# Chapter 14

# ASPHALT, FEEDSTOCKS, AND LUBRICANTS

## Asphalt

### 1. Summary

Diffusion of asphalt-rubber (AR) pavement and its associated existing technologies saves energy and reduces outlays, as summarized in Table 14-1 below. The instantaneous technical potential from deployment of *State Of the Art* technologies equates to a saving of 0.87 Quads of asphalt, or 51% of the total EIA *Annual Energy Outlook 2004 with Projections to 2025* (*AEO 2025*) forecasted consumption of 1.70 Quads (total of road and non-road use). This would equate to a saving of 131 million barrels of asphalt and road oil per year, or 0.36 million barrels per day. 95% of this saving is achieved in our *Coherent Engagement* policy scenario that incorporates stock turnover, giving 0.83 Quads of asphalt to be saved in 2025.

Incorporating road surfacing turnover in the more aggressive adoption case of 95% lane-mile coverage by 2025, the reduction in asphalt use is achieved at a net saving before valuing the asphalt that otherwise would have to be bought of about 15% (~$7.7 billion per year) of the forecasted U.S. paving budget.  In opportunity-cost terms, this is the equivalent of being paid the current per barrel asphalt price for each avoided barrel, plus an average premium of $62 for each of those saved barrels of asphalt. Three factors account for this. First, a significant lengthening of surface lifetime relative to the conventional asphalt surface means re-pavement frequencies are reduced. Second, layer thickness is also reduced. Both these factors contribute to a significant reduction in materials use and handling. In addition, average upfront agency cost per lane-mile is decreased. Table 14-1 details the asphalt usage and cost reductions.

Note that the savings in Table 14-1 do not include the opportunity cost of additional (non-asphalt) materials and labor, nor positive whole-system synergies should the additional strategy of using reflective paving materials also be pursued. These include Portland cement concrete (PCC), porous pavements, resin pavements, AC (Asphalt Cement) pavements using light-colored chip seals, and AC pavements using light-colored asphalt emulsion additives. For a discussion of the situations in which this is cost-effective, see [9].

Based on the estimates detailed below, our *Coherent Engagement* scenario therefore assumes that application of high-albedo pavement in the 20 largest metropolitan areas will back out 0.041 Quads, or 0.48%, from the 8.6 Quads of natural-gas use forecast for 2025 in *AEO*, and that this will happen via low-cost paving standards and policies to lower the market barriers examined in [9]. An additional non-paving related 0.064 Quads could also be backed out via roofs and shade from tree planting.

We have also excluded incremental benefits from significantly improved safety and noise-reduction potential that follows from paving roads with AR.

## 2. Summary of Model Results

While our model is approximate, to the first order we estimate that under the more aggressive *State Of the Art* (*SOA*) technology application with *Coherent Engagement* policies, where all resurfacing in the year 2025 is via AR pavement, and where 95% of all lane-miles have AR surfacing, some 0.83 Quads, or 49%, of all projected asphalt usage for 2025, could be saved. This represents 57% of the 1.44 Quads that is forecast to go into paving roads. Perhaps more important, we estimate that this saved energy would come at a net *negative* incremental cost to federal, state, and local governments, who stand to earn approximately $7.7 billion per year in 2025. The potential positive financial impact on public finance therefore would be substantial, as outlays to paving would drop down from $52 billion to $44 billion under this scenario.

Under our moderate *Conventional Wisdom* (*CW*) technology application, some 0.57 Quads, or 34%, of the 2025 forecasted total asphalt usage of 1.70 Quads, could be saved by conventional adoption of AR pavements. This represents 40% of the 1.44 Quads forecasted to be used in the asphalt paving industry. Again, this would be achieved at a *net saving* of about $5.3 billion per year in 2025: rather than spending $52 billion in that year, total spending on pavement would be $47 billion.

## 3. Background

In 2000 some 1.286 Quadrillion BTUs of asphalt were consumed in the US [1], about 85-86% of which went into road pavement [2], [3]. The remainder was consumed by the roofing industry. The chief commercial method for reducing asphalt consumption consists of paving with a thinner but more durable asphalt-rubber hot mix aggregate binder. As an improvement on conventional asphalt concrete road pavement, asphalt-rubber (AR) pavement has developed a long and positive track record since it was first patented in the 1960s.

