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

Friction Modifiers for Gasoline Eco-efficiency Analysis
Final Report – October 2012

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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 "Friction Modifiers for Gasoline 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 Friction Modifiers for Gasoline Eco-effiicency 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 or http://www.basf.com/group/corporate/en/sustainability/eco-efficiency-analysis/index

2. Content of this Submission

2.1. This submission outlines the study goals, procedures, and results for the Friction Modifiers for Gasoline 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, 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.

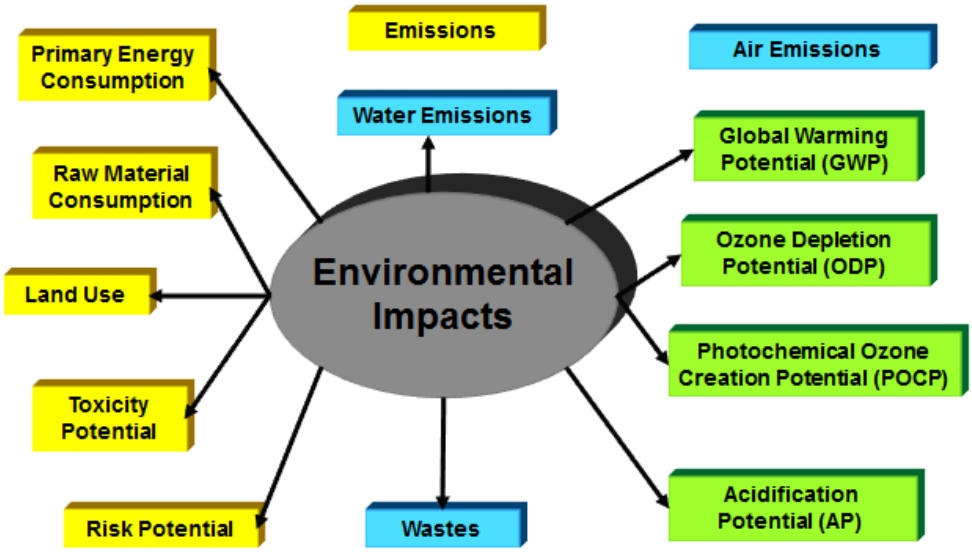

Figure 1: Environmental Impact categories

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.

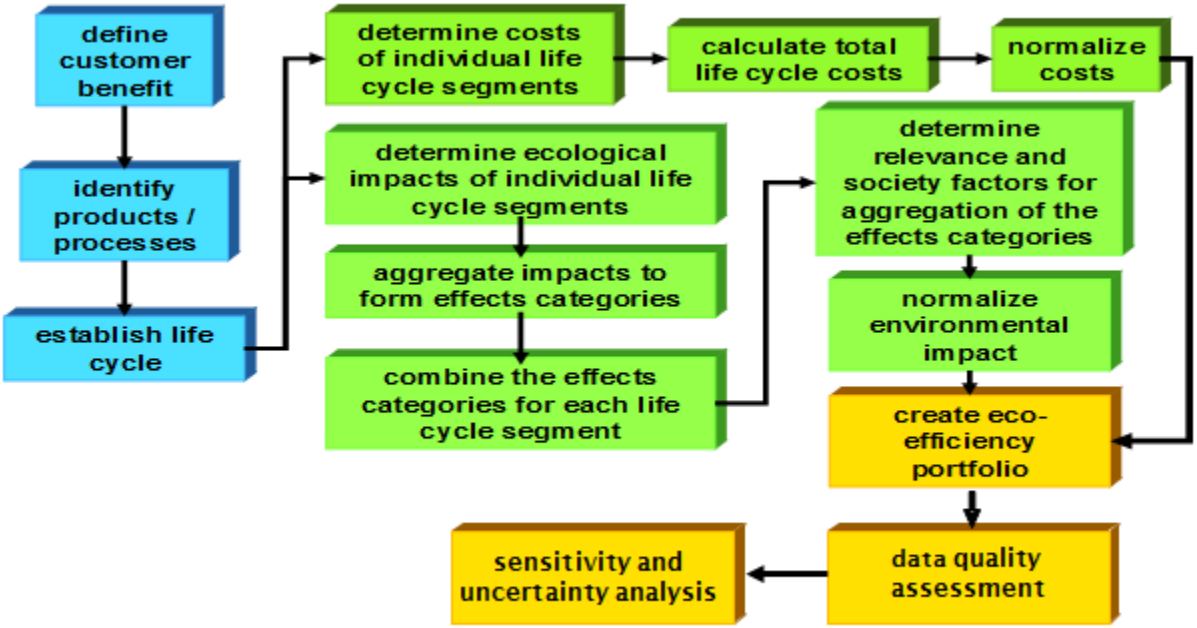

Figure 2: Overall process flow for Friction Modifiers for Gasoline EEA study

4. Study Goals, Decision Criteria and Target Audience

4.1. Study Goals*:*

Over the years, the US EPA has helped protect public health and impacts on the environment through many regulations and programs. One program, specific to the transportation industry, the clean fuels program, has made significant progress in limiting pollution from engines[5] by developing fuel quality requirements that complement vehicle and engine emission standards, and together limit pollution from a wide variety of vehicles, engines, and equipment. One example of this is the requirement for detergent additives in gasoline. These additives help remove and prevent the build-up of deposits in various locations in an engine which can negatively affect the performance of the engine. Other additives which can be added to gasoline, such as corrosion inhibitors and friction modifiers are not currently required by law to be included in gasoline but can have similar benefits to engine performance and ultimately help reduce negative impacts to the environment and drive more sustainable fuel solutions for consumers.

Studies show that approximately 10 % of the energy released by the combustion of gasoline in modern day automobile engines is lost due to internal friction in the engine[1]. Gasoline performance packages can be formulated with very effective friction modifiers which minimize the friction between the piston rings and the cylinder wall (see Figure 3), thus resulting in instantaneous fuel economy benefits.

Figure 3: Cross section of engine combustion chamber depicting cylinder walls (blue) and piston rings (red)

Enhanced fuel economy benefits the environment through reduced fuel production and consumption and reduced air emissions, as well as, benefiting the consumer through lower fuel costs. The specific goal defined for the Fuel Additives: Friction Modifiers for Gasoline Eco-efficiency Analysis will be to quantify the specific life cycle environmental and total life cycle cost impacts of using friction modifiers as additives in gasoline thus enabling a comprehensive and science based assessment on the sustainable benefits of friction modifiers. The study will enable an objective and holistic comparison between the impacts and costs required to produce the friction modifiers and the economic and environmental benefits achieved through their use.

This study compares two different gasolines additives packages: (1) base gasoline package with legally required detergency additives package but no friction modifiers (2) base gasoline package with identical detergency package as alternative 1 but enhanced with friction modifiers.

Specifically, this study reviewed the fuel economy improvements of gasoline containing friction modifiers using standardized test procedures such as the Highway Fuel Economy Test Cycle (HWFET). In many of the test programs conducted, the gasoline contained a range of detergent additive packages. These tests were conducted for various customers and the data/results are proprietary. To avoid any potential disclosure of confidential information while also insuring that the test results were equally and directly transferable to this study, test programs were designed and conducted which compared gasoline without detergents and gasoline without detergents but enhanced with friction modifiers. Assuming equal detergency levels in the gasoline, as is the basis for the two alternatives defined for this study, the expert judgment and experience of the team confirmed that the fuel economy increase and CO_2 emission reduction improvements observed in the test programs for the two detergent free gasoline alternatives would be practically identical to those observed for gasoline with detergents and thus could be used directly as the basis for this analysis.

The study considered application of these fuel packages specifically for gasoline in the United States market 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 average fuel price, anticipated annual miles driven, etc.

Study results will be used as the basis to guide product development in the area of fuel additives for gasoline as well as support external marketing claims around the environmental and economic benefits of gasoline additized with friction modifiers. The Eco-efficiency methodology will facilitate the clear communications of the study results to key stakeholders in the refinery, automotive and transportation industries and can also support the education and awareness of the benefits of friction modifiers to the end consumer.

4.2 Decision Criteria:

The context of this EEA study compared the life cycle environmental and cost impacts for additizing fuel with high performance friction modifier packages. Benefits relative to non-friction modified gasoline will be captured. The study goals, target audience, and context for decision criteria used in this study are displayed in Figure 4.

