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

**BASF's Eco-Efficiency Analysis Methodology  
February 2019**



**Submitted by:**

BASF Corporation  
100 Park Avenue, Florham Park, NJ, 07932

**Prepared by:**

Bruce Uhlman, Senior Manager, Applied Sustainability  
Tom Laginess, Senior Sustainability Specialist  
David Green, Manager, Applied Sustainability  
Peter Saling, Director, Sustainability Methods  
Anahí Grosse-Sommer, Senior Manager, Applied Sustainability  
Nicola Paczkowski, Senior Manager, Applied Sustainability  
Richard van Gelder, Senior Manager, Applied Sustainability

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## 1. Purpose and Intent of this Submission

- 1.1. The purpose of this submission is to establish BASF's methodology for performing Eco-Efficiency Assessments for the intent of having it validated under the requirements of NSF Protocol P352, Part A: Validation of the Eco-Efficiency Assessment Methodology. The methodology includes two strictly defined versions of Eco-Efficiency Assessments, the "EEA6" and "EEA10", with 6 and 10 fixed environmental impact criteria. Additionally, the "LCAflex" is a similar Eco-Efficiency Assessment assessing costs and environmental impacts but allowing a flexible selection of environmental criteria and impact assessment methodologies under certain conditions.
- 1.2. It is the intent of BASF to use the same validated Eco-Efficiency methodology and model to conduct Eco-Efficiency and LCAflex studies and have those studies submitted to NSF for verification under NSF Protocol P352, Part B: Validation and Verification of Eco-Efficiency Analyses.

## 2. Content of this Submission

- 2.1. This submission specifies the specific content and minimum requirements of an Eco-Efficiency Assessment (whether EEA6, EEA10 or LCAflex) conducted in accordance with BASF methodology, and includes the environmental and economic parameters considered, the weighting and normalization procedures to quantify the environmental impact 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. For simplification, in the following text "EEA" refers to all assessment types (EEA6, EEA10, and LCAflex) as the basic approach for all three is the same. The differences in the specific Eco-Efficiency Assessments will be addressed as needed.
- 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 Mastersheet.xlsm that is the computerized model programmed in Microsoft® Excel. An equivalent calculation model may be programmed in other software.

## 3. BASF's EEA Methodology

- 3.1. *Overview:* The process for performing a BASF EEA has been previously published [Saling et al 2002]<sup>1</sup> [Shonnard et al 2003]<sup>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, initially in partnership with an external consultant, and has since been further developed. BASF EEA follows the ISO 14040 [ISO 2006]<sup>3</sup> and 14044 [ISO 2006]<sup>3</sup> standards for the environmental assessment evaluation and ISO 14045 [ISO 2012]<sup>4</sup> for Eco-Efficiency assessment. In addition to these standards, BASF EEA also includes additional enhancements that allow for the expedient review and

decision-making at all business levels. Since its inception in 1996, BASF has completed over 650 analyses on a wide variety of products and processes.

The EEA evaluates the life cycle costs associated with the product or process by calculating the total costs related to, at a minimum, materials, labor, manufacturing, waste disposal, and energy. BASF EEA also evaluates the most relevant environmental impact categories and sufficient environmental impact as determined by the so-called "Relevance Check" described later.

While NSF Protocol P352 allows applicants the flexibility to implement and apply the results of Eco-Efficiency analysis studies based upon specific requirements, the overall procedure for the BASF EEA methodology is shown in Figure 1.

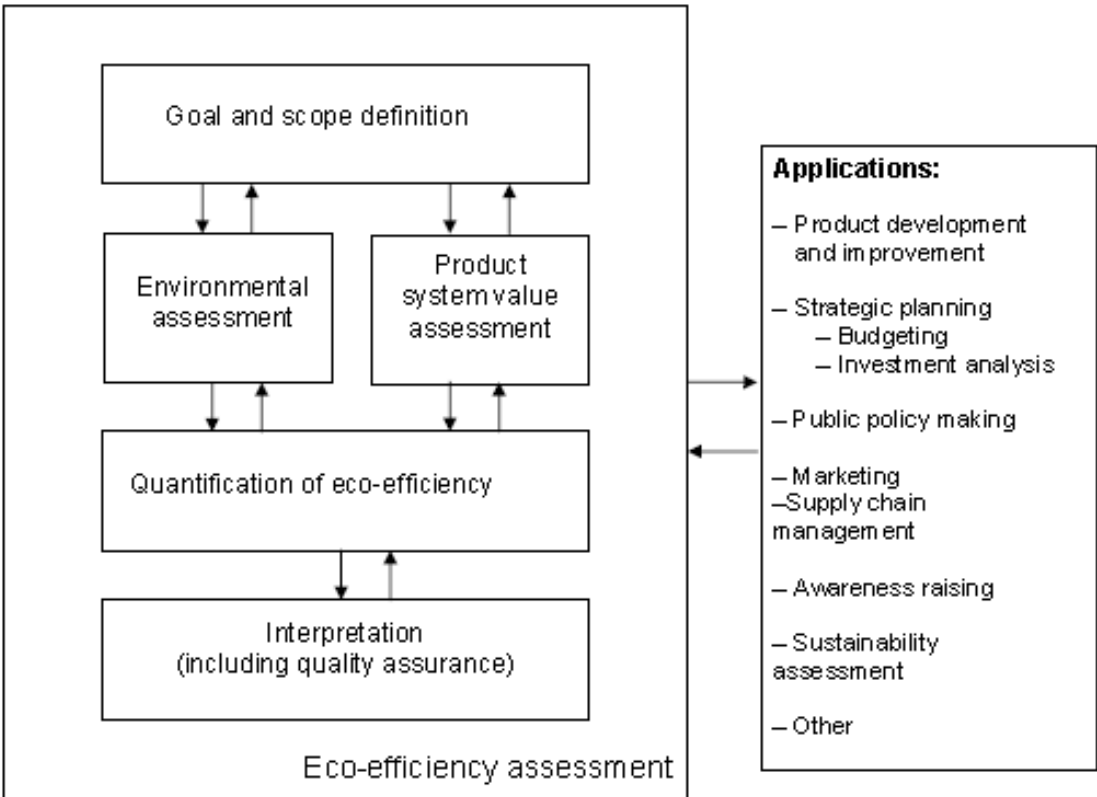


Figure 1: Phases of an Eco-efficiency assessment (from ISO 14045)<sup>4</sup>

3.2. *EEA6, EEA10 and LCAflex*: In order to address varying needs according to industry and geographic region three separate but similar Eco-Efficiency Assessment tools have been developed. The EEA6 and EEA10 have defined environmental impact categories as well as set impact assessment methods. The EEA6 includes six environmental impact categories expected to adequately cover environmental impact for most chemical products and processes. The EEA10 includes also impact categories which cover additional environmental aspects that become significant in, for example, assessments including bio based materials. The LCAflex is, in principle, completely flexible both in terms of environmental impact categories as well as impact assessment methods (see Table 1). However, the Relevance Check ensures that for each EEA6 and LCAflex

sufficient environmental impact is covered and the most relevant impact categories are included. If this is not the case, then an EEA10 assessment is required.