AR roads have multiple advantages over conventional roads, including reduction of reflective cracking, improvement in rehabilitation and skid resistance and lower noise, [4], [5], [6], a significantly longer life, a lower lifecycle cost, and, not the least, a significantly improved road safety record under wet driving conditions, [4], [7], [8]. AR pavements have been put to use in most climates, ranging from the generally very cold, e.g., Alberta (Canada) and Colorado to the generally hot, e.g., California, Arizona, and Texas, to the variable (hot, cold, and high at 7,000 feet above sea level), e.g., Michigan and Nebraska, [4], [5]. Experience to date uniformly indicates the performance is on par with or better than conventional pavement [4], [5], [6], [7].

As noted, experimentation with mixing crumb rubber from scrap tires into asphalt began in the 1960s. Refer to [7] for an overview of the history of AR pavement development. The most compelling factor we have seen cited as reason for a relatively slow take-off in usage has been process copyright protection. This was indicated by the fact that Arizona and Texas began using AR as a binder in pavement in earnest when the patent expired in

1992. Moreover, since then prices have dropped significantly, primarily due to competition [7]. Colorado, Nevada, California, Texas, and other states are now significantly expanding its usage.

Regarding safety and performance, it is worth noting that significant accident reduction rates have been conclusively determined. AR surfacing lowers accidents by about 50% in wet driving conditions; this in itself is reason to do AR roads, even at a cost premium. We have not incorporated societal benefits arising from reduced accident externalities. Conclusions from [5] include that major accidents have been reduced by 43% over all days and by 51% on wet days (not correcting for 34% more wet days after re-surfacing). Moreover, rutting and cracking decrease and noise levels are significantly lower, dropping by about 10% to 15% from 99.1 to 104.9 dBA, depending on measurement method, to about 91.8 dBA [4].

An important issue is the potential health effects to workers while laying the surface. No study to date concludes that AR pavement is mutagenic during or after application. However, conclusive pieces regarding increases in exposure include the results from Heritage, cited in [4] and [5], where PACsare marginally higher than in conventional asphalt; benzothiazole is an irritant and found as an additive in making rubber and is the likely cause of higher irritation. No other differences were noted. NIOSH notes that no fumes are mutagenic, that benzothiazole is found at all crumb rubber sites, and that eye, nose, and throat irritation appears to be higher on crumb rubber projects. Also, VOCs may be higher. The use of appropriate safety equipment to eliminate any irritation-related or other health effects should therefore be mandatory.

On emissions and general environmental impacts, Michigan DOT concludes that no significant increase in undesirable compounds have been detected, but, on the contrary, base asphalt and cement in fact give much higher emissions than rubber. They reach similar conclusions about operating conditions, but do note that a higher temperature may lead to a cleaner-burning process. Emissions of 14 analyzed pollutants are all similar. A benefit, noted elsewhere, is of course that solid waste levels decrease significantly, e.g. scrapped tire piles in Florida are now decreasing significantly. Importantly, the Florida DOT notes that there is a minimal impact on production operations and equipment, and that there are also minimal impacts on pavement operations (only slightly increased pavement laydown temperatures). Florida DOT also now sees decreasing rubber fractions in scrap tire piles, but also that there is a constant supply of tires in the rubber market.

FNF Construction Inc. used 2.3 million scrap tires in 2001 for AR road paving, and notes that there are several myths around AR application and current equipment. Important myths include that AR mixes will ruin customers' tanks, that contractors need specialized equipment, that there is a standardized viscosity testing procedure, that blend design cannot be varied, and that AR application is complicated [4], [5]. In reality none of these myths are true.

## 4. Assumptions and Methodology

Overview: We model the total agency costs for paving new roads and re-paving existing roads, calibrating our model's baseline *Business as Usual* (*BAU*) scenario to NEMS, and then forecasting usage under *CW* and *SOA*. The two scenarios basically estimate the costs of progressively more aggressive levels of deployment of asphalt-rubber road pavement as an alternative to conventional asphalt pavements. The calibration for *BAU* mimics the output from NEMS, and has virtually no deployment of AR road pavement.

Usage for asphalt in pavement is determined by lane-mile growth as well as standard road rehabilitation and maintenance strategies. Quantity- and cost-results from 2002 based on road-level data that were collected over an 11-year period determine our material usage in the two worlds of conventional asphalt and asphalt-rubber surfacing [8].

We make a number of simplifying assumptions to approximate the potential savings in both asphalt usage and costs, and we discuss these assumptions next. We then describe model calibration and the assumptions that go into our *CW* and *SOA* scenarios, before finishing up with a short discussion on the results in terms of savings potential and its costs, remaining asphalt use, and finally possible substitution options.

