Designation: D 7075 – 04

Standard Practice for Evaluating and Reporting Environmental Performance of Biobased Products[1]

This standard is issued under the fixed designation D 7075; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Biobased materials and products offer potential environmental benefits, energy savings, and reduced consumption of nonrenewable resources. However, there is a need for standard approaches and procedures for comparing the overall environmental benefits and burdens of biobased products and non-biobased products that are used in similar applications. Such comparisons are needed, among other uses, by industry and governmental institutions in selecting materials and products in making purchasing decisions.

An approach for determining the biobased content, resource consumption and environmental profile of biobased products has recently been published as an ASTM guide (D 6852), which provides a framework for assessing the environmental profile of a biobased product.

Guide D 6852 proposed the use of life cycle assessment (LCA) as the tool for assessing the environmental performance of biobased products and deferred to future ASTM standards for additional details.

The subject of this practice is to provide additional guidance for evaluating the environmental profile or performance of biobased products. For consistency in decision-making, the LCA approach shall be further defined for biobased products, although the overall approach is applicable for non-biobased products as well.

This practice is in accord with concepts and terminology used in ISO Standards on LCA (ISO 14040–14043) and is designed as a guide through the steps of LCA assessment. References are provided to the more detailed ISO Standards pertinent to each step.

This practice is aimed at technical professionals not directly involved in LCA evaluations who desire to become familiar with the methodology of LCA as it relates to biobased products.

1. Scope

1.1 Environmental performance shall be measured using the life-cycle assessment (LCA) approach. LCA is a "cradle-to-grave" approach that evaluates all stages in the life of a product, including raw material acquisition, product manufacture, transportation, use and ultimately, recycling (that is, "cradle to cradle" and waste management).

1.2 LCAs for biobased products shall be conducted and communicated in a similar manner, including consistent boundary conditions, functional units, environmental indicators, and reporting formats.

1.3 This practice is limited to environmental performance metrics and excludes other metrics such as those related to economics and social equity.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 6852 Guide for Determination of Biobased Content, Resources Consumption, and Environmental Profile of Materials and Products

D 6866 Test Methods to Determine the Biobased Content of Materials Using Radiocarbon and Isotope Ratio Mass Spectrometry

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[1] This practice is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.96 on Environmentally Degradable Plastics and Biobased Products.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D 7026 Guide for Sampling and Reporting Results for Determination of Biobased Content of Materials via Carbon Isotope Analysis

2.2 *ISO Standards:*

ISO 14040 Environmental Management—Life Cycle Assessment—Principles and Framework[3]

ISO 14041 Environmental Management—Life Cycle Assessment—Goal and Scope Definition[3]

ISO 14042 Environmental Management—Life Cycle Assessment—Life Cycle Impact Assessment[3]

ISO 14043 Environmental Management—Life Cycle Assessment—Life Cycle Interpretation[3]

ISO 14049 Environmental Management—Life Cycle Assessment—Examples of Application of ISO 14041 to Goal and Scope Definition and Inventory Analysis[3]

2.3 *U.S. Federal Government Document:*

Public Law 107-171 Farm Security and Rural Investment Act, May 13, 2002[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *biobased material(s)*, *n*—materials containing carbon based compound(s) in which the carbon comes from contemporary (non-fossil) biological sources.

3.1.1.1 *Discussion*—Carbon in contemporary (new, of that period) biological sources comes from recently fixed carbon dioxide (CO_2) present in the atmosphere using sunlight and energy (that is, via photosynthesis in plants).

3.1.1.2 *Discussion*—Solar radiation causes some carbon in the atmospheric CO_2 gas to become a radioactive isotope C-14. Once captured, the CO_2 decays to the stable isotope N-14. This process is slow on a human time scale; the C-14 content decreases by factor of two roughly every 5000 years. However, when it reaches fossil age, which is measured in millions of years, there is no more C-14 radioactive isotope left in the carbon. Thus, biobased carbon (contemporary carbon) has C-14 radioactivity associated with it that can be measured, while fossil carbon (non-biobased) has no radioactivity associated with it.

3.1.2 *biobased product*, *n*—product generated by blending or assembling biobased materials, either exclusively or in combination with non-biobased materials, in which the biobased material is present as a quantifiable portion of the total product mass of the product.

