The Chemical Company

Submission for Verification of Eco-efficiency Analysis Under NSF Protocol P352, Part B

Micro Surfacing Eco-efficiency Analysis Final Report - July 2010

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1. Purpose and Intent of this Submission

1.1. The purpose of this submission is to provide a written report of the methods and findings of BASF Corporation's "Micro Surfacing Eco-efficiency Analysis", with the intent of having it verified under the requirements of NSF Protocol P352, Part B: Verification of Eco-efficiency Analysis Studies.

1.2. The Micro Surfacing Eco-efficiency Analysis was performed by BASF according to the methodology validated by NSF International under the requirements of Protocol P352. More information on BASF's methodology and the NSF validation can be obtained at http://www.nsf.org/info/ecoefficiency.

2. Content of this Submission

2.1. This submission outlines the study goals, procedures, and results for the Micro Surfacing Eco-efficiency Analysis (EEA) study, which was conducted in accordance with BASF Corporation's EEA (BASF EEA) methodology. This submission will provide a discussion of the basis of the eco-analysis preparation and verification work.

2.2. As required under NSF P352 Part B, along with this document, BASF is submitting the final computerized model programmed in Microsoft® Excel. The computerized model, together with this document, will aid in the final review and ensure that the data and critical review findings have been satisfactorily addressed.

3. BASF's EEA Methodology

3.1. Overview:
BASF EEA involves measuring the life cycle environmental impacts and life cycle costs for product alternatives for a defined level of output. At a minimum, BASF EEA evaluates the environmental impact of the production, use, and disposal of a product or process in the areas of energy and resource consumption, emissions, toxicity and risk potential, and land use. The EEA also evaluates the life cycle costs associated with the product or process by calculating the costs related to, at a minimum, materials, labor, manufacturing, waste disposal, and energy.

3.2. Preconditions: The basic preconditions of this eco-efficiency analysis are that all alternatives that are being evaluated are being compared against a common functional unit or customer benefit. This allows for an objective comparison between the various alternatives. The scoping and definition of the customer benefit are aligned with the goals and objectives of the study. Data gathering and constructing the system boundaries are consistent with the functional unit and consider both the environmental and economic impacts of each alternative over their life cycle in order to achieve the specified customer benefit. An overview of the scope of the environmental and economic assessment carried out is defined below.

3.2.1. Environmental Burden Metrics:
For BASF EEA environmental burden is characterized using eleven categories, at a minimum, including: primary energy consumption, raw material consumption, greenhouse gas emissions (GHG), ozone depletion potential (ODP), acidification

potential (AP), photochemical ozone creation potential (POCP), water emissions, solid waste emissions, toxicity potential, risk potential, and land use. These are shown below in Figure 1. Metrics shown in yellow represent the six main categories of environmental burden that are used to construct the environmental fingerprint, burdens in blue represent all elements of the emissions category, and green show air emissions.

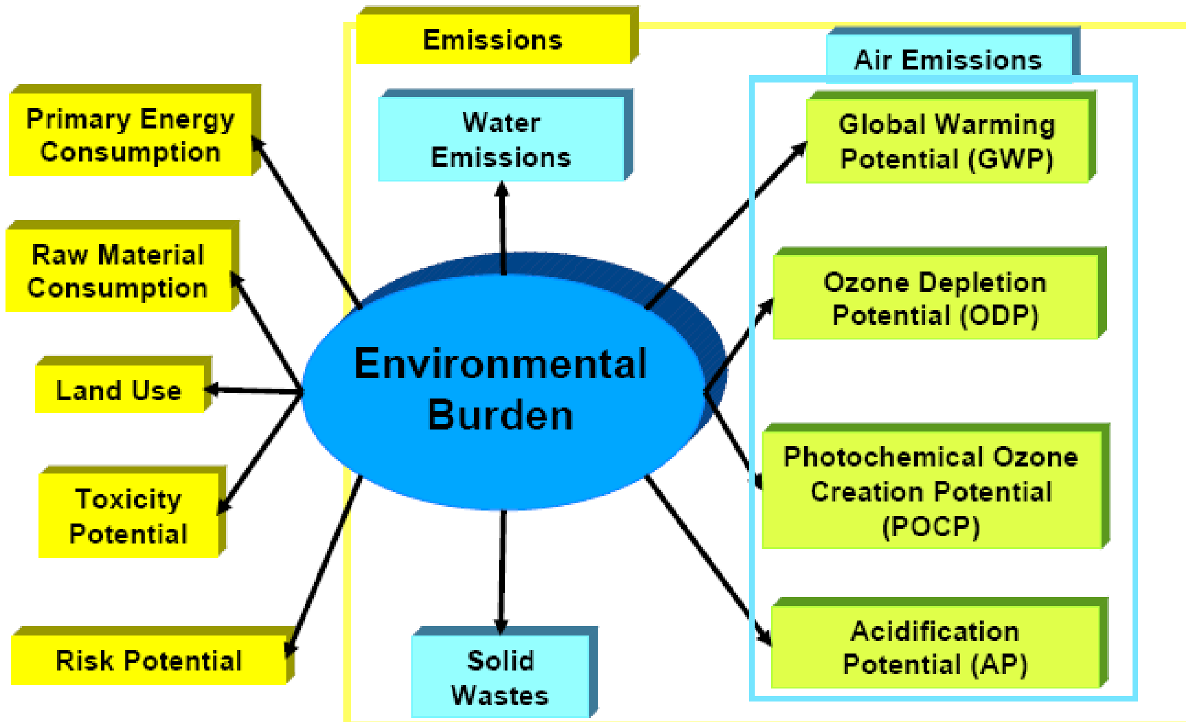

Figure 1. Environmental Impact categories

3.2.2. Economic Metrics:

It is the intent of the BASF EEA methodology to assess the economics of products or processes over their life cycle and to determine an overall total cost of ownership for the defined customer benefit ($/CB). The approaches for calculating costs vary from study to study. When chemical products of manufacturing are being compared, the sale price paid by the customer is predominately used. When different production methods are compared, the relevant costs include the purchase and installation of capital equipment, depreciation, and operating costs. The costs incurred are summed and combined in appropriate units (e.g. dollar or EURO) without additional weighting of individual financial amounts. The BASF EEA methodology will incorporate:

- the real costs that occur in the process of creating and delivering the product to the consumer;
- the subsequent costs which may occur in the future (due to tax policy changes, for example) with appropriate consideration for the time value of money; and
- costs having ecological aspect, such as the costs involved to treat wastewater generated during the manufacturing process.

3.3 Work Flow:

A representative flowchart of the overall process steps and calculations conducted for this eco-efficiency analysis is summarized in Figure 2 below.

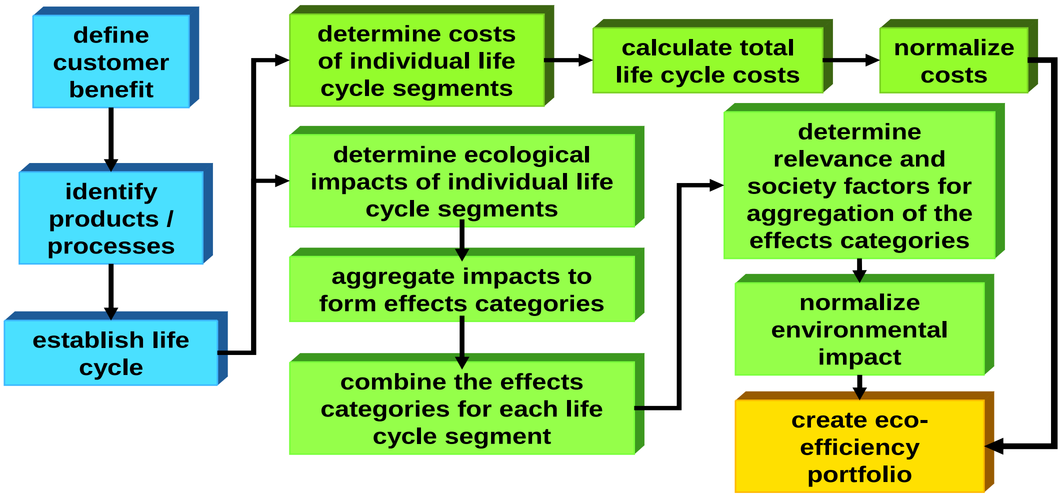

Figure 2: Overall process flow for Residential Insulation EEA study

4. Study Goals, Decision Criteria and Target Audience

4.1. *Study Goals*:

The specific goal defined for the Micro Surfacing Eco-efficiency Analysis was to quantify the differences in life cycle environmental impacts and total life cycle costs of asphalt pavement preservation technologies in the United States.

The study specifically compares two different pavement preservation technologies for urban roads: (1) a hot mix technology: Mill and Fill (two-inch Hot Mix Overlay) and (2) a cold mix technology: SBR polymer modified asphalt emulsion-based micro surfacing. The study considered application of these technologies across the United States as a whole with no specific focus on one region (e.g. Southwest, Northeast). Thus average national data was used for key study input parameters such as expected durability for each alternative, material compositions, costs etc.

It is well documented that the major factor influencing the lifetime environmental and cost impact of the road is how the profile and condition of the road influences the performance (fuel efficiency) of the traffic on the road[21]. The general findings of the Joint EAPA / Eurobitume Task Group on Fuel Efficiency[21] after a review of several relevant studies was that the differences in pavement types did not play a significant role in effecting the energy consumption of the traffic on the road. A more important factor influencing the fuel efficiency of the traffic was whether the pavements were in good condition with good surface characteristics (texture and roughness). Optimal maintenance and pavement preservation of the roads is therefore the key means to limit fuel consumption, greenhouse gas emissions and reduce the overall environmental impact of roads. Consistent with these findings, this study focused on two major maintenance technologies and assumed that these pavement preservation technologies were applied at a frequency and quality that the underlying performance and profile of the road remained the same for each alternative and thus no significant effect on the relative fuel efficiencies of the traffic was realized and thus did not need to be considered in the analysis as it was an identical impact for both alternatives.

Study results will be used as the basis to guide product development and manufacturing decisions that will result in more sustainable pavement preservation technologies as well as provide the necessary information to allow a clear comparison between the life cycle environmental and total cost impacts and benefits of various pavement preservation technologies. It will also facilitate the clear communications of these results as well to key stakeholders in the transportation industry who are challenged with evaluating and making strategic decisions related to the environmental and total costs trade-offs associated with different pavement preservation technologies.

4.2 Decision Criteria:

The context of this EEA study compared the environmental and cost impacts for pavement preservation technologies, specifically an asphalt emulsion based micro surfacing modified with SBR (styrene butadiene rubber) polymer (cold mix) and Mill and Fill (hot mix overlays) for urban roads on a regional level over the road's defined life cycle. The study was technology driven and required supplier and customer engagement. The study goals, target audience, and context for decision criteria used in this study are displayed in Figure 3.

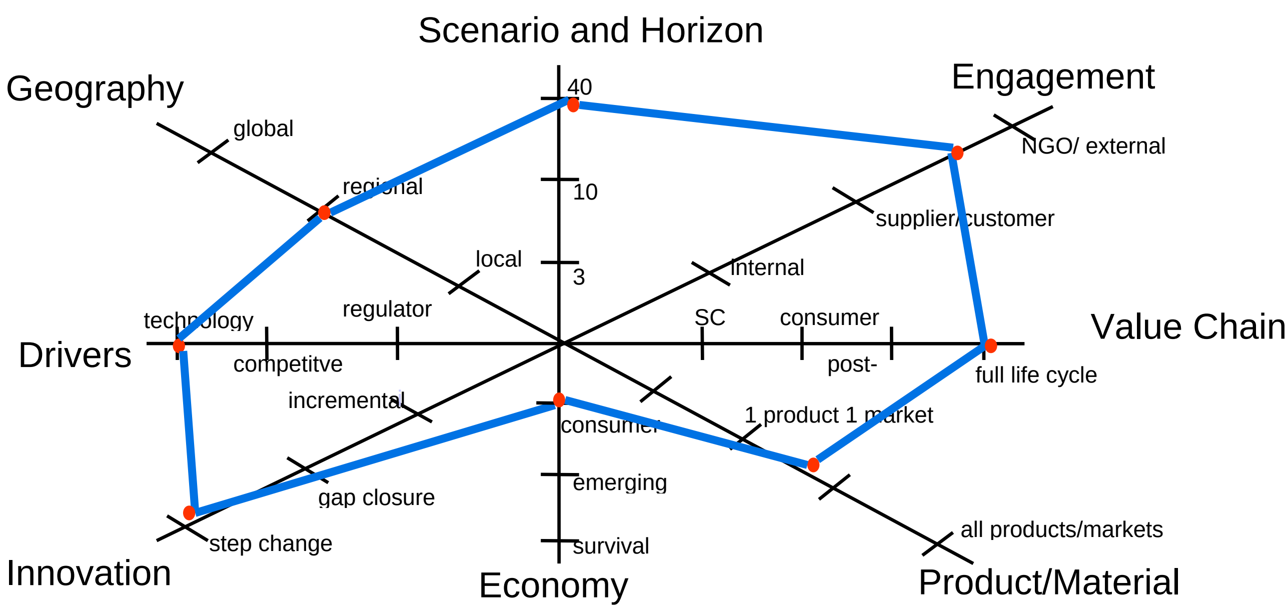

Figure 3. Context of Micro surfacing Eco-efficiency Analysis

4.3. *Target Audience*:

The target audience for the study has been defined as state and federal government agencies (e.g. DOT, Department of Transportation), customers and trade associations. It is planned to communicate study results in marketing materials and at trade conferences.

5. Customer Benefit, Alternatives and System Boundaries

5.1. *Customer Benefit*:

The Customer Benefit applied to all alternatives for the base case analysis is the preventive maintenance of a 1 mile stretch of a 12 foot lane of an urban road to a similar profile and performance using best engineering practices over a 40 year period. With regards to the life span to consider, the FHWA's (Federal Highway Association) LCCA Policy statement[3] states that an analysis period of at least 35 years be considered for pavement projects. Though this was specific to life cycle cost analyses, the same philosophy should apply to an eco-efficiency analysis.

5.2. *Alternatives*:

The product alternatives compared under this EEA study are (1) SBR polymer modified asphalt emulsion based micro surfacing (cold mix) and (2) mill and fill (two-inch hot mix overlay). These alternatives were selected as they represent the most commonly available technologies for pavement preservation for urban roads and represent the majority of the market share. An older but still applicable survey by AASHTO (American Association of State Highway and Transportation Officials)[19] also supports that Mill and Asphalt Overlay and Micro Surfacing are two of the most common preservation technologies and practiced in the majority of the US states.

