

**Submission for  
NSF Protocol P352  
Validation and Verification of Eco-efficiency  
Analyses, Part A.**

**BASF's Eco-Efficiency Analysis Methodology  
May 2009**



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## 1. Purpose and Intent of this Submission

- 1.1. The purpose of this submission is to establish BASF Corporation's methodology for performing Eco-efficiency Analyses for the intent of having it validated under the requirements of NSF Protocol P352, Part A: Validation of an Eco-Efficiency Analysis Methodology.
- 1.2. It is the intent of BASF Corporation to use the same validated eco-efficiency model to conduct several individual eco-efficiency studies and have those studies submitted to NSF for verification under NSF Protocol P352, Part B: Verification of Eco-Efficiency Analysis Studies.

## 2. Content of this Submission

- 2.1. This submission specifies the minimum content of an Eco-Efficiency Analysis (EEA) conducted in accordance with BASF Corporation's EEA (BASF EEA) methodology, and includes the environmental and economic parameters considered, the weighting and normalization procedures to quantify the environmental burden (environmental footprint) and economic costs (life cycle costing), as well as the process by which the data are evaluated for appropriateness and quality, followed by the options for presenting results and conclusions.
- 2.2. As required under NSF P352 Part A, BASF is submitting both a written document describing the elements of the BASF EEA methodology, and a computerized model that incorporates these elements into a working system. Enclosed with this document is BASF\_EEA\_Mastersheet.xls that is the computerized model programmed in Microsoft<sup>®</sup> Excel.

## 3. BASF's EEA Methodology

- 3.1. *Overview:* The process for performing a BASF EEA has been previously published<sup>(1,2)</sup> and it involves measuring the life cycle environmental impacts and life cycle costs for product alternatives for a defined level of output. In other words, a BASF EEA evaluates both the economic and environmental impacts that products and processes have over the course of their life cycle. The methodology was created by BASF, in partnership with an external consultant, and has since been further developed. BASF EEA is based upon the ISO 14040<sup>(3)</sup> standard for life cycle analyses, however in addition to this standard, it includes additional enhancements that allow for the expedient review and decision-making at all business levels. Since its inception in 1996, BASF has completed nearly 400 analyses on a wide variety of products and processes. At a minimum, BASF EEA evaluates the environmental impact of the production, use, and disposal of a product or process in the areas of energy and resource consumption, emissions, toxicity and risk potential, and land use. The EEA also evaluates the life cycle costs associated with the product or process by calculating the costs related to, at a minimum, materials, labor, manufacturing, waste disposal, and energy. While NSF Protocol P352 allows applicants the flexibility to implement eco-efficiency analysis studies based upon specific requirements, the overall procedure for the BASF EEA methodology is shown in Figure 1.

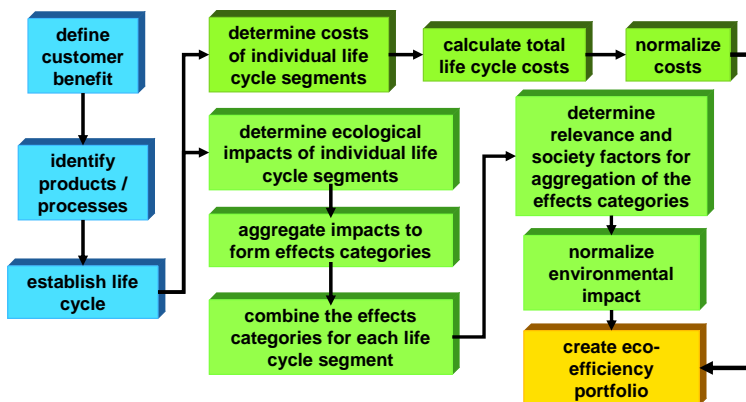


Figure 1: Overall process flow for BASF EEA methodology.

- 3.2. *Preconditions:* The basic preconditions in BASF EEA are as follows: 1) products or processes studied have to meet the same defined functional unit (aka customer benefit), 2) the entire life cycle is considered, and 3) both an environmental and an economic assessment are carried out.
- 3.3. *Work Flow:* A BASF EEA is worked out by following specific and defined ways of calculations: 1) calculation of total cost from the customer viewpoint, 2) preparation of a specific life cycle analysis for all investigated products or processes according to the rules of ISO 14040 ff, 3) determination of impacts on the health, safety, and risks to people, 4) assessing use of area over the whole life cycle, 5) calculation of relevance and calculation factors for specific weighting, 6) weighting of life cycle analysis factors with societal factors, 7) determination of relative importance of ecology versus economy 8) creation of an eco-efficiency portfolio, and 9) analyses of appropriateness, data quality, and sensitivities.

#### 4. Study Goals, Decision Criteria, and Target Audience

- 4.1. *Study Goals:* The starting point for a BASF EEA is to determine the specific goals for that study, which provides the context to define the target audience, alternatives for the study and its system boundaries. Also, the criteria for decision making is defined based upon consideration of economies, markets, and innovations. Figure 2 shows the conceptual diagram of study goals, target audience and context for decision criteria with the BASF EEA methodology.
- 4.2. *Context:* Development of the study goals and context for decision criteria includes defining the following, which are shown conceptually in Figure 2:
- 4.2.1. *Study Drivers*, e.g. R&D decisions, capital investment, market differentiation, process optimization, quantify benefits of the sustainable changes made to products, regulatory issues, response to green-washing claims, etc.;
- 4.2.2. *Target audience*, e.g. customers, regulators, consumers, academics, non-governmental organizations, etc.;
- 4.2.3. *Engagement*, e.g. internal use only, supplier/customer, or external use

- 4.2.4. *Geography*, e.g. global, regional, or local
- 4.2.5. *Product/Market*, e.g. 1 product/1 market, few products/1 market, 1 product/few markets, all products/all markets
- 4.2.6. *Time horizon*, e.g. 3 years, 10 years, 30 years, other
- 4.2.7. *Economy*, e.g. developed, emerging, under developed
- 4.2.8. *Life Cycle*, e.g. full life cycle, post-consumer, consumer, production
- 4.2.9. *Innovation*, e.g. incremental, gap closure, step change

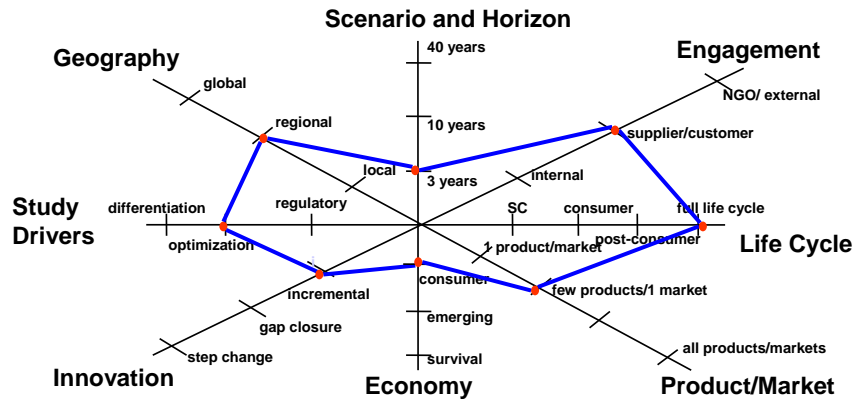


Figure 2: Conceptual diagram of study goals, target audience and context for decision criteria with BASF EEA methodology

## 5. Functional Unit, Alternatives and System Boundaries

- 5.1. *Functional Unit*: The term functional unit is defined in the International Standard ISO 14040 as the “quantified performance of a product system for use as a reference unit in a life cycle assessment.” For BASF EEA the term Customer Benefit (CB) is used as the defined level of output and basis of comparison rather than the term functional unit, however the CB is identical to the functional unit defined in ISO 14040. The CB will be defined specific to each BASF EEA and will take into consideration the elements described in Section 4 and incorporate a life cycle perspective in accordance with ISO 14040, ISO 14041, ISO 14042, and ISO 14043. For example, as discussed in Section 4, the target audience, engagement, geography, market, time horizon, economy, life cycle, and level of innovation should all be considered when selecting the CB. Justification will be provided as to the reasons for selecting a particular CB.
- 5.2. *Alternatives*: These represent the products or processes that will be compared in the BASF EEA, and for each EEA a minimum of two alternatives will be included. The alternatives will be defined specific to each BASF EEA and will take into account the CB, system boundaries and consideration of the elements described in Section 4. Each alternative must be analyzed against the same customer benefit and justification will be provided as to the reasons for selecting particular alternatives.

