exposition we assume a period's length to be the average length of a new tire's life (where R and Y account for the proportion of tires that are recycled for use in new tires and the yield from each of those recycled tires of crumb rubber for use in a new tire, respectively). Then for every pound of crumb rubber recycled into new tires in the current period, one would expect r to be the proportion of that pound to be recycled into new tires in the next generation of tires, r^2 the proportion of the currently recycled pound of crumb that would make it into new tires two generations (i.e., periods) hence, r^3 the proportion of the currently recycled pound that would make it into new tires three generations hence, and so on indefinitely. Fortunately, because r is less than one this sequence of ever smaller proportions of the currently recycled pound of crumb rubber that make it back into a future generation of new tires has a precise limit, 1/(1-r).

This is the <u>*benefits multiplier*</u> that one would want to apply, for example, to the 10,100 btu first cycle savings shown in Table 1 for crumb rubber that substitutes for virgin rubber, in order to compare the energy savings from closed-loop recycling of one pound of crumb rubber against, say, the 11,200 btu savings for tire derived fuel used in industrial boilers, where we are assuming for simplicity that a pound of crumb rubber is the same as a pound of tire derived fuel. As one can easily compute, r greater than .10 means that recovery of a pound of crumb rubber for use in manufacturing new tires will save more energy over that pound of crumb's life cycle than burning a pound of tire derived fuel in an industrial boiler, despite the figures in Table 1 that show the pound of tire derived fuel yields more energy savings in the first cycle than does the pound of crumb rubber.

Other Examples of Benefits Multipliers

One could enumerate many examples of benefits multipliers and develop a different multiplier to account for the entire life cycle of rubber in a used tire that goes through each feasible sequence of management options. To give an example for another possible sequence of management options, the calculation of lifecycle energy reductions associated with reuse, retreading and then recycling into new tires would involve adding 9,100 btus plus 23,500 btus, as previously discussed. To this one would also need to add 10,100 btus multiplied by the factor 1/(1-r). The resultant total would indicate the energy savings for each pound of used tires that go through the reuse, retread, closed-loop recycling sequence of management options.

A similar calculation would apply for the reuse, retread, punched/stamped product, and then closed-loop recycling sequence by adding in 7,700 btus. For this sequence one might reasonably assume that a used punched or stamped product could still be recycled into crumb rubber for use in a new tire. One could account for any degradation or loss of rubber during the stamped or punched product's life by reducing 10,100*(1/(1-r)) by the appropriate rubber degradation/loss factor.

Finally, one might also want to calculate a monetary value for energy or emissions reductions associated with a sequence of tire management options. In this case it would be desirable to account for the time value of money by discounting future savings by the real rate of interest i. For closed-loop recycling into new tires that begins in the current period, one can readily calculate that the current monetary value of an indefinite sequence of identical amounts saved in each period is equal to the savings in the first cycle multiplied by (1+i)/(1+i-r).

Ranking Tire Reuse, Recycling and Recovery Options – The Proposed Used Tire Management Hierarchy

After doing whatever is feasible to motivate vehicle owners and vehicle maintenance facilities to maintain adequate tire pressure and to use tires until their useful life is expended, Table 1 and the studies listed above provide a good deal of guidance on what recycling and recovery methods are best, other factors being equal. At the same time, emissions of some pollutants may be reduced by a management option while others are increased. So the table on first cycle energy savings and emissions reductions does not always provide an unequivocal choice among the options.

Also, as indicated in the previous sections, one must remember to account for future recovery cycles for those scrap tire management options that do not result in destruction of the tire rubber. That said, we are able to derive some general observations about the relative desirability of many used tire management options. The following subsections provide these observations, beginning with options likely to be most desirable most of the time down through options likely to be least desirable most of the time. This discussion supports the proposed used tire management hierarchy exhibited in Table 2.

