Eco-Efficiency Analysis

-Chip Seal Asphalt Resurfacing -

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Summary

- This study compares the economic and environmental impact of chip seal surface treatments using cold-applied polymer-modified emulsified asphalt vs. hot-applied polymer-modified asphalt with ground tire rubber.
- The Customer Benefit is the maintenance of a 1 mile stretch, 22 foot wide rural road.
- Road performance and application rates and energy consumption for the chipseals is assumed to be the same.
- The cold-applied chipseals are more eco-efficient because they contain less asphalt, do not require pre-coating of the aggregate and are applied at much lower temperatures.
- The hot-applied chipseal diverts used tires from landfills, but this environmental advantage is outweighed by the overall environmental effect of the higher asphalt content, pre-coating of the aggregate, and higher safety risks during application.
- Increasing the amount of asphalt used to pre-coat the aggregate noticeably worsens the hot chipseal's eco-efficiency.
- The hot chipseal is slightly less expensive to apply than the cold chipseal. Potential costs of health and safety incidents due to hot application are not considered in this study.

Chip Seal Resurfacing

Customer benefit (CB)	Hot alternative	Cold alternative
• **Preventative maintenance of the road to a similar profile and thickness using best engineering practices** *Dimensions: 1 mile stretch, 22 feet wide rural road.*	• **Hot Chip Seal, polymer-modified non-emulsified with ground tire rubber (AC-15-5TR or AC-20-5TR)**	• **Cold polymer-modified Chip Seal, emulsified asphalt (CRS-2P) using SBR or SBS polymers**

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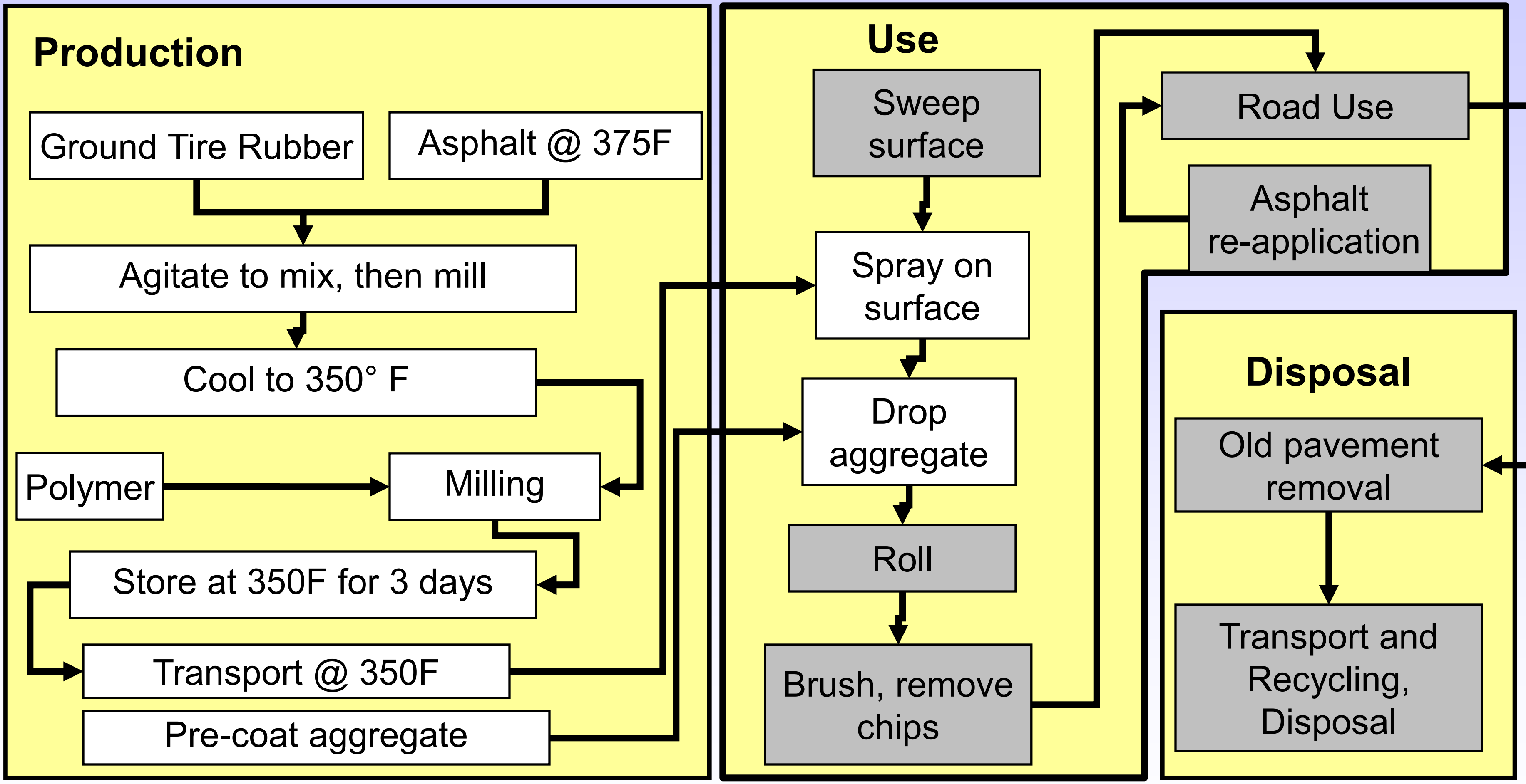
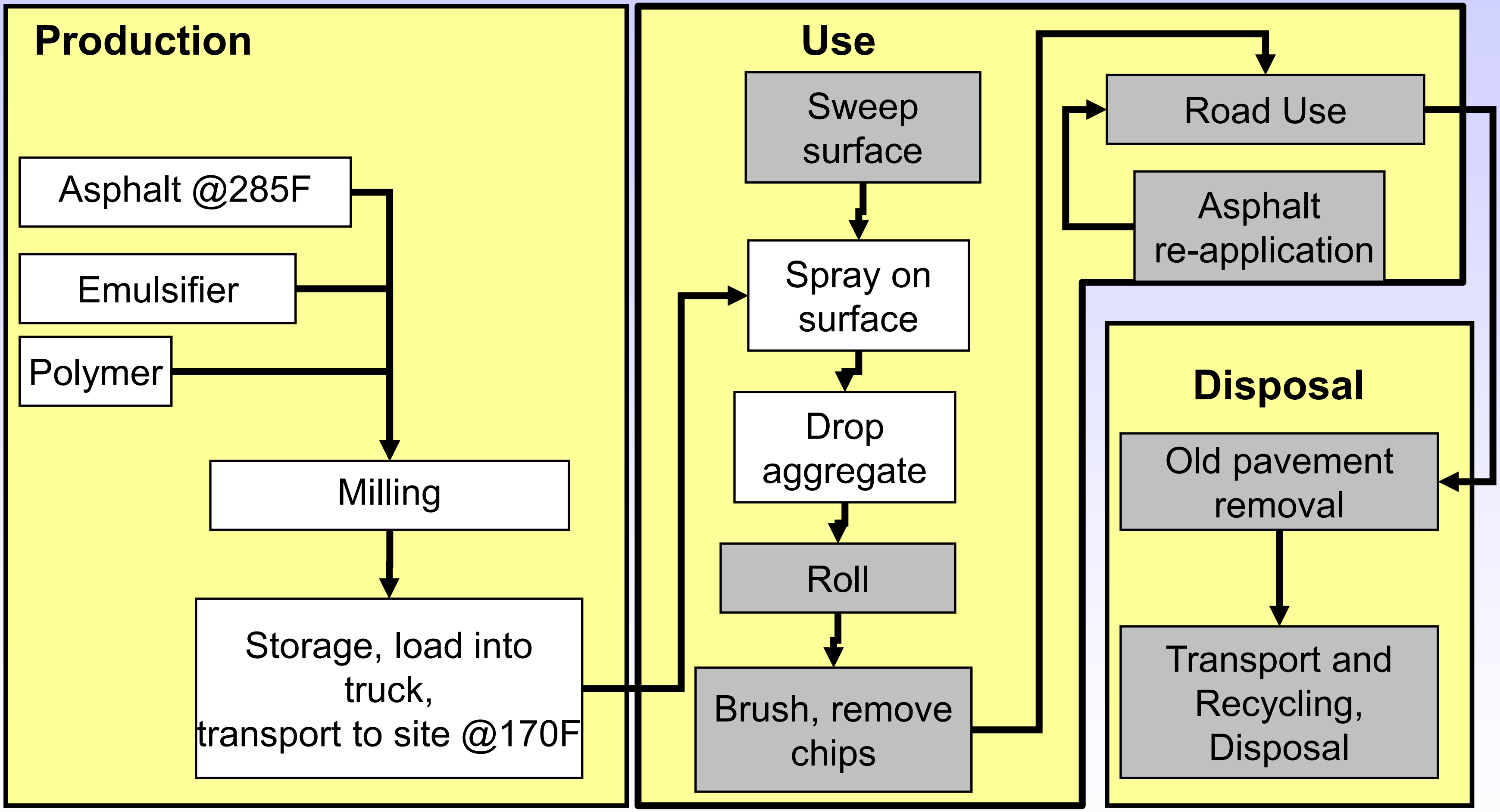
System Boundaries – Hot polymer-modified GTR Chip Seal (AC-15-5TR)



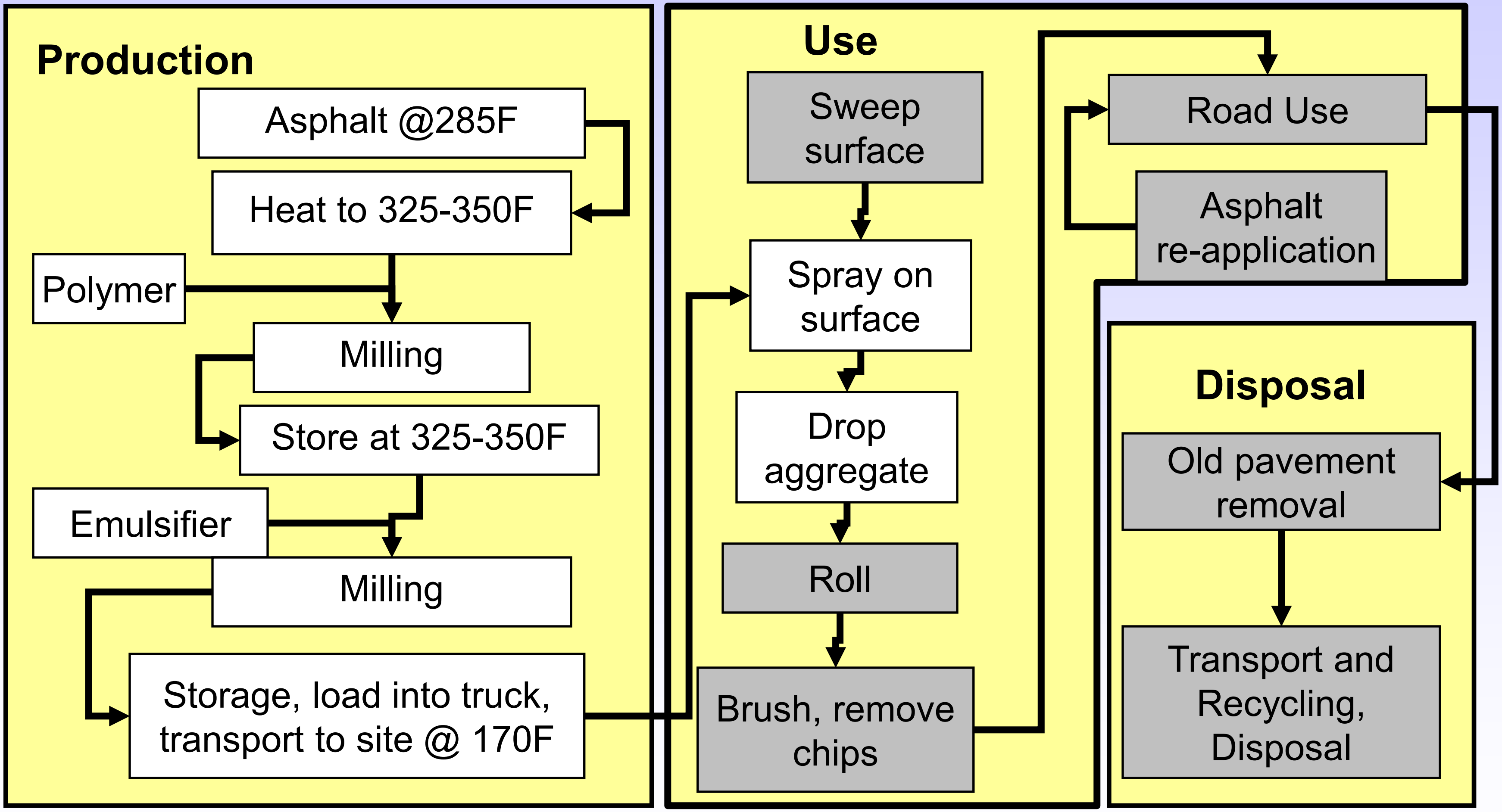
Grey boxes are not considered, since they are the same for all alternatives.

System Boundaries – Cold polymer-modified Asphalt Cement SBR Latex



Grey boxes are not considered, since they are the same for all alternatives.

System Boundaries – Cold polymer-modified Asphalt Cement SB/SBS Polymer



Grey boxes are not considered, since they are the same for all alternatives.

Base Case Assumptions

- All alternatives have the same:
  - Performance
  - Lifetime
  - -Aggregate size and type
  - -Traffic loading
- AC-20-5TR is the same as AC-15-5TR.
- Aggregate for the hot system is pre-coated with asphalt, using a process which requires 300MJ/ton of aggregate.
- Application to the road uses 50MJ diesel/ton for all alternatives.
- Energy to maintain temperature of hot asphalt during storage and application is not considered.
- Aggregate transport distances are the same for all alternatives (although typically pre-coated aggregate is transported further).
- Energy for grinding the tire rubber is not considered.
- Emissions during chipseal application are not considered.