5.3. *System Boundaries*:

The system boundaries define the specific elements of the production, use, and disposal phases that are considered as part of the analysis. The system boundaries for the two alternatives evaluated in this study are shown in Figures 4 and 5. Sections identified in gray were excluded from the analysis as they represented identical impacts for both alternatives (e.g. fuel efficiency of traffic on the road).

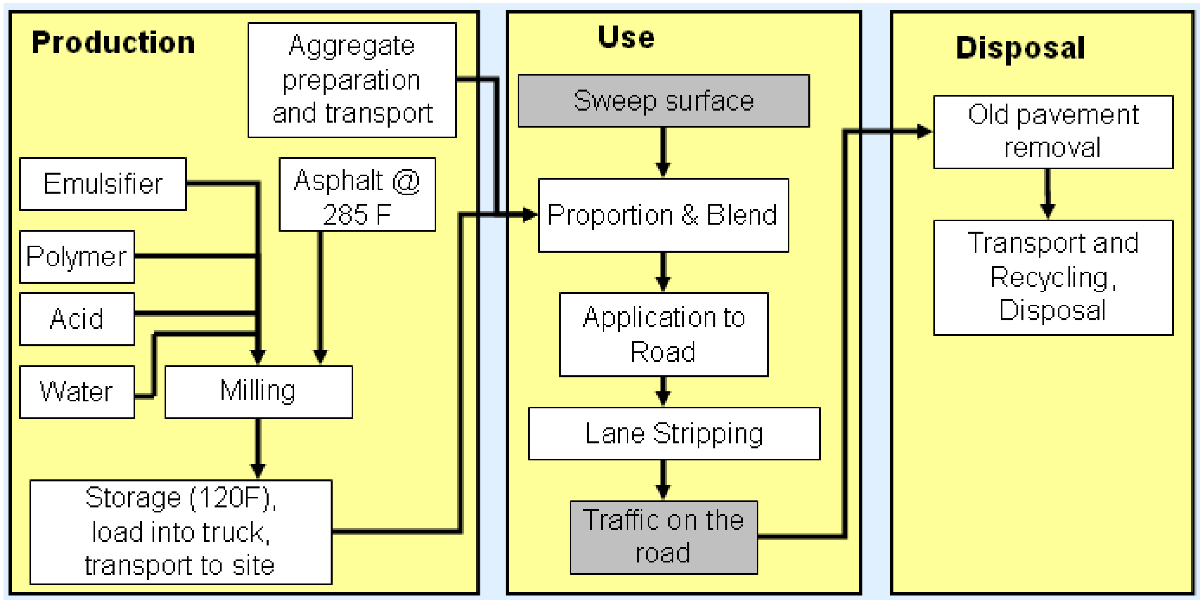

Figure 4. System boundaries - Micro Surfacing

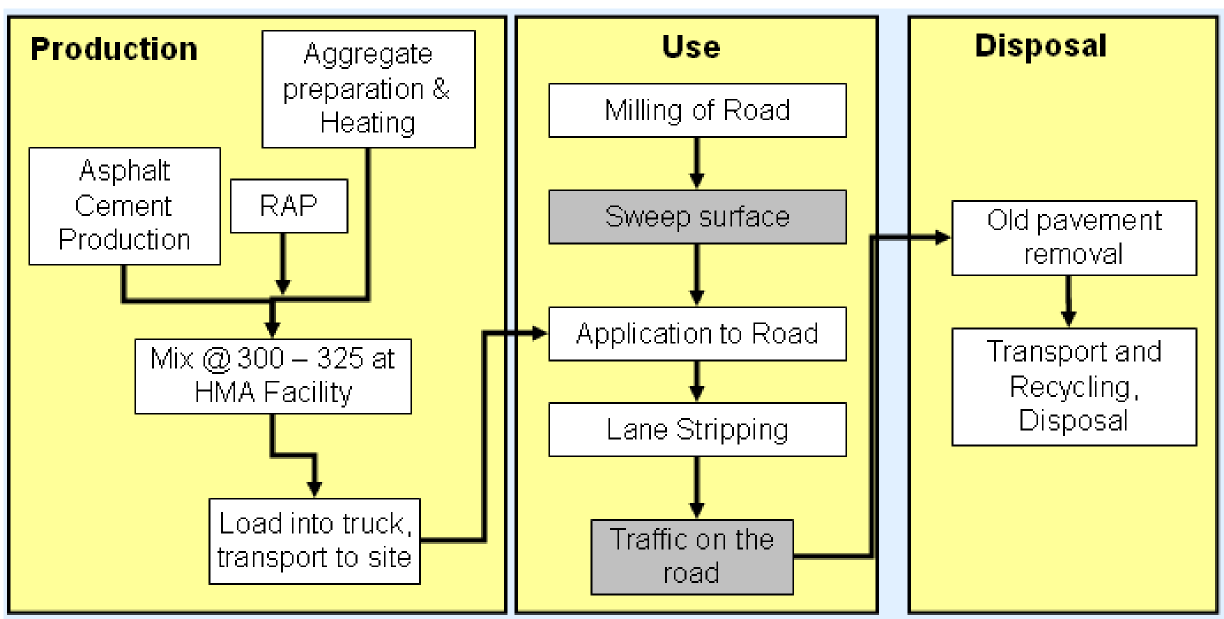

Figure 5. System boundaries – Mill and Fill (Hot Mix Overlay)

5.4 Scenario Analyses:

In addition to the base case analysis, three additional scenarios were evaluated to determine the sensitivity of the study final conclusions and results to key input parameters. The scenarios considered for this analysis were:

5.4.1. Scenario #1: Increased durability for Mill and Fill (relative to micro surfacing)

5.4.2 Scenario #2: Addition of a tack coat with the micro surfacing alternative

5.4.3 Scenario #3: Increased percentage of RAP in Mill and Fill

Results from these scenarios will be discussed along with the base case in Section 8, "Eco-efficiency analysis results and discussion."

6. Input Parameters and Assumptions

6.1. *Input Parameters*:

A comprehensive list of input parameters were included for this study and considered all relevant material and operational characteristics. Absolute input values as opposed to relative values were used.

6.1.1. *Binder – Tack Coat Parameters:*

The compositional data for the binders (CRS-2P for micro surfacing) and tack coats (SS-1_ were parameterized based on representative compositions for the industry and shown below in Table 1. The micro surfacing binder composition shown below was vendor supplied and reflects an average composition and is within the recommendations provided in the ISSA (International Slurry Surfacing Association) A143 mix design guideline for micro surfacing[1]. The Tack Coat was based on an SS-1, anionic grade emulsion and was also based on manufacturer's data[2]. The final distribution of aggregate and bitumen in the surface treatment is also summarized below.

Compositional Data		Microsurfacing	Mill and Fill
Binder Composition	(wgt%)		
Bitumen (asphalt cement)	%	47.4%	100.0%
Polymer			
SBS	%	0.0%	
SBR	%	6.6%	0.0%
Emulsifier	%	0.7%	0.0%
Mineral Filler	%	1.5%	0.0%
Water	%	43.8%	0.0%
TOTAL	%	100.0%	100.0%
Tack Coat (SS-1)	(wgt%)		
Bitumen	%		63.0%
Water	%		34.0%
Emulsifier	%		2.5%
Saponifier	%		0.5%
TOTAL	%		100.0%
Composition			
Aggregate	%	86.4%	95%
Bitumen	%	6.4%	5%
Other Binder Material	%	7.2%	

Table 1: General Product Formulations for study alternatives.

6.1.2. Production and Application Impacts for technologies

As the temperatures required for the manufacture and application of the two alternatives are drastically different (see Figures 4 and 5 above) it is essential that these impacts are considered. Impacts related to the energy required to produce and apply the two alternatives were based on information provided in a Life Cycle Assessment (LCA) report prepared for the Swedish National Road Administration by the IVL - Swedish Environmental Research Institute[4]. For both alternatives, storage of the binder and mix materials were not considered as both technologies are usually applied shortly after manufacture[5]. Due to similarities between the binder (CRS-2P) for the micro surfacing treatment and for the tack coat (SS-1), the energy requirement for the tack coat was estimated to be 10% higher than the CRS-2P binder because of the slightly higher temperature requirement (150 ^{O}F).

With regards to the application amounts, the quantities for micro surfacing were within the limits of the ISSA guidelines[1] and amounted to 20 lb_m/yd^2 for wheel rutting, conservatively applied across the entire road surface, with and additional 25 lb_m/yd^2 for the final surface treatment. A 2” application (which includes compaction) was assumed for the Mill and Fill (Hot Mix Overlay) alternative.

6.1.3. RAP (Reclaimed Asphalt Pavement)

Reclaimed asphalt pavement was included in the hot mix overlay alternative. By reutilizing RAP, the hot mix asphalt alternative is able to introduce existing aggregate and bitumen materials into the mix formula with virgin material and thus reduce the environmental and economic impact of producing additional virgin material. However, in order to maintain the same performance characteristics on the road and to eliminate any additional issues related to surface durability and quality control, many state agencies have limitations on the amount of RAP that can be utilized on the wear coarse of roads. For this study, the maximum amount of RAP allowed in the base case hot mix asphalt overlay was 10%. With RAP content less than 15%, normally there is no change in the performance grade of the binder required. A sensitivity analysis will be performed on the assumption related to the maximum amount of RAP (ref. section 8.4.3). It was also assumed that while RAP will be reutilized, it must first be taken off-site for processing prior to being introduced back into the hot mix asphalt.

6.2. Transportation

Maintaining an asphalt road over 40 years requires a significant quantity of material. Thus the environmental and cost impacts associated with transporting the materials to and from the job site are significant and are thus included in this analysis. The following assumptions were used when considering transportation:

- 100 km distance for bitumen, binder and tack coat
- 50 km for distance for aggregate

- 100 km for distance to landfill or recycling location (e.g. RAP reprocessing)

Table 2 reflects the logistical impacts for the life cycle logistical impacts associated with the two alternatives.

TRANSPORTATION IMPACT			
Production and Use		**Micro surfacing**	**Mill and Fill**
Truck fuel consumption	MJ/ton/km	2.2	2.2
Binder-Bitumen-Tack Coat			
weight transported	kg/CB	130286	132078
distance	km	100	100
Aggregate			
weight transported	kg/CB	827702	2324157
distance	km	50	50
Transportation Impact	kg/CB	957988	2456235
(minus road markings)	t*km/CB	54414	129416
DISPOSAL			
Quantity of Material	kg/CB	969951	2462760
Transportation Distance	km	100	100
Transportation Impact	t*km/CB	96995	246276
Amount of material recycled		90%	

Table 2: Logistical Impacts for each alternative

6.3. Costs

6.3.1. Life cycle costing

The long term economic impacts of the pavement preservation technologies evaluated were considered by conducting a life cycle cost analysis. Thus, in addition to initial costs (e.g. material and labor), all relevant future cost impacts are considered as well. Consistent with the guidance provided by the US DOT FHWA, constant dollars and real discount rates were considered[3]. For this study, both a financial discount rate and a social discount rate[11] were used. See section 6.3.3 for the justification for the specific rates used.

6.3.2. User Costs

User costs were evaluated for each alternative. User costs are defined as excess costs incurred by drivers on the road due to non-standard travel delays caused by agency (e.g. DOT) maintenance and construction activities which disrupt the normal flow of traffic. This approach is basically a way of placing a value on people's time that is impacted or disrupted by traffic delays. The FHWA normally groups user costs as vehicle operating costs (VOC), user delay costs and crash costs. Guidance for these costs was obtained from published LCA literature[8]. Specific to this study, as most pavements on the National Highway System (NHS) have similar VOCs[8], they were not considered for this study. In addition, crash costs were not considered though the frequency and type of accidents in construction zone are considered in our risk impact area (see Fig. 1). Consistent with the strategy proposed by Hicks and Epps, delay costs were accounted for by utilizing a simpler approach: lane rental fees. The value utilized for this study reflecting a moderately traveled urban road was estimated at $5,000 lane-mile/day[8]. Other research[20] conducted on lane rental fees indicate that this value can vary significantly based on factors such as the time of the day and region of the country. Never the less, this research indicates that this value can be much higher, ranging from $5,000 - $20,000 /day for a single lane. Thus the assumption of$5,000 may be conservative.

6.3.3. Discount Rates

As previously described, comprehensive life cycle costing for roads needs to consider both the actual costs incurred as well as the intangible costs associated with user costs. As both of these costs are distinctly different, a single discount rate cannot be applied. Thus both a financial discount rate (FDR) and a social discount rate (SDR) need to be used. Literature[12] documents the average US DOT financial discount rate as 4.8%, which falls within the FHWA range of 3-5%, and also cites additional research which places the range for the US DOT (FHWA) social discount rate between 4 - 8%. Thus for this assessment, 4.8% was used for the FDR and 6% for the SDR.

6.4. Durability

The durability or life expectancy of the pavement preservation technology will have a significant impact in determining the overall eco-efficiency of the alternatives. Durability will vary depending on the region of the country and climate, level and type of traffic usage, and the condition of the underlying pavement. Under the direction of the National Center for Pavement Preservation a survey was conducted of all state DOT agencies in order to collect a broad data set related to state DOT experiences with specific preservation technologies. Specific questions included:

- Agency's years of experience with a specific technology
- Most recent usage of several preservation technologies
- Expected average service life for a specific technology
- Total monetary expenditure for specific technologies

Over 17 state agencies respond to the questionnaire. Results related to the two alternatives considered in this study are summarized below:

a. Micro Surfacing:

- Over a third of the respondents had over 11 years of experience

- Over 70% had used micro surfacing since 2008
- Life expectancy ranged from 4 – 7 years with an average of 6 years. The median value was 5.9 years.

b. Mill and Fill (Hot Mix Overlay)

- Over 80% the respondents had over 16 years of experience
- Over 75% had used Thin Hot Mix Overlay in the last year
- Life expectancy ranged from 3 – 18 years with an average of 11 years. The median value was 10.9 years.

Other external references were consulted for information related to durability. NAPA collated field performance data[18] from many states for hot mix overlays and concluded a comparable range of durability of between 7 – 16 years. Also, a 2008 NAPA survey of state agencies established a range of durability of hot mix overlays between 7 – 14 years and 4 – 6 years for micro surfacing.

Based on the various data sources reviewed and the expert judgment and experiences of the team, values of 6 years and 11 years were used for micro surfacing and Mill and Fill (Hot Mix Overlay), respectively and deemed representative of the country as a whole. A scenario analysis (see section 8.4.1) will address the sensitivity of the results to these key assumptions.

6.5. Further Assumptions

6.5.1. Work Zone Accidents and Fatalities

A project specific impact accounting for work zone accidents and fatalities associated with road maintenance and construction activities was included. These statistics were incorporated with our other industry data in our Occupational Illnesses and Accidents impact group (depicted as our risk impact in Figure 2). Statistics were obtained from data collected by the Federal Highway Administration (FHWA)[13]. As each alternative requires a different amount of time to install, the frequency of injuries and fatalities related to the construction activities will be different. It was assumed for this study that the time required to install the hot mix overlay is 2 full days (8 hrs/day) and the micro surfacing treatment requires 2 lifts for a total of 4 hours over two days.