5.3. *System Boundaries:* The scope of any BASF EEA is defined by its system boundaries, which define the specific elements of raw material extraction, acquisition, transportation, production, use, and disposal that are considered as part of the analysis. BASF EEA considers the entire life cycle but then concentrates on the specific stages in a life cycle where the alternatives under consideration differ. It is important to note that the same life cycle stages must be included when analyzing each alternative. The system boundaries will be defined specific to each BASF EEA and will take into account the CB, alternatives and consideration of the elements described in Section 4 above as well as ISO 14041. Justification will be provided as to the reasons for selecting particular system boundaries. An example of three system boundaries is shown conceptually in Figure 3.

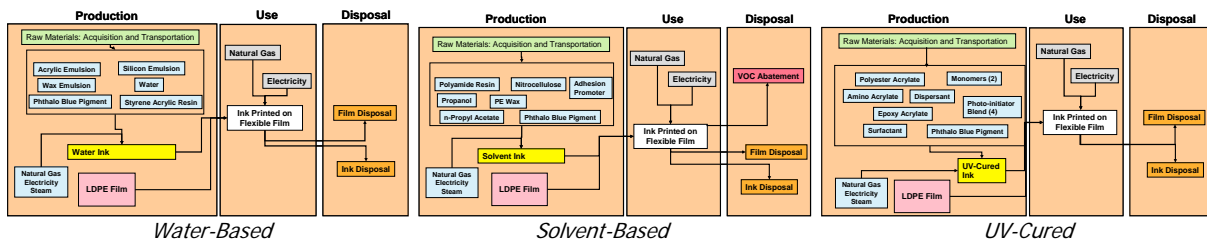


Figure 3. Conceptual diagrams of system boundaries for three technologies.

Process steps for the life cycle that are deemed to be the same, or sufficiently similar, for all alternatives under consideration do not have to be included in the analysis. For example, if the study is comparing three different manufacturing processes for the identical chemical X, then the use and the disposal phases do not have to be taken into account. Expert opinion is used when deciding if process steps can be excluded from the analysis. The written Final Report and/or Final Presentation shall clearly state those process steps that were not included in the analysis and consideration should be given in the data quality assessment as to the impact of exclusion.

## 6. Environmental Burden Metrics

6.1. *Overview:* For BASF EEA environmental burden is characterized using eleven categories, at a minimum, including: primary energy consumption, raw material consumption, global warming potential (GWP), 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 in Figure 4. Metrics shown in yellow represent the six main categories of environmental burden that are used to construct the environmental footprint, burdens in blue represent all elements of the emissions category, and green show air emissions.

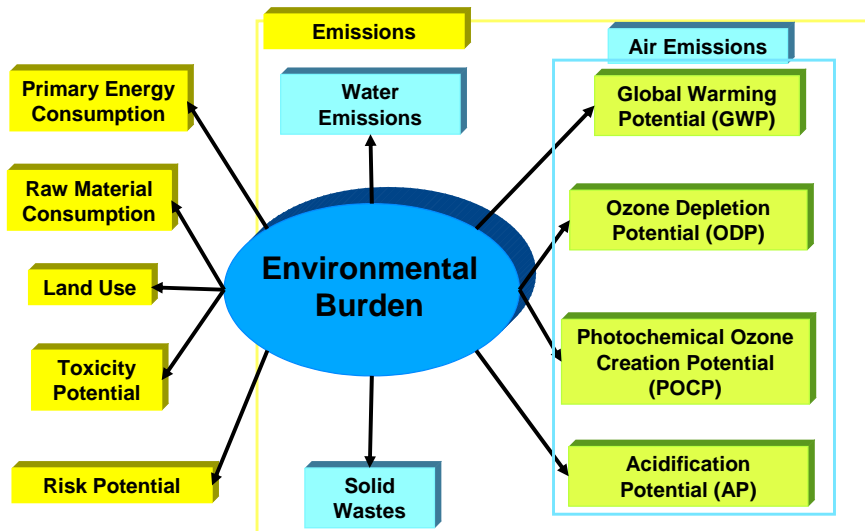


Figure 4: Environmental burden metrics for BASF EEA.

- 6.2. *Primary Energy Consumption*: includes the cumulative energy utilized during production, use, and disposal as well as the energy content remaining in the products. All forms of energy are converted back to their primary energy sources, measured in MJ/CB, and include: crude oil, natural gas, anthracite, lignite, uranium ore, water power, biomass and others. This captures conversion losses from electricity and steam generation. The energies from biomass feedstocks are included; however, not included is the sun energy that is needed to produce the biomass. The individual energy values are summed to obtain the total primary energy consumption to fulfill the CB.
- 6.3. *Raw Material Consumption*: Key raw materials consumed are calculated in terms of kg/CB. Raw materials are defined as the basic building blocks needed to create a product. At a minimum BASF EEA will consider the following raw materials: coal, oil, gas, lignite, uranium, NaCl, sulfur, phosphorus, iron, lime, bauxite, sand, copper, and titanium. These materials are selected as the raw materials to consider because they are the basic starting blocks for a wide range of polymers and products (i.e. coal as a raw material for electricity generation). Additional raw materials will be included as deemed necessary, with justification provided. Although the total raw material consumption is non-weighted, it is calculated as the sum of the individual weighted raw material consumption values needed to fulfill the CB. The weighting of the individual raw material consumption values are determined based on available reserves and demand for the specific materials.
- 6.3.1. Raw material consumption values are weighted with a factor that reflects the demand and exploitable reserves of the raw materials, according to the statistical calculations of the U.S. Geological Survey and other sources, so that the lower the reserves of a raw material and the higher the worldwide rate of consumption, the scarcer that material is and, therefore, the higher the weighting factor it is assigned. See Section 8 for a full discussion of weighting factors applied to raw material consumption. The U.S. Geological Society statistical calculations used in this section are independent of the Land Use environmental burden metric.

- 6.3.2. Renewable resources, which are assumed to have a sustainable system of management and a theoretically unlimited life span, consequently yields a weighting factor equal to zero. A sustainable system of management includes certifications such as the Forest Stewardship Council, Wildlife Habitat Council, and Sustainable Forestry Initiative. Renewable resources are thus considered in the other environmental burden metrics but not in that of raw material consumption. In cases when renewable raw materials are not sustainably managed (e.g., rainforest logging), the appropriate resource factor is applied.
- 6.3.3. The data sources for the demand and exploitable reserves, which are used in calculating the weighting factors, are provided in the Mik-values worksheet of the enclosed BASF\_EEA\_Mastersheet.xls. These sources provide data for how long a particular raw material will remain in production assuming today's economical methods for extraction and assuming that consumption remains constant.
- 6.4. *Air Emissions:* Air emissions are calculated in terms of mass of emissions generated per CB (kg/CB) over the entire life cycle. BASF EEA will consider at a minimum, but not be limited to, the following chemicals: CO<sub>2</sub>, SO<sub>x</sub>, NO<sub>x</sub>, CH<sub>4</sub>, non-methane volatile organic compounds (NM-VOC), halogenated hydrocarbons (HC), NH<sub>3</sub>, N<sub>2</sub>O, and HCl. These chemicals will be grouped and environmental burden reported under the following air emission categories:
- Global warming potential (GWP) - CO<sub>2</sub>, CH<sub>4</sub>, HC, N<sub>2</sub>O, reported as CO<sub>2</sub>-equivalents
  - Photochemical ozone creation potential (POCP) - NM-VOC, CH<sub>4</sub>, reported as ethene equivalents
  - Ozone depletion potential (ODP) - HC, reported as CFC-equivalents
  - Acidification potential (AP) - SO<sub>x</sub>, NO<sub>x</sub>, NH<sub>3</sub>, HCl, reported as SO<sub>2</sub>-equivalents
- 6.4.1. The amount of air emissions are weighted with a factor reflecting their potency regarding the global warming, acidification, smog creation, and ozone depletion potentials, as shown in the Mik-values worksheet of the enclosed BASF\_EEA\_Mastersheet.xls. For example, air emissions for each major greenhouse gas were adjusted for the 100-year GWP as defined by the Intergovernmental Panel on Climate Change<sup>(4)</sup>. See Section 8 for additional discussion of weighting factors applied to air emissions.
- 6.4.2. Whenever significant inputs to the analysis are in the form of biomass, provisions will be made to account for land use change emissions of CO<sub>2</sub>-equivalents. If land use change emissions are not included, it will be clearly stated as an assumption.
- 6.5. *Water Emissions:* Water emissions are assessed through a critical volumes approach, which considers both the total amount of emissions to water, as well as the ecological impact of the chemicals being emitted. The individual critical volumes are then summed for a particular life cycle stage in order to obtain an overall impact (L/CB). At a minimum BASF EEA will consider the following chemicals for water emissions: COD,

BOD, N-total, NH<sub>4</sub> as N, PO<sub>4</sub> as P, adsorbable organically bound halogens (AOX), heavy metals, hydrocarbons (to include detergents and oils), sulfate, and chlorine.