Material Inputs: In line with [9], we assume that the same long-term road maintenance strategy applies to all U.S. paved roads, although due to our relatively short time horizon, we simplify this strategy by assuming the existing stock of conventional asphalt roads have an average life of approximately 13 years and that asphalt-rubber (AR) roads last on average 16.5 years before repaving must occur. Annual lane-mile growth is determined by anticipated demand in new lane-miles, and we peg these off the anticipated growth in new housing starts [10], as new roads are largely constructed in line with suburban developments. Housing starts are anticipated to grow at about 0.98% annually. We introduce a small adder (0.055%) to account for growth related to non-housing factors. We determine the adder by calibrating to the NEMS-forecast for 2025.

In line with [8], we assume conventional asphalt *rehabilitation* includes an 11” thick and 12’ wide lane-mile that is coated by conventional asphalt-concrete. This conventional coating consists of 7% asphalt and 93% aggregates. If a road is *reconstructed* or built *new*, we simplify matters somewhat by assuming the usage of asphalt in either case is the same. We assume that both cases involve two additional base layers, consisting of a 4” aggregate base underneath a 6” bituminous treated base. We assume for simplicity that material usage and costs are the same per lane-mile for these two categories.

In the case of asphalt-rubber (AR) pavement, and again as in [8], we assume *rehabilitation* includes a 0.5” thick and 12’ wide lane-mile coated in AR *open graded* hot-mix. By volume this open graded AR hot-mix consists of 20% ground tire rubber and 80% hot paving grade asphalt, which is then added as a 9% component to 91% aggregate. The open graded AR hot-mix is laid on top of a 2” thick asphalt-rubber *gap graded* hot-mix. The gap graded AR hot-mix consists of the same 20/80 asphalt-rubber hot-mix, but this time added as slightly more dilute 7.5% component to 92.5% aggregate.In the case of *reconstructed* or *new* AR roads, these have as additional base layers an 8” aggregate base underneath a 6” layer of conventional asphalt concrete aggregate. Note that we have doubled the thickness of this layer to 6” in spite of the fact that the literature would suggest 3”—this to introduce conservatism in the modeling. This conventional asphalt concrete aggregate is mixed in the same proportion as for conventional roads, i.e., 7% asphalt and 93% aggregates. As in [8], we assume the energy inputs per lane-mile given in Table 14-2 above.

Scrap Tire Market: In the market for scrap tires the available supply consists of the current stockpile plus the annual available addition (total additions less current uses) plus an annual growth of supply that we assume will equal the growth of automobiles as determined in NEMS (approx 1.9% per year). We assume that the current share of the available (unused) annual scrap tire supply (currently about 300M tires/yr) will remain constant over time, and that this share is also going to be the share that befalls road pavement from the annual addition due to scrap tire supply-growth. We also assume that the cost of adding the shredded tires is subsumed as in [8] and in Table 14-3 overleaf. For simplicity we have assumed the same diffusion rates for diffusion of AR into paving new roads and re-paving old roads.

In this market, for *CW* we add the unused part of the annual supply, currently 33% or 96M tires (2000), see [11], to the current tire stockpile and to a constant share of tire supply growth, i.e., 33%. Both current stock and annual supply are those found in [11]. We also assume that by 2025 66% of all new roads will be paved by an AR mix, leading to 62% of the stock (6.68 million lane-miles) of paved roads in 2025 having an AR surface, up from 0.5% of the total of 5.2 million lane-miles currently covered by AR asphalt. In the *CW* scenario the stockpile of scrap tires continues to grow, going from about 0.69 b in 2000 to 1.9 b in 2025; a net stock reduction of 1.9 b tires vs. *BAU*.

For our *SOA* scenario, we assume that 100% of all new- and resurfaced road pavements that in 2000 were paved with conventional asphalt will be covered by AR-mix by 2025. This brings the tire stockpile down to 0.99BN tires, i.e., nearly back to the 2000 level. In *SOA*, some 90% of the lane-mile stock has an AR surface. Note that the *SOA* savings are achieved without the need to ‘capture’ scrap tires from other sources of demand. Extending the model to 2050 shows that after having declined to 0.67BN by 20352040, the tire stock, to a first-order approximation, actually begins to grow again beyond 2040, to reach about 1.0BN tires by 2050.

## 5. Cost assumptions

We assume that average costs are independent of geographic location within the U.S. In reality, costs differ by about +/– 30% [9], but for the purposes of this relatively simple nationwide evaluation, such differences are not overly important. We believe the simplification and transparency that is gained outweigh the importance of a small loss in second-order model outcome accuracy.