Input Data I

		Hot-GTR	Cold-SBR	Cold-SBS
CUSTOMER BENEFIT:				
Road Surface				
Length	mi	1	1	1
Width	ft	22	22	22
Area	sq. yard	12907	12907	12907
Lifetime	years	7	7	7
PRODUCTION				
Chip Seal Binder Composition				
Ground Tire Rubber	%	5.0%		
Asphalt Cement	%	93.0%	67.6%	67.6%
Polymer				
SBS	%	2.0%		2.1%
SBR	%		3.3%	
Emulsifier	%		0.2%	0.2%
Hydrochloric acid	%		0.2%	0.2%
Water	%		28.7%	29.9%
TOTAL	%	100.0%	100.0%	100.0%
Electricity	MJ/kg	0.04	0.01	0.03
Steam	kg steam/kg	0.12		0.04
Cooling Water	l/kg			0.69
Pre-coating of Aggregate with asphalt				
Asphalt by weight	%	0.5%		
Asphalt per CB	kg/CB	1125	0	0

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Input Data II

		Hot-GTR	Cold-SBR	Cold-SBS
APPLICATION & USE				
Application Rates[1]				
Chip seal binder	gal/sq. yd	0.38	0.44	0.44
Specific gravity		1.02	1.01	1.01
Density	lb/gal	8.5068	8.4234	8.4234
Rate	lb/sq. yd.	3.23	3.71	3.71
	kg/sq. yd.	1.47	1.68	1.68
Aggregate	sq. yd./cu. Yd.	119	120	120
Density	lb/cu. Yd.	4575	4575	4575
Rate	lb/sy	38.4	38.1	38.1
	kg/sq. yd.	17.4	17.29	17.29
Application Quantities				
Chip seal binder	**kg/CB**	**18,925**	**21,698**	**21,698**
Aggregate	**kg/CB**	**225,060**	**223,185**	**223,185**
Total material	kg/CB	243,985	244,883	244,883
Percentages				
Chip seal binder	%	8%	9%	9%
Aggregate	%	92%	91%	91%

1 From Table 4: Typical TxCOT Binder/Aggregate Combination Rates for G4 aggregate, OU Transportation Research Report, Aug 2002,

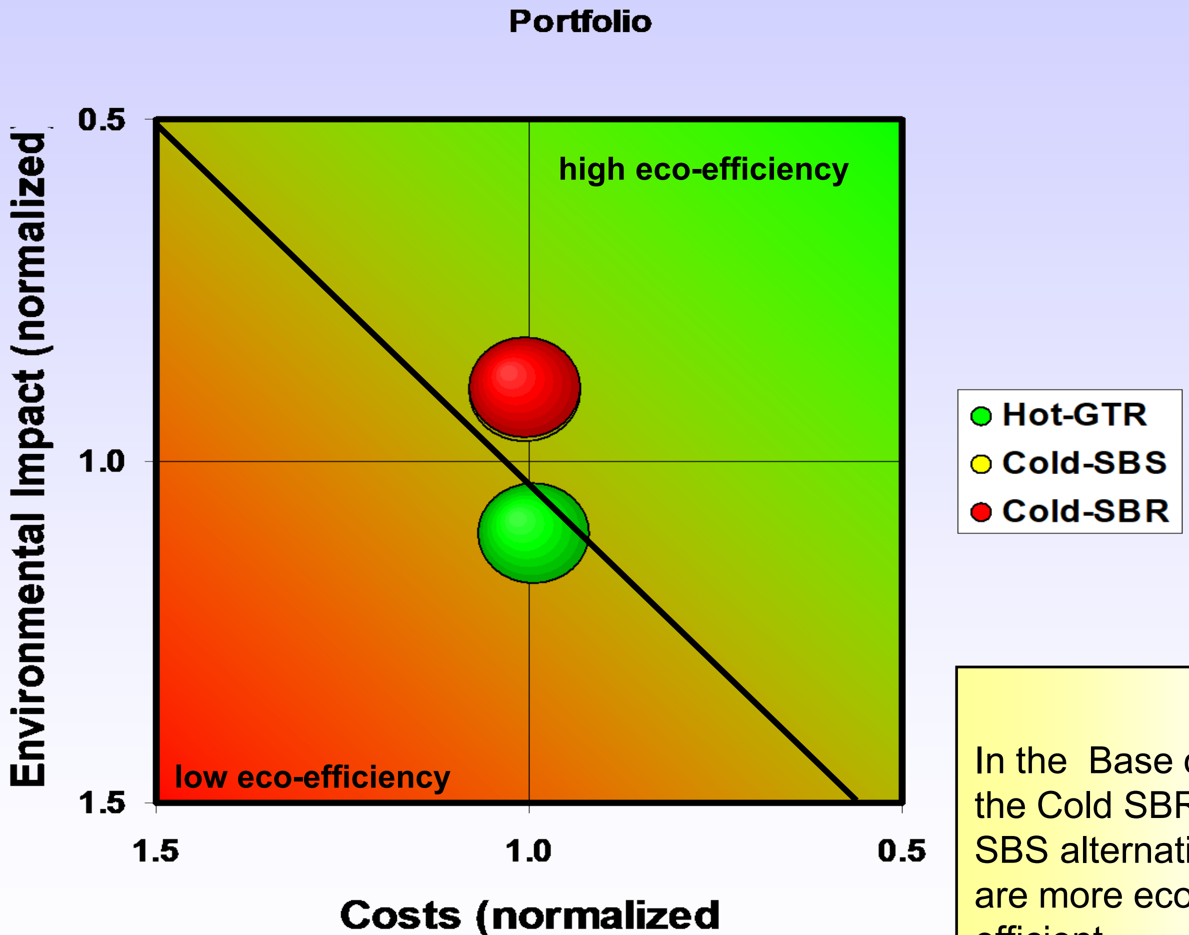
Input Data III

		Hot-GTR	Cold-SBR	Cold-SBS
TRANSPORTATION				
Truck fuel consumption	MJ/ton/km	2.2	2.2	2.2
Chip seal binder				
weight transported	kg/CB	18925	21698	21698
distance	km	100.0	100.0	100.0
Aggregate				
weight transported	kg/CB	225060	223185	223185
distance	km	100.0	100.0	100.0
Fuel consumption	**MJ/CB**	**107354**	**107749**	**107749**
	l/CB	2847	2857	2857
	t*km/CB	48797	48977	48977
UTILITIES				
Energy for application	MJ diesel/ton	50	50	50
	MJ/CB	12199	12244	12244
	l/CB	324	325	325
COST				
Chip seal material cost	$/yd2	$ 1.25	$ 1.27	$ 1.27
Fuel cost	$/gal	$ 1.50	$ 1.50	$ 1.50
Chip seal material cost	$/CB	$ 16,133	$ 16,391	$ 16,391
Fuel cost	$/CB	$ 1,256	$ 1,261	$ 1,261
Total	$/CB	$ 17,390	$ 17,652	$ 17,652

Results

Chipseal Eco-efficiency Portfolio – Base Case

•Resurfacing of a 1-mile, 22-ft wide road stretch, with a lifetime of 7 years, using chipseal



In the Base case the Cold SBR and SBS alternatives are more eco-efficient.

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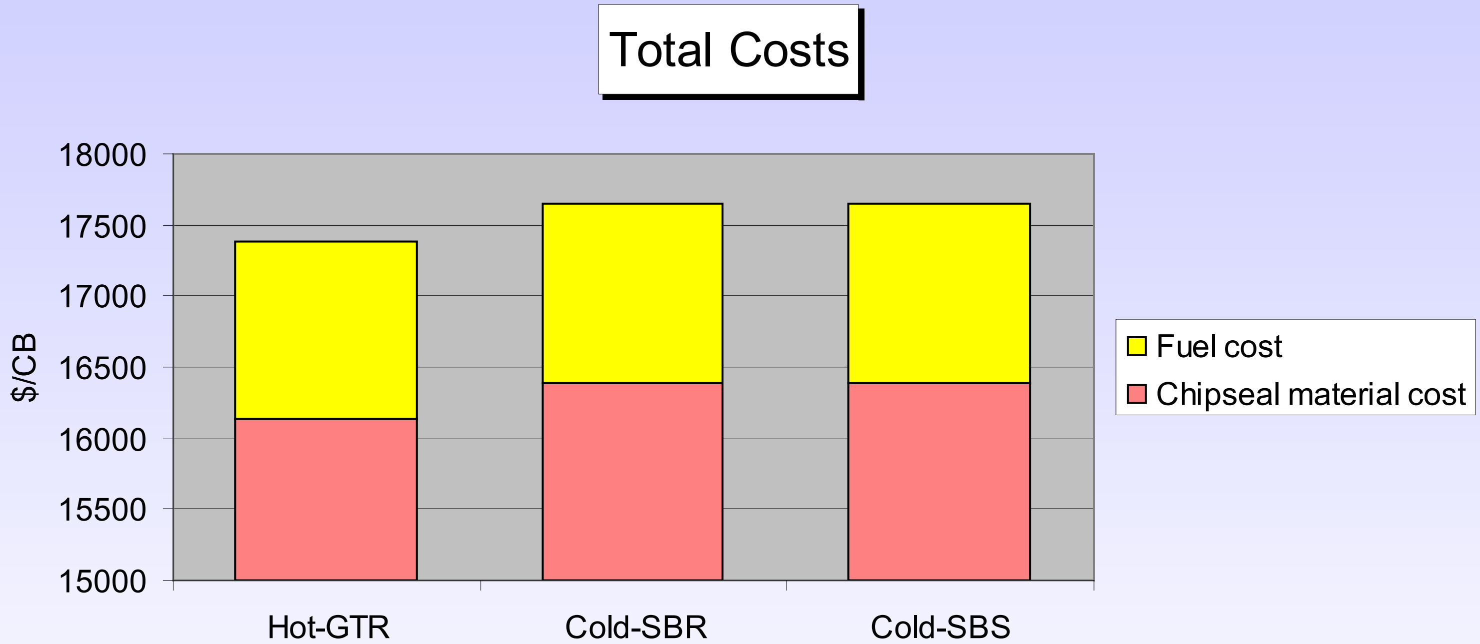
Application Costs



The hot chipseal is slightly less expensive than the cold chipseal alternatives.

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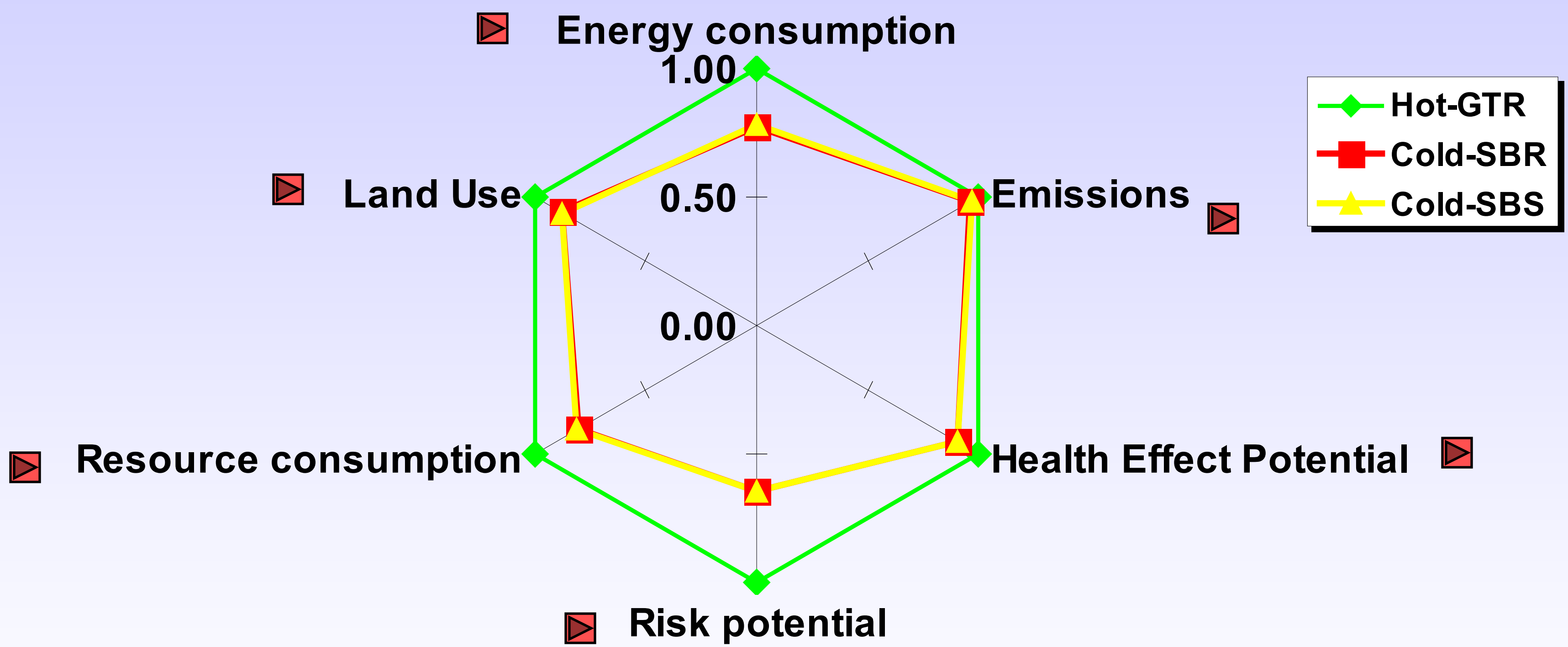
Ecological Fingerprint



1,0 = worst position, better results ordered relatively <1

Comments to the Ecological Fingerprint

- The cold chipseal alternatives have advantages in Risk Potential, Resource and Energy Consumption, Health Effect Potential and Land Use. They are lower risk because the asphalt is applied at a much lower temperature. They use less resources, energy and land because less asphalt is used in the chipseal itself; and the aggregate does not need to be pre-coated with asphalt.
- Although the hot GTR alternative diverts tires from landfills, this advantage is balanced to a large extent by higher emissions due to higher asphalt content and pre-coating of the aggregate, and disadvantages in the other environmental categories.