EEA6	EEA10	LCAflex
Abiotic depletion potential (minerals & metals, energy carriers)	Abiotic depletion potential (minerals & metals, energy carriers)	Abiotic depletion potential (minerals & metals, energy carriers)
Global warming potential	Global warming potential	Global warming potential
Photochemical ozone creation potential	Photochemical ozone creation potential	Photochemical ozone creation potential
Acidification potential	Acidification potential	Acidification potential
Human toxicity potential	Human toxicity potential	Ozone depletion potential
Eutrophication (marine and freshwater) or ecotoxicity	Eutrophication (marine and freshwater) or ecotoxicity	Water scarcity
	Ozone depletion potential	Land use
	Water scarcity	Eutrophication (terrestrial)
	Land use	Eutrophication (overall)
		Eutrophication (marine)
		Eutrophication (freshwater)
		Respiratory inorganics
		Ionizing radiation
		Human Toxicity potential
		Human Toxicity potential (cancer)
		Human Toxicity potential (non-Cancer)
		Particulate matter
		Ecotoxicity potential (freshwater)
		Ecotoxicity potential (terrestrial)
		Ecotoxicity potential (marine)

Table 1: Impact categories for EEA6 and EEA10 (required) and LCAflex (optional)

- 3.3. *Preconditions:* The basic preconditions in BASF EEA are as follows: 1) products or processes studied must meet the same defined customer benefit (also known as functional unit), 2) the entire life cycle is considered, 3) data gathering and constructing the system boundaries are consistent with the customer benefit and 4) both an environmental and an economic assessment are carried out.
- 3.4. *Work Flow:* Figure 2 presents a flow diagram for the preparation of a BASF EEA study. A BASF EEA study is worked out by following specific and defined ways of calculations: 1) after detailed discussions with the sponsors of the study, the functional unit, the alternatives to be evaluated and the system boundaries are discussed and agreed upon, 2) calculation of total cost from the customer/end-user viewpoint, 3) preparation of a specific life cycle analysis for all investigated products or processes according to the rules of ISO standards 14040 and 14044 with subsequent determination of impacts on various environmental categories (see Table 1) over the whole life cycle 4) normalization of single results, 5) weighting of normalized life cycle analysis results with societal factors, 6) determination of overall environmental impact expressed in person minutes (hours, days, weeks etc.) based on environmental impact of a society, 7) determination of overall costs expressed in person minutes (hours, days, weeks etc.) based on the GDP of a society 8) creation of an Eco-Efficiency portfolio following the requirements of ISO 14045, 9) analyses of appropriateness, data quality, uncertainties, completeness and sensitivities 10) Interpretation of results, reporting.

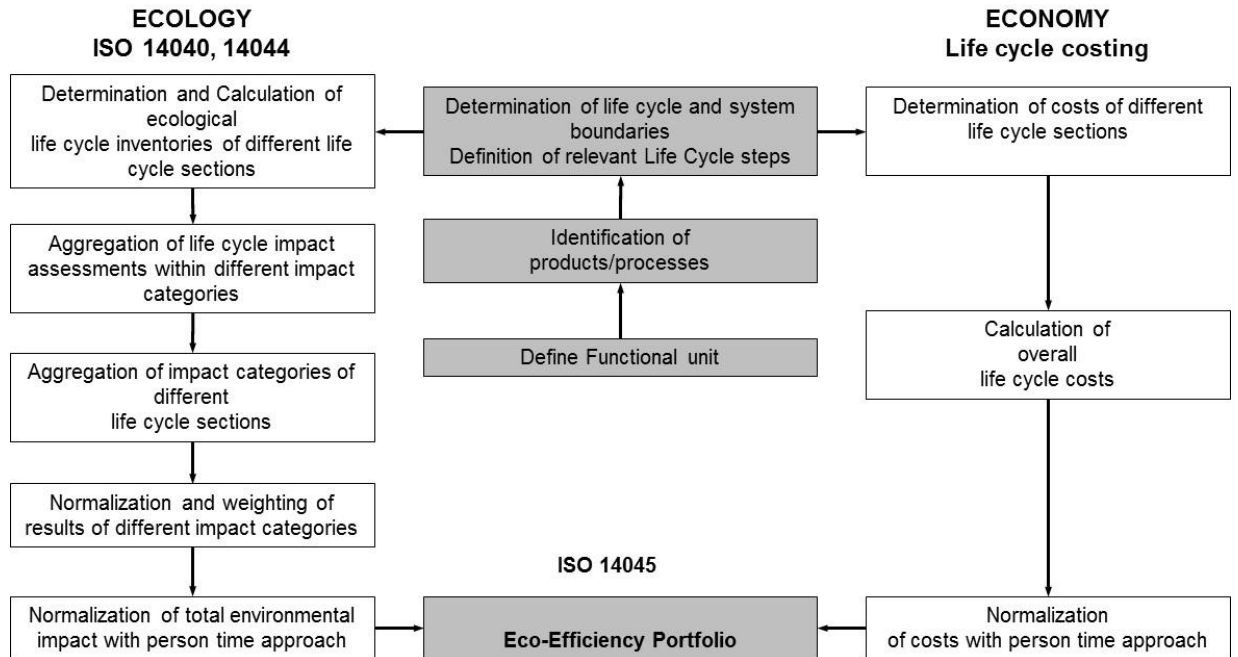


Figure 2: BASF flow diagram for the preparation of an EEA study

3.5. *Relevance Check*: The Relevance Check ensures that each Eco-Efficiency Assessment (a) covers sufficient environmental impact and (b) includes the relevant environmental impact categories. For the Relevance Check the environmental impact of the EEA10 is defined as 100%. The most relevant impact categories covering at least 80% of the total impact are determined automatically by the computerized model for each alternative assessed. Based on this Relevance Check, the BASF Eco-Efficiency Assessment is required, at a minimum, to cover all environmental impact categories for all alternatives according to this 80% coverage. It is possible to include additional environmental impact categories as well.

#### 4. Study Goals and Context

4.1. *Study Goals*: The starting point for a BASF EEA type study 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. It will be reported and assessed according to ISO 14040:2006, ISO 14044:2006 and ISO 14045:2012.