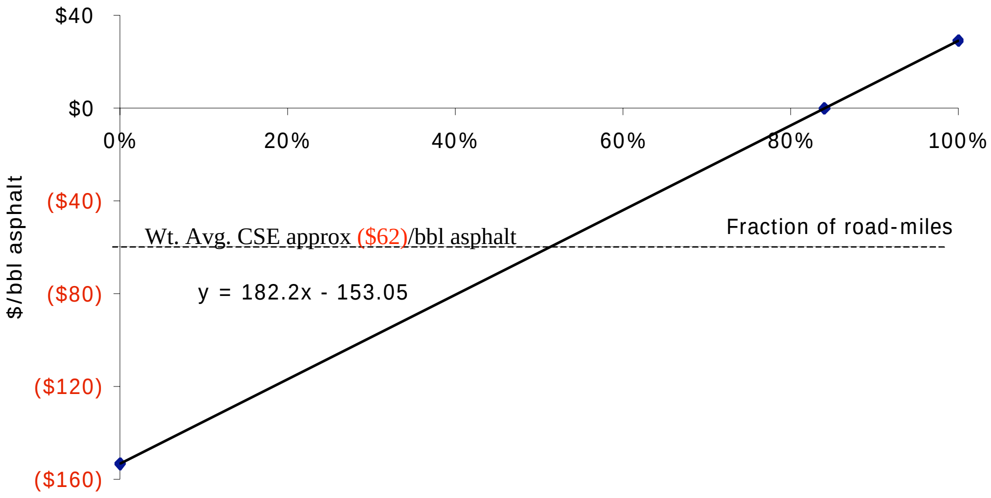
We use the definition of terms used in [9], Section II, and use only the agency-cost component of the FHWA lifecycle cost analysis method for roads, see [12], ignoring user costs and residual value calculations. This assumption simplifies the calibration because data on agency costs are easy to find, see [12], whereas nationwide data on user costs and residual values would need significant further estimation.

Next, we assume costs incurred by new paving and road reconstruction are the same, and also that rehabilitation costs are significantly smaller than the former two on a per lane-mile basis. We assume relatively small maintenance costs are subsumed by rehabilitation costs, and use the data in Table 14-3 for cost estimation:

**A**t the level of per lane-mile costs, we adjust two areas that have cost-implications. First, we adjust our assumed thickness. To be conservative, we augment the conventional asphalt concrete sublayer from 3 to 6 inches. This gives a total system AR thickness up from 13.5 to16.5 inches, comparing to 21.0 inches for the traditional layer system. This brings the CSE from –$160 to –$153/bbl, and total system savings in the year 2025 from $22.05b to $19.10b.

Finally, in probabilistic terms, AR roads are in fact cheaper in 8286% of the many lifecycle cases studied [8]; see also [4], [5]. This implies a marginal relationship between AR application and incremental cost, so that in 16% of the cases the costs are in fact higher. We recognize this via the following adjustment procedure. We assume the RMI CSE estimate is a best-case estimate, i.e. the first barrel saved is saved at $153 negative cost. We next assume that after 84% of the barrels have been saved, the remaining 16% of the barrels cost more than conventional asphalt roads. We then assume that the 84th percentile barrel has zero marginal cost. Next, assuming a straight-line marginal cost relationship, we're now saying that the 100th percentile has a positive cost, of exactly $29.14/bbl, as determined by the straight line (in *CW* these end-points are $152/bbl and $29.01/bbl, respectively). The weighted average CSE in the *SOA* case now (0.84 * 153 / 2) + (0.16 * 29 / 2) = 61.95/bbl. This figure is $61.65/bbl for *CW*, and is illustrated in Figure 14-1:

**Figure 14-1** Incremental CSE of AR ves asphalt pavement as a function of fractional demand for roads with firm surfaces, 2025 (*SOA* case)



## 6. Model calibration

Quantity: We have taken a simple approach to modeling that calibrates our model's *BAU* scenario by matching its pavement asphalt usage to NEMS total road asphalt and road oil usage forecasts for 2005 and 2025, and its costs to that of the sum of federal, state, and local road administrative agency costs for 1999. We then apply the model to forecast *CW* and *SOA* costs for 2025. Even though a small decline in demand from 2000 to 2005 was observed from NEMS, apparently explained by a general downturn in the construction industry, we use NEMS output for 2000 rather than 2005 for the quantity calibration, and ignore the minor demand-dip. The total asphalt usage for 2000 was 1.286 Quads, and we assume a constant share, 85%, is used for pavement every year [2], [3]. Applying the constant share to the NEMS forecast, 1.44 of 1.70 Quads total 2025 asphalt use is expected to go into the paving sector under *BAU*. We adjust the growth rate via the small adder (0.05%) to calibrate our *BAU* asphalt usage to NEMS usage in 2025.