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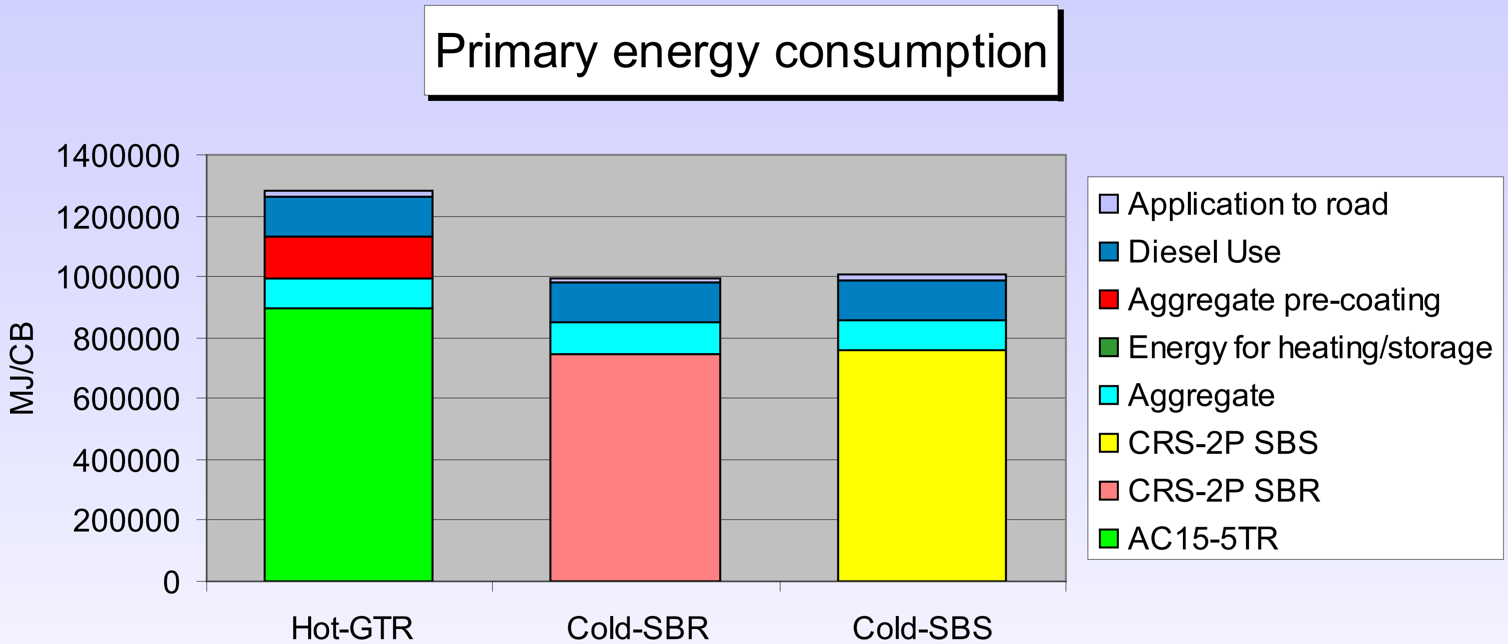
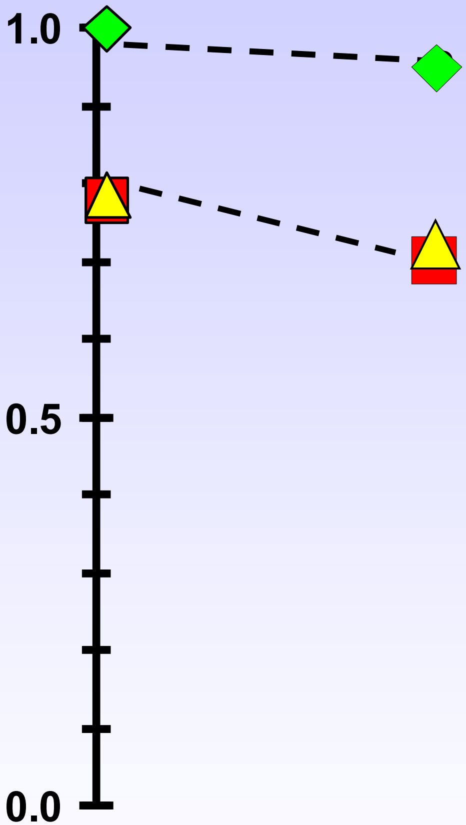
Energy consumption of the Alternatives



The biggest contributor to energy consumption is production of the chipseal. The hot chipseal product has a higher asphalt content which results in higher energy consumption. Pre-coating of the aggregate results in the hot alternative having higher total energy than the CRS alternatives.

Comments regarding energy consumption



The hot chipseal has a higher asphalt content which results in higher energy consumption. Pre-coating of the aggregate results in the hot alternative having higher total energy than the CRS alternatives.

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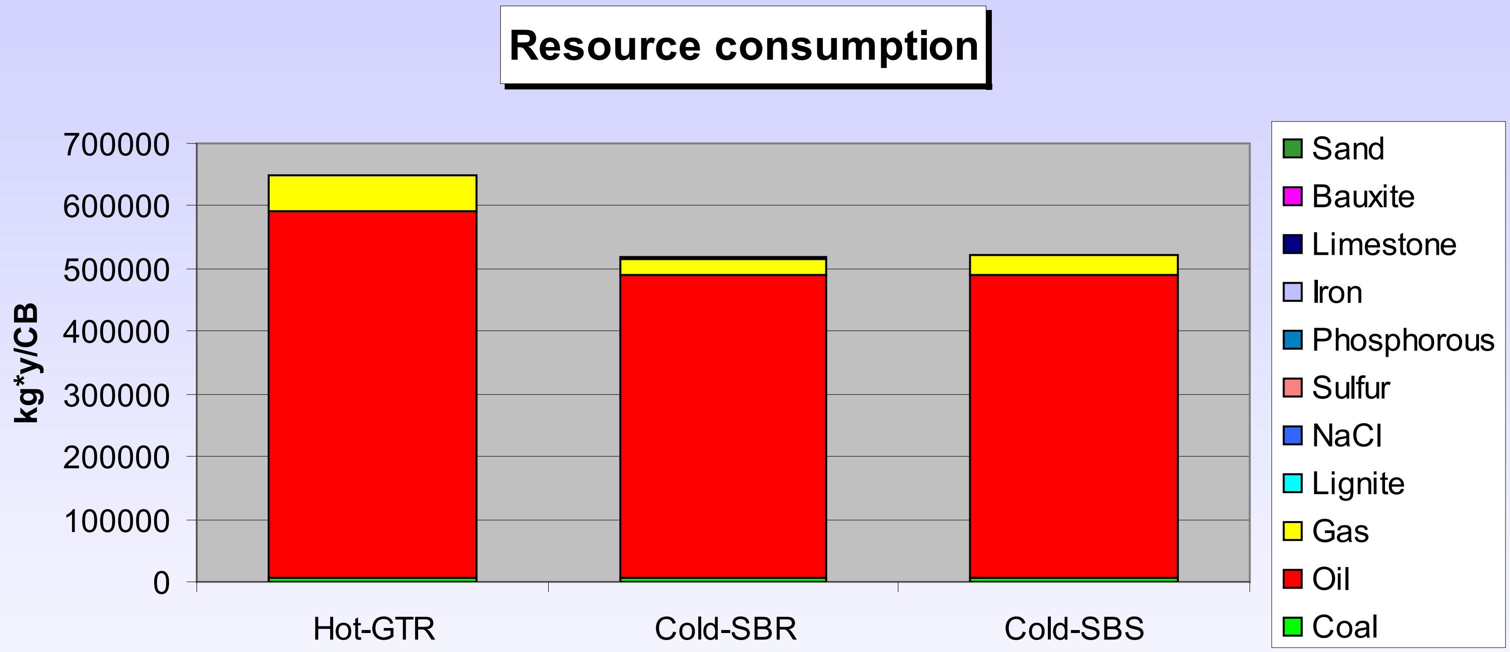
Resource consumption



The primary raw material consumed is oil used for asphalt production.

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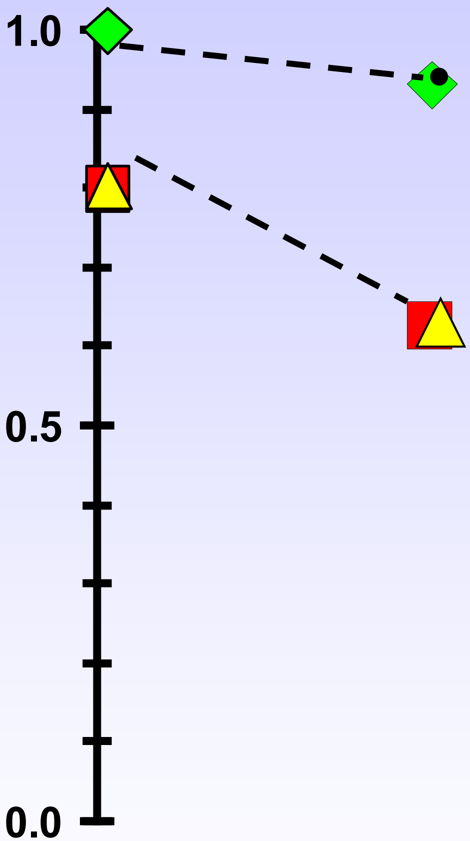
Comments regarding resource consumption



The hot alternative uses use more asphalt, which results in higher resource consumption.

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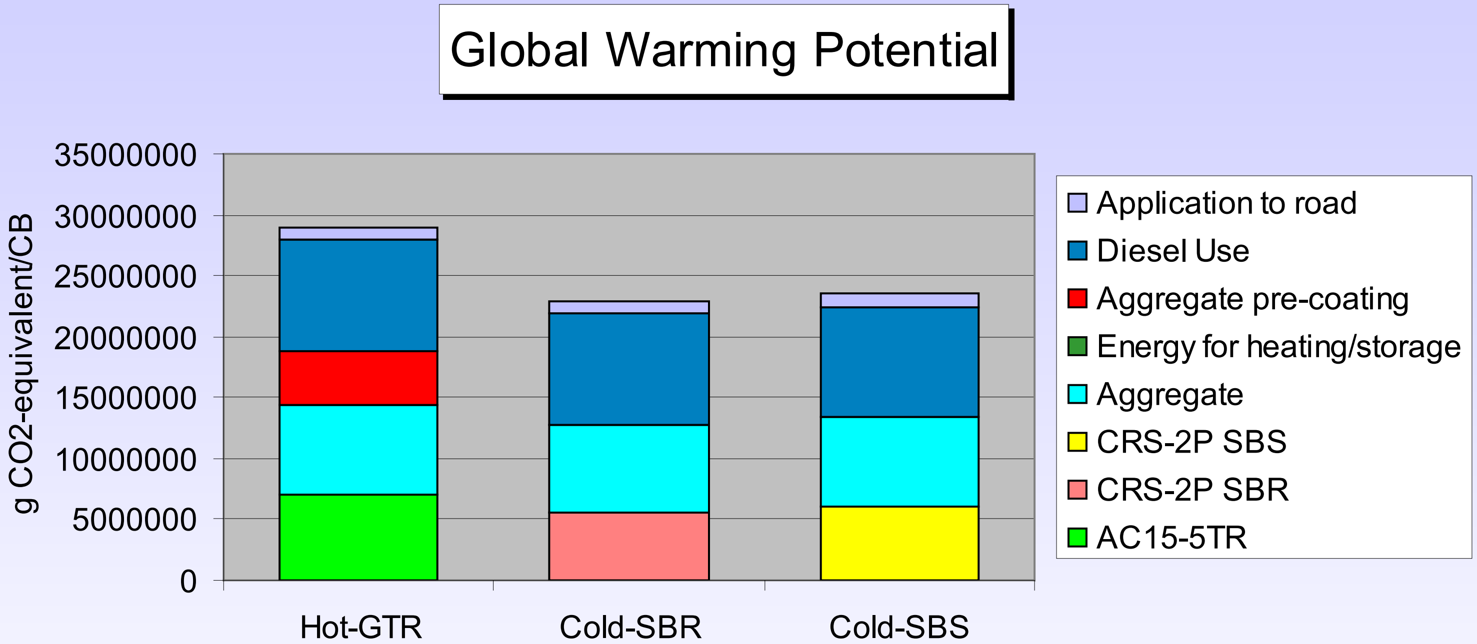
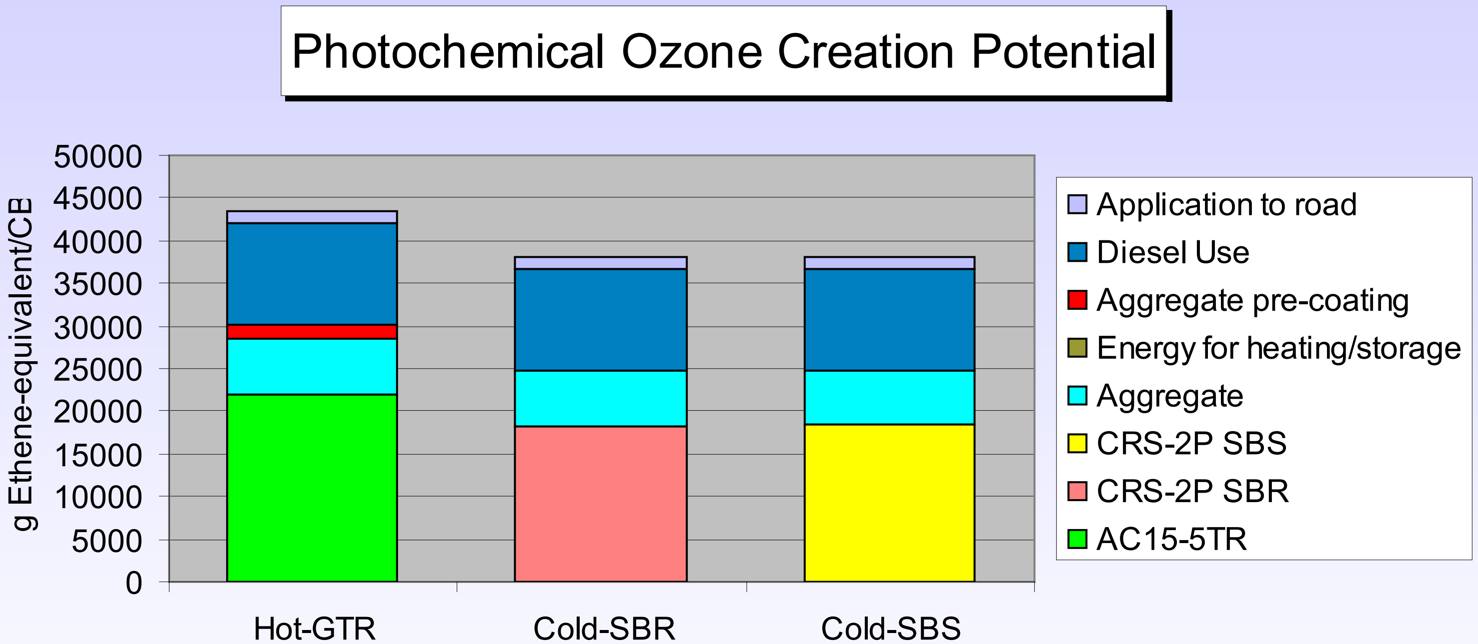
Global Warming Potential