4.2. *Study Context*: Development of the study goals and context for decision making should include consideration of the following criteria:

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. *Geography*, e.g. global, national/regional, or local
- 4.2.3. *Scenario and Horizon*, e.g. 3 years, 10 years, 40 years, or another timeframe
- 4.2.4. *Engagement*, e.g. customers, regulators, consumers, academics, non-governmental organizations (NGOs), internal use, etc.
- 4.2.5. *Life Cycle*, e.g. full life cycle, supply chain, production etc.
- 4.2.6. *Product and Market*, e.g. one product/one market, few products/one market, one product/few markets, all products/all markets etc.
- 4.2.7. *Economy*, e.g. developed, emerging, or under development
- 4.2.8. *Innovation*, e.g. incremental, gap closure, step change

The definition of the study goals and the scope also helps to identify the various points along the value chain (in the life cycle), where sustainability issues are the most prominent. Where this occurs, they should be included in the choice of system boundaries. To this end, initial research should be conducted to capture the economic and environmental aspects of the processes or products under consideration. This can range from desk research to additional consultation with specific institutions or data providers, or even extended to a wider involvement and discussion with various stakeholders. The range selected depends on both the complexity of the study and the requirements of the customer. The results of the analysis will also be used to make decisions on the specific data sources to be used within the study.

## 5. Functional Unit, Alternatives and System Boundaries

- 5.1. *Functional Unit*: The term functional unit (customer benefit) 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 functional unit or customer benefit (CB) is used as the defined level of output and basis of comparison in an Eco-efficiency assessment. The CB will be defined specific to each BASF EEA study and will take into consideration the elements described in Section 4 and incorporate a life cycle perspective in accordance with ISO 14040 and 14044. For example, as discussed in Section 4, engagement, geography, market, scenario and 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 EEA; a minimum of two alternatives will be included. The alternatives will be defined specific to each 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 functional unit 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. The studies consider the entire life cycle but then may concentrate on the specific stages in a life cycle where the alternatives under consideration differ. Following the ISO guidance, the practitioners ensure that an overall view about alternatives is given and the concentration on specific life cycle stages do not change the overall order of alternatives compared in the system. It is important to note that the same life cycle stages must be included when analyzing each alternative.

Process steps for the life cycles 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.

The system boundaries will be defined specific to each study and will take into account the CB, the alternatives analyzed and consideration of the elements described in Section 4 above as well as ISO 14040, 14044 and 14045. 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.

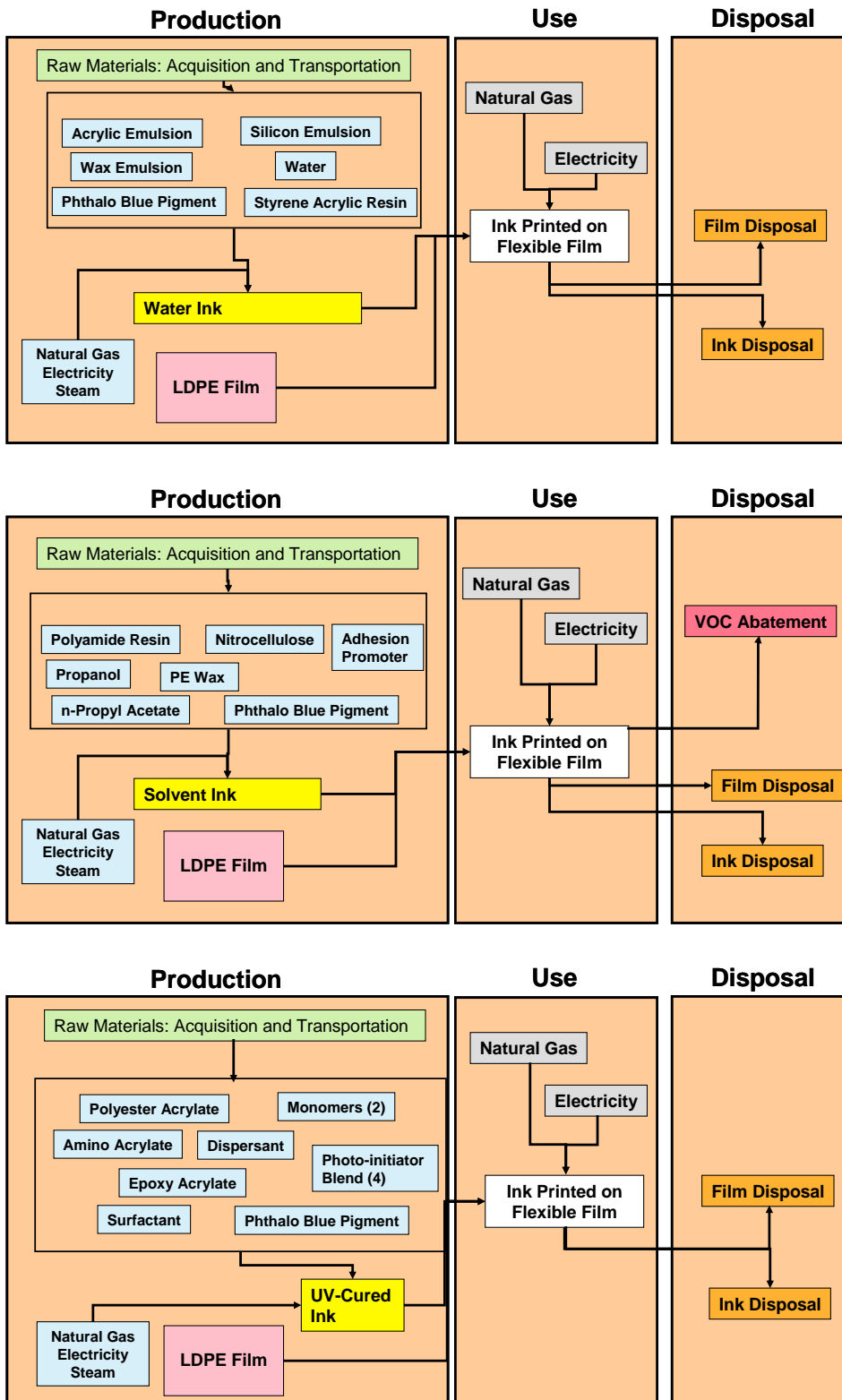


Figure 3: Conceptual diagrams of system boundaries for three technologies (Top: Water-based, Middle: Solvent-based, Bottom: UV-Cured)

## 6. Environmental Impact Metrics

- 6.1. *Overview:* For BASF EEA studies environmental impact is characterized using in EEA6 six, in EEA10 ten and in LCAflex a variable number of impact categories. The overview of required (for EEA6 and EEA10) or optional (for LCAflex) impact categories is given in Table 1. The assessment methods used for the different impact categories are fixed in EEA6 and EEA10 but are flexible in LCAflex to take into account specific customer needs.
- 6.2. *EEA6 and EEA10 Impact Assessments:* The following assessment methods are used in the EEA6 and EEA10 to determine the included impact categories.