6.5.1. For BASF EEA, critical volumes (CV) are calculated as the ratio of the amount of chemical emitted to the Maximum Emission Concentration (MEC) threshold limits, which are listed in the annex to the German waste water ordinance. The methodology considers total water discharge, which includes water emissions to both wastewater treatment systems and discharges to surface waters. The greater the water hazard posed by a substance, the lower its discharge concentration limit. For example, an emission of 200 mg NH<sub>4</sub>-N with an MEC threshold value 10 mg/L results in a critical volume of 20 L (CV = 200 mg/10 mg/L). Threshold limits are provided in the Mik-values worksheet of the enclosed BASF\_EEA\_Mastersheet.xls. There are no provisions to regionalize or localize the MEC values used in the calculation as it is likely these values are similar across geography, as they are common wastewater constituents with well established toxicity, and doing so would not be expected to significantly improve the accuracy of the results in relation to the high level of effort that would be required to localize the MEC values.

6.6. *Solid Waste Emissions:* In BASF EEA the solid waste emissions account for all materials disposed of in a landfill; therefore, materials that are recycled or reused are not counted as solid waste. Wastes are categorized as municipal, hazardous, construction, and mining; with a weighting factor applied to each type to account for potential impact. For example -- Municipal: household trash; Hazardous -- RCRA definition of hazardous waste; Construction: non-hazardous waste materials generated during building or demolition activities; Mining: non-hazardous earth or overburden generated during raw material extraction activities. The impacts are then summed to obtain an overall impact amount in kg/CB. The weighting factors are 1, 5, 0.2, and 0.04 for each waste category, respectively, and are subjective values intended to reflect the degree of potential environmental impact.

6.7. *Land Use:* BASF EEA allows for the consideration of land use as an environmental impact category based on the degree of land development needed to fulfill the customer benefit. Land use has five categories according to the degree of development that is needed. These categories include: i) No Development – untouched ecosystems, forests, lakes, rivers, wetlands; ii) Partially Developed – organic agriculture, green land, fallow, heterogeneous agriculture; iii) Developed – conventional agriculture, modified areas; iv) Covered – long-term paved areas, industrial areas, landfills, areas with buildings on them; and v) Covered and Divided – long-term paved areas that divide ecosystem areas, transportation areas such as streets, rail tracks, canals. The land use results are calculated based on the total amount of land used (m<sup>2</sup>/CB) for each of the five categories with weighting factors applied to categories iii – v to reflect the higher potential impact for these land uses. The weighting factors for the change from one land use category to another is based on the Hemeroby index, which describes various forms of land use, as well as discussions with the Institute for Applied Ecology (Öko-Institut e.V.). For example, since a change from intensive agriculture to sealed land is considered to be quite serious, this factor was obtained as the square of the factor (i.e. 1.5 squared, which equals 2.25). The weighting factors for land use are provided in the Mik-values worksheet of the enclosed BASF\_EEA\_Mastersheet.xls.

6.8. **Toxicity Potential:** For BASF EEA the toxicity potential is assessed not only for the final products, but for the entire pre-chain of chemicals used to manufacture the products as well. The quantities of each substance to be included in the analysis must be inventoried in order to calculate toxicity potential. The result is an assessment of life cycle toxicity potential that includes not only the final products but also the reactants needed in its manufacture. In addition, the toxicity potential is also quantified for the use and disposal stages of the life cycle. The general framework for performing the analysis of toxicity potential is described by Landsliedel and Saling<sup>(5)</sup> and is based upon the Hazardous Materials Regulations (R-phrases) outlined in Directive 67/546/EEC. This method was chosen because in order to score the toxicity of a substance, the consideration of all possible effects is needed. The R-phrase system is widely used in Europe for the classification of a substance's various toxic effects.

6.8.1. For BASF's Eco-efficiency analysis, the toxicity potential assessment focuses on human toxicity potential. Physical hazards (i.e. flammable, explosive, etc.) are considered in our risk potential assessment and to the extent that the Mik-values are related to ecological endpoints, ecological toxicity potential is taken into account in the water emissions assessment. The scoring system (Table 1) is based on six groups of toxic properties described by R-phrases. Each group is given a score, ranging from 100 – 1,000 based on the severity of the toxic effects. A substance is assigned to one of these groups by its toxic properties, also described by R-phrases. If there is only one R-phrase for the substance, it will be assigned to the appropriate group; however, if there are additional R-phrases the substance will be up-graded (*i.e.* +1). However, weak effects or local effects (group 1 and group 2 respectively) and the same effect caused by an additional exposure route (e.g. oral and dermal) will not lead to an up-grade. In general, there is only one upgrade for a substance, irrespective of how many additional R-phrases are present. Scoring for toxicity based on R-phrases shall be done according to the following scheme:

**Table 1:** Scoring system for toxic properties described by R-phrases

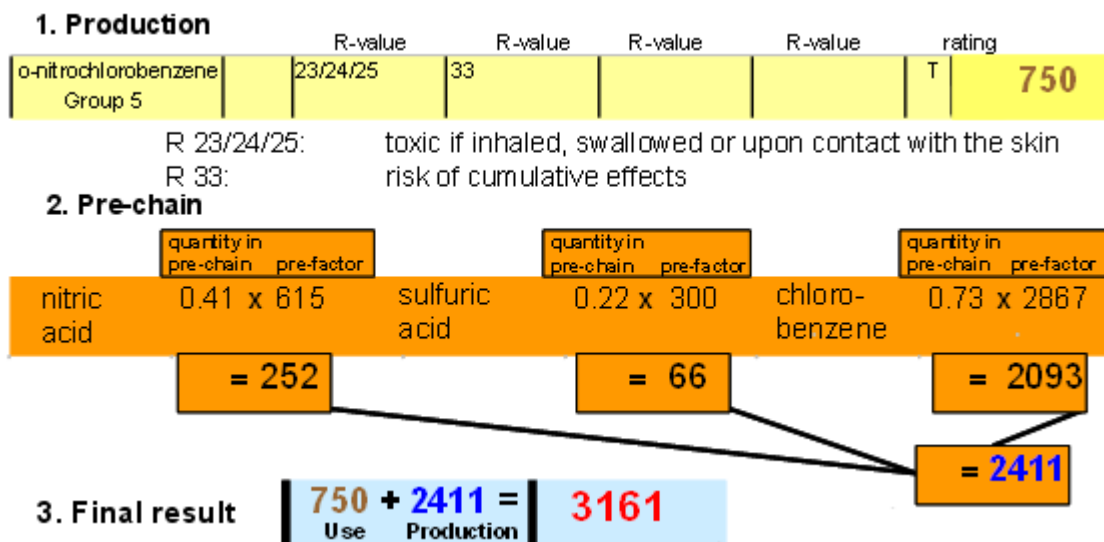
Group	Description	Toxic Effects given by R-Phrases	Score
1	Weak effects	R36, R38, R66, R67	100
2	Local effects	R21, R22, R34, R35, R37, R41, R42, R43, R62, R65	300
3	Acutely toxic Irreversible effects Reproductive toxicity suspected	R20, R24, R25	400
4	Severe irreversible effects Reproductive toxicity	R23, R27, R28, R29, R31, R33, R39, R48, R60, R63, R64, R68	550
5	Carcinogenic	R26, R32, R40, R45, R46, R49, R61	750
6		Only by combination	1000
+ 1	Up-grade by additional effects	Additional "strong" effects (all effects except those of group 1 & 2 and additional exposure routes)	

In the case where R-phrases are not specifically identified for a chemical but a material safety data sheet exists, health effect information obtained from the data sheet can be used to estimate the appropriate R-phrases. For data sheets which follow the OSHA recommendations for hazardous communications, relevant information can be found in the following sections: hazard identification, toxicological information or

regulatory information. However, in some cases limited or no toxicological information may exist for a substance. In these cases, valuable toxicological data can be obtained from related substances, structure-activity relationships and even data from the results of inadequate or preliminary tests. The estimation of possible toxic effects of substances utilizing any of these data sources, requires expert judgment and consultation with toxicologists.