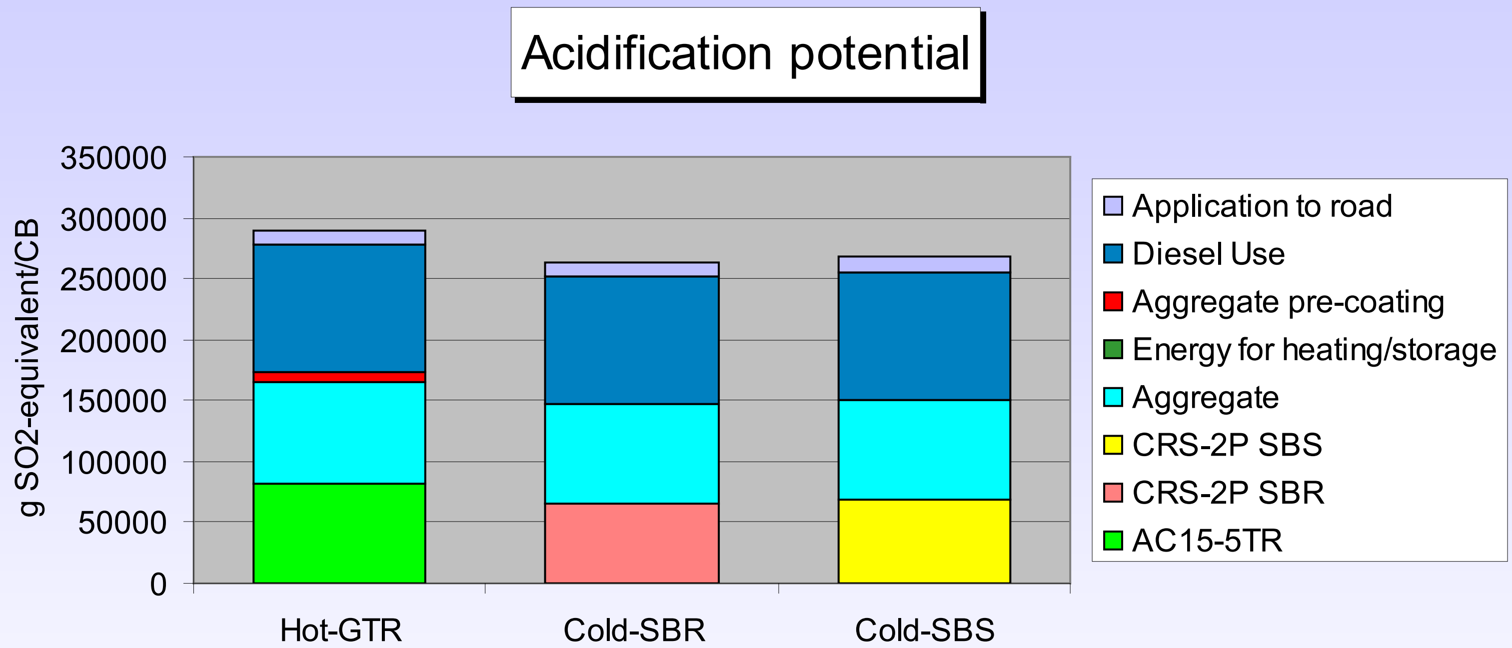
GWP is influenced by CO2 and CH4 emissions resulting from fuel produced and consumed during manufacturing of the chipseal pre-cursors. Diesel fuel used for transportation also has a large impact.

Photochemical Oxidant Creation Potential (Summer Smog)



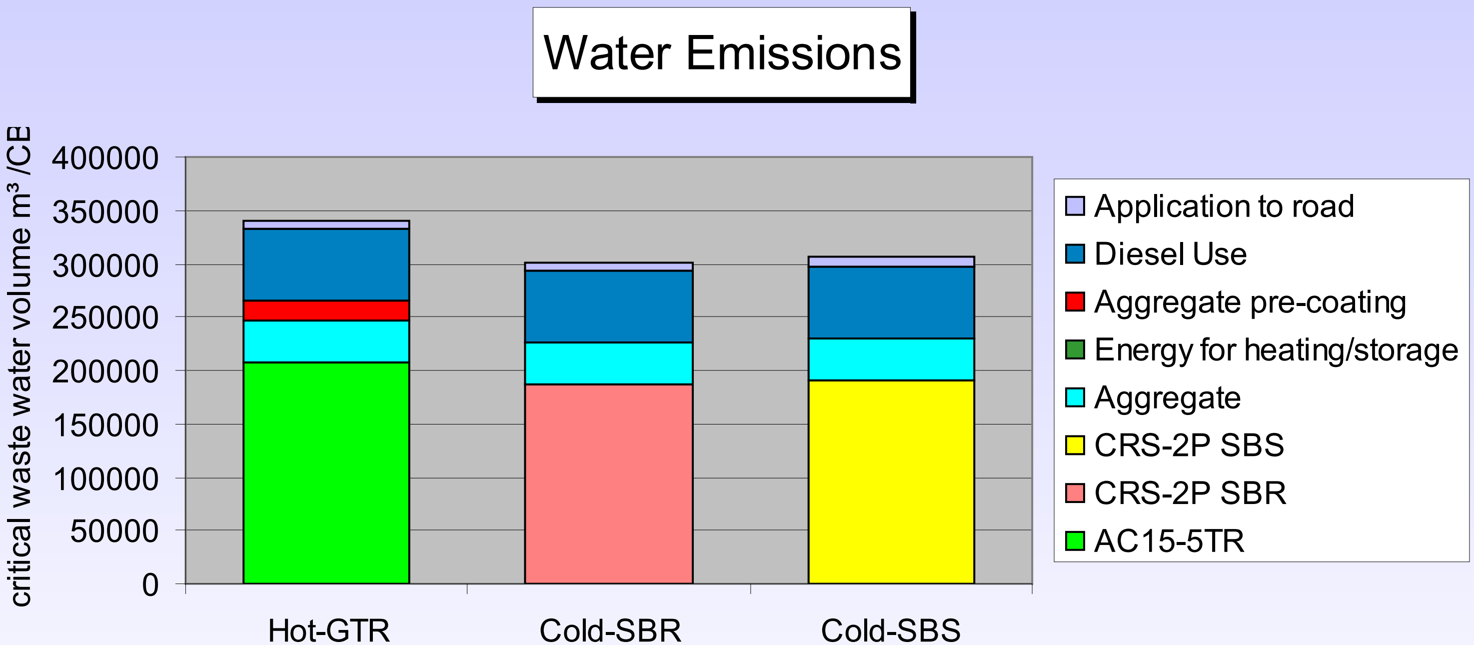
POCP is mostly due to the chipseal precursors, the energy used for aggregate production and the production and use of diesel fuel for transportation of materials.

Acidification potential



AP primarily results from NO_x, HCl, SO_x, and NH_3 generated by energy use during manufacture of the chipseal and aggregate, and by diesel fuel use.

Water emissions



Water emissions are most impacted by the asphalt and polymer in the chipseal. Production of diesel fuel used for transportation and the aggregate production process also contribute.

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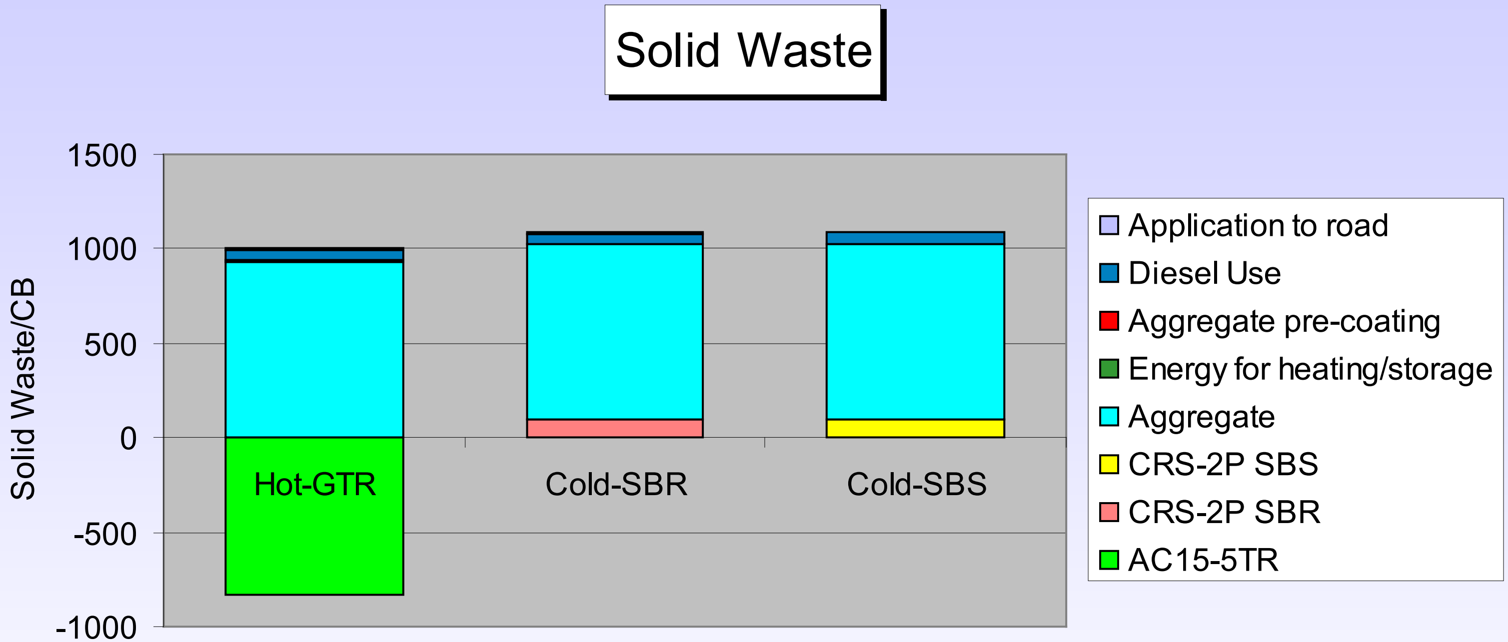
Solid Waste Emissions



Solid waste emissions result from the quarrying of the aggregate. The ground tire rubber alternative has the advantage of recycling material that would otherwise be solid waste.

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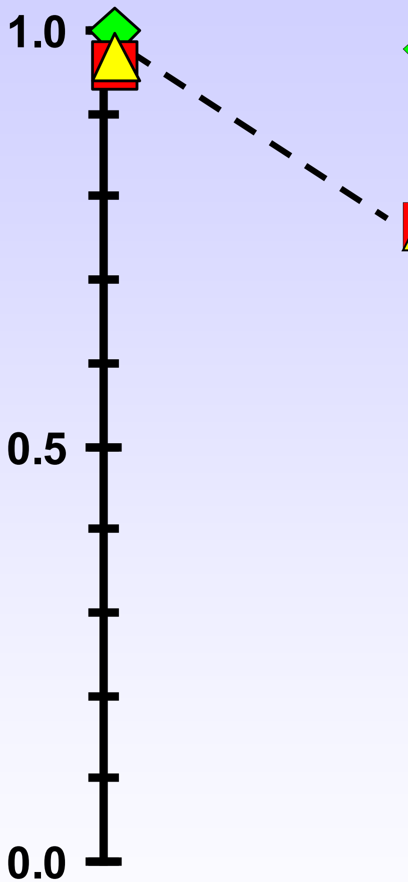
Comments regarding emissions



- The total emissions for the ground tire rubber (GTR) and the CRS-2P alternatives are very similar when air, water and solid waste emissions are considered.
- The CRS-2P alternatives use less asphalt, and do not require pre-coating of the aggregate. However, the advantage of the GTR in solid wastes, since tire waste to landfill is reduced, results in similar total emissions.