Table 2
Proposed Used Tire Management Hierarchy

Reuse
Retread
Crumb Rubber Substitutes for Virgin Rubber
Stamped/Punched Substitutes for Virgin Rubber
Energy Recovery or Civil Engineering Uses
Alternative Daily Cover
Landfilling

1. Reuse

With the exception of unusual circumstances – such as reuse markets that are very far away, or the case in which reuse substantially reduces the likelihood of future recycling or recovery of the reused tire once it is fully used – reuse of a partially used tire ranks at the top of the used tire management hierarchy. This is because reuse does not foreclose follow on management of the worn out tire by any of the recycling or recovery methods.

2. Retreading

As indicated in Table 1, retreading is top ranked among six recycling/recovery options on the basis of first cycle energy savings and reduced emissions of greenhouse gases, mercury, sulfur oxides and nitrogen oxides. However, it is next to the bottom in hydrocarbon reductions, and in fact results in increased emissions of those pollutants, most likely from the use of organic solvents in cementing the new tread on the old tire casing. Thus, to calculate the lifecycle impact of retreading one needs to weigh the negative impact of increased hydrocarbon emissions against the positive impacts of reduced energy use and reduced emissions of the other pollutants listed in the table.

Because retreading does not destroy the scrap tire's rubber, it also can be followed by any of the other recycling or recovery options.[3] On this basis, one must account for benefits from future management options that remain feasible for the retreading option because it does not destroy the rubber that remains in a scrap tire.

For example, in order to rank retreading against energy recovery, the decision maker would ordinarily need to introduce some sort of explicit or implicit valuation scheme to weight the first cycle energy and emissions impacts shown in Table 1, and to account for any time preference for benefits today versus tomorrow or later. As indicated by the table, retreading dominates energy recovery in five of the six impact categories, without even taking future recovery cycles into account. However, to offset the increased emission of hydrocarbons from retread-

[3] Also, buffings of rubber from the scrap tire before the new tread is cemented on to the old casing are highly marketable for products made from recycled rubber.

ing versus energy recovery, when the worn our retread is recycled it would have to go into crumb rubber use with a potential recycling and yield rate of 90% in perpetuity.

For retreading to beat the other management options in hydrocarbon emissions impacts, the perpetual recycling/yield rate for closed-loop tire recycling would have to be even higher than 90%.

Recycling/yield rates above 90% for crumb rubber into new tires or other products where crumb substitutes for virgin rubber is not realistic, so the decision maker at least needs to determine how to weight hydrocarbon emissions against the other five impact categories in order to rank retreading's desirability. Based on SRMG's research on the public health and climate change costs imposed on society by various types of pollutant emissions, retreading's increase in hydrocarbon emissions is more than offset by retreading's reductions in emissions in the other four pollutant categories shown in Table 1.[4] Because of this offset, retreading dominates the other recycling and energy recovery options in terms of societal benefits. Retreading thus should rank only below reuse in the used tire management hierarchy.

3. Crumb Rubber Substitutes for Virgin Rubber

Crumb rubber ranks below tire derived fuel (TDF) in energy savings, about equal to TDF in carbon dioxide reductions, and above TDF in mercury and sulfur oxide reductions in the first cycle of management according to the data shown in Table 1. It also likely outpaces TDF in nitrogen oxide and hydrocarbon reductions, based on data for whole tire incineration in cement kilns, although no explicit measurements are available for TDF. Furthermore, crumb may rank above TDF in terms of emissions of other toxics or metals besides mercury, although again no comprehensive comparison of scrap tire management options in terms of their impacts on releases of all toxics and metals is available at this point in time.[5]

As indicated in the discussion on benefit multipliers, a closed-loop recycling/yield rate of 10% or more for products using crumb rubber in place of virgin rubber compounds will result in greater energy savings for crumb rubber over its life cycle than for energy recovery from TDF. On this basis, crumb rubber uses that substitute for virgin rubber and steel should rank above TDF because a 10% recycling rate for crumb rubber in replacement of virgin rubber in products such as tires or mats is eminently achievable.