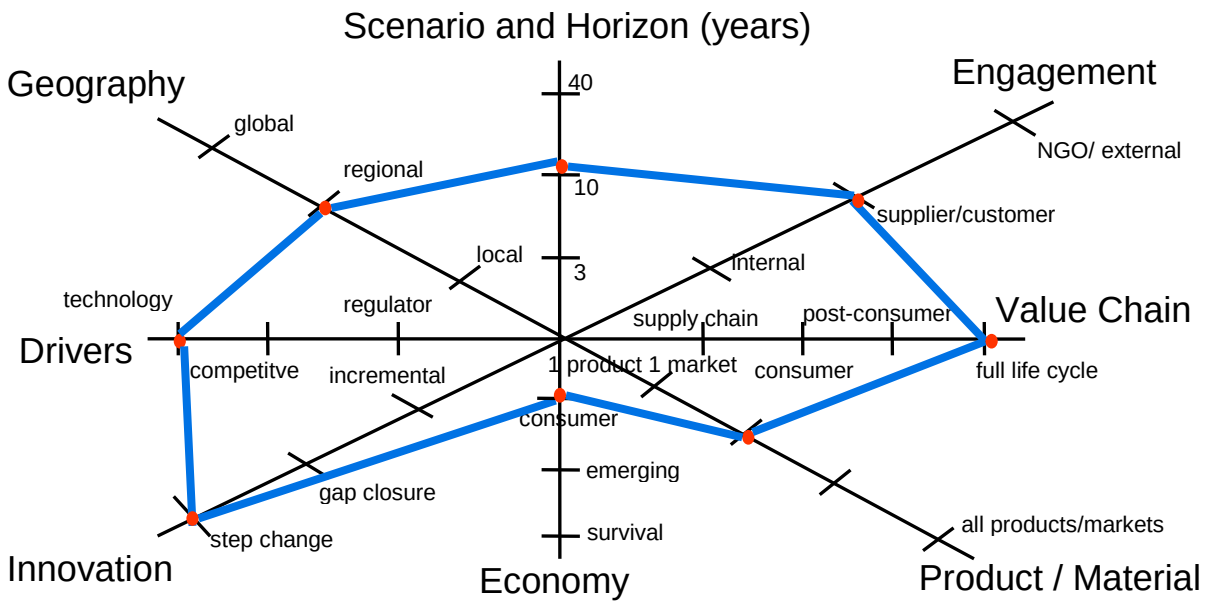

Figure 4: Context of Friction Modifiers for Gasoline Eco-efficiency Analysis

4.3. Target Audience*:*

The target audience for the study has been defined as oil refiners and gasoline producers, companies with large commercial automobile/truck fleets, state and federal government agencies (e.g. EPA (Environmental Protection Agency), DOT (Department of Transportation)), and the end consumer. 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 (CB)*:*

The Customer Benefit (identified also as CB) or Function Unit (FU) applied to all alternatives for the base case analysis is driving light duty vehicles (passenger cars and light trucks) with a gasoline powered engine 68,400 highway miles.

This is based on a vehicle being driven for approximately 152,000 miles over its lifetime, of which 45% of the total miles driven are highway miles. The other 55% of miles driven are considered city miles (start/stop) where the impacts of friction modifiers would be difficult to measure to a statistically significant level, so city miles were not considered to be part of this study. The average fuel economy for each alternative was determined through the standardized Highway Fuel Economy Test Cycle (HWFET)[13].

With regards to the basis for the miles driven, the NHTSA (National Highway Traffic Safety Administration)[2] and the FHWA (Federal Highway Administration)[3] reference the life time miles and annual miles driven for vehicles in the United States, respectively. Additionally, the split between highway and city miles driven for a vehicle is important to determine as the benefits of friction modifiers is maximized during highway driving conditions with minimal benefits during city driving. The US EPA Office of Transportation and Air Quality has published[4] recent figures for the ratios between city and highway miles driven. These were utilized to convert the lifetime miles driven to lifetime highway miles.

This study will quantify the change in fuel economy achieved by using friction modifiers as a gasoline additive. It will then compare the differential between the weight of friction modifier needed to deliver the enhanced fuel economy against the weight of the fuel saved through increased motor efficiency across the environmental impact and economic cost categories.

5.2. Alternatives:

The product alternatives compared under this EEA study cover (1) conventional gasoline manufactured in the United States which includes by law a detergent package with no friction modifiers and (2) conventional gasoline with the detergent package identical to alternative 1 but also enhanced with a friction modifier package.

5.3. System Boundaries:

The system boundaries define the specific elements of the production, use, and disposal phases of the life cycle that are considered as part of the analysis. The system boundary for the gasoline fuel additized with detergent additive and friction modifiers (FM) is depicted in Figure 5 while Figure 6 depicts the system boundary for the gasoline fuel additized with detergent additive but no friction modifier (FM).

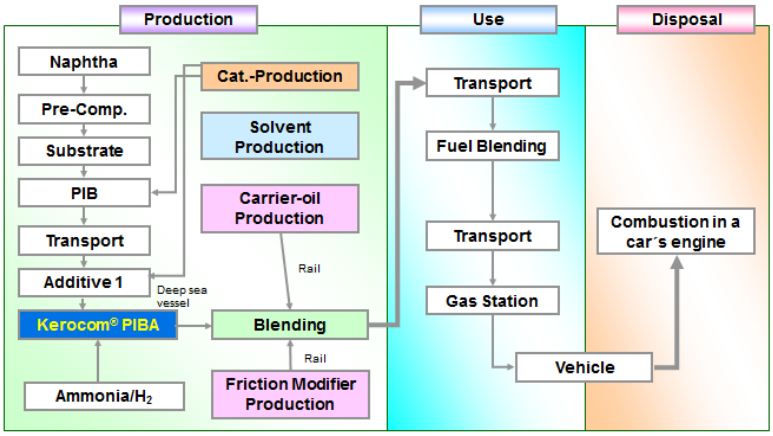

Figure 5: System boundary – Gasoline with Detergent Additive and Friction Modifiers

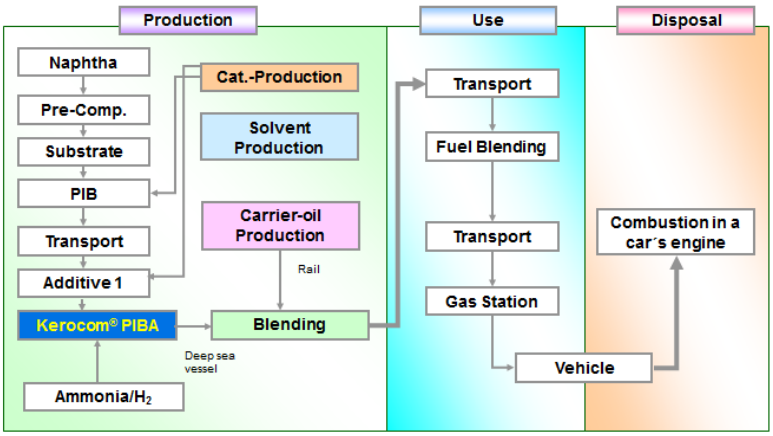

Figure 6: System boundary – Gasoline with Detergent Additive but without Friction Modifiers

All relevant life cycle stages including the production, use and combustion (end-of-life) of the friction modifier package components and the gasoline have been considered. No life cycle stages or processes within the defined life cycle were excluded from the EEA on the basis of being identical (or sufficiently similar) between the base case and the alternatives.

5.4 Scenario Analyses:

No scenario analyses were considered necessary for this analysis.

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. Differential input values as opposed to absolute values were utilized. Differential (relative) analysis

is appropriate and consistent with the scope and goals of the study as it will allow a clear comparison of the environmental impacts and benefits of friction modifiers as opposed to a study dominated by only fuel consumption if absolute values were considered. Additionally, differential (relative) analysis is also technically justified, as there is no change in the fuel economy results if the gasoline with or without friction modifiers contains detergents or not.

This section only provides input related to the friction modifier and engine testing, as other stages of the automobile's life cycle were considered identical (or sufficiently similar) for each alternative.

6.1.1. Detergency and Friction Modification Packages:

EPA requires the use of additives to control the formation of engine and fuel supply system deposits in all U.S. gasoline. Gasoline and fuel additives produced and commercially distributed for use in highway motor vehicles must be registered with the US EPA. The minimum allowable treat rate is that necessary to meet EPA's performance engine cleanliness specifications, although gasoline marketers can and often do use higher treat rates. A base detergency package utilized for both alternatives in this study is registered[6] and is confidential information. The exact formulations and ratios have been provided to NSF International as part of this verification. The detergent package consists of Kerocom® PIBA, a carrier fluid, solvent, corrosion inhibitor(s) and demulsifiers. The detergent treatment rate was constant for each alternative but the overall usage amounts are different as that is determined by the overall gasoline consumption required by each alternative to achieve the defined customer benefit (highway miles driven).

The compositional data and application rate for the friction modifier package is confidential but was provided to NSF International as part of the verification. It generally consists of a Kerocom® friction modifier and a solvent package. The overall usage amount of the friction modifier package is determined by the overall gasoline consumption required to achieve the defined customer benefit.

6.1.2. Fuel Efficiency Testing

The key environmental benefit of friction modifiers would be in the increased fuel economy for the vehicle. In order to determine scientifically if there is any fuel economy benefit of using friction modifiers in gasoline, specific tests measured under controlled conditions in a laboratory using standardized test procedures as specified by federal law were conducted. For this study, the Highway Fuel Economy Test Cycle (HWFET) was utilized for the test. The HWFET cycle is a chassis dynamometer driving schedule, developed by the US EPA for the determination of fuel economy of light duty vehicles. The fuel economy results are calculated via a carbon balance method dictated by the EPA vehicle emissions certification protocol. The fleet of light duty vehicles utilized in the test supporting this study is identified in Table 1 below.