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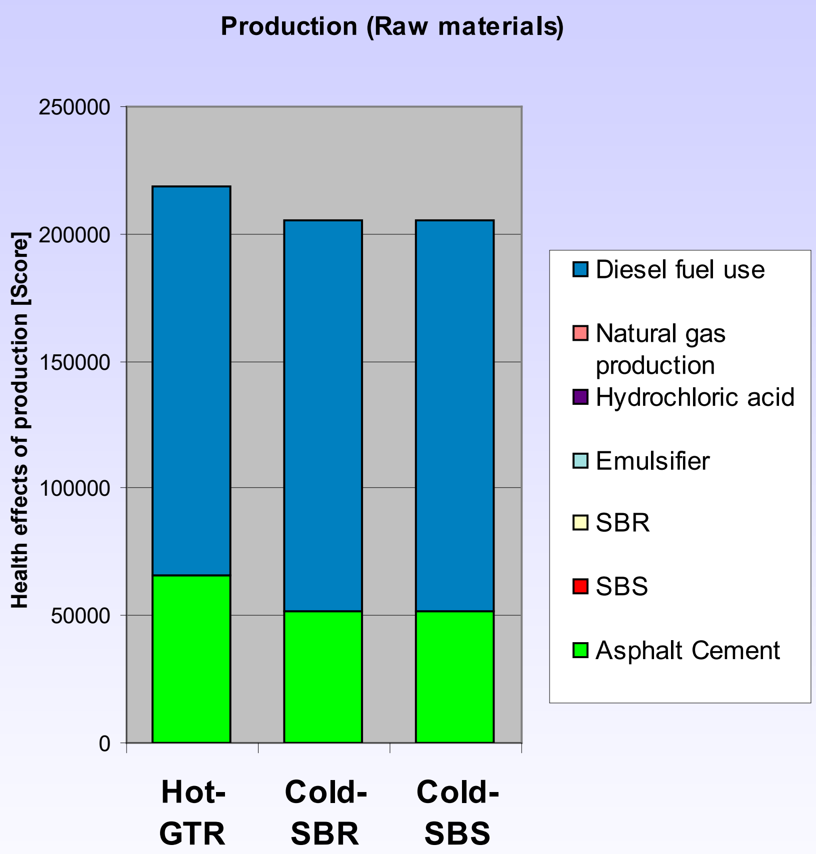
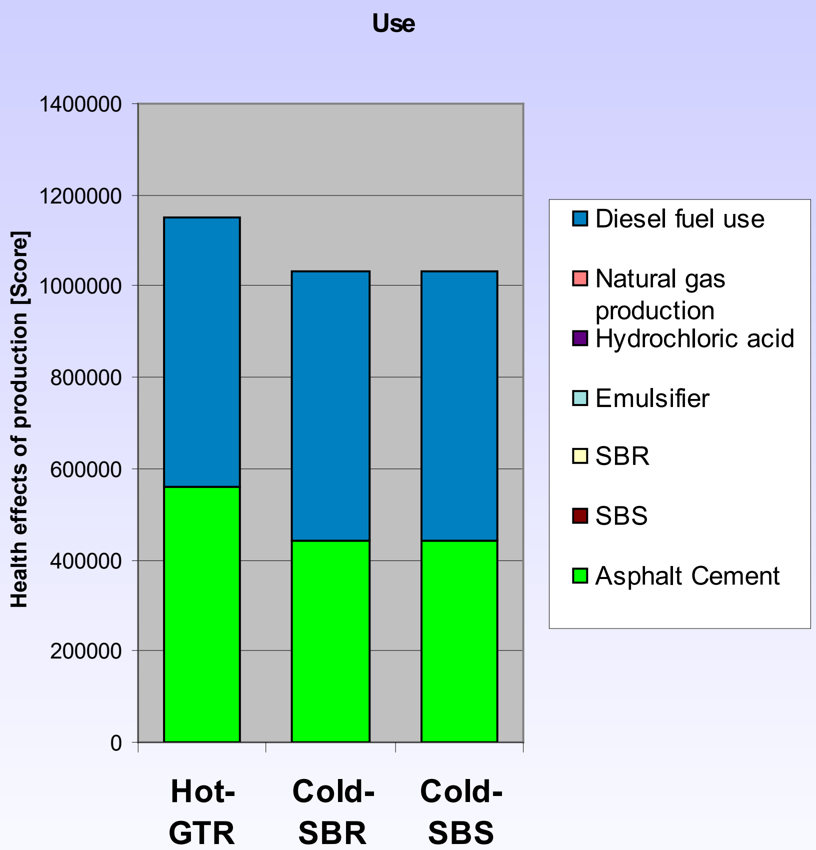
Health Effect Potential





The greatest health effect potential results from the diesel fuel used for transportation and from the asphalt cement.
Production is weighted at 25% and Use at 75%.

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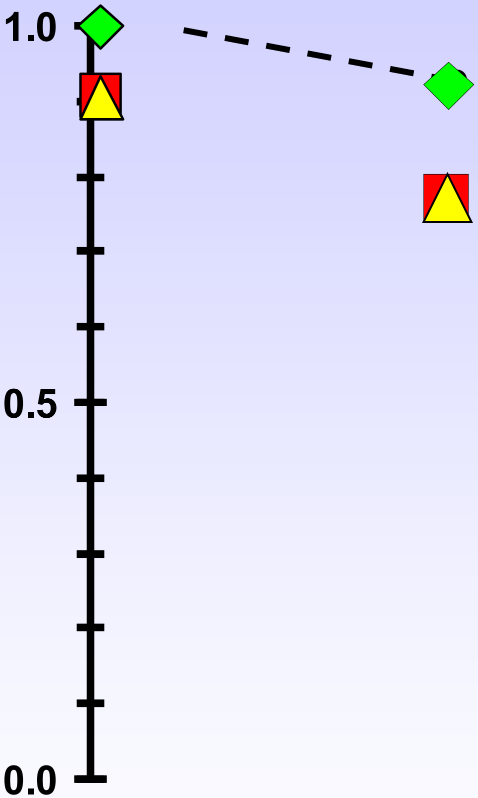
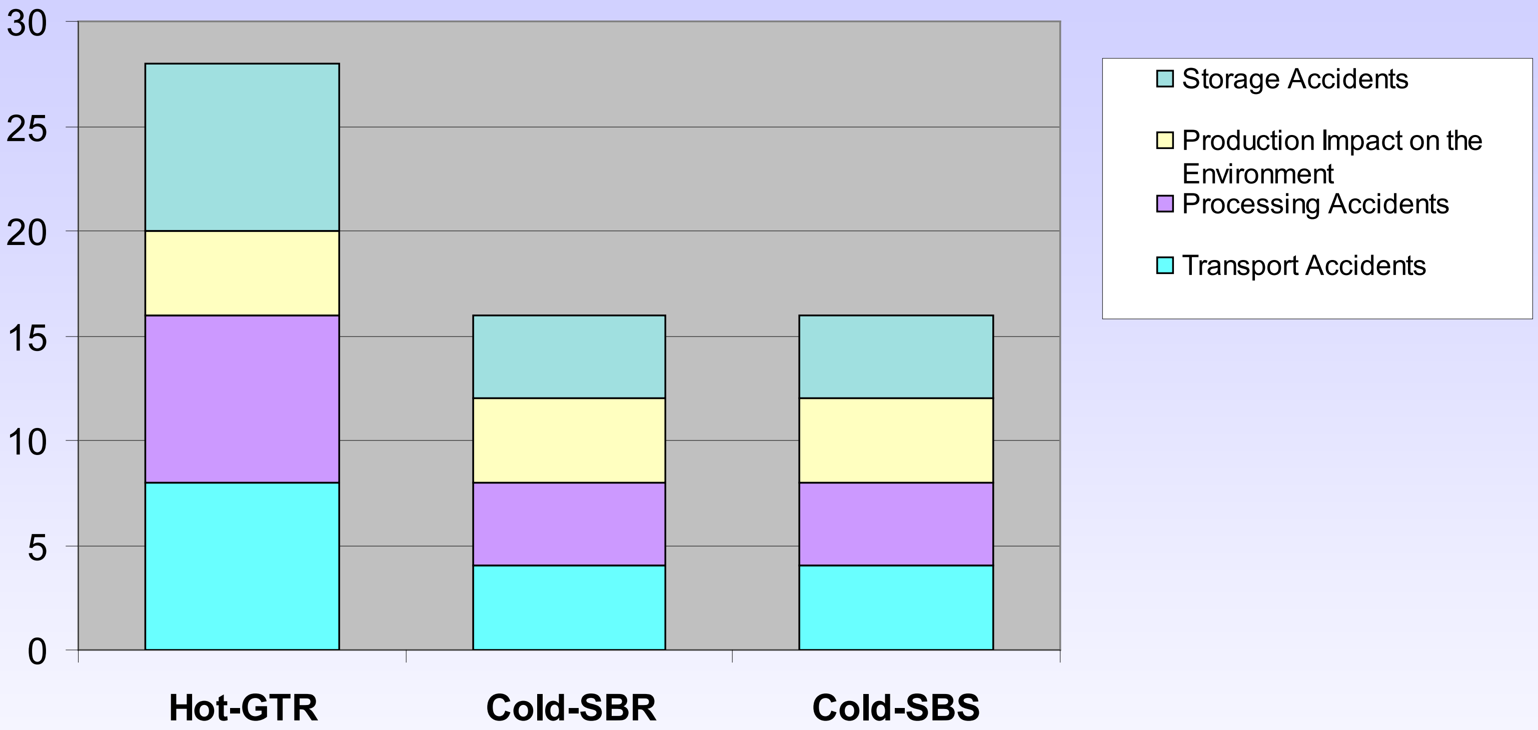
Comments regarding potential health effects



The hot alternative has higher health effect potential due to the higher quantity of asphalt cement which is used, which is an eye, skin and inhalation irritant.

Evaluation of the risk potential - Production



The hot chipseal uses more asphalt, which means higher probability of accidents during asphalt manufacture. It is also stored at higher temperatures than the cold alternatives, meaning there is a greater hazard present.

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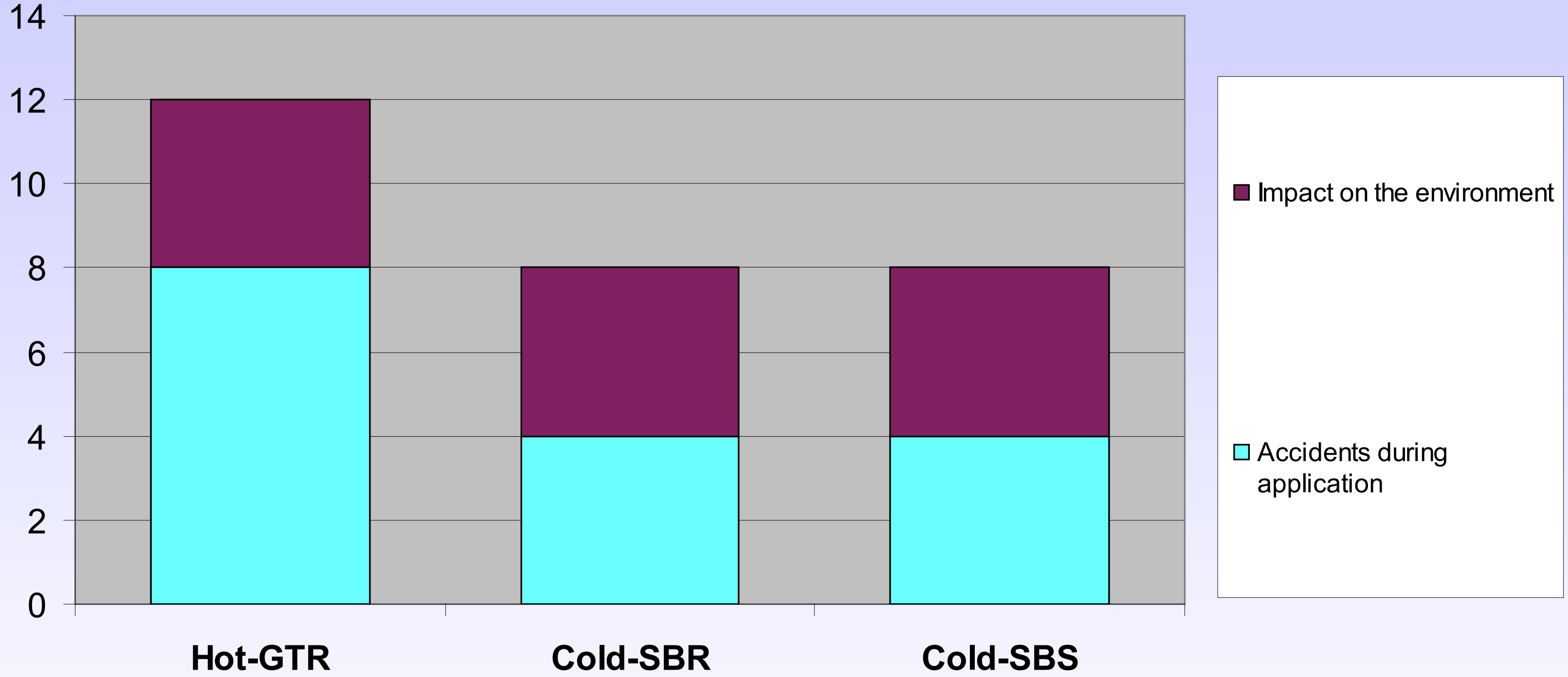
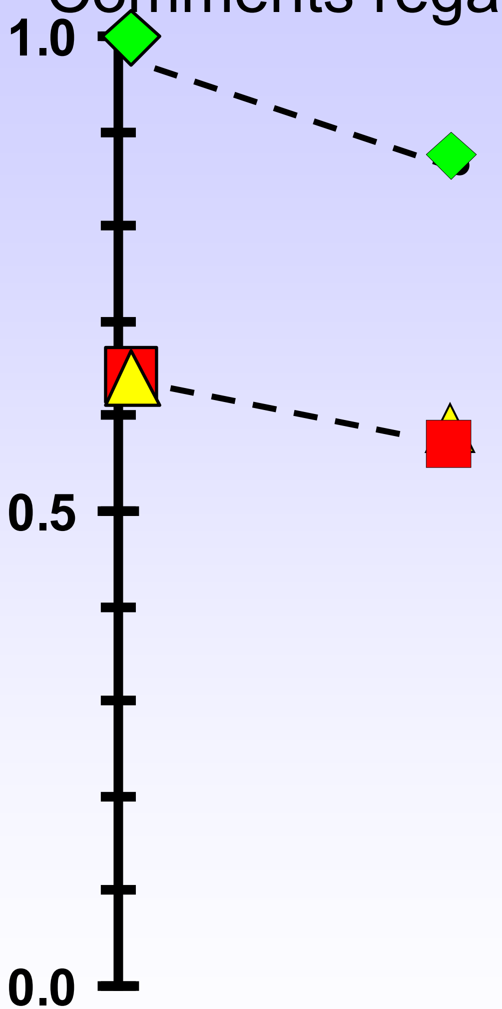
Evaluation of the risk potential - Use



Since the hot chipseal is applied at over 300 degrees F, the potential hazard to road workers is much higher than for the cold alternatives.

Comments regarding risk potential



The hot chipseal has higher risk because it is stored and applied at much higher temperatures than the cold chipseal. The hot chipseal also uses more asphalt, meaning more manufacture and handling of asphalt.