3.1.3 *elementary flow*, *n*—material or energy entering the system being studied, which has been drawn from the environment without previous human transformation, (per ISO 14040) and material or energy leaving the system being studied, which is discarded into the environment without subsequent human transformation (per ISO 14040).

3.1.4 *functional unit*, *n*—quantified performance of a product system for use as a reference unit in a life cycle assessment study (per ISO 14040).

3.1.5 *impact category*, *n*—class representing environmental issues of concern to which LCI results may be assigned.

3.1.6 *impact category indicator*, *n*—quantifiable representation of impact category, that is, CO_2 and CH_4 are quantifiable indicators of global warming impact category.

3.1.7 *life-cycle assessment*, *n*—collection and assembly of materials and energy input and output data including an evaluation of the potential environmental impacts of a specified product system.

3.1.8 *life-cycle impact assessment*, *n*—assessment of a product system's environmental performance through identification and evaluation of relevant impact categories.

3.1.9 *life-cycle inventory*, *n*—collection and assembly of materials and energy input and output data for a specified product system. LCI is only one of the phases in conducting an LCA and is not an assessment of the environmental impacts associated with the product system.

3.1.10 *organic material*, *n*—material containing carbon-based compound in which the element carbon is attached to other carbon atoms, hydrogen, oxygen, or other elements in a chain, ring, or three-dimensional structure.

3.1.11 *reference flow*, *n*—measure of the needed outputs from processes in a given product system required to fulfill the function expressed by the functional unit (per ISO 14041).

4. Summary of Practice

4.1 This practice outlines the recommended procedures for evaluating the environmental performance study and reporting environmental performance results for biobased products as well as fossil resource based products. An LCA approach shall be used which is based on the ISO 14040 series of LCA standards.

4.2 The general LCA methodology involves several distinct stages. The goal and scope definition steps spell out the purpose of the study and its breadth and depth. The inventory analysis step identifies and quantifies the environmental inputs and outputs associated with a product over its entire life cycle. Environmental inputs include water, energy, raw material, land and other resources. Outputs include releases to air, land, and water. However, it is not these inputs and outputs, or inventory flows that are of primary interest. Rather, it is their potential consequences, or impacts, on the environment that are of most concern. The next LCA step, impact assessment, characterizes these inventory flows in relation to a set of environmental impacts. For example, the impact assessment step relates carbon dioxide emissions, a flow, to global warming, an impact. Finally, the interpretation step combines the environmental impacts and describes the results in a manner and language in accordance with the goals of the LCA study.

4.3 LCA methods, some computerized, based on or in accord with ISO 14040 series, are available for evaluation of LCA. One well-recognized methodology, used as a starting point for several other methodologies is the Dutch CML (Center voor Milieukunde, Leiden, Holland).[5] In the United States, the EPA Office of Research and Development has

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[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[4] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401.

[5] CML: Product Innovation and Eco-Efficiency, Klostermann, J. E. M., Tukker, A., (eds), Centre for Environmental Science, University of Leiden, 1998.

compiled another widely known system named TRACI or Tools for Reduction of Chemical and Other Impacts.[6,7] A further comprehensive source that will be available in the future is SETAC/UNEP (United Nations Environmental Programme/Society of Environmental Toxicology and Chemistry) Life Cycle Initiative.[8] Each of these offers a set of impact categories into which individual pollutants and other environmental factors such as land use will be gathered.

4.4 There is considerable overlap between the various lists of impact categories that have been proposed and are used.

4.5 In this practice, the U.S. EPA TRACI methodology and list of impact categories and conversion factors for category indicators will be used. However, there is no universally applicable, comprehensive list of impact categories suitable for all applications and all materials. Such lists furnish only a point of departure to be augmented or reduced based on the particular situation.

4.6 LCA assessment involves values judgment and use of conversion factors that are subject to debate. Any method used to develop a LCA analysis for biobased products must be transparent and provide access to all data at all stages. All assumptions and value choices made must be clear and readily accessible to the user. The results for each selected environmental impact category must be reported.