Environmental impact categories	method [source]
ADP / abiotic depletion potential (fossil)	EU PEF [van Oers] <sup>5</sup>
ADP / abiotic depletion potential (minerals & metals)	EU PEF [van Oers] <sup>5</sup>
GWP / global warming potential	EU PEF [IPCC] <sup>6*</sup>
POCP / photochemical ozone creation potential	EU PEF [Van Zelm] <sup>7</sup>
AP / acidification potential	EU PEF [Seppälä] <sup>8</sup>
ODP / ozone depletion potential	EU PEF [WMO] <sup>9</sup>
Eutrophication potential (freshwater, marine)	EU PEF [Struijs] <sup>10</sup>
Human toxicity potential	BASF [Landsiedel, Saling] <sup>12</sup>
Resource Depletion, water (water scarcity)	EU PEF [Boulay] <sup>13</sup>
Land use, Soil Organic Matter (SOM)	EU PEF [Milà i Canals] <sup>14</sup>

\*but including biogenic assimilation

The specific scientific models used in EU PEF are shown in Table 2. The BASF method for determining the Human Toxicity Potential is described in [Landsiedel & Saling 2002]<sup>12</sup>. Due to some adjustments to that methodology since the above publication more details regarding the BASF Human Toxicity Potential are given in section 6.4.

Impact category	Indicator	Unit	Recommended default LCIA method
Climate change	Radiative forcing as Global Warming Potential (GWP100)	kg CO <sub>2</sub> eq	Baseline model of 100 years of the IPCC (based on IPCC 2013)
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11 eq	Steady-state ODPs as in (WMO 1999)
Human toxicity, cancer	Comparative Toxic Unit for humans (CTU <sub>h</sub> )	CTUh	USEtox model (Rosenbaum et al, 2008)
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTU <sub>h</sub> )	CTUh	USEtox model (Rosenbaum et al, 2008)
Particulate matter	Impact on human health	disease incidence	PM method recommended by UNEP (UNEP 2016)

Impact category	Indicator	Unit	Recommended default LCIA method
<b>Ionising radiation, human health</b>	Human exposure efficiency relative to $U^{235}$	kBq $U^{235}$ eq	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)
<b>Photochemical ozone formation, human health</b>	Tropospheric ozone concentration increase	kg NMVOC eq	LOTOS-EUROS model (Van Zelm et al, 2008) as implemented in ReCiPe 2008
<b>Acidification</b>	Accumulated Exceedance (AE)	mol H <sup>+</sup> eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)
<b>Eutrophication, terrestrial</b>	Accumulated Exceedance (AE)	mol N eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)
<b>Eutrophication, freshwater</b>	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe
<b>Eutrophication, marine</b>	Fraction of nutrients reaching marine end compartment (N)	kg N eq	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe
<b>Ecotoxicity, freshwater</b>	Comparative Toxic Unit for ecosystems (CTU <sub>e</sub> )	CTU <sub>e</sub>	USEtox model, (Rosenbaum et al, 2008) <sup>11</sup>
<b>Land use</b>	<ul style="list-style-type: none"> <li>• Soil quality index</li> <li>• Biotic production</li> <li>• Erosion resistance</li> <li>• Mechanical filtration</li> <li>• Groundwater replenishment</li> </ul>	<ul style="list-style-type: none"> <li>• Dimensionless (pt)</li> <li>• kg biotic production</li> <li>• kg soil</li> <li>• m<sup>3</sup> water</li> <li>• m<sup>3</sup> groundwater</li> </ul>	Soil quality index based on LANCA (Beck et al. 2010 and Bos et al. 2016)
<b>Water use</b>	User deprivation potential (deprivation-weighted water consumption)	m <sup>3</sup> world eq	Available WATER REmaining (AWARE) as recommended by UNEP, 2016
<b>Resource use, minerals and metals</b>	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	CML 2002 (Guinée et al., 2002) and van Oers et al. 2002.
<b>Resource use, fossils</b>	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ	CML 2002 (Guinée et al., 2002) and van Oers et al. 2002

Table 2: EU PEF impact categories and impact assessment models<sup>15</sup>

- 6.3. *LCAflex Impact Assessments:* For LCAflex the selection of impact categories is flexible and may include, in addition to the EEA6 and EEA10 categories, the categories shown below. At a minimum, the impact categories indicated by the Relevance Check are required. The assessment methods may be chosen from standard market tools such as EU PEF, Traci 2.1, ReCiPe and CML 2002 (2016). In addition, published and accepted methodologies for specific impacts may also be applied as described in section 6.2 (for example BASF Human Toxicity Potential [Landsiedel and Saling 2002]).

#### Additional Environmental impact categories (LCAflex)

Eutrophication (terrestrial)  
 Eutrophication (overall)  
 Respiratory inorganics  
 Ionizing radiation  
 Human toxicity potential (cancer)  
 Human toxicity potential (non-cancer)  
 Ecotoxicity potential (freshwater)  
 Ecotoxicity potential (terrestrial)  
 Ecotoxicity potential (marine)

This is an open list and can be extended (with published impact categories/methodologies) depending on the needs of the customers in various industries and in different regions.

All these impact categories may be aggregated to a total environmental impact if: (a) at least all the impacts indicated by the Relevance Check are included (b) if weighting factors obtained by a poll run by professional third parties exist for all impact categories (c) there is no double counting of an impact category (for example, if Eutrophication (overall) and Eutrophication (terrestrial) may not both be included in the aggregation to a total environmental impact since the terrestrial component would be counted twice).

It is possible to report additional categories in the LCAflex without including these in the aggregated total environmental impact.

- 6.4. *The BASF Human Toxicity Potential Method:* For BASF EEA the human 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 the final products as well as the reactants needed for their 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 [Landsiedel and Saling]<sup>12</sup> and was, in the first version, based upon the Hazardous Materials Regulations (R-phrases) as outlined in Directive 67/546/EEC. The R-phrase system was widely used in Europe for the classification of a substance's various toxic effects but has been replaced

by the H-phrase system of the Global Harmonized System (GHS). BASF Human Toxicity Methodology has been adapted to the new GHS classification scheme by mapping the R-phrases to the H-phrases of the new system.

- 6.5. *De Minimis Levels:* Materials or processes can be excluded from consideration in the key environmental impact metrics if they are viewed as being at de minimis levels (i.e. below minimum 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 Safety Data Sheets (SDSs) per the Global Harmonization System (GHS). In this case, 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 identified 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 followed by any subsequent costs incurred by its use and disposal. When different production methods are compared, the relevant costs included are normally further itemized along the various life cycle stages and include for example, operating costs, maintenance costs, the purchase and installation of capital equipment, depreciation, and waste disposal 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 an ecological aspect, such as the costs involved to treat wastewater generated during a manufacturing process.

- 7.2. *Economic Metrics:* The exact metrics chosen for a study depend upon the scope of the study, the identified functional unit, the alternatives considered, 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. Aggregation and the Person Time Concept

8.1. *Overview:* BASF's EEA methodology assesses environmental impacts and economic costs independently. The environmental impact categories are aggregated to an overall environmental impact using a conventional approach as recommended, for example, by the ILCD Handbook<sup>16</sup>. In a first step the impacts are normalized, followed by aggregating these with fixed weighting factors. Total life cycle costs are determined separately and combined with the total environmental impact in the Eco-Efficiency Portfolio.