6.8.2. The toxicity is evaluated not only for the final product, but also for the entire pre-chain, i.e. the chemicals needed to make the products, going all the way back to the basic raw materials that are extracted from the earth. Toxicity scoring for the pre-chain will be based on R-phrases and include an additional factor to account for the amount used in the pre-chain. The quantities of each substance to be included in the analysis must be inventoried in order to calculate toxicity potential. In addition, the toxicity potential is also quantified for the use and disposal stages of the life cycle. Figure 5 shows an example of scoring the production and pre-chain for o-nitrochlorobenzene.

Figure 5: Toxicity scoring for o-nitrochlorobenzene production and pre-chain.



6.8.3. As already discussed, the toxicity potential is quantified for the production, use, and disposal stages of the life cycle. From the standpoint of the final consumer the use phase is the most important so it is weighted at 70% of the total score while the production phase is weighted at 20% and disposal at 10%. These weighting factors, the sum of which equals 100%, were selected based on potential for exposure at each classification level. For instance, workers in the production phase are protected by way of personal protective equipment (PPE), OSHA regulations, etc., while consumers (i.e. use phase) are the least protected, thereby resulting in the highest weighting of 70%.

6.8.4. The toxicity potential can be modified based on exposure conditions such as the likelihood of contact with the substance and a substance's vapor pressure. BASF EEA may consider three exposure elements, as shown in Figure 6.

Figure 6: Exposure factors used in BASF EEA.

Category	Factor	Category	Factor	Category	Factor
• Closed System	0.01	• Vapor pressure low <1 mm Hg (133,3 Pa)	0.01	• Not persistent	1.0
• Partially Closed System	0.1	• Vapor pressure medium 1-3 mm Hg (133-400 Pa)	0.1	• Absorbed and reactive	3.16
• Open system	1.0	• Vapor pressure high >3 mm Hg (400 Pa)	1.0	• Remain in body	10.0

The determination of the category type to be selected for a given study is dependent on expert/reviewer opinion. A “closed” system is defined as a system where no external release or exposure to the surroundings is possible, e.g. a completely closed reactor. An “open” system is defined as one in which continuous exposure is possible, i.e. an open storage tank. A “partially closed” system falls between an open and closed system and can be considered to be a closed system that is occasionally opened in order to perform a given task.

6.8.5. With regard to nanoparticles, the BASF EEA has adopted the scientific definition of a nanoparticle, i.e. a particle having one or more dimensions of the order of 100 nm or less. The weighting factors associated with various forms of nanoparticles were derived by a panel of toxicology experts. A non persistent substance was deemed to have the same weighting as a substance with a high vapor pressure. A substance that remains in the body (i.e. persistent) was estimated by the toxicology community to be ten times worse than one that is non persistent. Finally, the weighting factor for a nanoparticle that is absorbed and reactive has been calculated as the geometric mean of the non persistent and persistent weighting factors (i.e. 1 and 10).

6.8.6. The toxicity potential of chemicals during the production phase can also be modified based on the safety standards present during the manufacturing of the chemicals / materials. High safety standards in a production facility may help mitigate any potential exposure operators may have to hazardous chemicals during any potential process upset or accident. Conversely, poor or low safety standards at a chemical or manufacturing plant will not help in minimizing the potential health hazards to operators associated with the substances being handled at a facility. Safety levels identified are high, medium and low. Weighting factors range from 1.0 for processes with low safety standards, 0.1 for medium and 0.01 for plants with high safety standards. Thus the potential health risk for processes manufactured under a high safety standard will be less than the same material manufactured with a process incorporating low safety standards.

6.9. *Risk Potential:* The risk potential in BASF EEA, includes physical hazards, and is established using assessments in the sense of an expert judgment and involves the following steps: a) definition of the possible hazards of all alternatives; b) itemizing the possible hazards into production, use and recycling modules; c) determination of the extent of the hazard and the probability of its occurrence and comparison of alternatives. This is not a quantitative risk analysis but rather a semi-quantitative assessment based on potential risks. The Risk Potential category does not include an evaluation of human health toxicity concerns, because they are examined in another section of the EEA.

- 6.9.1. The risk potential covers the physical hazardous during the production, use, and disposal phases and also considers the risk of explosion, flammability, storage accidents, worker illness and injury rates, malfunctions in product filling/packaging, transportation accidents, and any other risk deemed relevant to the study.
- 6.10. *Other Environmental Burden:* The BASF EEA may include additional environmental burden categories at the Study Director's discretion. In situations where additional environmental burden categories are used, the category will be defined along with necessary weighting and normalization factors for the category, the data sources for the category and reporting requirements.
- 6.11. *De Minimis Levels:* Materials or processes can be excluded from consideration in the six key environmental burden metrics if they are viewed as being at de minimis levels. Thus, eco-profiles or toxicity potential scores are not required for de minimis materials. The cutoff criteria for raw materials and energy consumption is < 1.0% while the cutoff criteria for toxicity potential is consistent with the OSHA Hazard Communication Standard requirements for development of Material Safety Data Sheets (MSDSs). The de minimis level is 1.0% unless the listed toxic/hazardous chemical is an OSHA-defined carcinogen. The de minimis level for OSHA-defined carcinogens is 0.1 %. Consideration is also given to the cumulative percentage of de minimis components not being considered for specific materials or unit operations. If the cumulative de minimis quantity not included in an impact assessment of a material or process is greater than 3%, then the project team will evaluate the significance and what potential impact this may have on the study results. As this will be done on a case by case basis, the decision of the project team and justification on what, if any, course of action was taken shall be clearly communicated in the final report.

## 7. Economic Metrics

- 7.1. *Statement of Intent:* 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 customer benefit (\$/CB). The approaches for calculating costs vary from study to study. When chemical products of manufacture are being compared, the sale price paid by the customer is 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. Regardless of the method used, 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); and
  - costs having ecological aspect, such as the costs involved to treat wastewater generated during the manufacturing process.

7.2. *Economic Metrics:* The exact metrics chosen for a study depend upon the CB, alternatives, system boundaries and consideration of the elements described in Section 4. Economic metrics included in BASF EEA, each of which must be consistently applied to each alternative, cover all relevant costs and, at times, revenue and, at a minimum, include consideration of the following:

- Raw material;
- Labor;
- Energy (electric, steam, natural gas, and other fuels);
- Capital investment;
- Maintenance;
- EH&S programs and regulatory costs;
- Illness & injury costs (medical, legal, lost time);
- Property protection & warehousing costs;
- Waste costs (hazardous, non-hazardous);
- Transportation;
- Training costs; and,
- Others, as applicable (e.g. taxes, levies).

7.3. *Time and Regional Value of Money:* Cost analysis in BASF EEA can be calculated as either a point in time or over a period of time that takes into account the time value of money. If the analysis is performed to account for the time value of money, then a Net Present Value, or similar metric, shall be calculated; with the time frame of the cash flow and assumed discount rate specified. The regional currency of the costs calculation shall be specified (e.g. US dollars, Euros) and exchange rates shall be applied when necessary.

7.4. *Cost Dimension Importance:* In a BASF EEA, the cost dimension and environmental dimension are weighted equally.

## 8. Weighting, Normalization and Factors

8.1. *Overview:* BASF's EEA methodology assesses environmental burdens and economic costs independently. Environmental impacts incorporate weighting factors, then normalization to obtain an environmental footprint and then aggregates to develop a relative environmental impact using relevance and societal weighting factors. The method used by BASF is based on a suggestion by the VNCI and the UBA. The application of these factors is shown in Figure 7. The advantages of taking this approach is as follows:

- Both a society-related and a scientific weighting system are used, and changes in society's attitude can be incorporated;
- Study specific relevance factors are calculated for each analysis;
- Relevance factors ensure that relatively high environmental burdens are more heavily weighted than relatively low ones; and
- A high relevance factor identifies critical environmental burdens.

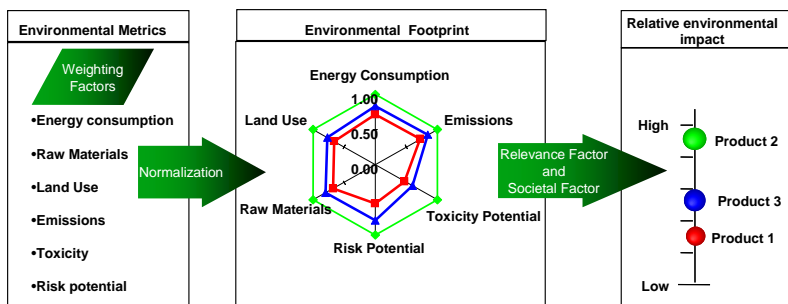


Figure 7: Application of weighting factors, normalization, relevance factors and societal weighting factors in BASF EEA.