5. Overview of Steps in Development of LCA

5.1 A schematic of the sequence of steps involved in development of a LCA is shown in Fig. 1. A life cycle assessment (LCA) consists of four independent elements (see Fig. 1), which have been standardized internationally (ISO 14040 series Standards, 1997-1999). These are:

5.1.1 Definition of goal and scope,

5.1.2 Life cycle inventory analysis (LCI),

5.1.3 Life cycle impact assessment (LCIA), and

5.1.4 Life cycle interpretation.

6. Life Cycle Goal and Scope Definition

6.1 *Describe the Scenario*—A brief description of the product and origin of environmental concerns will help the reader appreciate the significance of the subsequent steps. The basic assumptions should also be stated at this point.

6.2 *Define Goal of LCA*:

6.2.1 The goal defines the purpose of the LCA study in its broadest terms, with emphasis on the intended application of results of the study and the audience to whom the results will be conveyed.

6.2.2 A clear, unambiguous goal statement is key to proper formulation of subsequent steps.

6.3 *Define Scope of the Study*:

6.3.1 The scope defines the specific boundaries of the LCA in a way that the goal will be fulfilled. Such considerations would include:

6.3.1.1 Boundaries: cradle-to-gate versus cradle-to-grave study,

6.3.1.2 Process boundaries, which include all environmentally relevant steps, so that process flows in and out of the system, will be elementary flows,

6.3.1.3 The environmental impact categories to be considered must also be stated in the scope (see Section 8). This list must be comprehensive for the product system under evaluation and include any category indicators of concern,

6.3.1.4 This list maybe revised upon examination of material and energy flows (see Section 7),

6.3.1.5 Quality of data requirements (completeness of mass balances, precision, and so forth),

6.3.1.6 Allocation methods for shared operations,

6.3.1.7 Time element to be considered (inputs/outputs to be averaged over a period of time, for example, a year), and

6.3.1.8 Type and format of reporting of the study results.

6.3.2 The scope phase helps to assure that the goal is achieved and the work is done without excessive effort.

6.4 *Define Functional Unit*—Functional unit defines the amount of material or product needed to fulfill the stated task or service. It will form the basis of normalizing the inputs and outputs in the subsequent steps and allow comparison between products in a rational manner. Proper choice of functional unit is key to fair comparisons.

6.5 *Define Reference Flow*:

6.5.1 Reference flow is the amount of product required to fulfill the prescribed task of the functional unit. Reference flow is uniquely defined by the functional unit, but is expressed as weight of material or product, and is used to normalize the inputs and outputs from the system in the subsequent steps.

6.5.2 The flows of all inputs, from raw materials, energy to land use will be normalized to the reference flow.

6.6 *Define Unit Processes and Product System Boundaries*:

6.6.1 Process flow sheets that describe the unit operations involved in making the products with process inputs and outputs are developed or acquired to describe the boundaries specified by Goal and Scope.

6.6.2 Internal flows will not be required in subsequent steps, but are usually needed to complete and check the process flow sheets. All process flows are quantified and normalized to the reference flow.

6.7 The definition of unit processes is often the most extensive step in this sequence. However, the required operations have been usually described in detail in the course of the plant or system design for plant construction. If the system is already operational, the design figures have been checked during process operation.

6.7.1 The process flow sheets must include items such as transportation, distribution, and maintenance unless excluded in the definition of the goal and scope of the process.

6.8 Resource allocation must be done under agreed-upon, transparent rules.

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[6] Lippiatt, B. C., "BEES 3.0 Building for Environmental and Economic Sustainability Technical and User Guide," NISTIR 6916, National Institute of Standards and Technology, Gaithersburg, MD, October 2002.

[7] U.S. Environmental Protection Agency, "Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI): Users Guide and System Documentation," EPA/600/R/-02/052, U.S. EPA Office of Research and Development.