Costs: As to per-unit material costs, there is very good agreement between our model assumptions and the figures from the presentations at the Michigan May 2004 conference on asphalt rubber pavements [4], [5]. The presentations indicate a $15 incremental cost per ton of AR road pavement, which agrees with our figures almost to the nearest $0.10. This isn't adjusted for actual material use reduction, however, so pavement system cost is still well below baseline.

As to total spent, $116.0BN was spent on the U.S. highway system in 1999/2000. Of this, $87.2BN was spent on highway construction (capital outlays) and system preservation (maintenance). The latter figure includes paving costs, and, after an adjustment, serves as a useful calibration for our bottom-up modeled 2000 *BAU* paving cost estimate of $39.7BN for 2000. As total U.S. paving costs exclude many components that are included in capital and maintenance outlays, and as information on stand-alone agency costs for U.S. paving is difficult to find, we establish the adjustment by approximating the paving costs on a category-by-category basis. We estimate the portion of highway construction (capital outlays) and system preservation (maintenance) that goes towards paving and resurfacing the U.S. roadway system by applying estimates of approximate percentages to state cost classifications, found in Tables sf12ar.xls, tabs p1 through p6 at [12] on a category-by-category basis.

Specifically, we estimate that 100% of the following outlays can be considered resurfacing costs: reconstruction withoutadded capacity, restoration and rehabilitation, and resurfacing. We also applied the following percentages: 75% of reconstruction with added capacity; 50% of new construction, relocation, major and minor widening, and minor bridge rehabilitation; 25% of major bridge rehabilitation; 5% of new bridge construction; and 2.5% of bridge replacement. Adding up the estimated category paving outlays gives an approximate percentage of outlays at state level that goes towards paving. We assume approximate structural similarity across the three major jurisdictional levels, and apply this percentage to total local and (the minor) federal outlays. Total estimated paving outlays are then $38BN, which is within 4.4% of the estimate from our calibrated bottom-up model.

## 7. Deployment of Reflective AR pavement

Positive whole-system synergies from the additional strategy of using reflective paving materials should also be pursued. High-reflectivity pavements would further extend pavement life,and reduce urban heat island effects. In turn, a reduction in the heat island effect would reduce both peak electric demand and hence (mostly) demand for gas, and would also reduce car air-conditioning loads, in turn saving more oil. Smog formation reduction via reducing photochemical reaction rates can also be expected. To estimate the benefits of pursuing higher-reflectivity pavements such as Portland cement concrete (PCC), porous pavements, resin pavements, AC pavements using light-colored chip seals, and AC pavements using light-colored asphalt emulsion additives as a strategy to lower the urban heat island effect is not trivial. For a discussion of the situations in which these pavements are cost-effective on a stand-alone basis, see [9].

We make a rough estimate of the value of reduced heat islanding. Based on data from ongoing efforts in the metropolitan areas of Chicago, Sacramento, Salt Lake City, Baton Rouge, and Houston, [13], and [14], a pavement-related effect totaling 708 MW of peak power demand reduction was identified for these five metropolitan areas. Including vegetation, roofs, and other factors, a total avoided peak of 1,801 MW was identified as having resulted from all actual heat island reduction initiatives. A $64M contribution to total energy savings of $162M was also identified as a result of reflective pavements, but we note that this ignores avoided capacity costs. Results also indicate temperature reductions between 1 and 4 degrees F, net decreases in ozone in the modeling domain, and peak ozone decreases from 1 to 8 parts per billion [13], [15]. Additionally, health benefits would no doubt result as heat islands negatively impact health by contributing to extreme heat events and contributing to elevated ozone concentrations [13] (around 1,100 Americans die from extreme heat every year).