8.2. *Weighting Factors:* As described in Sections 6 and 7 above, weighting factors are applied to some environmental burden metrics to calculated equivalencies (e.g. CO<sub>2</sub>-equivalents) or to scale environmental burdens (e.g. raw materials). Not all environmental burden metrics have weighting factors applied (e.g. Primary Energy Consumption) and no weighting is given to economic metrics. The following is a summary of the weighting factors used in BASF EEA:

- Economic Metrics – No weighting factors applied.
- Primary Energy Consumption – No weighting factors applied.
- Raw Material Consumption – Weighting based on reserves and demand.
- Air Emissions – Weighting to calculate equivalent emissions as follows: GWP: CO<sub>2</sub>-equivalents; POCP: Ethene-equivalents, ODP: CFC-equivalents, and AP: SO<sub>2</sub>-equivalents
- Water Emissions – Weighting based on Maximum Emissions Concentration
- Solid Waste Emissions – Weighting based on category of waste.
- Land Use – Weighting based on types of land used.
- Toxicity Potential – Weighting based on life cycle stage.
- Risk Potential – Weighting based on life cycle stage.

8.2.1. Weighting factors are shown in the Mik-values worksheet of the enclosed BASF\_EEA\_Mastersheet.xls. The weighting factors are to be reviewed regularly, as deemed necessary, to determine if changes are needed. This review period should not exceed five years. Changes to the weighting factors should be noted in the “Up-dates EEA” worksheet.

8.3. *Normalization:* For each environmental burden metric the results are normalized in order to generate the Environmental Footprint plot, and then the normalized results for the six environmental burden metrics are aggregated into a single relative environmental impact score and represented in the EEA Portfolio. This normalization is done by dividing the amount for an environmental burden metric for each alternative by

the alternative with the highest value for that burden. An example of normalization is shown in Table 2.

Table 2: Example of normalization of primary energy consumption for five different alternatives

Alternative	Primary Energy Consumption	Normalized Value
auto 1	880958 MJ/CB	1.00
auto 2	834248 MJ/CB	0.95
auto 3	806222 MJ/CB	0.92
auto 4	862274 MJ/CB	0.98
auto 4 diesel	560306 MJ/CB	0.64

8.3.1. The normalized environmental burden metrics are shown on the “EEA\_Results” worksheet of the enclosed BASF\_EEA\_Mastersheet.xls and are represented in the Environmental Footprint plot.

8.4. *Relevance Factors*: The relevance factor reflects the level to which the emission (or energy consumption) contributes to the total emissions (or energy consumption) in a given geographic region and are used when aggregating the six environmental burden metrics into a single relative environmental impact score. They indicate how important the individual environmental burden metric is for a particular eco-efficiency analysis. Those factors are “scientific weighting factors” because they are not influenced by a definition but are calculated. The greater the contribution of an impact to the total category of the same impact (in North America, for example), the higher the relevance factor. The relevance factor for each environmental burden metric is calculated as follows:

$$\text{relevance factor} = \frac{\text{environmental burden metric}}{\text{total burden in region}}$$

8.4.1. BASF EEA has relevance data for the United States, Germany, Europe, Great Britain, Morocco, Japan, China and Brazil, and the appropriate factors are selected based on the system boundaries for the study. The relevance factors are to be obtained from publically available sources, with their references cited in the EEA\_Relevance worksheet of the Mastersheet.

8.4.2. The relevance factors are to be updated every seven years or as deemed necessary. Specific values, and sources, are shown in the “EEA\_Relevance” worksheet of the enclosed BASF\_EEA\_Mastersheet.xls. For the United States, the values are obtained primarily from the US EPA’s toxic release and water release inventories. Changes to the relevance factors should be noted in the “Up-dates EEA” worksheet.

8.5. **Societal Weighting Factors:** These factors are used when aggregating the six environmental burden metrics into a single relative environmental impact score. The purpose is to weight the individual burden metrics by a factor that accounts for the society’s opinion on the importance of that metric, relative to the other burden metrics. An example of a societal weighting factor scheme is shown in Figure 8. For these weighting factors, societal views of the individual ecological impact categories were determined jointly by Roland Berger Strategy Consultants and BASF through surveys, public opinion polling, expert interviews, etc., and recorded in a weighting scheme.

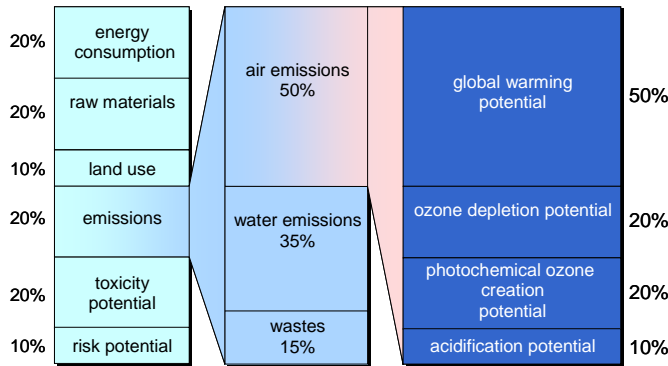


Figure 8: Example of societal weighting factors for BASF EEA.

8.5.1. BASF EEA has societal weighting factors data for the United States, Germany, Europe, Great Britain, Morocco, Japan, China and Brazil, and the appropriate factors are selected based on the system boundaries for the study.

8.5.2. The societal weighting factors are to be updated regularly, as deemed necessary, but not for a period to exceed seven years. Specific values, and sources, are shown in the “EEA\_Results” worksheet of the enclosed BASF\_EEA\_Mastersheet.xls. Changes to the societal weighting factors should noted in the “Up-dates EEA” worksheet.

8.6. **Calculation Factor:** Through the calculation factor, the environmental burden metrics are combined and ultimately plotted as a single point in a coordinate system. The calculation factor is determined for each environmental burden metric and is calculated as the geometric mean of the relevance factor and societal weighting factor according to the following formula:

$$Calculation\ Factor_{Env\ Metric} = \sqrt{relevance\ factor_{Env\ Metric} \times societal\ weighting\ factor_{Env\ Metric}}$$

8.6.1. The calculation factor is the final factor applied prior to calculating the relative environmental impact that is plotted as part of the Eco-Efficiency Analysis Portfolio.

8.7. **Economic Relevance Factors:** In a similar fashion that the environmental relevance factors are calculated, the total costs of a system can be related to the total sales of the manufacturing industry in the field under study. This, as in the case of the calculation of relevance factors for total environmental impact, will give a relevance factor that

reflects total costs. For BASF EEA this factor reflects to what extent the alternatives studied contribute to the gross domestic product of a country.

8.7.1. BASF EEA has economic relevance data for the United States, Germany, Europe, Great Britain, Morocco, Japan, China and Brazil, and the appropriate factors are selected based on the system boundaries for the study.

8.7.2. The economic relevance factors are to be updated regularly as deemed necessary, but not for a period to exceed seven years. Specific values, and sources, are shown in the "EEA\_Relevance" worksheet of the enclosed BASF\_EEA\_Mastersheet.xls. Changes to the relevance factors should be noted in the "Up-dates EEA" worksheet.

8.8. *BIP Relevance:* While economics and environmental burden are weighted equally at the start of a study, a BASF EEA compares the ratio of the final weighted total environmental burden to the final weighted total cost (E/C ratio) to determine if the economic or the environmental impacts were more influential for that study. With this system, where, for example, economic factors have a higher relevance than ecological factors, analyses can take a greater account of the total costs axis. This E/C ratio is called the BIP Relevance and utilized when developing the EEA Portfolio.

8.8.1. No updates to the BIP Relevance are necessary as this is a value calculated from other relevance factors which are updated. The BIP relevance result is shown on the "EEA\_Relevance" worksheet of the enclosed BASF\_EEA\_Mastersheet.xls.

## 9. Study Outputs, Final Report and Presentation

9.1. *Final Report and Final Presentation of Results:* BASF EEA methods, parameters, results and conclusions can be summarized in a written Final Report and/or Final Presentation. At a minimum, the Final Report and/or Final Presentation shall include a discussion of the following:

- Introduction and study goals;
- Customer Benefit, alternatives and system boundaries;
- Input parameters and assumptions;
- Method of Economic costs evaluation;
- Method of Environmental burden evaluation;
- Eco-efficiency analysis results and discussion;
- Data quality assessment;
- Sensitivity/uncertainty analysis, and
- Limitations of EEA study results
- References.