Light Duty Vehicles Tested in HWFET Cycle					
Light Duty Vehicle	Year	Engine	Dynamometer Inertia Weights (pounds)	Odometer Miles	Km
Chrysler PT Cruiser	2009	2.4L	3625	3,519	5,630
Mazda 3	2009	2.0L	3125	5,756	9,210
Mazda 3	2009	2.0L	3125	10,630	17,008
Toyota Camry	2009	2.4L	3750	14,334	22,934
Honda Accord	2009	2.4L	3750	20,231	32,370
Toyota 4Runner	2008	4.0L	4750	16,605	26,568
Chevrolet Malibu	2008	2.4L	3625	13,011	20,818
Pontiac G6	2009	3.5L	3625	1,613	2,581

Table 1: Light Duty Fleet Vehicles Tested in HWFET Cycle

The specific fuel economy values for each fleet vehicle, the exhaust gas composition (e.g. CO_2 emissions) as well as calculated standard deviations were not included in this report but were provided directly to NSF International for their review. In summary, vehicles that utilized gasoline additized with friction modifiers on average were able to increase their relative fuel economy by 1.17%. If the detergency levels of the gasolines used for each alternative are the same, it's expected that the overall quality of the engine exhaust would be the same with the only variation being the CO_2 concentration, which is the primary input parameter for the fuel economy calculation (efficiency). As expected, the automobiles which utilized friction modifiers were able to reduce CO_2 emissions by 1.16% (weight %) when compared to automobiles which used the base gasoline. The measured fuel economy increase and CO_2 emissions reduction improvements are statistically significant, as the measured test data and standard deviation calculations for the eight test vehicles in Table 1 showed a greater than 95% confidence level.

Note that the results used as the basis for this analysis are specific to the tests described above and performed for this specific fleet of vehicles. Results may vary depending on the individual cars selected, the specific test conditions, the base fuel selected and the composition and dosage amounts of the fuel additives. However, the project team felt that the selected fleet vehicles would provide representative results for the broader automobile landscape.

The eco-efficiency analysis assumes that other real world factors that impact fuel economy are equal for purposes of comparing the alternatives. These variables would include driving behavior, weather, traffic conditions, condition of highway and age and condition of the tires, to name a few.

6.2. Life Cycle Costs

The direct economic impact of enhanced fuel economy is purchasing less gasoline in order to travel a fixed distance. For this analysis, life cycle costs were built up for each alternative which included the cost of fuel and the cost of the additive packages (both detergent and friction modifiers).

Fuel costs were based on the national average paid at the pump ($3.51)[9] for regular gasoline while costs for the additive packages/components were provided directly by the producer (BASF)[10].

6.3. Further Assumptions

6.3.1. Engine Exhaust

In order to accurately calculate the fuel economy numbers for the various fleet vehicles undergoing the tests, the carbon (e.g. CO_2, CO etc.) in the engine exhaust is measured and a correlation[11] is made in order to determine the vehicles's fuel economy. Fuel economy calculations calculated from exhaust emissions are those mandated by the EPA in 40 CFR 600.113-88. However, in order to determine the full environmental impact of the engines exhaust, it is important to model all the constituents being emitted into the atmosphere. As each alternative will have different fuel economy figures, the emissions related to the production and consumption of gasoline is a significant differentiator between the alternatives. Table 2 below summarizes the basis for the emissions figures for the major emissions from the production / transport / use of gasoline.

Standard Fuel Production & Consumption - Emissions		
Particulates	mg/MJ gasoline	60
Carbon Monoxide (CO)	mg/MJ gasoline	700
Carbon Dioxide (CO2)	mg/MJ gasoline	66,130
SOx	mg/MJ gasoline	200
NOx	mg/MJ gasoline	860
Methane	mg/MJ gasoline	240
Non-Methane VOCs	mg/MJ gasoline	430

Table 2: Standard Emission Data – Gasoline Production, Transport & Use

7. Data Sources

The environmental impacts for the production, use, and disposal of the various 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. Overall, the quality of the data was considered medium-high to high. None of the eco-profiles data were considered to be of low data quality. A summary of the eco-profiles is provided in Table 3.

Eco-Profile	Source, Year	Comments
Kerocom® PIBA	2009	BASF Data
Carrier Fluid	2011	BASF Data
Corrosion Inhibitor	2010	BASF Data
Emulsifier	2002	BASF Data
Friction Modifier	2011	BASF Data
2-Ethylhexanol	1996	BASF Data
Gasoline Production and Use	US Avg., 1999	Most reliable profile available[7]
Xylene	Europe Avg., 1998	APME
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.		

Table 3: Eco-profile Data Sources

8. Eco-efficiency Analysis Results and Discussion

8.1. Environmental Impact Results:

The environmental impact results for the Friction Modifiers for Gasoline EEA are generated as defined in Section 6 of the BASF EEA methodology. In addition, and as noted in section 6.1, differential input values were used when comparing the alternatives. This was aligned with the stated goals and scope of the study. Considering this approach, the key differences between the alternatives are (1) incremental increase in amount (weight) of gasoline used due to fuel efficiency differences between the alternatives and (2) amount (weight) of friction modifier package used. The environmental results presented below in sections 8.1.1 through 8.1.9 are primarily driven by these two differences.

8.1.1. Primary energy consumption:

Consistent with the differential approach presented earlier in section 6.1, energy consumption, considered over the entire life cycle and depicted in Figure 7, shows that gasoline without friction modifiers uses significantly more energy over the defined life cycle. In comparison, the energy required to produce the friction modifiers is approximately 126 MJ of energy while the savings achieved through better fuel economy resulted in 2852 MJ, over a 20:1 ratio.

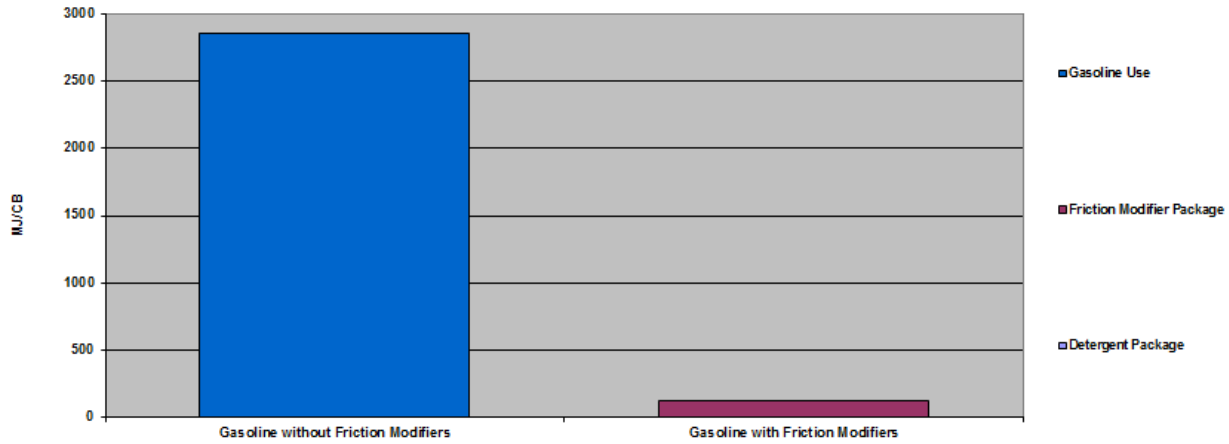

Figure 7: Primary Energy Consumption

8.1.2. Raw material consumption:

Figures 8 shows that the key driver for the raw material or resource consumption category is the extra gasoline required for the gasoline without friction modifiers alternative. Lower fuel economy requires more resources to be consumed over the life cycle. Similar to the energy consumption category the ratio of resources saved by the addition of friction modifiers is approximately 25:1. In fact, the 1.8 kg of friction modifier package was able to save 60 kg of gasoline over the 68,460 highway miles driven by an automobile over its lifetime.

Per the BASF EEA Methodology, individual raw materials are weighted according to their available reserves and current consumption profile. This methodology and the weighting factors used are appropriate considering the context of this study. As to be expected and indicated in Figure 9, oil is the most significant resource consumed followed by natural gas.