Crumb ranks below whole tire incineration in cement kilns for three of the six impact categories shown in Table 1 – energy savings, carbon dioxide reductions, and mercury reductions. On the other hand, energy recovery from tires in cement kilns increases emissions of nitrogen oxides and hydrocarbons compared with landfilling, according to life cycle assessment data provided in the appendices to van Beukering (1998). Whole tire combustion in cement kilns also reduces sulfur oxides emissions less versus landfilling than does recycling tires into crumb rubber applications where the crumb and recycled steel substitute for virgin materials.

Based on external costs for pollutant emissions exhibited in the April 2001 *UnEconomist*,

[4] See Table 3 in "Evaluating Externalized Costs in the Management of Discards," *The Monthly UnEconomist*, Vol. 3, No. 4, April 2001. That table indicates that the external cost in current dollars of hydrocarbon emissions would be less than $0.50 per pound, while the cost of nitrogen oxides is between $1 and $5 per pound, sulfur oxides between $1 and $2.50 per pound, and carbon dioxide between $0.001 and $0.014 per pound.

[5] For some indicative emissions data see Schwartz, Seymour I., and Robert A. McBride, "Using Waste Tires as Fuel: Challenging the Conventional Wisdom," Department of Environmental Science and Policy, University of California – Davis, October 2000. In this article the authors assert, "The often repeated claim that using TDF is environmentally beneficial cannot be supported if toxic emissions as well as criteria air pollutants are considered. Emissions testing when TDF replaces a portion of the coal fuel in cement kilns has shown a pattern of large percentage increases in some of the toxic compounds typically measured, particularly dioxins/furans, PAHs (which invariably show large increases), and metals such as lead and hexavalent chromium…," page 4.

and a recycling/yield rate of 20 to 25% for crumb in applications that substitute for virgin rubber and steel, crumb ranks above whole tire energy recovery.

Crumb dominates punched/stamp products and civil engineering chips in all six impact categories. Thus, in most situations where crumb rubber is substituting for virgin rubber and steel, we conclude that crumb ranks third, behind only reuse and retreading in societal benefits from scrap tire management options.

4. Punched or Stamped Product Substitutes for Virgin Rubber

Punched and stamped products rank behind crumb rubber in all impact categories. They also rank behind energy recovery in three of the six impact categories, and behind whole tire energy recovery but ahead of TDF in sulfur oxide reductions.

For recycling/yield rates at or above 30%, punched/stamped products that substitute for virgin rubber and steel forge ahead of TDF, even without taking into account their advantage over energy recovery methods in nitrogen oxide and hydrocarbon reductions. The recycling/yield rate needs to be above 40% for this recycling method to jump ahead of whole tire energy recovery.

The value of energy savings and carbon dioxide reductions dominate the increase in nitrogen oxides and hydrocarbons for energy recovery options in terms of societal benefits. Thus, unless one can be reasonably sure that punched stamped products can achieve a perpetual recycling/yield rate well above 30% one would conclude that energy recovery should rank above recycling into punched or stamped products based on first cycle impacts.

On the other hand, once the stamped/punched product has outlived its useful life the remaining rubber could enter a perpetual cycle of use as crumb rubber substituting for virgin rubber in other products. This fact plus the risk of other toxic compounds and heavy metals emissions associated with whole tire incineration and TDF lead to the conclusion that stamped/punched products should rank above whole tire incineration in cement kilns and TDF.

5. Energy Recovery and Civil Engineering Applications

Based on first cycle energy savings and emissions reduction, energy recovery methods of scrap tire management appear to rank fifth in the proposed tire management hierarchy. The reports already referenced above, as well as several studies by the California Integrated Waste Management Board (CIWMB), determined that energy recovery from scrap tires is a much preferable option to landfilling.[6] Some of the environmental benefits of substituting scrap tires for coal are indicated in Table 1 for the energy recovery options.