In the absence of program cost information, it is difficult to estimate a CCE for investing in reducing the heat island effect. However, we can construct a very simplified ‘what one would have to believe’ case. First, assume an initiative that covers the 20 largest U.S. metropolitan areas. Next, assume the financial savings generated from energy savings average to about $68M/5 x 20 cities = $270M/y. At $0.08 per kWh this converts to 3.38GWh, i.e., ~ 0.041 Quads of natural-gas peak power at 12,000 BTU/kWh. Assume next that the avoided capacity costs associated with the approximately 140MW x 20 = 2,800MW of avoided peak power is about $0.8M/MW x 2,800 M = $90M annually when reinvested at 4% real return. Believing for a moment that the total financial saving would be around $360M/y, the implication is that each city would be willing to invest up to $18M annually. Alternatively, $130M on an up-front basis could be invested—this is the per-city capacity value of $112M plus first-year saved energy of $18M, where future annual savings would be an annual budget surplus. Backing out the saved barrels of incremental oil savings from lowered car air conditioning would be considerably sketchier, so we ignore it for conservatism. In our *SOA* scenario we assume that standards and policies to lower the pavement-related market barriers examined in [9] will be pursued in the largest 20 metropolitan areas, and 0.041 Quads, or 0.48%, of natural gas will be backed out of the 8.6 Quads of natural gas use for 2025 forecast in *AEO 2025*.

## 8. Asphalt substitution options

We do not perform a detailed analysis of the various asphalt substitution options that currently exist or that will likely exist in the near future. Here we list some such options for completeness. They are: Portland cement concrete; porous pavements; various resin pavements; a mixture of appropriate geopolymeric cements and other compacting mechanisms; a mixture of asphalt and glass; asphalt and steelscrap; and finally asphalt-rubber-steelscrap.

## REFERENCES

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1 *Annual Energy Outlook 2004 with Projections to 2025,* Energy Information Agency, 2004.

2 “Asphalt Demand to Grow,” study by The Freedonia Group, 1 November, 2003, excerpt posted on http://rockproducts.com/ar/rock_study_asphalt_demand/

3 Tasker, N.P., “What do the cards hold for the asphalt industry?,” Transcript from Joint Meeting of the International Slurry Surfacing Association and the Asphalt Emulsion Manufacturers Association, Phoenix, 1995, posted at http://www.imperialasphalt.com/iagen.html

4 Hicks, Gary R. (2004), “Use of Asphalt Rubber in Pavements,” in Conference Proceedings, for Rubber Modified Asphalt Conference, Grand Rapids, MI, 19-20 May

5 Carlson, Doug (2004), “The Asphalt-Rubber Industry Perspective,” in *Conference Proceedings,* for Rubber Modified Asphalt Conference, Grand Rapids, MI, 19-20 May

6 Interview with Mr. Al Schulz, Tire Recycling Management Program, Alberta Government, Canada, week of 18 August 2003; have used AR since 2001 and have good experiences so far.

7 Way, G.B., “OGFC Meets CRM: Where the rubber meets the rubber,” Materials Group, Arizona DOT, Asphalt Conference, Atlanta, GA, 25 March, 1998, see http://www.rubberpavements.org/library/crm.asp

8 Jung, J-S., Kaloush, K E., and Way, G.B., "Life Cycle Cost Analysis: Conventional versus Asphalt Rubber Pavements,” Arizona State University, August 2002. Available at www.rubberpavements.org/library/LCCA-RPA2002.pdf

9 Ting, M., Koomey, J., and Pomerantz, M., “Preliminary evaluation of the lifecycle costs and market barriers of reflective pavements,” Energy Analysis Department, Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley

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National Laboratory, Berkeley, CA, November 2001. Available at http://enduse.lbl.gov/Projects/pavements.html

10 *Annual Energy Outlook 2003* Energy Information Administration, 2003

11 “US Scrap Tire Markets 2001,” Rubber Manufacturers Association, Washington, DC, December 2002, at www.rtinevada.com/pdfs/US_Scrap_Tire_Markets_2001.pdf

12 Tables hf2.xls, sf21.xls, sf12ar-p1.xls to –p6.xls, and sf12b.xls, Federal Highway Administration, at http://www.fhwa.dot.gov/ohim/hs00/hf.htm

13 Wong, E., “The U.S. Environmental Protection Agency’s Heat Island Reduction Initiative (HIRI): Status and Future Directions,” a summary of status and results of EPA-supported research, 2003. Downloadable from www.city.toronto.on.ca/cleanairpartnership/pdf/finalpaper_wong.pdf

14 Konopacki, S. and Akbari, H., “Energy Savings for Heat Island Reduction Strategies in Chicago and Houston (Including Updates for Baton Rouge, Sacramento, and Salt Lake City),” LBNL-49638, Lawrence Berkeley National Laboratory, 2002. From www.harc.edu/coolhouston/downloads/LBNLHoustonEnergyStudy.pdf