6.5.2. Lane striping

The study assumed that each time a surface treatment was applied, new lane striping was applied. The striping material was based on an epoxy resin based thermoplastic (ETP) with glass beads. Material composition was obtained from a

DOT standard[14]. Specific costs and application rates were provided by a vendor[16].

6.5.3. Disposal – End of Life

In addition to the base assumption that 10% of the asphalt road will perpetually be reused as RAP for the Mill and Fill alternative, it was also assumed that 90% of the road surface materials will be recycled in some capacity and thus will not be sent directly to the landfill. However, the logistical impacts of transporting the materials to their final end-of-life destination were considered.

7. Data Sources

7.1. The environmental impacts for the production, use, and disposal of the two alternatives were calculated from eco-profiles (a.k.a. life cycle inventories) for the individual components and for fuel usage and material disposal. Life cycle inventory data for these eco-profiles were from several data sources, including BASF specific manufacturing data and customer supplied data. Overall, the quality of the data was considered medium-high to high. None of the eco-profile data was considered to be of low data quality. A summary of the eco-profiles is provided in Table 3.

Table 3: Summary of eco-profiles used the eco-efficiency analysis

Eco-Profile	Source, Year	Comments
Microsufacing		
SBS polymer	2003	ChemSystems PERP report
SBR Polymer	1999	ChemSystems PERP report Styrene Butadiene/Butadiene Rubber
Portland Cement (mineral filler)	US Avg., 1996	Most reliable profile available[7]
Saponifier	US Avg., 1996	Most reliable profile available[7]
Emulsifier	US Avg., 1996	Most reliable profile available[7]
Aggregate	US Avg., 1996	Most reliable profile available[7]
Bitumen	2001	IVL Report. LCA of Roads[4]
Natural Gas	US Avg., 1996	Most reliable profile available[7]
Electricity	US Avg., 1996	Most reliable profile available[7]
Heating Oil - US	US Avg., 1996	Most reliable profile available[7]
Diesel Use - US	US Avg., 1996	Most reliable profile available[7]
Material to Landfill	BUWAL 250, 1998[9]	
Lane Striping	2009	Dept. of Transportation[14]
Transport	US Avg., 1996	Most reliable profile available[7]
BASF data sources are internal data, while the others are external to BASF. Internal data is confidential to BASF; however, full disclosure was provided to NSF International for verification purposes.		

8. Eco-efficiency Analysis Results and Discussion

8.1. *Environmental Impact Results*: The environmental impact results for the Micro Surfacing EEA are generated as defined in Section 6 of the BASF EEA methodology. The results for the base case scenario are presented below in sections 8.1.1 through

8.1.9. The eco-efficiency portfolio results for the scenario analyses are presented in section 8.4.

8.1.1. *Primary energy consumption*: Energy consumption, measured over the entire life cycle and depicted in Figure 6, shows that Micro Surfacing alternative has the lowest energy consumption, using approximately 6,000,000 MJ of energy per customer benefit. This is over 40% less energy consumption relative to the Mill and Fill (hot mix overlay) alternative. The biggest contributor to energy consumption for each alternative is the manufacture of the asphalt binder. Over the 40 year life cycle, micro surfacing uses almost 45% less bitumen than the hot mix overlay. Hotter production and application temperatures for hot mix overlay, as well as the increased fuel requirements for shipping larger amounts of material to and from the job site, also contribute to Mill and Fill having a higher energy impact. Micro surfacing has a higher impact in road markings due to the more frequent applications. The embodied energy of each individual material was provided in the eco-profiles supplied to NSF as part of this verification. By looking at only the modules in Figure 6 related to the production phase of the alternatives, it can be concluded that in addition to having a lower life cycle energy requirement, the embodied energy of micro surfacing technology is also less than the Mill and Fill alternative.

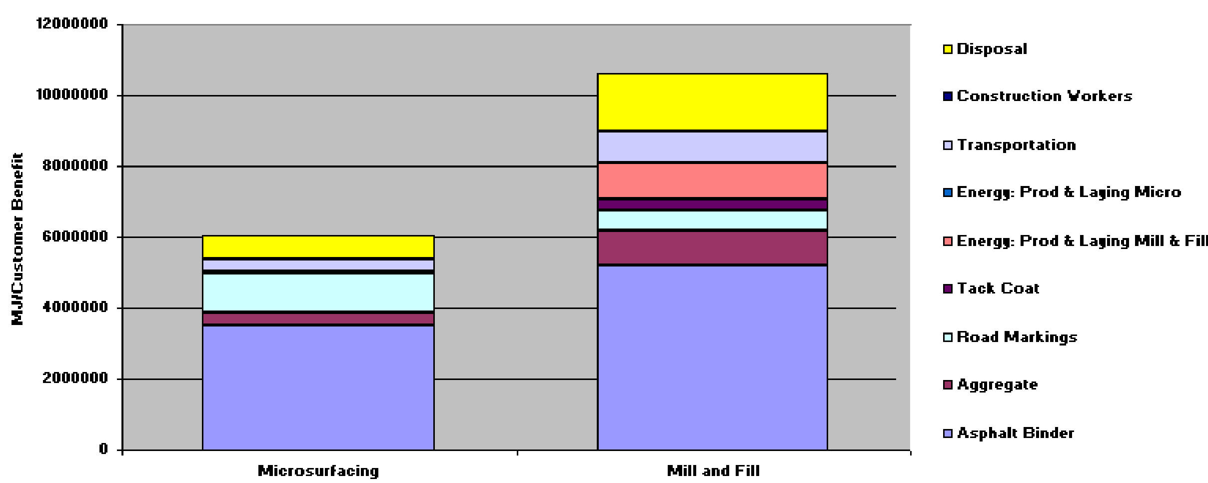

Figure 6. Primary energy consumption.

8.1.2. *Raw material consumption*: Figures 7 shows that the key drivers for the raw material or resource consumption are the asphalt binder, aggregate, road markings and the disposal/transportation modules. Though the resources are similar, the much higher quantity of materials required for the hot mix overlay contribute to its higher score. Even considering the use of RAP in the hot mix overlay, the micro surfacing technology uses over 50% less resources (by mass) or 43% less on a weighted basis. It should be noted that raw material consumption is the most relevant environmental impact category for this study.

Per the BASF EEA Methodology, individual raw materials are weighted according to their available reserves and current consumption profile. These weighting factors are appropriate considering the context of this study. As to be expected and indicated in Figure 8, oil is the most significant resource consumed. Though it is the largest resource used by weight, the lower relative weighting applied to the aggregate compared to oil, allows the aggregate to have a much lower overall weighting. As highlighted above, micro surfacing utilizes significantly less oil and aggregate over the life cycle to achieve the same desired performance and profile of the road relative to the hot mix overlay. Titanium, a scare resource, is a noticeable resource being consumed due to its use as a pigment material in the lane striping. Micro surfacing has a higher impact in the usage of titanium due to the more frequent lane striping activities.

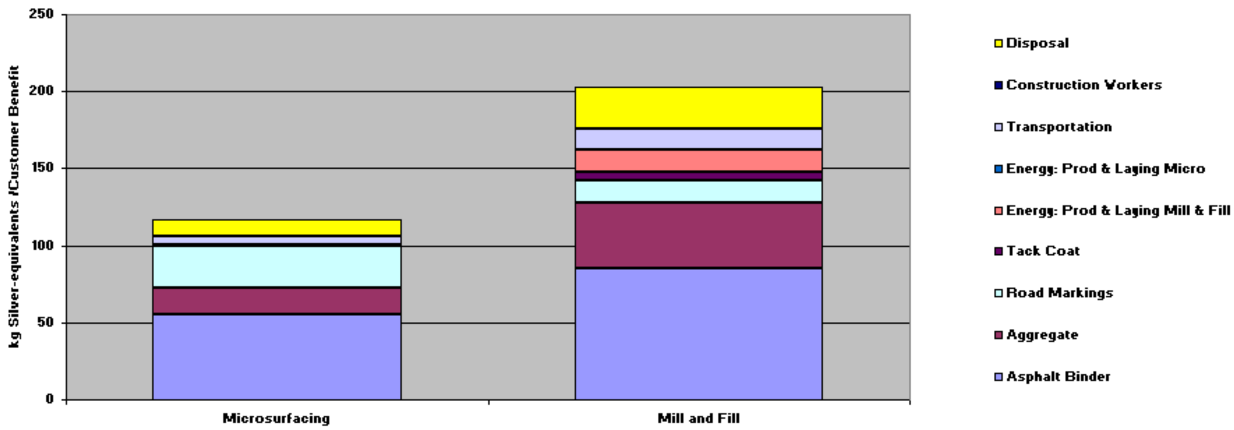

Figure 7. Raw Material consumption by Module.

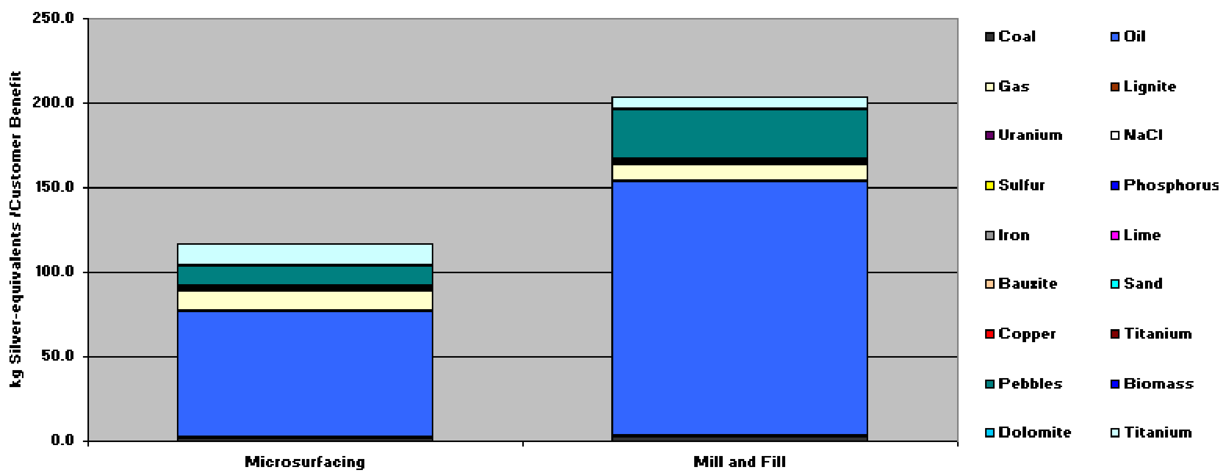

Figure 8. Raw Material consumption by Type.

8.1.3. *Air Emissions*:

8.1.3.1. *Greenhouse Gases (GHG)*: Figure 9 shows that the highest carbon fingerprint occurred in the Mill and Fill (hot mix overlay) alternative, with a measurement of nearly 261,000 kg of CO_2 equivalents per customer benefit.

Micro surfacing had the lowest carbon footprint, which resulted in the emission of around 145,000 kg of CO_2 equivalents per customer benefit. This is almost a 45% reduction. The higher GHG emissions for the hot mix overlay are primarily a result of the increased energy required to produce and apply the material and the significantly higher quantity of aggregate required, 2.5 times more than micro surfacing.

The lane striping material is also a significant contributor to greenhouse gases for the micro surfacing alternative due to the emissions related the manufacturing of the epoxy resin.

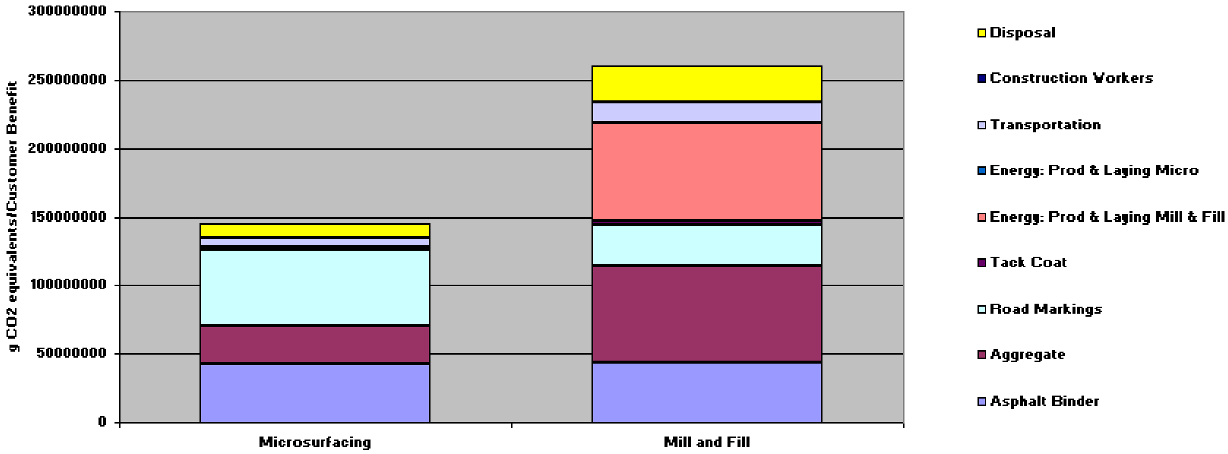

Figure 9. Greenhouse Gas Emissions.

8.1.3.2. *Photochemical ozone creation potential (smog)*: The lowest emissions for ground level ozone creation potential occur for micro surfacing. Figure 10 shows that POCP is highest for the Mill and Fill alternative because it requires over twice the amount of material to be shipped to and from the manufacturing and job sites. The impact is specifically attributed to the methane and non-methane VOCs emitted during the combustion of fuel during the transportation of the pavement materials.

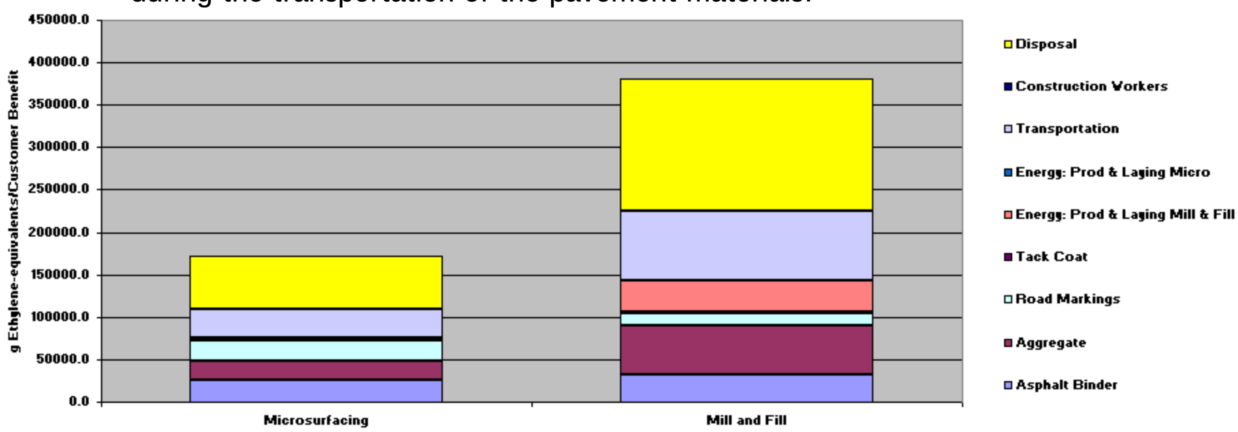

Figure 10. Photochemical ozone creation potential.