9.2. *Representations of Results:* Results of a BASF EEA are represented as bar charts for cost and each of the eleven environmental burden metrics, an Environmental Footprint plot, and an Eco-Efficiency Analysis Portfolio. Figure 9 provides examples of these outputs from a BASF EEA.

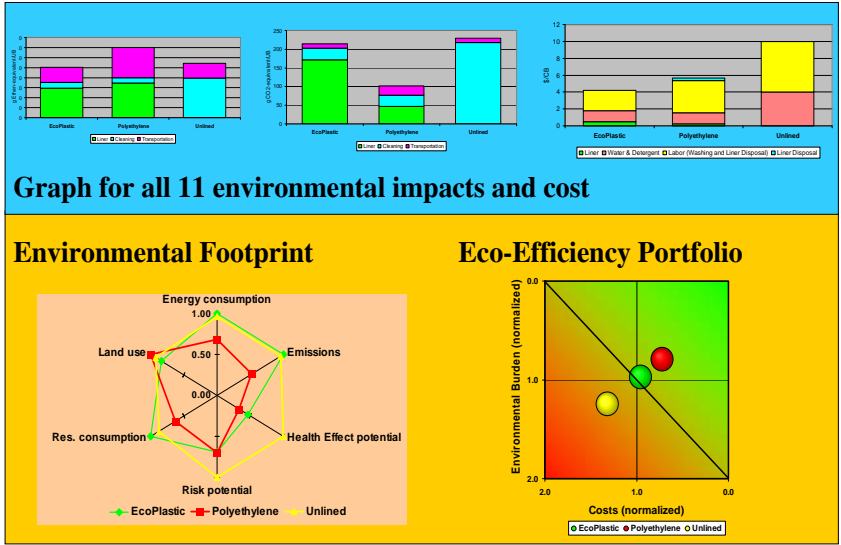


Figure 9: Examples of study output from a BASF EEA. Bar chart, Environmental Footprint and Eco-Efficiency Analysis Portfolio.

The BASF EEA methodology allows results to be graphically depicted and discussed, and may assist in decision processes for implementing the most eco-efficient alternative. This contributes to more sustainable development, and supports acceptance of applicable investment and purchasing decisions. The basis for subsequent decisions may be backed with appropriate data, and the effectiveness of the particular measures may be reviewed and documented.

9.3. *Bar Charts:* At a minimum, each BASF EEA shall include bar charts that show the results of the analysis for the economic and each of the environmental burden metrics. At a minimum, the bar charts should be generated based on weighted results, but not results that have been normalized or have had the relevance, societal or BIP factors applied. If deemed appropriate, bar charts based on normalized, relevance, societal and/or BIP factors can be added in addition to the weighted charts.

9.4. *Environmental Footprint:* After weighting and normalization procedures have been carried out for the environmental burden metrics, the appropriate computed values are collected in a specific plot, the Environmental Footprint, as shown in Figure 9. This diagram shows the environmental advantages and disadvantages of the considered alternatives in a relative comparison with each other. The alternative that lies furthest out and has the value of 1 is the least favorable alternative in the category in question. The closer to the origin (0) an alternative lies, the more favorable it is. The axes are mutually independent, so that an alternative that, for example, does well on energy consumption can do less well with regard to emissions. The environmental footprint makes it possible to identify environmental impact drivers and give clues as to the areas in which improvements should be achieved in order that the overall system may be optimized.

9.5. *Eco-Efficiency Analysis Portfolio:* The BASF Eco-Efficiency portfolio was developed to graphically depict both economic and environmental results on a single 2x2 matrix (see Figure 9). The normalized values from the Environmental Footprint are aggregated into

a single relative environmental impact through the use of the relevance, societal and BIP factors and plotted against costs. Because environmental impact and cost are equally important, the most eco-efficient alternative is the alternative with the largest perpendicular distance above the diagonal line. Alternatives whose summed economy and environmental ratings are identical are considered to be equally eco-efficient.

## 10. Life Cycle Inventory Data – Eco-Profiles

10.1. *Overview:* BASF manages its life cycle inventory (LCI) data in a manner consistent with ISO 14041. LCI data is one of the types of information critical to performing a BASF EEA, the other being the model parameters, and an LCI is essentially an inventory of input/output data with respect to the product or process under consideration. For BASF EEA the term “Eco-Profile” is used in place of life cycle inventory. The general process of selecting Eco-Profiles for use in BASF EEA, shown schematically in Figure 10, involves using existing Eco-Profiles or creating a new one and using a specific Eco-Profile or an analogous one. General descriptions of *existing*, *new*, *specific* and *analogous* Eco-Profiles are provided in Section 10.4. All Eco-Profiles used in a BASF EEA should be provided in the “Gen Eco-profiles” worksheet, and can be seen, as an example, in the enclosed BASF\_EEA\_Mastersheet.xls. See Section 10.8 for BASF EEA reporting requirements in regards to development and use of Eco-Profiles.

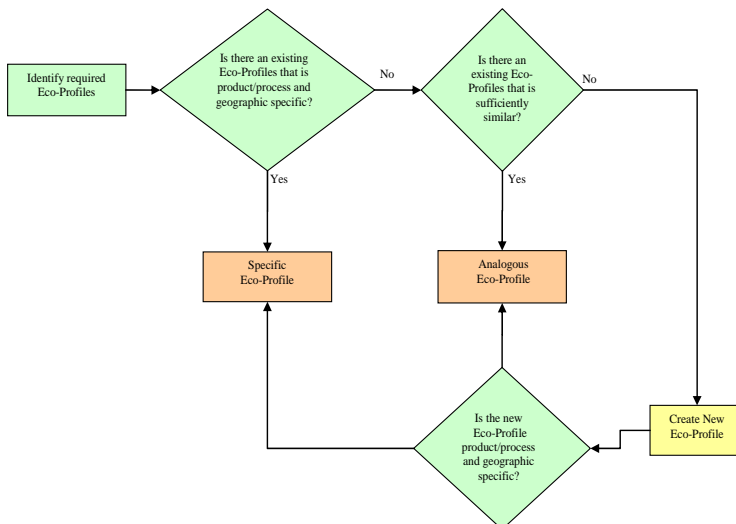


Figure 10: Process flow for selecting Eco-Profiles.

10.2. *Identifying Required Eco-Profiles:* The goals of the study, the defined CB, alternatives and system boundaries (as discussed in Section 4 above) are considered when identifying what specific Eco-Profiles are necessary for a given BASF EEA. Because the process of completing a BASF EEA is often iterative, as data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the necessary Eco-Profiles, and; therefore, there should be an ongoing evaluation of the appropriateness and quality Eco-Profiles throughout the BASF EEA study.

10.3. *Elements of BASF's Eco-Profiles:* The BASF Eco-Profile shall contain, at a minimum, all of the elements that comprise the environmental burden metrics, except for toxicity and risk that are described in Sections 6.8 and 6.9, respectively. As shown in Figure 11, the Eco-Profile is organized by the categories of energy, raw materials, air emissions, water emissions, solid waste and land use with the corresponding units for each category. The empty spaces under the Material category allow for the addition of other raw materials that may be required. Data from the Eco-Profile is used to calculate the environmental burdens for the analysis where one element may impact more than one environmental metric. Methane (CH<sub>4</sub>), for example, is chemical that impacts both the GWP and POCP burdens. Weighting factors are also applied to the Eco-Profile data, for example, for the amount of coal (kg) needed to fulfill the CB.

Fuels		unit	Air Emissions		
	coal	MJ		CO2	mg
	oil	MJ		SOX	mg
	nat. gas	MJ		NOX	mg
	hydro	MJ		CH4	mg
	nuclear	MJ		NM-VOCs	mg
	lignite	MJ		halog. HC	mg
	other	MJ		NH3	mg
	biomass	MJ		N2O	mg
	sum	MJ		HCl	mg
Material			Water Emissions		
	water	kg		COD	mg
	Coal	kg		BOD	mg
	Oil	kg		N-total	mg N
	Gas	kg		NH4 as N	mg N
	Lignite	kg		PO4 as P	mg P
	Uranium	kg		AOX	mg
	NaCl	kg		HM	mg
	Sulfur	kg		HC	mg
	Phosphorus	kg		sulfate	mg
	Iron	kg		chloride	mg
	Lime	kg	Solid Wastes		
	Bauxite	kg		municipal waste	kg
	Sand	kg		special waste	kg
	Copper	kg		construction waste	kg
	Titanium,	kg		mining waste	kg
			Land use		
				no development	m2
			II	partially developed	m2
			III	developed	m2
			IV	covered	m2
			V	covered and divided	m2

Figure 11: BASF Eco-Profile elements.