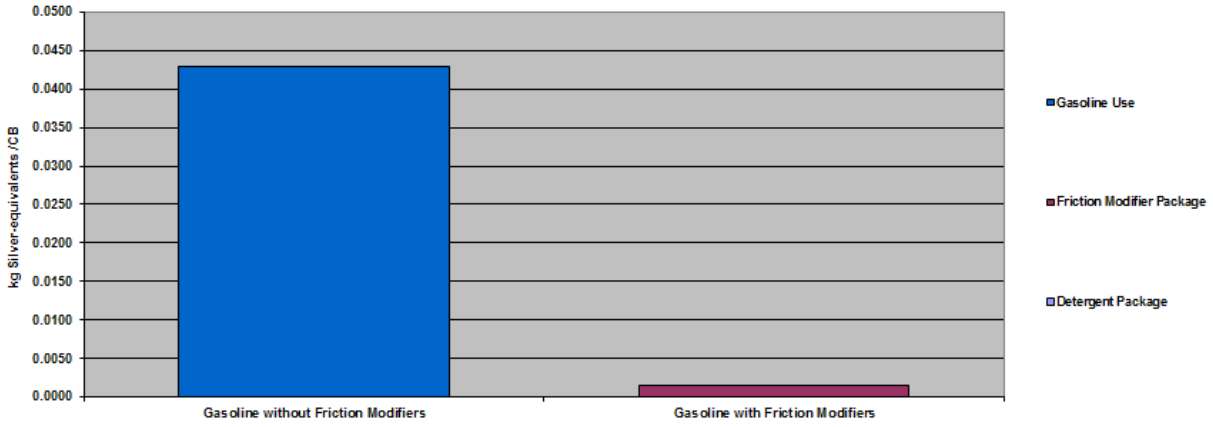

Figure 8: Raw Material Consumption by Module

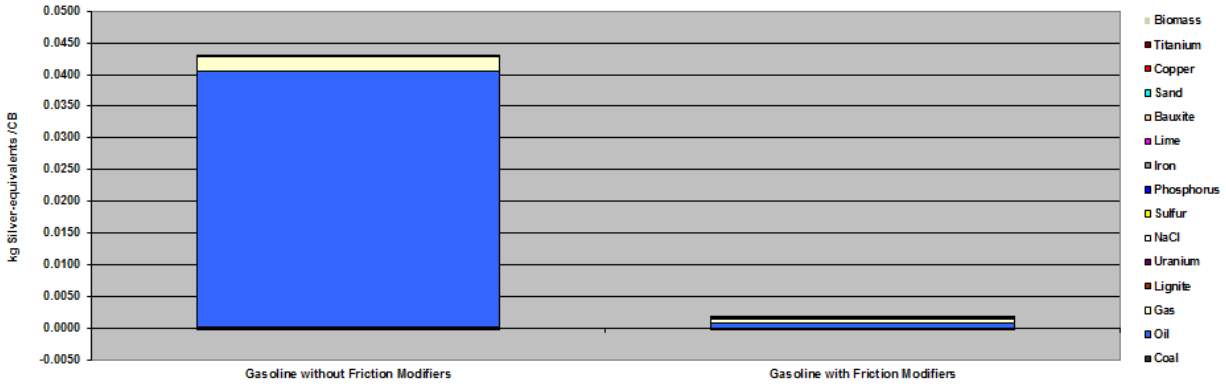

Figure 9: Raw Material Consumption by Type

8.1.3. Air Emissions:

8.1.3.1. Global Warming Potential (GWP):

Figure 10 shows that the highest global warming potential (carbon fingerprint) occurred in the gasoline without friction modifiers with a value of 187.5 kg of CO_2 equivalents per customer benefit. Production of the friction modifiers resulted in emissions of around 3.1 kg of CO_2 equivalents per customer benefit. The gasoline with friction modifiers was able to save the GHG emissions from the production and combustion of over 22 gallons (83.3 liters) of gasoline over the life time of the automobile. This is savings multiplier of over 60x based on the greenhouse gas emissions required to produce the friction modifiers.

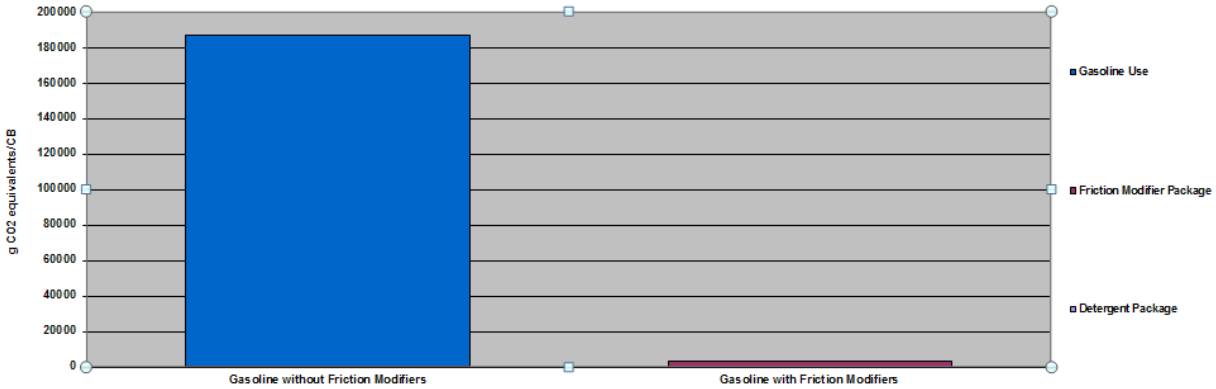

Figure 10: Greenhouse Gas Emissions

8.1.3.2. Photochemical ozone creation potential (smog):

The lowest contributor to ground level ozone creation potential occurs for the gasoline with friction modifiers, with a value of 2.68 g ethylene equivalents/CB. Figure 11 shows that POCP is highest for gasoline without friction modifiers alternative (1.12 kg ethylene equivalents/CB) because of the resulting emissions from the production and use of extra gasoline.

Combustion of the additional fuel contributes to the emissions of methane and non-methane VOCs, two key smog contributors. In adddition, nitrogen oxides produced in the emissions of vehicle exhausts can also contribute to formation of photochemical ozone (smog). Photochemical ozone creation potential is the most relevant air emission for this study.

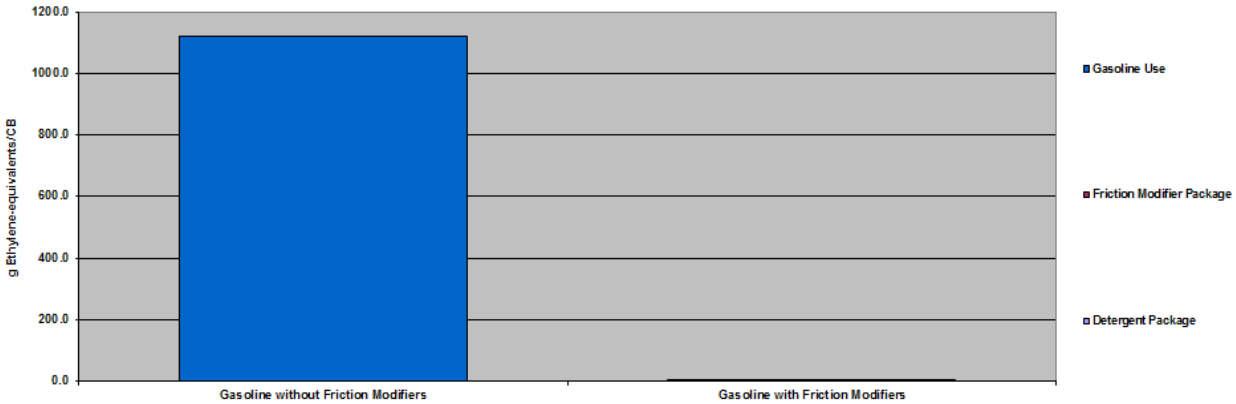

Figure 11: Photochemical Ozone Creation Potential (POCP)

8.1.3.3. Ozone depletion potential (ODP):

All of the alternatives result in a minimal ozone depletion potential, measured at about 1.5 mg CFC-11 equivalents per customer benefit for the alternative which utilized friction modifiers. Figure 12 indicates that the ODP comes predominately from the pre-chain chemistries involved in the precursor materials used in the friction modifiers. Overall, ODP is the least relevant air emission and accounts for less than 0.01% of the total environmental impact for each of the systems.

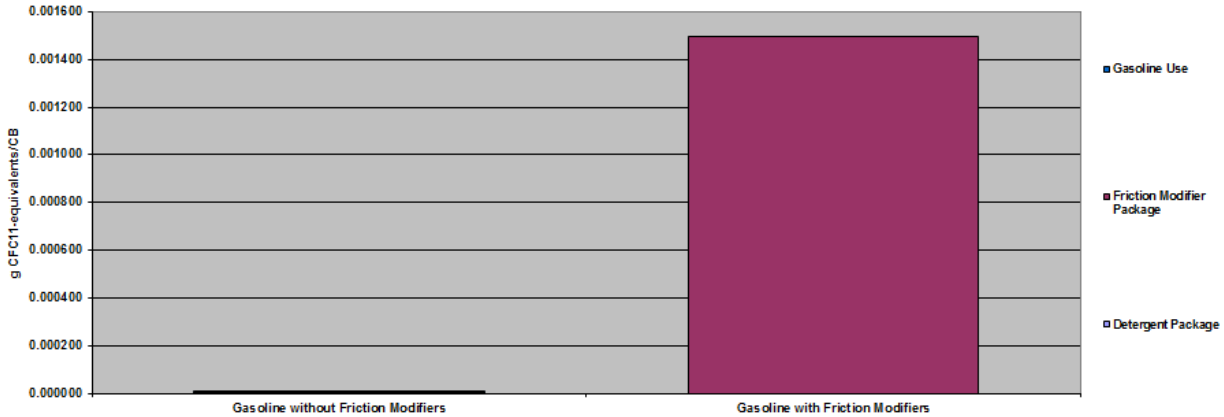

Figure 12: Ozone Depletion Potential

8.1.3.4. Acidification potential (AP):

It can be seen from Figure 13 that overall, gasoline with friction modifiers has a significantly lower acidification potential over the entire life cycle than the other alternative. With emissions of around 2080 g of SO_2 equivalents per customer benefit, the gasoline without friction modifiers has the highest

acidification potential. Gasoline with friction modifiers emitted only 14.3 g of SO_2 equivalents per customer benefit. This large difference in acidification potential resulted primarily from the NO_x and SO_x generated during the burning of the gasoline during the driving of the automobile.