[8] United Nations Environmental Programme, Division of Technology, Industry & Economics Production and Consumption Branch, 39 – 43 quai Andre Citroen, 75739 Paris, Cedex 15, France, www.uneptie.org/sustain/lcinitiative

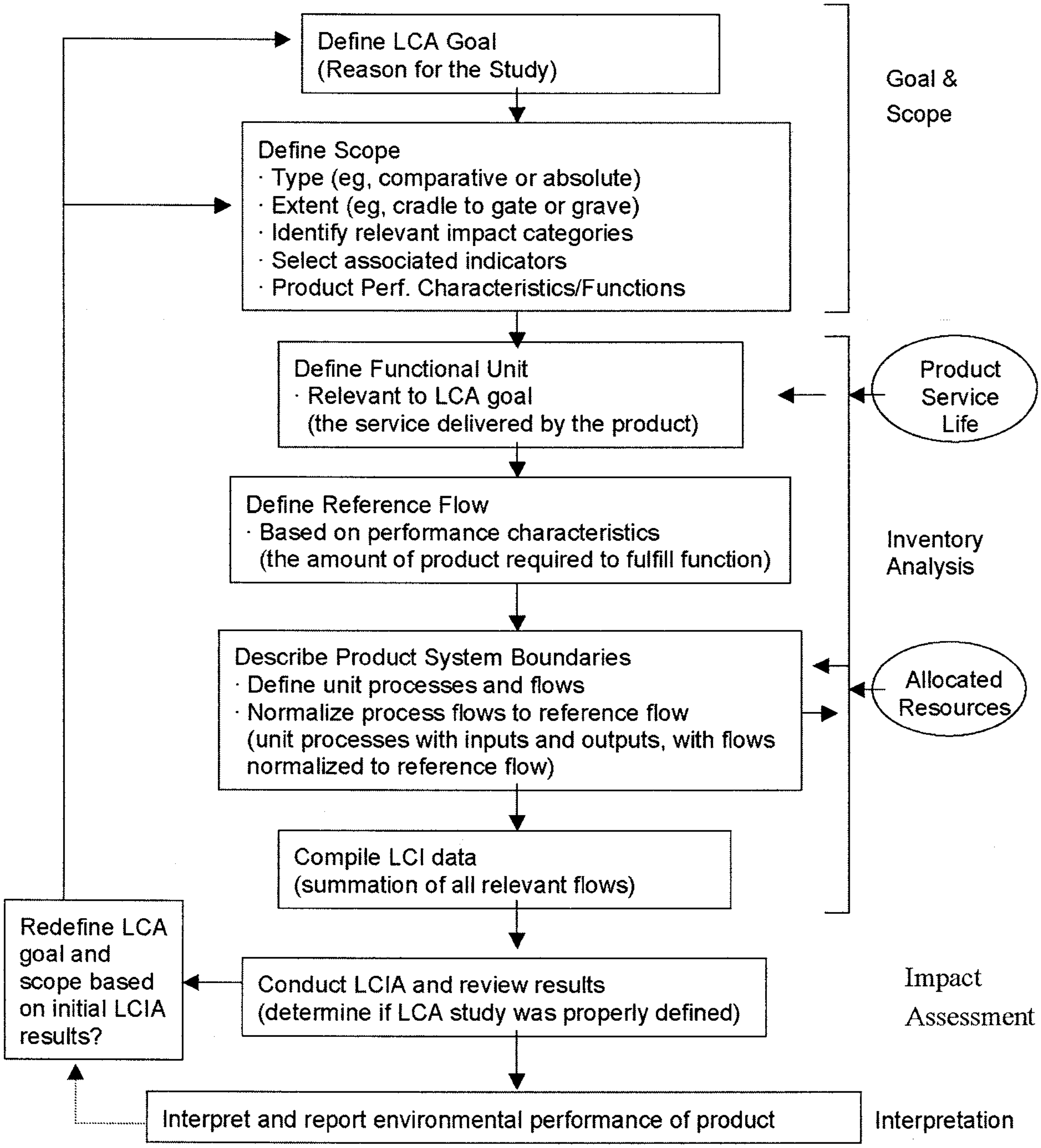

FIG. 1 Overview Process for Evaluating and Reporting Environmental Performance of Biobased Products

7. Life Cycle Inventory

7.1 The process flow sheets will be reduced to include only the inputs and outputs across the system boundary. The elementary flows to individual process steps are combined to form the LCI tables. For example, most unit processes involve energy input/output. For LCI purposes, these elementary flows are combined into a single number, provided that they represent the same kind of energy source. The list of elementary flows to be included is determined in the scope and depends, of course, on the purpose of the study as stated in the goal.

7.2 The LCI table must include all category indicators associated with the impact categories as well as other elementary flows.