8.1.3.3. *Ozone depletion potential (ODP)*: All of the alternatives result in a minimal ozone depletion potential, measured in a range from 74 - 135 g CFC equivalents per customer benefit. Figure 11 indicates that the ODP comes predominately from the pre-chain chemistries involved in the precursor materials used in the thermoplastic striping material used in the road markings. Overall, ODP is the least relevant air emission and accounts for around 1% of the total environmental impact for each of the systems.

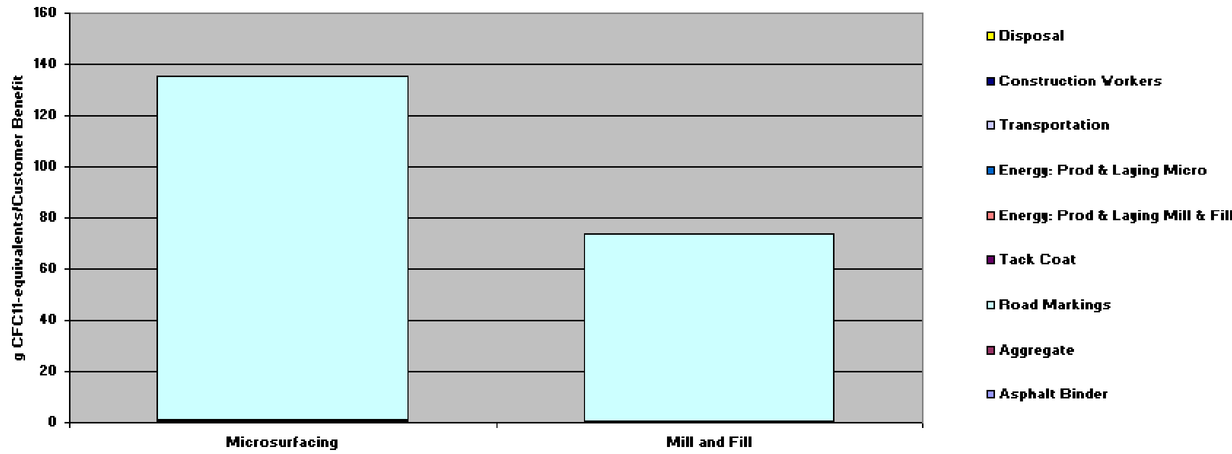

Figure 11. Ozone depletion potential.

8.1.3.4. *Acidification potential (AP)*: It can be seen from Figure 12 that overall, micro surfacing has a significantly lower acidification potential over the entire life cycle, with emissions of 16,400 g of SO_2 equivalents per customer benefit. Mill and Fill has the highest acidification potential, with emissions of 648,000 g of SO_2 equivalent per customer benefit. Acidification potential primarily results from NO_x, and SO_x generated during the burning of the fuel oil for the heating of the aggregate and asphalt for the Mill and Fill (hot mix overlay). Also, fuel and electricity consumption for the milling and transportation of the aggregate also contribute.

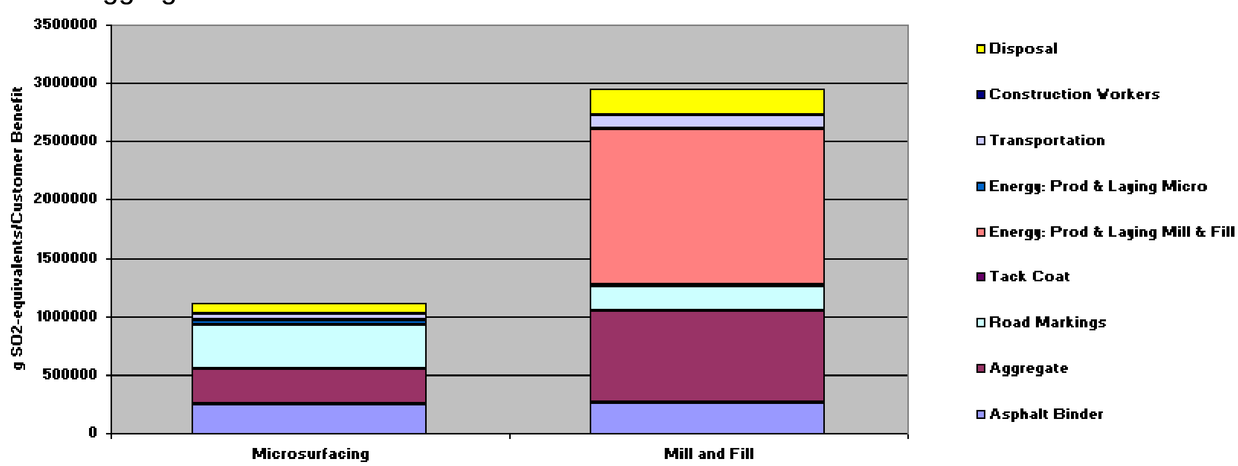

Figure 12. Acidification potential.

Utilizing the calculation factors shown in Figure 28, Figure 13 shows the normalized and weighted impacts for the four air emissions categories (GWP, AP, POCP and ODP) for each alternative. Mill and Fill has a higher air emission impact than micro surfacing over its life cycle.

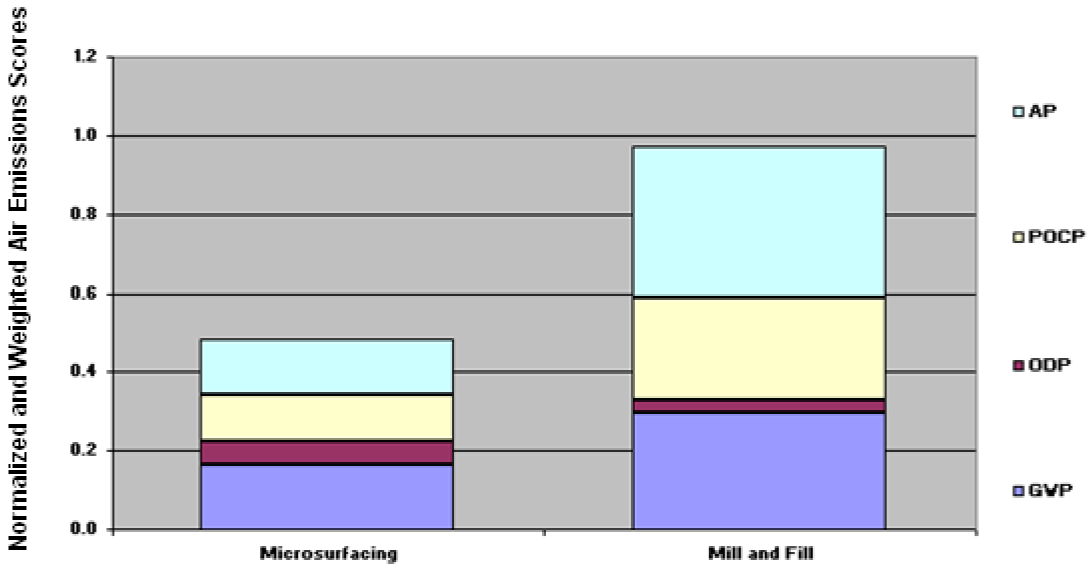

Figure 13. Overall Air Emissions

8.1.4. *Water emissions*: Figure 14 displays that relative to Mill and Fill, micro surfacing has the highest critical waste water volume requirement. These water emissions are attributed to the hydrocarbons, COD and Cl^- emissions generated during the manufacture of the thermoplastic striping material, specifically the epoxy resins. Excluding the impact of the road markings, the remaining water emissions for each alternative are about equivalent.

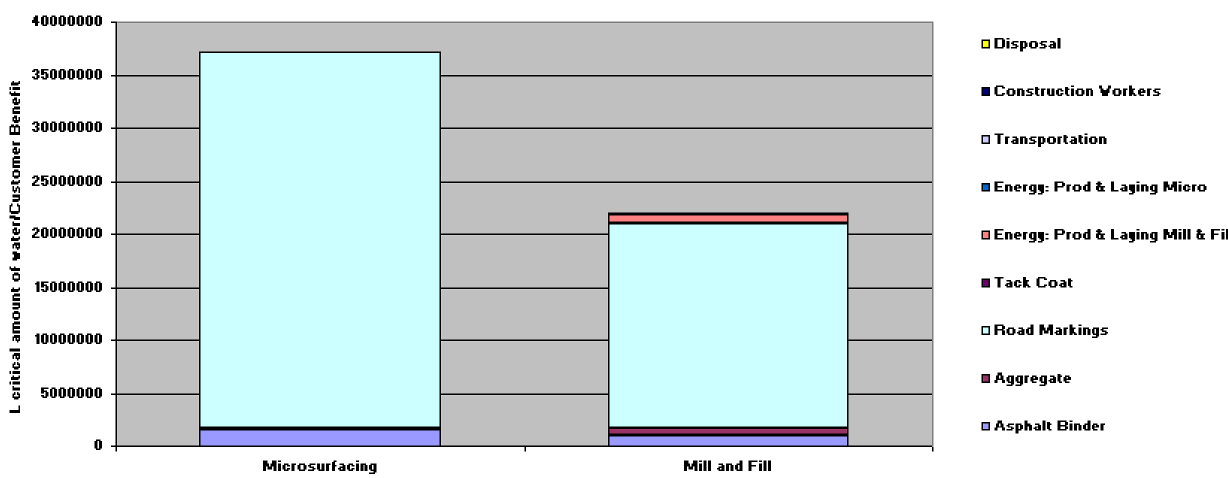

Figure 14. Water emissions.

8.1.5 *Solid waste generation*: Solid waste emission categories considered for this study included municipal, special, construction and mining wastes. Solid waste emissions for each alternative are depicted below in Figure 15 and are mostly the result of material sent to landfill (disposal module). This impact relates directly to the total weight of the alternatives and how much can be recycled. Material sent to landfill does take into consideration the amount of perpetual RAP used in Mill and Fill and ultimately that 90% of the pavement materials can be recycled in some form. As to be expected, the Mill and Fill alternative, which uses more than 250% of the amount of material than micro surfacing, has the highest impact in this category.

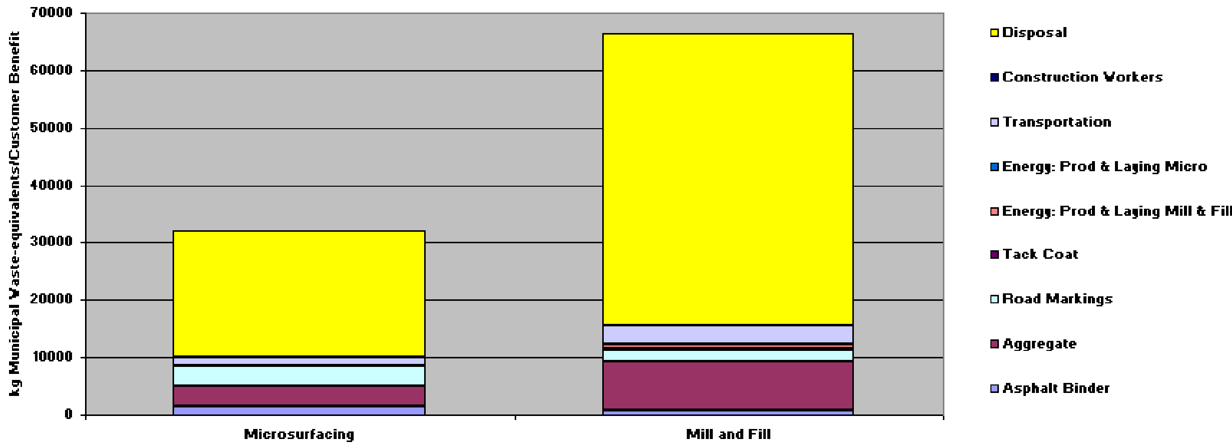

Figure 15. Solid waste generation.

Utilizing the calculation factors shown in Figure 28, a composite of the cumulative impact of the three main emission areas of air, water and solid waste is depicted in Figure 16. Mill and Fill scores higher overall and has the highest score for air and solid waste emissions, though it did have the lowest score for water emissions.

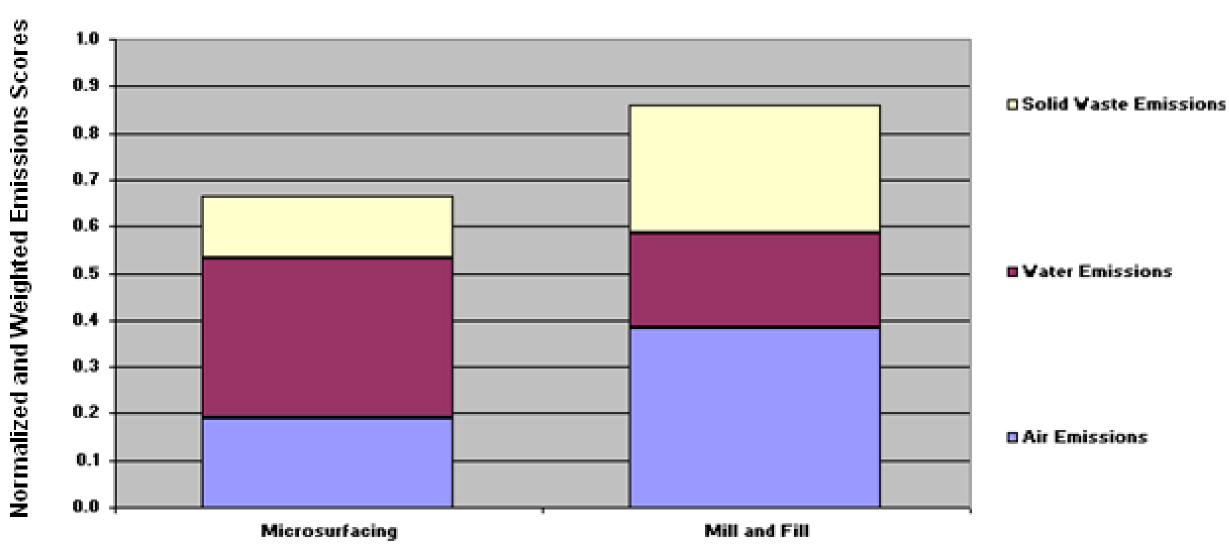

Figure 16. Overall Emissions Scores

8.1.6 *Land use*: As displayed in Figure 17, energy required for the production and application of the Hot Mix Overlay is the largest contributor to land use. Mining wastes (aggregate production) as well as solid waste disposal of the materials not recycled also contribute.