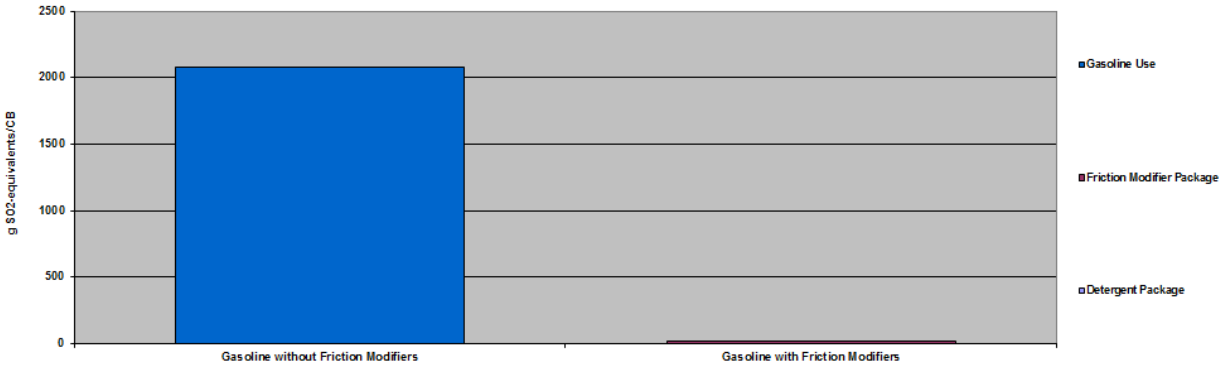

Figure 13: Acidification Potential.

Utilizing the calculation factors shown in Figure 28, Figure 14 shows the normalized and weighted impacts for the four air emissions categories (GWP, AP, POCP and ODP) for each alternative. The gasoline without friction modifiers alternative scored highest in the GWP, AP and POCP categories. The ODP category was not considered relevant for this study.

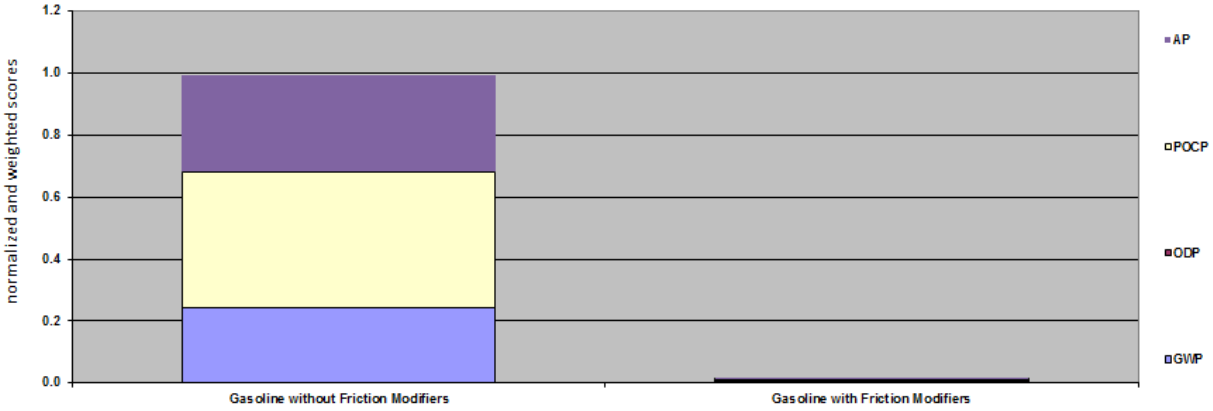

Figure 14: Overall Air Emissions

8.1.4. Water emissions:

Figure 15 displays that the overall water emission is highest for the gasoline alternative without the friction modifier package. This is driven by the increased water emissions from the production and use of the extra gasoline. Specific water emissions are attributed mostly to hydrocarbons but also to COD and BOD emissions. Gasoline without friction modifiers alternative scored an impact of over 3,000 liters of grey water equivalents/CB while the gasoline with friction modifiers alternative scored an impact of 532 liters of grey water equivalents/CB.

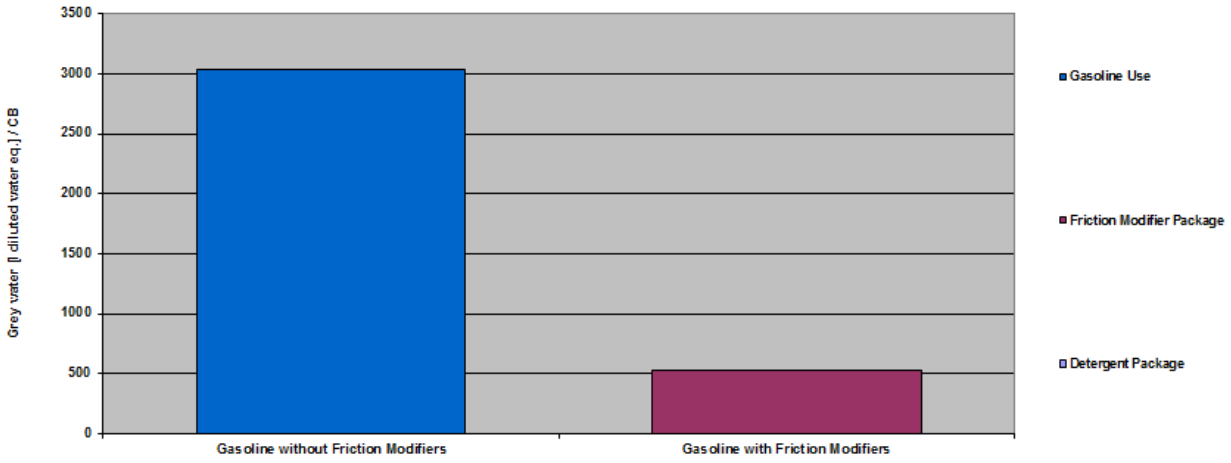

Figure 15: Water Emissions

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 16 and are mostly the result of the special waste generated during the production of the gasoline. Gasoline without friction modifiers contributed the highest impact of over 1.42 kg of municipal waste equivalents. Gasoline with friction modifiers reduced solid waste emissions over the life cycle with a resulting emission of around 34 gram equivalent of municipal waste.

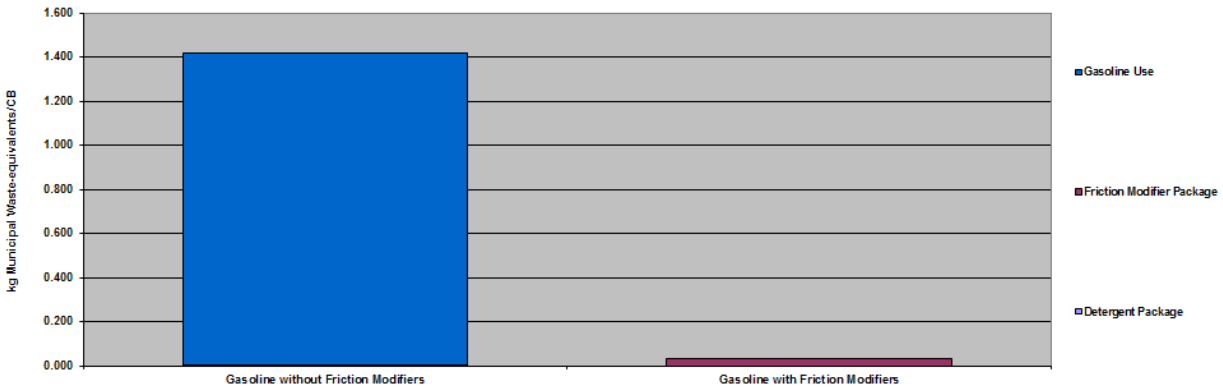

Figure 16: Solid Waste Generation

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 17. The gasoline without friction modifiers alternative clearly scored the highest in each of the three categories.

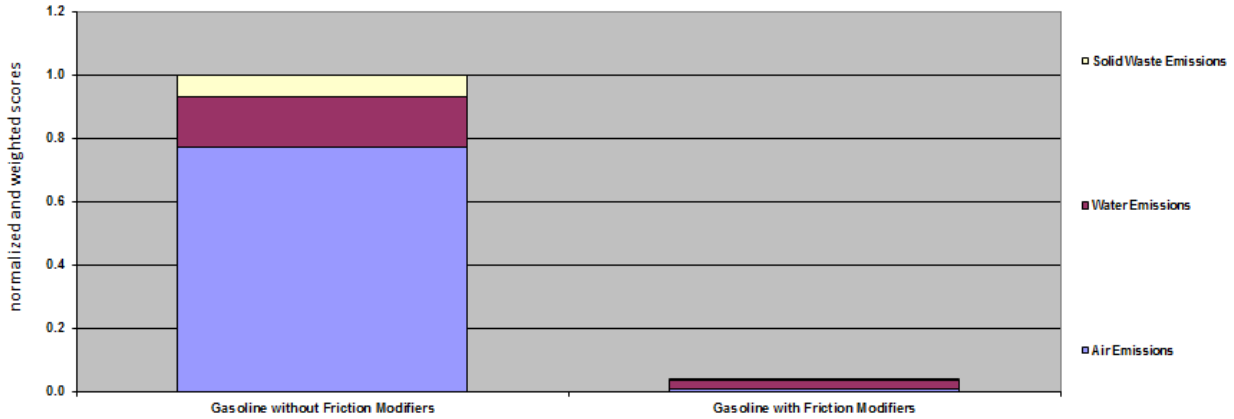

Figure 17: Overall Emissions Scores

8.1.6 Land use*:*

As displayed in Figure 18, the extra gasoline required to make up for the differences in fuel economy between the alteratives was the key contributor to the land use category. Through promotion of better fuel efficiency, the gasoline alternative with friction modifiers accounted for the lowest impact in land use, 0.19 m^2*yr per customer benefit vs. over 105 m^2*yr for the gasoline without friction modifiers alternative.