8.2. *Normalization:* The normalization step uses external (study-independent) values. The environmental normalization values used are global values provided with standard market approaches. For TRACI impact categories reference US statistics (e.g. tons CO<sub>2</sub>e/year emitted in the US) are used, while for other impact categories global statistics are used<sup>17</sup>. For the normalization of the total costs global GDP (gross domestic product) is used. This value should be updated yearly and documented in the BASF Mastersheet.xlsx (or equivalent calculation model).

8.3. *Weighting*. The normalized values are aggregated using weighting factors established by the EU PEF<sup>17</sup>.

The aggregated environmental and economic values for each alternative are divided by the number of inhabitants globally to obtain a single score total environmental impact expressed in person time (e.g. person years).

8.4. *Eco-Efficiency*. The total environmental impact and the total costs, both expressed in terms of person time, are combined on the Eco-Efficiency Portfolio, described in more detail in 9.5

## 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. The single results are linked with the predefined functional unit or customer benefit (CB). At a minimum, the Final Report and/or Final Presentation shall include a discussion of the following:

- Executive summary
- Introduction and study goals;
- functional unit, alternatives and system boundaries;
- Input parameters and assumptions;
- Method of Economic impacts evaluation;
- Method of Environmental impact evaluation;
- Eco-Efficiency analysis results, interpretation 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 total costs and each of the environmental impact metrics (Table 1). An example for such a single bar chart graph is given in Figure 4. Additionally, an Environmental (Ecological) Footprint plot (Figure 5) and an Eco-Efficiency Analysis Portfolio (Figure 6) will be reported. The BASF EEA methodology allows results to be graphically depicted and discussed and may assist strategic decision making for implementing the most eco-efficient alternative. This contributes to more sustainable products and processes 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 impact metrics. At a minimum, the bar charts should be generated based on characterized results, but not results that have been normalized or weighted. Figure 4 shows an indicative bar chart for representing an environmental impact. The bar diagrams give an indication in what



life cycle steps process and product changes may be having the largest impact and thus offer the greatest potential improvement opportunities.

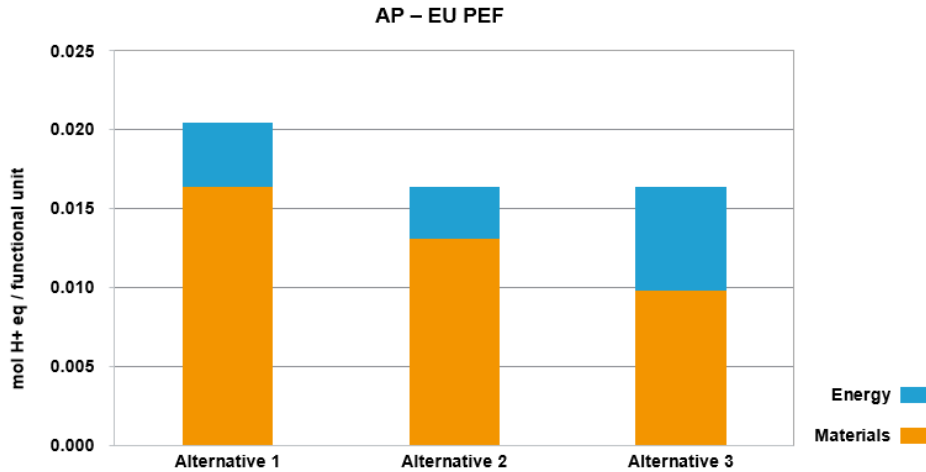


Figure 4: Single results of environmental impact, e.g. Acidification potential

9.4. *Environmental (Ecological) Footprint*: The environmental Footprint shows the environmental impact of the alternatives relative to one another in all the assessed impact categories. The alternative that lies furthest out and has the value of 1.00 is the least favorable (highest impact) alternative in the category under consideration. The closer to the origin (0, 0 coordinate) an alternative lies, the more favorable (less environmental impact) it is. In principle, it is possible to change the direction of the results to the opposite if it is clearly described in the report. The axes coordinates are calculated independent of one another, so an alternative that, for example, does well in abiotic depletion (resource depletion – mineral, fossil) can perform worse with regards to consumptive water use (resource depletion water). A representative Footprint is depicted below in Figure 5.

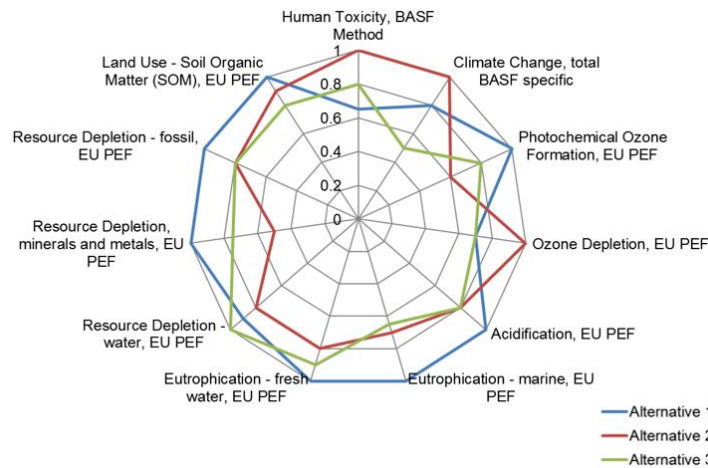


Figure 5: Comparison of alternatives in an Environmental Footprint (EEA10)

9.5. *Eco-Efficiency Analysis Portfolio and Index*: The BASF Eco-Efficiency portfolio was developed to graphically depict both economic and environmental results on a single matrix. The total environmental impact is plotted against total costs; both values are expressed in terms of person time. The eco-efficiency is inversely proportional to the distance from an alternative to the origin (0, 0). A diagram of the Eco-Efficiency Index shows these distances for all alternatives. Alternatives whose Eco-Efficiency Index are within a specified sensitivity (normally 10%) are considered to be equally eco-efficient. Because the Eco-Efficiency Portfolio always includes the point (0, 0), it is normal for most alternatives to be located closer to the lower left corner; this is not an indication of low eco-efficiency (Figure 6).