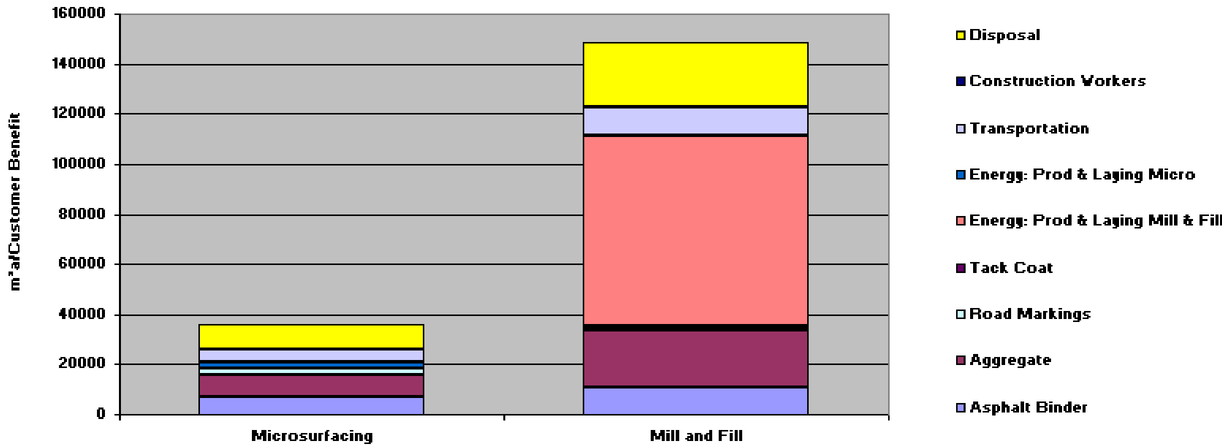

Figure 17. Land use.

8.1.7 *Toxicity potential*: The toxicity potential for the various pavement preservation alternatives was analyzed for the production, use and disposal phases of their respective life cycles. For the production phase, not only were the final products considered but the entire pre-chain of chemicals required to manufacture the products were considered as well. Human health impact potential in the Use phase consists of the material applications (e.g. asphalt, lane striping). Toxicity potential in the Disposal phase comes from the removal and transport of the materials to a landfill or other end-of-life destination. Nanoparticles were not included in the chemical inputs of any of the alternatives

Inventories of all relevant materials were quantified for the three life cycle stages (production, use and disposal). Consistent with our methodology's approach for assessing the human health impact of these materials (ref. Section 6.8 of Part A submittal), a detailed scoring table was developed for each alternative broken down per life cycle stage. This scoring table with all relevant material quantities considered as well as their R-phrase and pre-chain toxicity potential scores were provided to NSF International as part of the EEA model which was submitted as part of this verification. Figure 18 shows how each module contributed to the overall toxicity potential score for each alternative. The values have been normalized and weighted. The toxicity potential weightings for the individual life cycle phases were production (20%), use (70%) and disposal (10%). These standard values were not modified for this study from our standard weightings.

As to be expected the application of the materials (binder, asphalt, striping material) as well as the higher weighting placed on the exposure during the use phase contributed the largest amount to the toxicity potential for each alternative. As the materials themselves are quite similar or identical in the case of the striping material, the main difference between the alternatives is thus the quantity of materials applied. As the hot mix overlay requires over twice the amount of material, the Mill and Fill scores the highest.

Figure 19 shows how the scoring is distributed across the life cycle stages. Consistent with the discussion above, the USE phase is the most significant, followed by the production and the final disposal. A high safety standard was assumed for the manufacturing processes for the raw materials. For the Use phase, an allowance was made to take into consideration the open nature of the application process. Finally, no reduction in the scores based on exposure conditions was applied for the disposal phase of the materials as the potential for human contact during removal and disposal of the materials is high.

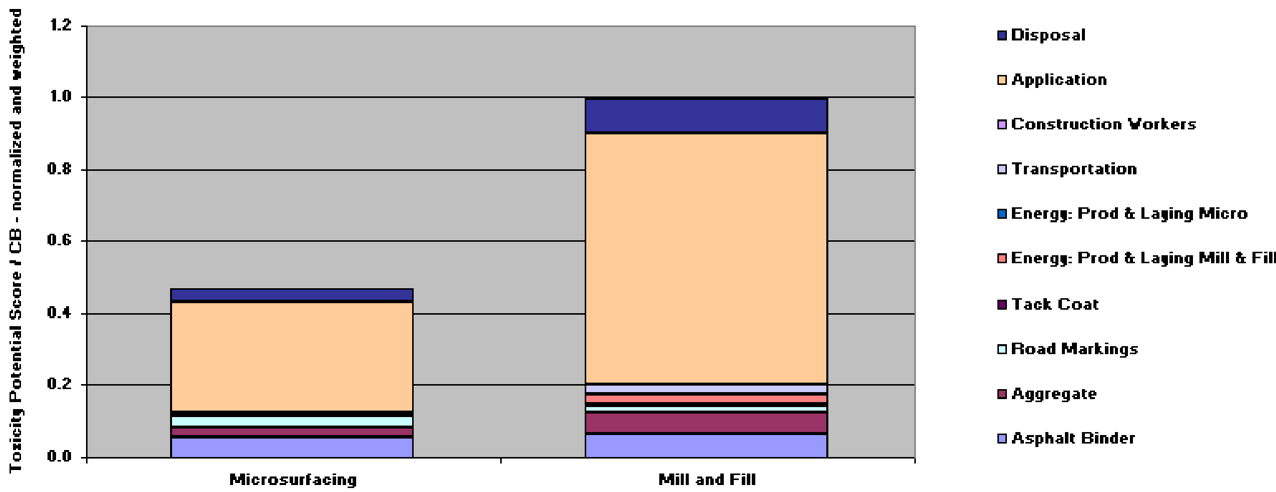

Figure 18. Toxicity potential – Modules

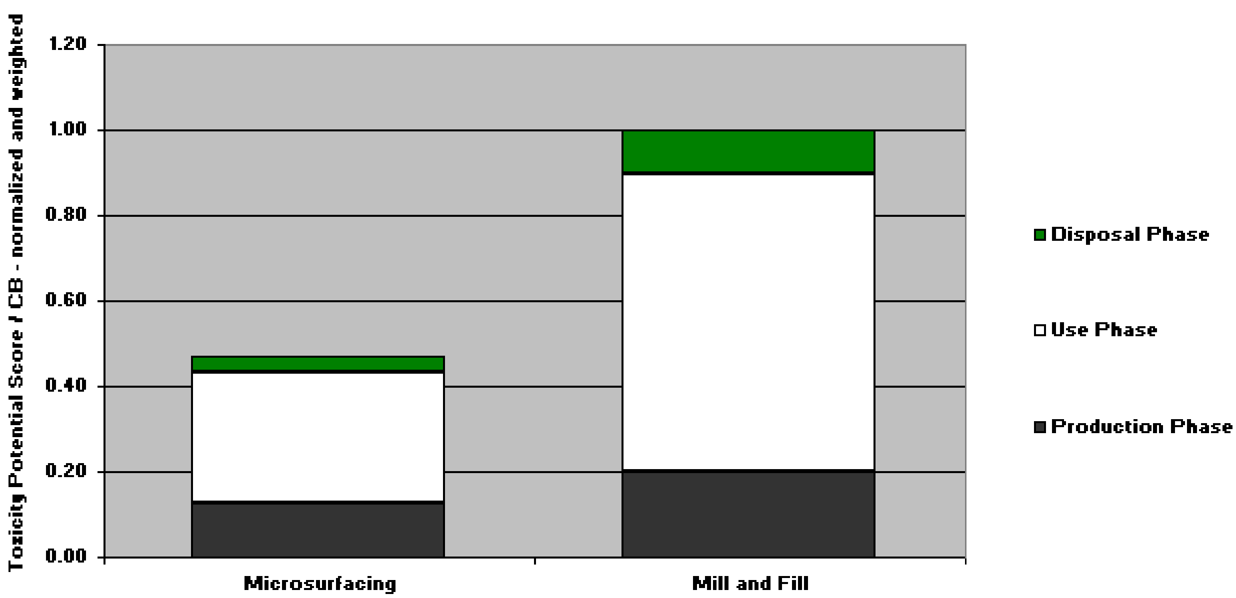

Figure 19. Toxicity potential- Life Cycle Phases

8.1.8. *Risk (Occupational Illnesses and Accidents potential)*:
All the materials and activities accounted for in the various life cycle stages were assigned specific NACE codes. NACE (Nomenclature des Activities Economiques)

is a European nomenclature which is very similar to the NAICS codes in North America. The NACE codes are utilized in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the business economy and is broken down by specific industries. Specific to this impact category, the NACE codes track, among other metrics, the number of working accidents, fatalities and illnesses and diseases associated with certain industries (e.g. chemical manufacturing, petroleum refinery, inorganics etc.) per defined unit of output. By applying these incident rates to the amount of materials required for each alternative, a quantitative assessment of risk is achieved.

In Figure 20, the greatest Occupational Illnesses and Accident potential occurs for the hot mix overlay (Mill and Fill). The module which contributes to the highest risk potential for occupational illnesses and accidents is the aggregate, by far the largest single resource used in the alternatives. The longer construction time required for the Mill and Fill alternative exposes the construction workers to a higher risk of construction related injuries and fatalities.

This study put a 10% weighting on a risk category associated with the risk of burns, fires and injuries related to the production and application temperatures for each alternative. Figure 21 shows the normalized and weighted overall risk category score for each alternative with this additional impact considered. Naturally, as the production and application temperatures are much higher for the hot mix overlay compared to the cold mix micro surfacing technology, the Mill and Fill alternative scores highest in this specific risk category as well as overall.

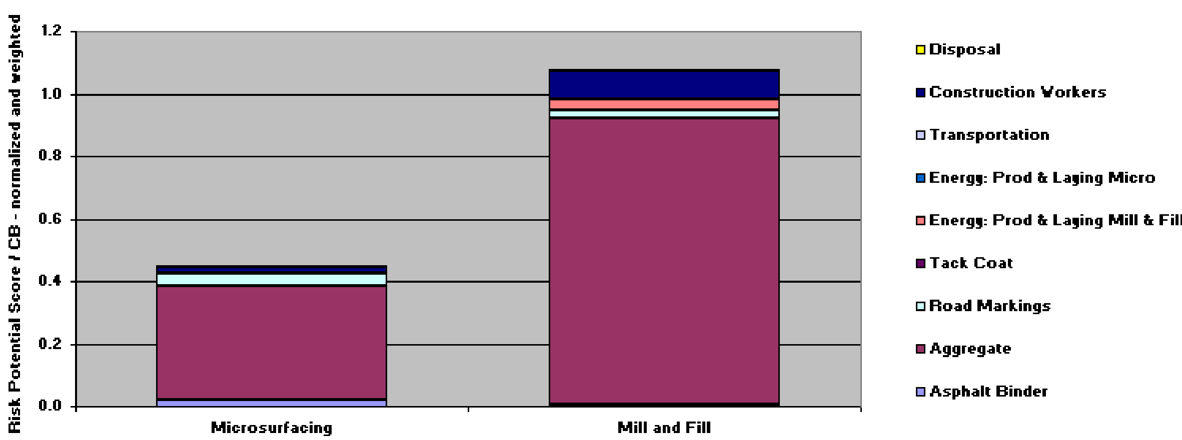

Figure 20. Risk Potential (Occupational Illnesses and Accidents) – per module

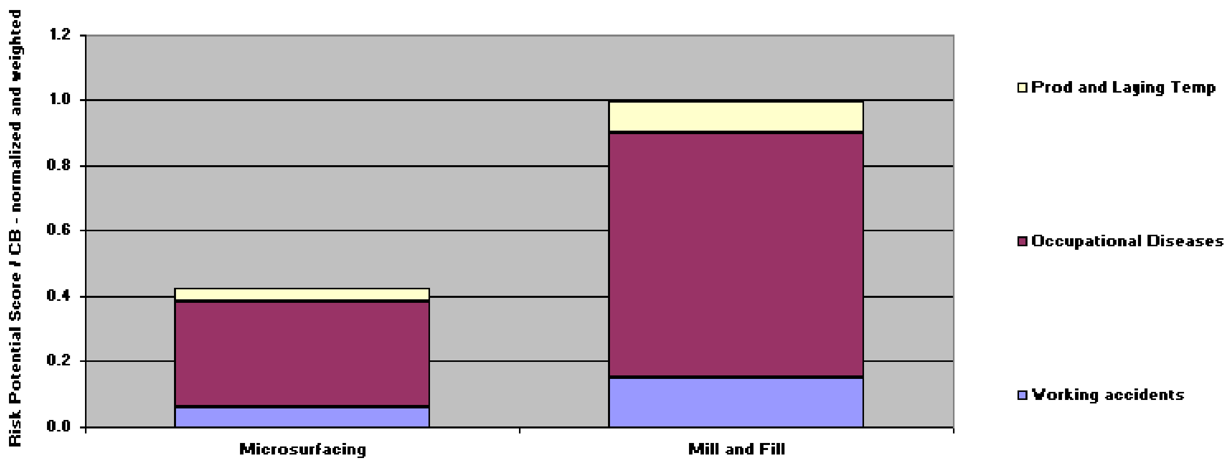

Figure 21. Risk Potential – per impact category

8.1.9. *Environmental fingerprint*: Following normalization, or normalization and weighting with regards to the emissions categories, the relative impact for all six of the main environmental categories for each alternative is shown in the environmental fingerprint (Figure 22). Mill and Fill (hot mix overlay) has the highest environmental impact on a weighted basis in all of the main categories; however it did perform better than micro surfacing in the water emission subcategory and in the air emission, ozone depletion. Micro surfacing performs the best in all of the main categories on a weighted basis due to requiring the least amount of material over the life cycle while still maintaining the desired road characteristics and performance. Overall, micro surfacing uses less than 50% of the amount of materials required for Mill and Fill.