However, a significant uncertainty surrounding this assessment of energy recovery is, as has been indicated previously, the possibility of increased emissions of toxic compounds or heavy metals as a result of the use of scrap tires in place of other fuels in cement kilns or industrial boilers. For example, zinc emissions apparently increase significantly when TDF is used in industrial boilers due to the zinc in zinc oxide used to make rubber compounds and in brass coatings applied to steel wires in tires. Concern over zinc emissions may have been part of the reason for the recent decrease in TDF usage in Oregon. Cadmium compounds, copper and chromium are other heavy metals that are found in scrap tires.

These concerns regarding energy recovery uses for scrap tires are not adequately assessed as yet in the available literature on lifecycle impacts of used tire management options. In addition, there are environmental benefits of civil engineering uses for scrap tires that also have not been adequately assessed. These considerations suggest placing energy recovery and civil engi-

[6] CIWMB, *Effects of Waste Tires, Waste Tire facilities and Waste Tire Projects on the Environment*, May 1996; Carnot, *Final Report 1997 Criteria Pollutant Tests During the TDF Trial Burn at Stockton Cogen, Inc.*, prepared for CIWMB and Air Products and Chemicals, Inc., September 1997; and Carnot, *Final Report 1997 Emission Tests for TDF Trial Burn Program at Stockton Cogen, Inc. Volume 1*, September 1997.

neering uses for scrap tires as equivalents on the tire management hierarchy despite the fact that, based on the low energy requirements for crushing rock and/or mining gravel, civil engineering uses for scrap tires result in very small energy savings.

Land use and habitat disturbances from mining and processing of gravel and other aggregates may cause significant impacts that can be avoided by use of shredded/chipped scrap tires as an aggregate substitute.[7] In addition, the use of crumb rubber for road surfacing in products such as RMA may result in significant environmental benefits as a result of decreased use of petroleum products in road surfacing.

It should also be mentioned again that there might be civil engineering applications, such as use of tire bales for roadbed construction, where the road durability is improved to such an extent that several applications of crushed rock over a number of years may be avoided. In that case there would be higher energy savings and associated emissions reductions associated with this particular civil engineering application that are not adequately reflected by the data shown in Table 1.

Finally, it should be noted that although crumb rubber used as a substitute for materials other than virgin rubber likely will have lower energy savings and pollution reductions, there might be other lifecycle impacts of equal or higher importance that should be taken into account. For example, if crumb rubber is substituted for sand in a playground application, the energy savings and emissions reductions will be substantially less than when crumb rubber is substituted for virgin rubber. At the same time, Table 1 does not show any data for impacts to users of recycled rubber products, such as reduced injuries in the case of playgrounds made from crumb rubber rather than sand, gravel, or woodchips. Such lifecycle impacts may be significant enough to reverse any ranking of management options based solely on the first cycle data shown in Table 1.

6. Alternative Daily Cover

Alternative daily cover (ADC) appears to offer virtually no energy savings as a substitute for cover dirt, unless the cover material has to be trucked in from much farther away than the source of ADC. We are not including as part of our analysis the transportation from the point of production of the recycled tire product or material to the site of its use, so this possibility is not a factor in developing the proposed tire management options hierarchy. Such local conditions do need to be factored into any decision on use of a specific management method in a specific community. Based on the likelihood of reduced land use and habitat impacts when ADC is substituted for cover materials acquired from natural systems, ADC merits being ranked above landfilling on the used tire management hierarchy.