7.3 It may be impossible and of little value to include all material inputs and outputs to a product or production process. For example, some materials are consumed in such small quantities that their contribution to the final LCA results would be negligible. However, other inputs (such as energy) are considered critical and need to be incorporated in totality. There are no preset, unique rules for data inclusion. For proper management of data, such rules must be established (usually under scope). Following are some guidelines to be considered:

7.3.1 Because of their associated environmental burdens, all energy inputs, including electricity, steam, and compressed air, shall be recorded.

7.4 Any omitted inputs should not have significant environmental burdens. Criteria for including small material inputs are: *(1)* the product contains a highly toxic input such as cyanide, phenol, hexavalent chromium, or any other significant hazardous compounds, and *(2)* the cost of the input is high, potentially indicating scarce resources or high energy consumption.

7.4.1 Some outputs may be excluded from the LCI if they do not carry significant environmental burdens. For example, solid waste or co-products for which the accumulated tonnage represents less than 1 % (by mass fraction) of the total waste or co-product tonnage for the production process might be excluded, unless they contain highly toxic compounds.

7.4.2 General site operations and capital equipment shall be excluded from the LCI. Inputs and outputs not directly related to industrial activities (such as cafeteria inputs and outputs, building heat, and restroom operations) shall not be taken into account. Flows related to people and offices shall not be included because they are not unique to the product production process. The capital equipment associated with the site facility shall also be excluded. Capital equipment is often found to be a minor contributor to environmental performance.

7.4.3 Only elementary flows that cross site boundaries shall be included in the LCI. Internal flows for a product production process, including both inputs and outputs, shall not be included. For example, if steam is produced in an on-site boiler, the amount of steam energy entering the production process shall not be reported because it is an internal flow subject to double counting. Its use is already accounted for through the boiler inputs (for example, heavy fuel oil) and outputs (emissions).

8. Life Cycle Impact Assessment

8.1 The U.S. EPA TRACI methodology[7] will be used as point of departure. This approach uses eleven major impact categories widely accepted as key concerns in the environmental community.

8.2 The environmental impacts are calculated by the formula:

$$\text{Impact Index}_j = \sum m_i \times P_{j,i} \qquad (1)$$

where:

j = designates impact category (for example, as global warming),
i = designates category indicator (for example, CO_2),
m_i = quantity (mass, area, and so forth) of category indicator i, and
$P_{j,i}$ = factor for conversion of category indicator i to reference indicator equivalent.

8.2.1 The conversion factor for the reference indicator is 1.

8.2.2 For example, let:

j = global warming.

i = CH_4, methane.

$P_{j,i}$ = GWP_i (see Note 1) = grams of CO_2, with the same heat trapping potential over 100 years as 1 g of reference material (CO_2 is the reference indicator for global warming).

GWP (methane) = 23. That is: 1 g of methane is equivalent to 23 g of CO_2 in effectiveness of heat trapping.

8.2.3 Tables of category indicator conversion factors for various impact categories are given in the Appendix. As noted in the Appendix, these conversion factors are updated periodically. Check ASTM for latest version of this Standard.

8.3 The impact categories used by EPA[7] are shown below (see Note 1):

8.3.1 Global warming potential (CO_2 equivalents),

8.3.2 Acidification (H+ equivalents),

8.3.3 Eutrophication (N equivalents),

8.3.4 Fossil fuel depletion (MJ surplus energy),

8.3.5 Habitat alteration (threatened and endangered species count/acre),

8.3.6 Water intake (litres),

8.3.7 Criteria air pollutants–solid particles (microDALYs),

8.3.8 Smog (NO_x equivalents),

8.3.9 Ecological Toxicity (2,4-D equivalents),

8.3.10 Ozone depletion (CFC-11 equivalents), and

8.3.11 Human Health (C7H7 equivalents).

NOTE 1—Habitat alteration will be removed from next revision of TRACI. Furthermore, Human Health will be expressed in two categories: cancer (as benzene equivalents/kg emission) and noncancer (as toluene equivalents/kg emission).

8.4 Not all of the categories may be germane to a specific LCA. However, all these categories must be considered and either included or marked as not applicable, together with reasons for this decision. These reasons may originate from the nature of the case under study or the study goals. For example, habitat alteration would usually imply new construction or alteration of use of land or water, which may not be the case.