Though applied more frequently, micro surfacing scored the lowest in resource consumption, the most relevant environmental impact for this study, because of its significant reduction in the amount of binder and aggregate used. This significant reduction in material usage also benefits micro surfacing in the Toxicity Potential and Occupational Illnesses and Accidents categories. As the materials being used for each alternative are relatively the same, scoring in these areas is thus strongly dependant upon the amount of material used over the life cycle. Thus micro surfacing scores much better relative to Mill and Fill. Micro surfacing also scores the lowest in energy requirement, the second-most relevant environmental impact for this study, due to its lower overall consumption of binder (specifically bitumen), its lower manufacturing and application temperatures as well as the reduced logistical impacts of shipping less material to and from the job site.

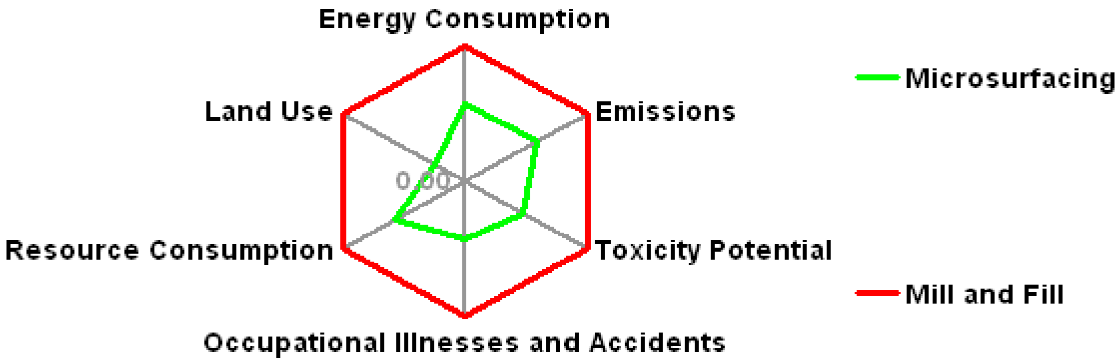

Figure 22. Environmental fingerprint.

8.2. *Economic Cost Results*:

The life cycle cost data for Micro Surfacing EEA are generated as defined in Section 7 of the BASF EEA methodology and described in section 6.3 above. As highlighted in section 6.3.3 the study considered the time value of money and calculated the net present value of future costs. The results of the life cycle cost analysis and depicted in Table 4 and Figure 23 found that the micro surfacing alternative has the lowest life cycle costs and the alternative with the highest life cycle cost is the Mill and Fill. Micro surfacing specifically has lower material and user costs but because of the more frequent requirements for striping, has a higher lane striping life cycle cost.

Material costs, which also include the labor charges associated with the installation, are obviously the main contributor to the overall life cycle costs. Representative average material costs were obtained for each alternative from multiple manufacturers. The costs compare favorable to the range of costs cited in the NAPA state agency survey[19]. In addition, the annual costs reported in the NAPA survey of state agencies cites the annual costs for thin overlays as around $3,000/lane mile. When this figure is adjusted for the two-inch overlay considered in this study the adjusted cost is very close (less than 8% variance) to the yearly life cycle cost/lane mile calculated in this study.

Table 4: Life cycle costs

Life Cycle Costs		Micro surfacing	Mill and Fill
Material Cost	$/yd2	$4.00	$9.25
Material and Labor Costs	$/CB	$97,079	$136,037
Disposal Costs	$/CB	$3,650	$7,900
Lane Rental Fees	$/CB	$7,740	$19,505
Striping Fee	$/CB	$15,633	$9,651
Total Cost	$/CB	$124,103	$173,093

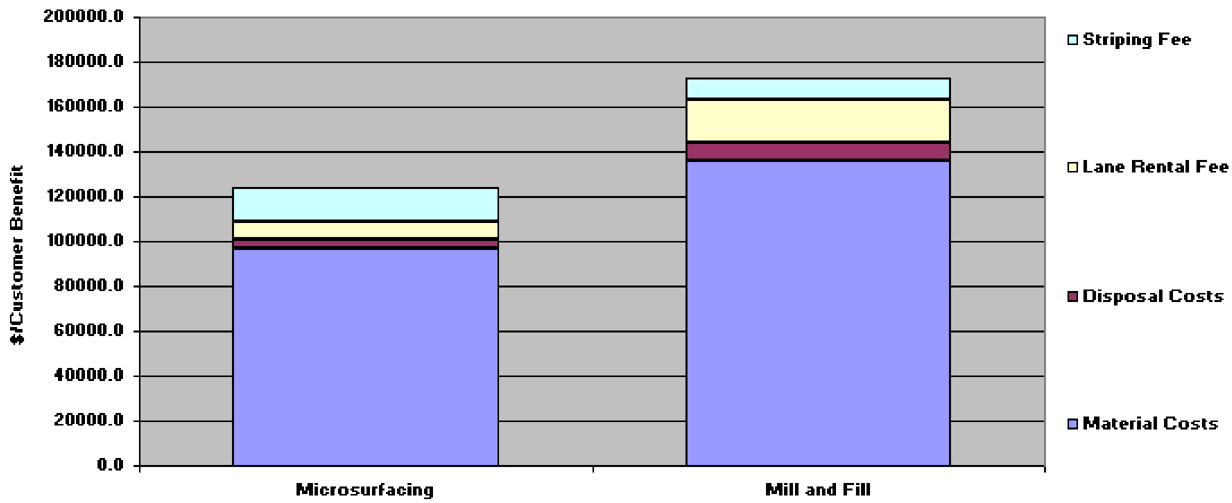

Figure 23. Life cycle costs - modules

8.3. *Eco-efficiency Analysis Portfolio*:

The eco-efficiency analysis portfolio for the Micro Surfacing EEA has been generated as defined in Section 9.5 of the BASF EEA methodology. Utilizing relevance and calculation factors, the relative importance of each of the individual environmental impact categories are used to determine and translate the fingerprint results to the position on the environmental axis for each alternative shown. For a clearer understanding of how weighting and normalization is determined and applied please reference Section 8 of BASF's Part A submittal to P-352. Specific to this study, the worksheets "Relevance" and "Evaluation" in the EEA model provided to NSF as part of this verification process should be consulted to see the specific values utilized and how they were applied to determine the appropriate calculation factors. Specific to the choice of environmental relevance factors and social weighting factors applied to this study, factors for the USA (national average) were utilized. The environmental relevance values utilized were last reviewed in 2007 and the social weighting factors were recently updated in 2009 by an external, qualified third party organization.

Figure 24 displays the eco-efficiency portfolio for the base case analysis and shows the results when all six individual environmental categories are combined into a single relative environmental impact and combined with the life cycle cost impact. Because environmental impact and cost are equally important, the most eco-efficient alterative is the one with the largest perpendicular distance above the diagonal line and the results from this study find that Micro Surfacing is the most eco-efficient alternative due to its combination of lower environmental burden and having the lowest life cycle cost.

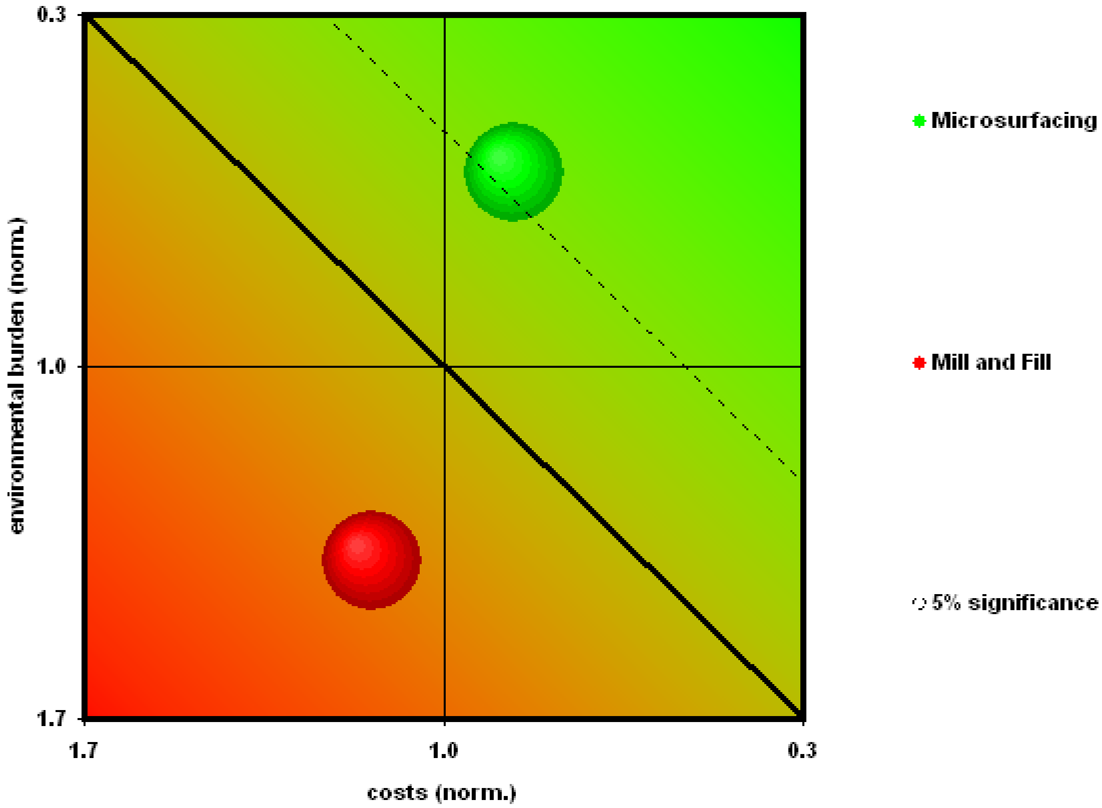

Figure 24. Eco-efficiency Portfolio – Preventive Maintenance Technologies – Urban Road

8.4. Scenario Analysis:

8.4.1.

Scenario #1: Increased Durability for Mill and Fill:

For this scenario the only input variable modified was the expected durability for the Mill and Fill alternative which was increased from the base case value of 11 years to 17 years. As expected for this scenario analysis, Mill and Fill (Hot Mix overlay) increases its relative eco-efficiency significantly relative to micro surfacing (see Figure 26). By increasing its durability by over 50% from the base case, Mill and Fill utilizes almost 35% less material over its life cycle to perform the same customer benefit. Figure 25 below shows that resource consumption, still the most relevant overall environmental impact for the study, for Mill and Fill decreases from the base case value of 203 kg silver equivalents/customer benefit (Figures 7 and 8) to around 131 kg silver equivalents/customer benefit. As discussed in section 6.4, the median average durability for Mill and Fill from the state agency survey was 11 years (base case value). Only around 18% of the respondents had experiences with Mill and Fill durability in the range of 17 - 18 years with none citing durability in excess of 18 years. In addition, the performance study reported by NAPA[19], only reported a maximum performance life of thin overlay of 16 years. Thus the selection of 17 years is a reasonable upper end expectation.

All other assumptions remaining the same, Mill and Fill with hot mix overlay would require a durability of almost 20 years to be of equivalent eco-efficiency of micro surfacing. In addition, over 30% of the respondents also noted durability experiences with micro surfacing of 7 years, one year longer than the base study assumption of 6 years. An increase in one year for micro surfacing would be quite significant with a potential reduction in material usage by almost 15%. Based on the sensitivity results to the key study variable of durability among the two alternatives, it is reasonable to conclude that micro surfacing will maintain its preferable eco-efficiency relative to Mill and Fill over all reasonable durability assumptions.

Results indicated from this sensitivity analysis can be applied as well to a scenario where a reduction in the thickness of the hot mix overlay is considered. Reducing the thickness of the hot mix overlay from two inches (base case) to 1.5 inches (commonly referred to as thin hot mix overlay), while achieving the same durability of 11 years and road performance characteristics, would reduce overall material requirements by 25%. This is less than the effects represented below in Figure 26 (a decrease in material consumption by 35% for Mill and Fill); therefore, micro surfacing is still a more eco-efficient alternative than either the two-inch hot mix overlay or the 1.5 inch thin hot mix overlay.

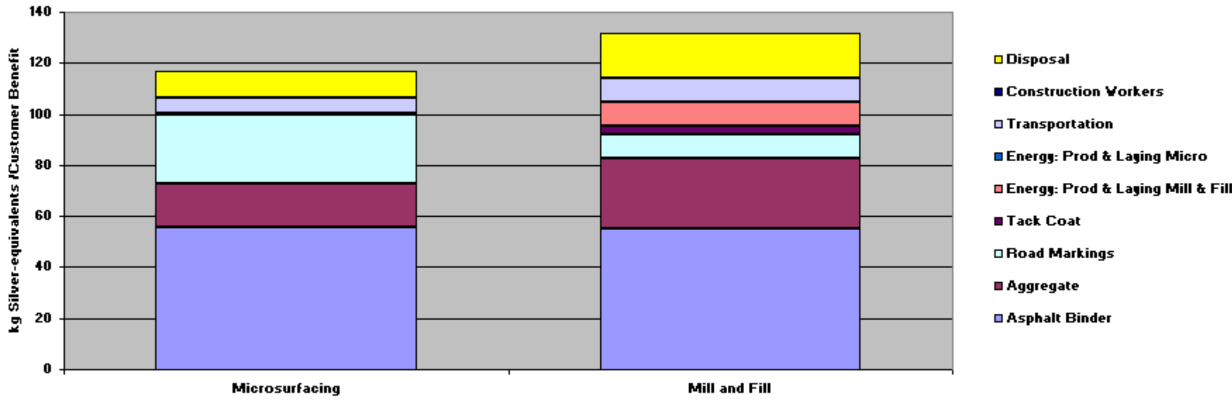

Figure 25. Resource Consumption (Scenario #1)

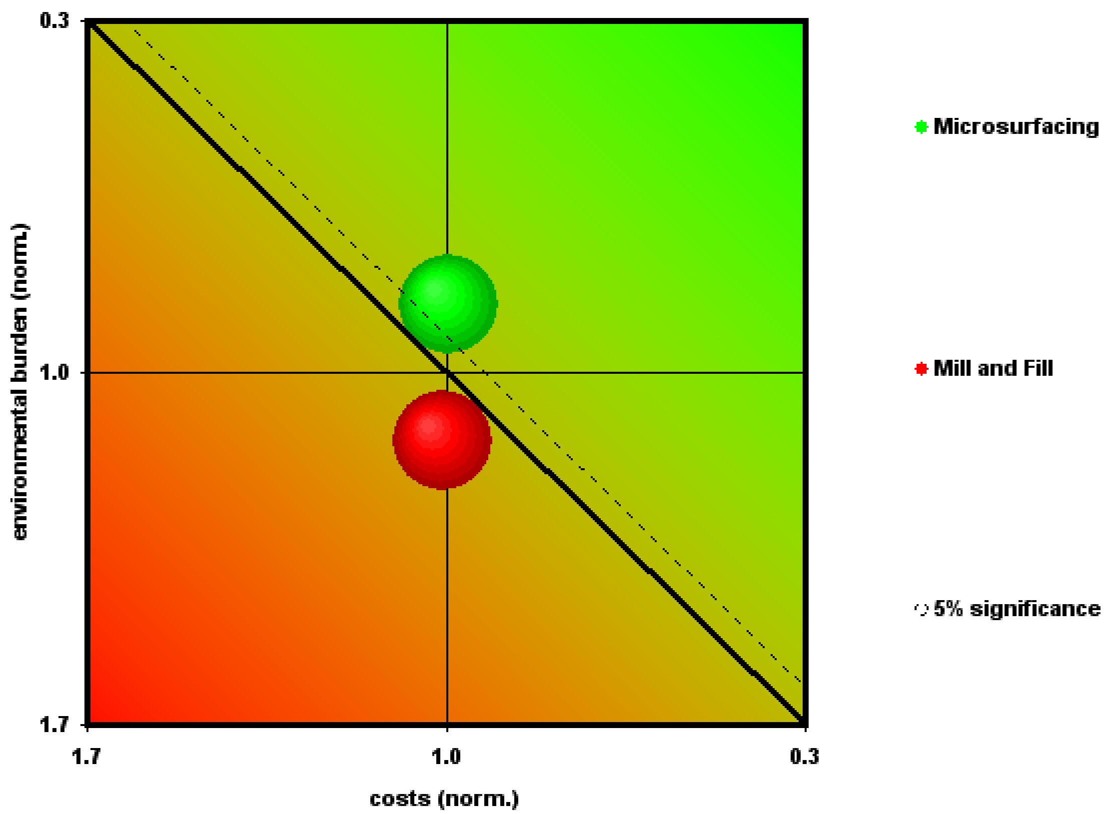

Figure 26. Scenario #1: Eco-efficiency Portfolio, Increased Durability for Mill and Fill

8.4.2. *Scenario #2: Tack coat for Micro Surfacing*.