Other Interesting Results on Tire Recycling and Recovery Options

The three studies listed above also have other provocative bits of wisdom to offer regarding scrap tire management, some of which are counter intuitive and may conflict with conventional wisdom. One is the finding by van Beukering and Janseen (2001) that increased tire life may raise rather than lower negative tire lifecycle impacts. They obtain this result in a scenario under which tire manufacturers offer periodic improvements in fuel efficiency performance of their tires. In this case, the production of longer-life tires reduces the use of newer, more fuel efficient tires. Since 95% of a tire's lifecycle impacts occur in use, this longer use of relatively less fuel-efficient tires outweighs the lower use of resources in making new tires to replace the long-life tires.

Another intriguing finding by this same study is that …"by monitoring tire pressure more cautiously, significant financial and environmental gains can be achieved. No technological solution such as eco-tires or the development of tires with a longer lifetime can surpass this scenario. In

[7] The article "Gravel mines rouse foes in rural counties," in The Oregonian newspaper, May 10, 2000, enumerates some of these concerns regarding gravel mining.

other words, it is primarily the consumer, and much less the tire manufacturers that can contribute to environmental management. Of course, if the consumer purchases eco-tires and improves the tire pressure, environmental damage is reduced the most."[8] This claim is supported by the UK Environment Agency's finding that about 200 liters, or about 53 gallons, of fuel are consumed during a tire's lifetime just to overcome friction from its contact with road surfaces.[9] Furthermore, an online document by two University of Washington graduate students estimates that proper inflation and balancing of tires can extend their lifetime by as much as 40%.[10]

A third finding by van Beukering and Janseen is also confirmed by other studies – cheaper, less durable passenger car tires cause negative impacts on tire retreading. This reduces the environmental benefits available from tire retreading, and increases the environmental costs caused by an increase in the relatively more environmentally damaging production of new tires.

About The Monthly UnEconomist

This monthly online newsletter available at www.ZeroWaste.com (or www.SoundResource.com) intends to provide insight and analysis on the everyday economics of recycling and the unpriced or underpriced environmental benefits of reducing waste disposal and replacing virgin-content products with products manufactured from recycled materials. In addition to *The Monthly UnEconomist*, Sound Resource Management's website ZeroWaste.com also offers recycling markets price history graphs, reports on a variety of topics including the economic and environmental benefits of recycling, and GarboMetrics - elegant, yet not mysterious tools and spreadsheet models for solid waste and recycling.

These materials are all available for no charge at www.ZeroWaste.com. User feedback is encouraged via info@ZeroWaste.com, and substantive comments will be published in our newsletter whenever they add to our understanding of recycling.

As an example of newsletter content, some issues of the *UnEconomist* analyze northwestern and northeastern U.S recycling market prices for nine recycled materials (mixed paper, ONP, OCC, glass containers, tin cans, UBC, PET bottles, HDPE natural bottles, and HDPE colored bottles). These prices are tracked by online graphs updated quarterly.

In addition, some issues of the *UnEconomist* are devoted to GarboMetrics, economic models for managing and analyzing solid waste and recycling. These newsletter issues explain the structure and use of GarboMetric models provided at ZeroWaste.com for such purposes as designing garbage customer rate structures and correctly comparing garbage rates in different communities. GarboMetric models and corresponding issues of *The Monthly UnEconomist* can be downloaded at no charge from www.ZeroWaste.com.

[8] Van Beukering and Janssen (2001), p. 108.
[9] UK Environment Agency (1998), Executive Summary, p. 1.
[10] Japhet Koteen and Molly Vogt, *Analyzing the environmental impacts and intervention points in the tire life cycle*, 1999, available at http://students.washington.edu/mvogt/tires/tire_index.html, estimate reported on page 2 of Recommendation section.