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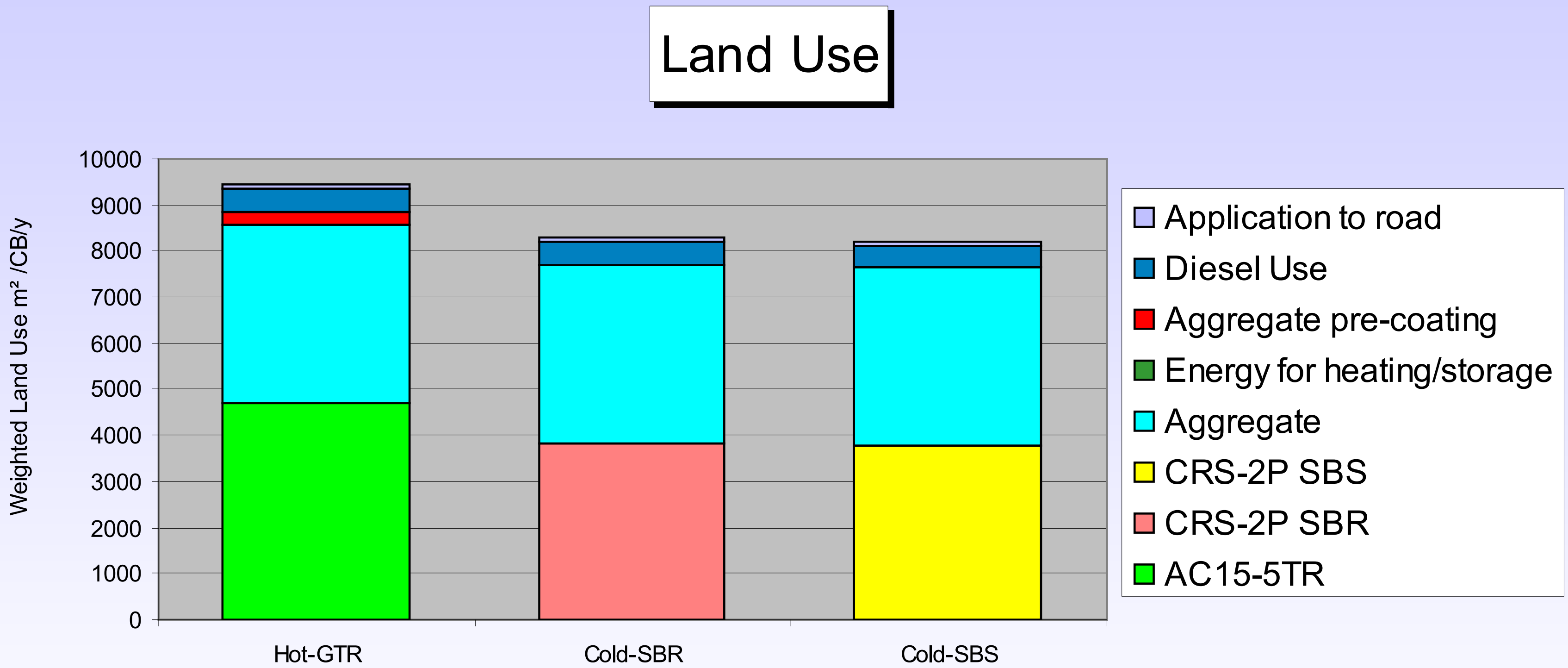
Land Use



Aggregate quarrying and chipseal production has the greatest affect on land use.

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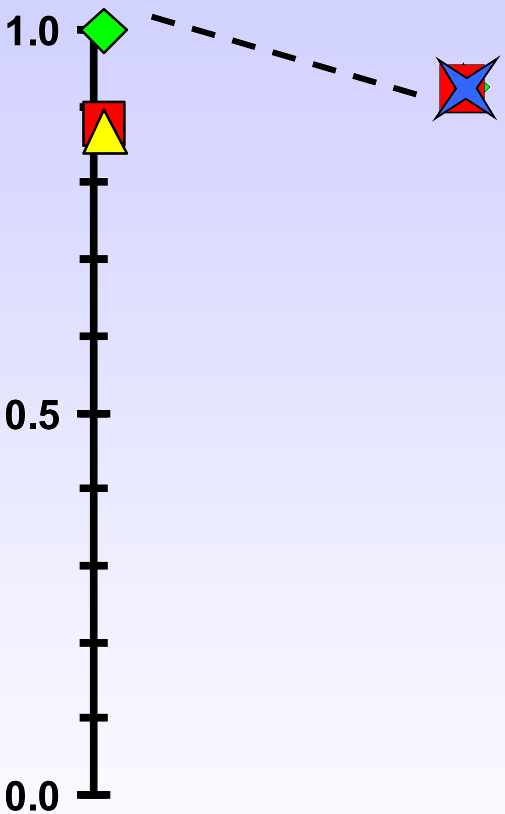
Comments regarding Land Use



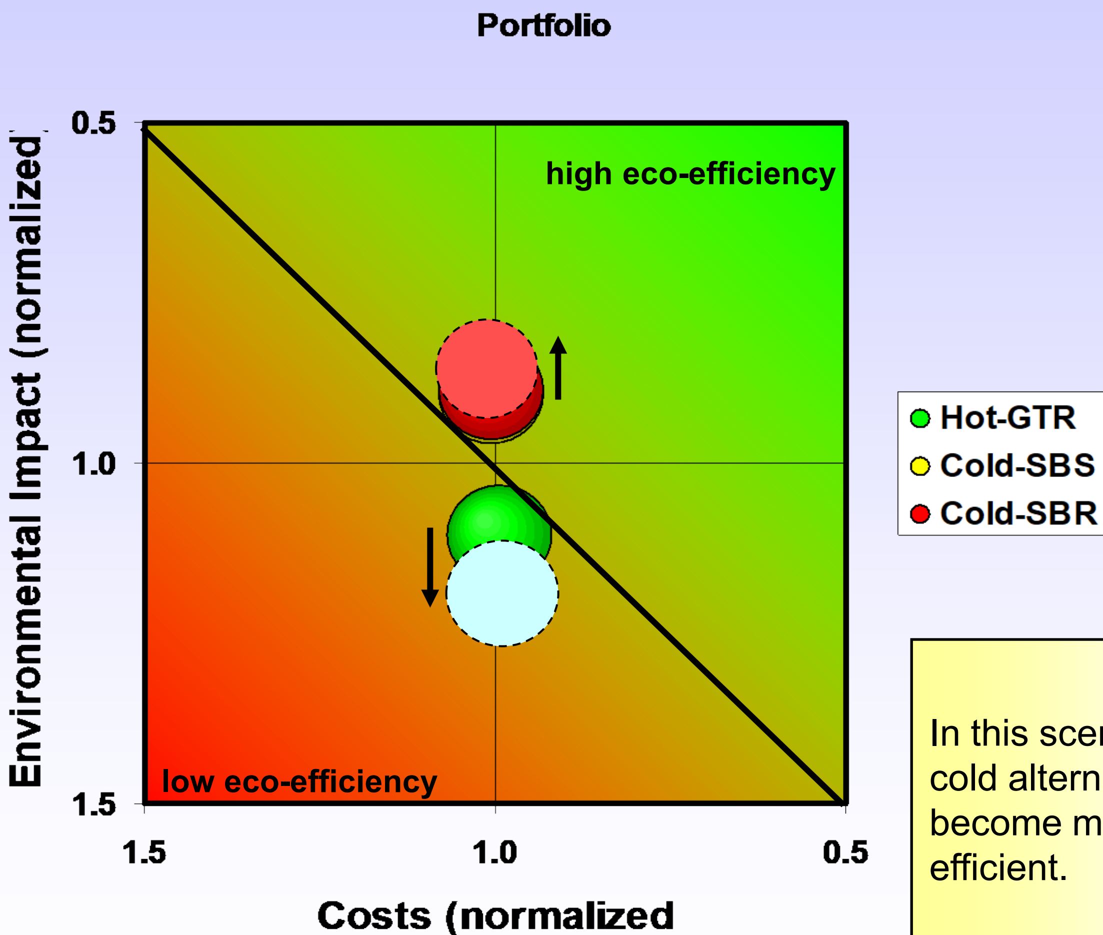
The hot alternative has slightly greater land use because of the higher quantity of asphalt cement.

Scenarios

Scenario 1: 2% asphalt is used for pre-coating of the aggregate for the hot alternative.
Scenario 2: Aggregate road coverage is 125yd2/yd3 for cold and 139 yd2/yd3 for hot chipseals.
Scenario 3: The vapor pressure of the cold-applied chipseal is 30% that of the hot applied chipseal.

Scenario 1: 2% asphalt is used for pre-coating of the aggregate for the hot alternative.

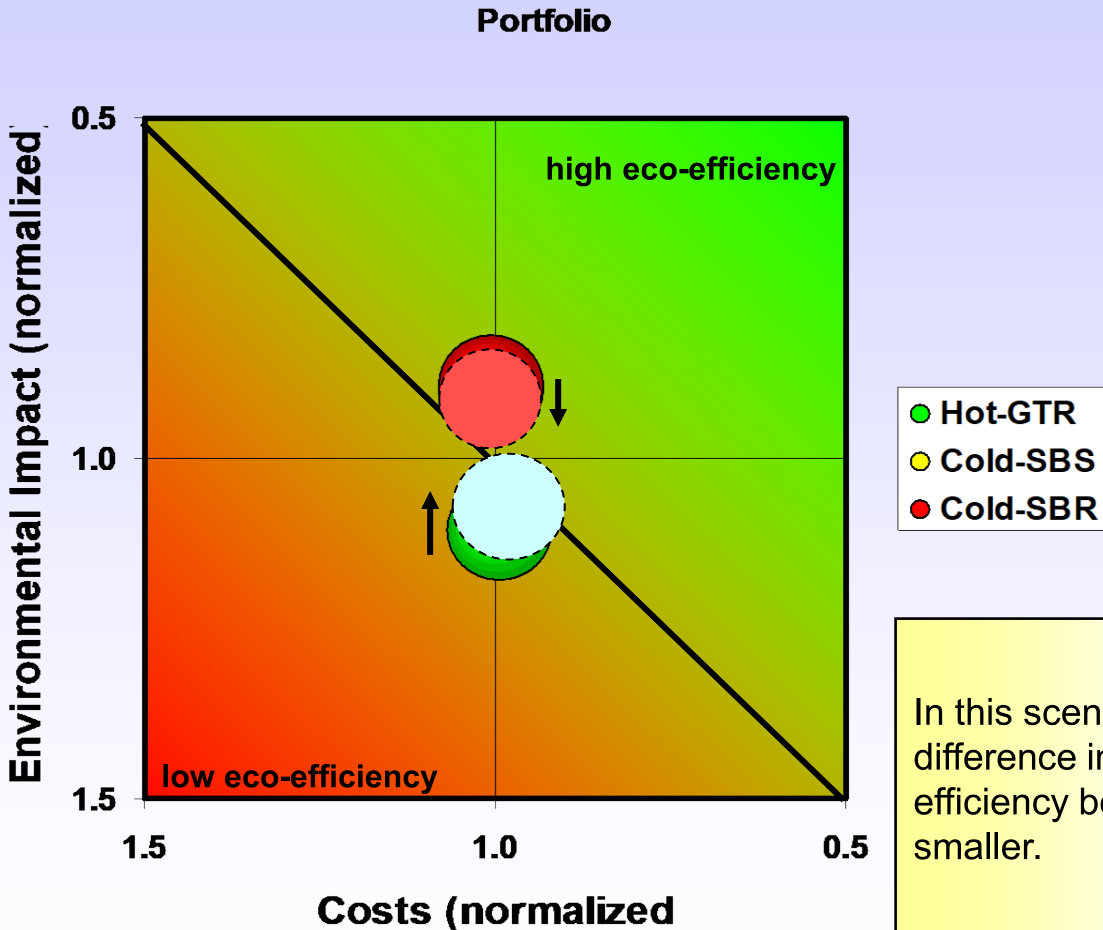
•Resurfacing of a 1-mile, 22-ft wide road stretch, with a lifetime of 7 years, using chipseal



In this scenario the cold alternatives become more eco-efficient.

Scenario 2: Aggregate road coverage is 125yd2/yd3 for cold and 139 yd2/yd3 for hot chipseals.

•Resurfacing of a 1-mile, 22-ft wide road stretch, with a lifetime of 7 years, using chipseal



In this scenario the difference in eco-efficiency becomes smaller.

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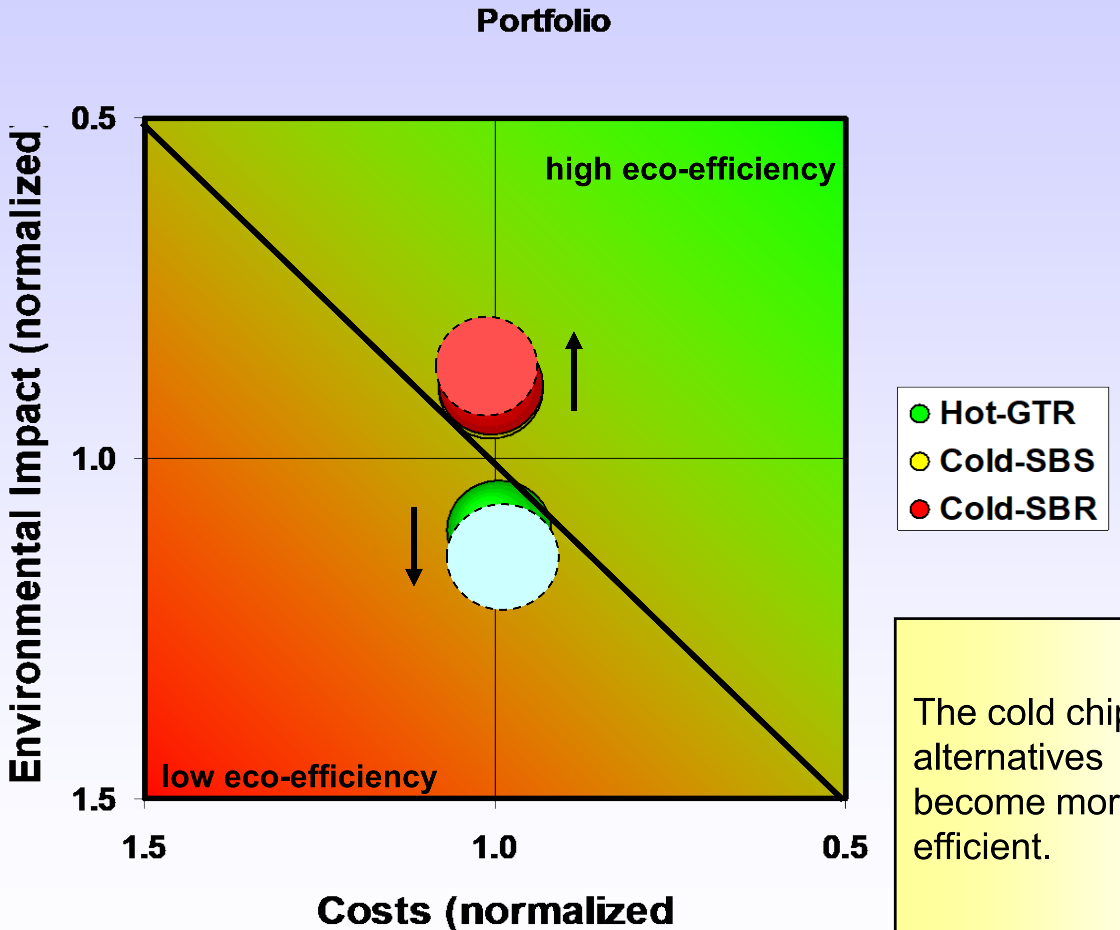
Scenario 3: The vapor pressure of the cold-applied chipseal is 30% that of the hot applied chipseal*.