A sensitivity analysis was run including a tack coat application for both alternatives and the eco-efficiency results are shown in Figure 29. The base case analysis only included a tack coat for Mill and Fill. Normally, for micro surfacing, a tack coat is not required unless the surface to be covered is extremely dry and raveled or is concrete or brick[1]. Thus the only differentiation relative to the base case analysis is the introduction of a new material to the micro surfacing alternative. The tack coat (SS-1) is described in section 6.1.1 and its formulation (material composition) is presented in Table 1. When included in Scenario #2, the use of a tack coat increased the life cycle energy requirement for micro surfacing by slightly less than 10% (Figure 27). The life cycle energy consumption increased from the base case value of 6,025,000 MJ/customer benefit to around 6,600,000 MJ/CB. In addition, the addition of the tack coat accounted for an increase in material consumption (SS-1 emulsion) by almost 18 tons in absolute terms but only around 9 tons on a weighted material basis (Figure 28), relative to the base case analysis. These were the two major impact areas impacted in the study. Considering these impacts, the relative eco-efficiency of Mill and Fill increased by around 7% but micro surfacing was still significantly more eco-efficient.

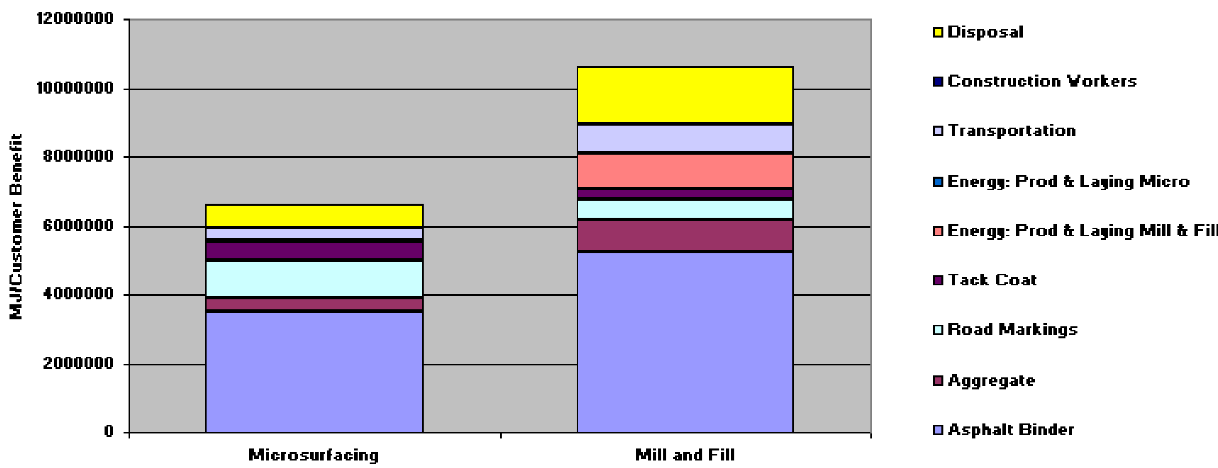

Figure 27. Energy Consumption (Scenario #2)

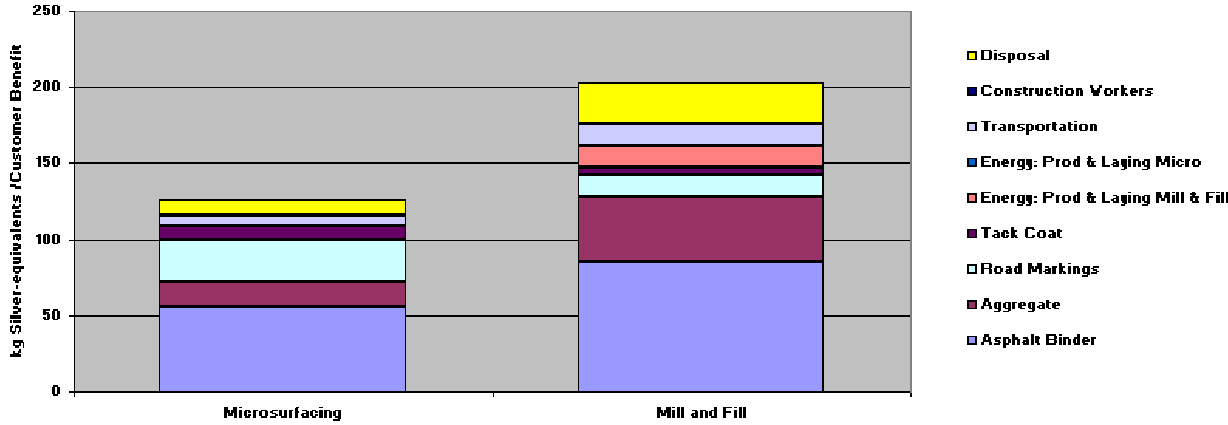

Figure 28. Raw Material Consumption (Scenario #2)

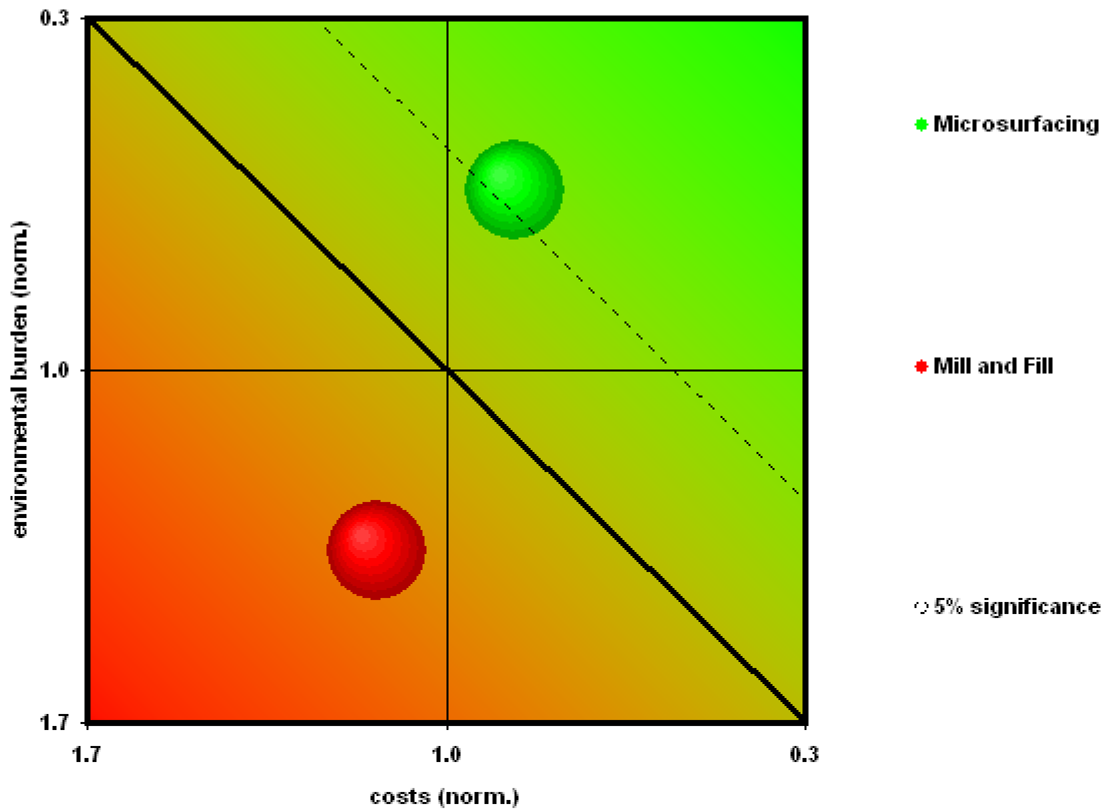

Figure 29: Scenario #2: Eco-efficiency Portfolio, Tack Coat for Micro Surfacing

8.4.3.

Scenario #3: Increase RAP in Mill and Fill

As presented in section 6 which addresses Input parameters and assumptions, the base case study assumed 10% RAP in the Mill and Fill alternative. While all state highway agencies permit the use of RAP in base and binder courses, 10 agencies do not permit the use of RAP in surface courses with many other having restrictions on its specific use[18]. States that approve the use of RAP in surface courses generally permit from 10 to 30 percent RAP[17]. In a recent article in an industry trade magazine, a representative from the National Asphalt Pavement Association (NAPA) is quoted as recommending around a 40% replacement of the virgin binder with binder material from RAP[16]. With regards to the reclaimed aggregate, special attention needs to be taken with regards to the processing and blending in order to insure no adverse effects on the pavement performance. A sensitivity analysis was conducted utilizing 40% RAP in the hot mix overlay wear course with no changes in the binder performance grade, the overall performance of the road or any other input parameters for Mill and Fill. There were no changes to the input parameters for micro surfacing.

This modification reduced the use of virgin materials for Mill and Fill by almost 735 tons of material. It also reduced the relative energy consumption (Figure 30) and resource consumption (Figure 31) for the Mill and Fill alternative by almost 30% relative to the base case analysis. As can be seen in the eco-efficiency portfolio in Figure 32 below, increasing the percentage of RAP in Mill and Fill increased the relative eco-efficiency of hot mix overlays by approximately 35% relative to micro surfacing. However, micro surfacing was still the more eco-efficient alternative.

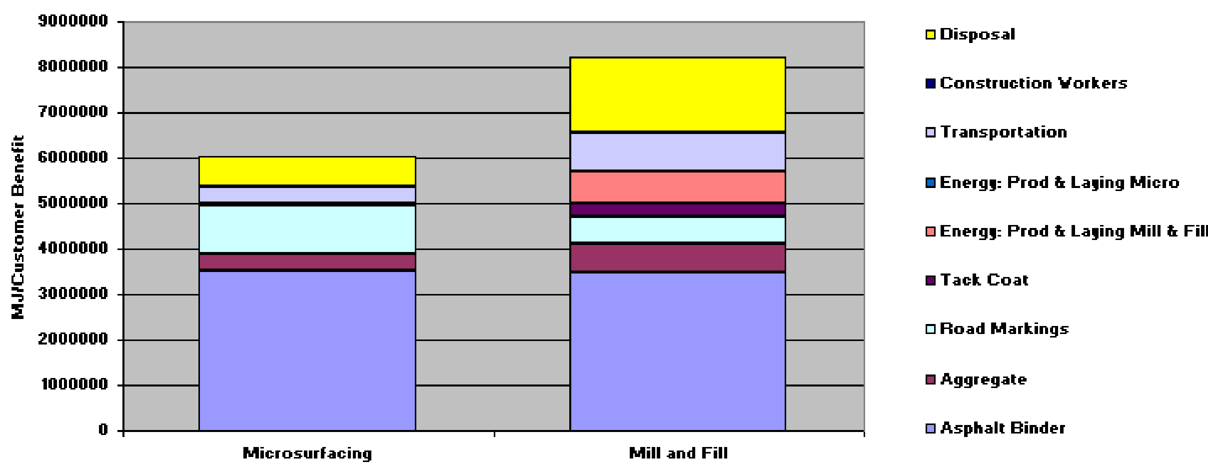

Figure 30. Energy Consumption (Scenario #3)

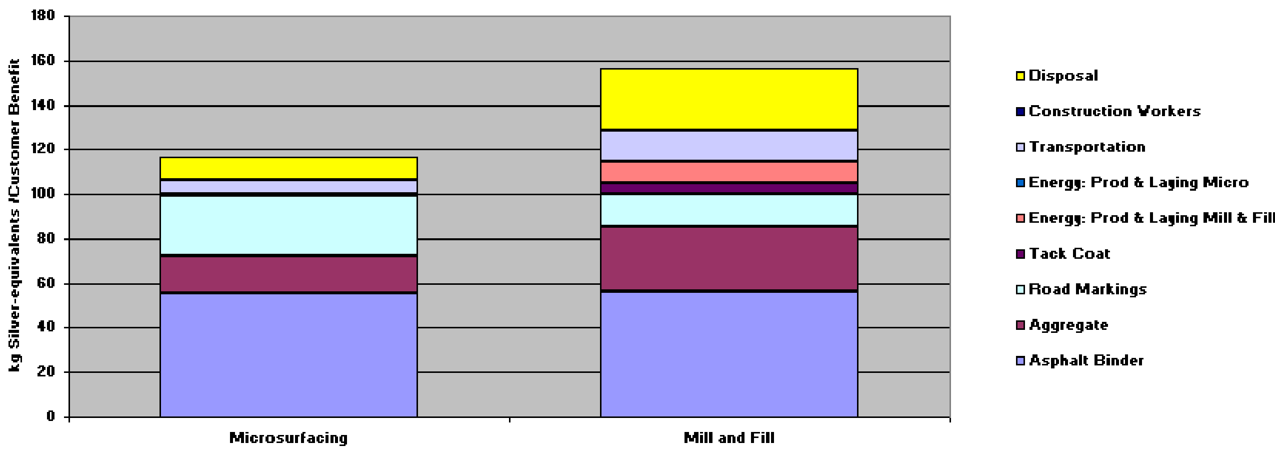

Figure 31. Resource Consumption (Scenario #3)