10.4. *Selecting Eco-Profiles for Use in Study:* The process of selecting Eco-Profiles for use in BASF EEA is based on expert judgment. Once the required Eco-Profiles for a particular study are identified, then existing Eco-Profiles are used or new ones are created. Furthermore, the Eco-Profiles used in the study will be either specific or analogous. An *existing* Eco-Profile is one that was previously calculated by BASF or was obtained from a reputable external source (e.g. customer, supplier, US Life Cycle Inventory database, scientific literature) A *new* Eco-Profile is created by BASF especially for a given EEA. A *specific* Eco-Profiles means the input/output data match very closely the product or process under consideration. An *analogous* Eco-Profiles means that the input/output data is sufficiently similar the product or process under

consideration. The following decision criteria for evaluating the suitability of Eco-Profiles for use in a BASF EEA shall be considered:

- Scope of study: Selected Eco-Profiles should align with the goals of the study, the defined CB, alternatives and system boundaries (as discussed in Section 4 above).
- Product/process specificity: In general, eco-Profiles for a specific product/process are preferred, over analogous Eco-Profiles that may be based on industry averages. If product/process specific Eco-Profiles are not pre-existing, then an analogous Eco-Profile can be used.
- Geographic specificity: Eco-Profiles created for within the geographic context of the study are preferred, in general, to Eco-Profiles for regions outside the study context. An exception to this rule is if an international Eco-Profile is deemed superior to the domestic Eco-Profile.

10.5. *Time horizon:* In general, Eco-Profiles created within three years of the date of the EEA are preferred over older Eco-Profiles.

10.6. *Creating New Eco-Profiles:* The BASF procedure for creating Eco-Profiles involves the compilation and quantification of material and energy inputs and outputs for each unit process within the system boundaries throughout its life cycle. For a BASF EEA, these inputs include the use of energy, raw materials and land use, with outputs including releases to air, water and land. In addition, BASF EEA considers toxicity and risk potential as “outputs”. The sources of data can include existing ecological studies, questionnaires for production plants, scientific publications, analogies and expert judgments. The procedures used for data collection vary depending on the scope, unit process or intended application of the study as defined in Section 4 above. As acknowledged in ISO 14041, data collection for development of an Eco-Profile can be a resource-intensive process and practical constraints on the scope of data collection are considered in the BASF EEA process.

10.7. *Calculating Eco-Profiles:* BASF utilizes the Boustead Model (ver 5.0) as its primary means for calculating Eco-Profiles. Boustead is a commercially available software (website: <http://www.boustead-consulting.co.uk/>) that is both a database and a LCI modeling tool. This tool is a life cycle analysis industry standard and was developed by Boustead Consulting Ltd. which has over 35 years experience in LCA consulting. Calculations done in Boustead are based on a unit operation process that allows it to analyze highly complex linear and non-linear systems without resorting to approximations or simplifications which may otherwise introduce inaccuracies. A unit operation is a process which produces a single product, see Figure 12. Each of these unit operations will take its inputs from other upstream unit operations and its output product will act as a feed for further downstream operations. In general, a unit operation will be independent of the upstream operations that are feeding it and the downstream operations that are taking its products and, therefore, any unit operation can be analyzed without reference to the other unit operations within the system.

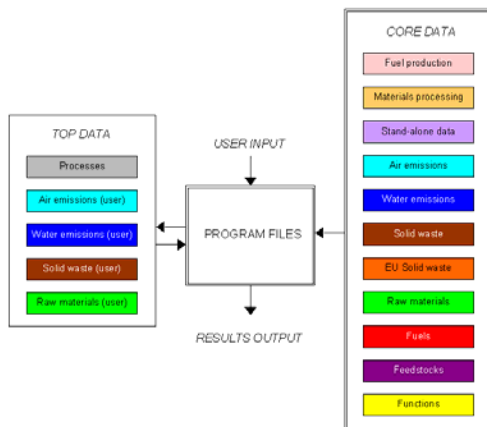


Figure 12: Structure of Boustead Model showing how Eco-Profiles are calculated.

Source: <http://www.boustead-consulting.co.uk/products.htm>

10.8. *Eco-Profile Reporting Requirements:* The presentation and/or final report of BASF EEA results should include a description of the Eco-Profiles used in the study and assessment of the appropriateness of the Eco-Profiles as related to the goals of the study, the defined CB, alternatives and system boundaries (as discussed in Section 4 above). Evidence of sufficiency and/or expert judgments used should be articulated in a transparent manner. In addition, the presentation or report shall contain a data quality assessment in regards to the Eco-Profiles which identifies critical uncertainties, or sensitivities, that have significant impacts on study results. It is not necessary to describe every Eco-Profile that was potentially available for use in the study, as this may be extremely resource-intensive and is, therefore, not consistent with ISO 14041.

## 11. Use of Relative Inputs

11.1. *Absolute vs. Relative Inputs:* The BASF EEA methodology allows for analysis based on both absolute inputs and relative inputs. When there is a high degree of similarity in the analysis between inputs into the model (e.g. composition, energy, assumptions related to production, use and disposal of the alternatives), performing the analysis utilizing relative inputs often provides a higher degree of resolution to the results and does not effect results or conclusions. Relative inputs mean the data in the EEA, such as raw material usage and energy inputs, are based on differences in the amounts rather than the absolute amount. For BASF EEA, relative amounts are calculated by subtracting the usage of the alternative with the lowest amount from the other alternatives. For example, if all three alternatives use a catalyst in the amounts of 5, 4 and 2 kg/CB the relative inputs would be 3, 2 and 0 kg/CB.

11.2. *Selective Use of Relative Inputs:* Selective use of relative inputs is acceptable in that they may be used for some economic and environmental metrics in a study but not necessarily for every metric. Selective use of relative inputs is consistent with ISO 14040 ff as it provides a means for greater clarity of results. For example, life cycle impacts of automobiles is often dominated by gasoline consumption during the vehicles service life and by selecting relative inputs only for gasoline usage it provides better

resolution in regards to the impact of the other metrics (e.g. materials, energy, supply chain logistics).

- 11.3. *Reporting Requirements:* The presentation and/or final report of BASF EEA results shall include a description of relative inputs used within the model and the appropriateness of using them as it relates to the goals of the study, the defined CB, alternatives and system boundaries (as discussed in Section 4 above). In addition, the presentation or report shall contain a data quality assessment in regards to the use of relative data which identifies critical uncertainties, or sensitivities, that have significant impacts on study results.

## 12. Data Quality Objectives

- 12.1. *Data Quality Statement:* Because the process of developing a BASF EEA is often iterative, as data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the inputs/outputs. The BASF EEA methodology calls for an ongoing consideration of the appropriateness, accuracy and preciseness of input data throughout the study.
- 12.2. *Sensitivity and Uncertainty Considerations:* A BASF EEA shall include an assessment of both sensitivity and uncertainty in regards to study inputs and outputs. The scope of this assessment should be based upon the study as defined in Section 4, and shall include an evaluation of the quality of the input/output data in relation to the Relevance and Calculation factors for the study. These factors are specific to each BASF EEA, as they are calculated values, and they are summarized in two graphs provided in the "EEA\_Relevance" worksheet. Examples of these graphs are shown in Figure 13.