8.5 There may be other impact categories specific to the study in consideration, which should be included in the scope. The list of impact categories must be reexamined in view of the inventory data and appropriate changes made in the scope.

8.6 The quality of the data will be questioned and the validity of the initially stated goal and scope examined. The goal and scope of the study may be redefined in light of the initial findings and the study refined to meet the new goal. System boundaries may be found to be improper and may have to be redefined at this stage and the process repeated in an iterative manner.

9. Life Cycle Interpretation

9.1 The findings from the impact assessment are converted into specific statements, or recommendations, or both with regard to the environmental performance of the product or process, in accordance with the stated goal of the study. The study goals are again reevaluated and the study subjected to another iteration, if deemed necessary.

9.2 Often the interpretation involves translation of the technical results into language accessible to nontechnical audience.

9.3 A sensitivity analysis must be carried out, with particular emphasis on category indicators whose mass flow is subject to fluctuation.

9.4 The conclusions and all supporting data are forwarded to reporting phase.

9.5 Significant environmental issues are identified.

9.6 Completeness of the study is evaluated.

9.7 Results are examined for internal consistency.

10. Report of the LCA Study

10.1 Environmental performance results for biobased products shall be communicated in a transparent manner and, if applicable, in a manner that supports the desired end use, such as a purchasing decision process. In such cases two reports may be appropriate; a primary report and a summary report.

10.2 The primary report shall be aimed at the environmental science professional and presented in sufficient detail for a technical review of the results.

10.3 The summary report is designed to inform the lay audience of the issues and simplify any decision making based on the results of the LCA study.

10.4 To facilitate comparisons among all product alternatives, the format shall be equally applicable to reporting environmental performance results for petroleum-based products and biobased products.

10.5 Since there is no universally accepted method for conducting a LCA, transparency in reporting is of paramount importance.

10.6 The primary report will include the following specific items:

10.6.1 Description of product under consideration, including its function and reasons leading to the study.

10.6.2 Goal, in a very clear manner.

10.6.3 Scope, including a list of impact categories and category indicators considered.

10.6.4 Definition of functional unit.

10.6.5 Definition of reference flow.

10.6.6 Flow sheets of unit processes with elementary flows across the system boundaries. Engineering type flow sheets with internal flows are encouraged for completeness and transparency. Background data must be shown for flows, which are derived solely by computation. Since the flow sheets may be quite extensive, electronic availability of such data is sufficient, even if the report is in printed form.

10.6.7 LCI table showing total elementary flows across the system boundaries must be available. The table may also be also quite extensive and may be made electronically available.

10.6.8 Results of impact assessment in tabular form.

10.6.9 Sensitivity analysis for all major flows and flows that may be subject to fluctuations.

10.6.10 Listing of all significant assumptions made in the course of the LCA study.

10.7 The primary report must be sufficiently detailed such that it can be critically examined and evaluated by a third party.

10.8 The summary report must contain a table of results for all impact categories. Depending on user, the results may also be displayed graphically. The emphasis will be on the needs and expected background of the end user.

11. Keywords

11.1 biobased products; environmental performance; life-cycle assessment

APPENDIX

(Nonmandatory Information)

X1. CATEGORY INDICATOR CONVERSION FACTORS[9]

X1.1 The following numbers are upgraded periodically. Check ASTM for latest version of this practice.

$$\text{Impact Index}_j = \sum_i mi\, P_{j,i} \qquad \text{(X1.1)}$$

where:

j = impact category,
i = emission/category indicator,
m_i = mass/quantity of emission, and
$P_{j,i}$ = impact potential of indicator i in terms of reference potential ($P_i = 1$ for reference emission).

j = GLOBAL WARMING POTENTIAL

Flow (i)	GWP_i (CO_2-equivalents)
Carbon Dioxide (CO_2, fossil)	1
Carbon Tetrafluoride (CF_4)	5700
CFC 12 (CCl_2F_2)	10 600
Chloroform ($CHCl_3$, HC-20)	30
Halon 1301 (CF_3Br)	6900
HCFC 22 (CHF_2Cl)	1700
Methane (CH_4)	23
Methyl Bromide (CH_3Br)	5
Methyl Chloride (CH_3Cl)	16
Methylene Chloride (CH_2Cl_2, HC-130)	10

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[9] Lippiatt, B. C., “BEES 3.0 Building for Environmental and Economic Sustainability Technical and User Guide,” NISTIR 6916, National Institute of Standards and Technology, Gaithersburg, MD, October 2002, pp. 11–24.