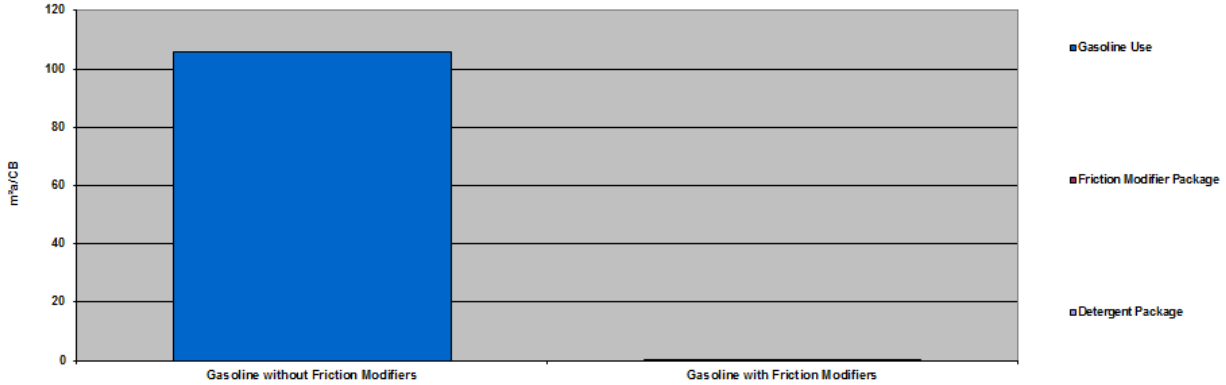

Figure 18: Land Use

8.1.7 Toxicity potential*:*

The toxicity potential for the various gasoline 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 use (combustion) of the gasoline. Toxicity potential in the Disposal phase was negligible for both alternatives. 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 BASF's EEA 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 19 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 the standard weightings.

As to be expected the major influencing factor was the fuel economy differences between the alternatives. Gasoline without friction modifiers required more gasoline to be produced and used over the life cycle. The toxicity potential related to the production and use of the gasoline far outweighed that of the friction modifiers. Though the toxicity points for production of gasoline and the friction modifiers are similar, the quantity of material produced is much different. As noted in section 8.1.2 (Raw material consumption) only 1.8 kg of friction modifiers was required and it resulted in the savings of over 60 kg of gasoline.

Figure 20 shows how the scoring is distributed across the life cycle stages. The toxicity potential of all modules that occur during the production phase of the life cycle are aggregated in the SUM Production module. This aggregation is also done for the use phase (SUM Use) and disposal phase (SUM Rec./Disp.).

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 and the vapor pressure of the materials. 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.

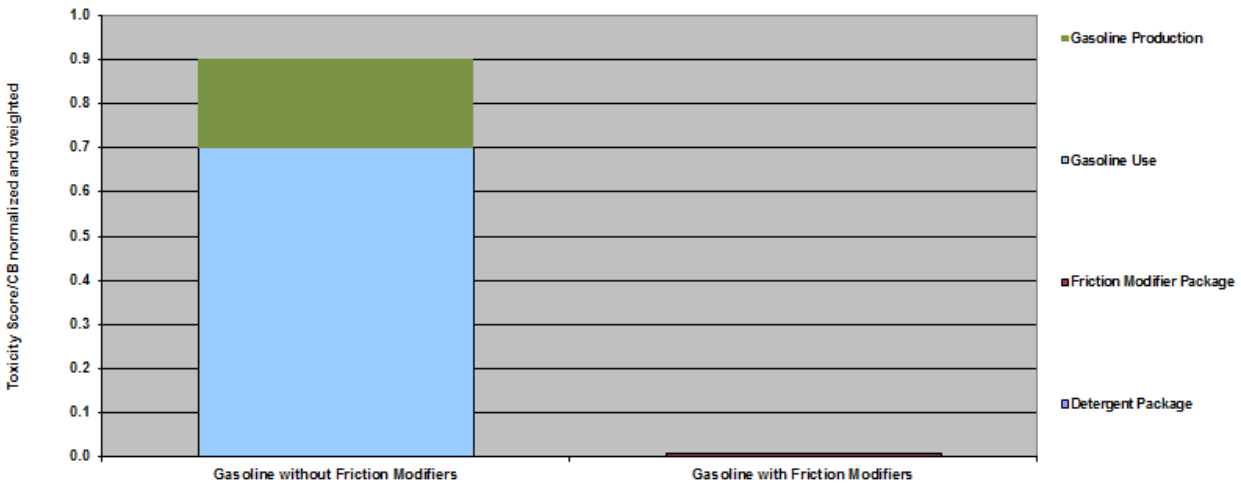

Figure 19: Toxicity Potential – Modules

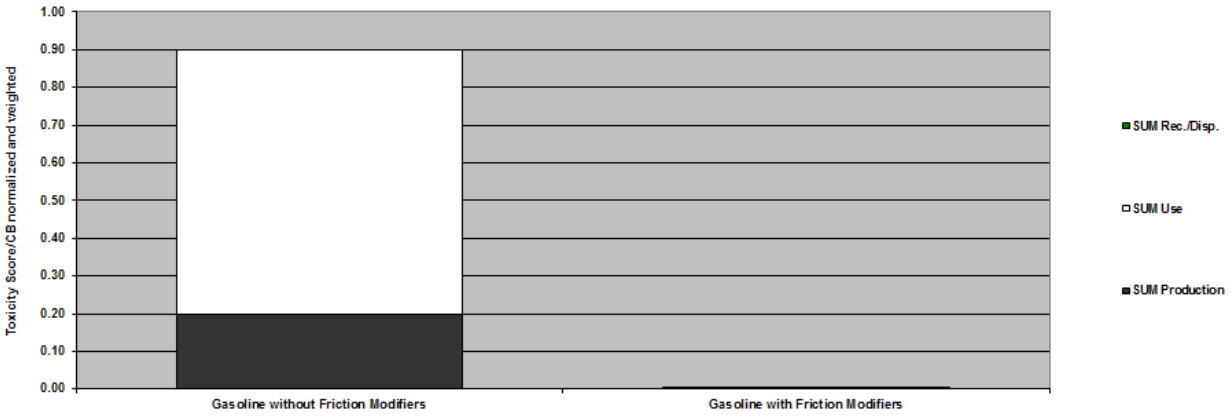

Figure 20: Toxicity Potential- Life Cycle Phases

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[12]. 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, 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 21, the greatest Occupational Illnesses and Accident potential occurs for the gasoline without friction modifiers. The module which contributes to the highest risk potential for occupational illnesses and accidents is gasoline usage. This is to be expected as the extra gasoline usage by the alternative without friction modifiers is the single largest resource consumed over the life cycle. As previously discussed in section 8.1.2, 60 kg of extra gasoline was required to be produced and consumed for alternative one in order to compensate for the lower fuel economy. The risks associate with the production of the friction modifiers package was about 40% of the total risk for gasoline usage.

As depicted in Figure 22, occupational diseases were the most relevant risk category for each alternative. No unique risk categories were identified for this study so the standard weighting between working accidents and occupational diseases was maintained.

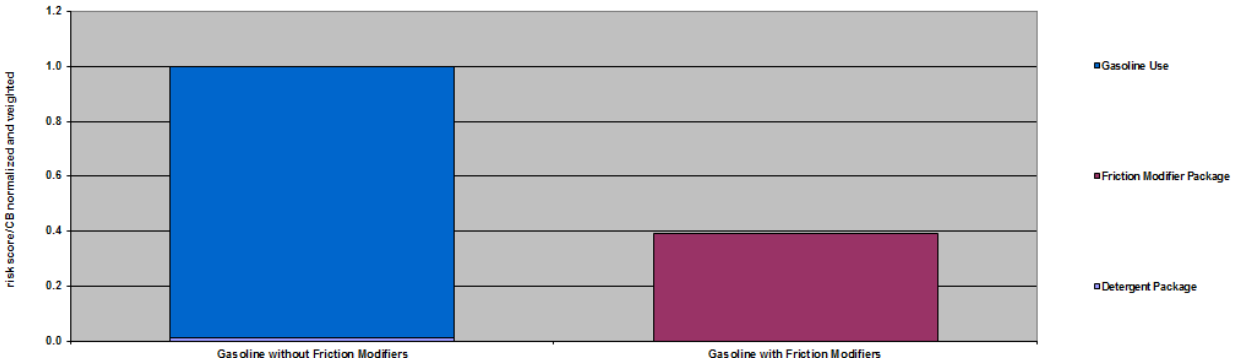

Figure 21: Risk Potential (Occupational Illnesses and Accidents) – per Module

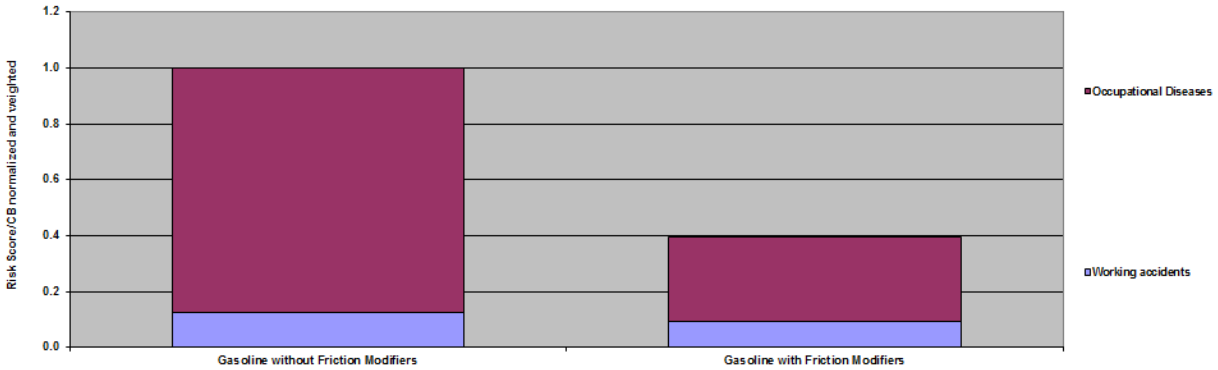

Figure 22: Risk Potential – per Impact Category

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 23). The gasoline without friction modifiers package clearly had the highest environmental impact on a weighted basis in all of the main categories. As disscused previously in the individual impact categories, the higher life cycle impacts is directly related to the lower fuel economy which required more

gasoline production and usage. The environmental impact savings related to this significantly outweigh the environmental impacts (investment) required to produce the friction modifiers. The environmental fingerprint clearly shows that there is a strong environmental value proposition for fuel additives, such as friction modifiers, which can deliver measurable improvements in fuel economy as the impacts to produce them are clearly trumped by the environmental savings achieved through their use.