Table 1

First Cycle Energy Savings and Pollution Reductions from Tire Reuse, Recycling and Recovery Options vs. Landfilling

	Energy Savings (btu/pound)		CO2 Reductions (pounds/ton)		Mercury Reductions (pounds/ton)		SOx Reductions (pounds/ton)		NOx Reductions (pounds/ton)		Hydrocarbon Reductions (pounds/ton)	
Reuse of Used Tires	9,100	(1)	8.13E+06	(1)								
Retreading	23,500	(2)	2.13E+07	(2)	8.64E-04	(2)	1.39E+01	(2)	2.43E+01	(2)	-3.20E+00	(2)
Crumb Rubber (mechanical grind)												
- substitute for virgin rubber/steel	10,100	(3)	9.74E+06	(2)	4.14E-04	(2)	6.42E+00	(2)	1.15E+01	(2)	2.17E-01	(2)
- substitute for other materials	< 10,100		< 9.74E+06		< 4.14E-04		< 6.42E+00		<1.15E+01		<2.17E-01	
Punched/Stamped Products												
- substitute for virgin rubber/steel	7,700	(4)	6.98E+06	(9)	2.83E-04	(9)	4.34E+00	(9)	7.71E+00	(9)	1.65E-01	(9)
- substitute for other materials	< 7,700		< 6.98E+06		< 2.83E-04		< 4.34E+00		<7.71E+00		<1.65E-01	
Energy Recovery												
- whole tires in cement kilns	13,400	(5)	1.20E+07	(2)	4.84E-04	(2)	5.14E+00	(2)	-3.28E+00	(2)	-8.92E-01	(2)
- tire derived fuel in industrial boilers	11,200	(6)	1.00E+07	(11)	4.05E-04	(11)	4.29E+00	(11)	?	(12)	?	(12)
Civil Engineering Shreds/Chips	<400	(7)	<.04	(7)	?		?		?		?	
Alternative Daily Cover	0	(8)	0	(10)	0	(10)	0	(10)	0	(10)	0	(10)

Notes

(1) Assumes 25% life remaining and 36,500 btu energy use for production of one pound of new tires.
(2) Source: Pieter van Beukering, et al, Waste Management and Recycling of Tires in Europe, Institute for Environmental Studies, Amsterdam, The Netherlands, December 1998.
(3) Source: Beukering, op. cit., adjusted to assume crumb is substituted for high grade rather than low grade rubber. Estimate of energy avoided for virgin steel is for average of car (11%) and truck (25%) tire steel content assumed in Beukering.
(4) Assumes avoidance of 50% of energy used to make rubber and steel in a tire. K.P. Jones of the International Rubber Study Group in London presented a paper "Rubber and the Environment" at the International Rubber Forum in Liverpool in June 1997 that listed production of synthetic rubbers as requiring between 46,000 and 75,000 btu/pound. Polybutadiene and polypropylene were at the low end, and polyurethane and butyl rubber were at the high end of this range.
(5) Source: Beukering, op. cit.
(6) Based on Scrap Tire Management Council (STMC section of www.rma.org) estimated heating value for tire derived fuel of 15,500 btu/pound after removal of at least 96% of wire. Assumes 75% recovery of weight of scrap tire as TDF and use of 400 btu/pound for shredding and removal of wire.
(7) According to David R. Wilburn and Thomas G. Goonan, "Aggregates from Natural and Recycled Sources: Economic Assessments for Construction Applications - A Materials Flow Analysis," U.S. Geological Survey Circular 1176, p. 10 crushed stone requires 54 million joules of energy per ton. This equates to about 26 btu/pound. Keoleian, et al, "Life Cycle Energy, Costs and Strategies for Improving a Single-Family House," Journal of Industrial Ecology, Vol. 4, No. 2, estimate about 400 btu/pound to produce gravel. Shredding scrap tires into civil engineering chips is a partial offset.
(8) Assumes energy used to shred tires for ADC is equivalent to energy necessary to produce standard daily cover materials.
(9) Estimate based on energy savings for punched/stamped products.
(10) Estimate based on zero energy savings.
(11) Estimate based on differential between energy savings for whole tires in cement kilns and TDF.
(12) Increased NOx and hydrocarbon emissions from whole tire use in cement kilns may not be reliable basis for estimating emissions from use of TDF in industrial boilers.