Nitrous Oxide (N_2O)	296
Trichloroethane (1,1,1-CH_3CCl_3)	140

j = ACIDIFICATION POTENTIAL

Flow (i)	AP_i (Hydrogen-Ion Equivalents)
Ammonia (NH_3)	95.49
Hydrogen Chloride (HCl)	44.7
Hydrogen Cyanide (HCN)	60.4
Hydrogen Fluoride (HF)	81.26
Hydrogen Sulfide (H_2S)	95.9
Nitrogen Oxides (NO_x as NO_2)	40.04
Sulfur Oxides (SO_x as SO_2)	50.79
Sulfuric Acid (H_2SO_4)	33.3

j = EUTROPHICATION POTENTIAL

Flow (i)	EP_i (Nitrogen-equivalents)
Ammonia (NH_3)	0.12
Nitrogen Oxides (NO_x as NO_2)	0.04
Nitrous Oxide (N_2O)	0.09
Phosphorus to air (P)	1.12
Ammonia (NH_4^+, NH_3, as N)	0.99
BOD5 (Biochemical Oxygen Demand)	0.05
COD (Chemical Oxygen Demand)	0.05
Nitrate (NO_3^-)	0.24
Nitrite (NO_2^-)	0.32
Nitrogenous Matter (unspecified, as N)	0.99
Phosphates (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, H_3PO^4, as P)	7.29
Phosphorus to water (P)	7.29

j = FOSSIL FUEL DEPLETION POTENTIAL

Flow (i)	FP_i (surplus MJ/kg)
Coal (in ground)	0.25
Natural Gas (in ground)	7.8
Oil (in ground)	6.12

j = HABITAT ALTERATION POTENTIAL (LAND USE)

Flow (i)	TED_i (T&E count/m^2)
Land Use (Installation Waste)	6.06E-10
Land Use (Replacement Waste)	6.06E-10
Land Use (End-of-Period Waste)	6.06E-10

j = CRITERIA AIR POLLUTANT POTENTIAL

Flow (i)	CP_i (microDALYs/g)
Nitrogen Oxides (NO_x as NO_2)	0.002
Particulates (>PM10)	0.046
Particulates (<=PM 10)	0.083
Particulates (unspecified)	0.046
Sulfur Oxides (SO_x as SO_2)	0.014

j = SAMPLE OF HUMAN HEALTH POTENTIAL (CANCER/NONCANCER)

Flow (i)	HP_i (Toluene-equivalents)
Cancer—(a) Dioxins (unspecified)	38 292 661 685 580
Noncancer—(a) Dioxins (unspecified)	2 286 396 218 965
Cancer—(a) Diethanol Amine ($C_4H_{11}O_2N$)	2 532 000 000
Cancer—(a) Arsenic (As)	69 948 708
Cancer—(a) BenzoCancer--(a) pyrene ($C_{20}H_{12}$)	34 210 977
Noncancer—(a) Mercury (Hg)	19 255 160
Noncancer—(w) Mercury (Hg^+, Hg^{++})	18 917 511
Cancer—(a) Carbon Tetrachloride (CCl_4)	17 344 285
Cancer—(w) Arsenic (As^{3+}, As^{5+})	17 210 446
Cancer—(w) Carbon Tetrachloride (CCl_4)	16 483 833
Cancer—(a) Benzo(k)fluoranthene	12 333 565