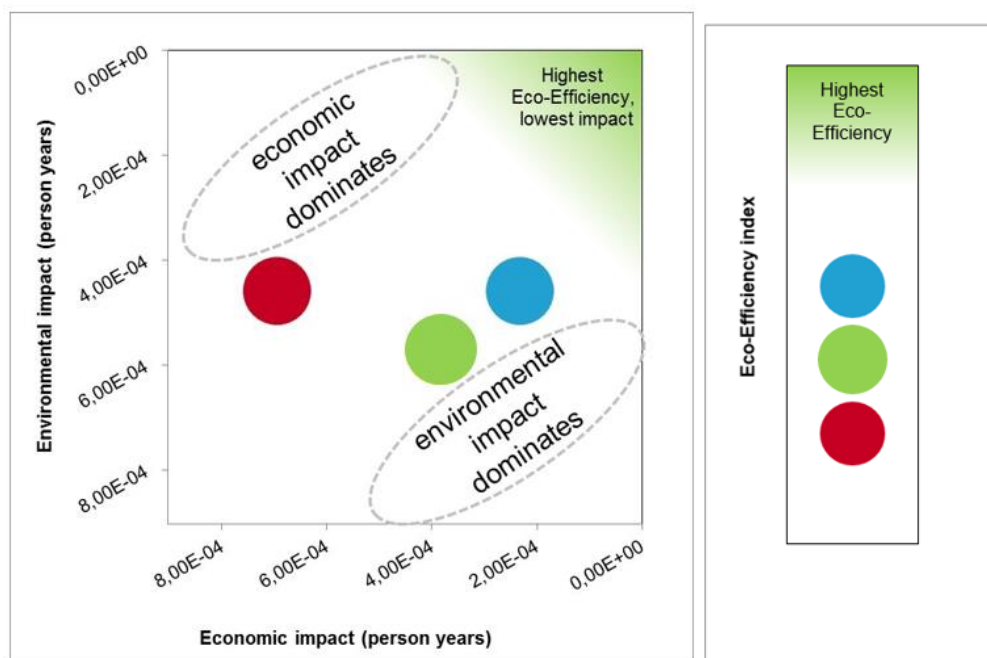


Figure 6: The Eco-Efficiency Portfolio and Index

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

10.1. *Overview*: BASF manages its life cycle inventory (LCI) data in a manner consistent with ISO 14040 and ISO 14044. LCI data is one of the types of information critical to performing a BASF EEA, the other being the model parameters. LCI is essentially an inventory of input/output data with respect to the product or process under consideration. Input/output data includes about 3000 flows or more required to calculate the impact categories shown in Table 1 and is stored in the BEST database or similar database (see 10.7 for a more detailed explanation). From the BEST database LCIA (life cycle impact assessment) are extracted for use in the BASF mastersheet.xlsx (or equivalent calculation model). The LCIA are obtained by multiplying all the flows of the LCI with corresponding characterization factors from the various assessment methods (e.g. TRACI). It is also possible to extract an LCI from a database, with the impact assessment performed subsequently. BEST and other databases use primary

data sets as well as secondary data sets. Both types can be used and selected for studies if a consistent data quality management is applied.

The general process of selecting Eco-Profiles for use in BASF EEA, shown schematically in Figure 7, 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 LCIA used in a BASF EEA should be provided in the "LCIA" worksheet, and can be seen, as an example, in the enclosed BASF Mastersheet.xlsx. See Section 10.8 for BASF EEA reporting requirements in regard to development and use of Eco-Profiles.

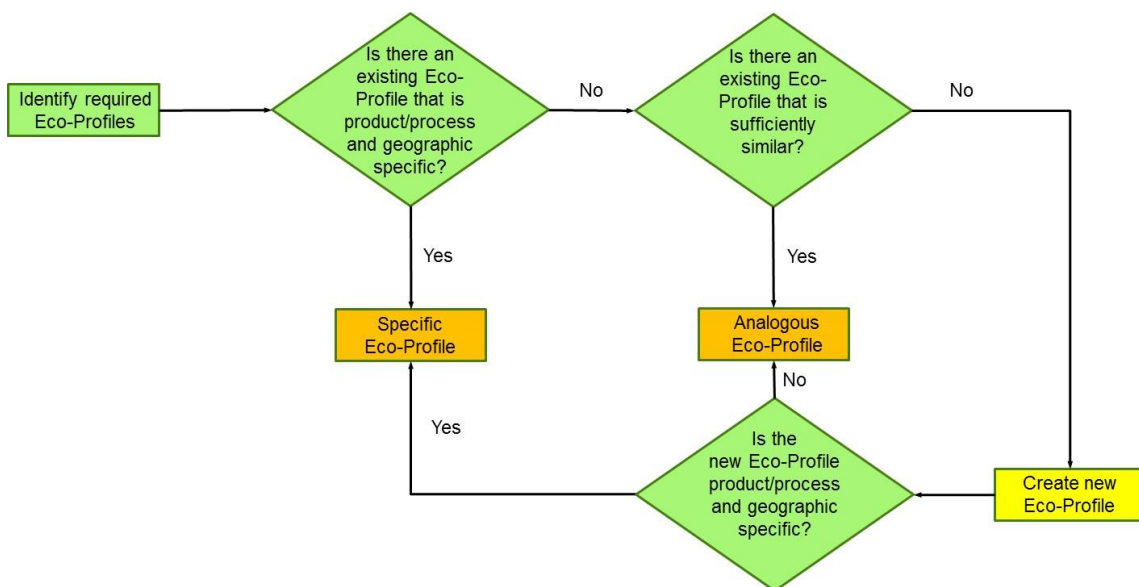


Figure 7: Process flow for selecting Eco-Profiles

- 10.2. *Identifying Required Eco-Profiles:* The goals of the study, the defined functional unit, 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 is 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 of the Eco-Profiles throughout the BASF EEA study.
- 10.3. *Elements of LCIA:* The basic BASF LCIA shall contain all of the elements that comprise the environmental impact metrics. As shown in Figure 8, different impact assessment methods are integrated in the LCIA format derived from the LCI to allow for flexible selection of impact assessment methods in the LCAflex. In some cases, one flow may impact more than one environmental metric. Methane (CH<sub>4</sub>), for example, is a chemical that impacts both the GWP and POCP impacts.