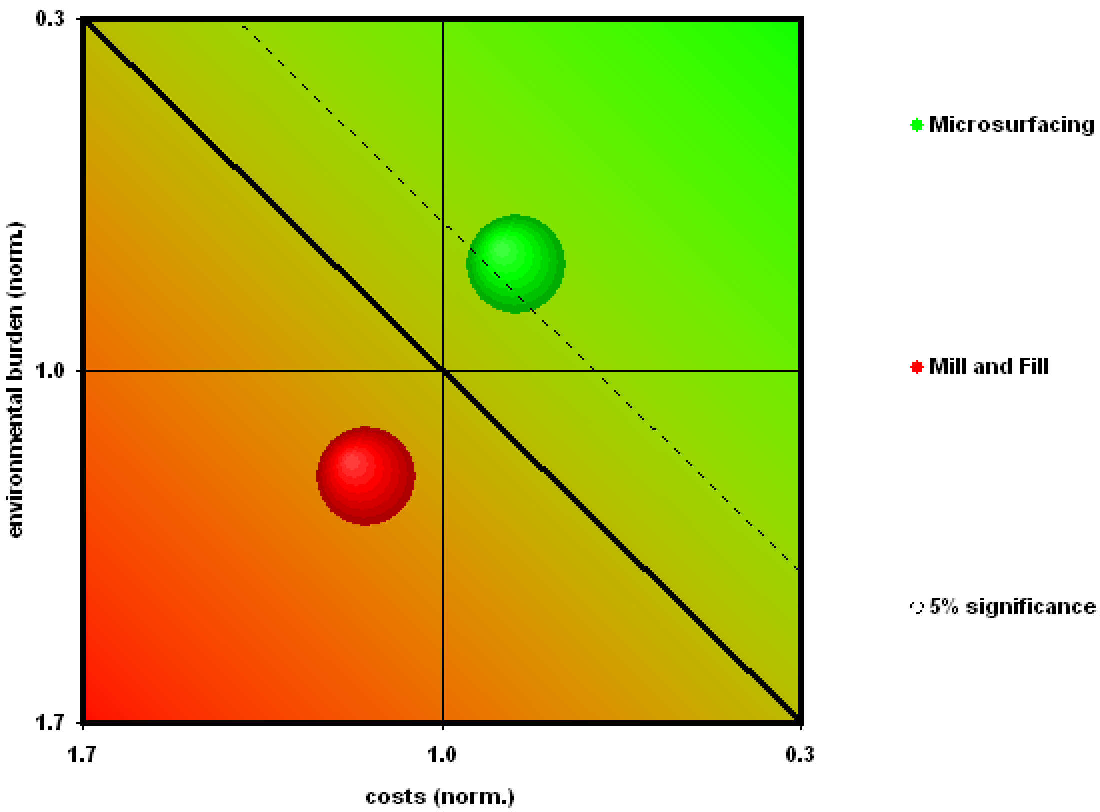

Figure 32: Scenario #3: Eco-efficiency Portfolio,, Increased RAP to 40% in Mill and Fill

9. Data Quality Assessment

9.1. *Data Quality Statement*: The data used for parameterization of the EEA was sufficient with most parameters of high data quality. Moderate data is where industry average values or assumptions pre-dominate the value. No critical uncertainties or significant data gaps were identified within the parameters and assumptions that could have a significant effect on the results and conclusions. The Eco-profiles utilized were deemed of sufficient quality and appropriateness considering both the geographic specificity of the study as well as the time horizon considered. Table 5 provides a summary of the data quality for the EEA.

Table 5: Data quality evaluation for EEA parameters.

Parameter	Quality Statement	Comments
Asphalt Parameters		
Binder Formulation	High	Known formulations from manufacturer. Eco-profiles developed specifically for this study are based on current technologies and company data.
Tack Coat Formulation	High	Known formulation based on current industry data.
Production and Application Impacts	Moderate-High	External life cycle analysis by Swedish IVL Research Institute.
Application Rates	Moderate-High	Industry guidelines. Assumed values are reasonable given study context and goals
Waste Parameters		
RAP amount and Disposal methods	Moderate-High	Assumed method and values are reasonable given study context and goals.
Transportation Distances	Moderate-High	Assumed values are reasonable given study context and goals.
Distance and fuel consumption	Moderate	Assumed values are reasonable given study context and goals.
Durability	High	State Agency survey by 3rd party.
Costs		
Pavement Preservation Technology	High	Supplier provided data.
Disposal Costs	Moderate-High	Current price for region of study. Assumed values are reasonable given study context and goals.
Lane Rental Fees	Moderate-High	Recommendation from industry literature.[8]
Lane Striping Fees	High	Supplier provided data.

10. Sensitivity and Uncertainty Analysis

10.1. *Sensitivity and Uncertainty Considerations:*

A sensitivity analysis of the final results indicates that the environmental impacts were more influential or relevant in determining the final relative eco-efficiency positions of the alternatives. This conclusion is supported by reviewing the BIP Relevance (or GDP-Relevance) factor calculated for the study. The BIP Relevance indicates for each individual study whether the environmental impacts or the economic impacts were more influential in determining the final results of the study. For this study, the BIP Relevance indicated that the environmental impacts were significantly more influential in impacting the results than the economic impacts (reference the "Evaluation" worksheet in the Excel model for the BIP Relevance calculation). The main assumptions and data related to environmental impacts were:

- Durability
- Percentage of RAP used
- Application Rates

As the data quality related to these main contributors were of high to moderate high quality and scenario variations were run related to them (see section 8.4) , this strengthened our confidence in the final conclusions indicated by the study. A closer look at the analysis (see Figure 33) indicates that the impact with the highest environmental relevance was resource consumption followed by energy and toxicity potential. This is to be expected, as the quantity of raw or recycled materials required by our alternatives to fulfill the customer benefit drive the overall study results. Air emissions are by far the most important in the emissions category. More specifically, AP and POCP are considered the two most important air emissions. The calculation factors (Figure 34), which considers both the social weighting factors and the environmental relevance factors, indicate which environmental impact categories were having the largest affect on the final outcome. Calculation factors are utilized in converting the environmental fingerprint results (Figure 22) into the final, single environmental score as reflected in our portfolio (Figure 24). The impacts with the highest calculation factors were the same as those with the highest environmental relevance factors, with regards to the six main impact categories. The input parameters that were related to these impact categories have sufficient data quality to support a conclusion that this study has a low uncertainty. The social weighting factors considered for this study did influence some minor reprioritization of the impact categories represented in the emissions and air emissions sub-categories. Water emissions increased importance relative to air emissions, and the impact of GHG received higher relative weighting for the air emissions, replacing POCP as the second most relative air emission.

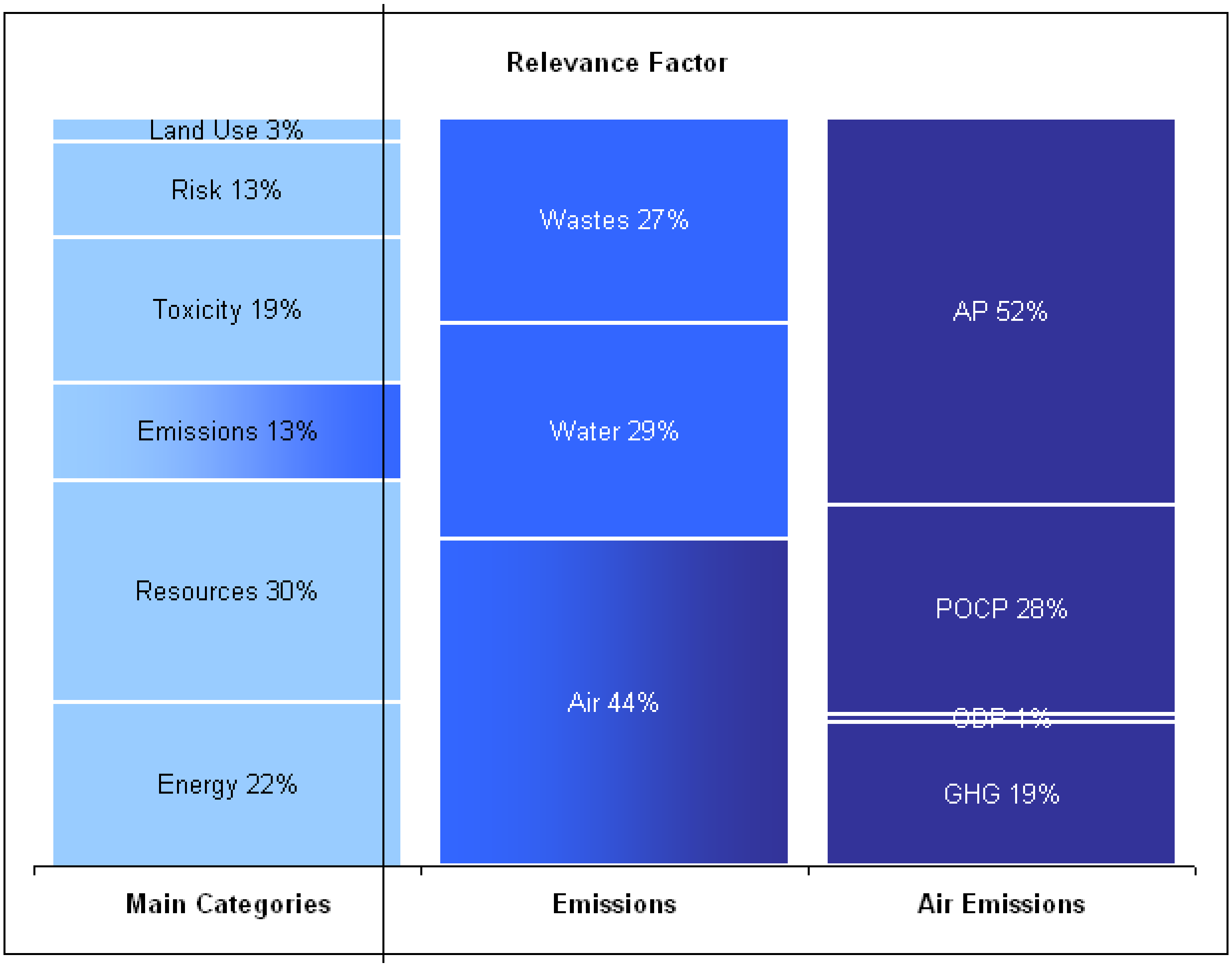

Figure 33. Environmental Relevance factors that are used in the sensitivity and uncertainty analyses.

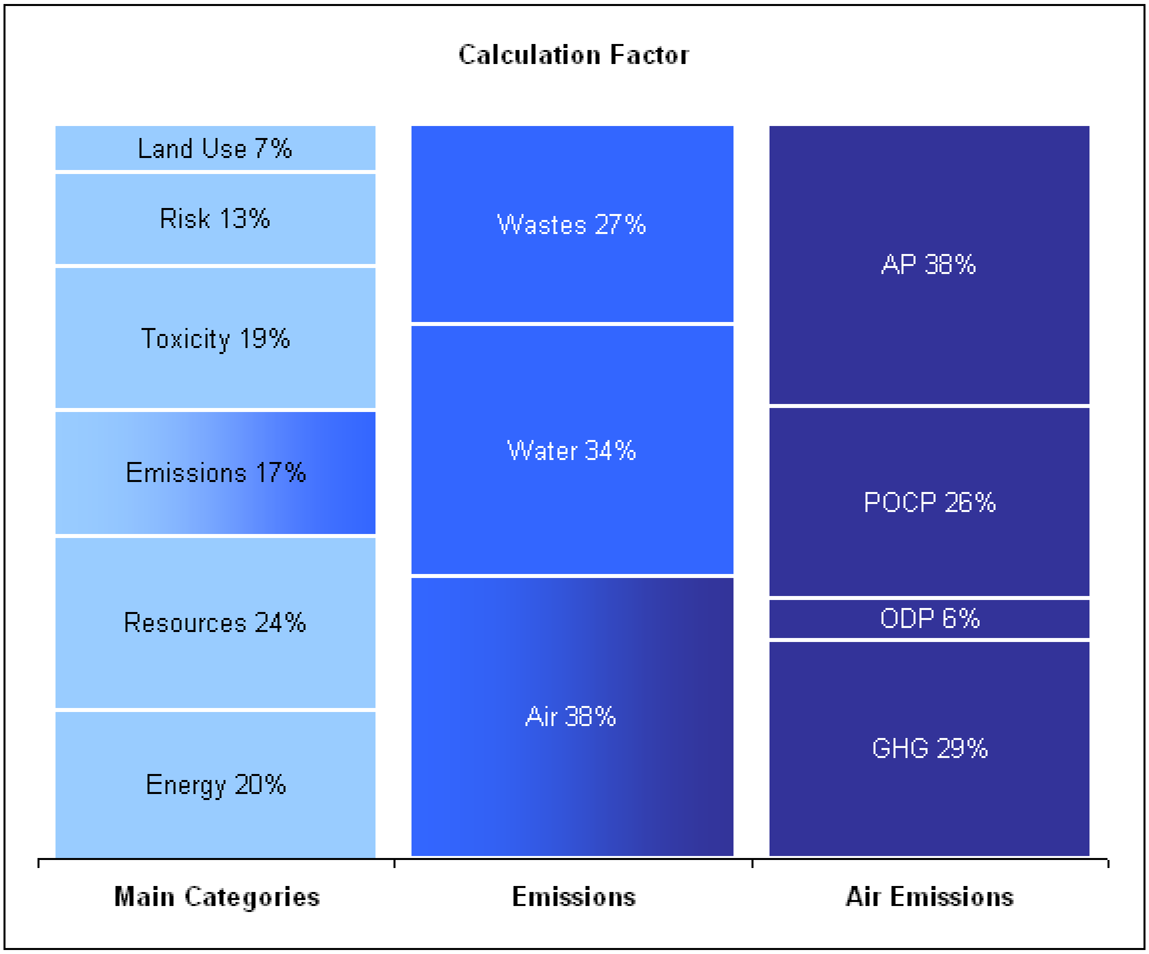

Figure 34. Calculation factors that are used in the sensitivity and uncertainty analyses.

10.2. *Critical Uncertainties:*

There were no significant critical uncertainties from this study that would limit the findings or interpretations of this study. The data quality, relevance and sensitivity of the study support the use of the input parameters and assumptions as appropriate and justified.

11 Limitations of EEA Study Results

11.1. *Limitations*:

These eco-efficiency analysis results and its conclusions are based on the specific comparison of the production, use, and disposal, for the described customer benefit, alternatives and system boundaries. Transfer of these results and conclusions to other production methods or products is expressly prohibited. In particular, partial results may not be communicated so as to alter the meaning, nor may arbitrary generalizations be made regarding the results and conclusions.

12. References

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