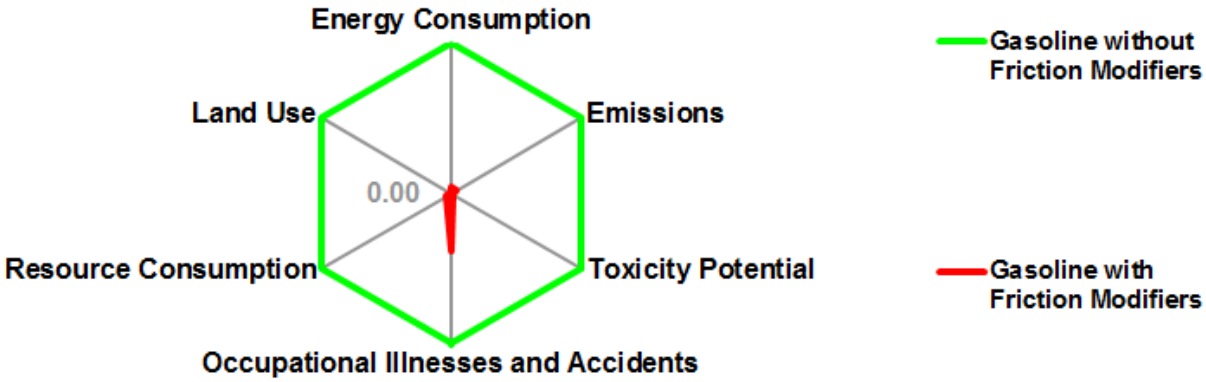

Figure 23: Environmental Fingerprint

8.2. *Economic Cost Results*:

The life cycle cost data for Friction Modifiers for Gasoline EEA are generated as defined in Section 7 of the BASF EEA methodology and described in Section 6.2 above. The results of the life cycle cost analysis based on a present value approach (PV) are depicted in Figure 24 and demonstrate that the alternative with the lowest life cycle costs was the gasoline with friction modifier package. Differences in overall life cycle costs were driven predominately by the cost associated with the extra gasoline required for the alternative with the lower fuel economy. In relation to the extra fuel cost ($76.50/CB) the friction modification package only cost around $4.5/CB. Because of the extra fuel consumed for the alternative without friction modifiers, additional detergent package costs were incurred for the gasoline without friction modifier alternative ($0.03/CB). Overall, this study clearly shows that there is significant financial incentive for the inclusion of friction modifiers in gasoline, which can demonstrate measurable increases in fuel economy. The cost to savings ratio is roughly 17:1 for friction modifiers.

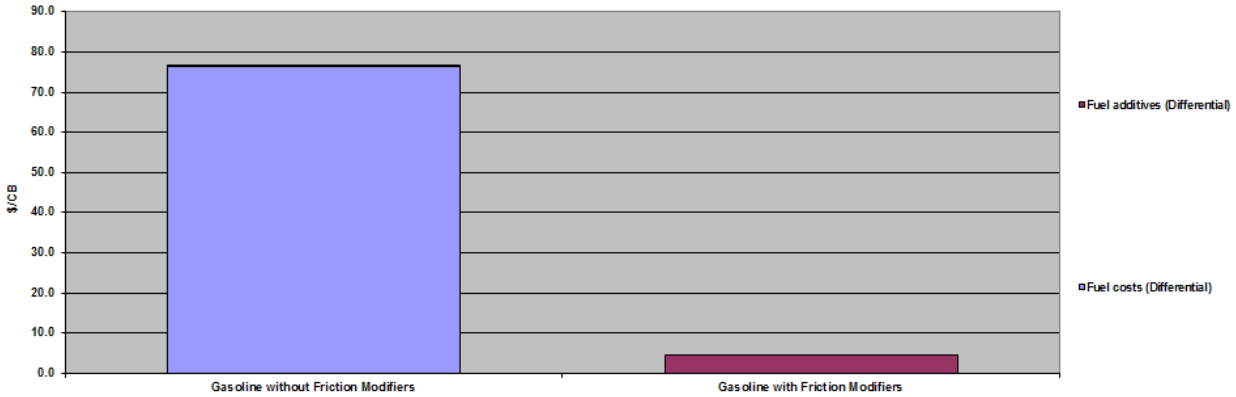

Figure 24: Life Cycle Costs - Modules

8.3. Eco-efficiency Analysis Portfolio:

The eco-efficiency analysis portfolio for the Friction Modifiers for Gasoline 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 2009 and the social weighting factors were recently updated in 2009 by an external, qualified third party organization[8].

Figure 25 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 clearly that the gasoline with the friction modifier package is the most eco-efficient alternative due to its combination of significantly

lower environmental burden and significantly lower life cycle costs.

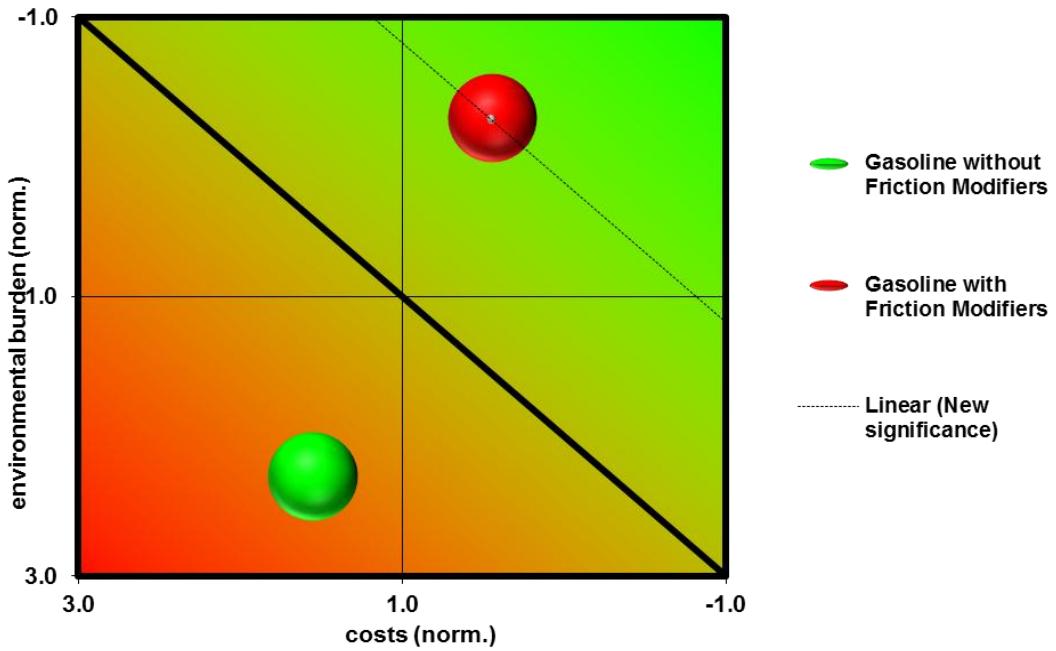

Figure 25: Eco-efficiency Portfolio – Friction Modifiers for Gasoline

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 4 provides a summary of the data quality for the EEA.

Parameter	Quality Statement	Comments
Fuel Additives Packages		
Detergency Package	High	Known formulations from manufacturer. Eco-profiles developed specifically for this study are based on current technologies and company data.
Friction Modifiers Package	High	Known formulations from manufacturer. Eco-profiles developed specifically for this study are based on current technologies and company data.
Fuel Economy Test	High	Standardized Government Test procedure. 40 CFR 600.113-88
Costs		
Fuel Additives Packages	High	Supplier provided data. Current 2012.
Gasoline	Moderate-High	Current price for region of study. Assumed value is reasonable given study context and goals.

Table 4: Data Quality Evaluation for EEA Parameters

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:

- Application rate of Fuel Additives
- Fuel Economy Test Results

As the data quality related to these main contributors was of high quality, this strengthened our confidence in the final conclusions indicated by the study. A closer look at the analysis (see Figure 26) indicates that the impact with the highest environmental relevance was the emissions category (air specifically) followed by toxicity potential and resource consumption. This is to be expected, as the previous discussions showed the extra quantity of gasoline produced and the emissions related to its use were the main environmental drivers.

Air and water emissions are by far the most important in the emissions category. More specifically, AP and GWP are considered the two most important air emissions, which is normally the case when the combustion of fossil fuels is a main driver.