- Resurfacing of a 1-mile, 22-ft wide road stretch, with a lifetime of 7 years, using chipseal



The cold chipseal alternatives become more eco-efficient.

*Base case assumes 3mmHg for asphalt at 354F, and 1 to 3mmHg at 170F.

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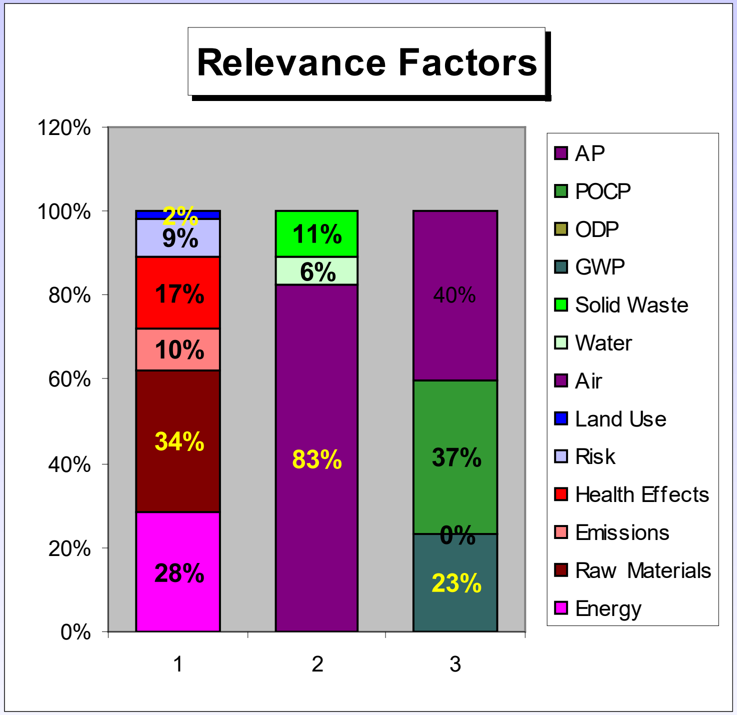
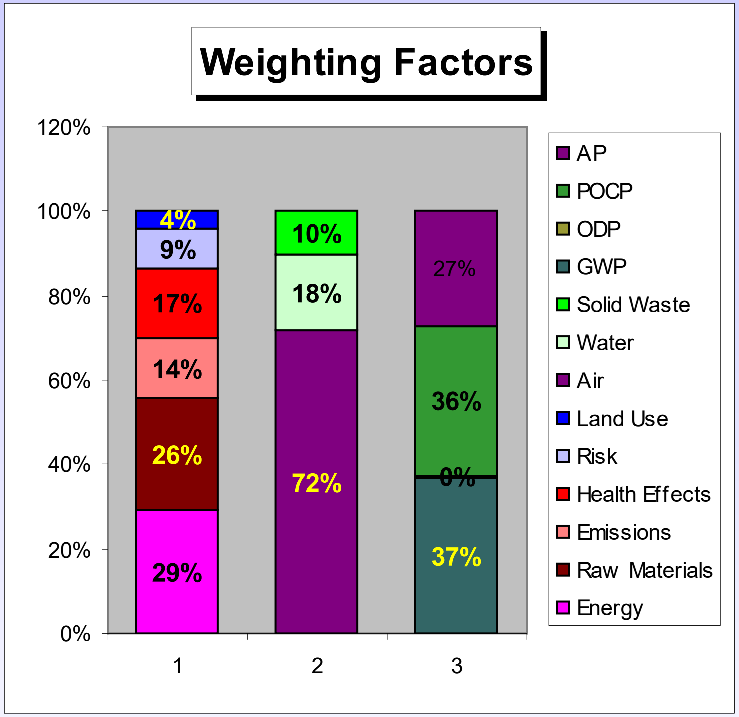
Relevance and weighting factors for Chipseal





The biggest factors in the environmental impact are raw materials and energy consumption. Air emissions are the most important, followed by water and solid waste.

Back up - Slides

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BASF Rating, weighting and evaluation scheme - base case

Weighting factors [%]

Materials consumption	20%
Energy consumption	27%
Emissions	20%
Health effect potential	18%
Risk potential	10%
Use of area	5%
Total	100%

Air emissions	**51%**
Water emissions	**41%**
Soil emissions	**8%**
Total	100%

GWP	**40%**
ODP	**20%**
POCP	**25%**
AP	**15%**
Total	100%

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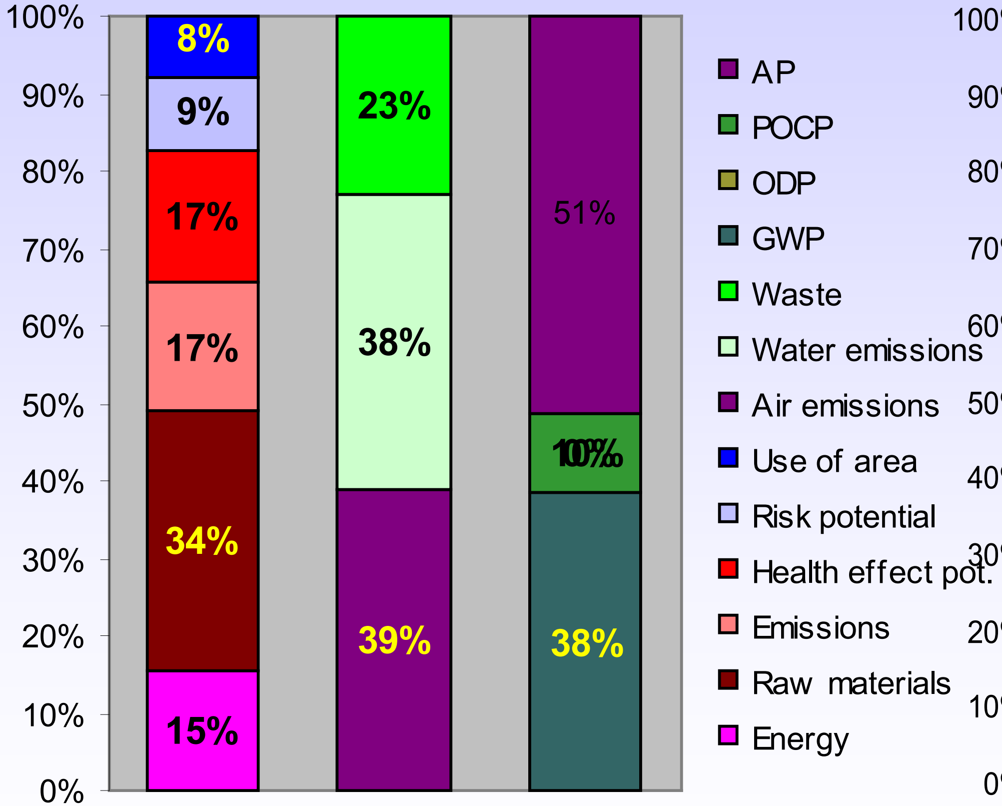
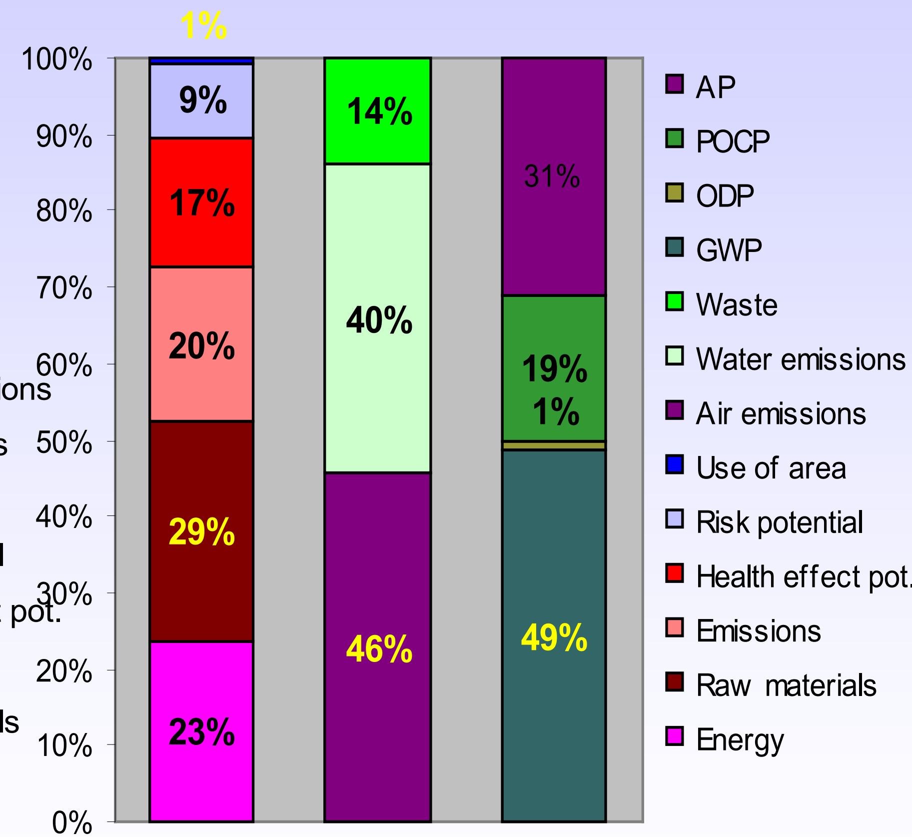
The weighting factors





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Calculation factors

	Germany	USA				Savant	Nylon 6,6	Alternative 2	Alternative 3	Alternative 4	Alternative 5
CO2 (1000 t/a)	861000	5598000	5598000	GWP:	Relevance	9.82092058	17.8076456	a	a	a	a
SOX (1000 t/a)	1292	17820	17820	7,339,800	normalized	32.5%	38.5%	#VALUE!	#VALUE!	#VALUE!	#VALUE!
NOX (1000 t/a)	1780	22180	22180	ODP	Relevance	0.1627%	1.4025%	a	a	a	a
CH4 (1000 t/a)	3484	28800	28800	170.0	normalized	0.0%	0.0%	#VALUE!	#VALUE!	#VALUE!	#VALUE!
KW (1000 t/a)	1705	16250	16250	POCP	Relevance	218.8465%	471.3290%	a	a	a	a
Halogen. KW (1000 t/a	6.9	170	170	6,962	normalized	7.2%	10.2%	#VALUE!	#VALUE!	#VALUE!	#VALUE!
NH3 (1000 t/a)	625	65.4	65.4	AP	Relevance	1819.1490%	2374.0954%	a	a	a	a
N2O (1000 t/a)	160	1200	1200	33,735	normalized	60.2%	51.3%	#VALUE!	#VALUE!	#VALUE!	#VALUE!
HCl (1000 t/a)		302	302		Average	755.0626%	1156.8979%	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
					Total					Total	
COD(t/a)	1932000	4220662.5	4220663	56,276							
BOD(t/a)	322000	844132.5	844133	56,276						**Air**	
N-Summary (t/a)	805000	1012959	1012959	56,276							
NH4-N(t/a)	268333	3591	3591	359							
P-Ges(t/a)	37500	56275.5	56276	56,276		Savant	Nylon 6,6	Alternative 2	Alternative 3	Alternative 4	Alternative 5
AOX(t/a)	5820	56275.5	56276	56,276	Relevance	1102.6290%	1729.5050%	a	a	a	a
HM(t/a)	1512	4852	4852	4,852							
HC(t/a)	3023	112551	112551	56,276							
SO4 (t/a)	18331515	56275500	56275500	56,276							
Cl- (t/a)	37244983	56275500	56275500	56,276							
Total				455,415							
						Savant	Nylon 6,6	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Municipal waste (Mio t	29.8	188.7	188.7	188.70	Relevance	554.8172%	1056.2329%	a	a	a	a
Regulated waste(Mio t											

Explanations of the eco-efficiency portfolio according to BASF

- The overall cost calculation and the calculation of the ecology fingerprint constitute independent calculations of the economic and ecological considerations of a complete system possibly with different alternatives. If it is assumed that ecology and economy are equally important in a sustainability study, a system that is less advantageous economically can compensate for this disadvantage by a better ecological assessment and vice versa. Alternatives whose products are identical when assessed economically and ecologically are considered to be equally eco-efficient.
- In order to be able to illustrate eco-efficiency, BASF has developed the eco-efficiency Portfolio according to BASF.
- The figures calculated from the ecology fingerprint are multiplied by weighting factors. This yields the portfolio figure with which the individual criteria are entered into the total sum of the environmental assessment. After all the individual criteria have been added up, the total sum of the environmental assessment of an alternative is obtained. The plotting into the Portfolio is then carried out via the mean of the particular overall ecological position.

Explanations of the ecology fingerprint according to BASF

- After normalization or normalization and weighting have been carried out for the emissions, the appropriate computed values are collated in a specific plot, the Ecology Fingerprint according to BASF. This shows the ecological advantages and disadvantages of the considered alternatives in a relative comparison with each other. The alternative that lies furthest out and has the value 1 is the least favorable alternative in the compartment in question; the further in an alternative lies, the more favorable it is.
- The axes are independent of each other so that an alternative which is, for example, favorable in terms of energy consumption may be less favorable in terms of emissions.
- Using the ecology fingerprint, it is possible to find starting points as to the areas in which improvements should be achieved in order to optimize the whole system effectively.

Assessment of the environmental loads

The values obtained, namely the material balance and impact estimate (greenhouse potential, ozone depletion potential, photochemical ozone formation potential, acidification potential, amount of polluted water, amount of waste, energy consumption and raw material consumption) are collated with assessment factors to give a parameter for the environmental loads. The assessment factors comprise the following:

- a *social factor:*
  What value does society attach to the reduction of the individual potentials?
- a r*elevance factor*:
  What is the proportion of the emission under consideration in relation to the total emissions for the applicable geographic area (e.g. the U.S.A.)?

Calculation of the energy consumption

The energy consumption is determined over the whole life span. It describes the consumption of primary energy. The sum of fossil forms of energy before production and of the renewable forms of energy before harvest or use is shown. Thus conversion losses from the production of electricity and steam are recorded. In the case of BASF processes, BASF-specific data are used. In the case of non-BASF processes, the UCPTE data record [1] is used. However, it is also possible to calculate specific scenarios for the production of electricity and steam, e.g. for site comparisons.