Cancer—(w) Hexachloroethane (C_2Cl_6)	8 415 642
Cancer—(w) Phenol (C_6H_5OH)	8 018 000
Noncancer—(a) Cadmium (Cd)	4 950 421
Cancer—(a) Trichloropropane (1,2,3-$C_2H_5Cl_3$)	3 587 000
Cancer—(a) Chromium (Cr III, Cr VI)	3 530 974
Cancer—(a) Dimethyl Sulfate ($C_2H_6O_4S$)	2 976 375
Cancer—(a) Cadmium (Cd)	1 759 294
Cancer—(a) Indeno (1,2,3,c,d) Pyrene	1 730 811
Noncancer—(a) Lead (Pb)	1 501 293
Cancer—(a) Dibenzo(a,h)anthracene	1 419 586
Cancer—(a) Benzo(b)fluoranthene	1 356 632
Cancer—(a) Benzo(bjk)fluoranthene	1 356 632
Cancer—(a) Lead (Pb)	748 316
Cancer—(a) Ethylene Oxide (C_2H_4O)	650 701

j = SAMPLE OF SMOG POTENTIAL

Flow (i)	SP_i (Toluene-equivalents)
Furan (C_4H_4O)	3.54
Butadiene (1,3-$CH_2CHCHCH_2$)	3.23
Propylene ($CH_3CH_2CH_3$)	3.07
Xylene (m-$C_6H_4(CH_3)_2$)	2.73
Butene (1-$CH_3CH_2CHCH_2$)	2.66
Crotonaldehyde (C_4H_6O)	2.49
Formaldehyde (CH_2O)	2.25
Propionaldehyde (CH_3CH_2CHO)	2.05
Acrolein (CH_2CHCHO)	1.99
Xylene (o-$C_6H_4(CH_3)_2$)	1.93
Xylene ($C_6H_4(CH_3)_2$)	1.92
Trimethyl Benzene (1,2,4-$C_6H_3(CH_3)_3$)	1.85
Acetaldehyde (CH_3CHO)	1.79
Aldehyde (unspecified)	1.79
Butyraldehyde ($CH_3CH_2CH_2CHO$)	1.74
Isobutyraldehyde ($(CH_3)_2CHCHO$)	1.74
Ethylene Glycol ($HOCH_2CH_2OH$)	1.4
Acenaphthene ($C_{12}H_{10}$)	1.3
Acenaphthylene ($C_{12}H_8$)	1.3
Hexanal ($C_6H_{12}O$)	1.25
Nitrogen Oxides (NO_x as NO_2)	1.24
Glycol Ether (unspecified)	1.11
Methyl Naphthalene (2-$C_{11}H_{10}$)	1.1
Xylene (p-$C_6H_4(CH_3)_2$)	1.09
Toluene ($C_6H_5CH_3$)	1.03

j = OZONE DEPLETION POTENTIAL

Flow (i)	OP_i (CFC-11-equivalents)
Carbon Tetrachloride (CCl_4)	1.1
CFC 12 (CCl_2F_2)	1
Halon 1301 (CF_3Br)	10
HCFC 22 (CHF_2Cl)	0.06
Methyl Bromide (CH_3Br)	0.6
Trichloroethane (1,1,1-CH_3CCl_3)	0.1

j = ECOLOGICAL TOXICITY POTENTIAL

Flow (i)	EP_i (2,4-D-equivalents)
(a) Dioxins (unspecified)	2 486 822.73
(a) Mercury (Hg)	118 758.09
(a) Benzo(g,h,I)perylene ($C_{22}H_{12}$)	4948.81
(a) Cadmium (Cd)	689.74
(a) Benzo(a)anthracene	412.83
(a) Chromium (Cr VI)	203.67
(w) Naphthalene ($C_{10}H_8$)	179.8
(a) Vanadium (V)	130.37
(a) Benzo(a)pyrene ($C_{20}H_{12}$)	109.99
(a) Beryllium (Be)	106.56
(a) Arsenic (As)	101.32
(a) Copper (Cu)	89.46
(w) Vanadium (V^{3+}, V^{5+})	81.82

(a) Nickel (Ni)	64.34
(w) Mercury (Hg^+, Hg^{++})	58.82
(a) Cobalt (Co)	49.45
(a) Selenium (Se)	35.07
(a) Fluoranthene	29.47
(w) Copper (Cu^+, Cu^{++})	26.93
(a) Chromium (Cr III, Cr VI)	24.54
(w) Cadmium (Cd^{++})	22.79
(w) Formaldehyde (CH_2O)	22.62
(a) Zinc (Zn)	18.89
(w) Beryllium (Be)	16.55
(a) Lead (Pb)	12.32

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