The calculation factors (Figure 28), 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 23) into the final, single environmental score as reflected in our portfolio (Figure 25). 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 (Figure 27) only had a minor influence in adjusting the relative weightings of a few impact categories represented in the emissions and air emissions sub-categories. Higher societal relevance for water and solid waste emissions helped increase their respective weighting relative to air emissions. Likewise, GHG emissions received the highest societal relevance in the air emissions category and thus increased its respective weighting relative to all the other air emissions.

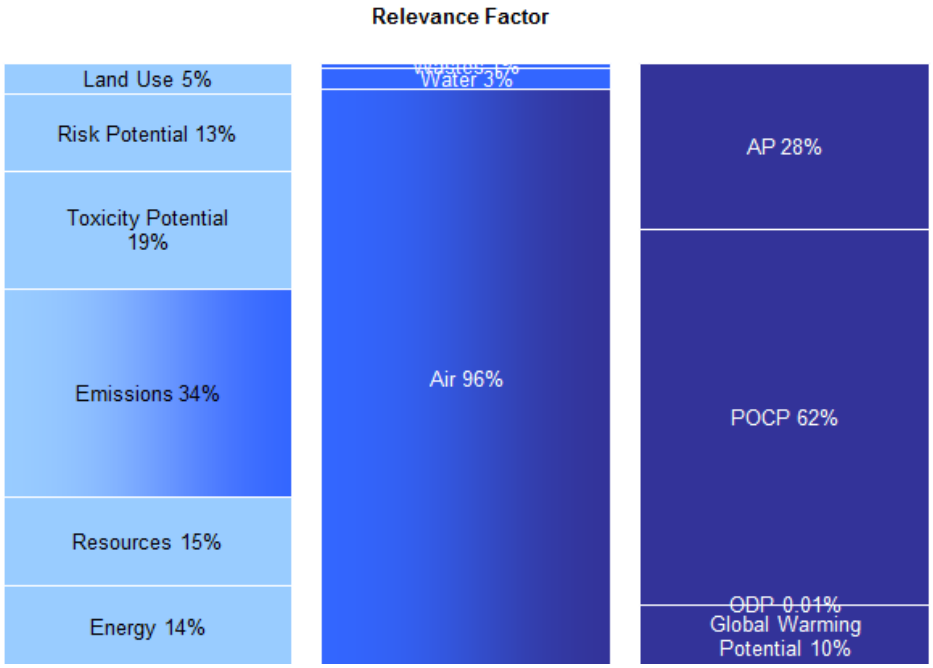

Figure 26: Environmental Relevance Factors that are used in the Sensitivity and Uncertainty Analyses

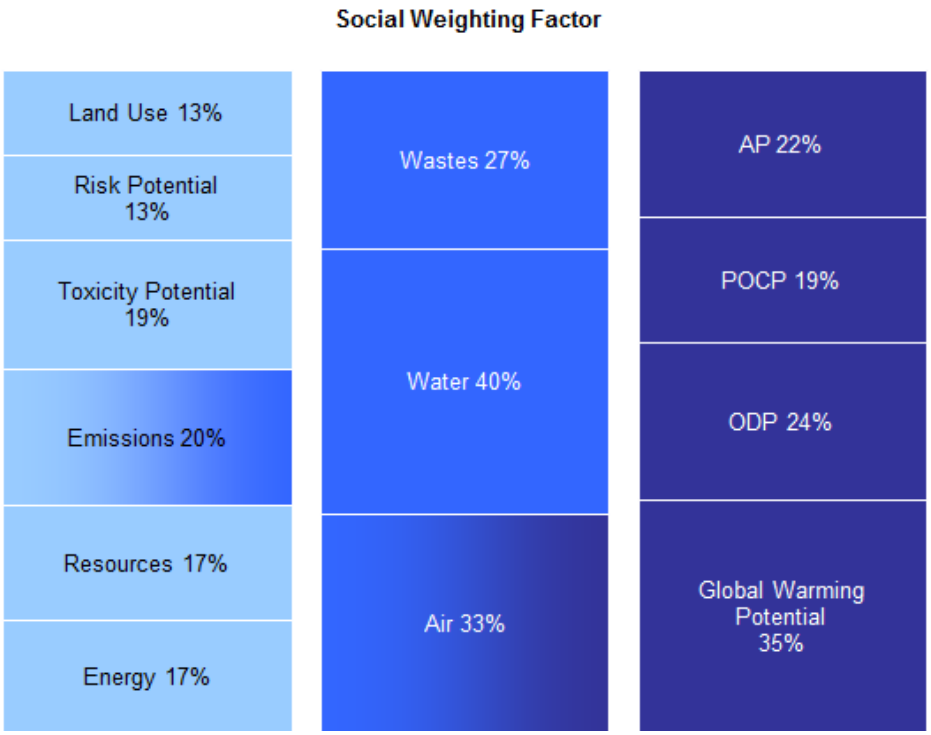

Figure 27: Social Weighting Factors that are used in the Sensitivity and Uncertainty Analyses

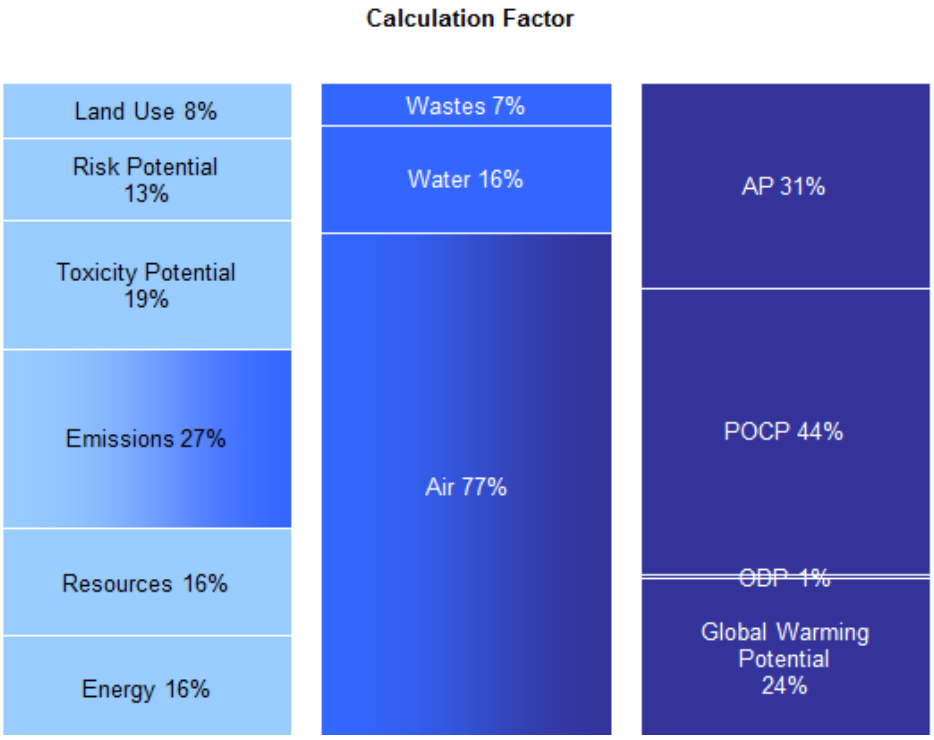

Figure 28: Calculation Factors that are used in the Sensitivity and Uncertainty Analyses

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

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

[1] Keropur® technical brochure EVO1104e. BASF SE Automotive and Refinery Chemicals February 2011. www.basf.com/keropur

[2] Vehicle Survivability and Travel Mileage Schedules DOT HS 809 952 Technical Report January 2006 publisher: NHTSA's National Center for Statistics and Analysis. Page 2.

[3] http://www.fhwa.dot.gov/ohim/onh00/bar8.htm. Bar Chart. US DOT FHWA. Office of Highway Policy Information. Updated April 4, 2011

[4] Fuel Economy Labelling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates. EPA420-R-06-017 December 2006. US EPA Office of Transportation and Air Quality. Page 8.

[5] http://www.epa.gov/otaq/fuels/basicinfo.htm US Environmental Protection Agency website

[6] http://www.epa.gov/otaq/fuels/registrationfuels/registeredfuels.htm US Environmental Protection Agency website. List of Registered Fuels and Fuel Additives.

[7] Boustead Consulting Ltd UK, The Boustead Model 5.1.2600.2180 LCA database

[8] TNS Infratest Landsberger Strasse 338 Munich Germany 80687

[9] AAA (American Automobile Association) website http://fuelgaugereport.aaa.com/?redirectto=http://fuelgaugereport.opisnet.com/index.asp which is provided daily updates from the Oil Price Information Service (OPIS) http://www.opisnet.com/.
12 month average national price for self-serve, regular unleaded gas. Price as of 6/1/12.

[10] BASF Product Marketing Manager, Automotive Fuel Additives. Prices as of February 2012

[11] Fuel economy calculations for FTP, HFET, US06, SC03 and cold temperature FTP tests. Electronic Code of Federal Regulations (e-CFR™). National Archives and Records Administration. http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=da4578e9ab40db2b7b84f6d56b477e10&rgn=div8&view=text&node=40:30.0.1.4.43.2.13.8&idno=40

[12] European Commission, eurostat http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:Statistical_classification_of_economic_activities_in_the_European_Community_(NACE)

[13] United States Environmental Protection Agency (US EPA); Testing and Measuring Emissions http://www.epa.gov/nvfel/testing/index.htm