The energy consumption figures are assigned to the individual types of energy. The consumption of the various forms of primary energy is taken into account according to the consumption of raw materials.

In the category of “energy consumption”, there is no further conversion to specific impact categories. The energy consumption figures of all the alternatives that have been calculated are normalized among each other, the least favorable alternative being given the value of 1; the other alternatives are arranged on an axis of 0 to 1 relative to this and a hierarchy is formed. All other categories of the environment load axis are later compared with each other in this way.

In order to calculate the total energy requirement, the upper calorific value of the primary energy equivalent is used. For this, the following forms of energy are taken into account: hard coal, oil, gas, brown coal, nuclear energy, hydraulic power, biomasses and others.

[1] West European Electricity Coordination System
(union pour la coordination de la production et du transport de l`éléctricité)

Determination of the material consumption

In the case of material consumption, first the mass of raw materials is determined that the process in question requires. The individual materials are weighted according to the time span of their resources [5].

In the case of renewable raw materials, sustainable farming is assumed. Therefore, the resource that has been removed has been renewed in the period under consideration. This means an endless time span and thus resource factor 0. Of course, in the case of renewable raw materials from non-sustainable farming (e.g. rainforest clearance), an appropriate resource factor is used for the calculation.

High energy consumption can be correlated with low materials consumption, if renewable raw materials such as wood or hydraulic power are used. What therefore appears to be double counting of raw material and energy consumption is not the case with these two categories.

[5] U.S. Geological Survey, Mineral Commodity Summaries, 1997; Römpp Chemie Lexikon, Thieme, Stuttgart; Institut für Weltwirtschaft, Kiel; D. Hargreaves et al, World Index of Resources and population, Dartmouth publishing, 1994; World resources, Guide to the Global Environment, Oxford 1996; Deutsches Institut für Wirtschaftsforschung, Berlin

Determination of air emissions

Air emissions, split up into different types of gases, are recorded separately and added up over the whole life span. In most processes, the emission of carbon dioxide is the most dominant air emission in terms of quantity. This emission is frequently followed by the sulfur and nitrogen oxides as well as laughing gas and hydrocarbons in terms of quantity. The life span-related emissions are for example also determined for the use of electricity as a source of energy. As a rule, these impact the manufacturing process through the consumption of sources of primary energy.

The effect of these air emissions in the environment varies depending on the type of emission. In order to take account of this, the various emission quantities are linked to scientifically determined assessment factors [2]. Using this method, the emissions of 11 kg of carbon dioxide have the same greenhouse effect as 1 kg of methane. These so-called impact categories are used for each emission. Some emissions, for example the emission of methane, play a role in several impact categories. The impact categories that are taken into consideration in the eco-efficiency analysis are the greenhouse potential, summer smog, acid rain and ozone depletion.

[2] UBA Texts 23/95

Procedure for assessing water emissions

The assessment of water pollution is carried out by means of the “critical volume” model. For each pollutant that enters the water, the theoretical water volume is calculated that would be impacted by the emitted pollutant freight up to the statutory limit value (critical load). The partial volumes calculated for each pollutant are added up to yield the “critical volume”.

The adjoining table shows the factors for calculating the critical volume. The requirements that are made on the wastewater for the entry point into the surface water and laid down in the appendices to the German Wastewater Regulation (AbwV) are the basis for the factors.

These limit values are generally based on the relevance of the emitted substance for the environment; in some cases, technical aspects were also taken into account in fixing the values. In spite of this restriction, BASF prefers this procedure on account of the:

- complete database for most of the emissions
- wide recognition of the Wastewater Regulation and broad acceptance of the limit values in the appendices.

Tab.: Water emissions; model of the critical water volume; calculation factors used

Parameter	Require-ment on waste-water (mg/l)	Factors for calculating “critical volumes”	*Appendix to Wastewater Regulation (AbwV)*
COD	75	1/75	*No. 1*
BOD *No* 5	15	1/15	*No. 1*
Total N	18	1/18	*No. 1*
NH_4-N	10	1/10	*No. 1*
Total P	1	1	*No. 1*
AOX	1	1	*No. 9*
Heavy metals	∅ 1	1	*No. 9*
HC	2	½	*No. 45*

COD: chemical oxygen demand; BOD_5: biochemical oxygen demand;. Total N: total nitrogen; NH_4-N: ammonium nitrogen; Total P: total phosphorus; AOX: adsorbable organic halogen compounds; heavy metals: Sum of copper, zinc, lead, cadmium, chromium, mercury. HC: sum of hydrocarbons

Assessment of the environmental burden of solid waste

The results of the material balance for waste are summarized into three waste categories: Special waste, domestic-like waste and building rubble/rubbish. In the absence of other assessment criteria, the average costs for the particular recycling and the treatment or disposal of the waste are used to form the impact potential. Production residues that are incinerated are included in the overall calculation according to the use of incineration energy and the emissions that occur during incineration.

Determination of the health effect potential

- The toxicity potential in the eco-efficiency analysis is balanced by means of an assessment scheme developed by BASF. Fundamental provisions of the Hazardous Substances Regulation regarding classification and labeling are taken into account. These toxicological assessments produce various R phrases. Toxicologists assign figures of 0 - 1000 to each R phrase or each combination of R phrases according to their risk potential. For example, the classification R 26/27, very toxic, receives 750 points and the considerably less critical category R 35, corrosive, 300 points (see example on next page). The figures that have been calculated are then balanced and added along the life span described for all the starting products and intermediates. In this way, a life span-related toxicity potential is obtained for each of the substances involved in the eco-efficiency analysis.
- The calculated index figures are multiplied by the amounts of substances used and thus yield the overall assessment.
- When balancing substances under “use”, only the substance categories are balanced; the pre-chain is not used in this part of the assessment, since it has already been taken into account in production and is no longer of importance in the use phase.
- The results of these assessments are expressed in dimensionless assessment figures and can then be compared with each other by normalizing and weighting the various life span phases.
- It is always potential values that are calculated. In order to be able to assess an actual risk to humans, additional calculations on the exposure of humans, uptake of the substance, etc., are needed.

Determination of the health effect potential using a process developed by BASF

Health effect potential

Example

- R 26/27: 750 points, very toxic (T+)
- R 23/25 = 550 points, toxic (T)
- R 20/22 = 400 points, harmful (Xn)
- R 35 =300 points, corrosive (C)
- R 38 =100 points, irritating (Xi)

Calculation

Substance 1, R 26/27, 750 points

Prechain: 0 P

Total 750 P

Use: 0.5 kg
Factor:
0.5*750 = 375 P

Substance 2, R 35, 300 points

Prechain: 0 P

Total 300 P

Use: 0.5 kg
Factor:
0.5*300 = 150 P

Substance 3, R 20/22, 400 points
Prechain:
375 P
+ 150 P= 525 P

Total: 925 P

Use:
400 points

Production:
925 points

Determination of the risk potential

- The risk potential in the eco-efficiency analysis is established using assessments in the sense of an expert judgement. The focus is always on the question of the severity of the damage that an operation can cause, multiplied by the probability of it happening.
- In the risk potential, the damage considered is that which can be attributed for example to physical reactions. Examples would be explosion or fire hazards and transport risks.
- Further possibilities are the consideration of the impurities in the product, incorrect uses of the product, incorrect storage, etc. The criteria of the risk potential are variable and may be different in each study, because they are adapted to the circumstances and special features of the particular alternatives. The number of risk categories may also vary.
- Data from, for example, accidents in various industries or in various occupations may also be included, as for example safety data on various types of reaction in the chemical industry.
- Here, too, all aspects of the whole life span are considered and summarized in assessment figures.
- It is always potentials that are calculated. In order to be able to estimate a risk actually occurring to a human, additional calculations and estimates are required.

Assessment of the area requirement

Area is not consumed like a raw material but, depending on the type, scope and intensity of the use, areas are changed so radically that they are impaired or even destroyed in their ability to perform their soil function. Apart from the direct loss of fertile soil, there are a series of consequential impacts, for example, cutting into ecosystems, loss of living space for flora and fauna, etc. The area requirement is assessed by weighting the areas using the principal type of use and in relation to the relevance of the area requirement .

The uses of the area are considered in the light of how necessary they are for establishing the customer‘s use. Since virtually all the agricultural land in Europe is under cultivation, the origin of the areas is not crucial. For special questions (e.g. conversion of rainforest to plantations), there is no difficulty in extending the consideration of the area requirement in this direction.

The life span is composed of building time, time in operation and demolition and is put in relation to the overall capacity of the system. In the case of the reduction of non-renewable resources, the recultivation time is taken into account.

<u>The area requirement is split up according to the principal type of use</u>

Natural	Unaffected ecosystems	Assessment factor 0
Close to nature	Forestry use, forest areas and bio-agriculture close to nature	Assessment factor 1
Semi-natural	Semi-natural agricultural use, grassland	Assessment factor 2
Remote from nature	Agricultural use and arable cropping remote from nature	Assessment factor 4
Sealed	Sealed and impaired area, industrial areas	Assessment factor 16
Sealed & separating	Traffic areas that split up ecosystems (roads, railways and waterways)	Assessment factor 32

Assessment of the Area Requirement: Examples						
Materials	**Amoun**	**Area II**	**Area III**	**Area IV**	**Area V**	**in m2**
Platinum from enrichment	100kg	11415.00	11415.00	2647.42	665.28	
Aluminum 0% recycled	100kg	23.25	23.25	3.43	0.91	
Polypropylene	100kg	9.45	9.45	1.84	0.09	
Cement	100kg	0.37	0.37	0.06	0.07	
Energy						
Hard coal for D	t	5.71	5.71	5.71	0.76	
Leadfree gasoline from refin	t	43.79	43.79	1.26	0.48	

Assessment of the Area Requirement: Determination of the Numerical Values

	Alternative 1			Alternative 2		
	Numerical value	Factor	Numerical value	Numerical value	Factor	Numerical value
Area II	4	2	8	2	2	4
Area III	10	4	40	5	4	20
Area IV	0.6	16	9.6	0.6	16	9.6
Area V	0.1	32	3.2	1.2	32	38.4
Sum			60.8			72

FINAL

Glossary

Glossary of abbreviations and technical terms used I

AOX: Abbr. for adsorbable organic halogen, a category of water emissions.

AP: Abbr. for acidification potential or acid rain. In this impact category, the effects of air emissions that lower the local pH values of soils and can thus e.g. cause forest dieback are taken into account .

BOD: Abbr. for biological oxygen demand. This is a method for determining wastewater loads.

CH_4: Abbr. for methane.

Cl^-: Abbr. for chloride.

COD: Abbr. for chemical oxygen demand. This is a method for determining wastewater loads.

CO_2: Abbr. for carbon dioxide

Critical volume: Operand for assessing the extent to which wastewater is polluted by mathematically diluting the wastewater with fresh water until the prescribed limit value is reached. This volume of fresh water that has been added is referred to as the critical volume.

CB (Customer Benefit): Use unit. All calculations are converted to the use unit that has previously been defined when fixing the use for the customer.

Domestic waste: Waste that may be deposited on a normal household landfill.

Glossary of abbreviations and technical terms used II

Emissions: Emissions are categorized as emissions into air, water and soil. This general division is subdivided into various types of emission.

Energy unit: Energy is expressed in megajoules (MJ). 1 **MJ** is equivalent to 3.6 kilowatt hours (**kWh**).

Feedstock: The energy content that is bound in the materials used and can be used e.g. in incineration processes.

GWP: Abbr. for global warming potential, the greenhouse effect. This impact category takes into account the effects of air emissions that lead to global warming of the earth's surface.

Hal. HC: Abbr. for halogenated hydrocarbons.

Halogenated NM VOC: Abbr. for halogenated non-methane hydrocarbons.

HC: Abbr. for various hydrocarbons or hydrocarbon emissions into water.

HCl: Abbr. for hydrogen chloride.

HM: Abbr. for heavy metals.

Impact potential: Name of an operand that mathematically takes into account the impact of an emission on a defined compartment of the environment.

Material consumption: In this category, the consumption of raw materials is assessed linked to their time span. Thus, a raw material with a shorter time span is assessed more critically than a material with a very long time span.

Glossary of abbreviations and technical terms used III

NH_3: Abbr. for ammonia emissions.

NH_4^+: Abbr. for emissions of ammonium into water.

NM VOC: Abbr. for non-methane volatile organic compound.

N_2O: Abbr. for laughing gas emissions.

NO_x: Abbr. for various nitrogen oxides.

Normalization: In the eco-efficiency analysis, the worst value of each category is normalized to the value of 1. All the more favorable values are given correspondingly smaller values.

ODP: Abbr. for ozone depletion potential, damage to the ozone layer. This impact category takes into account the effects of air emissions that lead to the destruction of the ozone layer of the upper layers of air and thus to an increase in UV radiation.

PO_4^{3-}: Abbr. for emissions of phosphate into water.

POCP: Abbr. for photochemical ozone creation potential. This effect category takes into account the effects of local emissions that lead to an increase in ozone close to the ground and thus contribute to what is known as summer smog.

Glossary of abbreviations and technical terms used IV

Risk potential: Here, the effects of risk factors in the whole life span are assessed. Here, risks such as transport risks, dangers of explosion, dangers of accidents, etc. are assessed.

Rubble, rubbish: Material that can be deposited as building material or that e.g. is obtained in mining coal, metals, etc. and used e.g. for filling up old shafts.

SO_x: Abbr. for various sulfur dioxides.

SO_4^{2-}: Abbr. for emissions of sulfates into water.

Special waste: Waste that has to be deposited on a special landfill.

System boundary: It limits what is considered for the balance in the study.

Glossary of abbreviations and technical terms used V

Time span: The period for which a raw material is still available and can be used. The current use of the raw material in relation to what is currently known to be the amount that is still available and can be used industrially is the basis for the assessment.

Total N: Collective term for all water pollutants that contain nitrogen and that cannot be included in one of the other categories.

Health effect potential: In this category, the effect of the substances involved is assessed with regard to their effect on human health. It relates solely to possible material effects in the whole life span. Further data have to be used to assess a direct risk.

The symbols have the following meanings: T+: very toxic; T: toxic; Xn: harmful; C: corrosive; Xi: irritating.