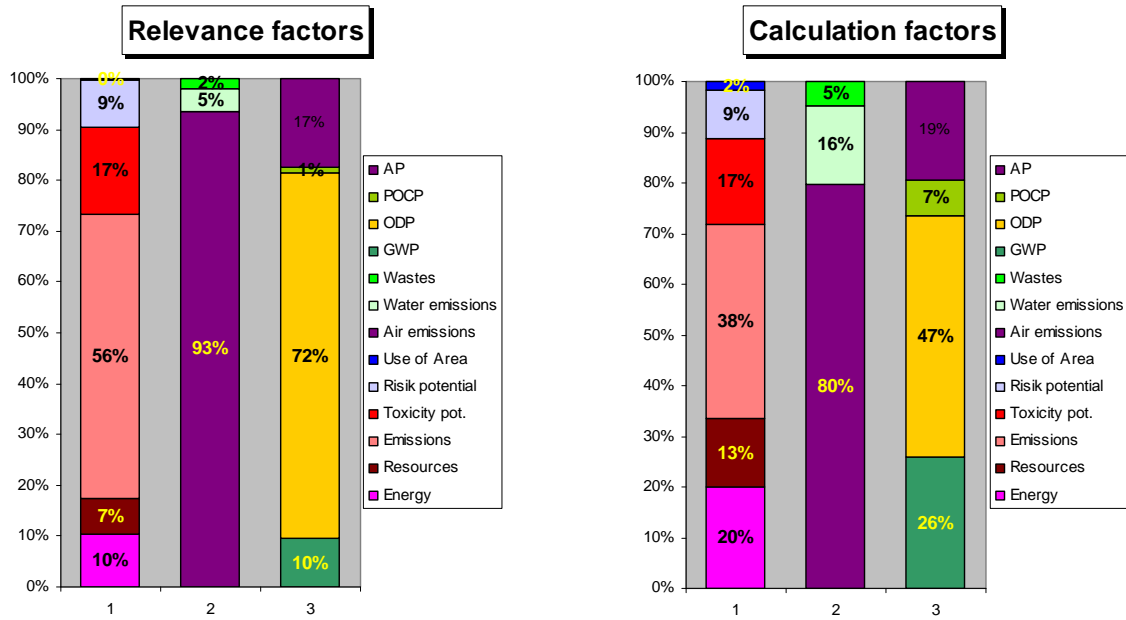


Figure 13: Example of graphs of relevance factors and calculation factors that are used in sensitivity and uncertainty analysis for BASF EEA.

12.3. *Reporting Requirements:* Findings from the data quality assessment, which identifies critical uncertainties, or sensitivities, that have significant impacts on study results, shall be included in the written Final Report and/or Final Presentation.

### 13. Statements of Limitations and of Validation of EEA Study Results

13.1. *Limitations:* At a minimum, each report or presentation of study results will carry the following statement regarding limitation of 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.”

13.2. *Validation:* The report or presentation should include, at a minimum, the following statement if, and only if, the study was performed in complete accordance with BASF EEA methodology validated under the requirements of NSF P352:

- “This Eco-Efficiency analysis was performed by BASF according to the methodology validated by NSF International under the requirements of Protocol P352, Part A. More information on BASF’s methodology and the NSF validation can be obtained at [http://www.nsf.org/info/eco\\_efficiency/](http://www.nsf.org/info/eco_efficiency/) “. Slight modifications to this statement are allowed, if required.

## 14. BASF EEA Mastersheet.xls

14.1. *Overview:* BASF has developed a computerized model that incorporates all elements and formulas for calculating a BASF EEA into a working system computerized model programmed in Microsoft® Excel. This system is the BASF\_EEA\_Mastersheet.xls spreadsheet

14.2. *Elements:* The following table describes the function of each worksheet contained within BASF\_EEA\_Matersheet.xls and Figure 14 is a process flow diagram that shows how information is processed within the spreadsheet. Note: The BASF\_EEA\_Matersheet.xls contains worksheets for conducting Socio-Eco-Efficiency (SEE) studies, which are not part of this application and, therefore, those worksheets are listed as Not Applicable.

Worksheet Name	Contents	Comments
Input Parameters	Study specific parameters are input on this page, including alternatives, formulation information, material and energy usage. Cost, tox and risk data are NOT entered here.	The formats and inputs to this page will vary for each specific EEA.
General data	Establishes the modules for the study. This worksheet is populated with data from the Input Parameters worksheet.	This provides raw material and energy usage per Customer Benefit (CB) from which all environmental impact calculations are performed.  Data on this page are in units of material per CB (Usage/CB).
Costs	Cost calculations are done on this page, and linked to EEA_Results worksheet.	The formats and inputs to this page will vary for each specific EEA.
Gen Eco-profiles	External life cycle inventory (LCI) data are entered into this sheet and form the basis from which environmental impacts are calculated.	LCI data from Gen Eco-profiles represents Environmental Impact per unit of material. (Impact/Usage)
EEA_Results	Results for EEA are provided on this page, including: final environmental scores, weighting factors, ecological footprint, portfolio and scenario analysis.	
EEA_Diagr	This worksheet contains bar charts of the EEA results	
E_prof 1 thru 10 BASF EEA Mastersheet allows for the comparison of ten different alternatives, so there are ten E-prof worksheets.	Impact per CB for each module is calculated on this page. Data on this sheet are calculated based on data from General data and Gen Eco-profiles.	Formula for calculation is as follows:  $\text{E\_prof (Impact/CB)} = \text{General data (Usage/CB)} \times \text{Gen Eco-profiles (Impact/Usage)}$
RiskPot	Risk calculation is done here, based on data from E_prof and other risk information	
ToxPot	Toxicity calculation is done here, according to BASF EEA methodology, based on external toxicity data.	
Alt.1 thru 10 BASF EEA Mastersheet allows for the comparison of ten different alternatives, so there are ten Alt. worksheets.	Total impact per module is summed based on data in E_prof and then totaled for all modules to obtain total environmental burden.	
EEA_Relevance	Data for calculation of relevance factors and weighting factors	

SEE_Results	N/A	Does not apply because this sheet is only for Socio-Eco-Efficiency analysis. This sheet has no impact on EEA results.
Social_diagr.de	N/A	Does not apply because this sheet is only for Socio-Eco-Efficiency analysis. This sheet has no impact on EEA results.
Social_diagr.en	N/A	Does not apply because this sheet is only for Socio-Eco-Efficiency analysis. This sheet has no impact on EEA results.
Social_stat	N/A	Does not apply because this sheet is only for Socio-Eco-Efficiency analysis. This sheet has no impact on EEA results.
Mik-values	Weighting factors for air emission, water emission, solid waste emission, raw material consumption, and land use.	Weighting factor values are used in the EEA_Results worksheet.
Up-dates EEA	Running log of updates to EEA model.	Most of this language is in German
Updates_SEE	N/A	Does not apply because this sheet is only for Socio-Eco-Efficiency analysis. This sheet has no impact on EEA results.
Boustead	Provides a summary of LCI module numbers. Boustead is name of program that BASF uses for its LCI data.	Data on this page are not used at all in the EEA calculation.

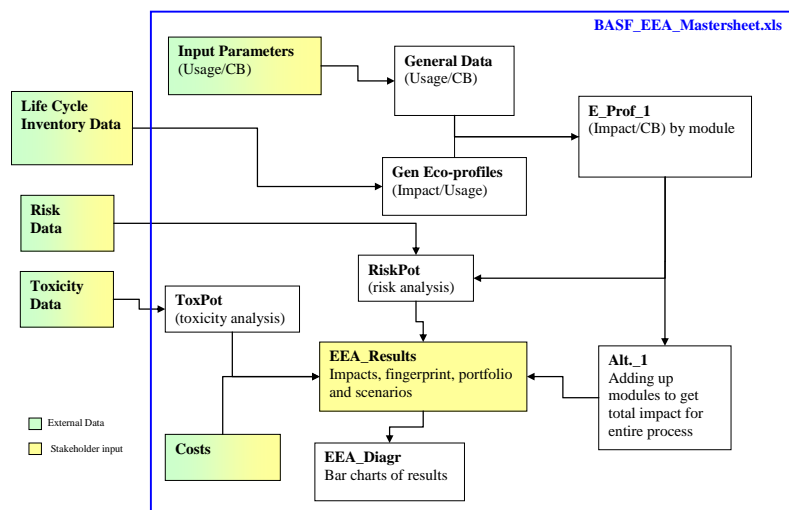


Figure 14: Process flow diagram for BASF EEA analysis using BASF\_EEA\_Mastersheet.xls.

## 15. References

- <sup>1</sup> Saling, P., A. Kicherer, B. Dittrich-Kraemer, R. Wittlinger, W. Zombik, I. Schmidt, W. Schrott, and S. Schmidt. 2002. Eco-efficiency Analysis by BASF: The Method. *Int. J. Life Cycle Assess.*, 7 (4): 203.
- <sup>2</sup> Shonnard, D.; Kicherer, A; and Saling, P. Industrial Applications Using BASF Eco-Efficiency Analysis: Perspectives on Green Engineering Principles. *Environ. Sci. Technol.* 2003, 37, 5340-5348.
- <sup>3</sup> ISO, International Organization for Standardization. Environmental Management-Life Cycle Assessment-Principles and Framework; ISO 14040:1997(E); ISO: 1997.
- <sup>4</sup> Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: *Climate Change 2007: The Physical Science Basis.*

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<sup>5</sup> Landsliedel, R.; Saling, P. Assessment of Toxicological Risks for Life Cycle Assessment and Eco-efficiency Analysis. *Int. J. Life Cycle Assess.* 2002, 7 (5), 261-268.