Reference flow		Product A
BEST-ID		16761
Unit		kg
Amount		1.0
Region		
Year		1/1/11 12:00
Completeness		3
Reliability		5
<b>Climate Change</b>		
Climate Change - CML 2001		0
Climate Change - fossil & LULUC - CML 2001	kg CO2 eq	2.09122803
Climate Change - CO2 biogenic assimilation - CML 2001	kg CO2 eq	-0.007772511
Climate Change - CO2 biogenic emissions - CML 2001	kg CO2 eq	0.007391296
Climate Change - CO2 biogenic net - CML 2001	kg CO2 eq	-0.000381215
Climate Change - total - CML 2001	kg CO2 eq	2.090846815
Climate Change - EF 1.8		0
Climate Change - fossil - EF 1.8	kg CO2 eq	2.14607744
Climate Change - LULUC - EF 1.8	kg CO2 eq	0.000180145
Climate Change - CO2 biogenic assimilation - EF 1.8	kg CO2 eq	0
Climate Change - CO2 biogenic emissions - EF 1.8	kg CO2 eq	0.000247951
Climate Change - CO2 biogenic net - EF 1.8	kg CO2 eq	0.000247951
Climate Change - total - EF 1.8	kg CO2 eq	2.146505535
Climate Change - ReCiPe 2016 v1.1 (H)		0
Climate Change - fossil & LULUC - ReCiPe 2016 v1.1 (H)	kg CO2 eq	2.139882066
Climate Change - CO2 biogenic assimilation - ReCiPe 2016 v1.1 (H)	kg CO2 eq	-0.007772511
Climate Change - CO2 biogenic emissions - ReCiPe 2016 v1.1 (H)	kg CO2 eq	0.007449637
Climate Change - CO2 biogenic net - ReCiPe 2016 v1.1 (H)	kg CO2 eq	-0.000322873
Climate Change - total - ReCiPe 2016 v1.1 (H)	kg CO2 eq	2.139559193
Climate Change - TRACI 2.1		0
Climate Change - fossil & LULUC - TRACI 2.1	kg CO2 eq	2.074189227
Climate Change - CO2 biogenic assimilation - TRACI 2.1	kg CO2 eq	-0.007772511
Climate Change - CO2 biogenic emissions - TRACI 2.1	kg CO2 eq	0.007369418
Climate Change - CO2 biogenic net - TRACI 2.1	kg CO2 eq	-0.000403053
Climate Change - total - TRACI 2.1	kg CO2 eq	2.073786134
<b>Climate Change - BASF specific</b>		<b>0</b>
Climate Change - fossil - EF 1.8	kg CO2 eq	2.14607744
Climate Change - LULUC - EF 1.8	kg CO2 eq	0.000180145
Climate Change - CO2 biogenic assimilation - BASF specific	kg CO2 eq	-0.007772511
Climate Change - CO2 biogenic emissions - BASF specific	kg CO2 eq	0.007455487
Climate Change - CO2 biogenic net - BASF specific	kg CO2 eq	-0.000317024
Climate Change - total - BASF specific	kg CO2 eq	2.14594056

<b>Photochemical Ozone Formation</b>		
Photochemical ozone formation - CML 2001	kg ethene eq	0.000790466
<b>Photochemical ozone formation - EF 1.8</b>	<b>kg NMVOC</b>	<b>0.003423463</b>
Photochemical oxidant formation - ReCiPe 2016 v1.1 (H)	kg NOx eq	0.244568235
Photochemical ozone formation - TRACI 2.1	kg O3 eq	0.058475969
<b>Ozone Depletion</b>		
Ozone layer depletion - CML 2001	kg R11 eq	6.72274E-09
<b>Ozone depletion - EF 1.8</b>	<b>kg CFC-11 eq</b>	<b>8.05771E-09</b>
Ozone depletion - ReCiPe 2016 v1.1 (H)	kg CFC-11 eq	3.0056E-07
Ozone depletion - TRACI 2.1	kg CFC-11 eq	8.49235E-09
<b>Acidification</b>		
Acidification potential - CML 2001	kg SO2 eq	0.004028357
<b>Acidification - EF 1.8</b>	<b>mol H+ eq</b>	<b>0.004786364</b>
Terrestrial acidification - ReCiPe 2016 v1.1 (H)	kg SO2 eq	0.003216934
Acidification - TRACI 2.1	kg SO2 eq	0.003984127
<b>Eutrophication Ter.</b>		
Eutrophication - terrestrial - EF 1.8	mol N eq	0.00305535
<b>Eutrophication Mar.</b>		
<b>Eutrophication - marine - EF 1.8</b>	<b>kg N eq</b>	<b>0.00096689</b>
Marine eutrophication - ReCiPe 2016 v1.1 (H)	kg N eq	4.43746E-05
<b>Eutrophication Fresh</b>		
<b>Eutrophication - fresh water - EF 1.8</b>	<b>kg P eq</b>	<b>1.23478E-05</b>
Freshwater eutrophication - ReCiPe 2016 v1.1 (H)	kg P eq	1.23477E-05
<b>Eutrophication Aquatic</b>		
Eutrophication - TRACI 2.1	kg N eq	0.001134661
<b>Eutrophication Overall</b>		
Eutrophication - CML 2001	kg PO4 3- eq	0.000365655
<b>Human Tox (Cancer)</b>		
Human toxicity cancer effects - EF 1.8	CTUh	2.34678E-08
Human health - carcinogenics - TRACI 2.1	CTUh	3.1842E-09
Human toxicity cancer - ReCiPe 2016 v1.1 (H)	kg 1,4-DB eq	0.002463907
<b>Human Tox (non-Cancer)</b>		
Human toxicity non-cancer effects - EF 1.8	CTUh	8.93537E-08
Human health - non-carcinogenics - TRACI 2.1	CTUh	8.92621E-08
Human toxicity non-cancer - ReCiPe 2016 v1.1 (H)	kg 1,4-DB eq	0.257550509
<b>Human Tox overall</b>		
Human toxicity - CML 2001	kg DCB eq	0.577522326
<b>Ionizing Radiation</b>		
Ionizing radiation - EF 1.8	kBq U235 eq	0.009343312
Ionizing radiation - ReCiPe 2016 v1.1 (H)	Bq Co-60 eq	0.001681286
<b>Respiratory Inorganics / Particulate matter</b>		
Respiratory inorganics - EF 1.8	Disease ind	3.83904E-08
Particulate matter formation - ReCiPe 2016 v1.1 (H)	kg PM2.5 eq	0.001005683
Respiratory effects - TRACI 2.1	kg PM2.5 eq	0.00030884

<b>Freshwater Ecotox (all emissions included)</b>		
Freshwater aquatic ecotoxicity - CML 2001	kg DCB eq	0.028085372
Ecotoxicity - EF 1.8	CTUe	0.655274568
Freshwater ecotoxicity - ReCiPe 2016 v1.1 (H)	kg 1,4-DB eq	0.001295653
Ecotoxicity - TRACI 2.1	CTUe	0.412264267
<b>Terrestrial Ecotox</b>		
Terrestrial ecotoxicity - CML 2001	kg DCB eq	0.001048987
Terrestrial ecotoxicity - ReCiPe 2016 v1.1 (H)	kg 1,4-DB eq	0.311970201
<b>Marine Ecotox</b>		
Marine aquatic ecotoxicity - CML 2001	kg DCB eq	98.3834986
Marine ecotoxicity - ReCiPe 2016 v1.1 (H)	kg 1,4-DB eq	0.002870224
<b>Resource Depletion (water)</b>		
Resource depletion water - AWARE EF 1.8	m3 world eq	0.024994125
Resource depletion water - Pfister midpt	m3 eq	0.001210811
Water depletion - ReCiPe 2016 v1.1 (H)	m3	0.008686075
<b>Resource Depletion (elements, minerals and metals)</b>		
Resource depletion - elements - CML 2001 ultimate	kg Sb eq	1.74045E-07
Resource depletion - elements - CML 2001 economic	kg Sb eq	7.15198E-07
Resource depletion - minerals and metals - EF 1.8	kg Sb eq	1.73521E-07
Resource depletion - metals - ReCiPe 2016 v1.1 (H)	kg Cu eq	0.000274318
<b>Resource Depletion (fossil)</b>		
Resource depletion - fossil - CML 2001 ultimate	MJ	70.00571359
Resource depletion - fossil - EF 1.8	MJ	70.27938872
Resource depletion - fossil - ReCiPe 2016 v1.1 (H)	kg oil eq	1.651186706
Resource depletion - fossil - TRACI 2.1	MJ Surplus	9.956782347
<b>Resource Depletion (Total)</b>		
Resource Depletion - mineral, fossil - OBSOLETE EU PEF v1.09	kg Sb eq	1.09828E-06
<b>Land use (total)</b>		
Land use - Soil Organic Matter (SOM) (EU PEF v1.09)	kg C deficit	0.060675518
Soil quality index LANCA - EF 1.8	Pt	0.186440278
Land use ReCiPe 2016 v1.1 (H)	annual cro	0.0025354
<b>Other environmental indicators</b>		
CED total	MJ	70.50172934
CED fossil	MJ	70.27943729
CED Biobased renewable	MJ	0.007944487
CED Non-biobased renewable	MJ	0.214347557
Blue water	kg	9.30319877