15 Taha, H., Chang, S.C., and Akbari, H., “Meteorological and Air Quality Impacts of Heat Island Mitigation Measures in Three U.S. Cities,” LBNL-44222, Lawrence Berkeley National Laboratory, 2000. Downloadable from http://www-library.lbl.gov/docs/LBNL/442/22/PDF/LBNL-44222.pdf

## Table 14-1: Asphalt use and cost under three scenarios, 2025

| | | | **2025** | | *2000* |
|---|---|---|---|---|---|
| | Units | ***BAU*** | ***CW*** | ***SOA*** | *Comparison* |
| **Basic Statistics on Roadways and Tires** | | | | | |
| US paved roadways | (M ln-mi) | 6.34 | 6.34 | 6.34 | *4.87* |
| US roadways paved with asphalt | (M ln-mi) | 6.31 | 2.22 | 0.31 | *4.83* |
| US roadways paved with asphalt-rubber | (M ln-mi) | 0.04 | 4.12 | 6.03 | *0.04* |
| US roadways paved with asphalt-rubber | (% of tot) | 0.6% | 65% | 95% | |
| Available stock of scrap tires | (M tires) | 3,772 | 1,870 | 994 | *692* |
| Reduction in stockpile vs. BAU | (M tires) | n/a | (1,902) | (2,778) | |
| Reduction in stockpile vs. BAU | (%) | n/a | 50% | 74% | |
| **Energy Savings, Instantaneous Potential** | | | | | |
| Total consumption of asphalt | (Quads/y) | 1.70 | 0.826 | 0.826 | *1.29* |
| Consumption of asphalt in road pavements | (Quads/y) | 1.44 | 0.572 | 0.572 | *1.09* |
| Saved asphalt from paving sector | (Quads/y) | n/a | 0.869 | 0.869 | |
| Saved asphalt from paving sector | (Mbbl/y) | n/a | 131 | 131 | |
| Saved asphalt from paving sector | (Mbbl/d) | n/a | 0.359 | 0.359 | |
| Inst. Pot. Redct'n v. EIA 2025 tot asphalt | (%) | n/a | 51% | 51% | |
| Inst. Pot. Redct'n v. paving 2025 total | (%) | n/a | 60% | 60% | |
| **Energy Savings, with Stock Turnover** | | | | | |
| Saved asphalt from paving sector | (Quads/y) | n/a | 0.572 | 0.826 | |
| Saved asphalt from paving sector | (Mbbl/y) | n/a | 86 | 125 | |
| Saved asphalt from paving sector | (Mbbl/d) | n/a | 0.236 | 0.341 | |
| Saved asphalt in paving as percent of EIA | (%) | n/a | 34% | 49% | |
| Saved asphalt in paving as percent of paving | (%) | n/a | 40% | 57% | |
| **Cost Savings** | | | | | |
| Total paving outlays | ($BN) | $ 52.42 | $ 47.11 | $ 44.71 | *$ 39.74* |
| Incremental cost in paving outlay *vs.* BAU | ($BN) | n/a | ($5.32) | ($7.71) | |
| Incremental cost in paving outlay vs. BAU | (%) | n/a | -10% | -15% | |
| Cost of Saved Energy (per bbl asphalt) | ($/bbl) | n/a | ($61.65) | ($61.95) | |
| Cost of Saved Energy (per gal asphalt) | ($/gal) | n/a | ($1.47) | ($1.47) | |

## Table 14-2: Input Energy Comparison, Conventional Asphalt vs. Asphalt-Rubber Pavements

### Conventional Asphalt Pavement

| | Reconstruction or New | | | | Rehabilitation | | | |
|---|---|---|---|---|---|---|---|---|
| | Vol % of Layer | Vol % Asphalt | Vol % Rubber | Vol % Aggreg. | Vol % of Layer | Vol % Asphalt | Vol % Rubber | Vol % Aggreg. |
| AR Open Graded | | | | | | | | |
| AR Gap Graded | | | | | | | | |
| Conv. Asphalt Concrete | 52% | 3.7% | | 48.7% | 100% | 7.0% | | 93.0% |
| Bituminous Treated Base | 29% | 1.0% | | 27.6% | | | | |
| Aggregate Base | 19% | | | 19.0% | | | | |
| | | 4.7% | 0.0% | 95.3% | | 7.0% | 0.0% | 93.0% |
| | | | | 100.0% | | | | 100.0% |
| Total Volume (cu feet / lane-mile) | | | | 110,856 | | | | 26,394 |
| Component Volume (cu ft / ln-mi) | | 5,173 | - | 105,683 | | 1,848 | - | 24,547 |
| Component Volume (bbl / ln-mi) | | 922 | - | 18,825 | | 329 | - | 4,372 |
| Tires per lane-mile | | | | | | | | |