Figure 8: BASF LCIA elements (shown in three parts)

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 etc.) A *new* Eco-Profile is created by BASF especially for a given EEA. A *specific* Eco-Profile means the input/output data match very closely to the product or process under consideration. An *analogous* Eco-Profile 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 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/transformation, with outputs including releases to air, water and land (solid waste). In addition, BASF EEA considers toxicity “outputs”. The sources of data can include existing ecological studies, questionnaires completed by 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 14040 and ISO 14044, 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 previously utilized the Boustead Model (ver. 5.0.11) and “BEST”, an open LCA software type developed by BASF and GreenDelta, Berlin (<http://www.greendelta.com/>). BASF no longer uses either of those models and currently uses the commercially available life cycle assessment modeling software from GaBi ts (ver. 8.5.0.79) for calculating Eco-Profiles.
- 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 functional unit (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 regard 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 14040 and ISO 14044.

## 11. Scope of studies

- 11.1. *System boundaries:* The ISO 14040 and 14044 define in which way system boundaries of a study have to be defined. The BASF EEA methodology follows this requirement. In cases, where there is a high degree of similarity in the analysis between inputs into the model (e.g. energy consumption, mass, assumptions related to production, use and disposal of the alternatives etc.), performing the analysis utilizing differential inputs often provides a higher degree of resolution to the results. The system boundary determines which unit processes shall be included within the LCA. The

selection of the system boundary shall be consistent with the goal of the study. The criteria used in establishing the system boundary shall be identified and explained. Decisions shall be made regarding which unit processes to include in the study and the level of detail to which these unit processes shall be studied.

The deletion of life cycle stages, processes, inputs or outputs is only permitted if it does not significantly change the overall conclusions of the study. Any decisions to omit life cycle stages, processes, inputs or outputs shall be clearly stated, and the reasons and implications for their omission shall be explained. Decisions shall also be made regarding which inputs and outputs shall be included and the level of detail of the LCA shall be clearly stated.

It is an iterative process to identify the inputs and outputs that should be traced to the environment, i.e. to identify which unit processes producing the inputs (or which unit processes receiving the outputs) should be included in the product system under study. The initial identification is made using available data. Inputs and outputs should be more fully identified after additional data are collected during the course of the study, and then subjected to a sensitivity analysis.

- 11.2. *Cut-off criteria:* The cut-off criteria for initial inclusion of inputs and outputs and the assumptions on which the cut-off criteria are established shall be clearly described. The effect on the outcome of the study of the cut-off criteria selected shall also be assessed. Several cut-off criteria are used in LCA practice to decide which inputs are to be included in the assessment, such as mass, energy and environmental significance. Making the initial identification of inputs based on mass contribution alone may result in important inputs being omitted from the study. Accordingly, energy and environmental significance should also be used as cut-off criteria in this process. It should be decided which inputs and outputs data have to be traced to other product systems, including flows subject to allocation.

The presentation and/or final report of BASF EEA results shall include a description of cut-off rules and processes 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).

The system should be described in sufficient detail and clarity to allow another practitioner to duplicate the inventory analysis.

## 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. Geographic, technological and temporal appropriateness of the data is considered in the selection of input data. Sensitivity calculations are used to determine whether any specific inputs, assumption or life cycle inventory are critical for result stability.

- 12.2. *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 functional unit, 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. More information on BASF’s methodology and the NSF validation can be obtained at <http://www.nsf.org/services/by-industry/sustainability-environment/product-transparency-reporting>”. Slight modifications to this statement are allowed, if required.



## 14. BASF Mastersheet.xlsm

- 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 Mastersheet.xlsm spreadsheet. In general, the information and setups of the Mastersheet can be implemented and utilized in the BEST software as a platform as well and other data formats and databases may be used as well.
- 14.2. *Elements:* Table 3 describes the function of each worksheet contained within the BASF Mastersheet.xls Note: The BASF Mastersheet.xlsm contains worksheets for conducting Socio-Eco-Efficiency (SEE) studies, which are not part of this application and, therefore, those worksheets are not listed here.

Worksheet Name	Contents	Comments
Input Parameters	Study specific parameters are input on this page, including alternatives, formulation information, materials and energy usage. Cost, and toxicity 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 functional unit or customer benefit (CB) from which all environ. Impact calculations are performed. Data on this page are in units of material per CB (use/CB).
Costs	Cost calculations are done on this page and linked to Portfolio and impact cat. Worksheet.	The formats and inputs to this page will vary for each specific EEA.
Tool Selection	Selection of tool and, for LCAflex, also impact assessment methods	
Relevance Check	Determines the relevant impact categories required to cover at least 80% of environmental impact	The relevant categories are indicated here and on the 'Tool Selection' page (in red).
Portfolio and impact cat.	EEA results are provided on this page, including: final environmental scores, environmental footprint, and EEA portfolio.	
Contribution analysis	Contributions to specific impact categories, both at the module and LCIA level, are shown on this page.	
LCIA	Life cycle impact assessment (LCIA) data are entered into this sheet and form the basis from which environmental impacts are calculated.	LCIA data represents Environmental Impact per unit of material (Impact/Usage)
Alt.1 thru 10	Total impact per module is summed based on data in LCIA and then totaled for all modules to obtain total environmental impact.	BASF Mastersheet.xlsm allows for the comparison of ten different alternatives, so there are ten Alt. worksheets.
Data for graphs		Processing page, for internal (calculation) use only
Manager results	Diagrams of all impact categories, EEA portfolio and environmental footprint.	
TNS%	Weighting factors obtained by external consultant TNS Infratest	
Factors Person Minutes	Documentation of GDP and inhabitants for calculation of normalized impact in terms of person time	

Table 3: Worksheets include in BASF Mastersheet.xlsm file

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