### Asphalt-Rubber Pavement

| | Reconstruction or New | | | | Rehabilitation | | | |
|---|---|---|---|---|---|---|---|---|
| | Vol % of Layer | Vol % Asphalt | Vol % Rubber | Vol % Aggreg. | Vol % of Layer | Vol % Asphalt | Vol % Rubber | Vol % Aggreg. |
| AR Open Graded | 3% | 0.2% | 0.1% | 2.8% | 20% | 1.4% | 0.4% | 18.2% |
| AR Gap Graded | 12% | 0.7% | 0.2% | 11.2% | 80% | 4.8% | 1.2% | 74.0% |
| Conv. Asphalt Concrete | 36% | 2.5% | | 33.8% | | | | |
| Bituminous Treated Base | | | | | | | | |
| Aggregate Base | 48% | | | 48.5% | | | | |
| | | 3.5% | 0.2% | 96.3% | | 6.2% | 1.6% | 92.2% |
| | | | | 100.0% | | | | 100.0% |
| Total Volume (cu feet / lane-mile) | | | | 87,101 | | | | 13,197 |
| Component Volume (cu ft / ln-mi) | | 3,041 | 206 | 83,855 | | 824 | 206 | 12,168 |
| Component Volume (bbl / ln-mi) | | 542 | 37 | 14,937 | | 147 | 37 | 2,167 |
| Tires per lane-mile | | | 533 | | | | 533 | |

*Breakdown of mixes:*

| *Asphalt-Rubber Mix* | Vol % |
|---|---|
| Tire Rubber | 20% |
| Hot Asphalt | 80% |
| *A-R Hot-Mix in Crumb-Rubber Agg. Modif. Mix* | |
| AR Open Graded | 9.0% |
| AR Gap Graded | 7.5% |
| *Hot-Mix Asphalt in Conventional Asphalt Aggregates* | |
| Conv. Asphalt Concrete | 7.0% |
| Bituminous Treated Base | 3.5% |
| Aggregate Base | 0.0% |

## Table 14-3: Input Cost Comparison, Conventional Asphalt *vs.* Asphalt-Rubber Pavements

### Conventional Asphalt Pavement

| | Reconstruction or New | | | Rehabilitation | | |
|---|---|---|---|---|---|---|
| **Road Layer** | Thickness (in) | Unit Cost ($/sq-yd-in) | Lane-mi Cost ($/ln-mi) | Thickness (in) | Unit Cost ($/sq-yd-in) | Lane-mi Cost ($/ln-mi) |
| AR Open Graded | | | | | | |
| AR Gap Graded | | | | | | |
| Conv. Asphalt Concrete | 11 | $ 1.70 | $ 131,620 | 5 | $ 1.70 | $ 59,827 |
| Bituminous Treated Base | 6 | $ 1.00 | $ 42,231 | | | |
| Aggregate Base | 4 | $ 0.55 | $ 15,485 | | | |
| Avg Annual Maint Cost | | | $ 1,279 | | | $ 1,279 |
| Total, excl. maint. | 21 | | $ 242,810 | 5 | | $ 76,724 |
| Volume (cubic feet) | 110,856 | | | 26,394 | | |

### Asphalt-Rubber Pavement

| | Reconstruction or New | | | Rehabilitation | | |
|---|---|---|---|---|---|---|
| **Road Layer** | Thickness (in) | Unit Cost ($/sq-yd-in) | Lane-mi Cost ($/ln-mi) | Thickness (in) | Unit Cost ($/sq-yd-in) | Lane-mi Cost ($/ln-mi) |
| AR Open Graded | 0.5 | $ 2.50 | $ 8,798 | 0.5 | $ 2.50 | $ 8,798 |
| AR Gap Graded | 2 | $ 2.40 | $ 33,785 | 2 | $ 2.40 | $ 33,785 |
| Conv. Asphalt Concrete | 6 | $ 1.70 | $ 71,793 | | | |
| Bituminous Treated Base | | | | | | |
| Aggregate Base | 8 | $ 0.55 | $ 30,969 | | | |
| Avg Annual Maint Cost | | | $ 497 | | | $ 497 |
| Total, excl. maint. | 16.5 | | $ 186,395 | 2.5 | | $ 54,610 |
| Volume (cubic feet) | 87,101 | | | 13,197 | | |